International Foundation
High Altitude Research Stations
Jungfraujoch + Gornergrat HFSJG

Activity Report 2020

International Foundation
High Altitude Research Stations
Jungfraujoch + Gornergrat HFSJG
Sidlerstrasse 5
CH-3012 Bern / Switzerland

Telephone +41 31 631 40 52
URL: https://www.hfsjg.ch

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Message of the President

Dear Reader, while writing this message of the President beginning of 2021, in a certain sense I'm pretty confident that I'm not alone when I say I'll be glad to wave goodbye to 2020. It's probably fair to say that this has been one of the most difficult years in recent times facing the global pandemic COVID situation. Could 2021 possibly be worse? It's difficult to imagine. I certainly hope it isn't and we are all desperate for a return to some sense of normality. With that I would like to express my sincere thanks to all of you for acting responsibly during this challenging period of time and especially to our custodians at the Jungfraujoch station, our partners at Jungfraujoch and Gornergrat, all the scientists and the HFSJG staff with our Director Prof. Dr. Markus Leuenberger and our managing director of the Stellarium Gornergrat Dr. Timm Riesen for guiding us successfully and with exemplary dedication through the year 2020.

Due to this unfavourable set of circumstances, we had to postpone many of our plans which were foreseen to be realized during the year 2020. But nevertheless, as it is outlined in the following 'Report of the Director' still we can look back on many valuable results which have been achieved even under difficult and sometimes complicated conditions.

As one of the consequences of the actual situation, beginning of 2021 we decided in agreement with all our Delegates of the Foundation to convene our next HFSJG board meeting in Interlaken not as it was planned in fall 2021, but only on October 21-22 2022, still in Interlaken. Yet, we intend to keep the date of September 8^{th}/9^{th} 2023 for the then following board meeting in Zermatt and by that we would be back on track again. With this cautious planning we anticipate that these future meetings could be organized and held under more favorable conditions.

Despite the extraordinary circumstances during the year 2020, the Stellarium Gornergrat was quite successfully on track and well guided by the managing director Dr. Timm Riesen; he perfectly highlights the achievements of this public outreach project in his yearly report (*vide infra*). At this time, we note that during 2020 a discussion was opened for a new collaborative network between four Swiss partners on the one side, namely the NCCR PlanetS which includes researchers from Universities of Bern, Geneva, Zürich and ETH Zürich and Lausanne, the Geneva Observatory, our HFSJG Foundation and the Stellarium Gornergrat, and Institutions from Chile which include the Pontifica Universidad Catolica de Chile and the Museo Interactivo Mirador in Santiago. Importantly, from the European Organization for Astronomical Research, the European Southern Observatory (ESO) takes actively and supportively part in these ongoing discussions. The idea of this new collaboration is to establish/define in Chile a sister observatory station of the Stellarium Gornergrat, which by its location would be perfectly complementary to the Swiss one in terms of southern *versus* northern hemisphere and day to night shifts. It's an excellent concept to connect two such stations on different continents and it would broaden to a large extent the pedagogical activities on both sides. These discussions were also promoted by the Swiss Ambassador in Chile, however we are aware that the realisation of the concept will take some time and clearly the current extraordinary situation prevents its quick implementation. Similarly, in another development, in the pre-alps south of Bern in Uecht, a new Swiss Space and Sustainability Observatory (www.s3o.org) is under construction and its opening is planned for the end of 2022. Also in this case, a collaboration with the Stellarium Gornergrat is envisaged and currently under discussion.

As I already mentioned in my Message of the President for the Activity Report 2019, in the year 2022 we will celebrate the 100-years anniversary of the formation of the Jungfraujoch commission, which today is active under the umbrella of the Swiss Academy of Sciences. It was this committee which initiated and realized the construction of our research building on the Jungfraujoch site, which was finally opened in the year 1931. We have been fortunate to open an early discussion during 2020 with Dr. Leander Diener, a Historian from the University of Zürich, about this topic. He set himself the task of writing a book concerning the history of the Jungfraujoch research station in the context of the scientific and political situation during the late 19^{th} and early 20^{th} century with a national but also international view. The importance of the establishment of the International Foundation HFSJG in 1930 for the high-altitude research station but also for the Swiss scientific community will be elaborated as well. Definitely, it's an ambitious but also very exciting project and we look forward to see its timely completion in 2022.

While looking forward to the future of our Foundation, with great dismay did we hear that our former President and Honorary President, Prof. Dr. Hans Balsiger, passed away in January 2021. We know that he stood up for the concerns of our International Foundation with great and tireless commitment and he shaped the Foundation with his foresight and perseverance in his work. We will keep an honourable memory of him and his legacy within our International Foundation.

I wish you all good health and we will do our best to live up to a statement we received recently from one of our Delegates, saying that one of many things about HFSJG is the feeling of family.

Bern, March 2021 Silvio Decurtins

"High in the Swiss Alps scientists in a small research station are busy fingerprinting the atmosphere." J. Palmer, *Nature* **577**, 464–466 (2020)

The entrance doors to the research station and the Sphinx-laboratories were renewed and updated with the logos of the new members of our Foundation (pictures above). The scientific exhibition was also updated, especially with a new panel of MeteoSwiss with a new graphic (picture below).

Report of the Director

All of us, due to the Covid pandemia, will well remember the year 2020. And, as we all know, it is still going on. The situation will also influence our activities in 2021 as it did in 2020. We had to postpone campaigns, working days as well as many visits, among them the visit of our former custodian couples at Jungfraujoch that was planned for May, 2020.

We were lucky that the 5th VAO Symposium could be held on February 4-6, 2020, just before the lock-down was announced by the Swiss Federal Government.

Figure 1. Participants of the 5th VAO Symposium held at the Department of Chemistry and Biochemistry of the University of Bern, Switzerland on February 4-6, 2020.

Figure 2. During the Welcome session: From right to left: Prof. Dr. Silvio Decurtins (President HFSJG), Prof. Dr. Christian Leumann, Rector University of Bern, Christoph Neuhaus, State Councillor of the Canton of Berne, Prof. Dr. Markus Leuenberger (Director HFSJG).

The symposium was opened by Prof. Dr. Markus Leuenberger as representative and co-organizer of the International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat.

Welcome speeches were given by Prof. Dr. Christian Leumann, Rector University of Bern, Dr. Christian Barth, Director General of the Bavarian Ministry of the Environment and Consumer Protection, Germany, Christoph Neuhaus, State Councillor of the Canton of Berne, Dr. Paul Steffen, Vice Director of the Federal Office for the Environment (FOEN), Dr. Petr Blížkovský, Secretary General Committee of the Regions and Prof. Dr. Michael Bittner, VAO Coordinator and Chair of the VAO Board.

A video welcome note was given by André Jol, Head of the Adaptation and LULUCF Division, European Environment Agency. As observers of the VAO spoke Prof. Dr. Michael Rast, European Space Agency and Dr. Marianne Elmi, Vice General Secretary of the Alpine Convention.

Figure 3. VAO Board, VAO observers (ESA and Alpine Convention) and the Secretary General of the Committee of the Regions of the European Union (right).

At Gornergrat, the Stellarium project has been attracting many pupils and students. Several Matura theses used data from Stellarium Gornergrat.

The Foundation HFSJG

In 2020, no Board meeting was held and the Board duties taken care of by mail confirmation. The activity report as well as the statement of accounts for the year 2019 have been approved. As of January 2020, Prof. Dr. Tong Zhu from the Peking University, China is the representative of the new member of the Republic of China in our Foundation HFSJG. A very warm welcome to our family.

As of January 2020, the Jungfraujoch Commission of the Swiss Academy of Sciences (SKHFJ) is newly presided by Prof. em. Dr. Urs Baltensperger. Due to the Covid-situation, no SKHFJ meeting was held in 2020.

The annual HFSJG user meeting took fortunately place at the University of Bern on September 11, 2020. The director informed the participants about SNF-subsidy, the different renovation work done or to be performed in our infrastructures in particular about the new air-conditioning system for the Sphinx laboratories and the new meteostation at the Jungfrau East Ridge station. Furthermore, about the Virtual Alpine Observatory initiative to establish a European Grouping of Territorial Cooperation (EGTC). Martin Gysel, PSI and Martin Steinbacher, Empa reported about updates of the European Infrastructure networks ICOS and ACTRIS. Lukas Emmenegger, Empa, reported about the collaborative effort to install a new heated inlet system with which we hope to circumvent local emission contamination by moving the intake away from the tourist terrace. Timm Riesen reported about the Stellarium

Gornergrat, its success to attract pupils as well as students using their facilities to investigate space objects.

Joan and Martin Fischer announced the termination of their working contract, after 20 years of engagement, per end of January 2021. Therefore, we initiated the search for these combined position of facility managers in August 2020. After the evaluation of 35 applications, we selected Daniela Bissig and Erich Furrer. We welcome them and wish them an excellent start as well as Joan and Martin Fischer all the best for upcoming activities.

Figure 4. Daniela Bissig/Erich Furrer (left, new custodians) and Joan and Martin Fischer (right, former custodians).

We sadly took notice of the decease of Prof. em. Dr. Hans Balsiger, a former president HFSJG, honorary president and enthusiastic promoter of the Stellarium Gornergrat project and an inestimable supporter of our Foundation HFSJG.

The High Altitude Research Station Jungfraujoch

The High Altitude Research Station Jungfraujoch was again very attractive for researchers. In 2020, 32 (2019: 35) research institutions were active at Jungfraujoch. About 25 of 40 (2019: 44) research projects at Jungfraujoch are automated and remotely accessible by their corresponding institutions.

The framing of our activities in international programmes is important. Among others, the following involvements are well established: The two programmes, Global Atmosphere Watch (GAW) and the Network of Detection of Atmospheric Composition Change (NDACC), can count on many projects conducted at Jungfraujoch. Of particular interest are the two European infrastructures ICOS (Integrated Carbon Observation System) with associated projects such as Ringo. Here the contract agreement between the HFSJG and partners with the ICOS-RI was initiated in 2020 and signed in early 2021. Additionally, ACTRIS (Aerosols, Clouds, and Trace gases Research InfraStructure Network) has been positively evaluated for becoming listed in the Swiss Roadmap of Research Infrastructures. In both networks Jungfraujoch is a central site. However, international embedment is not restricted to these networks but extends to a large variety of programmes, listed in Table 1.

In 2020, we started with replacing the air conditioning system at the Sphinx laboratories. The two new labs on level 1 have already been equipped in June 2020 with new units, which are driven by a heat exchanger that is placed in the Coudé Room under the Cupola. The second step will be made in May or June 2021 when we undertake a complete renovation of the lab on level 2. Additionally, a new heated inlet system has been installed in May 2020, it should allow us to circumvent local emissions as it accesses the air 80 meters away from the tourist terrace.

In 2020, projects with principal investigators from five different countries as displayed in Figure 5 could be welcomed and hosted at Jungfraujoch. When taking collaborations into account, the number of countries involved increases to 12 as visible in Figure 6. All this information can also be retrieved from the HFSJG Webpage: http://www.hfsjg.ch/jungfraujoch/researchprojects/overview.php

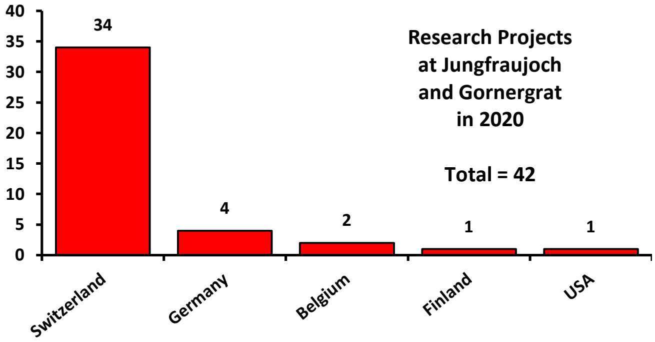

Figure 5. Number of research projects at the High Altitude Research Stations Jungfraujoch and Gornergrat in 2020 by country.

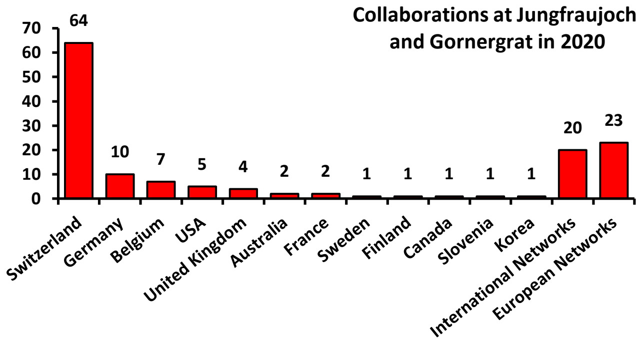

Figure 6. Number of collaborations at the High Altitude Research Stations Jungfraujoch and Gornergrat in 2020.

From experience over the last decades, the number of working days is varying quite strongly from year to year. This was up to now mainly due to the number of campaigns present during a year. In 2020, however, the Covid pandemic led to the lowest number of working days in the last 20 years. The number decreased from 707 in 2019 to 350 in 2020. The spent working days' distribution is also significantly less dispersed and is led by Swiss followed by German and US organisations as seen in Figure 8.

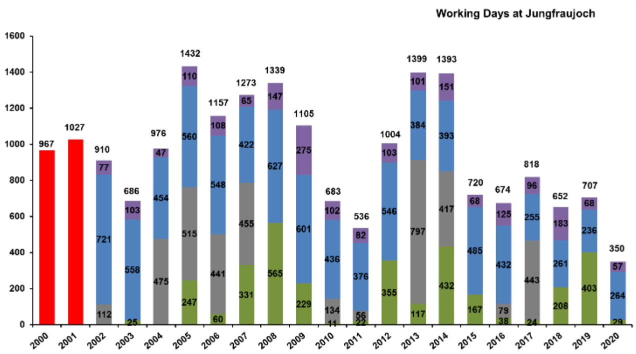

Figure 7. Number of working days spent by scientists at the High Altitude Research Station Jungfraujoch during the past years. The number is split into four categories since 2002, i.e. medical campaigns (green), CLACE campaign (grey), atmospheric research (blue), others (purple).

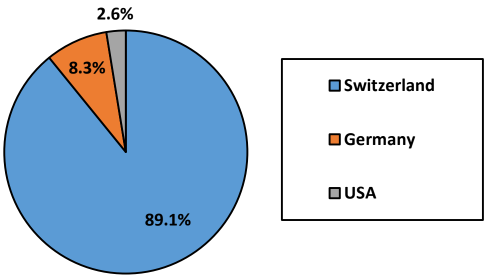

Figure 8. Percentage of person-working days in 2020 at the High Altitude Research Station Jungfraujoch per country.

The research conducted at Jungfraujoch resulted in the following output in 2020:

- 26 refereed publications
- 38 conference presentations / posters
- 1 popular publications and presentations
- 10 data publications and reports
- 2 bachelor- (0), master- (2) and PhD (0) theses
- 1 book / edited books

Jungfraujoch research was presented once again at many national and international conferences in 2020 including:

5th Virtual Alpine Observatory Symposium, Bern, Switzerland, February 4-6, 2020; European Geosciences Union General Assembly 2020, virtual conference, Austria, May 4-8, 2020; Swiss Chemical Society Fall Meeting, virtual conference, Switzerland, August 24-25, 2020; ICOS Science Conference, virtual conference, Liechtenstein, September 15-17, 2020; 18th Swiss Geoscience Meeting, virtual, November 6, 2020; Joint GAW Web Meeting of Expert Team- Atmospheric Composition Measurement Quality (ET-ACMQ) and QA-Central Facilities (QA-CF's), virtual, September 29, 2020; BMKG focus group discussion, virtual conference, November 12, 2020; GAWTEC webinar, virtual, December 7, 2020; ICOS CH National Meeting, virtual, September 3, 2020; WMO/GAW report #255, World Meteorological Organisation, 2020; American Geophysical Union Fall Meeting 2020, December 1-17, 2020, (virtual conference due to CoViD-19); European Aerosol Conference, Aachen, Germany, August 31 – September 4, 2020 (virtual conference due to CoViD-19);

Regarding research, I would like to highlight three investigations: (i) Trends of atmospheric water vapour in Switzerland from ground-based radiometry, FTIR and GNSS data from the Automated GNSS Network Switzerland (AGNES); (ii) Separating 'free tropospheric conditions' from those 'influenced by the planetary boundary layer'; (iii) Bats recordings at Jungfraujoch.

(i) Vertically integrated water vapour (IWV) is expected to increase globally in a warming climate. To determine whether IWV increases as expected on a regional scale, we present IWV trends in Switzerland from groundbased remote sensing techniques and reanalysis models, considering data for the time period 1995 to 2018. We estimate IWV trends from a ground-based microwave radiometer in Bern, from a Fourier transform infrared (FTIR) spectrometer at Jungfraujoch, from reanalysis data (ERA5 and MERRA-2) and from Swiss ground-based Global Navigation Satellite System (GNSS) stations. Using a straightforward trend method, we account for jumps in the GNSS data, which are highly sensitive to instrumental changes.

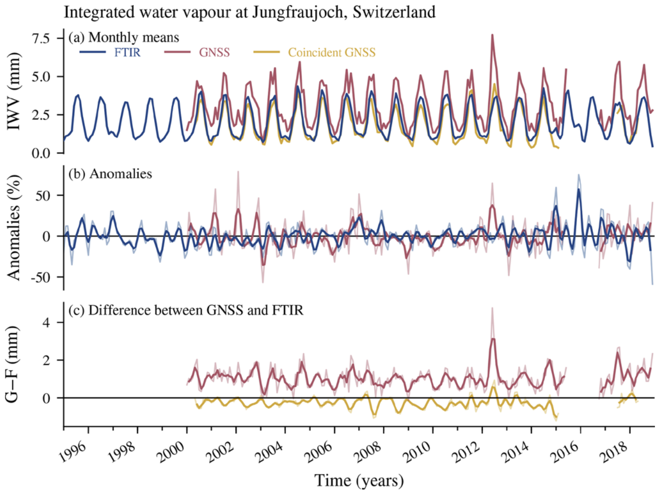

Figure 9. Monthly means of IWV from the FTIR spectrometer and the GNSS station at Jungfraujoch (Switzerland). Shown are GNSS means once using the full hourly sampling and once using data only at the same time as the FTIR measured (coincident GNSS). The monthly means of FTIR and coincident GNSS have been resampled to correspond to the 15th of each month. (b) Anomalies from the climatology((data climatology)=climatology) for FTIR data and fully sampled GNSS data. (c) Differences between GNSS (G) and FTIR (F) data, using the full GNSS data and GNSS data coincident with the FTIR. The bold lines in (b) and (c) show the data smoothed with a moving mean window of 3 months; the thin pale lines show the unsmoothed monthly data.

We found that IWV generally increased by 2% per decade to 5% per decade, with deviating trends at some GNSS stations. Trends were significantly positive at 17% of all GNSS stations, which often lie at higher altitudes (between 850 and 1650m above sea level). Our results further show that IWV in Bern scales to air temperature as expected (except in winter), but the IWV– temperature relation based on reanalysis data in the whole of Switzerland is not clear everywhere. In addition to our positive IWV trends, we found that the radiometer in Bern agrees within 5% with GNSS and reanalyses. At the Jungfraujoch high-altitude station, we found a mean difference of 0.26mm (15 %) between the FTIR and coincident GNSS data, improving to 4% after an antenna update in 2016. In general, we showed that ground-based GNSS data are highly valuable for climate monitoring, given that the data have been homogeneously reprocessed and that instrumental changes are accounted for. We found a response of IWV to rising temperature in Switzerland, which is relevant for projected changes in local cloud and precipitation processes.

Bernet, L., Brockmann, E., Von Clarmann, T., Kämpfer, N., Mahieu, E., Mätzler, C., Stober, G., and Hocke, K. (2020). Trends of atmospheric water vapour in Switzerland from ground-based radiometry, FTIR and GNSS data.

(ii) Land surfaces are the source of radon in the atmosphere, where its sole sink is radioactive decay (half-life: 3.8 days). Thus, radon is a tracer of recent land contact of an air mass and it indicates, in principle, whether a measurement was *'influenced by the planetary boundary layer'*. The PDF of the log-transformed values can closely be reproduced by the sum of two fitted normal distributions. They most likely represent air masses *'influenced by the planetary boundary layer'* and *'free tropospheric conditions'* (Figure 1). Other allocations of the two distributions, say to summer and winter, or

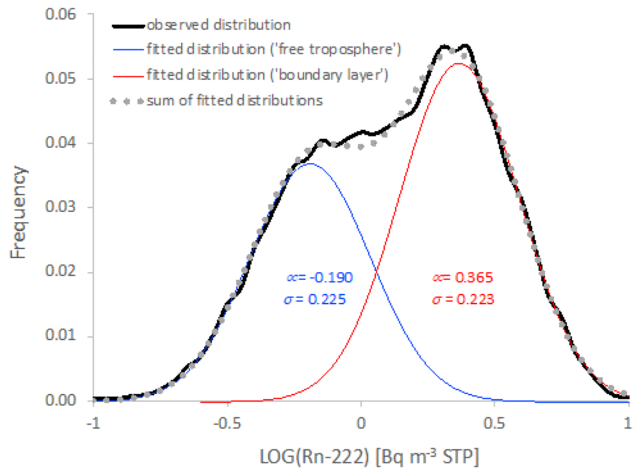

Figure 10. Probability density function (PDF) of radon concentration values (log-transformed) observed during the past five years at Jungfraujoch. The observed PDF is closely reproduced by the sum of two weighed PDFs most likely representing 'free troposphere' and air masses influenced by the 'boundary layer'.

southern and northern approach of air masses seem less likely because the differences in radon concentrations between these categories are less pronounced and not so systematic. The best-matching relative weights found in the fitting process were 0.415 for the PDF 'free troposphere' and 0.585 for the PDF 'boundary layer'. In other words, *'free tropospheric conditions'* seem to have occurred over the past five years less often (41.5%) than conditions *'influenced by the planetary boundary layer'* (58.5%).

(iii) In 2011 (May, Aug, Sept, Oct), using a batlogger, we detected for the first time that bats fly over the Jungfraujoch. A crossing of such high altitudes in the alpine region in connection with seasonal migration was unknown until then (Zingg & Bontadina 2016).
In 2020, the highest number of bat call sequences was recorded when the median air temperatures at night was above 0°C. Ten bat species and one unidentified call (rodent?) could be detected acoustically from May to October 2020.
In terms of altitude and weather conditions, the Jungfraujoch in Switzerland is a border zone for many living creatures. The infrastructure of the research station makes it possible to carry out studies on living organisms in this border zone that would otherwise not be possible. Studies on organisms in extreme areas provide information about their plasticity and temporary adaptability. Long-term monitoring at such extreme places contributes valuable information on seasonal variations and the consequences of climate change.

Zingg, P.E., Bontadina, F. 2016. Migrating bats cross top of Europe. PeerJ Preprints 4:e2557v1. https://doi.org/10.7287/peerj.preprints.2557v1

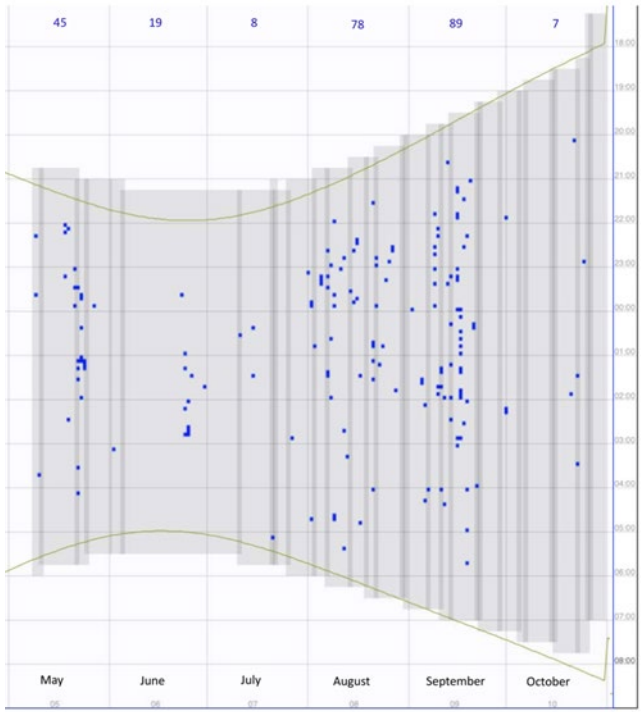

Figure 11. Temporal distribution of bat call sequences recorded by the batlogger C at the research station during the nights from 8 May to 29 October 2020. Horizontal axis: months May to October; vertical axis: nighttime between sunset (upper green line) and sunrise (lower green line). The grey vertical shading shows the nocturnal operating time of the batlogger (overlaps of the grey shading have no meaning). Numbers at the top of the image: Monthly sum of sequences with bat echolocation calls. A blue dot represents all sequences with bat echolocation calls within a 5-minute interval.

Additional scientific highlights were published in several peer-reviewed journals:

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- Blumenstock, T., et al., Characterisation and potential for reducing optical resonances in FTIR spectrometers of the Network for the Detection of Atmospheric Composition Change (NDACC), accepted for publication in Atmos. Meas. Tech., 2020, 1–17, doi: 10.5194/amt-2020-316, in press.
- Brunner, C. and Z.A. Kanji, Continuous online-monitoring of Ice Nucleating Particles: development of the automated Horizontal Ice Nucleation Chamber (HINC-Auto), Atmos. Meas. Tech. Discuss. [preprint], https://doi.org/10.5194/amt-2020-306, *in press*, 2020.
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Table 1. List of major nationally and internationally coordinated networks and/or research programs where Jungfraujoch is a key station.

NDACC	Network for the Detection of Atmospheric Composition Change Primary Site (https://www.ndsc.ncep.noaa.gov/)
GAW, GAW-CH	Global Atmosphere Watch, Global GAW Station (https://community.wmo.int/activity-areas/gaw , and http://www.meteoschweiz.admin.ch/home/forschung-und-zusammenarbeit/internationale-zusammenarbeit/gaw.html)
GAW-PFR	GAW Aerosol Optical Depth (AOD) Network (https://www.pmodwrc.ch/weltstrahlungszentrum/worcc/gaw-pfr-network/)
GCOS	Global Climate Observing System (http://www.wmo.int/pages/prog/gcos/)
GCOS-CH	Swiss GCOS office (http://www.meteoschweiz.admin.ch/home/forschung-und-zusammenarbeit/internationale-zusammenarbeit/gcos.html)
AGAGE	Advanced Global Atmospheric Gases Experiment Collaborative Sampling Station (http://agage.eas.gatech.edu/)
NADIR/NILU	NILU's Atmospheric Database for Interactive Retrieval (http://www.nilu.no/nadir/)
EUMETNET	Network of European Meteorological Services (http://www.eumetnet.eu/)
SwissMetNet	Automatic Measuring Network of MeteoSwiss (http://www.meteoschweiz.admin.ch/home/mess-und-prognosesysteme/bodenstationen/automatisches-messnetz.html)
RADAIR	Swiss Automatic Network for Air Radioactivity Monitoring (https://www.naz.ch/en/themen/messnetze.html)
ICOS	Integrated Carbon Observation System (https://www.icos-ri.eu/)
NADAM	Netz für automatische Dosis-Alarmierung und Meldung https://www.naz.ch/
NABEL	Nationales Beobachtungsnetz für Luftfremdstoffe - National Air Pollution Monitoring Network (https://www.bafu.admin.ch:NABEL)
AGNES	Automated GPS Network for Switzerland (http://www.swisstopo.ch/pnac)
PERMASENSE	Wireless Sensing in High Alpine Environments (http://www.permasense.ch/)
PERMOS	Permafrost Monitoring Switzerland (http://www.permos.ch/)
NMDB	Real-Time Database for High Resolution Neutron Monitor Measurements (http://www.nmdb.eu)
E-GVAP I + II	The EUMETNET GPS Water Vapour Programme (http://eumetnet.eu/)
ACTRIS	ACTRIS is the European Research Infrastructure for the observation of Aerosol, Clouds, and Trace gases (http://www.actris.eu/)
Swiss Glacier Monitoring Network	Federal Office for the Environment (BAFU) (https://www.glamos.ch/)
EARLINET-ASOS	European Aerosol Research Lidar Network – Advanced Sustainable Observation System (http://www.earlinetasos.org)
NORS	Network of Remote Sensing (http://nors.aeronomie.be)
AGACC-II	Advanced exploitation of Ground based measurements, Atmospheric Chemistry and Climate applications (http://agacc.aeronomie.be)
EMEP	European Monitoring and Evaluation Programme (http://www.emep.int)
GAIA-CLIM	Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring (http://www.gaia-clim.eu/)
QA4ECV	Quality Assurance for Essential Climate Variables (http://www.qa4ecv.eu/)
Ringo	Readiness of ICOS for Necessities of integrated Global Observations (https://www.icos-ri.eu/ringo)

Most of the measurements made at Jungfraujoch are publicly available via the respective databases, many of them in real or near real-time. Further information can be found at www.hfsjg.ch.

As expected, there was a substantial reduction in number of visitor groups in our infrastructures at Jungfraujoch and Gornergrat.

A selection of additional individual and group visitors in 2020 is given in the following:

- LUDOK/Swiss Tropical and Public Health Institute, 11.03.2020
- Prof. Joel Mesot, ETHZ-Präsident, Prof. Martin Vetterli, EPFL-Präsident und Journalisten Ringier-Verlag, 12.07.2020
- Kantonsschule Seetal, 10.08.2020
- EPFL students, 21.08.2020
- MIRO Analytical AG, 10.09.2020
- Gymnasium Liestal, Basel, 17.09.2020
- Gymnasium Neufeld, Bern, 18.09.2020
- Architekturdepartement ETH Zürich, 13.10.2020
- Gymnasium Thun, 19.10.2020

Regarding Jungfrau East Ridge (JER), the measurements are ongoing. Two studies using data from the East Ridge are now accepted for publication. Both discuss differences in aerosol loads and CO_2 concentrations between the two Jungfraujoch sites, Sphinx and East Ridge observatories. This is a first major step of making this new location visible for a wider science community. Furthermore, the meteostation has finally been installed at the East Ridge. It contains a 3D as well as a 2D wind sensor complemented by a pressure, temperature and relative humidity sensor.

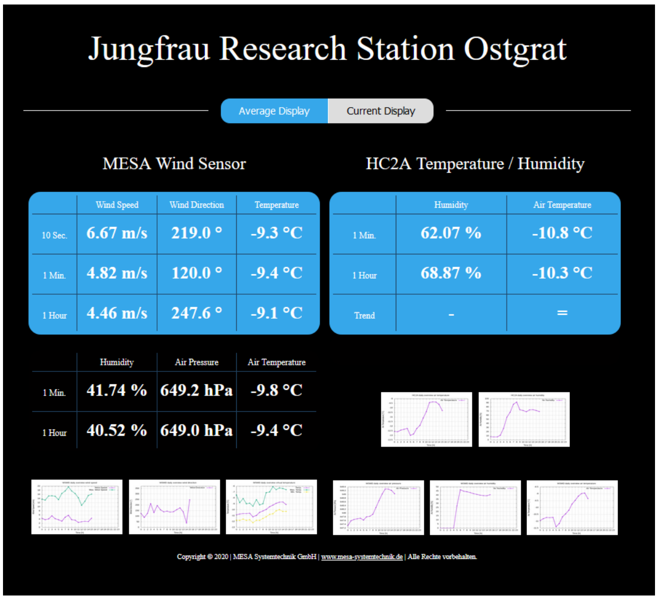


Figure 12. Average display of the 2D sensor data of the MESA Systemtechnik GmbH.

In 2020, a significant reduction of media attention was observed due to the Covid-situation. In 2020 18 (2019: 55) reports featuring our activities were available through television (2) and radio (1) broadcasts as well as printed articles (8) and reports on the internet (7). See section "The International Foundation HFSJG in the News".

Most of the measurements made at Jungfraujoch are publicly available via the respective databases, many of them in real or near real-time. Further information can be found at www.hfsjg.ch.

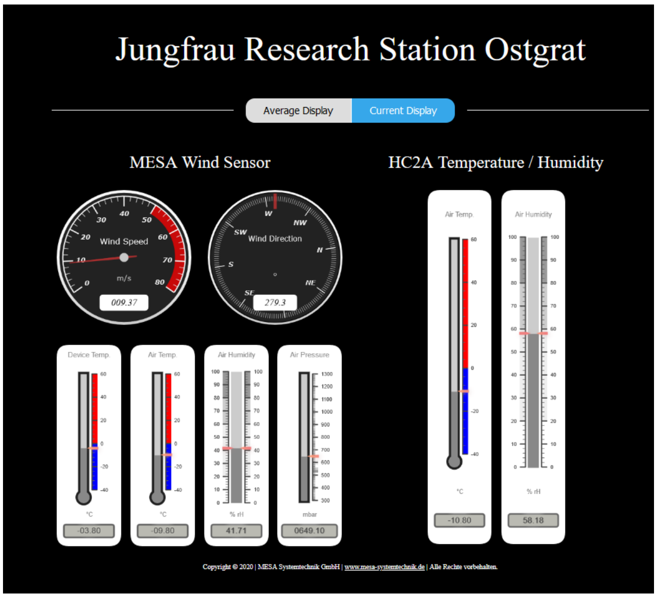


Figure 13. Current display of the 2D sensor data of the MESA Systemtechnik GmbH.

Also due to the Covid-situation, the annual coordination meeting for all institutions working at Jungfraujoch was cancelled. The new person in charge for the infrastructure and technique of the Jungfrau Railway (JB) is Dominik Liener. Markus Balmer terminated his contract with the JB in summer 2020.

The High Altitude Research Station Gornergrat

"Stellarium Gornergrat" was the only project ongoing at Gornergrat in 2020. A total of 47 working days was spent at Gornergrat (Figure 14). An incredible high number of 606 visitors were attending tours, professionally guided by Dr. Timm Riesen at the Gornergrat Observatory. Again Stellarium Gornergrat – the public outreach project – is performing well. More about observation and pedagogical activities can be found in the report about "Stellarium Gornergrat".

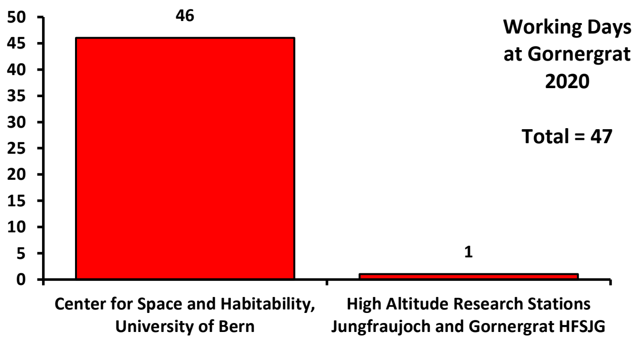


Figure 14. Number of working days at the High Altitude Research Station Gornergrat in 2020 by research groups.

Summary and Acknowledgements

Last year I wrote that 2019 was exceptional. Indeed, it was exceptional with the two awards received. But the year 2020 is an extraordinary year. The Covid pandemia changed most of our daily behaviour. We experienced this hardly imaginable situation in many aspects, as for instance through restrictions in our mobility, the regulations for and postponements of campaigns, the significant reduction of overnight stays of scientists and partly also in the accessibility to our facilities.

This very difficult and new situation has been managed and dealt with patience, social and personal responsibilities, foresight by our custodians, scientists, HFSJG staff at Bern as well as our partners at Jungfraujoch and Gornergrat. I would like to express my sincere thanks to all of you.

Despite these difficult times, we still can report about positive outcomes in 2020 as for instance the installation of the new heated inlet system, a truly collaborative effort among the different organisations of Empa, HFSJG, PSI, UBern as well as companies such as Hillesheim GmbH, Rock Tec AG, Air Glacier etc. Similarly, the installation of the new meteostation at Jungfrau East Ridge that delivers data since last autumn 2020. Not to forget the installation in parts of the new air conditioning units at the Sphinx observatory.

As every year so far, I am very happy to report about an impressive amount of outcomes from the two Research Stations Jungfraujoch and Gornergrat. From a high number of peer-reviewed publications, over conference contributions to public outreach activities including public lectures, etc. Congratulations to all the contributors. I very much appreciate your work that shows the public and me that you make use of our infrastructure in a tremendous and efficient way. Thank you very much.

The year 2020 has been a wonderful but also very harsh year economically for the Jungfrau Railways:

Wonderful with the successful construction of the complex V-Cableway project and its opening on December 5, 2020 as announced since a couple of years. This is truly a masterpiece of work, as a Swiss clock, based on dedicated planning and controlling of every puzzle piece exactly at the right time. Congratulations to everybody who contributed to this achievement.

Harsh when considering the restrictions that had to be faced by the Jungfrau Railways with the lock-down in spring 2020 and ongoing mobility restrictions that influenced the touristic sector massively.

I wish the Jungfraubahn Holding AG improved conditions without restrictions that many tourists can visit and enjoy the impressive attractions at Jungfraujoch and its surroundings. I am convinced that the Jungfraubahn Holding AG under the leadership of Prof. Thomas Bieger, president of the Board and Mr. Urs Kessler, Chief Executive Officer will manage these economic losses induced by the pandemia and soon flourish again. I wish them all the best in the years to come.

We are very thankful to receive support from many different sections at Jungfraujoch to run our infrastructures, namely Mr. Markus Balmer (Head of Jungfrau – Top of Europe) and to his successor Dominik Liener, Stefan Würgler (Head of operations), the Jungfraubahn Holding AG, the technical services (Mr. Andreas Wyss and his team). Thank you very much.

“Stellarium Gornergrat” has reached the adult phase and steadily extends its network with attractive undertakings for the public and guests at Gornergrat such as “Dining with the stars” and the guided tours by the managing director Dr. Timm Riesen. He writes in his report that the “Stellarium Gornergrat” supported several matura theses, one of which was dealing with a successful exoplanet transit. Congratulations to the “Stellarium Gornergrat” team. The success would not have been possible without the dedicated promotion by Mrs. Nicole Marbach and Mr. Thomas Marbach at the Kulmhotel Gornergrat. Hospitality is a key part of success, as nicely demonstrated at Gornergrat.

Similarly, as with the Jungfrau Railways, these times are very difficult for the Burgergemeinde Zermatt and Gornergrat Railways due to reductions in frequencies using their infrastructures. Therefore, we are very grateful for their support of the Foundation’s activities. I cordially thank Mr. Andreas Biner, president and Mr. Fernando Clemenz and Mr. Leo Schuler of the Burgergemeinde Zermatt. Mr. Jean-Pierre Schmid, president and Mr. Fernando Lehner, Chief Executive Officer and his representative in the HFSJG Board, Mr. Marcel Mooser and Mr. René Bayard of the Matterhorn Gotthard Railway and the Gornergrat Railway for their support regarding person and material transport. Thank you all very much for your continued support.

This year was also very demanding for our administrative staff at Bern. Home office was on the agenda for an extended period and still continues. Here I would like to thank in particular Dr. Rolf Bütikofer (IT responsible person) who well managed the steadily increasing demands. Thank you Rolf. Mrs. Claudine Frieden (secretary) guaranteed a smooth operation of the Foundation as every year despite a reorganisation of her office to the home-office. I also would like to thank Mr. Karl-Martin Wyss for his competent services as our treasurer, Mrs. Theres Trachsel for the bookkeeping, and the CORE Treuhand Cotting AG, Bern (Mr. Harro Lüdi) for the professional auditing.

The University of Bern is not only a member of our Foundation but supports us in many ways, for instance when organizing symposia as done again in the last year. Therefore, I express my sincere thanks to its Rector Prof. Dr. Christian Leumann for his participation and welcome speech at the opening session of the 5th VAO symposium and the continued support of our Foundation, for the hospitality and for the support of our administration. I like to thank the Physics Institute for hosting the office of Stellarium Gornergrat within their Centre for Space and Habitability.

Finally, I would particularly like to thank Prof. Dr. Silvio Decurtins for his committed work as president of our Foundation. He consequently and convincingly promotes our Foundation.

I conclude by saying hope dies last, better times will come. I would love to welcome you on Top of Europe or on Gornergrat in our research infrastructures. On behalf of the Directorate HFSJG, best regards to all of you.

M. Leuenberger

Bern, February 19, 2021 Markus Leuenberger

Research statistics for 2020

High Altitude Research Station Jungfraujoch

Institute	Country	Research with overnight stay	Research during the day only
Institute for Atmospheric and Climate Science, ETH Zurich	Switzerland	43	18
Dr. med. Rainald Fischer, Lungenärztliche Praxis München	Germany	29	
Empa, Swiss Federal Laboratories for Materials Testing and Research	Switzerland	26	49
Klima- und Umweltphysik, Physikalisches Institut, Universität Bern	Switzerland	14	12
Amt für Geoinformation, Baselland	Switzerland	11	3
University of Denver	USA	9	
Laboratory of Atmospheric Chemistry, Paul Scherrer Institute	Switzerland	5	12
Laboratory of Environmental Chemistry, Paul Scherrer Institute	Switzerland	5	
Armasuisse Wissenschaft und Technologie	Switzerland	4	6
Berner Fachhochschule, Technik und Informatik, Photovoltaiklabor, Burgdorf	Switzerland	4	1
Bundesamt für Landestopografie swisstopo	Switzerland	4	1
Bundesamt für Gesundheit	Switzerland	4	
Geographical Institute, University of Zürich	Switzerland	4	
VAW-Glaziologie, ETH Zürich	Switzerland	3	5
Physikalisches Institut, Universität Bern (Cosmic Rays)	Switzerland	2	6
Institut für Geologie, Universität Bern	Switzerland	2	3
Institut für Umweltwissenschaften, Universität Basel	Switzerland	1	1
Physikalisch-Meteorologisches Observatorium PMOD, World Radiation Center WCR, Davos	Switzerland	1	
Zürcher Hochschule der Künste	Switzerland	1	
MeteoSwiss, Payerne	Switzerland		22
University of Bern, Department of Chemistry and Biochemistry	Switzerland		21
International Slackline Association, Bern	Switzerland		7
ETH Zürich, Permasense	Switzerland		5
Bat research conservation & consulting BRCC	Switzerland		4
Institute of Veterinary Physiology, University of Zurich	Switzerland		2
TOTAL		**172**	**178**

	Overnight stays	Visits with no overnight stay
Visitors, workers	859	
Media / film / TV and radio	9	6
HFSJG administration	3	9
Total including researchers	**1043**	**193**

Long-term experiments and automatic measurements at the High Altitude Research Station Jungfraujoch

Institute	Experiment / Measurements
Institut d'Astrophysique et de Géophysique de l'Université de Liège B-4000 Liège	Atmospheric physics and solar physics
Royal Belgian Institute for Space Aeronomy B-1180 Brussels	Atmospheric physics and atmospheric chemistry
Federal Office of Meteorology and Climatology MeteoSwiss CH-1530 Payerne	Atmospheric physics and atmospheric chemistry (radiation measurements) Global Atmosphere Watch Radiation Measurements
Federal Office of Meteorology and Climatology MeteoSwiss CH-8044 Zürich	Weather observations
Bundesamt für Landestopographie swisstopo CH-3084 Wabern-Bern	Automated Global Positioning System Network AGNES
Paul Scherrer Institute Laboratory of Atmospheric Chemistry CH-5232 Villigen PSI	Atmospheric physics and atmospheric chemistry
Paul Scherrer Institute Laboratory of Atmospheric Chemistry CH-5232 Villigen PSI	The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS)
Paul Scherrer Institute Laboratory of Atmospheric Chemistry CH-5232 Villigen PSI	Global Atmosphere Watch (GAW) Aerosol Program
Physikalisch-Meteorologisches Observatorium Davos World Radiation Center CH-7260 Davos Dorf	Solar and terrestrial radiation measurements and Aerosol depth monitoring
Empa - Swiss Federal Laboratories for Materials Science and Technology CH-8600 Dübendorf	Atmospheric chemistry (O_3 - and NO_x measurements) and National Air Pollution Monitoring Network (NABEL)
Empa - Swiss Federal Laboratories for Materials Science and Technology CH-8600 Dübendorf	Halogenated greenhouse gases and Advanced Global Atmospheric Gases Experiment (AGAGE)
Empa - Swiss Federal Laboratories for Materials Science and Technology CH-8600 Dübendorf	Continuous measurements of stable CO_2 isotopes
Empa - Swiss Federal Laboratories for Materials Science and Technology CH-8600 Dübendorf	Integrated Carbon Observation System Switzerland (ICOS-CH)
Abteilung für Weltraumforschung und Planetologie Physikalisches Institut Universität Bern CH-3012 Bern	Astrophysics (cosmic ray measurements)
Berner Fachhochschule Technik und Informatik Photovoltaik-Labor CH-3400 Burgdorf	Photovoltaic power plant
Universität Heidelberg Institut für Umweltphysik D-69120 Heidelberg and Abteilung für Klima- und Umweltphysik Universität Bern CH-3012 Bern	Long term observations of $^{14}CO_2$
Abteilung für Klima- und Umweltphysik Universität Bern CH-3012 Bern and Bundesamt für Strahlenschutz D-78098 Freiburg i.B.	^{85}Krypton measurements
Abteilung für Klima- und Umweltphysik Universität Bern CH-3012 Bern	High precision carbon dioxide and oxygen measurements
Abteilung für Klima- und Umweltphysik Universität Bern CH-3012 Bern	Flask comparison of CO_2 and O_2/N_2 on Jungfraujoch
Max Planck Institut für Biogeochemie D-07745 Jena	Flask comparison of CO2 and O2/N2 on Jungfraujoch
Eawag CH-8600 Dübendorf	7Be and 10Be in monthly precipitation

Institute	Experiment / Measurements
Abteilung für Klima- und Umweltphysik Universität Bern CH-3012 Bern	Water isotope measurements on monthly integrated precipitation samples
Nationale Alarmzentrale Bundesamt für Bevölkerungsschutz CH-8044 Zürich	NADAM Automatic Dose Alarm and Monitoring Network (ambient dose rate)
Bundesamt für Gesundheit CH-3003 Bern	RADAIR Measurements of radioactivity in the air and DIGITEL aerosol sampler
VAW Laboratory of Hydraulics, Hydrology and Glaciology ETH Zürich CH-8092 Zürich	Glacier measurements
Swiss Federal Institute for Snow and Avalanche Research SLF CH-7260 Davos Dorf	Permafrost monitoring in the Jungfrau East Ridge
Department of Geography University of Zürich CH-8057 Zürich	Permasense: Permafrost monitoring in alpine rock walls
Institut für Umweltgeowissenschaften Universität Basel CH-4056 Basel	Measurement of ^{222}Rn for atmospheric tracer applications

The new 2020 air sampling inlet system at Jungfraujoch

Martin K. Vollmer[1], Martin Steinbacher[1], Markus C. Leuenberger[2,3], Lukas Emmenegger[1]

[1] Laboratory for Air Pollution / Environmental Technology, Empa, Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland
[2] Climate and Environmental Physics, Physics Institute and Oeschger Centre for Climate Change Research, University of Berne, Switzerland
[3] International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat, Sidlerstrasse 5, Bern, Switzerland

martin.vollmer@empa.ch

Part of this programme: CLIMGAS-CH, ICOS, AGAGE, GAW, NABEL

Keywords: atmospheric chemistry; air sampling

1. Project initiation

At the Jungfraujoch atmospheric research station, the current main inlet for trace gas observations was installed in 1994 next to the sphinx cupola, about 5 m above the upper research platform and about 10 m above the tourist platform (Photograph 1). It is a heated stainless steel inlet reaching approximately 2 m above the laboratory roof with an inner diameter (ID) of 90 mm and a very high flow rate of 50 m^3 h^{-1}. The air stream temperature at the lower end of the main manifold is kept at 10 °C. In the laboratory, the inlet is equipped with a manifold, where individual instruments draw sample air. About 10 years ago, it was realized that local emissions from the nearby tourist infrastructure are occasionally contaminating the atmospheric samples.

Photograph 1. Preexisting air inlets at Jungfraujoch: Left) Main air inlet for trace gases next to Sphinx cupola. Right) Inlet for aerosols. Both inlets remain active. Photographs: left, Empa, right, M. Vollmer.

2. Preliminary inlet system

Thus, in August 2012, a custom-built air inlet (called 2012-Mönch inlet) was placed to the end of the ridge, ~30 m NE of the tourist platform (Photograph 2). The inlet served for halocarbon measurements (HALCLIM / CLIMGAS-CH projects) and eliminated the significant contaminations of the hydrochlorofluorocarbons (HCFCs) HCFC-22 and HCFC-142b that were previously observed at the main cupola inlet system.

Photograph 2. Aerial view of Jungfraujoch from north. The main air inlet is positioned ~1 m to the left of the cupola (solid arrow). The 2012-Mönch inlet is visible as a small structure in the snow to the very left at the edge of the ridge (dashed arrow). It was replaced by the 2020 inlet at the same location. Photograph: Jungfrau Railways.

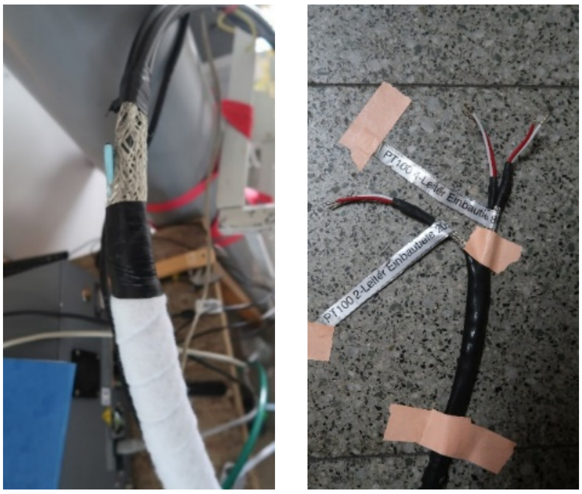
In its latest design, the 2020-Mönch inlet consisted of a cone-shaped aluminum head which held the sampling tube in place (no filters used), and which was protected by a reversed aluminum cup. It was mounted on a vertical bar, fixed in the rock, and extended to about 1.5 m above the rocky ground to prevent the inlet cup from being covered in snow. The sampling tube (1/2" OD Synflex 1300) was unprotected and unheated, and led along the ridge and under the tourist platform to the N-facing wall of the Sphinx, from where it extended vertically and through the pump room exhaust pipe into the laboratory on the 2nd floor. Overall, this inlet system allowed meaningful measurements of HCFC-22 and HCFC-142b. However, occasional difficulties arose, such as physical damage and snow up, the latter leading to depletion of halogenated compounds (mainly CH_3Cl and CH_3Br) or complete clogging by snow and ice.

3. Project description

In 2019, the need for an improved, heated inlet system and additional sampling lines led to the design of the new 2020 inlet. This new system consists of three heated bundles of three sampling tubes each in a flexible pipe for physical protection.

All air sampling tubes were originally ~100 m long. Seven of them are SERTOflex (12 mm OD, 8.1 mm ID, Serto AG, Frauenfeld, Switzerland), which is of identical structure than Decabon / Synflex 1300, with an innermost ethylene copolymer coating on a slit overlapping aluminum layer, and an outer high-density polyethylene jacket. One tube is made of perfluoroalkoxy alkane (PFA) polymers (12 mm OD, 10 mm ID, purchased at PKM SA, Lyss, Switzerland; manufacturer: Camitec, Recklinghausen, Germany), and the last tube is an antistatic polytetrafluoroethylene (PTFE) tube (12 mm OD, 10 mm ID) (purchased at Walter Krebs Labortechnik + Handel, Maintal, Germany; manufacturer: Bola). The latter two were added for sampling of reactive gases (PFA) and aerosols (antistatic PFTE).

Bundles of 2 × 3 SERTOflex tubes and one with the remaining three tubes were assembled to heated bundles (Bundles, A, B, and C, respectively) at Hillesheim GmbH (Waghäusel, Germany). Three tubes and a self-regulating heating band (HBR-Illw-10) were wrapped with a steel mesh for improved heat conduction, followed by an insulation layer, and covered with a polyamide (PA6) mesh (Photograph 3). Two PT-100 temperature sensors were originally installed after about 20 m and 80 m in each bundle. The bundles are protected by a flexible corrugated polyamide tube (Hillesheim, PA12, 54.1 mm OD). The heated end at the inlet side is sealed to prevent humidity from entering the bundles. At this end, the polyamide mesh covering heating tape, tubes and insulation form a sling to facilitate the installation on the rock. The bundles weigh each about 100 kg.



Photograph 3. Details for heated bundles. Left) Heating band (light blue), metal mesh, and insulating tissue (white) for one bundle of three tubes. Right) PT-100 sensors. Photographs: M. Vollmer.

Further protection is provided by a polyethylene high-density (PEHD) corrugated pipe (Mauderli, Schachen, Switzerland, UG-Agroplast SN4, DN 150, 0.96 kg m^{-1}) with 140 mm ID, 160 mm OD.

4. Assemblage and Transport

The Covid-19 pandemic caused largely reduced tourist traffic, allowing for the use of the Grindelwald Grund tourist bus parking lot for insertion of the three bundles into the protective pipe (Photograph 4). The bundles were individually marked at 1 m intervals with colored tape. In addition to the three bundles, an electrical power cable (3 × 2.5 mm^2) and an additional pulling rope were inserted into the pipe. The entire tube/pipe assemblage (~400 kg) was coiled and transported to the Jungfraujoch tourist platform by helicopter (Photograph 4).

Photograph 4. Assemblage and transport of the air inlet tubing: Left) Insertion of three bundles of heated tubing into protective pipe at the Grindelwald Grund tourist bus parking lot (photograph M. Vollmer). Right) Transport of coiled assemblage to Jungfraujoch (photograph: R. Käser).

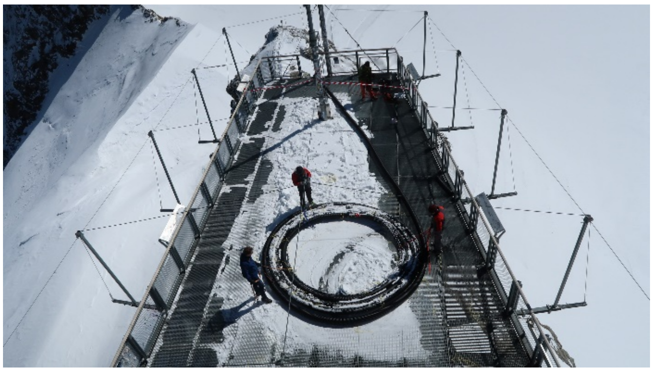
5. Installation

Installation of the inlet line assemblage was conducted by Rock Tec (Schattenhalb, Switzerland) on 6/7 May 2020, in collaboration with employees of the Jungfrau Railways, Empa scientists, HFSJG research station personnel, and others. The projected path for the tubing is shown in Photograph 5.

Photograph 5. Projected routing for the assemblage consisting of the protective pipe with the nine inlet tubes. Photograph: Rock Tec.

The inlet-side was drawn onto the ridge extending NE from the tourist platform (Photograph 6) and secured to the rock with clamps (Photograph 7). Following this, the building-side end was uncoiled and fitted onto the T-beams underneath the tourist platform. Next, the inlet line assemblage was fed into the building through a core-drilled hole into the Sphinx basement room adjacent to the door-accessible upper part of the old elevator shaft (Photograph 8).

The protective pipe was removed from the indoor section, leaving ~75 m of protected outdoor pipe. There is a pipe union at 50 m from the inlet, connecting the two individual pipe sections.



Photograph 6. Uncoiling the air inlet tube assemblage from the tourist platform to the inlet at the end of the ridge. Photograph: M. Guillevic.

Photograph 7. Tube assemblage. Photograph: M. Vollmer.

The three bundles were routed into the old elevator shaft and mounted vertically on its SW wall and through an obsolete duct in the wall to the 1st floor into the original 'dark' room (earlier used for photo film development), adding a length of about 11 m. The custom-made heating control system is also in this room. The remaining bundles' ~7–10 m long heating mesh, insulation and corrugated PA tubing was removed, leaving ~9–12 m of bare sample tubing to be routed to the individual end-point uses. Temperatures were found in the range 9–11 °C in the basement and 4–6 °C in the elevator shaft for the measurement period 1–15 April 2020.

Photograph 8. Feedthrough of inlet assemblage from outdoor (left) into Sphinx basement, and feedthrough to the old elevator shaft (right). The three bundles of heated inlet tubes and the electrical cable (grey) are routed to the first floor. A spare pull-through string (yellow) was left in the pipe. The brake-through to the outside and the protective pipe end were foamed, the latter fitted with a small (outside capped) tube (black, downward facing) for potential air purging of the protective pipe. Photograph: M. Vollmer.

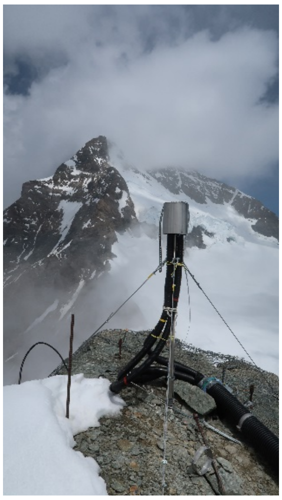
A new inlet head and cup were designed by Empa and installed along with the new tubing. The cone-shaped aluminum head is 1.3 m above ground and fits nine tubes. A reversed aluminum cup (20 cm diameter, 26 cm height) is mounted onto the inlet head for protection. The head is fitted to a stainless steel mounting pole (36 mm ID, 3.2 mm wall thickness), which is put over a steel bar that is placed in a ~1 m pre-drilled hole. The mounting pole is anchored with wires (Photograph 9). These also serve as lightning conductor as does a metal band, which is mounted on top of the inlet cup and connected to the wire mesh in place for rock fall prevention. Unused tubing is capped (12 mm nylon caps) at both ends to prevent contaminated air flow from the laboratories to the inlet. The inlet is currently not heated and the sampling tubes are not fitted with any filters. However, observations of occasional wind-induced accumulation of snow/ice on the inlet cup have led to ongoing discussions on a potential future heating of the inlet head and cup.

At the inlet side, the tube heating ends about 1.5−2 m before the inlet head, i.e. just before the pole. The tubing is protected by PA12 flexible polyamide tubes, which are wrapped around the bare 12 mm OD tubing. The entry of the heated bundles into the protective pipe (Photograph 10) is plugged with a cotton towel.

Photograph 9. Left) Inlet with cup removed, showing the head with the tubes fitted through, and the structure above for mounting the cup. Right) Inlet with cup installed. See also Photograph 8. Photographs: M. Vollmer.

The outdoor section of the installation includes an undesired syphon about 20 m from the inlet. We considered the risk of sample tube clogging (primarily by water) as low. However, if this problem arises, it would potentially require dismantling the assemblage on the inlet side and lowering it over the rocks to drain the water. To prevent water from accumulating in the protective pipe in the syphon, several drainage holes were drilled into lowest section of the pipe.

Using GPS devices, the new inlet coordinates were measured as 46° 32' 51.96" N, 7° 59' 9.18" E, (GPS accuracy 2.5 m). This suggests that the inlet is 32 m north and 67 m east of the Meteo Terrace geodetic point (46° 32' 50.9375" N, 7° 59' 6.0268" E, WGS 84, 3578.31 m asl). Using map coordinates and aerial photographs, the latitudinal displacement appears too large, while the longitudinal one seems reasonable. The altitude of the inlet cup was estimated (using GPS, barometer, and rope lengths) by referencing against the visitor platform altitude (3571.8 m asl) and determined as 3561 (±2) m asl. By comparison, the main cupola inlet is at 46° 32' 51.18" N, 7° 59' 6.65" E, (accuracy 4 m) and 3585.7 m asl.



Photograph 10. Air sampling inlet on ridge ~30 m NE of tourist platform. Left) Nine sample tubes are fitted into the inlet head. Right) Inlet showing the protective pipe (clamped to the rock) and the three bundles of three sample tubings each. Note that only the ground-layed sections of the bundles are heated, the vertical sections are unheated PA tubes wrapped around the sample tubes (for physical protection). Photographs: M. Vollmer

6. Functional tests

On June 9/10 2020, the installed sample tubes were checked for potential leaks. The tubes were capped at the inlet and pressurized with nitrogen gas to 2.5 bar. Pressure declines for the individual tubes (tested over 2 min after equilibration time) were found ≤2 mbar min^{-1}, confirming the absence of major leaks. Using a Picarro 2401 analyzer, ambient air was drawn from the inlet and measured for carbon dioxide (CO_2), methane (CH_4,), and carbon monoxide (CO). Mole fractions for each of these gases agreed between the nine tubes within the precisions and small ambient fluctuations at the time. Using a soda lime CO_2 scrubber attached to the inlet side on a few selected tubes resulted in vanishing CO_2 concentrations, thereby supporting the above finding of the absence of leaks. Finally, the tube heating was turned on (to setpoints 10 °C and 20 °C) while the gas concentrations were monitored on one tube. Changes in gas concentrations, which could have potentially been assigned to heating and/or degassing, were of the same magnitude as typical 1 hr natural fluctuations (~2 ppm for CO_2, ~2 ppb for CH_4, and ~10 ppb CO). Overall, we conclude that the system conserves sample integrity, at least for these three gases.

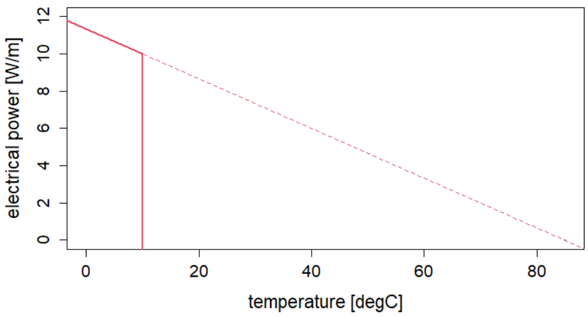
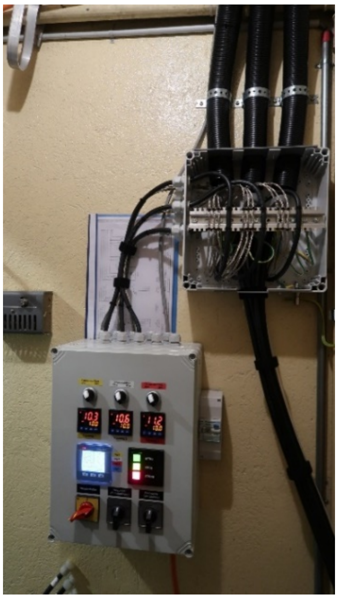


Figure 1. Electrical heating power as a function of temperature. The custom-built control unit shuts off the heating at 10 °C (solid line). The dashed line represents the characteristics of the HBR-Illw-10 heating band according to the manufacturer.

The temperature control system was custom-made at Empa and is designed to control each individual tube bundle separately (Photograph 11). Because ~10 m of the heating structure was removed during the installation, the temperature sensors are now positioned at ~10 m and ~70 m from the control unit. Therefore, the first sensors are located indoors (in the basement or in the elevator shaft), while the second sensors are outdoor, ~20 m from the inlet. The self-regulating heating line (Figure 1) of each bundle can be individually switched on/off by the temperature controller, based on one predefined (~10 m or ~70 m) sensor output. So far, this control is set to 10 °C and monitored by the indoor sensor. In addition to this functionality, the temperature control system also displays the instantaneous power consumption of each bundle and the cumulative power consumption of all bundles.

As an example, a heating cycle for Bundle A was recorded on 26 January 2021, when outdoor temperature was −24 °C and the protective pipe partially covered with snow. For a set temperature of 10 °C, heating was initiated at ~9.8 °C (with ~7 kW and quickly declining) and lasted ~1 min. Temperatures overshot to 11.8 °C and slowly declined to 10 °C in another 8 min, before the next cycle started. Electric power consumption was ~0.1 kWh. Shortly before the restart of the heating, the temperature for the outside sensor was recorded at 0.5 °C.



Photograph 11. Heating control system (Sphinx building, first floor). Control box (left), box with lid removed is the connection to the self-regulating heating components, with three bundles exiting at top, and nine individual air inlet tubes exiting at bottom. Bundle A (red) B (yellow) C (white). Photograph: M. Vollmer.

7. Sampling start

By the end of 2020, the two instruments "jungfraujoch-medusa" and "empa-aprecon" were sampling through this system (both Bundle A). The design of the air-sampling modules of these instruments is such that a continuous flow of air through the individual tubes is ensured. Backflow of contaminated laboratory air to the inlet, and subsequent draw-in through a tubing in use has been show to occur (when some of the unused tubes were still uncapped) and to potentially falsify the measurements. It is therefore crucial to maintain continuous sampling flows, or prevent backflow through shut-off valves. Failures of these systems need to be communicated to other instrument operators, and systems no longer in use require the inlet tubes to be plugged at both ends.

In conclusion, in May 2020, a new air inlet system was installed at Jungfraujoch. An unheated inlet head/cup was installed at the edge of the ridge ~30 m to the NE of the tourist platform at coordinates 46° 32' 51.96" N, 7° 59' 9.18" E, and at an altitude of 3561 (±2) m asl. The inlet tubes are not fitted with any filters. Nine air sampling tubes are assembled, three each in an insulated and heated (nominal temperature 10 °C) bundle protected by a polyamide tube. The total inlet tubes length is 100 m, consisting of two heated sections (77 m outdoor and 11 m indoor) and a remaining unheated section (9−12 m). Seven of the air sampling tubes are SERTOflex (12 mm OD, 8.1 mm ID), one is a perfluoroalkoxy alkane (PFA) polymer, (12 mm OD, 10 mm ID), and one is an antistatic polytetrafluoroethylene (PTFE) tube (12 mm OD, 10 mm ID). The inlet next to the cupola and the aerosol inlet remain operational, especially for reactive gases and aerosol sampling, for which short residence times from the outside to the analyzer are crucial.

Acknowledgements

This is a truly collaborative project of many different partners. It was financed by HFSJG with significant in kind contributions from Empa and Jungfrau Railways. Specifically, the following contributors to this project are acknowledged: Silvio Harndt (Empa) designed and installed the heating system. Urs Hintermüller (Empa) designed the new inlet head/cup. Constructive discussions on design and realization of the new system were held with Andreas Wyss and Toni Eilert (Jungfrau Railways), Pierre Dalban (Geotest), Martin Fischer and Ruedi Käser (HFSJG), Ernst Gerber (Mauderli AG), Stefan Reimann (Empa) and Hans Rudolf Vollmer. The inlet system was installed by Rock Tec (Andreas Ammann, Andreas Reist, Joel Wicki, Adrian Andermatt), with help during various stages by Christian Schlunegger and Severin Peyer (Jungfrau Railways), Myriam Guillevic (Empa) and Phillippe Kindler. Stephan Henne (Empa) helped with the leak-tests and Picarro measurements.

Internet data bases

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https://agage.mit.edu/

Scientific publications and public outreach 2020

Magazine and Newspaper articles

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Address

Empa
Laboratory for Air Pollution/Environmental Technology
Ueberlandstrasse 129
CH-8600 Dübendorf
Switzerland

Contacts

Dr. Martin K. Vollmer / Dr. Martin Steinbacher
Tel.: +41 58 765 4242 / 4048
e-mail: martin.vollmer@empa.ch / martin.steinbacher@empa.ch

The weather in 2020

Stephan Bader[1], Brigitta Klingler Pasquil[2]

[1] Climate Division MeteoSwiss, Zurich-Airport, Switzerland
[2] English translation

stephan.bader@meteoswiss.ch

Report for the International Foundation HFSJG

Record warmth again: in Switzerland the year 2020 was just as warm as the previous record year 2018. A winter with record-breaking high temperatures was followed by the third-warmest spring with a persistent dry period. Summer brought two moderate heat waves. In August and in October there was some massive precipitation south of the Alps and in nearby areas. Early in December abundant snowfall led to above-average snow totals in many regions of the Alps.

As can be seen in table 1 below, the temperature 2020 was well above the normal values 1981–2010 (reference period), with a significantly higher deviation in the high Alpine region Jungfraujoch in comparison to the lowland region Berne north of the Alps. Precipitation amounts were within the normal values at both measurement sites.

Switzerland as warm as in the record year 2018

The annual temperature in Switzerland 2020 amounted to 6.9 °C - just as high as in the previous record year 2018. Ten months were milder than normal values for the period 1981–2010. October showed below-average values. The June temperature matched normal values. Three months showed very high values: averaged over the entire country it was the second-mildest February, the third-mildest April and the fourth-mildest November since measurements started in 1864.

Record warmth on Jungfraujoch

In the Alps and on the elevated region of the Jura individual meteorological stations registered the warmest year since the beginning of observations: the high alpine stations Jungfraujoch and Grimsel, Grächen in the Valais at medium altitudes and Chaumont in the Jura. In La Chaux-de-Fonds (Jura) a narrow record temperature was measured.

Mildest winter since observations started

Switzerland and the Jungfraujoch recorded the mildest winter since measurements started. On Jungfraujoch the winter temperature 2019/2020 reached -9.5 °C. January came in as the second-warmest, February as the fifth-warmest since measurements started in 1933.

A winter temperature on a similar high level has occurred so far only in one year in the almost 90-year old history of observations: In the winter of 1989/1990 the temperature on the Jungfraujoch reached -9.7 °C. All other winters in the measurement series were below -10 °C.

Table 1: Annual values 2020 referring to the parameters temperature and precipitation as well as the deviations from the reference period 1981–2010 for the stations Jungfraujoch and Berne. As precipitation is not measured on Jungfraujoch the values pertaining to the Kleine Scheidegg are used here.

	Jungfraujoch	*Berne*
Average temperature	-5.4 °C	10.3 °C
Deviation	+1.8 °C	+1.5 °C
Precipitation	1600 mm	1037 mm
Deviation	98 %	98 %

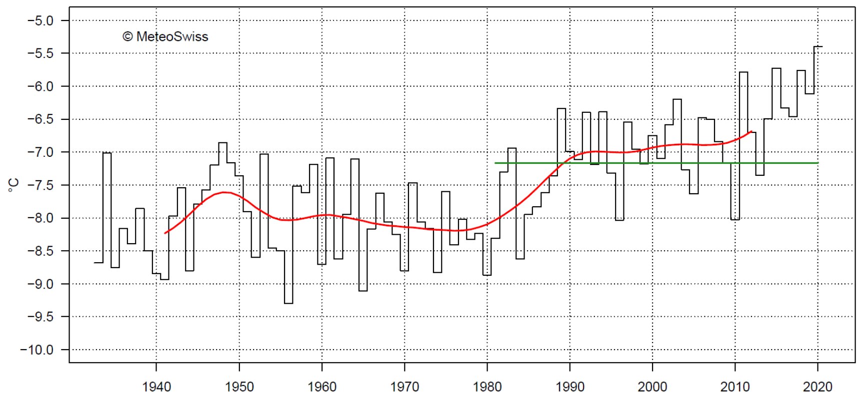

Figure 1. Annual temperature from 1933 to 2020 on Jungfraujoch (3580 m asl). The year 2020 reached -5.4°C. The red line shows the weighted average over 20 years. The green dashed line shows the Normal 1981–2010 (-7.2 °C).

South of the Alps: a dry start to the year

Most areas in Switzerland recorded sufficient precipitation viewed over the whole winter, with totals between 100 and 120 %, regionally also 130 % of normal values 1981–2010. In the south and south-east of Switzerland individual regions received below-average totals, with 60 to 90 % of normal values.

A marked lack of precipitation was experienced south of the Alps in January and February. Here, certain regions registered only 5 to 10 % of normal values 1981–2010. In February, totals remained mostly below 10 %, locally even below 5 % of normal values. In contrast, the rest of Switzerland – thanks to frequent humid and mild westerly and south-westerly currents – recorded 150 to 200 % in many areas, locally even up to 250 % of normal values 1981–2010.

North of the Alps: plenty of winter sunshine

North of the Alps, sunshine duration in winter reached in many areas 130 to almost 160 % of normal values 1981–2010. In the Alps and south of the Alps figures were mostly between 100 und 130 % of normal values. The regions north of the Alps experienced the third- to fifth-sunniest winter since observations started at the end of the 19th century. January made an important contribution to this, with new sunshine records at all four meteorological stations with records dating back over more than 100 years.

Stormy times

February 2020 was stormier than usual. In many locations north of the Alps it was the stormiest February since observations started in 1981. Switzerland experienced three winter storms in the first half of February. The storm ‘Sabine’ of 10 February was the strongest. On the Plateau wind speeds reached a maximum of 90 to 120 km/h in many parts. On Jura elevations maximum wind speeds were recorded of between 140 and 160 km/h, in summit areas of between 160 to 200 km/h.

Warmest spring on Jungfraujoch

After the mildest winter the Jungfraujoch registered the warmest spring since measurements started in 1933. Spring temperature rose to -6.9 °C, that is 2.5 °C above normal values 1981–2010. Averaged over the entire country, spring was the third-warmest since beginning of the measurements in 1864.

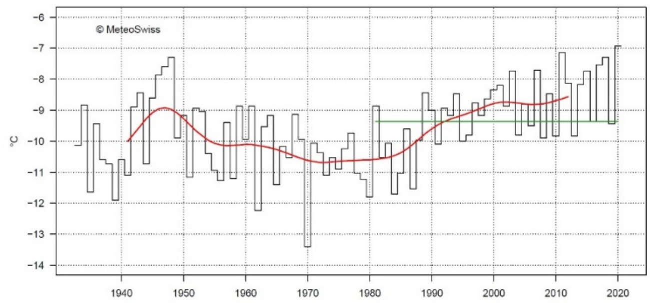

Figure 2. Spring temperature from 1933 to 2020 on Jungfraujoch (3580 m asl). Spring 2020 reached -6.9 °C. The green line shows normal values 1981–2010 (-9.4 °C). The red line shows the 20-year running average.

Extremely sunny in certain regions

Along with a temperature high, spring 2020 also registered extreme values for sunshine duration. In many areas in and north of the Alps they reached from 130 to 160 % of normal values 1981–2010. The Jungfraujoch registered 601 hours of sunshine: the fourth-sunniest spring since the start of observations in 1960.

Persistent drought

As a consequence of frequent fair-weather situations, precipitation totals in spring reached only 50 to 70 % of normal values 1981-2010 in many areas of Switzerland. This was the result of a persistently dry period lasting from mid-March to the end of April. Especially in April, precipitation totals reached only 40 to 60 % of normal values in many parts. In north-western Switzerland, on the eastern Plateau and on the central slopes north of the Alps April totals were, in many parts, only 30 % or less of normal values.

Moderate heatwaves in summer

After an early summer with average temperatures, the strongest heat spells developed towards the end of July and in the first half of August. The first heatwave with daily maximum temperatures of 30° C and above began in western Switzerland on 27 July, lasting until 1 August. In the South hot weather started on 28 July and lasted until 2 August.

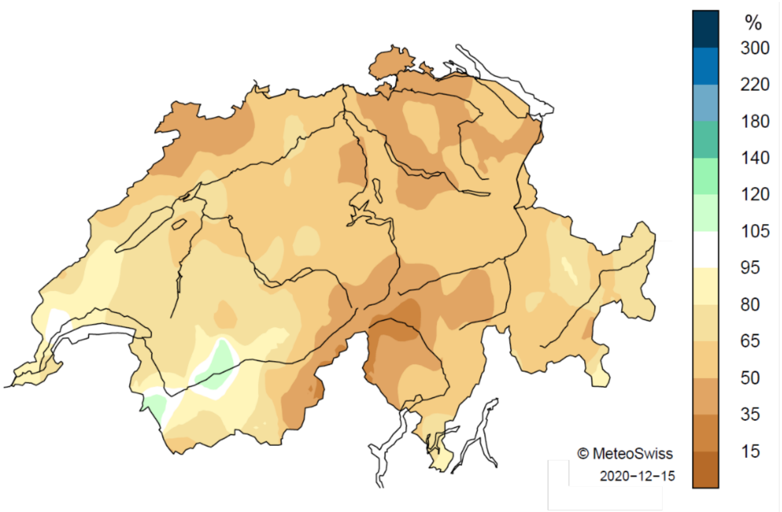

Figure 3. Regional distribution of precipitation totals March to April 2020 as percentage of normal values 1981-2010.

On 6 August the second heatwave started south of the Alps; on 7 August north of the Alps. The period with daily maximum values of 30 °C and above lasted six to seven days, depending on the individual region. Temperature peaks remained mostly below 34 °C on both sides of the Alps. Compared with the substantial heatwaves of the past two decades, heat spells in summer 2020 remained moderate and – in certain areas – even slight.

Severe storms at the end of August

From 28 to 30 August a sustained south-westerly current brought warm and humid air to the area south of the Alps. On 28 and 29 August 2020 the Ticino and nearby areas of the Grisons experienced massive amounts of precipitation. Several meteorological stations recorded rain totals of an average August month within two days. On 29 and 30 August severe precipitation also extended over the eastern slopes north of the Alps.

Contrasting weather in autumn

The autumn months September and November brought generally mild and sunny weather. In certain regions, November turned out especially sunny. In some local areas of the Alps, as on Jungfraujoch, the second-sunniest November in the 60-year measurement series was registered. In the Basel measurement series, stretching over 100 years, it was the third-sunniest November.

The downside to these sunny conditions: September was very short of precipitation, and some areas remained without any precipitation at all. There was extremely little precipitation also in November. Averaged over the entire country, rain totals reached only 20 %, in certain regions south of the Alps less than 5 % of normal values 1981−2010.

Severe storms in mid-October

October, however, showed itself cool and wet with massive and severe precipitation early in the month. Triggered by a strong south-westerly current accompanied in some parts by hurricane-like southerly winds, strong precipitation affected areas predominantly south of the Alps, but also the Valais, the Bernese Oberland, Central Switzerland and the Grisons. In the affected regions several stations with over 100-year measurement series registered the second- to fourth-highest 1-day totals. Binn in the Valais and Sedrun in the Grisons noted record totals.

A lot of snow at the beginning of winter

Coinciding with the meteorological beginning of winter some snow fell in the north, even in lower areas. Two days later strong snowfall set in south of the Alps, later extending over the Alps towards the north. Within two days Lugano received 25 cm of fresh snow, many Alpine regions 40 cm to almost 1 meter. Individual stations registered the highest 2-day fresh snow total for the month of December since the start of observations.

With further snowfall, the 3-day fresh snow total rose to 1,2 to 1,4 meters in certain mountain regions of the Ticino and the Grisons. Towards mid-December, snow depths in many areas of the Alps were considerably above the long-term average (source: SLF Davos).

During a strong southerly Föhn situation on 28 December southern Switzerland again received 15 to 30 cm of fresh snow. In Lugano, December fresh snow totals rose to 47 cm. The last time Lugano experienced a similar or even larger amount of fresh snow was in 2005 with 45 cm and 1981 with 65 cm.

Annual balance

In many parts of Switzerland, the annual temperature 2020 exceeded normal values 1981-2010 by 1.4 to 1.7 °C. South of the Alps and in the Engadine values were 1.0 to 1.4 °C above normal, in some Alpine regions up to 1.8 °C above normal values. Averaged over the entire country, the result is an annual temperature 1.5 °C above normal values. Just as in 2018, this corresponds to the highest value since the beginning of observations in 1864.

North of the Alps, annual precipitation 2020 mostly reached 80 to 100 % of normal values 1981–2010. South of the Alps in the Engadine, precipitation was mostly between 90 and 100 % of normal values. Some stations registered annual totals of just about 110 % of normal values.

Looking at sunshine duration, the annual total 2020 was in many parts between 110 and 130 % of normal values 1981–2010. In the Valais, in the Engadine sunshine duration amounted to between 100 and 110 % of normal values. Basel experienced its sunniest year since the beginning of measurements with 2057 hours of sunshine, for Berne and Zurich it was the third-sunniest year with 2155 hours and 2056 hours, respectively. All three stations have homogenized data on sunshine duration dating back to the 1880s.

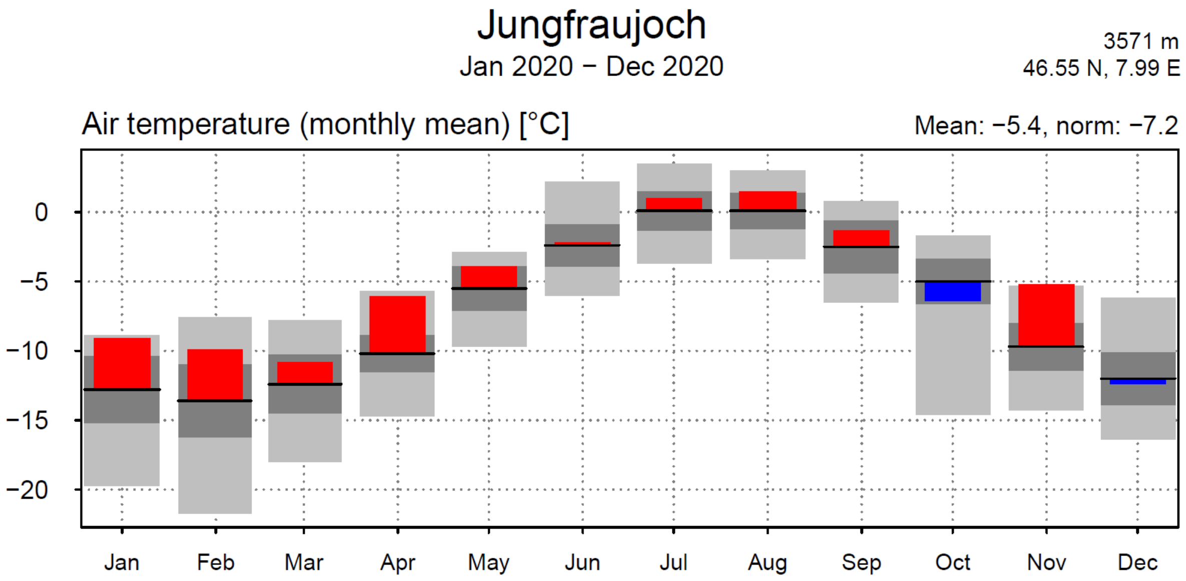

Figure 4. Monthly mean temperature 2020 on Jungfraujoch (3580 m asl) in relation to the monthly long-term mean value 1981–2010 (solid black lines). Red bars show above, blue bars below normal monthly temperatures. The dark grey ranges show the monthly long-term mean fluctuation (standard deviation 1981–2010). The light grey ranges show the highest and the lowest monthly mean temperature since observations started.

Address

Bundesamt für Meteorologie und Klimatologie MeteoSchweiz
Abteilung Klima
Operation Center 1
Postfach 257
CH-8058 Zürich-Flughafen
e-mail: klimainformation@meteoschweiz.ch
http://www.meteoschweiz.admin.ch/home.html?tab=overview

High resolution solar infrared Fourier transform spectrometry: application to the study and long-term monitoring of the Earth's atmosphere

Emmanuel Mahieu[1], Christian Servais[1], Olivier Flock[1], Irene Pardo Cantos[1], Maxime Prignon[1], and Ginette Roland[1]

[1] Institute of Astrophysics and Geophysics – University of Liège, Liège, Belgium

emmanuel.mahieu@uliege.be

Part of this programme: NDACC, GAW-CH, ACTRIS

Keywords: Earth's atmosphere; climate change; greenhouse gases; ozone layer; air quality; remote sensing; infrared spectroscopy; atmospheric circulation

1. Project description

The Liège team has a long tradition in the monitoring of the Earth's atmosphere. Indeed, the first observations and investigations were carried out by Pr Marcel Migeotte and collaborators in the late 1940s, using a grating infrared spectrometer. This instrument was then installed at the Jungfraujoch station and infrared spectra were systematically recorded in 1950-1951 such as to cover the 2.8 to 23.7 micrometer (µm) spectral range (Migeotte et al., 1956). The next period was dedicated to the study of the sun and to the production of photometric solar atlases, using a 7 m grating spectrometer, in single then double pass mode. In the mid-1970s, the team resumed its atmospheric monitoring activities which are still ongoing nowadays. Since the mid-1980s, Fourier Transform InfraRed (FTIR) instruments are used, allowing to record very high resolution and signal-to-noise wide-band solar infrared spectra. This sustained effort has led to an unrivalled collection of infrared spectra which is unique worldwide in terms of length, measurement density and quality. At the end of 2020, we reached 37 years of continuous FTIR measurements at the Jungfraujoch station!

The main objectives of the team are essentially twofold: (i) maintain the instrumentation operational while also improving its performance, (ii) analyse the spectra in order to produce high-level geophysical parameters and valorise them.

In 2020 and given the travel restrictions, it was only possible to collect remote observations. Altogether and before any averaging, about 2600 high resolution infrared solar spectra have been collected on 84 days. The failure of a KVM adapter prevented the recording of spectra in August. Thanks to the invaluable support of the custodians, the problem was fixed and normal operations resumed in early September.

The analysis of our spectra allows us to determine the abundance of an increasing number of key constituents of the Earth atmosphere (currently more than 30, see Table 1), playing a role in ozone depletion, climate change, or affecting air quality. Numerous target species are therefore relevant to the Montreal Protocol on substances that deplete stratospheric ozone (e.g. CFCs, HCFCs, HCl) and/or to the Paris Agreement (COP21) to mitigate climate change (e.g. CO_2, CH_4, N_2O).

Table 1. List of atmospheric species (>30) currently retrieved from the Jungfraujoch observational database

Greenhouse gases; support to the Paris Agreement[1]	H_2O, CO_2, CH_4, N_2O, CF_4, SF_6
Ozone-related; support to the Montreal Protocol	O_3, NO, NO_2, HNO_3, $ClONO_2$, HCl, HF, COF_2, CFC-11, CFC-12, HCFC-22, HCFC-142b, CCl_4, CH_3Cl
Air quality; support to the EU-Copernicus programme	CO, CH_3OH, C_2H_6, C_2H_2, C_2H_4, HCN, HCHO, HCOOH, NH_3, PAN
Other	OCS, N_2, various isotopologues[2]

[1]) Figure 1 displays the multi-decadal time series of four of these strong greenhouse gases.
[2]) an isotopologue is a molecular twin that differs from the reference molecule in the isotopic composition.

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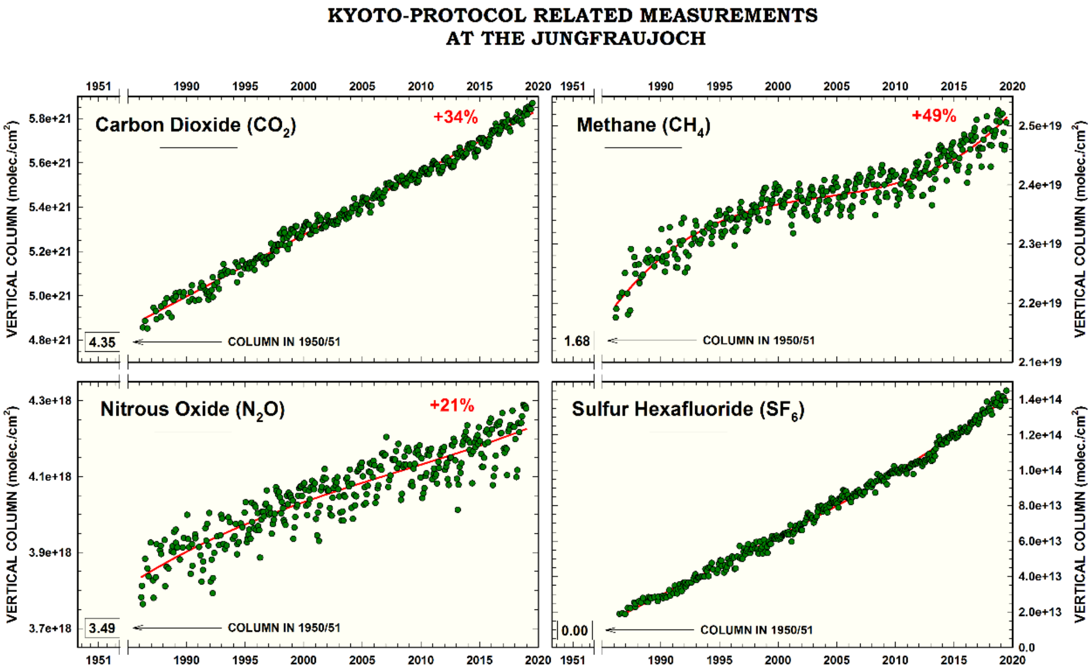

Figure 1. Multi-decadal evolution of the monthly averages of the total vertical columns, expressed in molecules per square centimeter, of four of the greenhouse gases monitored at the Jungfraujoch station, and comparison with their abundance in the middle of the last century (see Mahieu et al., 2019).

Internet data bases

http://labos.ulg.ac.be/girpas/en/publications
http://labos.ulg.ac.be/girpas/en/
ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/jungfrau/hdf/ftir/
ftp://ftp.cpc.ncep.noaa.gov/ndacc/RD/jungfrau/hdf/ftir/

Collaborating partners / networks

Dr. S. Reimann, Dr. M. Steinbacher, and Dr M.K. Vollmer, Empa, Dübendorf
Dr. F. Conen, Institut für Umweltgeowissenschaften, Universität Basel
Prof. M. Leuenberger, Climate and Environmental Physics, University of Bern
Dr M. De Mazière, Dr S. Chabrillat and teams, Royal Belgian Institute of Space Aeronomy (BIRA-IASB, Ukkel, Belgium)
Dr M.P. Chipperfield and team, University of Leeds, Leeds, U.K.
Dr J. Notholt and M. Palm, University of Bremen, Bremen, Germany
Dr G.C. Toon, California Institute of Technology, NASA-JPL, Pasadena, CA
Mr J. Hannigan, National Center for Atmsopheric Resaerch, Boulder, CO
Dr T. Blumenstock and team, IMK, Karlsruhe Institute of Technology, Germany
Dr E.V. Fischer, Colorado State University, Fort Collins, CO
Dr B. Franco, Université Libre de Bruxelles (ULB), Bruxelles, Belgium.
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ACE-FTS and IASI satellite teams

Scientific publications and public outreach 2020

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Address

GIRPAS (Groupe Infra-Rouge de Physique Atmosphérique et Solaire)
Institut d'Astrophysique et de Géophysique – Université de Liège
Quartier Agora, Allée du 6 Août, 19, Building B5A
B-4000 Liège (Sart Tilman)
Belgium

Contacts

Dr. Christian Servais – Project leader
Tel.: +32 4 366 9784
e-mail: christian.servais@uliege.be

Olivier Flock
Tel.: +32 4 366 9790
e-mail: o.flock@uliege.be

Dr. Emmanuel Mahieu
Tel.: +32 4 366 9786
e-mail: emmanuel.mahieu@uliege.be

Irene Pardo Cantos
Tel.: +32 4 366 9789
e-mail: i.pardocantos@uliege.be

Maxime Prignon
Tel.: +32 4 366 9785
e-mail: maxime.prignon@uliege.be

Dr. Ginette Roland
Tel.: +32 4 342 2594
e-mail: g.roland@uliege.be

Vincent Van De Weerdt
Tel.: +32 4 366 9767
e-mail: vincent.vandeweerdt@uliege.be

Diane Zander
Tel.: +32 4 366 9770
e-mail: diane.zander@uliege.be

Atmospheric composition monitoring at ISSJ

Michel Van Roozendael[1], Martine De Mazière[1], Bart Dils[1], Caroline Fayt[1], Martina Friedrich[1], François Hendrick[1], Christian Hermans[1], Bavo Langerock[1], Gaia Pinardi[1], Corinne Vigouroux[1], Minqiang Zhou[1]

[1] Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Ukkel, Belgium

michelv@aeronnmie.be

Part of this programme: NDACC, ACTRIS, S5P-MPC/VDAF, CAMS, C3S, AC SAF

Keywords: atmospheric composition; long-term monitoring; optical remote sensing; vertical inversion methods; satellite and model validation

1. Project description

1.1 UV-Vis observations

BIRA-IASB has been operating UV-visible ground-based spectrometers at the Jungfraujoch station since the early nineties. We started monitoring the total columns of stratospheric NO_2 and ozone using a SAOZ (Système d'Analyse par Observations Zénithales) system, which was complemented by a MAX-DOAS instrument installed in 2010. The latter instrument allowed to monitor the free-tropospheric content of HCHO (Franco et al., 2015), in addition to the long-term trends in stratospheric NO_2, assessed with the SAOZ instrument (Hendrick et al., 2012). Ozone and NO_2 measurements were also regularly used in satellite validation exercises (see e.g. Garane et al., 2018; Compernolle et al., 2020).

In 2019 a planned update of the SAOZ instrument had to be postponed due to team-related issues. Again in 2020 the renewal of the BIRA-IASB instrumentation (SAOZ and MAX-DOAS) had to be postponed, this time due to the Covid-19 crisis. As a result, the stratospheric and tropospheric UV-visible trace gas monitoring has been on hold since July 2019. A replacement system for the SAOZ is ready at BIRA-IASB and will be installed at the station as soon as possible in 2021. Similarly, the spare parts necessary to restart the MAX-DOAS instrument were purchased and are ready for shipping.

We hope to be able to reinitiate our working programme as part of the Belgian contribution to NDACC and to the recently launched ACTRIS ESFRI project. Within ACTRIS, BIRA is responsible for the coordination of trace-gas remote-sensing measurements (see below), which includes central processing of NO_2, O_3 and HCHO data from the overall MAX-DOAS community.

1.2 International coordination activities

As mentioned above, BIRA-IASB is responsible in the European ACTRIS Research Infrastructure (www.actris.eu) for the Reactive Trace Gases Remote Sensing (RTGRS) component, and in particular for the Topical Center for this component, called CREGARS, for which currently it is the Lead. Together with the University of Liège and the University of Bremen, it plans to manage the CREGARS-FTIR Unit. The implementation of CREGARS-FTIR is ongoing. The FTIR instrument that is operated by the University of Liège at Jungfraujoch together with the BIRA-IASB UV-Vis spectrometers will be proposed as an ACTRIS RTGRS Belgian National Facility; it will receive operational support from CREGARS. The processing of the Jungfraujoch FTIR data by the CREGARS FTIR central data processing system (CDPS) has already been tested successfully for operational implementation. BIRA-IASB is also coordinating a Belgian federally funded project ACTRIS-BE that supports the implementation of ACTRIS at the Belgian federal level, during the period Dec. 2018- Dec. 2022. From 2022 onwards, ACTRIS target data recorded at the Jungfraujoch will also become available from the ACTRIS data portal.

BIRA-IASB is in charge of the CAMS-27 contract which aims at guaranteeing a continuous rapid-delivery and quality-controlled NDACC data stream to CAMS. In addition, it is responsible for the use of these NDACC data, including the Jungfraujoch SAOZ, MAXDOAS and FTIR data, for the validation of various products of the Copernicus Atmospheric Monitoring Service (CAMS), led by ECMWF. Results are reported at http://nors-server.aeronomie.be/, at https://global-evaluation.atmosphere.copernicus.eu, as well as in quarterly validation reports at https://atmosphere.copernicus.eu/eqa-reports-global-services. Jungfraujoch NDACC data are included as soon as they are submitted to the NDACC database, after successful quality control at BIRA-IASB.

Similarly, BIRA-IASB is in charge of the Sentinel-5 Precursor (S5P) operational validation service (VDAF) within the ESA S5P Mission Performance Center (MPC). In this context, BIRA-IASB coordinates the validation of the S5P products using NDACC data, including the Jungfraujoch FTIR data (see Vigouroux et al., 2020; Sha et al., 2021)

In the frame of the Copernicus Climate Change Service (C3S), BIRA-IASB is responsible for the ingestion of long-term NDACC ozone, CO and CH_4 time series in the Climate Data Store (CDS; https://cds.climate.copernicus.eu/). Long-term Jungfraujoch FTIR and UVVIS ozone time series will soon become available in the CDS; Jungfraujoch FTIR CO and CH_4 data will follow soon after.

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http://www.ndacc.org/ (data archival in NDACC data base)
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Notes:

- All the data sets submitted in these data bases are generated using HDF GEOMS formats
- The NDACC database is 'read' by the CAMS validation server on a daily basis, for using the data for the validation of the CAMS NRT and re-analysis products. A similar facility has been implemented for the S5P-MPC VDAF system.

Collaborating partners / networks

Dr. E. Mahieu, Université de Liège, Liège, Belgique
Dr. M. Chipperfield, University of Leeds, Leeds, UK
Dr. A. Pazmino, LATMOS, Guyancourt, France
Prof. P. Coheur, Université Libre de Bruxelles, Brussels, Belgium
International Network for the Detection of Atmospheric Composition Changes (NDACC)
OMI, TROPOMI (S5P), and Metop GOME-2 and IASI satellite communities
KNMI and S&T for the CAMS and S5P MPC Validation Server
CNR (Italy) and ECMWF for the delivery of NDACC data to C3S
ACTRIS: Strong responsibilities at European and Belgian level

Scientific publications and public outreach 2020

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Address

Royal Belgian Institute for Space Aeronomy
Ringlaan 3
B-1180 Brussels
Belgium

Contacts

Dr. Michel Van Roozendael (primary contact point)
Tel. +32 2 373 04 16
e-mail: michelv@aeronomie.be

Prof. Martine De Mazière
Tel. +32 2 373 04 00
e-mail: martine@ aeronomie.be

The Global Atmosphere Watch Aerosol Program at Jungfraujoch

Benjamin Brem[1], Martine Collaud Coen[2], Alejandro Keller[3], Günther Wehrle[1], Robin Modini[1], Urs Baltensperger[1] and Martin Gysel-Beer[1]

[1] Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland
[2] Federal Office of Meteorology and Climatology, MeteoSwiss, 1530 Payerne, Switzerland
[3] University of Applied Sciences and arts Northwestern Switzerland, Windisch, Switzerland

benjamin.brem@psi.ch; martin.gysel@psi.ch

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Keywords: atmospheric aerosol particles; aerosol climatic effects; aerosol optical properties; aerosol size distribution; cloud condensation nuclei; carbonaceous aerosol; novel aerosol instrumentation

Aerosol monitoring

Aerosol particles affect the Earth's climate by influencing the atmospheric energy budget through direct and indirect effects. Direct effects (aerosol – radiation interactions, ARI) are the scattering and absorption of radiation by aerosol particles. Indirect effects (aerosol – cloud interactions, ACI) refer to the role of particles as cloud condensation nuclei (CCN) and ice-nucleating particles (INP). The climate relevance of both ARI and ACI results from their effect on the planetary albedo (incoming shortwave radiation). ACI furthermore affect the Earth's outgoing longwave radiation. The IPCC report states ARI and ACI remain one of the major uncertainties in the anthropogenic radiative forcing due to their limited scientific understanding.

The Global Atmosphere Watch (GAW) program is an activity coordinated by the World Meteorological Organization (WMO) to gain a better understanding on aerosol particles worldwide. The goal of GAW is to ensure long-term measurements in order to detect trends and to develop an understanding of these trends. With respect to aerosols, the objective of GAW is to determine the spatial-temporal distribution of aerosol properties related to climate forcing and air quality up to multi-decadal time scales. The GAW monitoring network consists of 31 global (including the Jungfraujoch site) and about 400 regional stations. The aerosol program at Jungfraujoch is further a member of the Pan-European Aerosols, Clouds, and Trace gases Research Infra Structure (ACTRIS).

The aerosol records at Jungfraujoch are among the most extensive within Europe and worldwide. By the end of 2020, some specific observations have been performed continuously for 25 years (Figure 1). The current GAW long term monitoring instrumentation at the Jungfraujoch is consisting mainly of instruments to determine the basic physical and optical properties of aerosol particles (Table 1). For these measurements, ambient air is sampled via a heated inlet (25°C), designed to prevent ice build-up and to evaporate cloud droplets at an early stage, ensuring that the residual particles of cloud droplets and ice crystals are also sampled. Data are delivered to GAW and ACTRIS data warehouses, including near real time data provision.

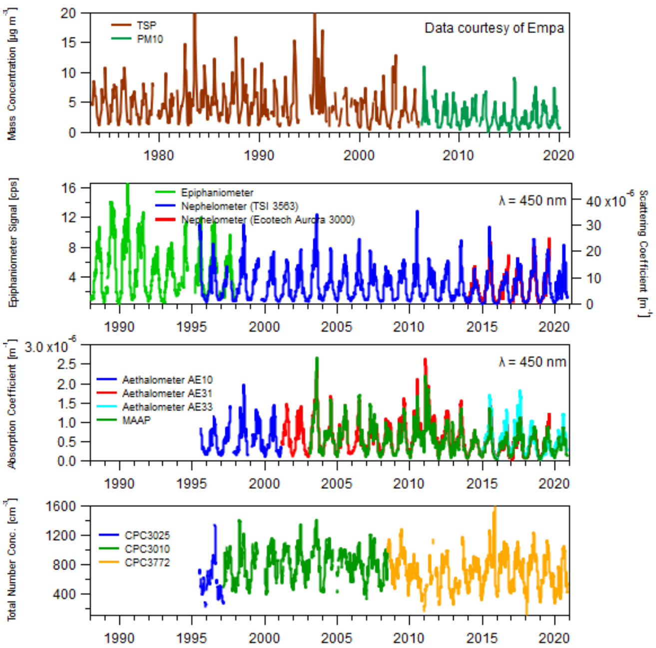

Figure 1. Temporal evolution of the continuously measured aerosol parameters at the Jungfraujoch (30-day running average of the daily average values). Particle mass concentration data values in the top panel are in courtesy from Empa/NABEL.

Multidecadal trend analysis of in situ aerosol radiative properties

Identifying trends is one of the main goals of the GAW aerosol program. A highlight in this regard was the publication “Multidecadal trend analysis of *in situ* aerosol radiative properties around the world” by Martine Collaud Coen. In this major effort, a long-term trend analysis of aerosol optical properties was performed on time series from 52 stations situated across five continents. The time series of measured scattering, backscattering and absorption coefficients as well as the derived single scattering albedo, backscattering fraction, scattering and absorption Ångström exponents covered at least 10 years and up to 40 years for some stations. The non-parametric seasonal Mann–Kendall (MK) statistical test associated with several pre-whitening methods and with Sen’s slope was used as the main trend analysis method. Currently, scattering and backscattering coefficient trends are mostly decreasing in Europe and North America and are not statistically significant in Asia, while polar stations exhibit a mix of increasing and decreasing trends. The trends for the light scattering coefficient at Jungfraujoch (JFJ) in an ensemble with the stations Mount Rainier National Park (MRN) and Mauna Loa (MLO) are shown in Figure 2 as an extract from the very comprehensive paper.

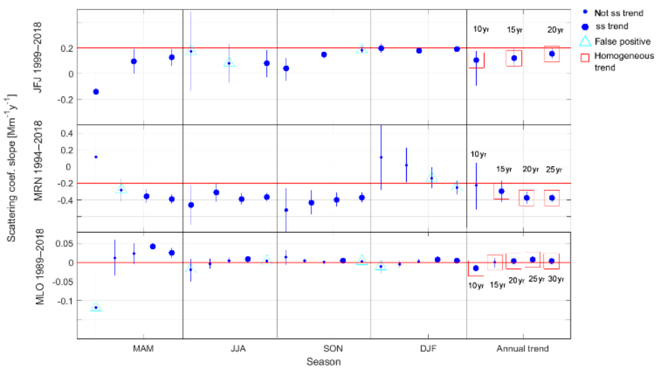

Figure 2. Seasonal MK results for the light scattering coefficient trend for three stations with long time series: JFJ, MRN and MLO. The trends are plotted for the last 10-year period (2009–2018) as well as for all possible longer periods (15 years = 2004–2018 to 30 years = 1989–2018). The seasons correspond to meteorological seasons (MAM: March–April–May, JJA: June–July–August, SON: September–October–November and DJF: December–January–February). The dots correspond to the slope, large dots being statistically significant at the 95% confidence level, whereas small dots are not statistically significant. The cyan triangles correspond to false positive trends (with type 1 error). Red squares correspond to annual trends where the seasonal results are homogeneous.

As shown in Figure 2, the light scattering coefficients show negative annual trends for all of the analyzed periods, with the most recent 10-year period with a larger negative slope than the longer periods. Spring and fall are the seasons at JFJ with the strongest statistical significant trends, while winter has a small and less significant negative trend, indicating that the free tropospheric aerosol burden might be less affected by those trends. This is also indicated by the practically invariant MLO data that is in the free troposphere all year round (Figure 2). The light absorption coefficient as well as the single scattering albedo show also slightly, but statistically significant decreasing trends at JFJ for the 10- and 15-year periods analyzed. Please refer to the publication for further details.

Employment of novel tools for the continuous characterization of the carbonaceous fraction in ambient aerosol

Total aerosol carbonaceous mass (TC) is a major constituent of the atmospheric fine aerosol particle mass. However, this fraction is not yet continuously monitored at GAW sites with an adequate time resolution. Adding a TC measurement is thus crucial to complement the existing measurement programs for a comprehensive interpretation impact of aerosols on our climate. Currently, the visible light absorbing, more elemental part of carbonaceous aerosols is permanently monitored by the means of various filter based Aethalometer type instruments. However, no information on the organic carbon and especially the non-visible-light absorbing carbon is available.

Commercial thermo-optical methods for characterization of carbonaceous aerosol are expensive and not ready for continuous standalone operation. To fill this gap, the “fast thermal carbon totalizator” (FATCAT) has been developed by FHWN, a carbonaceous aerosol measurement system for long-term monitoring of TC. FATCAT collects a sample on a sinter metallic filter, which is subsequently heated to 800°C under an oxidizing atmosphere. Further oxidation of the evolved carbonaceous material is achieved by a catalyzer located downstream of the heating unit. TC detection is achieved by means of a NDIR CO_2 measurement. The fast heating cycle of 50 seconds allows a low limit of detection (LoD) of 0.2 µg of carbon (µg-C). At the reduced atmospheric pressure of the JFJ, which limits the sampling flow of the device to 6 lpm, this is enough to measure TC concentrations with a LoD=0.3 µg-C/ m^3 using a time resolution of two hours.

Since July 2020, a FATCAT has been deployed at the Sphinx observatory aerosol inlet for an unsupervised long-term measurement campaign. To date, the generated data is already the longest high time resolution TC dataset ever measured at the JFJ site. Figure 3 shows a data subset for the month of September of these measurements, together with the black carbon data determined by the GAW MAAP instrument.

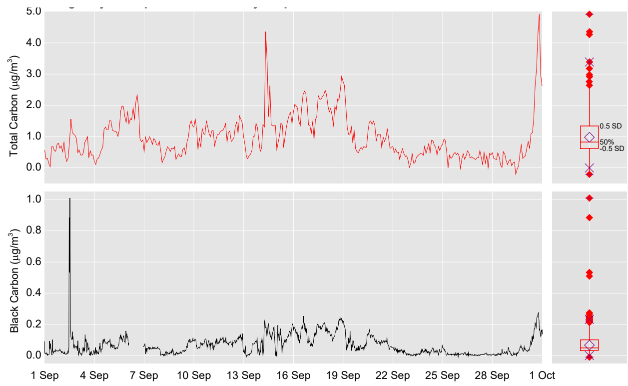

Figure 3. Time series and box plot for total carbon, measured by means of FATCAT, and black carbon concentration, measured by means of MAAP, during September 2020. Several episodes of high carbonaceous material concentration can be observed, originating mainly from local construction by the Jungfrau Railways but also from long-range transported emissions from Californian wildfires.

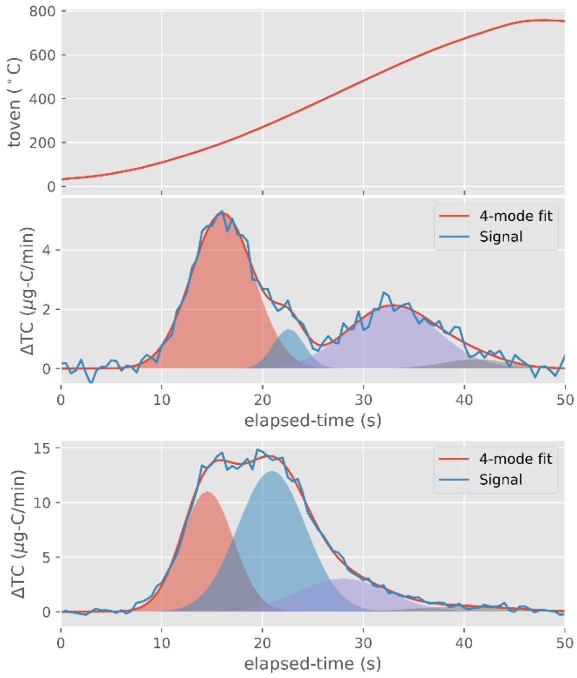

Figure 4 Total carbon thermograms for two events with high black carbon concentration. The top panel shows the filter temperature during analysis. The lower two panels show the differential total carbon signal (blue line) and a 4-mode fit (red line and filled curves). The red, blue, violet, and grey fitted components originate from materials with increasingly higher temperature stability. The red component is identified with the higher volatility fraction of condensed organic compounds. The other components allow the differentiation of samples with high thermal stability, like diesel soot from the Jungfraujoch construction site (e.g., top thermogram; September 2nd), from samples with low thermal stability, like biomass burning aerosol from the California wildfires (e.g., bottom thermogram; September 30th).

The sample analysis further produces thermograms of the evolving carbon from the filter with well-defined components (Figure 4). Aerosol particl es containing more refractory, crystalline carbon from fossil fuel combustion, *e.g.* from diesel engine emissions, tend to evolve at high temperatures, whereas aerosol particles from biomass burning sources containing more amorphous organic carbon tend to decompose and evolve at lower temperatures. Therefore, source specific fingerprints for various combustion emissions are distinguishable.

Several high TC episodes during September show the typical pattern of biomass combustion. With the identified fingerprint and back trajectories, these episodes were attributed to long-range transported emissions from Californian wildfires. Local diesel soot emissions, originating from construction machinery operated at the JFJ were also frequently identified. Therefore, the resulting dataset and post-analysis data products represent an improvement to the available measurement inventory as it can also serve as quality control for other measurement techniques already deployed - or to be deployed - at GAW sites. Prominently, measurements of eBC via MAAP or Aethalometer and organic mass using ToF-ACSM require calibration and are susceptible to systematic errors. TC measurement data can be used in parallel for these devices as a quality check but also to warrant total carbon mass closure and reduce systematic biases.

Internet data bases

http://www.psi.ch/lac
http://www.psi.ch/lac/gaw-monitoring-nrt-data
https://www.meteoswiss.admin.ch/home/research-and-cooperation/international-cooperation/gaw.html
http://ebas.nilu.no
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https://www.meteoswiss.admin.ch/home/climate/climate-change-in-switzerland/aerosol-and-climate.html
https://www.meteoswiss.admin.ch/home/climate/the-climate-of-switzerland/specialties-of-the-swiss-climate/saharan-dust-events.html

Collaborating partners/ networks

Prof. Margit Schwikowski-Gigar, LUC, PSI
Dr. A. Haefele, Dr. J. Klausen, MeteoSwiss, Payerne
Prof. U. Lohmann, Prof. T. Peter, Institute for Atmospheric and Climate Science, ETH Zürich
Dr. C. Hüglin, Dr. S. Henne, Dr. M. Steinbacher, and Dr. S. Reimann, Empa, Dübendorf
Dr. Franz Conen, Institut für Umweltgeowissenschaften, Universität Basel
Prof. M. Leuenberger, Climate and Environmental Physics, University of Bern
Prof. E. Weingartner, Institut für Aerosol- und Sensortechnik, Fachhochschule Nordwestschweiz, Windisch
Prof. A. Wiedensohler, Dr. T. Müller, Dr. S. Henning, ECAC and TROPOS, Leipzig, Germany
Dr. E. Andrews, NOAA, Boulder, USA
Prof. M. Kulmala and Prof. F. Bianchi Department of Physics, University of Helsinki, Helsinki, Finland
Griša Močnik, University of Nova Gorica Centre for Atmospheric Research, Ljubljana, Slovenia

Scientific publications and public outreach 2020

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https://web.fhnw.ch/plattformen/digitalbytes/fhnw-messgeraet-weist-russ-aus-kalifornischen-waldbraenden-auf-dem-jungfraujoch-nach/

Addresses

Laboratory of Atmospheric Chemistry
Paul Scherrer Institute (PSI)
Forschungsstrasse 111
CH-5232 Villigen
Switzerland

Office fédéral de météorologie et de climatologie MétéoSuisse
Chemin de l'Aérologie 1
CH-1530 Payerne
Switzerland

Institute for Sensors and Electronics
University of Applied Sciences and Arts Northwestern Switzerland (FHNW)
CH-5210 Windisch
Switzerland

Contacts

Dr. Martin Gysel-Beer
Tel.: +41 56 310 4168
martin.gysel@psi.ch

Dr. Martine Collaud Coen
Tel.: +41 58 460 9428
martine.collaud@meteoswiss.ch

Dr. Alejandro Keller
Tel.: +41 56 202 7484
alejandro.keller@fhnw.ch

Aerosol Optical Depth measurements from the GAW-PFR network

Stelios Kazadzis[1], Natalia Kouremeti[1], Julian Gröbner[1]

[1] Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, Davos, Switzerland

stelios.kazadzis@pmodwrc.ch

Part of this programme: WMO-GAW, GCOS

Keywords: aerosol optical properties; solar radiation

1. Project description

The GAW-PFR Network

Aerosol optical depth (AOD) is the most important parameter related to aerosol radiative forcing studies. Multiwavelength AOD has been defined as an essential climate variable from various global bodies and agencies such as the Global Climate Observing System, the Global Atmosphere Watch (GAW) Program of the World Meteorological Organization, the European Space Agency Climate Change Initiative and others.

Ground-based sun-photometers have been deployed during the last 20-25 years in order to provide long term series of AOD measurements at various locations. PMOD/WRC during the start of the 90's has developed the Precision Filter Radiometer (PFR) that has been used for long term AOD measurements under a GAW-PFR Network of sun-photometers started in 1995 at Davos Switzerland and from 1999 at other locations, worldwide (Kazadzis et al., 2018a).

Currently, more than 40 PFR instruments are operating worldwide. 15 of them are located in locations defined by the WMO Scientific Advisory Group for aerosols and maintained/calibrated by PMOD/WRC (including the Jungfraujoch station) (Figure 1).

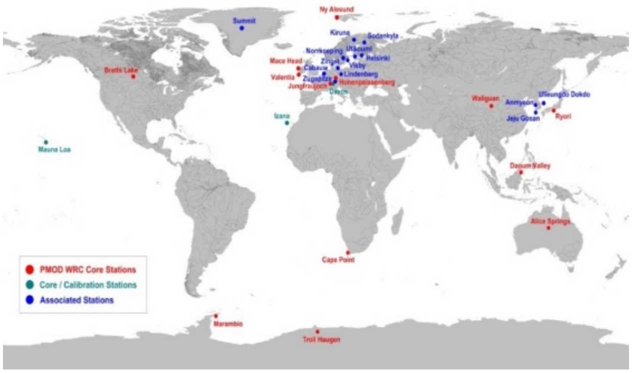

Figure 1. The GAW-PFR network.

Another 14 instruments owned by scientific institutes are also associated with PMOD/WRC as they are regularly calibrated by the WRC section WORCC that is the WMO defined World Aerosol Optical depth Research and Calibration Center. WORCC mandate also includes actions towards world AOD homogenization (Kazadzis et al., 2018b, Nakajima et al., 2020) and measurements for high altitude stations including Jungfraujoch, Mauna Loa, USA (Toledano et al., 2018) and Izana, Tenerife, Spain (Cuevas et al., 2019). An overview of the results of the GAW-PFR station measurements till 2018 have been presented in Kazadzis et al., 2019.

Aerosol Observations at Jungfraujoch (JFJ) have started in 1999 (Figure 2). PFR instruments are measuring direct sun irradiance and only under cloudless sky conditions (minutes) they derive the AOD in four wavelengths and the Ångström exponent. Table 1 shows the current GAW-PFR instrumentation. The instrument specifications are according to WMO recommendations.

Table 1. Current GAW-PFR *AOD instrumentation at Jungfraujoch.*

Instrument type	PFR-N
Measuring wavelengths (nm)	368, 412, 500, 862
Field-of-view (deg)	2.5
FWHM (nm)	3.5-5.5
Measurement principle	Sun pointing on tracker

During the period 2018-2020 JFJ activities have been included (together with all other GAW-PFR instruments) in the project "GCOS - The Global Atmosphere Watch Precision Filter Radiometer (GAW-PFR) Network for Aerosol Optical Depth long term measurements" funded by the Federal Office of Meteorology and Climatology MeteoSwiss / International Affairs Division, Swiss GCOS Office.

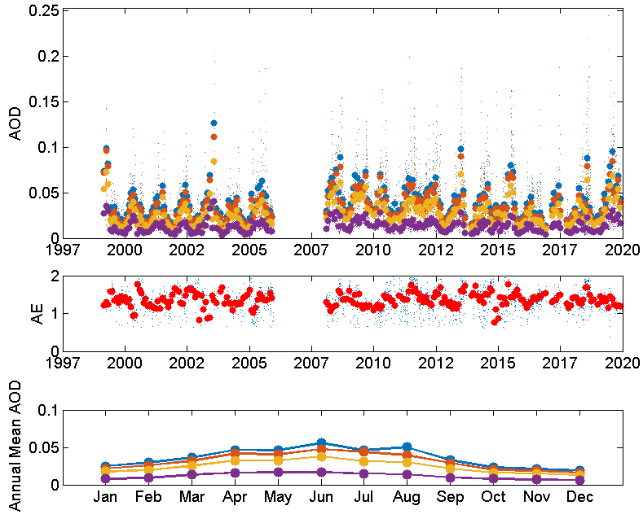

Figure 2. Jungfraujoch time series of AOD at the 4 PFR wavelengths, Ångström exponent and intra-annual AOD variability.

An overview of AOD and AE for the GAW-PFR high altitude stations including JFJ, showed that mean and median AOD500nm (Figure 3 up) is decreasing with increasing altitude with the exception of Mountain Walliguan (WLG) station due to the dust related intrusions reported. AEs for Davos, Jungfraujoch and Mauna Loa are in the range of 1.3 to 1.4, very close to Ångström's classic value of 1.3 for natural aerosols. While for Izana (IZO) and WLG closer to 1.1 and 0.9 indicating an additional contribution of coarse aerosols with an AE smaller than 1. In addition, the intra-annual variability is presented showing a JFJ AOD variability of 0.015 to 0.035 at 550nm. (Figure 3 down).

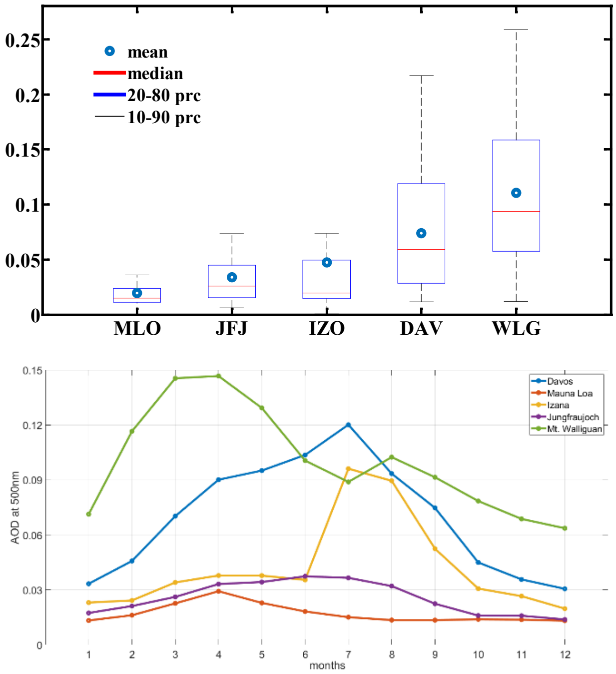

Figure 3. AOD500nm (up) mean and median for 5 high altitude stations: (MLO-3.4km, IZO-2.3km, JFG 3.5km, WLG-3.8km, DAV-1.6km). Intra-Annual monthly mean AOD at 500nm (down).

Trend analysis

The monthly/seasonal Kendall test, a generalization of the Mann-Kendall (MK) test, a non-parametric test that can be applied to time-series with seasonal cycles and missing values, has been used. The Seasonal Kendall test gives a statistic representing the "strength" and direction but not slope of the trend. The latter is determined by Sen's method which is robust to the influence of outliers as it takes the median value of all pairs of slope values. Data used were daily values of AODs, and AE at JFJ station (Figure 4).

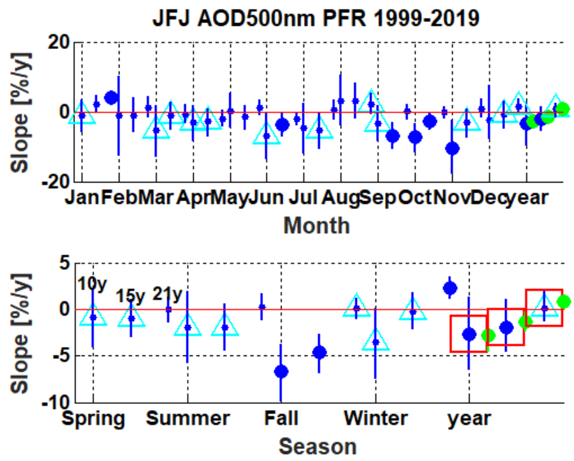

Figure 4. Results of the MK test for long term GAW-PFR time series at Jungfraujoch, Switzerland. Results are shown as trends for AOD per year for each month (up) and season (down) for different (10, 15, total year) periods. Larger circles represent 95% level statistical significant trends. Green points represent the trends without dividing the data to seasons. Red boxes represent trends that are homogeneous for the 4 meteorological seasons.

Using the MK test GAW-PFR high mountain stations showed small but negative trends (IZO, MLO, WLG) while JFJ showed a small but positive trend mostly associated with the second decade of measurements. In the case of JFJ the AOD trend per decade is 0.001-0.002. Trend results from JFJ are presented in the following Table 2(a-c).

Table 2. Tables with AOD at 500nm (a) and 862 nm (b) and AE (c) trend results. MK: Mann- Kendal, WH: Weatherhead et al., 1998 test. Blue statistically significant 66% (WH).

(a) AOD 500nm		Trends	(%/year)	Trend (x1E-2 AOD/year)	AOD500 nm
Station	Years	MK ± 2 sigma	WH ± 2 sigma	MK	Median
JFJ	21	0.659 ± 0.894	1.250 ± 0.756	0.008	0.012

(b) AOD 862nm		Trends	(%/year)	Trend (x1E-2 AOD/year)	AOD862nm
Station	Years	MK ± 2 sigma	WH ± 2 sigma	MK	Median
JFJ	21	0.396 ± 0.873	0.636 ± 0.774	0.002	0.006

(c) AE		Trends	(%/year)	Trend (x0.1 AE/yr)	AE
Station	**Years**	**MK ± 2 sigma**	**WH ± 2 sigma**	**MK**	**Median**
JFJ	21	0.049 ± 0.244	0.025 ± 0.179	0.005	0.997

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Internet data bases

http://ebas.nilu.no

Collaborating partners / networks

Dr. L. Vuilleumier, MeteoSwiss, Payerne
Dr. Martine Collaud, MeteoSwiss, Payerne

Scientific publications and public outreach 2020

Refereed journal articles and their internet access

Nakajima, T., M. Campanelli, H. Che, V. Estellés, H. Irie, S.-W. Kim, J. Kim, D. Liu, T. Nishizawa, G. Pandithurai, V.K. Soni, B. Thana, N.-U. Tugjsurn, K. Aoki, S. Go, M. Hashimoto, A. Higurashi, S. Kazadzis, P. Khatri, N. Kouremeti, R. Kudo, F. Marenco, M. Momoi, S.S. Ningombam, C.L. Ryder, A. Uchiyama, and A. Yamazaki, An overview of and issues with sky radiometer technology and SKYNET, Atmos. Meas. Tech., **13**, 8, 4195–4218, doi: 10.5194/amt-13-4195-2020, 2020. https://doi.org/10.5194/amt-13-4195-2020, 2020.

Address

Physikalisch-Meteorologisches Observatorium Davos
World Radiation Center
Dorfstrasse 33
CH-7260 Davos Dorf
Switzerland

Contacts

Dr. Stelios Kazadzis
Tel.: +41 81 417 5137
e-mail: stelios.kazadzis@pmodwrc.ch

Dr. Natalia Kouremeti
Tel.: +41 81 417 5167
e-mail: natalia.kouremeti@pmodwrc.ch

Long-term study of aerosol particle formation in the free troposphere

Federico Bianchi[1], Janne Lampilahti[1], Diego Aliaga[1]

[1] Institute for Atmospheric and Earth System Research, Helsinki, Finland

federico.bianchi@helsinki.fi

Part of this programme: ACTRIS

Keywords: new particle formation; air ions; free troposphere

1. Project description

A neutral cluster and air ion spectrometer (NAIS) has been measuring air ion (0.8-42 nm) and aerosol particle (2-42 nm) number size distributions at the Sphinx observatory, at Jungfraujoch, since November 2019. These measurements are continuing, and the goal of the project is to collect multiple years of data in order to form a comprehensive picture of new particle formation at the Sphinx observatory.

An important aspect of the data analysis regarding the year 2020 is to see if the COVID-19 lockdown and the associated travel restrictions had any effect on the aerosol particle and air ion concentrations.

The data continues to show low concentrations of negative cluster (sub-2 nm) ions compared to the positive cluster ions (Figure 1). This is likely related to the so-called atmospheric electrode effect, which would be enhanced at mountain peaks or ridges.

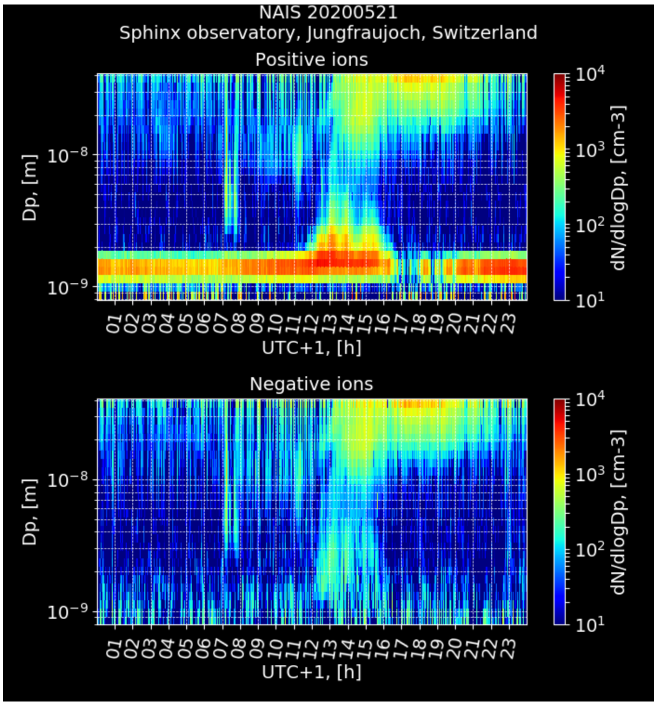

Figure 1. The number-size distribution of negative and positive ions measured at Jungfraujoch by the NAIS on May 21, 2020.

Collaborating partners / networks

Dr. M. Gysel, Paul Scherrer Institute (PSI), Villigen, Switzerland

Address

Institute for Atmospheric and Earth System Research
University of Helsinki
Gustaf Hällströmin katu 2a
FI-00560 Helsinki

Contacts

Dr. Federico Bianchi
Tel: +358 40 326 8723
e-mail: federico.bianchi@helsinki.fi

Ice nucleating particles and ice multiplication at moderate supercooling

Franz Conen[1], Claudia Mignani[1], Lukas Zimmermann[1]

[1] Department of Environmental Sciences, University of Basel, Basel, Switzerland

franz.conen@unibas.ch

Keywords: mixed-phase clouds; ice nucleation; snow crystals; secondary ice

1. Project description

In this project we study the role of ice nucleating particles (INPs) in mixed-phase clouds. Jungfraujoch is an ideal place for that because it often is shrouded in clouds with temperatures below 0 °C. We started 10 years ago by sampling aerosol particles with liquid impingers to determine the concentration of bacteria and INPs active at moderate supercooling in free tropospheric air (Xia et al., 2013); developed a method for analysing INPs on archived PM_{10} filters (Conen et al., 2012); and described the seasonality in INP concentrations at Jungfraujoch (Conen et al., 2015) as well as the main factors driving their short-term variation, such as removal from clouds by precipitation (Stopelli et al., 2015, 2016). Though we found in precipitation on Jungfraujoch a prominent ice-nucleating bacterium, *Pseudomonas syringae*, its contribution to the overall population of INP active at -8 °C was very small (Stopelli et al., 2017).

In 2018 we began to analyse single snow crystals (dendrites) for embedded INPs to see what fraction of these beautiful crystals, which form within a narrow temperature range (-12 °C to -17 °C), may be of primary origin. Our results showed that only about one in eight dendrites were initiated by an INP and the remainder had probably grown from ice splinters, such as generated during ice-ice collision in clouds (Mignani et al., 2019). During winter 2020/2021 we would have liked to continue this work with a BSc project, but had to change our plans because of the unpredictable situation regarding health and safety regulations at various levels. Therefore, progress has been very limited. Nevertheless, we have started to build several improved copies of the instrument (i.e.: portable coldstage) used by Mignani et al. (2019). We intend to distribute these instruments to colleagues in other regions (e.g.: Svalbard, Hokkaido, ...) so that the experiments started at Jungfraujoch on INPs in single snow crystals can be replicated in other locations. Whoever is interested in repeating these analyses and has the time and ability to do so, please get in contact with us.

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Collaborating partners / networks

Dr. M. Gysel, Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen, Switzerland
Dr. S. Reimann, Dr. C. Hüglin, Dr. M. Steinbacher, Ms. C. Zellweger-Fäsi, and Dr. A. Fischer, Laboratory for Air Pollution/Environmental Technology, Swiss Laboratories for Material Science and Technology (Empa), Dübendorf, Switzerland

Address

Department of Environmental Sciences
University of Basel
Bernoullistrasse 30
CH-4056 Basel
Switzerland

Contact

Dr. Franz Conen
Tel.: +41 61 207 0481
e-mail: franz.conen@unibas.ch

Monitoring of ice cloud forming aerosols at the Jungfraujoch: automation of HINC for continuous INP monitoring

Zamin A. Kanji[1] and Cyril Brunner[1]

[1] Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland

zamin.kanji@env.ethz.ch

Part of this programme: GAW

Keywords: ice nucleation; ice nucleating particles; ice forming particles; ice formation; INP; aerosol; aerosol cloud interaction

1. Project description

The limited knowledge of aerosol-cloud interactions introduces large uncertainties when simulating the radiative forcing in climate models. The physical and optical properties, as well as the evolution of precipitation of a cloud heavily depends on the hydrometeor phase. One pathway to form ice crystals in the troposphere is via ice nucleating particles (INPs) which make up only a tiny fraction of all tropospheric aerosols. For accurate climate forecasts and projections, the parametrization of cloud processes and information such as the concentrations of INPs are needed. Presently, no automated INP counter is available and the data acquisition still requires a human operator.

To address this restriction, we developed a fully automated online ice nucleation particle counter, through an adaptation of an existing custom-built instrument, the Horizontal Ice Nucleation Chamber (HINC), called HINC-Auto (Brunner and Kanji, 2020). HINC-Auto was deployed in February 2020 at the High Altitude Research Station Jungfraujoch (JFJ). The measured data is available in near real-time on the PSI aerosol website.

In the second phase of the project, the measurements of HINC-Auto will be used to investigate three specific research questions:

I. What is the diurnal and seasonal variability of INP concentrations at the JFJ?

II. How do anthropogenic aerosols influence the INP concentrations in the troposphere?

III. What is the seasonal frequency and contribution of Saharan dust to the INP concentrations at the JFJ?

These research questions arose during previous studies as they are important in understanding the connection between INPs and ice formation within clouds. However, the missing availability of a monitoring INP counter resulted in a case study analysis with too little data to conclusively address these questions. HINC-Auto is the first online INP counter to measure continuously for more than 45 days. In fact, the 11-month of continuous INP data measured in 2020 at the JFJ look very promising to allow a robust response to the stated research questions.

We will publish the findings in two manuscripts in 2021. The first manuscript will discuss the influence of Saharan Dust on the free tropospheric INP concentration and present evidence on how remote sensing can be used to deduce atmospheric pathways of INPs. The manuscript is currently in preparation. The second manuscript will shed light upon the diurnal and seasonal variability of INP concentrations at the JFJ. Both these research questions can only be answered because of the long-term monitoring of INP concentrations now installed and fully running at JFJ. Meanwhile, we aim to continue the INP measurements with HINC-Auto at the JFJ to study seasonal pattern.

Internet data bases

https://www.psi.ch/en/lac/projects/last-72h-of-aerosol-data-from-jungfraujoch

Collaborating partners / networks

Dr. M. Steinbacher, Dr. Ch. Zellweger, Dr. M. Vollmer and Dr. S. Reimann, EMPA, Dübendorf
Dr. Franz Conen and Mignani Claudia, Institut für Umweltgeowissenschaften, Universität Basel
Dr. M. Gysel and Dr. B. T. Brem, Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen

Scientific publications and public outreach 2020

Refereed journal articles and their internet access

Brunner, C. and Z.A. Kanji, Continuous online-monitoring of Ice Nucleating Particles: development of the automated Horizontal Ice Nucleation Chamber (HINC-Auto), Atmos. Meas. Tech. Discuss. [preprint], https://doi.org/10.5194/amt-2020-306, *in press*, 2020.

Conference papers

Brunner, C. and Z. A. Kanji, A new instrument for continuous monitoring of ice nucleating particles, 5th Virtual Alpine Observatory Symposium, Bern, Switzerland, February 4-6, 2020.

Brunner, C. and Z. A. Kanji, A new instrument for continuous monitoring of ice nucleating particles, European Aerosol Conference, Aachen, Germany, August 31 – September 4, 2020 (virtual conference due to CoViD-19).

Lacher, L., H. Clemen, X. Chen, S. Mertes, D. Weber, J. Schrod, M. Gysel-Beer, M. Steinbacher, A. Zipori, J. Schneider and Z. A. Kanji, A strudy on the relaritonship between ice activity, chemical composition and long-range transport of aerosol particles measured at the Jungfraujoch Station, European Aerosol Conference, Aachen, Germany, August 31 – September 4, 2020 (virtual conference due to CoViD-19).

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Address

Institute for Atmospheric and Climate Science
ETH Zürich
CHN O 16.3
Universitätstrasse 16
CH-8092 Zürich
Switzerland

Contacts

Dr. Zamin A. Kanji
Tel.: +41 44 633 6161
e-mail: zamin.kanji@env.ethz.ch

Global Atmosphere Watch radiation measurements

Laurent Vuilleumier[1], Gilles Durieux[1], David Vernez[2]

[1] Federal Office of Meteorology and Climatology MeteoSwiss, Payerne, Switzerland
[2] Center for public health and primary care medicine (Unisanté), University of Lausanne, Switzerland

laurent.vuilleumier@meteoswiss.ch

Part of this programme: GAW

Keywords: solar irradiance; ultraviolet, visible, infrared and spectral irradiance; precision filter radiometer (PFR); pyranometer; pyrheliometer; UV biometer; aerosol optical depth (AOD); integrated water vapour (IWV)

1. Project description

The goal of the Global Atmosphere Watch Radiation Measurement program at Jungfraujoch is providing long-term monitoring of surface downward radiation fluxes. It is conducted in the framework of the GAW Swiss Alpine Climate Radiation Monitoring program (SACRaM), which applies operational guidelines similar to those of the international Baseline Surface Radiation Network, except for the daily maintenance requirements due to the remote nature of the site. In 2020, an excellent degree of data availability was achieved, especially considering the challenging conditions at Jungfraujoch. On average, the data availability for radiation parameters reached 99%. Achieving this level of data availability for continuous automatic monitoring at Jungfraujoch implies a constant effort to sustain the highest achievable accuracy, stability and continuity in the measurements.

The measurement program includes shortwave (solar spectrum) and longwave (infrared thermal) broadband measurements as well as UV broadband measurements. Short- and longwave measurement series are important for climate research, while UV measurements are of interest for both public health and exploring the relationship between the evolution of the ozone layer and radiation. Broadband radiation is measured both as global downward hemispheric irradiance and as direct sun irradiance.

In addition, direct spectral irradiance is also measured, which allows aerosol optical depth (AOD) and integrated water vapour (IWV) column to be determined. In association with the WMO GAW Precision Filter Radiometer (PFR) network, MeteoSwiss operates such sun photometers at the four SACRaM stations measuring the direct irradiance in 16 narrow spectral bands within the range 305-1024 nm since 1998. One of the four sites is Jungfraujoch, characterized by an alpine environment and partial free tropospheric conditions. At nine wavelengths, aerosol optical depth (AOD) is computed at times when no clouds are in the path of the direct solar beam.

In 2020, research within the SACRaM network did not focus on the Jungfraujoch. On the other hand, there were studies on ground-based radiation estimates inferred using large-scale datasets based on satellite data.

In particular, a UV climatology for Switzerland has been developed to provide risk estimates at population level (Vuilleumier et al., 2020). The dataset provides global UV erythemal irradiance at a spatial resolution of 1.5–2 km and an hourly temporal resolution over fifteen years. Validation with ground-measured data showed that the expanded uncertainty for low hourly UVI values (UVI < 3) is about ± 0.3, while for high hourly UVI values (UVI > 6) it can go up to ± 1.5. In clear-sky situation, the uncertainty is about 10–15%. This climatology accurately reproduces UV dependencies on solar zenith angle, cloudiness, atmospheric ozone content, aerosol optical depth and altitude. It has a spatial resolution sufficiently high to adequately resolve mountain effects. In addition, it has a temporal resolution sufficiently high to establish the variation of irradiance during the day.

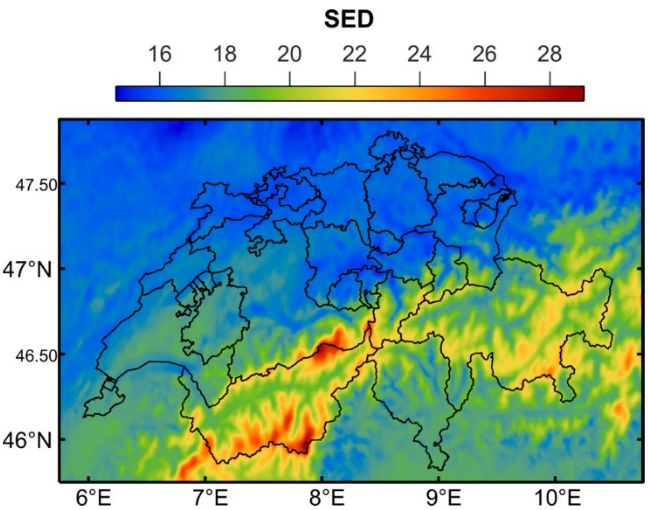

Figure 1. Map of average all-sky UV erythemal daily doses (SED) across Switzerland. UV daily doses (24 h exposure) are computed for every pixel and every day of the 15-year climatology and a temporal average over all days is computed for each pixel.

As an example, Fig. 1 shows for every pixel the average UV daily dose on a flat horizontal surface expressed in standard erythemal dose (SED). First, the UV daily dose is computed by integrating the average UV irradiance of the 24 h for each pixel and each day of the 15-year climatology and then a temporal average over all days is computed for each pixel. The average daily doses in Fig. 1 are between 15 and 29 SED and the spatial variability is mainly related to topography. The highest doses are found in the Alps, and particularly on summits and ridges such as the Jungfraujoch, while lower doses are found in lowlands and valleys. There are three reasons that explain why UV intensity is higher in mountains: the atmosphere traversed by UV radiation is thinner, there is less cloudiness above high mountains (when low clouds are present summits and ridges are above the cloud layer) and the surface albedo is higher due to snow.

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Internet data bases

http://www.meteoswiss.admin.ch/home/measurement-and-forecasting-systems/atmosphere/strahlungsmessnetz.html
http://wrdc.mgo.rssi.ru/

Collaborating partners / networks

Dr. S. Nyeki, Dr. J. Gröbner, "Physikalisch-Meteorologisches Observatorium Davos" (PMOD) World Radiation Center (WRC)
Dr. D. Vernez, Dr. J.-L. Bulliard, "Centre universitaire de médecine générale et santé publique, Unisanté, Lausanne"

Address

Office fédéral de météorologie et de climatologie MétéoSuisse
Station Aérologique
Ch. de l’Aérologie 1
CH-1530 Payerne
Switzerland

Contacts

Dr. Laurent Vuilleumier
Tel.: +41 58 460 9541
e-mail: laurent.vuilleumier@meteoswiss.ch

Maintentance of SwissMetNet and solar radiation station

Gilles Durieux[1], Stéphane Vincent[1], Stéphane Purro[1], Bertrand Equey[1]

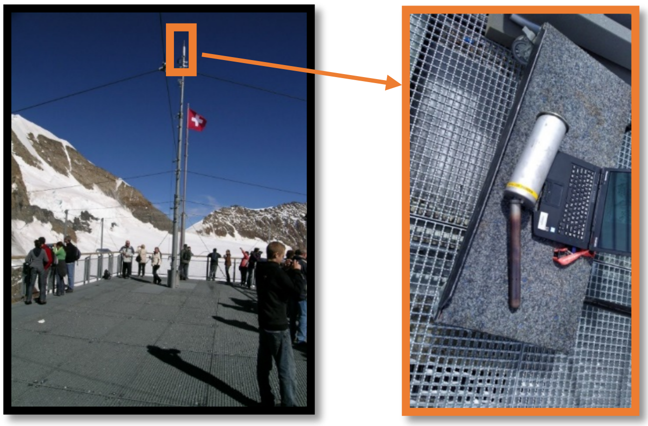
[1] Federal Office of Meteorology and Climatology MeteoSwiss, Payerne, Switzerland

gilles.durieux@meteoswiss.ch

Keywords: anemometer; sensor; wind

1. Project description

During 2020, on several occasions, we encountered breakdowns on the Rosemount anemometer installed at the Sphinx, on the tourists' terrace. For unknown reasons, the anemometer was damaged and need to be replaced.



As this is an old technology, which is no longer available on the market and supported by the supplier, it has become very complicated, even almost impossible to repair the sensor. The Rosemount anemometer detects wind by measuring the differential pressure across the wind probe. The anemometer at a high sample rate takes two differential pressure measurements – one for the North South wind vector, the other for the East-West vector. This pressure data is convert into wind vectors by the instrument microcontroller and then fed into several filters and gust detection algorithms. Due to its design and measuring principle, this sensor can be heavily heated, which makes it extremely resistant to harsh environment like the one encountered at Jungfraujoch. It is used on other site on the MeteoSwiss network, for which we also experience severe weather conditions (Saentis).

MeteoSwiss has decided to start a project in order to select a new instrument to replace the Rosemount. The new instrument will have to fulfil a certain number of requirements to be able to withstand these extreme weather conditions experienced at our high altitude stations. The high data quality and availability to which our services are bound requires top-level instruments coping with WMO standards and guideline. This is a typical example of an instrument's change on the network, which will require a careful assessment and test for its selection.

Address

Office fédéral de météorologie et de climatologie MétéoSuisse
Station Aérologique
Ch. de l'Aérologie 1
CH-1530 Payerne
Switzerland

Contacts

Gilles Durieux
Tel.: +41 58 460 9276
e-mail: gilles.durieux@meteoswiss.ch

Quality assurance and quality control of CO_2 observations

Martin Steinbacher[1], David Steger[1], Lukas Emmenegger[1], Christoph Hüglin[1]

[1] Laboratory for Air Pollution / Environmental Technology, Empa – Swiss Federal Laboratories for Materials Science and Technology, Duebendorf, Switzerland

martin.steinbacher@empa.ch

Part of this programme: ACTRIS, EMEP, GAW, ICOS, IG3IS, NABEL

Keywords: atmospheric chemistry; air quality; trace gases; greenhouse gases; long-term monitoring

1. Project description

Empa launched its first atmospheric measurements at Jungfraujoch in 1973 as part of an early engagement of Switzerland in a programme organised by the Organisation for Economic Co-operation and Development (OECD). In 1978, Empa and the Swiss Federal Office for the Environment (FOEN/BAFU) initiated the Swiss National Air Pollution Monitoring Network (NABEL), with Jungfraujoch (JFJ) being one of the first 8 sites. In 1990/1991 the NABEL network was extended to 16 monitoring stations that are distributed across Switzerland. The monitoring stations represent the most important air pollution levels ranging from the urban kerbside to the remote background. The NABEL site at Jungfraujoch is such a remote site; it represents the lower free troposphere in central Europe.

The current measurement program at Jungfraujoch includes continuous in-situ analyses of ozone (O_3), carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). Particulate matter is measured as PM10 (particles < 10 µm), PM2.5 (< 2.5 µm), PM1 (< 1 µm), and the particle number concentration (PNC) between 0.18 and 18 µm is also recorded continuously. All these data are stored as 10-min averages. An extended set of halocarbons (e.g. CFCs, HFCs), sulphur hexafluoride (SF_6) and a selection of volatile organic compounds (VOCs) (alkanes, aromatics) are measured with a time resolution of two hours. Daily samples are taken to quantify particulate sulphur and PM10.

A comprehensive calibration, quality assurance (QA) and quality control (QC) strategy is of utmost importance when performing atmospheric composition measurements. This is particularly true when measurements are long-term and part of a network of stations to ensure that the observed variability and trends are not due to changes in the instruments' sensitivity, and to allow for a best possible compatibility of the different time series within the network or across several networks, respectively. The latter also requires a well-documented traceability to internationally agreed scales, which are maintained by either National Metrology Institutes or assigned Central Calibration Laboratories in case of the Global Atmosphere Watch (GAW) programme of the World Meteorological Organisation (WMO). The required quality and quantity of the data are defined by so-called data quality objectives (DQOs). DQOs specify tolerable levels of measurement uncertainty and/or network compatibility based on the scientific question of interest or the decisions to be made (WMO, 2017). Within the context of GAW, DQOs are released as part of GAW reports (available via the WMO library, https://library.wmo.int/) or in the peer-reviewed literature as those publications often have a wider visibility in the scientific community. Sometimes, several resources are available, for example in the case of tropospheric ozone. There, DQOs for traditional GAW goals such as the detection of long-term changes in ozone background concentrations are given in a GAW report (WMO, 2013), but more explicit requirements for specific scientific questions, such as requirements for the validation of air quality models or satellite-borne ozone data, were released in a later publication (Tarasick et al., 2019).

DQOs are particularly demanding for carbon dioxide (CO_2) observations due to its long atmospheric lifetime, the strong interaction with the biosphere and consequently only small spatial gradients. The DQOs for greenhouse gases like CO_2 are regularly reviewed during the bi-annual Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques – GGMT (WMO, 2020). The desired compatibility goal, understood as "*the scientifically-determined maximum bias among monitoring programmes that can be included without significantly influencing fluxes inferred from observations with models*" for measurements in well-mixed background conditions is 0.1 ppm in the Northern hemisphere. To meet this goal, an internal reproducibility including instrumental imprecision, uncertainties in the traceability chain or uncertainties due to gas handling and drying of about 0.05 ppm (or roughly 0.1 permil at a level of 400 ppm) needs to be achieved (WMO, 2020). These specifications require high-precision instrumentation, a comprehensive QA/QC strategy, and a close and unbroken link to one of the internationally accepted primary scales. Operators of European greenhouse gas observations in pristine regions teamed up under the umbrella of the Integrated Carbon Observation System (ICOS) Research Infrastructure (www.icos-ri.eu). Members of ICOS, which is recognized as a contributing network to GAW, benefit from access to a Central Analytical

Laboratory in Germany, which provides references gases directly traceable to the WMO scales maintained by GAW's Central Calibration Laboratories. For an optimum compatibility, ICOS also developed detailed specifications in terms of operation, like number of calibration gases, and specifies requirements in terms of sample periphery, like drying units, tubing material, models of pressure regulators etc. (ICOS RI, 2020). ICOS stations also undergo a rigorous assessment prior to acceptance to the network. The assessment procedure is documented in a recent publication by Yver-Kwok et al. (2021). A minimum of three high-pressure cylinders are required for a weekly to bi-weekly calibration, and two additional target tanks are used to track the short-term and longer-term performance of the instrumentation. Data from all ICOS stations are sent daily to the Atmospheric Thematic Centre (ATC) in France for centralized data processing. There, the data sets are split into subsets of in-situ (ambient air) data, target data and calibration data and further processed (see Figure 1 for illustration). Target data are measured up to once per day, are treated as unknowns in the same way as the in-situ data and are used as quality indicators and timely markers in case of problems.

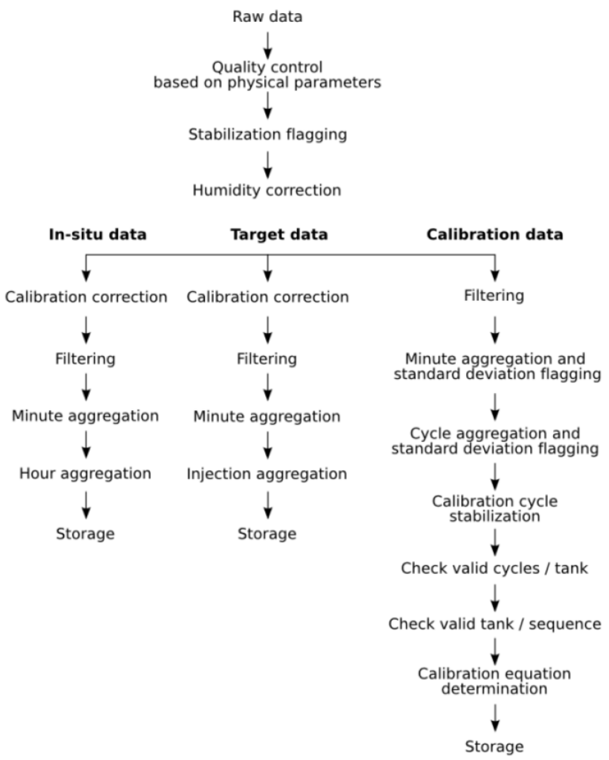


Figure 1. Schematic of data treatment during automatic processing at the ICOS Atmospheric Thematic Centre (taken from Hazan et al., 2016).

Standardized output is generated for visual inspection and quality control and is made publically available on the ICOS ATC panel board (https://icos-atc.lsce.ipsl.fr/dp). One of those plots is shown in Figure 2. The multi-panel figure shows the ambient air data on top, followed by the standard deviation of the ambient air data, the continuous measurement repeatability (CMR) defined as the monthly average of the standard deviations of short-term target raw data over 1 min intervals, the long-term repeatability (LTR) calculated as the standard deviation of the averaged short-term target measurement intervals over 3 days, and the difference of the calibrated short-term target data to its assigned value. The enhanced levels of LTR uncertainty and short-term target bias at the beginning of the period were caused by a problem with the sample drying. These numbers could be flattened when changing the drying unit in early November 2017. A series of other automatically generated plots are updated once a day and are made available on the ATC webpage.

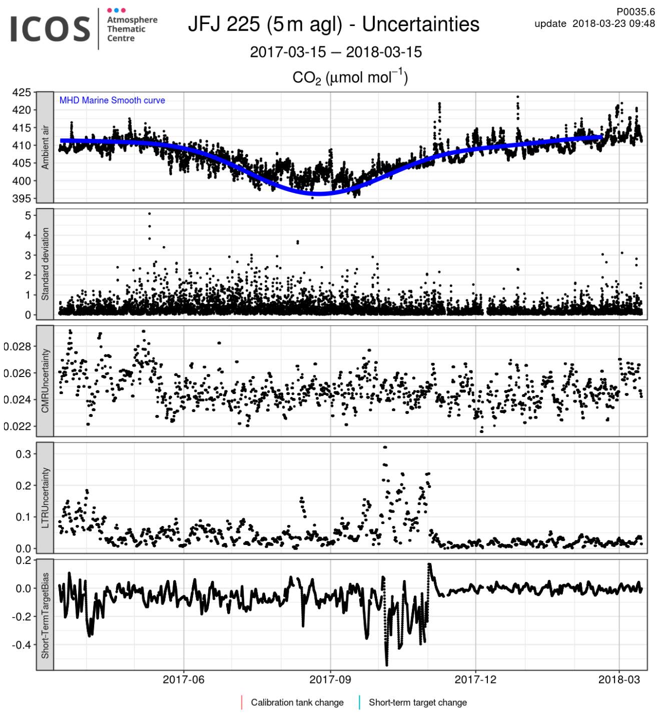


Figure 2. Standardized ICOS summary plot for atmospheric CO_2 data from Jungfraujoch. See the text for details. The smoothed curve for Mace Head (in blue) is added for visual guidance to the plots of all stations to simplify the comparison (taken from Yver-Kwok et al., 2021).

Next to the background station Jungfraujoch, CO_2 is also measured at the NABEL stations Haerkingen, Payerne and Rigi-Seebodenalp. The observations close to the highway in Haerkingen started in 2007 mainly as an indicator for the intensity of the traffic influencing the site. In more recent years, CO_2 measurements were also launched at Payerne and Rigi-Seebodenalp, partly facilitated through the availability of multi-species analyzers allowing to measure CO and CO_2 with the same instrument. In 2019, calibration and traceability of the CO_2 measurements at Payerne and Rigi-Seebodenalp were also implemented. Due to the rather large variability at Haerkingen, Payerne and Rigi-Seebodenalp (see Figure 3), a relaxed QA/QC strategy can be followed, and a simplified calibration scheme is applied. Instruments are regularly calibrated with CO_2-free air and one reference tank. Concentrations in the reference tanks are assigned by WMO/GAW's World Calibration Centre for CO_2 at Empa and are, thus, also traceable to the common GAW scale. The atmospheric variability on the Swiss plateau (observed at Haerkingen and Payerne) is largely driven by meteorology, such as the intensity of venting of the plateau or the occurrence of inversions. The measured CO_2 concentrations at Haerkingen are usually higher than at Payerne due to the vicinity of the highway, but persistent episodes with particularly low (e.g. in late February/ early March 2020) or high concentrations (e.g. in mid-March 2020) can be observed at both sites. The elevation of the Rigi-Seebodenalp station (1031 m asl) results in significant less variability than on the Swiss plateau but there is still more scatter than at Jungfraujoch, which is mostly exposed to free tropospheric air masses.

The CO_2 measurements at the four NABEL stations also serve as reference for the recently established Carbosense network (http://carbosense.wikidot.com). The Carbosense network is a uniquely dense CO_2 sensor network across Switzerland, which includes more than 250 low-cost sensors measuring CO_2. Due to the large number of sensors, network control and sensor calibration requires novel QA/QC approaches. Prior to deployment, all sensors are calibrated in a pressure and climate chamber as well as in ambient conditions when being exposed next to a reference instrument for several weeks. Once deployed, sensor data are corrected for interferences of atmospheric water vapour, followed by an outlier and drift correction and a final consistency check (Müller et al., 2020). The high-precision NABEL data are used for sensor calibration and assessment of the sensors' long-term performance as well as for correcting the sensor drifts during field operation.

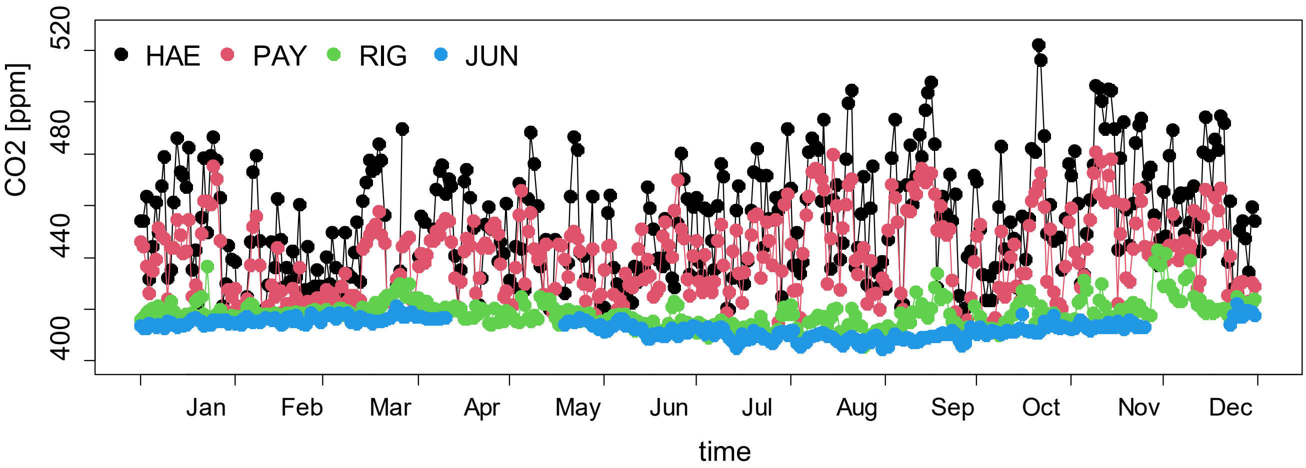


Figure 3. Daily averages of CO_2 mole fractions in 2020 at Jungfraujoch (blue) and other lower elevation sites of the Swiss National Air Pollution Monitoring Network, Haerkingen (HAE, black), Payerne (PAY, red), and Rigi-Seebodenalp (RIG, green).

Acknowledgements

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https://icos-atc.lsce.ipsl.fr/JFJ

Collaborating partners / networks

Bundesamt für Umwelt (BAFU) / Federal Office for the Environment (FOEN)
Belgian Institute for Space Aeronomy, Brussels
Climate and Environmental Physics, University of Bern
Environmental Geosciences, University of Basel
Institut d'Astrophysique et de Géophysique, Université de Liège
Institute for Atmospheric and Climate Science, ETH Zurich
Laboratory for Atmospheric Chemistry, Paul Scherrer Institut
MeteoSchweiz
World Meteorological Organisation (WMO)
ACTRIS – Aerosol, Clouds, and Trace Gases Research Network
EMEP – European Monitoring and Evaluation Programme
GAW – Global Atmosphere Watch
ICOS – Integrated Carbon Obervation System Research Infrastructure
IG3IS – Integrated Global Greenhouse Gas Information System
NABEL – Swiss National Air Pollution Monitoring Network
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Henne, S., D. Brunner, M.K. Vollmer, M. Steinbacher, M. Leuenberger, J. Mohn, S. Reimann, L. Emmenegger, Top-down Estimation of Swiss non-CO2 Greenhouse Gas Emissions in Support of National Inventory Reporting to UNFCCC, 18th Swiss Geoscience Meeting, virtual, November 6, 2020.

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Address

Empa
Laboratory for Air Pollution/Environmental Technology
Ueberlandstrasse 129
CH-8600 Dübendorf
Switzerland

Contacts

Dr. Martin Steinbacher
Tel.: +41 58 765 4048
e-mail: martin.steinbacher@empa.ch

Continuous measurement of stable CO_2 isotopes at Jungfraujoch, Switzerland

Simone M. Pieber[1], Béla Tuzson[1], Stephan Henne[1], Ute Karstens[2], Martin Steinbacher[1], Lukas Emmenegger[1]

[1] Laboratory for Air Pollution and Environmental Technology (Empa), Duebendorf, Switzerland
[2] ICOS Carbon Portal, Lund University, Sweden

simone.pieber@empa.ch

Part of this programme: GAW, ICOS, RINGO

Keywords: stable CO_2 isotopes; quantum cascade laser absorption spectroscopy; atmospheric simulations

1. Project description

Long-term observations of carbon dioxide (CO_2) provide direct information about their variability and rate of change in the atmosphere. Co-located observations of stable CO_2 isotope ratios add unique information on the CO_2 fluxes between the different pools involved in the carbon cycle owing to isotopic fractionation during environmental processes. Atmospheric CO_2 concentration and its stable isotope ratios ($\delta^{13}C$ and $\delta^{18}O$) are measured continuously and simultaneously by in-situ quantum cascade laser absorption spectroscopy (QCLAS) since December 2008 at the Jungfraujoch research station as previously described (Tuzson et al., 2008 and 2011; Sturm et al. 2013). These unique high frequency data enable the analysis of variations at minutes time-scales. We use these data for an evaluation of 3-hourly atmospheric transport model simulations of CO_2, which can be subsequently used to derive $\delta^{13}C$-CO_2 estimates.

We utilize two independent atmospheric transport models FLEXPART-COSMO (Empa, Henne et al. 2016) and STILT-ECMWF (ICOS Carbon Portal, Kountouris et al. 2018) in order to generate regional CO_2 simulations for Jungfraujoch (JFJ). Both models were run in a receptor-oriented approach, following 'sampled' air masses backward in time and as such providing surface source sensitivities (“concentration footprints”). Convoluting these with spatially and temporally resolved anthropogenic emission inventories and biosphere CO_2 fluxes, allows for quantitative simulation of CO_2 mole fractions at the receptor site. The models differ regarding the implementation of the Lagrangian particle dispersion and are driven by output from two different numerical weather prediction systems. Furthermore, they are run for two different domain sizes (Europe ("large", 33°N-73°N, -15-35°E, STILT-ECMWF) and Western Europe ("small", 36.06-57.42°N, -11.92-21.04°E, FLEXPART-COSMO)), respectively. Both are combined with an optimized product for boundary conditions (background CO_2) provided by C. Rödenbeck (Jena CarboScope, JCS). The regional CO_2 simulations are based on anthropogenic and ecosystem fluxes taken from the EDGAR v4.3 inventory (Janssens-Maenhout et al., 2019) and the Vegetation and Photosynthesis Model (VPRM), respectively (Mahadevan et al., 2008).

2. Results

Figure 1 presents QCLAS based CO_2 observations and simulations. Figure 1a provides a time-series of QCLAS based CO_2 concentration measurements at JFJ as well as the simulated CO_2 concentration of the total signal (regional component plus background). A regression analysis reveals for the regional signal of all years a coefficient of determination (r^2) of around 0.4 for STILT-ECMWF and FLEXPART-COSMO on a 3-hourly time-resolution. Thus, we capture 40% of the signals variability. Figures 1b-e show multi-annual monthly means of the regional simulated CO_2 contributions based on b) anthropogenic and c-e) ecosystem fluxes. Both anthropogenic and ecosystem fluxes are slightly larger for the STILT-ECMWF model, which is in parts related to the larger domain size. However, both models highlight the dominance of ecosystem contributions to the regional CO_2 at JFJ over anthropogenic contributions. We attribute this to a combination of the timing of emission strength and the intensity of the atmospheric transport of regional air masses from the planetary boundary layer (PBL) to JFJ.

Previous analysis by Herrmann et al. (2015) demonstrated that JFJ's PBL exposure is enhanced by a factor 1.5-2.5 in April and August/September, and by a factor of 3-4 from May-July, when compared to the winter months Dec-Feb (factor = 1). This transport seasonality correlates with the emissions strength seasonality of the biosphere, which peaks during the warm season. Instead, the transport seasonality anti-correlates with the anthropogenic emissions flux strength, which peaks during the cold period, owing to the enhanced burning of fuels for domestic heating. This limits the exposure of JFJ to anthropogenic CO_2 compared to ecosystem CO_2. However, it needs to be noted that CO_2 concentrations and simulations show largest discrepancies during summer, indicating an overestimation of the ecosystem uptake in the simulations.

The simulated CO_2 mole fractions per source and sink category were further used to estimate ambient $\delta^{13}C$-CO_2 values, which we compared with the unique continuous $\delta^{13}C$-CO_2 measurements

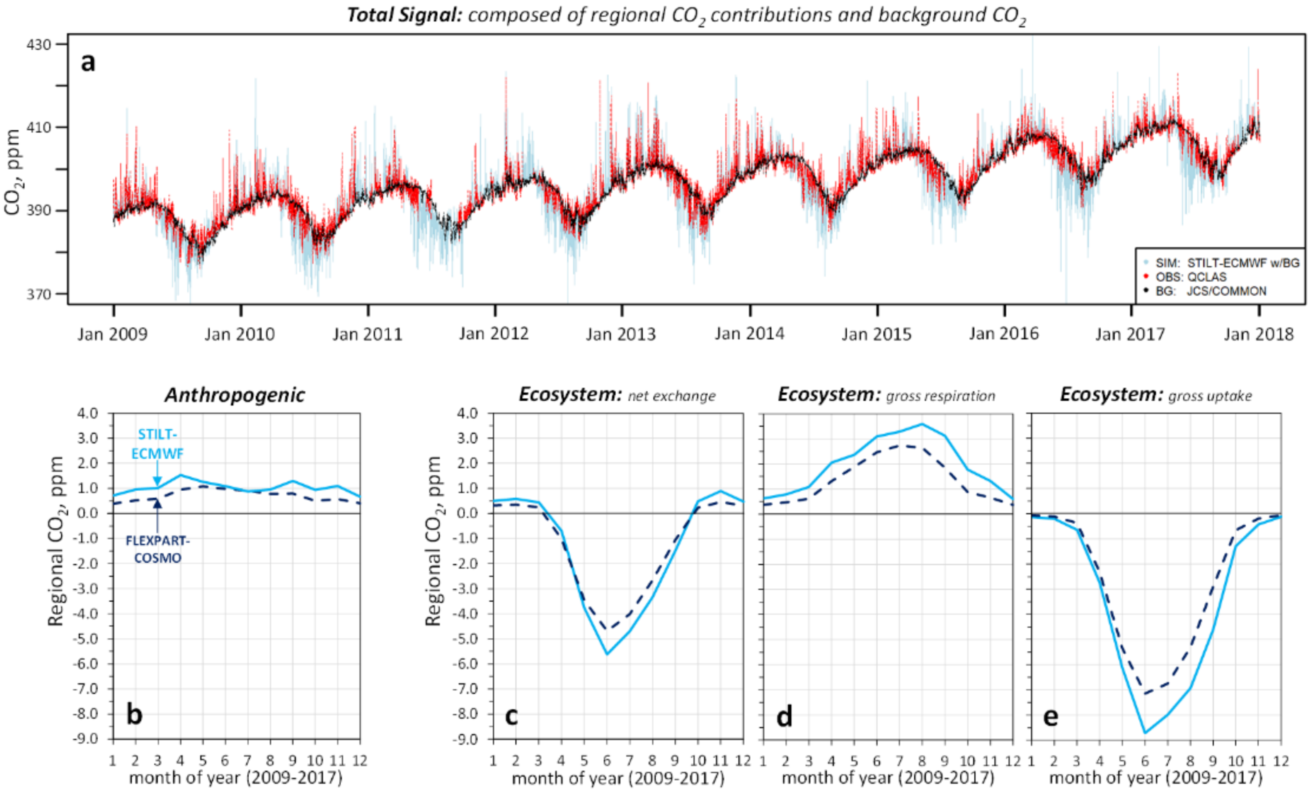

Figure 1. CO_2 concentration und regional CO_2 contributions at JFJ. a) Time-series of QCLAS observations (OBS), CO_2 simulations based with STILT-ECMWF (SIM) and CO_2 background (BG) based on Jena Carboscope (JCS) boundary conditions, b-e) multi-annual monthly means of simulated CO_2 contributions based on b) anthropogenic and c-e) ecosystem fluxes during 2009-2017 (STILT-ECMWF vs. FLEXPART-COSMO). The net ecosystem exchange in c) is composed of d) ecosystem gross respiration and e) ecosystem gross uptake.

available for JFJ from a quantum cascade laser absorption spectrometer. We find that around 35% of the observed variability in the regional $\delta^{13}C$-CO_2 signal can be captured by the simulations.

3. Conclusions and Outlook

Both model simulations, STILT-ECMWF and FLEXPART-COSMO, explain around 40% of the regional CO_2 variability at JFJ on a 3-hourly time resolution – a remarkable achievement considering the complex alpine topography and the low intensity of regional signals. Highest agreement between model and observation is observed during spring, lowest in summer, when the simulations appear to overestimate the photosynthetic uptake. Regarding the CO_2 contributions, biosphere components outweigh anthropogenic components and account for at least 50% of the regional CO_2 concentrations at JFJ even during the winter months. The $\delta^{13}C$-CO_2 estimates based on the CO_2 simulations capture the observations variability by around 35%. This is remarkable considering the apparent challenges of simulating ambient $\delta^{13}C$-CO_2 concentrations for JFJ, such as the remote location and low signal-to-background ratio, alongside the substantial influence of biosphere contributions, and the high degree of mixing of various sources in the regional air masses captured at JFJ.

In the future, the additional use of further tracers such as e.g., atmospheric radiocarbon ($^{14}CO_2$) measurements during regional pollution events, as well as atmospheric potential oxygen (APO) estimates based on atmospheric O_2/N_2 measurements can provide additional means to further constrain the fraction contributed by anthropogenic and biosphere fluxes. This might allow achieving additional insight on the model simulations performance to provide a representative picture on the regional CO_2 variability at JFJ.

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Internet data bases

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Collaborating partners / networks

ICOS Carbon Portal, Lund University, Sweden
Institut für Umweltgeowissenschaften, University of Basel
Climate and Environmental Physics, University of Bern
Max Planck Institute for Biogeochemistry, Jena, Germany
GAW – Global Atmosphere Watch
ICOS – Integrated Carbon Observation System
RINGO – Readiness of ICOS for Necessities of integrated Global Observations

Scientific publications and public outreach 2020

Conference Papers

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Address

Laboratory for Air Pollution and Environmental Technology
Empa
CH-8600 Duebendorf
Switzerland

Contacts

Dr. Simone M. Pieber
Tel.: +41 58 765 4397
e-mail: simone.pieber@empa.ch

Dr. Béla Tuzson
Tel.: +41 58 765 4642
e-mail: bela.tuzson@empa.ch

Dr. Lukas Emmenegger
Tel.: +41 58 765 4699
e-mail: lukas.emmenegger@empa.ch

High precision carbon dioxide and oxygen measurements at Jungfraujoch

Markus C. Leuenberger[1], Michael F. Schibig[2], Peter Nyfeler[2], Christoph Reinhard[2], Hanspeter Moret[2]

[1] Climate and Environmental Physics, Physics Institute and Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland
and
Director of the International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat (HFSJG), 3012 Bern
[2] Climate and Environmental Physics, Physics Institute and Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland

markus.leuenberger@climate.unibe.ch

Part of this programme: ICOS

Keywords: CO_2 measurements; O_2 measurements

1. Project description

Oxidation ratios of different processes like photosynthesis, respiration or fossil fuel combustion are relatively stable over time. Therefore, combined CO_2 and O_2 measurements can be used to determine how much of the emitted CO_2 is taken up by the ocean and the biosphere and how much stays in the atmosphere.

The in-situ CO_2 and O_2 measurements were continued throughout the whole year with mainly minor interruptions due to technical issues. As in previous years, the record shows an increase of the atmospheric CO_2 mole fraction modulated by the seasonal cycle due to mainly photosynthesis and respiration.

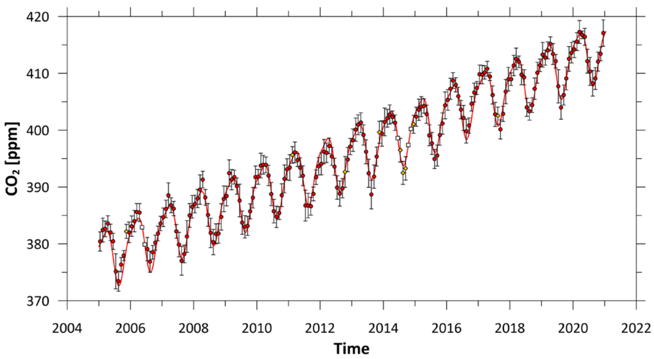

Figure 1. Monthly averages of the CO_2 measurements from Jungfraujoch (Sphinx) calculated using filtered nightly hourly means (22:00-3:59 UTC) from 2005 to 2020. The red dots mark months with a coverage better than 50 %, the yellow diamonds correspond to months where the coverage is less than 50 %, the empty squares represent months with no measurements at all, they were calculated using the 2-harmonic fit function, which is represented by the red line.

To calculate the annual CO_2 increase and the seasonality at Jungfraujoch, only night-time values (22:00-3:59 UTC) were used because they represent mostly background air from the free troposphere. Months with a coverage of less than 50 % were excluded from further calculations. The CO_2 trend from 2005 to 2020 was calculated to be 2.29 ± 0.03 ppm yr^{-1} (Figure 1). The average seasonal amplitude over this period was 10.92 ± 1.17 ppm with a maximum in March/April and a minimum in August.

Due to the COVID-19 pandemic, many countries had partial or complete lockdowns, tourism and travel was reduced as were many economic operations. The global CO_2 emission reduction in 2020 due to the COVID-19 policy was estimated by Friedlingstein et al. (2020) to be about 8 %.

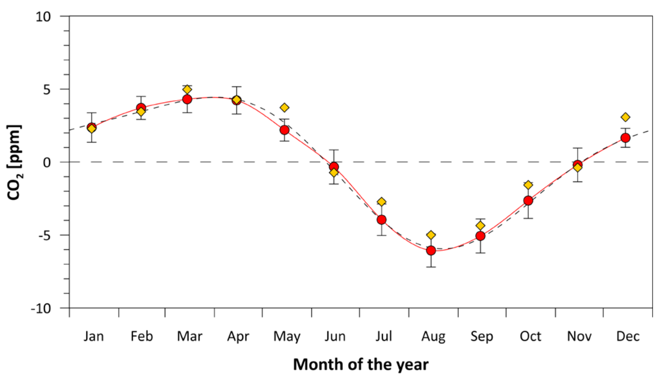

Figure 2. Monthly averages of the detrended 2020 CO_2 measurements are represented by the orange diamonds, the red line with the red dots shows the average seasonality over the years 2005-2019 with their standard deviation, which follows very close the 2-harmonic fit function calculated based on the data 2005-2019 indicated by black dashed line.

However, this decrease is hardly traceable in the CO_2 measurements at Jungfraujoch yet. The CO_2 increase calculated based on filtered night-time values over a ten year period from 2010-2019 is 2.47 ± 0.05 ppm yr^{-1}, the increase from 2011-2020 including the COVID-19 year is 2.45 ± 0.05 ppm yr^{-1} which is the same within the uncertainties. Also when detrending and deseasonalizing the data using the filtered night-time data from 2005-2019 and calculating averages of the months of this 15 year period, the monthly averages of the year 2020 lie mostly within the uncertainty and are not generally lower (Figure 2).

Temperature control issues of the inlet system showed to have a strong effect on the O_2 content of air in close contact with the heated walls of the inlet system. In order to measure unaffected air a dip tube was installed in January 2020. The system samples now air from the center of the inlet sysem, where the effects of the heating on the O_2 content of the sample air is much smaller as was indicated in short tests in late 2019.

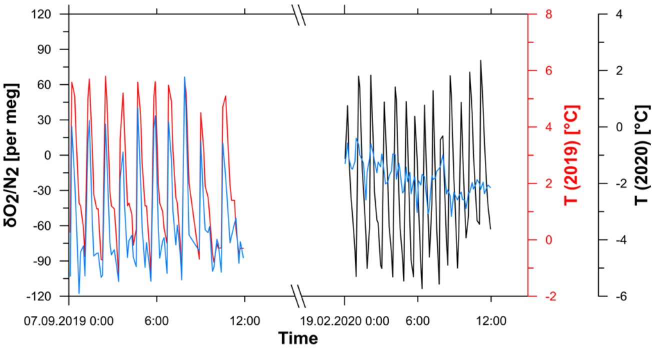

Figure 3. Detrended and deseasonalized $\delta O_2/N_2$ measurements (blue line) show a strong influenced of the temperature (red line, red y-axis) on the oxygen measurements before the installment of the dip tube in January 2020, the measurements with the dip tube in 2020 show no such influence of the temperature anymore (black line, black y-axis).

Comparing measurements from phases with instable temperature control before and after the installation of the dip tube (Figure 3) confirm the results of the short test. The influence of the temperature on the oxygen measurements vanished with the dip tube. When using the first 10 years of measurements (2005-2014) to calculate a 2-harmonic fit funciton with slope and extrapolating it until the end of the year 2020 (Figure 4), the phase of the bad temperature control and its influence on the meausurements become clearly visible. However, the data of the year 2020 with the dip tube match the extrapolated fit function perfectly, indicating that the oxygen meaurements are fine again.

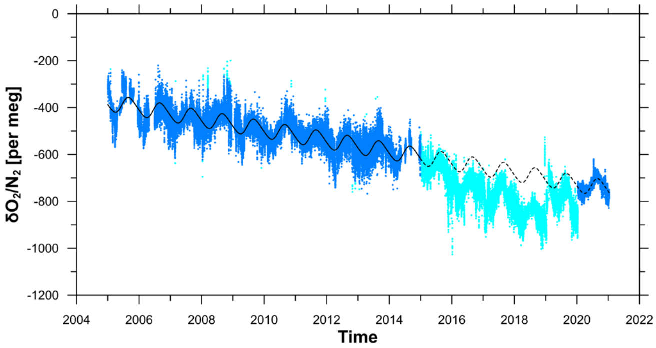

Figure 4. Hourly averages of $\delta O_2/N_2$ measurements at the Sphinx observatory, the light blue dots represent all available hourly averages, the dark blue dots are the hourly averages after sigma-filtering, where the values from 2015 until 2019 were not considered due to the influence of the inlet temperature regulation on the O_2 content of the sampled air. The black line represents a 2-harmonic fit function based on the filtered values from 2005 to 2014, the dashed black line shows its extrapolation until the end of 2020.

Correcting the oxygen data from 2015 to 2019 using the temperature of the inlet system is still work in progess, a completely satisfactionary solution has not been found yet.

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Internet data bases

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Collaborating partners / networks

ICOS, ICOS-CH-partners
GAW, GAW-CH
Cooperative Global Atmospheric Data Integration Project; (2019): Multi-laboratory compilation of atmospheric carbon dioxide data for the period 1957-2018; obspack_co2_1_GLOBALVIEWplus_v5.0_2019_08_12; NOAA Earth System Research Laboratory, Global Monitoring Division http://dx.doi.org/10.25925/20190812.
SwissGCOS (Roundtables)
EMPA (Laboratory for Air Pollution / Environmental Technology)
MPI BGC Jena (Dr. Armin Jordan and staff members)
ICOS-ICOS - Flask and Calibration Laboratory
Technologie Center Felsenkeller (TCF), Jena, Germany

Scientific publications and public outreach 2020

Conference Papers

Schibig, M.F., P. Nyfeler, M.C. Leuenberger, Influence of SARS-CoV-2 lockdown on atmospheric background CO_2 values measured at Jungfraujoch, oral presentation, ICOS-CH annual meeting, virtual, September 3, 2020.

Schibig, M.F., P. Nyfeler, M.C. Leuenberger, Influence of SARS-CoV-2 lockdown on atmospheric background CO_2 values measured at Jungfraujoch, poster presentation, ICOS science conference, virtual, September 15-17, 2020.

Address

University of Bern
Physics Institute
Climate and Environmental Physics
Sidlerstrasse 5
CH-3012 Bern
Switzerland

Contacts

Prof. Dr. Markus Leuenberger
Tel.: +41 31 631 4470
e-mail: markus.leuenberger@climate.unibe.ch

Flask comparison on Jungfraujoch

Armin Jordan[1,2], Heiko Moossen[2], Willi A. Brand[2], Michael Rothe[2], Peter Nyfeler[3], Michael F. Schibig[3], Vasileios Mandrakis[3], Markus Eritt[1,2], Markus Leuenberger[3]

[1] Max Planck Institut für Biogeochemie, Jena, Germany
[2] Integrated Carbon Observation System (ICOS), Flask and Calibration Laboratory, Jena, Germany
[3] Climate and Environmental Physics Division, Physics Institute, University of Bern, Switzerland

markus.leuenberger@climate.unibe.ch

Part of this programme: associated to ICOS, GAW

Keywords: flask sampling; trace gas measurement; isotope ratio analysis; flask measurements; inter-comparison; oxygen and carbon dioxide measurements; greenhouse gas

1. Project description

The flask sampling for the intercomparison between Max Planck Institute Jena (MPI) and the University of Bern (UBE) was ongoing during the reporting period. For UBE, flasks were taken every week and measurements are available until the end of 2020. For MPI flasks were filled every second week and data are updated until mid-June 2020.

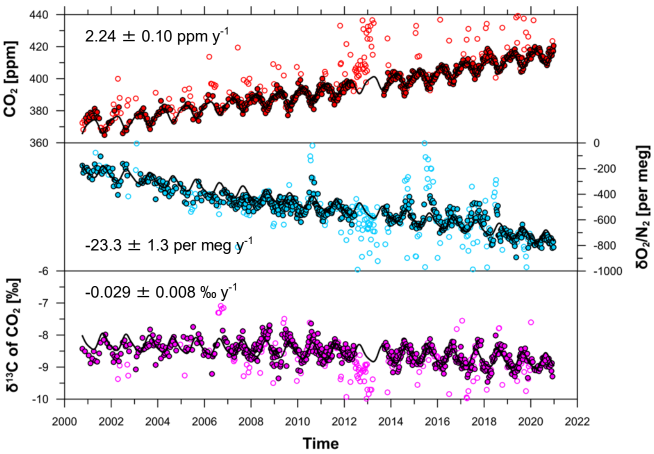

Figure 1. CO_2 (red), $\delta O_2/N_2$ (blue) and $\delta^{13}C$ of CO_2 (magenta) values as measured by the University of Bern. Circles correspond to all measurements, filled circles represent background values. Black lines are harmonic fits based on the background values. Trends are given with the corresponding uncertainties.

As discussed in previous reports, there were some issues with the measurements, e.g. leaky sampling lines, leaky water traps. But also flask samples that were measured long after sampling can be off due to diffusion of the gases through the Viton O-rings in the UBE flask valves. After excluding samples with obvious issues and filtering the UBE data for background conditions, the calculated long term trend from 2005 to 2020 for CO_2, $\delta O_2/N_2$ and $\delta^{13}C$ of CO_2 is 2.24 ± 0.10 ppm y^{-1}, -23.3 ± 1.3 per meg y^{-1} and -0.029 ± 0.008 ‰ y^{-1}, respectively. These values are in good agreement with the in-situ measurements for CO_2 and $\delta O_2/N_2$. On a first glance, the comparison between the UBE and the MPI values looks fine (Figure 2). When filtering the UBE and MPI datasets for background values and calculating the slopes over the common period (end of 2007 to mid-2020), the annual CO_2 increases correspond to 2.45 ± 0.11 ppm y^{-1} (UBE) and 2.38 ± 0.12 ppm y^{-1} (MPI), the annual $\delta O_2/N_2$ slopes are -20.0 ± 1.9 per meg y^{-1} (UBE) and -25.2 ± 1.4 per meg y^{-1} (MPI), and the annual changes of $\delta^{13}C$ of CO_2 are -0.043 ± 0.009 ‰ y^{-1} (UBE), and -0.026 ± 0.006 ‰ y^{-1} (MPI), respectively. While the agreement of the CO_2 slopes is good and the same within the uncertainty, it is slightly worse for $\delta O_2/N_2$ and $\delta^{13}C$ of CO_2 where the values do not agree within the given uncertainty.

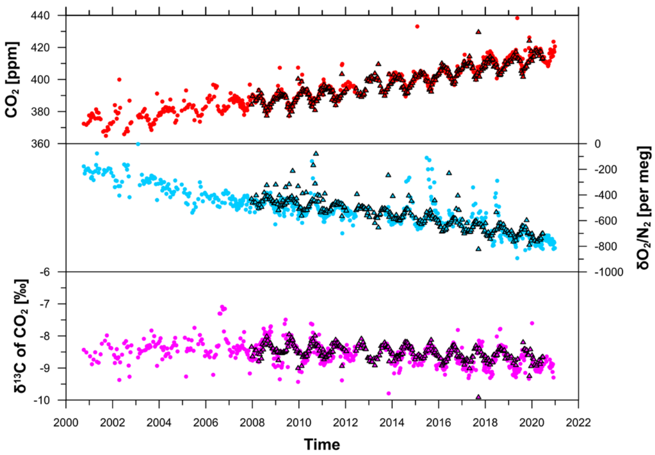

Figure 2. CO_2 (red), $\delta O_2/N_2$ (blue) and $\delta^{13}C$ of CO_2 (magenta) values as measured by both laboratories University of Bern (points, valid values) and MPI-BGC Jena (triangles, valid values).

The seasonalities of the UBE and the MPI datasets for CO_2, $\delta O_2/N_2$ and $\delta^{13}C$ of CO_2 are 9.41 ± 0.82 ppm (UBE) and 10.53 ± 1.18 ppm (MPI), 152.2 ± 57.5 per meg (UBE) and 117.7 ± 45.0 per meg (MPI), and 0.805 ± 0.198 ‰ (UBE), and 0.508 ± 0.053 ‰ (MPI), respectively. The seasonality agrees within the uncertainty for CO_2 and $\delta O_2/N_2$, but not for $\delta^{13}C$ of CO_2.

When looking at the differences between the two datasets (Figure 3), a period of enhanced differences in CO_2 from August 2017 until August 2018 catches the eye. A possible reason for this enhanced difference might be an increasing delay in measuring the UBE flasks due to lab issues, sometimes of up to more than one year. As mentioned further up, the Viton used to seal the UBE flasks allows for some permeation of gases (Sturm et al. 2004) and the applied correction seems to become increasingly insufficient the longer flasks have to be stored before measuring. The comparison of the two datasets shows that meeting the WMO compatibility goals for extended networks remains challenging as already mentioned in van der Laan et al. (2013), where a detailed comparison of the first four years was shown.

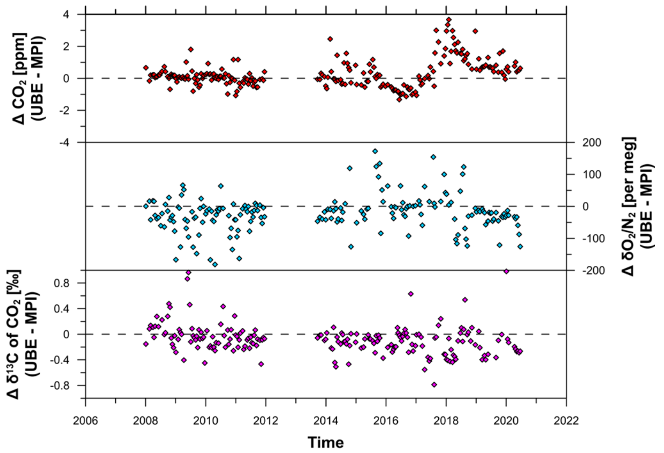

Figure 3. Differences (UBE – MPI) of CO_2 (red), $\delta O_2/N_2$ (blue) and $\delta^{13}C$ of CO_2 (magenta) measurements.

In summer 2020, the ICOS flask sampler was brought to Jungfraujoch and connected to the NABEL inlet system at the Sphinx roof top as the other analyzers measuring for ICOS. First tests showed that the preinstalled pump was insufficient to operate at the altitude of JFJ. It was not able to maintain the needed pressure and flow. The pump was replaced with a more powerful model in fall. Also the pressure sensors used to control the sampling process do not seem to meet the necessary requirements to operate reliably at JFJ. This made it rather difficult to adjust the sampler's back pressure valves properly and an external pressure sensor had to be used to do so. Therefore, the pressure readings in the sampling meta data are not trustworthy.

In fall, the flask sampler was additionally connected to the new "Mönch" inlet line with a manually actuated three-way valve. Now it is possible to sample from the well-known NABEL inlet where the other ICOS systems are currently sampling from as well as from the new inlet further away from the touristic activities, which might become the new standard inlet.

Since the end of October 2020, the flask sampler is sampling on a regular basis for ICOS. Samples have been sent for analysis to the ICOS central lab in Jena with results still pending. In addition to the ICOS flask samples, which are taken every third day, the flask sampler fills a flask every Friday morning during the sampling of the traditional UBE flask sampling. The main goal is to get data on the comparability of the traditional flask sampling done by the custodians and the new automated flask sampling done by the sampler.

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Address

Max Planck Institut für Biogeochemie
Hans Knöll Str. 10
D-07745 Jena
Germany

Contacts

Dr. Armin Jordan
Tel.: +49 3641 57 6403
e-mail: ajordan@bgc-jena.mpg.de

Collaborating partners / networks

International Foundation Hochalpine Forschungsstationen Jungfraujoch und Gornergrat (HFSJG)
Oeschger Centre for Climate Change Research, University of Bern
ICOS-RI partner, ICOS-CH partners

Scientific publications and public outreach 2020

Conference Papers

Schibig, M.F., P. Nyfeler, M.C. Leuenberger, Flask sampling program at Jungfraujoch, oral presentation, 5th VAO Symposium, Bern, Switzerland, February 4-6, 2020.

Schibig, M.F., P. Nyfeler, M.C. Leuenberger, ICOS flask sampler tests in Bern, oral presentation, ICOS Science Conference, virtual, September 15-17, 2020.

Benchmarking of an optical sensor for the measurement of particulate matter and cloud droplets

Ann-Kathrin Goßmann[1], Benjamin Brem[2], Frederik Weis[1], Maximilian Weiß[1]

[1] Palas GmbH, Partikel- und Lasermesstechnik, Karlsruhe, Germany
[2] Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

ann-kathrin.gossmann@palas.de; benjamin.brem@psi.ch

Part of this programme: none, but topically related to: GAW, ACTRIS, NABEL

Keywords: aerosols; particulate matter; cloud droplets; optical particle counter; optical particle size spectrometer

Project description

Fine dust and aerosol particles affect the climate and people's health and therefore monitoring of both is receiving more and more attention from scientists and regulatory agencies. One widespread technique to measure aerosol particles are optical aerosol spectrometers based on angular light scattering. These devices often use an external upstream aerosol drying system or require to be connected to a central heated sampling inlet to be able to measure the aerosol particle concentrations and size distributions accurately and reproducible. One of these devices is the FIDAS from PALAS GmbH, which can be connected directly to a central heated inlet or set up with an ancillary upstream dryer.

In the course of the development of a new generation, small footprint, optical fine dust monitoring device (AQ Guard), Palas made an effort to downsize the whole measuring system and also the aerosol dryer with the aim to provide a device that is easy to facilitate and independent of central heated probe inlets (for example for difficult accessible or remote measurement sites). The critical point in downsizing, however, is the drying system. The aim of the measurement campaign at the Sphinx Observatory was to test two approaches for that: (i) a specially developed water content algorithm to calculate the water content in the aerosol and calculate the dry distribution from the undried one and (ii) a miniaturized dryer system. The water content algorithm was previously developed based on prior collected FIDAS measurement data at Puy du Dome (France). Jungfraujoch (JFJ) was chosen as a further testing location for both approaches, because it is situated in high alpine extreme conditions and the possibility to measure in clouds, which is particularly useful and interesting for the algorithm approach.

The AQ Guard prototype device was mounted on the Sphinx Observatory terrace and a FIDAS as reference was connected to the central GAW aerosol inlet inside the Sphinx laboratory. Measurements of both devices were recorded and compared regarding fine dust mass concentrations (PM), total aerosol number concentrations and particle size distributions.

The tests of water content algorithm (i) showed that the low sample flow of the AQ Guard (1 l /min compared to 5 l/min for FIDAS) seems to be too small to sample enough particles to get the counts necessary for a statistically sound algorithm output at the often very clean conditions at the JFJ. However, this could be solved with longer averaging times of the measured aerosol size distributions in the future. Nevertheless, a further development of the algorithm is necessary, for which the data collected provide a good basis.

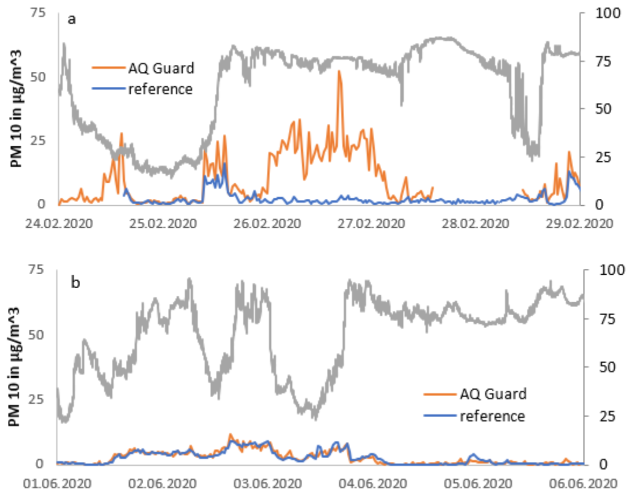

Figure 1. a: PM 10 values of the AQ Guard (in orange) mounted on the Sphinx terrace without (a) and with (b) drying in comparison to the FIDAS reference (in blue) in the Sphinx laboratory connected to the GAW aerosol inlet. Ambient relative humidity (in grey) is displayed as an indicator for general aerosol humidity and water content in the air.

The obtained PM 10 data for Sphinx terrace mounted AQ Guard with switched off aerosol drying in comparison to FIDAS reference in the Sphinx Laboratory is shown in Figure 1a. It can be seen, that in times of high humidity and fog the PM 10 value of AQ Guard is too high. In contrast, with the aerosol drying system turned on (Figure 1b); both devices are in good agreement. In general, the tests of the downsized aerosol dryer showed promising results and the dryer did not fail during phases of the various extreme ambient conditions with very high relative sub saturated humidity and supersaturated cloud conditions, during mostly freezing (sub-zero °C) temperature conditions.

Address

Palas GmbH Partikel- und Lasermesstechnik
Greschbachstraße 3 b
D-76229 Karlsruhe
Germany

Laboratory of Atmospheric Chemistry
Paul Scherrer Institute
Forschungsstrasse 111
CH- 5232 Villigen PSI
Switzerland

Contacts

Ann-Kathrin Gossmann
ann-kathrin.gossmann@palas.de

Dr. Benjamin Tobias Brem
Tel.: +41 56 310 2465
benjamin.brem@psi.ch

Halogenated greenhouse gases at Jungfraujoch

Martin K. Vollmer[1], Matthias Hill[1], Paul Schlauri[1], Myriam Guillevic[1], Stephan Henne[1], Lukas Emmenegger[1], Stefan Reimann[1]

[1] Laboratory for Air Pollution / Environmental Technology, Empa – Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland

martin.vollmer@empa.ch

Part of this programme: CLIMGAS-CH/HALCLIM, AGAGE, ACTRIS, NABEL

Keywords: atmospheric chemistry; ozone-depleting gases; greenhouse gases

1. Project description

Halogenated synthetic greenhouse gases (GHGs) and ozone-depleting substances (ODSs) have been monitored at Jungfraujoch since 2000 as part of the BAFU-funded project “HALCLIM”, which was extended into “CLIMGAS-CH” in 2018. These measurements are combined with atmospheric transport models for identifying and quantifying national and regional emissions of non-CO_2 greenhouse gases (Switzerland and neighboring countries). For these synthetic greenhouse gases the "top-down" (observation-based) estimates are used to support "bottom-up" estimates of the national reporting authorities, that are based on industry information (import / export / manufacture). Furthermore, the measurements help to track global trends of ODSs and GHGs in the “background” air. Measurements at Jungfraujoch comprise a suite of more than 50 compounds, such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs and SF_6), and hydrofluorocarbons (HFCs), which are regulated under the Montreal Protocol on Substances That Deplete the Ozone Layer, and the Kyoto Protocol, and additional compound classes such as hydrofluoroolefines (HFOs) and halogenated hydrocarbons. Most of these compounds are core substances measured by the AGAGE program (Advanced Global Atmospheric Gases Experiment), of which Empa is a partner. Individual measurements are conducted on 2 L of sampled air and using a gas chromatograph-mass spectrometer (GC-MS) analytical technique (Miller et al., 2008).

For the 2020 activities we report on the installation of a new instrument, Aprecon-GC-ToF-MS (Advanced-preconcentration gas chromatograph time-of-flight mass spectrometer) for measurements of halogenated trace gases at Jungfraujoch (Photograph 1). The instrument features new technologies, foremost allowing for a near complete “fingerprint” trace gas scanning of the atmosphere at very low concentration levels. The Aprecon-GC-ToF MS will be run in parallel with the existing Medusa-GCMS for an extended period of time to provide a thorough on-site instrumental comparison.

From a historic perspective, CLIMGAS-CH/HALCLIM started in 2000 with an Adsorption-Desorption-System (ADS) GC-MS, developed by the University of Bristol (Simmonds et al., 1995). In 2008, it was replaced by a Medusa-GC-MS developed at the Scripps Institution of Oceanography (SIO, Miller et al., 2008). In December 2020, the Medusa-GC-MS was complemented by the Aprecon-GC-ToF-MS system, developed by Empa.

Photograph 1. Advanced preconcentration (Aprecon) GC-Tof-MS installed at Jungfraujoch. Custom-built preconcentration unit on top of the gas chromatograph. ToF-MS in foreground behind computer screens.

Parts-per-trillion (ppt, pmol mol^{-1}) and parts-per-quadrillion (ppq, fmol mol^{-1}) mole fraction detection of atmospheric trace constituents requires, in most cases, a sample preconcentration to enhance the detector signal size. All three above-mentioned systems use a cold-trap collection of 2 L sample (air or calibration standard), with a trap-heated desorption for subsequent GC injection. The ADS was equipped with a single trap packed with Carbotrap, Carboxen 1003, and Carboxen 1000, and refrigerated to ~−50 C using Peltier elements. The Medusa uses a two-trap system with HayeSep D packing material and a closed cycle refrigeration system (Cryotiger, Polycold), allowing for trapping temperatures at

~−160 C. The two-trap system enables a sample cryofocusing and a substantial removal of large fractions of the main constituents of the atmosphere (O_2, N_2, noble gases, CO_2). The refrigeration system of the Medusa in the entire AGAGE network is in process of being replaced by a Stirling cooler system (Sunpower), allowing for lower and more controlled trapping temperatures (~−180 °C), with the Jungfraujoch Medusa having undergone this change in spring 2020. Aprecon is designed similar to a Stirling-equiped Medusa with two traps, however, in addition, the two traps can be lifted off the refrigeration plate before heating and compound desorption (Eyer et al., 2016, and technology adopted by the National Oceanic and Atmospheric Administration, NOAA, Miller et al., unpublished work). This technology necessitates less heat input to the traps/baseplate and hence a faster recovery to subsequent trapping temperatures.

The measurement systems have also undergone other improvements over time, related to valve technology, sample size determinations, but most notably, chromatographic separation as well. While the ADS was fitted with a CPSil-5 silicone capillary column, the Medusa was originally equipped with a single Porabond Q capillary column. This was later modified to allow for the measurement of the powerful greenhouse gas nitrogen trifluoride (NF_3), by an additional Gaspro column, through which only the first high-volatility compound desorption is routed in the typical Medusa staggered desorption technique (Arnold et al., 2012; change to NF_3 mode at Jungfraujoch in April 2014). The Aprecon instrument is equipped with Gaspro columns only but include a main (60 m) and an additional 5 m long precolumn to backflush late-eluting compounds, which would otherwise disturb the measurements of subsequent sample injections. This improvement was, among other reasons, a requirement for the significant change in the MS detection system.

MS acquisition in both ADS and Medusa systems are quadrupole MS (q-MS, Hewlett Packard, later Agilent Technologies) with upgrades to the latest models available. The Aprecon-GC-ToF-MS however is equipped with a Time-of-Flight mass spectrometer (H-TOF, Tofwerk, Thun). Several technical and software improvements and adaptations were necessary for using the ToF-MS in combination with high-precision GC measurements. There are two significant advantages of the ToF-MS over the q-MS: first, an entire fragment mass range (here set to 24 m/z–300 m/z), and virtually up to >900 fragments can be measured simultaneously with the ToF-MS. This compares to only 10−15 simultaneously measured fragment ions with the q-MS, when in selected ion mode (scan mode is not yielding sufficient sensitivity). Second, this ToF-MS has a significantly larger mass resolution (~4'000) compared to the q-MS (1), allowing for improved separation of compounds based on fractional masses of the ionized fragments. These advantages allow for detecting and measuring many more compounds in the atmosphere. They allow for studying hitherto unknown compounds, to determine their atmospheric abundances and trends, and thereby to determine the present and potential future impact on the chemistry of Earth's atmosphere. While the detection and identification of new compounds are also addressed with this new measurement technique, and require innovative tools that are under development, the present report is focussed on a first comparison of in-situ measurements for the Medusa GCMS and the Aprecon-GC-ToF-MS for known compounds.

With the installation of the Aprecon-GC-ToF-MS in early December 2020, a preliminary one-month long on-site intercomparison between the two instruments at Jungfraujoch is now possible. The two instruments draw air samples from an upgraded inlet system at the end of the ~40 m long ridge extending NE from the visitor terrace. Each instrument's air sampling module is connected to a separate heated inlet line (100 m, Synflex 1300, 12 mm OD). Calibration of the two instruments is based on individual whole air quaternary (working) and tertiary transfer standards, ultimately linked to the same AGAGE SIO primary calibration scales for the individual compounds. From a suite of >50 substances, a selection of five has been chosen for an illustrated comparison in Fig. 1.

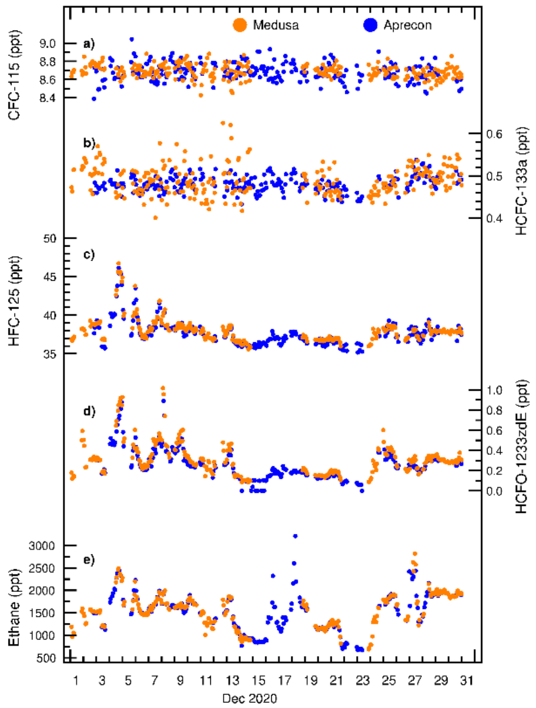

Figure 1. Jungfraujoch records of five selected trace gases for December 2020 for the Medusa GC-MS (in orange, operated 2008 – present) and the Aprecon GC ToF-MS (in blue, operated Dec 2020 – present). Halogenated trace gases of one each of four generations are selected plus one hydrocarbon (ethane).

Mole fractions for the five compounds range from sub-ppt to lower ppb (nmol mol^{-1}). Absolute mole fractions generally agree well and the atmospheric variability, if present, is being tracked similarly by the two instruments. Nevertheless, significant differences are present for some compounds (e.g. HFC-125), which however are masked by the large variabilities in the record. In general, this first in-situ comparison reveals somewhat poorer sensitivities, detection limits and measurement precisions for the Aprecon-GC-ToF-MS. Also, admittedly, the five example compounds shown in Fig. 1 belong to the group of well-compared compounds. There are also some compounds, for which the Aprecon-GC-ToF-MS shows significantly different absolute mole fractions and/or poorer precisions compared to the Medusa-GC-MS. Efforts are now underway to understand these discrepancies, and some have already been assigned to coelution (in mass and/or time), which will need improved integration techniques. Further on-site tests (non-linearities, system blanks) are underway to perform a rigorous evaluation of the new system under field station conditions — laboratory tests have so far shown promising results. Overall, the performance of the new Aprecon-GC-ToF-MS looks very promising

Acknowledgements

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Collaborating partners / networks

Bundesamt für Umwelt (BAFU) / Federal Office for the Environment (FOEN)
Advanced Global Atmospheric Gases Experiment (AGAGE): https://agage.mit.edu/
Tofwerk, Thun, Switzerland
Aerodyne Research Inc, Billercia (MA), USA
University of Bristol
Korea Polar Research Institute
CSIRO Oceans and Atmosphere
ACTRIS – Aerosol, Clouds, and Trace Gases Research Network
NABEL – Swiss National Air Pollution Monitoring Network
Institut d'Astrophysique et de Géophysique, Université de Liège
World Meteorological Organisation (WMO)
EMEP – European Monitoring and Evaluation Programme
GAW – Global Atmosphere Watch
ICOS – Integrated Carbon Obervation System Research Infrastructure
IG3IS – Integrated Global Greenhouse Gas Information System

Scientific publications and public outreach 2020

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Address

Empa
Laboratory for Air Pollution/Environmental Technology
Ueberlandstrasse 129
CH-8600 Dübendorf
Switzerland

Contacts

Dr. Martin K. Vollmer
Tel.: +41 58 765 4242
e-mail: martin.vollmer@empa.ch

Separating 'free tropospheric conditions' from those 'influenced by the planetary boundary layer'

Franz Conen[1], **Lukas Zimmermann**[1]

[1] Department of Environmental Sciences, University of Basel, Basel, Switzerland

franz.conen@unibas.ch

Part of this programme: ICOS

Keywords: planetary boundary layer; free troposphere; tracer

1. Project description

A wide range of atmospheric constituents are measured at Jungfraujoch. During the analysis of acquired data, one often asks whether *'free tropospheric conditions'* prevailed or whether measurements were *'influenced by the planetary boundary layer'* during a particular time interval. To inform judgements on that matter we continuously monitor the concentration of radon (^{222}Rn) in air aspired from outside the Research Station Jungfraujoch. Land surfaces are the source of radon in the atmosphere, where its sole sink is radioactive decay (half-life: 3.8 days). Thus, radon is a tracer of recent land contact of an air mass and it indicates, in principle, whether a measurement was *'influenced by the planetary boundary layer'*. However, setting a threshold in radon concentration above or below which either condition is met, was so far a largely arbitrary judgement. For this year's report, we analysed the probability density function (PDF) of all radon concentration values acquired during the past five years, a total of 42'450 one-hour measurements made between November 2015 and December 2020. The PDF of the log-transformed values can closely be reproduced by the sum of two fitted normal distributions. They most likely represent air masses *'influenced by the planetary boundary layer'* and *'free tropospheric conditions'* (Figure 1). Other allocations of the two distributions, say to summer and winter, or southern and northern approach of air masses seem less likely because the differences in radon concentrations between these categories are less pronounced and not so systematic. The best-matching relative weights found in the fitting process were 0.415 for the PDF 'free troposphere' and 0.585 for the PDF 'boundary layer'. In other words, *'free tropospheric conditions'* seem to have occurred over the past five years less often (41.5%) than conditions *'influenced by the planetary boundary layer'* (58.5%). Between the median of the distributions is a difference of 1.7 Bq m^{-3} (STP) or 1.1 Bq m^{-3} (local conditions). However, the distributions also have some overlap. Roughly, the highest 10% of 'free troposphere' values are larger than the lowest 10% of 'boundary layer' values (Table 1). Still, we think the separation of both distributions provides for a more informed judgement than before in setting of a threshold radon concentration below which *'free tropospheric conditions'* are likely.

When in doubt regarding the condition during an atmospheric measurement at Jungfraujoch, we can now say with about 90% confidence (10% false positives) that it was done in *'free tropospheric conditions'* when the concurrent radon concentration was below 1.0 Bq m^{-3} (STP) or below 0.64 Bq m^{-3} (local conditions; note: concentration values displayed on our website (radon.unibas.ch) are for local conditions).

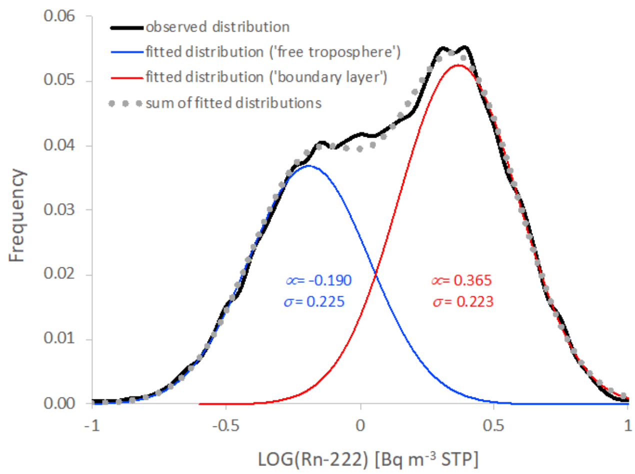

Figure 1. Probability density function (PDF) of radon concentration values (log-transformed) observed during the past five years at Jungfraujoch. The observed PDF is closely reproduced by the sum of two weighed PDFs most likely representing 'free troposphere' and air masses influenced by the 'boundary layer'.

Table 1. Back-transformed median, upper and lower 10th perentile of the two fitted distributions shown in Figure 1. Note: values displayed on our website (radon.unibas.ch) are for local conditions.

		median	percentile	
			10 th	*90 th*
'free troposphere'	*STP*	0.6	0.3	1.3
	local conditions	0.4	0.2	0.8
'boundary layer'	*STP*	2.3	1.2	4.5
	local conditions	1.5	0.8	2.9

Collaborating partners / networks

Dr. M. Gysel, Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen, Switzerland

Dr. S. Reimann, Dr. C. Hüglin, Dr. M. Steinbacher, Ms. C. Zellweger-Fäsi, and Dr. A. Fischer, Laboratory for Air Pollution/Environmental Technology, Swiss Laboratories for Material Science and Technology (Empa), Dübendorf, Switzerland

Dr. Alastair Williams, Dr. Alan Griffiths, Dr. Scott Chambers, Australian Nuclear Science and Technology Organisation (ANSTO), Sydney, Australia

Address

Department of Environmental Sciences
University of Basel
Bernoullistrasse 30
CH-4056 Basel
Switzerland

Contacts

Dr. Franz Conen
Tel.: +41 61 207 0481
e-mail: franz.conen@unibas.ch

Long-term observations of $^{14}CO_2$ at Jungfraujoch

Markus Leuenberger[1], Ingeborg Levin[2], Samuel Hammer[2,3]

[1] Climate and Environmental Physics Division, Physics Institute, University of Bern, Switzerland
[2] Institute of Environmental Physics, Heidelberg University, Germany
[3] ICOS Central Radiocarbon Laboratory, Institut für Umweltphysik, Heidelberg University, Germany

markus.leuenberger@climate.unibe.ch

Associated to programme: ICOS (https://www.icos-ri.eu/)

Keywords: carbon dioxide; carbon cycle dynamics; radiocarbon; fossil fuel CO_2

1. Project description

Since 1986, radiocarbon observations on carbon dioxide sampled at Jungfraujoch are being performed by the Heidelberg University. The responsibility of taking the samples moved to the University of Bern in 2018 due to the involvement in the Integrated Carbon Observation System Research Infrastructure (ICOS-RI). Jungfraujoch is an official ICOS class-1 station. The sampling protocol follows the specifications given by the atmospheric specification document for ICOS stations (ICOS RI, 2020). The measurements are done at the Central Radiocarbon Laboratory (CRL) at the Institute of Environmental Physics of Heidelberg University and the data are available via the ICOS Carbon Portal (www.icos-cp.eu).

Also this year the ^{14}C record from Jungfraujoch has been used widely as reference in many publications (*Levin et al.*, 2020; *Niu et al.*, 2021; *Rose et al.*, 2020; *Yver-Kwok et al.*, 2021; *Zheng et al.*, 2020; *Zhou et al.*, 2020).

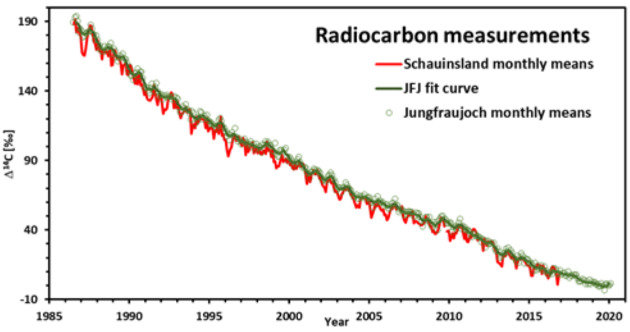

Figure 1. Atmospheric $\Delta^{14}CO_2$ observations at Jungfraujoch (green circles) in comparison to values of the Schauinsland station (red curve). The green line corresponds to a 5-months running mean of the Jungfraujoch values.

Radiocarbon is decreasing due to the exchange with the other carbon-containing reservoirs such as the ocean and the land-biosphere, but since the 1990s almost exclusively due to the ongoing (global) input of ^{14}C-free fossil fuel CO_2 into the atmosphere i.e. the global Suess effect (Fig. 1).

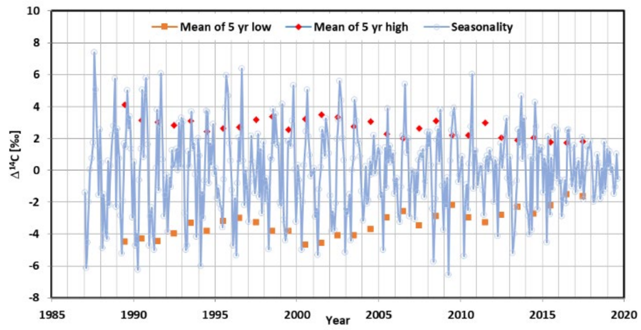

Figure 2. Seasonal amplitude of the Jungfraujoch record based on the monthly values from 1987 to 2020.

The seasonal amplitude at Jungfraujoch shows inter-annual variability as documented in Fig. 2. Over recent years the amplitude seems to be smaller compared to previous periods as documented by the 5 yr minimum and maximum values. The reason for this seasonality decrease is yet unknown.

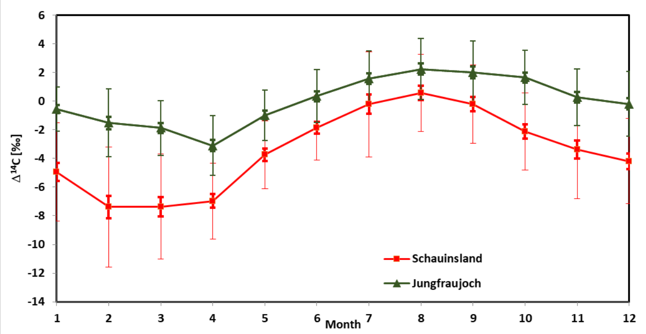

Figure 3. Mean seasonality of the Jungfraujoch and Schauinsland (shifted by the mean offset for the two stations during the overlapping period, i.e. 3.5 ‰). Corresponding uncertainty (1σ, thin line) and (1σ of the mean, thick line) based on the monthly values from 1987 to 2020 for Jungfraujoch and 1987 to 2016 for Schauinsland. January corresponds to month 1.

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Collaborating partners / networks

International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat (HFSJG)
ICOS-RI partner, ICOS-CH partners

Scientific publications and public outreach 2020

Refereed journal articles and their internet access

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Address

Climate and Environmental Physics Division
Physics Institute
University of Bern
Sidlerstrasse 5
CH-3012 Bern
Switzerland

Contacts

Prof. Dr. Markus Leuenberger
Tel.: +41 31 631 4470
e-mail: markus.leuenberger@climate.unibe.ch

Radiocarbon measurements of atmospheric methane

Sönke Szidat[1], Matthias Bantle[1], Christophe Espic[1]

[1] Department of Chemistry, Biochemistry and Pharmaceutical Sciences &
Oeschger Centre for Climate Change Research, University of Bern, 3012 Bern, Switzerland

szidat@dcb.unibe.ch

Keywords: methane; radiocarbon; source apportionment

1. Project description

We employ radiocarbon (^{14}C) measurements of atmospheric methane (CH_4) in order to determine its fractions of fossil sources (such as natural gas and fossil-fuel combustion) and contemporary sources (e.g. agriculture and wetlands) (Lassey et al., 2007). This approach benefits from the fact that ^{14}C is extinct in fossil fuels due to their old age, whereas contemporary sources show a modern radiocarbon level (Szidat, 2020). These results shall refine the understanding and quantification of individual sources of CH_4. Methane contributes substantially to global warming already today as the second most important anthropogenic greenhouse gas and may even become more relevant in the future as climate change could dramatically increase CH_4 natural emissions (Dlugokencky et al., 2011).

In 2020, we continued with the collection of grab samples (duration one hour) of ambient air at the Sphinx observatory at Jungfraujoch every second week (Fig. 1). In total 17 air samples of ~100 L (at STP) each from February/March and May to December were transferred to Bern in PE-AL-PE bags (TESSERAUX, Germany). There, CH_4 and CO_2 were extracted from the air samples using a preconcentration and purification setup that involves a gas-chromatography (GC) separation of the carbon-containing gases (Espic et al., 2019). The ^{14}C content of both gases was measured at the Laboratory for the Analysis of Radiocarbon with AMS (LARA) at the University of Bern (Szidat et al., 2014).

$^{14}CH_4$ measurements of atmospheric air from the continental background site Jungfraujoch were compared with results of two other strategic sites in Switzerland, i.e. the Beromünster tall tower as a rural background site and the Department of Chemistry, Biochemistry and Pharmaceutical Sciences of the University of Bern as an urban site. The comparison of the results from Beromünster and Jungfraujoch is of special importance, as it provides the potential of quantifying contributions of fossil and contemporary sources as well as $^{14}CH_4$ emissions of nuclear power plants in the vicinity of the rural site. Such a comparison has been performed in a similar way for the quantification of emissions of carbon dioxide (CO_2) using radiocarbon measurements (i.e. of $^{14}CO_2$) since 2012 (Berhanu et al., 2017). The $^{14}CH_4$ measurements in 2020 confirmed the results of 2019 that Jungfraujoch is well suited as continental background station for $^{14}CH_4$. The variability of the individual measurements from Jungfraujoch was again much smaller than for the rural and the urban sites.

Figure 1. Collection of air samples at Jungfraujoch. Picture: N. Arnosti.

In 2021, our activities at Jungfraujoch shall be extended within the framework of the Sinergia project "Radiocarbon Inventories of Switzerland (RICH): An integrated approach to understand the changing carbon cycle" that is funded by the Swiss National Science Foundation (SNSF). We will set up an automated sampling system at Jungfraujoch that allows a continuous collection of ambient air samples for an integrated determination of $^{14}CH_4$. This data will serve as reference for regional source apportionment of methane using ^{14}C that shall be performed at different sites in Switzerland.

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Internet data bases

https://www.14c.unibe.ch/
http://p3.snf.ch/project-193770

Collaborating partners / networks

Prof. T.I. Eglinton, Department of Earth Sciences, ETH Zurich
Dr. F. Hagedorn, Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf
Dr. H. Graven, Department of Physics, Imperial College London
Prof. M. Leuenberger, Climate and Environmental Physics, University of Bern
Dr. D. Brunner, Dr. S. Henne, Empa, Dübendorf
Dr. L. Wacker, Laboratory of Ion Beam Physics, ETH Zurich
Dr. S. Hammer, Institute of Environmental Physics, Heidelberg University

Scientific publications and public outreach 2020

Conference Papers

Espic, C., M. Battaglia, R. Schanda, M. Leuenberger, S. Szidat, Radiocarbon measurements of atmospheric methane, Virtual Alpine Observatory (VAO), 5th VAO-Symposium, Bern, Switzerland, February 4-6, 2020.

Address

Laboratory for the Analysis of Radiocarbon with AMS
Department of Chemistry, Biochemistry and Pharmaceutical Sciences
University of Bern
Freiestrasse 3
CH-3012 Bern
Switzerland

Contacts

Prof. Dr. Sönke Szidat
Tel.: +41 31 631 4308
e-mail: szidat@dcb.unibe.ch

^{85}Kr Activity Determination in Tropospheric Air

Andreas Bollhöfer[1], Clemens Schlosser[1], Martina Konrad[1], Sabine Schmid[1] and Roland Purtschert[2]

[1] Bundesamt für Strahlenschutz, Rosastr. 9, D-79098 Freiburg, Germany

[2] Climate and Environmental Physics, Physics Institute and Oeschger Centre for Climate Change Research, University of Bern, Switzerland

abollhoefer@bfs.de

Keywords: Krypton; ^{85}Kr; radioactivity in air; reprocessing plants

1. Project description

Monitoring of tropospheric ^{85}Kr activity concentrations at Jungfraujoch (JFJ) has started in 1990 and was continued in 2020. Krypton is separated from about 10 m^3 of air continuously collected during one week and sent to the Bundesamt für Strahlenschutz in Freiburg i.Br. to measure the ^{85}Kr activity concentration. Since 2014 the noble gas laboratory at BfS in Freiburg is accredited according to DIN EN ISO/IEC 17025 [1].

The major sources of atmospheric ^{85}Kr are nuclear reprocessing plants. During the last few decades, the most relevant emitter is the facility in La Hague in France, followed by the facility in Sellafield, UK. Due to its half-life of 10.74 years ^{85}Kr accumulates in the atmosphere if the release rate from all reprocessing activities exceeds the decay rate of the ^{85}Kr inventory in the atmosphere. Over the last ten years the baseline ^{85}Kr activity concentration was rather stable indicating a relatively stagnant global reprocessing capacity.

Krypton-85 emissions to the atmosphere from La Hague are characterized by pulsed releases. The released plumes can be detected at sampling stations located downwind even at distances of a few hundred kilometres (spikes in Figure 1a). Amplitude and frequency of activity concentration peaks at Freiburg but also at JFJ are generally highest during periods of high reprocessing activities in La Hague. Above the planetary boundary layer the strength and frequency of such spikes however are reduced compared to stations at lower altitudes. A statistical evaluation of almost 30 years of ^{85}Kr data from the JFJ compared to data from Freiburg shows that above baseline ^{85}Kr activity concentrations are lower at JFJ and, on average, activity concentrations in winter are lower than in summer (the complete dataset is published in [1] and [2]). Very rarely however (e.g. late April 2019) peaks in ^{85}Kr at JFJ may have similar or even higher amplitudes as in Freiburg. This can be caused by vertical thermal convection of boundary layer air e.g. due to intense warming and/or trajectories of air masses that originate from La Hague but bypass the area of Freiburg i.Br.

In the first half of 2020 the frequency and amplitude of ^{85}Kr peaks were slightly reduced compared to earlier years. This observation, which is valid for both stations Freiburg and JFJ, is potentially caused by reduced reprocessing capacity and consequently emissions at La Hague due to the Covid-19 pandemic. Emissions from La Hague were significantly lower in the first half compared to the second half of 2020. A slightly decreasing trend of the ^{85}Kr baseline (Figure 1 c) indicates that in 2020 global ^{85}Kr emission could not compensate for radioactive decay.

The location of the JFJ sampling site for ^{85}Kr sampling is crucial because of its altitude. Krypton-85 activity concentrations are representative for the northern tropospheric background level and are important for the assessment and quantification of environmental radioactivity and radiation exposure in Germany and Switzerland [3,4]. The data are also used for scientific studies on the dispersion and transport of air masses, e.g. the inter-hemispheric exchange [5]. The known temporal ^{85}Kr activity evolution in the atmosphere is also the basis for dating groundwater on timescales of decades [1,5,6].

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Scientific publications and public outreach 2020

Refereed Journal articles and their internet access

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Data books and reports

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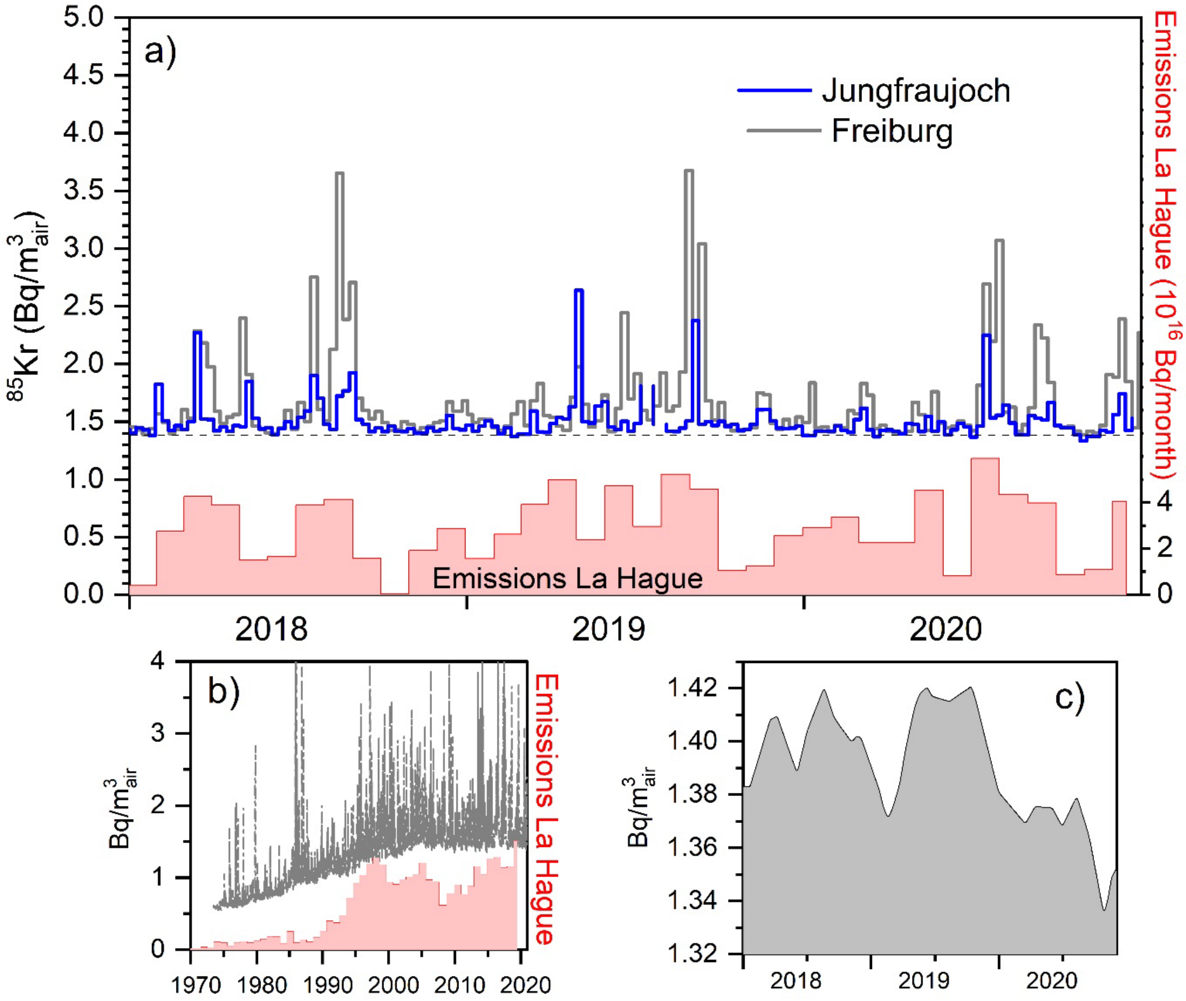

Figure 1. a) Measured atmospheric ^{85}Kr activity concentrations in weekly air samples, collected at Jungfraujoch (3500 m asl) and Freiburg i. Br. (280 m asl), during the last three years. The red columns represent the monthly emissions from La Hague (data provided by ORANO, 2021). The dotted line represents a baseline activity concentration of approximately 1.4 Bq/m$^3_{air}$. b) ^{85}Kr data for Freiburg i. Br. and the yearly emission from La Hague (in arbitrary units) over the last 50 years. c) Running 2-month average of the minimal ^{85}Kr activity concentrations as a proxy of the northern hemisphere ^{85}Kr baseline.

Address

Bundesamt für Strahlenschutz
Rosastr. 9,
D-79098 Freiburg
Germany

Contacts

Dr. Andreas Bollhöfer
Tel.: +49 30 18333 6770
e-mail: abollhoefer@bfs.de

Aerosol Radioactivity Monitoring at the Jungfraujoch

Pierre Beuret[1], Matthias Müller[1], Philipp Steinmann[1], Sybille Estier[1]

[1]Federal Office of Public Health, Bern, Switzerland

philipp.steinmann@bag.admin.ch

Part of this programme: Radenviro, URAnet

Keywords: atmospheric radioactivity; URAnet; Digitel; Radon; aerosols; radioisotope; alpha activity; beta activity

1. Alpha-Beta monitoring using the FHT59S monitor

An automatic aerosol radioactivity monitor FHT59S for the continuous detection of total alpha and total beta-activity is operated at Jungfraujoch research station by the Swiss Federal Office of Public Health. This monitor is part of the URAnet Network and has the following particular features:

- Real-time (30 min) detection of any increase of radioactivity in the air at the altitude of 3400 m above sea level.
- A detection limit for artificial beta radioactivity as low as 0.1 Bq/m³. Such a high sensitivity is possible due to the very low Radon daughter concentration at this altitude.

Additional aerosol samples are taken using a Digitel High-Volume-Sampler. These samples are sent to the laboratory in Berne and are analysed for radioisotopes using HPGe-Gamma-spectrometry.

1.1 Comments on the alpha/beta measurements 2020

Figure 1 (Jungfraujoch) and Figure 2 (Weissfluhjoch, the second high-altitude station operated by the FOPH, 2685 m a.s.l.) show the natural alpha radioactivity, the calculated artificial beta radioactivity and the moving average of the ratio of total α-activity to total (natural) β-activity for the period January 1 to December 31, 2020.

This figure highlights that:

- Natural alpha radioactivity, i.e. Radon daughter products, is mainly transported up to the Jungfraujoch by air masses from the lowlands, since the highest values are usually observed in summer (from Mai to October) when thermal air convection is higher than in winter. It is the inverse from what is observed at the lowland sites. During autumn and winter, the Radon daughter products are kept below the Jungfraujoch altitude due to the thermic inversion in the lowlands (see upper part of Figure 1).
- The highest values of artificial beta mean concentration, about 0.2 Bq/m³, occur during fast increases or decreases of the alpha concentration. This is an artefact due to the delay of the automatic compensation (see below).
- The highest ratios of total β-activity to total α-activity are observed when the (natural) alpha radioactivity concentrations are the lowest.
- These same effects are also observed at the station of the Weissfluhjoch with higher values for the alpha concentration (Figure 2).
- The highest values are measured during the month of September at both high altitude stations.

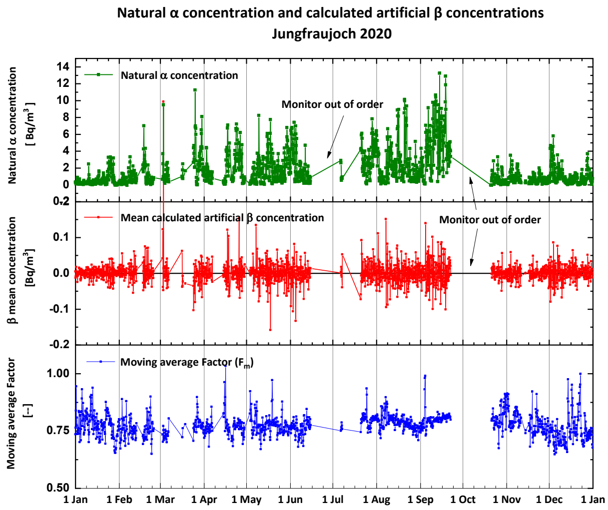

Figure 1. Results of RADAIR measurements in 2020 at the Jungfraujoch. Top: total (natural) α-activity concentration; mid: calculated artificial β-activity concentration; bottom: moving average of total α to total (natural) β-activity. For a better readability, only 4 points per day are represented.

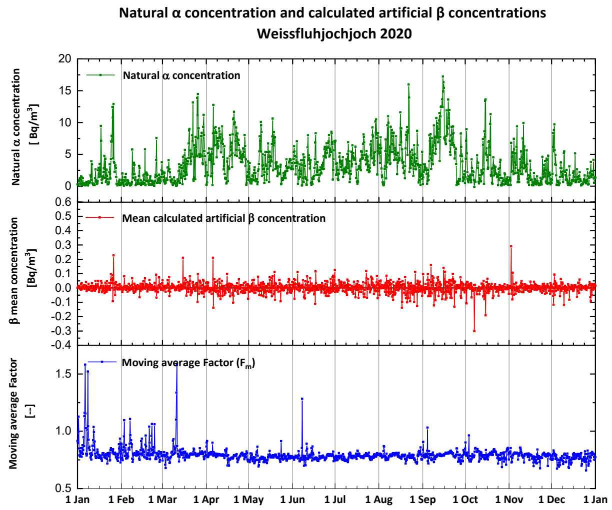

Figure 2. Results of RADAIR measurements in 2020 at the Weissfluhjoch. Top: total (natural) α-activity concentration; mid: calculated artificial β-activity concentration; bottom: moving average of total α to total (natural) β-activity. For a better readability, only 4 points per day are represented.

A zoom of the Figure 1 from March 2 to March 4 shows a peak of the natural alpha radioactivity come when the north wind blows and causes a displacement of air masses from the low land. This new air contains Radon daughter products, which are measured a few hours later at the Jungfraujoch. This sudden rise of the natural alpha concentration is difficult to compensate; for that reason the beta concentration also increases (see Figure 3).

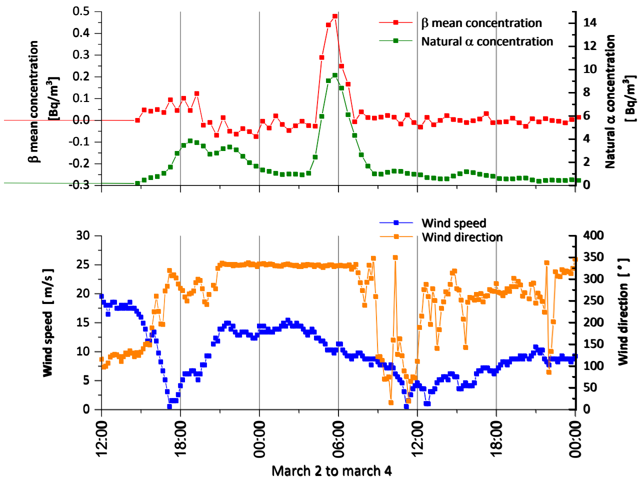

Figure 3. Results Jungfraujoch 2020. Top: Example of the peaks of the natural α and beta concentration (March 2 – March 4); bottom: The mean wind speed and the wind direction during this period.

Figure 4 shows the histogram of the calculated artificial beta radioactivity in aerosol for 2020 (and 2019). The calculation is done automatically by the monitor by applying an α/β-compensation technique (see below for more details).

- No calculated artificial beta concentration above the detection limit (i.e. the background signal) was observed;
- 95 percent of the beta concentrations recorded in 2020 was below 0.05 Bq/m³.
- The histogram recorded for 2020 is very symmetric; this shows that the automatic compensation technique was very good.
- Note that there are some values greater than 0.10 Bq/m³ (see Figure 1).

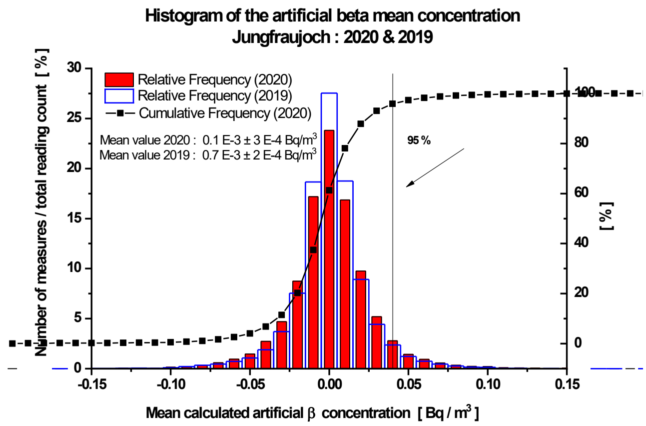

Figure 4. Histogram of calculated artificial beta concentrations at Jungfraujoch 2020.

In most cases, when the alpha concentration increases slowly, the beta concentration is correctly compensated.

For normal situations, i.e. with no artificial radioactivity in the air, the net beta radioactivity at the Jungfraujoch, calculated using the alpha-beta compensation technique, is less than 0.10 Bq/m³. At the top of Europe, a radiation incident causing an increase of the artificial beta radioactivity in the atmosphere of as low as 0.10 Bq/m³ would therefore be detected within 30 minutes.

1.2 Calculation of the artificial Beta-activity

Automatic α/β-compensation: this technique applied by our aerosol monitoring stations is based on the simultaneous measurements of gross alpha (A_g) and gross beta (B_g) radioactivity of the aerosols collected on a filter. The net (artificial) beta radioactivity (B_n) is then calculated by the following formula:

$B_n = B_g - (A_g / F)$.

The ratio (A_g/B_g) corresponds to the slope of the curve of the α-activities as a function of β-activities. The experience has shown that it is relatively constant and yields approximately 0.75.

With the current version of the software, the monitor calculates the average of the n (n>10) last ratios (A_g/B_g), as long as this latter is included between thresholds values (here 0.6 and 1.5). This mean ratio will give the factor F_m with which the net (artificial) Beta radioactivity (B_n) will be calculated.

This gives a new correction equation: $B_n = B_g - (A_g / F_m)$

1.3 Comments on technical aspects (RADAIR)

In spring and in early summer the motion sensor of the filter tape was defective. It was not possible to repair due to the first Covid-19 related lock-down. At the end of September, the monitor was stopped due to a disturbing noise from the monitor with unknown cause. In fact, it was only the cooling fan of the computer. In addition, the heating of the air intake was defective, too. In October, the fan was repaired and the circuit breaker of the heating of the air intake was replaced by a new system; so now the mountain jackdaws have warm feet again!

2. Digitel Jungfraujoch 2020

2.1 Digitel High-Volume-Sampler: Introduction

The Digitel DHA-80 High Volume Sampler (HVS) is an automatic air sampler with a typical air flow rate of 0.6 m^3/min. Aerosols are collected on glass fibre filters of 150 mm in diameter. The pump maintains a constant flow rate independent of dust load on the filter. Filter change intervals are programmed in advance and the sampler is controlled remotely by an internet connection.

The filters are automatically changed once a week and are measured at the end of the month in the laboratory using a coaxial HPGe gamma-ray detector during 1-2 days. Thereafter, activities of radioactive isotopes are corrected by considering the corresponding half-lifes and the time between sampling and measuring.

^{7}Be and ^{210}Pb are naturally occurring nuclides. ^{7}Be has a cosmogenic origin. Around 70% of ^{7}Be is produced in the stratosphere by spallation of carbon, nitrogen and oxygen. ^{210}Pb is a long-lived decay product of uranium series (^{238}U) which gets into the air from radioactive noble gas ^{222}Rn exhaled from the Earth's Crust.

2.2 Results

Figure 5 shows the concentration (µBq/m^3) of ^{7}Be, ^{210}Pb, ^{131}I and ^{137}Cs between 2011 and 2020.

Concentrations of ^{7}Be and ^{210}Pb remained quasi constant. A slight increase of ^{210}Pb during summer can be observed, which is due to convection of ^{210}Pb-rich air masses from the Plateau. ^{7}Be concentration seems to be slightly increased during summer, too. This is related to the tropopause thinning at mid-latitudes resulting in air exchange between stratosphere and troposphere.

As a consequence of the nuclear accident of Fukushima in March 2011, filters were measured directly after changing (once a week) in order to detect radioactive isotopes released by the nuclear power plant more quickly. Therefore, time between sampling and measuring was significantly smaller than before.

The increased concentration of ^{131}I and ^{137}Cs in 2011 can be clearly related to the nuclear accident of Fukushima. First increased concentrations were measured by the end of March 2011 and achieved a maximum at the beginning of April. ^{131}I could never be detected at Jungfraujoch before the nuclear accident and has not been since the end of April 2011. ^{137}Cs was occasionally detected also before March 2011.

Between Mai and August 2013 and 2019, the filters were measured once a week in order to better follow possible inputs of stratospheric air over this time period.

Note that due to a technical problem, sampling in November and December was not continuous.

Internet data bases

http://www.radenviro.ch

Collaborating partners / networks

Gilles Durieux, MeteoSwiss, Payerne

Address

Federal Office of Public Health
Schwarzenburgstrasse 165
CH-3003 Bern
Switzerland

Contacts

Dr. Philipp Steinmann
Tel.: +41 58 465 1911
e-mail: philipp.steinmann@bag.admin.ch

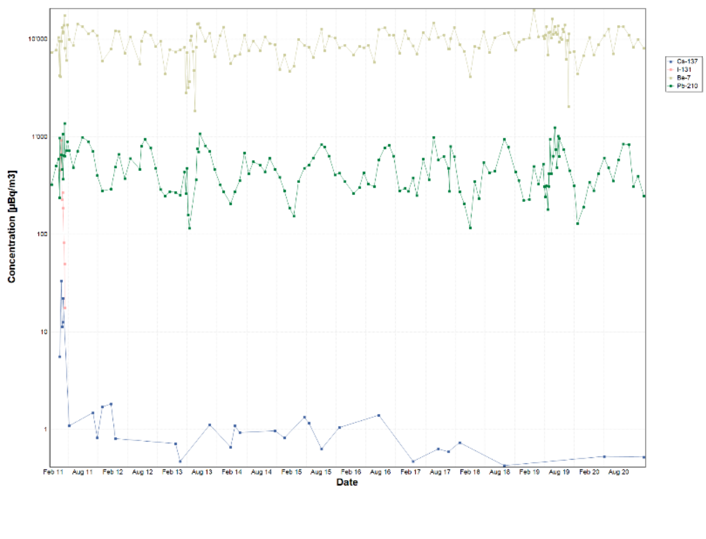

Figure 5. Concentration (µBq/m^3) of ^{7}Be, ^{210}Pb, ^{131}I and ^{137}Cs between 2011 and 2020, Station Jungfraujoch.

Neutron monitors – Study of solar and galactic cosmic rays

Rolf Bütikofer[1]

[1] Physikalisches Institut, Universität Bern, Bern, Switzerland

rolf.buetikofer@space.unibe.ch

Part of this programme: NMDB

Keywords: Astrophysics; cosmic rays; neutron monitors; solar, heliospheric and magnetospheric phenomena

1. Project description

The Physikalisches Institut at the University of Bern, Switzerland, operates two standardized neutron monitors (NM) at Jungfraujoch: an 18-IGY NM (since 1958) and a 3-NM64 NM (since 1986). NMs provide key information about the interactions of galactic cosmic radiation (GCR) with the plasma and the magnetic fields in the heliosphere and about the production of energetic CRs at or near the Sun (solar cosmic rays, SCR), as well as about geomagnetic, atmospheric, and environmental effects. The NMs at Jungfraujoch are part of a worldwide network of standardized CR detectors. By using the Earth's magnetic field as a giant spectrometer, this network determines the energy dependence of primary CR intensity variations near Earth in the energy range ~500 MeV to ~20GeV. Thereby, NMs ideally complement space observations which mainly cover the energy range below the range of NMs.

Furthermore, the high altitude of Jungfraujoch provides a good response to solar protons ≥3.6 GeV and to solar neutrons with energies as low as ~250 MeV. NMs also play an important role in the space weather domain.

In 2020, operation of the two NMs at Jungfraujoch was pursued without major problems. The recordings of the NM measurements are published in near real-time in the neutron monitor database NMDB (http://www.nmdb.eu). Figure 1 shows the relative monthly count rates of the IGY neutron monitor at Jungfraujoch (lower panel) since it was put into operation in 1958. The GCR are always present, and their intensity shows an 11-year variation in anti-correlation with the solar activity characterized by the smoothed sunspot number plotted in the upper panel of Figure 1.

In September 2020 an international group of experts co-sponsored by NASA and the National Oceanic and Atmospheric Administration (NOAA) informed that the solar activity minimum occurred in December 2019 with again very low sunspot number. The 13-month smoothed monthly total sunspot number for the sunspot minima since 1940 are listed in Table 1. The sunspot minimum in December 2019 marks also the beginning of solar activity cycle 25. The duration of solar cycle 24 lasted 11.0 years which corresponds to the average duration of solar cycles.

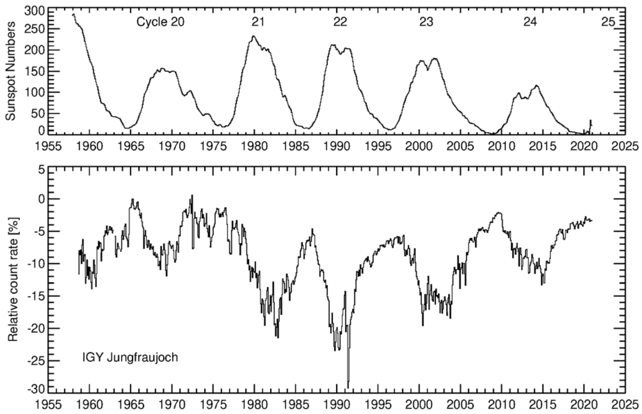

Figure 1. Smoothed monthly total sunspot numbers (Source: WDC-SILSO, Royal Observatory of Belgium, Brussels (www.sidc.be/silso/datafiles), top panel), relative pressure corrected monthly average counting rates of IGY neutron monitor at Jungfraujoch (bottom panel) for the years 1958-2020. The neutron monitor count rate is expressed in relative units with respect to May 1965.

Table 1. 13-month smoothed monthly sunspot number during the sunspot minima since 1944.

Year-Month	Sunspot number
1944-02	12.9
1954-04	5.1
1964-10	14.3
1976-03	17.8
1986-09	13.5
1996-08	11.2
2008-12	2.2
2019-12	1.8

From the data of the IGY NM, it seems that in addition to the ~11 year cycle the galactic cosmic ray intensity near Earth during the current solar activity minimum is lower and the course of the NM counting rate shows a flat maximum compared to the maximum during the last solar activity minimum in autumn 2009. I.e. in addition to the ~11 year cosmic ray variation in antiphase to solar activity, there is also a ~22 year variation. This effect is most probably related to the reversal of the polarity of the solar magnetic field every ~11 years, i.e. a periodicity of ~22 years.

When the solar magnetic field is pointing towards the Sun in the northern hemisphere (negative polarity of solar magnetic field), the time profiles of NM count rates are peaked (around 1965, 1986, 2010), whereas the maximum NM count rates are more flat during epoch with opposite solar magnetic polarity (in the 1970s, 1990s and during the current solar activity minimum). Cosmic ray particles entering into the inner heliosphere arrive more from polar regions during times with positive polarity and more along equatorial regions when the polarity of the solar magnetic field is reversed. Particles arriving along the equatorial region are more sensitive to the latitudinal change of the tilt angle of the neutral current sheet and as consequence the maximum cosmic ray intensity near Earth is peaked around those activity minima. In contrast, the cosmic ray intensity maxima around solar activity minima with the opposite solar magnetic field polarity result in more flat maxima as the access of particles through polar regions is not strongly affected by changes of the current sheet.

The data taking system used at the two NM stations at Jungfraujoch were introduced more than 30 years ago. During the last years, more and more problems to maintain this system showed up as some spare parts are no longer available. During the NMDB project (founded under the European Union's FP7 programme (contract no. 213007)) in 2008/09, the Spanish partners developed a new data taking system. Unfortunately, the system is not sufficiently documented in the delivery report and the person, who mainly designed the electronics of the new system, left the Spanish cosmic ray group soon after the official end of the NMDB project. Some time ago our colleagues from the cosmic ray group at the Christian-Albrechts University of Kiel decided to develop a new data taking system themselves and offered to produce these systems also for the Swiss neutron monitor stations. A first test device was put in operation in late 2018 at the NM station on the roof of the Institut für Exakte Wissenschaften at the University of Bern. In October 2020 Stephan Böttcher from the University of Kiel integrated the new data taking system in the IGY NM on the roof of the Sphinx building at Jungfraujoch. Since October 2020 the new system operates in parallel with the old data taking system. It is now a matter of ensuring that the trigger voltage settings in the new system are set optimally so that the count rates of both systems go in parallel. When the correct trigger levels are found, the correction factors for efficiency for each of the three counter tubes sections must be adapted that the count rate of the new data taking system is equal to the count rate of the old data taking system. Afterwards the old system can be definitely relieved by the new data taking system. This should be the case in 2021.

The dosimetric measurements with a GammaTracer device inside the detector housing of the NM64 neutron monitor were continued in 2020.

Internet data bases

http://cosray.unibe.ch
http://www.nmdb.eu

Collaborating partners / networks

European FP7 Project Real-Time Database for High Resolution Neutron Monitor Measurements (NMDB): http://www.nmdb.eu
Robert Wimmer-Schweingruber, Bernd Heber, Christian Steigies, Stephan Böttcher, Extraterrestrial Physics Department of the Institute for Experimental and Applied Physics of the Christian-Albrechts University of Kiel, Germany
Vladimir Mares, Thomas Brall, Werner Rühm, Helmholtz Zentrum München, 85764 Neuherberg, Germany

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Mares, V., T. Brall, R. Bütikofer, W. Rühm, Influence of environmental parameters on secondary cosmic ray neutrons at high-altitude research stations at Jungfraujoch, Switzerland, and Zugspitze, Germany, Radiation Physics and Chemistry, 168, doi: 10.1016/j.radphyschem.2019.108557, 2020.
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Bütikofer, R., Why Cosmic Ray Monitoring at High Altitude?, 5th VAO Symposium, Bern, Switzerland, February 4-6, 2020.

Address

Physikalisches Institut
Universität Bern
Sidlerstrasse 5
CH-3012 Bern
Switzerland

Contacts

Dr. Rolf Bütikofer
Tel.: +41 31 631 4058
e-mail: rolf.buetikofer@space.unibe.ch

Evaluating the contribution of Marine Aerosols to the Mo Surface Water Cycle

Thomas Nägler[1], Edel O'Sullivan[1], Niklaus Waber[1]

[1] Institut für Geologie, Universität Bern, Bern, Switzerland

thomas.naegler@geo.unibe.ch

Keywords: aerosols; Mo-Isotopes; anthropogenic input; geochemical proxy; paleo-oceanography

1. Project description

The project aims to deliver a robust evaluation of the isotope budgets of different molybdenum (Mo) sources in continental environments. This is important not only to studies of the modern Mo surface cycle (e.g. for discrimination between natural and anthropogenic airborne Mo), but also as a key input parameter in models reconstructing paleo-oceanic environmental conditions. All models of the ancient global Mo cycle throughout the geological record (Mo as paleo redox proxy) depend on constraints from modern Mo fluxes. Mo isotopic composition (δ^{98}Mo) of river waters around the globe are significantly enriched in heavier Mo isotopes relative to their Mo source (bedrock). A hitherto unconstrained potential source of elevated δ^{98}Mo is precipitation of marine aerosols (ocean water: elevated δ^{98}Mo) as indicated by Sr isotope (^{87}Sr/^{86}Sr) and δ^{98}Mo signature data from small streams in the vogues mountains, France (Nägler et al. 2020). This additional 'heavy Mo source' would be a new component in the mass balance and - in contrast to the canonical hypothesis of light δ^{98}Mo retention in soils - not been erased by steady state conditions. Based on the scarce literature and own Mo concentration data a singular quantity of 20 L of precipitation is needed to obtain the amount of Mo necessary for δ^{98}Mo measurements (≥ 20 ng).

Given these analytical constraints, we face the difficulty to obtain 20 L of precipitation without contamination by a few nanograms of Mo from sampling equipment. To resolve this problem, we chose the approach of snow sampling. The Mo isotope-, Sr isotope-, trace element and δ^{18}O compositions of snow samples from three locations with varying proximity to the nearest coastline and at different altitudes are targeted:

1) High Altitude Research Station Jungfraujoch (HFSJ); chosen because aerosols as well as atmospheric δ^{18}O have been studied here for a long time; anthropogenic aerosol contribution is low; snow is readily available; the altitude is significantly different from the other sampling sites; Aerosols can originate from the both sides of the alps, and the origin of snow can be readily traced by its δ^{18}O signature. Interpretation of the Jungfraujoch (JFJ) results will strongly rely on the continuous records from the JFJ station (mainly δ^{18}O and meteorological conditions). 4 sampling campaigns at the HFSJ will be necessary to investigate seasonal variations.

2) Strengbach Catchment, Vogues Mountains, France, http://ohge.unistra.fr, monitored “field laboratory” since > 30 years; here Nägler et al. (2020) found evidence for a Mo contribution from marine aerosols in the surface waters; making the site a prime source for the current project.

3) East coast of Newfoundland & Labrador, Canada: Existing collaborations, abundant snowfall as well as verified contribution from seaspray to precipitation were the base of this choice. This site is the extreme counterpart to the HFSJ.

Unfortunately, the current Covid-19 situation forces us to choose alternative sites for 2 and 3 this winter: The Swiss Jurassic Mountains (Chasseral) to be the intermediate sample between the Atlantic ocean and HFSJ, and potentially the west coast of Ireland to replace 3 as near-coastal samples, this time rainwater.

Distinguishing between marine aerosols, continental and/or organic dust and anthropogenic particulates is essential to this study and will be carried out via the parallel trace element analysis of dust extracted from snow samples.

An additional dataset of stream waters draining the snow sampling areas of the Jungfraujoch also complements the primary precipitation data to help identify the controlling mechanics altering the initial δ^{98}Mo of the snowmelt as it enters the surface cycle. The stream waters included are as followed:

1) Trümmelbach catchment: meltwater draining the Eiger Glacier to the west of the sampling locations of the HFSJ, interacting with Jurassic carbonate rocks with likely differing δ^{98}Mo signatures.

2) Anunbach catchment draining the Jegi Glacier and/or streamwaters draining the Anunglacier: depending on conditions underfoot, these glaciers are the closest readily-accessible glacier/ snowmelt-draining stream waters to the Jungfraujoch on the southeast side of the sampling region of the HFSJ.

2. Progress 2020: Field work (i.e. activities outside perimeter of the Research Station and Sphinx):

Snow samples were collected during two sampling excursions in July and November 2020. During the summer excursion we collected the first two samples (7/20JFJ-01 and -02;) and tested the equipment (Figure 1 and 2). Prior to the first sampling campaign all material necessary for snow collection (e.g. barrels, shovels, tapes etc.) has been exhaustively tested in the lab for potential contamination with Mo and Sr.

Figure 1. Sampling 2. November 2020, Jungfraujoch. Details in Figure 2.

Figure 2. 'Mo free' Sampling: All plastic (PE) material, no metal parts; left shovel, 60 L barrels with double plastic bags as liners; right: The protruding part of the plastic bags is rolled in and secured with tape.

Based on the experiences of the first excursion at the HFSJ, during the second sampling excursion 8 samples were collected (11/20JFJ-03 to -10). This time samples were collected after a period of snowfall from two levels within the snow column. The two sampling periods will serve as a comparison between summer and winter snow accumulations.

Figure 3. Test setup of rainfall-collection equipment.

Three stream water samples were collected from the Trümmelbach catchment in August 2020, sampling directly below the Eiger Glacier where the water flows over bare carbonate rock, at a middle section of the catchment where soil and vegetation increases in volume, and on the valley floor just before the confluence with the Weisse Lütschine. Additionally, a test sample of rainwater in Dublin, Ireland was collected in December 2020 to test the method of collection using only the pre-cleaned material used for snow collection i.e., PE plastic bags and PTFE containers only (Figure 3), to minimise addition of unwanted Mo from equipment and handling. The first sampling of snow at the Chasseral Region is scheduled for the 21.01.2021.

3. Results

For snow samples from the first campaign in late summer 2020 chemical and water isotope ($\delta^{18}O$, $\delta^{2}H$) of snow samples have been produced. These data are supported by similar data produced on the three creek waters that form the discharge of melt-water from the Eiger- and Guggi-glaciers in the valley south of Kleine Scheidegg (East of Biglenalp). The data confirm the enrichment of chemical compounds and heavy water isotopes by cycled melting-freezing-evaporation effects during the summer months. Comparison with data collected in early winter (sampling performed), spring and early summer will be of high interest also with respect to the expected different accumulation of Mo during the seasons.

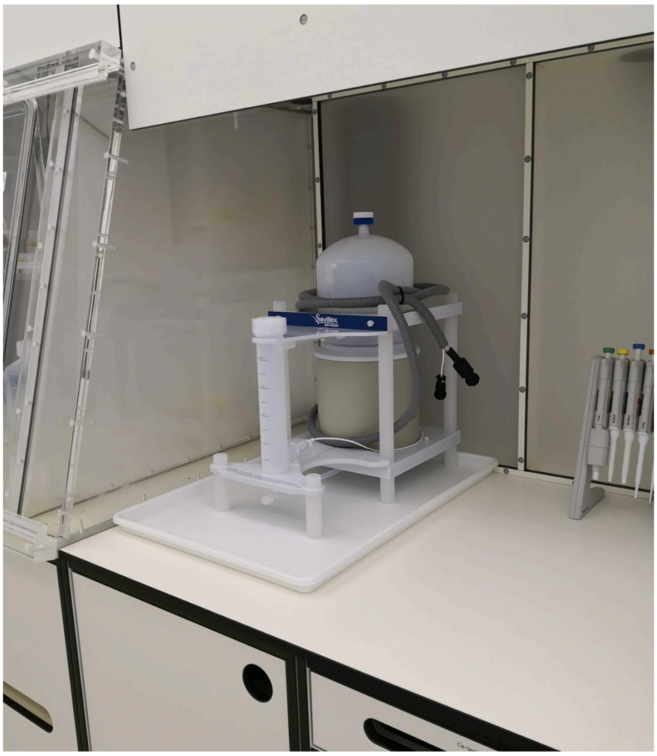

Figure 4. Distillation unit for evaporating snow samples.

Preliminary Mo data of snow samples point to a concentration of 0.07 nM Mo. This is about 20 times less than the Mo concentration in the measured streams, but ca. 7 times the Mo concentration of the only rainwater sample from the Strengbach catchment, vogues mountains, France presented in Nägler et al. (2020). The source of the Mo will be approached by δ^{98}Mo and trace element data. Recently the first samples passed the evaporation process (Figure 4).

A first successful δ^{98}Mo measurement demonstrates the principal feasibility of the method. Its result is in line with a natural, continental source. Thus - as expected - the samples from the Jungfraujoch appear to be suitable as a representative of the continental Mo end member contribution for mixing models of European precipitation sources in terms of Mo concentration and isotope composition.

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Collaborating partners / networks

Dr. Michael G. Babechuk, Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Canada
Prof. Marie-Claire Pierret-Neboit, Laboratoire d'Hydrologie et Géochimie de Strasbourg, EOST, Université de Strasbourg, CNRS, Strasbourg, France

Address

Universität Bern
Institut für Geologie
Baltzerstrasse 1+3
CH-3012 Bern
Switzerland

Contacts

Prof. Thomas Nägler
Tel.: +41 31 631 8752
e-mail: thomas.naegler@geo.unibe.ch

Automated GNSS Network Switzerland (AGNES)

Elmar Brockmann[1], Dominique Andrey[1], Daniel Ineichen[1], Leïla Kislig[1], Jürg Liechti[1], Simon Lutz[1], Urs Wild[1]

[1] Swiss Federal Office of Topography (swisstopo), Bern, Switzerland

elmar.brockmann@swisstopo.ch

Part of this programme: EUMETNET/E-GVAP, MeteoSwiss, STARTWAVE

Keywords: GPS; GLONASS; Galileo; BeiDou; GNSS; GNSS-Meteorology; Positioning; Integrated Water Vapor; Zenith Path Delay; GNSS Tomography; Geotectonics

1. Project description

The station is part of the Automated GNSS Network of Switzerland (AGNES) consisting of 31 sites, equipped with GNSS receivers and antennas. In Spring 2015, the complete AGNES network, with the exception of Jungfraujoch, was enhanced from GPS and GLONASS (the Russian equivalent of GPS) to a Multi-GNSS network which is capable to track also satellites of the European Galileo System and the Chinese BeiDou System. Jungfraujoch station was enhanced to Multi-GNSS together with the installation of the new MeteoSwiss observation platform end of 2017.

AGNES is a multi-purpose network which serves as reference for surveying, real-time positioning (positioning service swipos GIS/GEO) and for scientific applications (geotectonics and GNSS-meteorology). The station JUJO/JUJ2 is mainly contributing to scientific applications. Troposphere path delays derived from the swisstopo processing are provided to MeteoSwiss on an hourly basis. Furthermore, the data are sent to the European meteo community EUMETNET, where the data are available for all meteo agencies for numerical weather predictions. At the moment, UK METO, MeteoFrance, DMI, and KNMI are using the GNSS-derived troposphere models routinely in the weather forecasts. This activity is coordinated by the EGVAP project. Currently, a continuation of this EUMETNET project is planned. The results are also sent to the Institute of Applied Physics (IAP) of the University of Berne where the data contribute to the STARTWAVE database. It is worth to mention that our final troposphere products (delivered with 1-2 weeks delay) are also used by PMOD/WRC Davos for the calibration of the pyrgeometer.

In 2013 the new COST project named GNSS4SWEC (Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate) started. The focus of swisstopo's investigations is the long-term behaviour of the troposphere parameters. Due to the fact that we re-processed all Swiss and European GNSS data since 1996 with a homogeneous set of modelling parameters, we have a first data set which might help to detect possible changes in water vapour over time. Till now, the time series suffered from software changes and also from modelling changes which resulted in "jumps" in the troposphere time series. With a complete reprocessing of all data from 1996 – 2014 a long time span is covered with identical modelling of observations. This modelling is also continued till today. Nevertheless, antenna changes at stations have a significant influence to the long-term consistency (e.g. also the new Jungfraujoch mast installation and the new antenna which is capable to track all modern GNSS satellite system whereas the old antenna was only capable to track GPS. The GNSS4SWEC project finished 2017. The final report was drafted Mid 2018 and was made available in written form end of 2019. Below we show some figures, showing the troposphere long-term data of JUJO (GPS-only) and JUJ2 (Multi-GNSS).

Beginning March 2020 (not correlated with the Corona lock-down), a storm blew away the radome of the antenna. Data were still collected, but due to a different antenna behaviour, the corresponding derived coordinates (heights) and troposphere parameters were significantly degraded. Since that time, no data were used. It took till July 14, that the antenna was removed by MeteoSwiss colleagues. A longer repair process continued. Redundant radome material was provided by MeteoSwiss and the antenna could be repaired, temporarily, in the swisstopo lab. The antenna was placed back mid of October and data could be collected and analysed successfully since then. Thanks to intervention from MeteoSwiss, another repair should be scheduled for 2021, taking advantages from the experience MeteoSwiss has in operating instruments under the harsh conditions of high altitude stations.

swisstopo operates a monitor web platform pnac.swisstopo.admin.ch where all important results are available online. The complete computing center migrated from redhat6 server to redhat8 server End of 2020.

Fig. 1 shows the long-term troposphere estimates for JUJO and JUJ2 (after almost 10 months of interruption in 2020), its internal formal errors (RMS) and the corresponding amplitude spectrum. The annual variations are obvious.

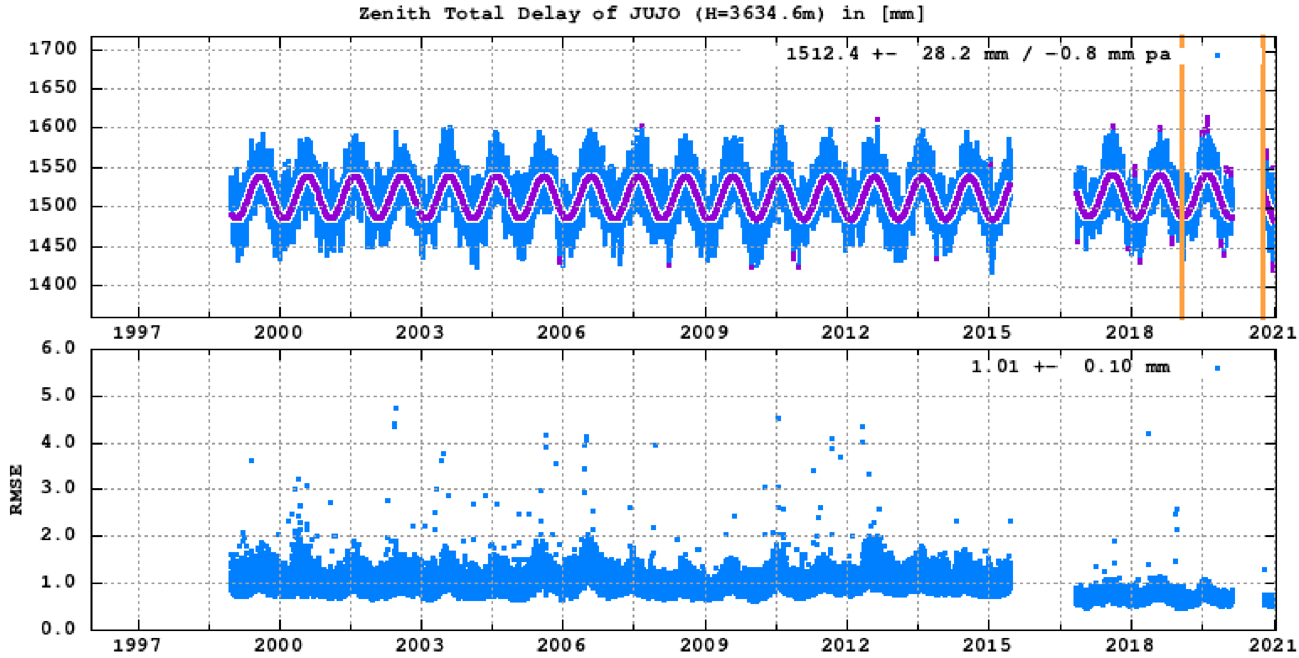

Figure 1. Long-term troposphere estimates for JUJO / JUJ2 (http://pnac.swisstopo.admin.ch/resplt/juj2_trp.gif).

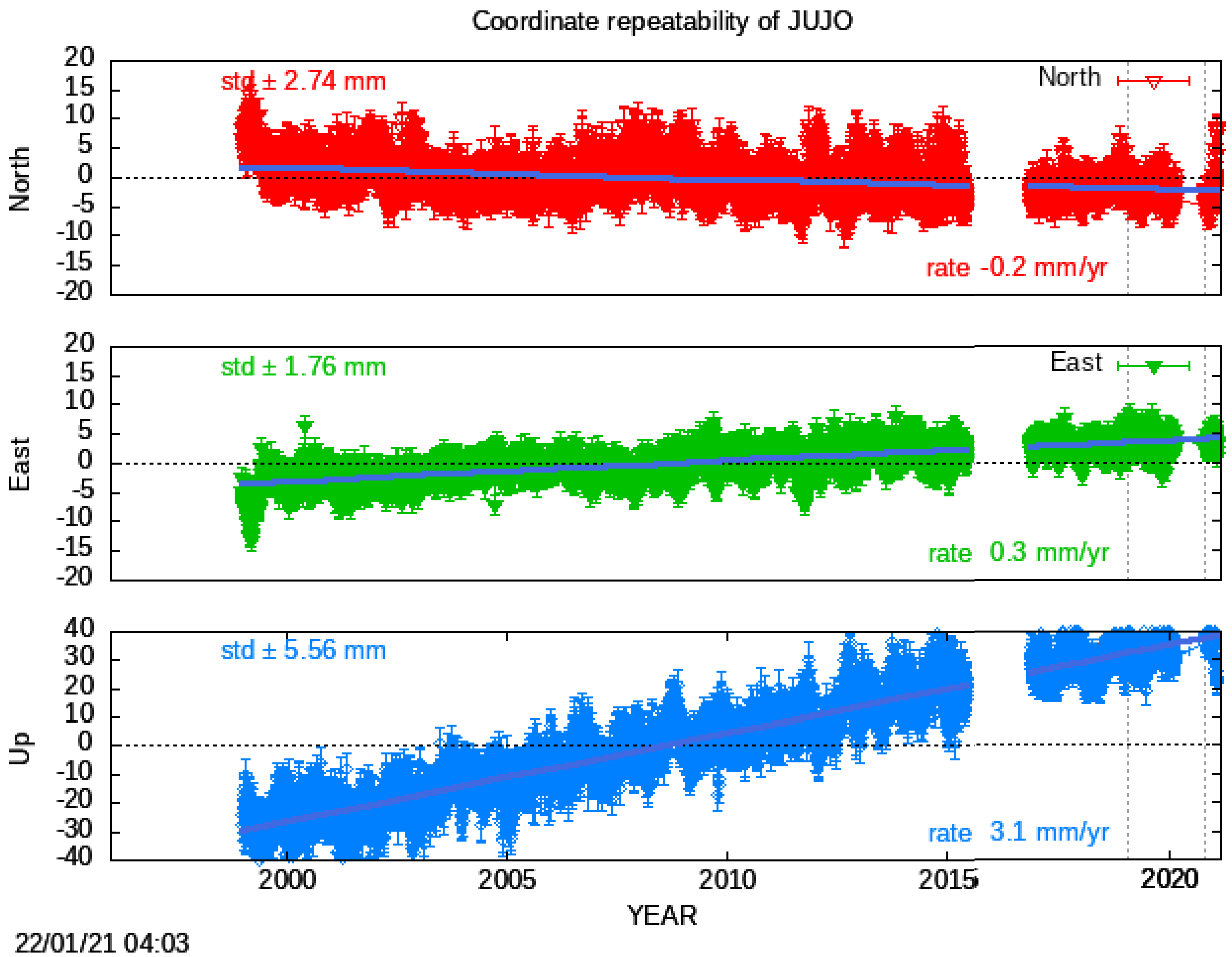

Figure 2. Long-term coordinate estimates for JUJO / JUJ2 (horizontal movement with respect to Zimmerwald, vertical movement w.r.t European Plate; http://pnac.swisstopo.admin.ch/resplt/juj2_vel.gif).

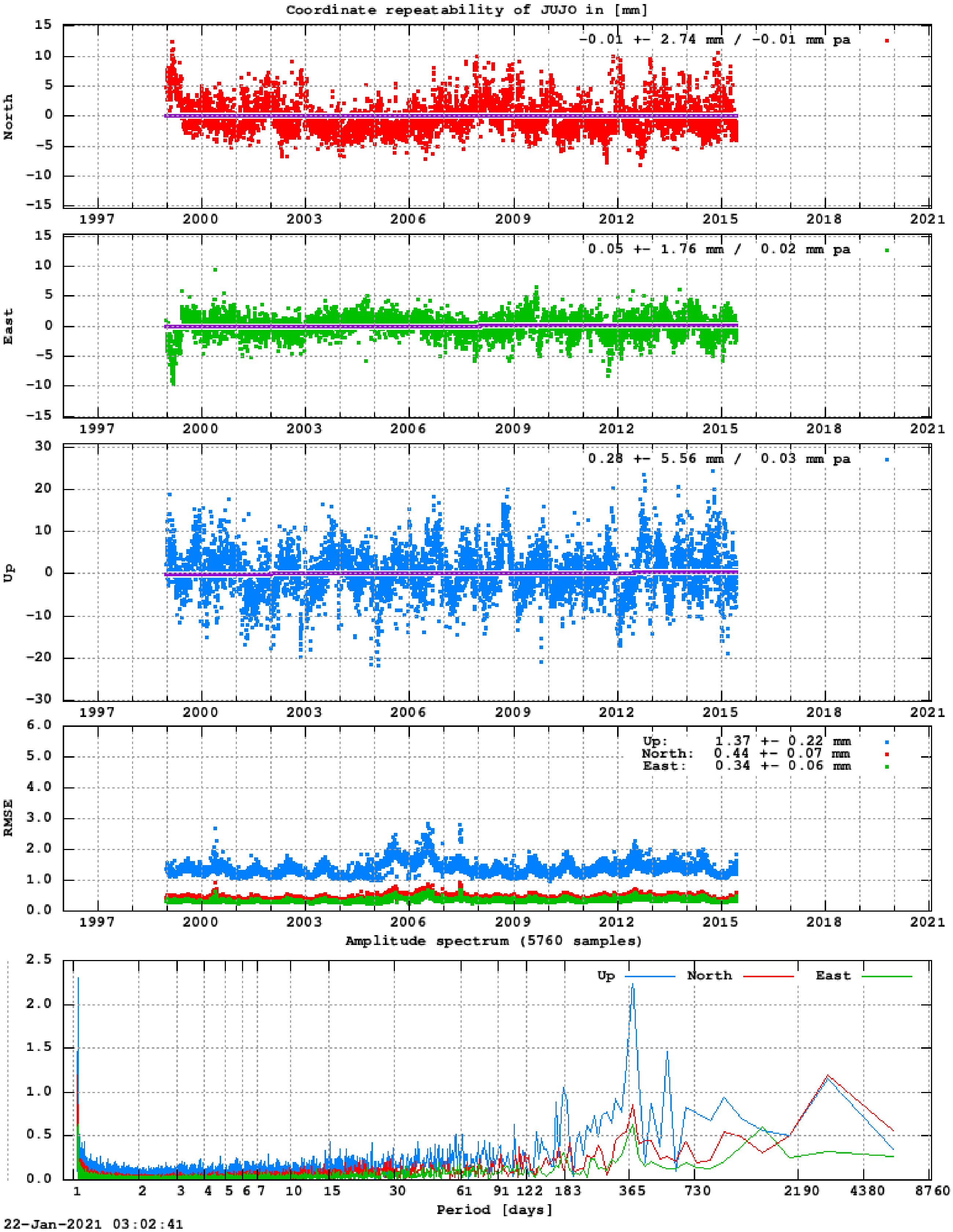

Figure 3. Long-term coordinate estimates for JUJO / JUJ2 (velocities removed; rms and fourier spectrum added; http://pnac.swisstopo.admin.ch/resplt/juj2_fft.gif).

Bernet et al. (2020) calculated trends of integrated water vapor (IVW), after converting ZTD to IVW, for all Swiss permanent sites. JUJO/JUJ2 shows a quite small trend compared to other stations. If this is due to the high altitude is not proofed. Generally, we see a positive trend for all Swiss sites pointing in the direction that with a higher temperature more water vapor can be stored in the atmosphere. Graphs which were later refined for the publication were already shown in the annual report of the last year.

Coordinate time series in the local system North, East and Up of JUJO/JUJ2 are shown in Fig. 2. The time series covers data from 1999 till 2021 – in total about 21 years. Our reference station Zimmerwald (ZIMM) covers a time span of 25 years. The estimated station velocity is easily visible – mainly for the height component we see an uplift of 3 mm/yr with respect to the European Plate. This is the strongest uplift signal compared to all other Swiss permanent stations. Removing this signal from the coordinate time series shows that some seasonal effects are visible in all three components (see Fig. 3). This is due to the instability of the meteo mast. The effect is visible with the new setup, only, because the daily repeatability was considerably improved with the new Multi-GNSS equipment.

Further results of the processing is available online (updated routinely):
http://pnac.swisstopo.admin.ch/pages/en/qsumjuj2.html

Official static coordinates in the Swiss national coordinate reference system for JUJ2 are published on: http://pnac.swisstopo.admin.ch/pages/en/chtrf.html

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Internet data bases

http://www.swisstopo.ch
http://pnac.swisstopo.admin.ch

Collaborating partners / networks

Dr. Alexander Haefele, Dr. Rolf Rüfenacht, MeteoSwiss, Payerne
Dr. Philippe Steiner, Dr. Daniel Leuenberger, MeteoSwiss, Zürich
Dr. Rolf Dach, Prof. Dr. A. Jäggi, University Berne, Astronomical Institute
Dr. Kelemens Hocke, Dr. Leonie Bernet, University Berne, Institute for Applied Physics
Dr. Julian Gröbner, Dr. Christine Aebi, PMOD/WRC Davos
Prof. Alain Geiger, Dr. Karina Wilgan, Dr. Roland Hohensinn, Dr. Endrit Shehaj, ETH Zurich, Dep. of Civil, Env. and Geomatic Eng., Geodesy and Photogrammetry

Address

Bundesamt für Landestopographie
Seftigenstrasse 264
CH-3084 Wabern
Schweiz

Contacts

Dr. Elmar Brockmann
Tel.: +41 58 469 0256
e-mail: elmar.brockmann@swisstopo.ch

Glaciological investigations on Grosser Aletschgletscher

Andreas Bauder[1,2], Matthias Huss[1,2,3]

[1] Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW), ETH Zürich, Zürich, Switzerland
[2] Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft WSL, Birmensdorf, Switzerland
[3] Department of Geosciences, University of Fribourg, Fribourg, Switzerland

bauder@vaw.baug.ethz.ch

Part of this programme: Glacier Monitoring in Switzerland (GLAMOS)

Keywords: glacier fluctuations; mass balance, snow and firn accumulation; ice melt; ice volume change

1. Project description

Long-term glacier observations have been carried out in the frame of Glacier Monitoring in Switzerland (GLAMOS) in order to document variations of Grosser Aletschgletscher and to include annual length change measurements since 1880, accumulation and mass balance measurements starting in 1918, and repeated map or aerial photograph surveys, respectively. In an ongoing project the length, area, volume, and mass changes are continuously observed applying modern remote sensing techniques, as well as direct field measurements. The research activities are focused on long-term trends and seasonal fluctuations.

Mass balance components including firn accumulation and ablation are measured in detail at one location on Jungfraufirn. Seasonal observations at the end of winter and end of summer are performed. During winter snow accumulation is the dominating process while ablation of snow and ice occurs in the summer period. Thus, results from seasonal mass balance measurements allow separating the processes of accumulation and ablation. First measurements at this site were started more than a century ago in 1918. Between 1950 and 1985 an extensive network of measurements distributed over the entire glacier surface was maintained. Presently only two sites are surveyed, with a second measurement maintained by Pro Natura since 1992 on the glacier tongue (Figure 1). During the past observation period 2019/20 annual mass balance was observed at two additional sites on the glacier tongue between Konkordiaplatz and Märjelen.

In the last observation period (2019/20) a record low amount of snow accumulation at the end of winter was registered at the site on Jungfraufirn in the vicinity of Jungfraujoch. The summer 2020 was characterized by above-average melting (see Figure 1). As a combination of small accumulation and intense melt, the annual balance is one of the three most negative years in the observational record of more than 100 years. The annual mass balance on the glacier tongue was less negative than in the two previous observation periods. Nevertheless, a loss of more than 12m of ice was registered at this site at about 2000 m asl.

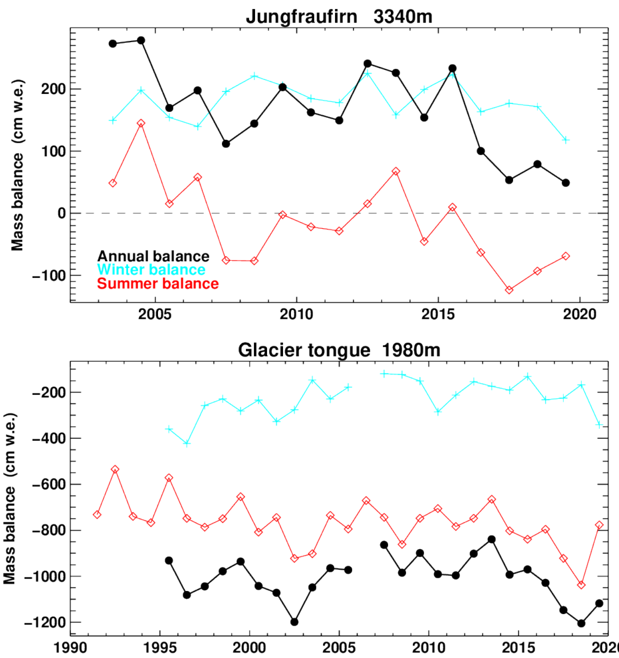

Figure 1. Winter, summer and annual mass balance (in centimetres water equivalent) at the two sites with ongoing measurement series on Jungfraufirn (top) and on the glacier tongue (bottom).

In addition to the measurements of mass balance components at some selected sites, the ice volume change of the entire Grosser Aletschgletscher is evaluated periodically by comparison of digital elevation models (DEMs) representing the surface topography. Over the past 100 years accurate DEMs exist for 1927, 1957, 1980, 1999, 2009 and 2017, respectively.

In a recent effort on data rescue by GLAMOS, the data quality of the historic mass balance measurements has been systematically assessed by checking archived original field notes and old reports and additional meta-information has been collected. An improved data set of over 1’700 point accumulation and melt measurements performed on Grosser Aletschgletscher since 1918 was compiled. Based on this new quality-checked data set and the available independent ice volume changes, the glacier-wide mass balance of Grosser Aletschgletscher has been re-evaluated (see Figure 2). The largest glacier in the Alps experienced a significant reduction of about 60m in mean ice thickness over the last 100 years. An initial steady retreat until the early 1970s is interrupted by two decades with a balanced mass budget and is followed by a more pronounced and still ongoing mass loss with an almost doubled rate.

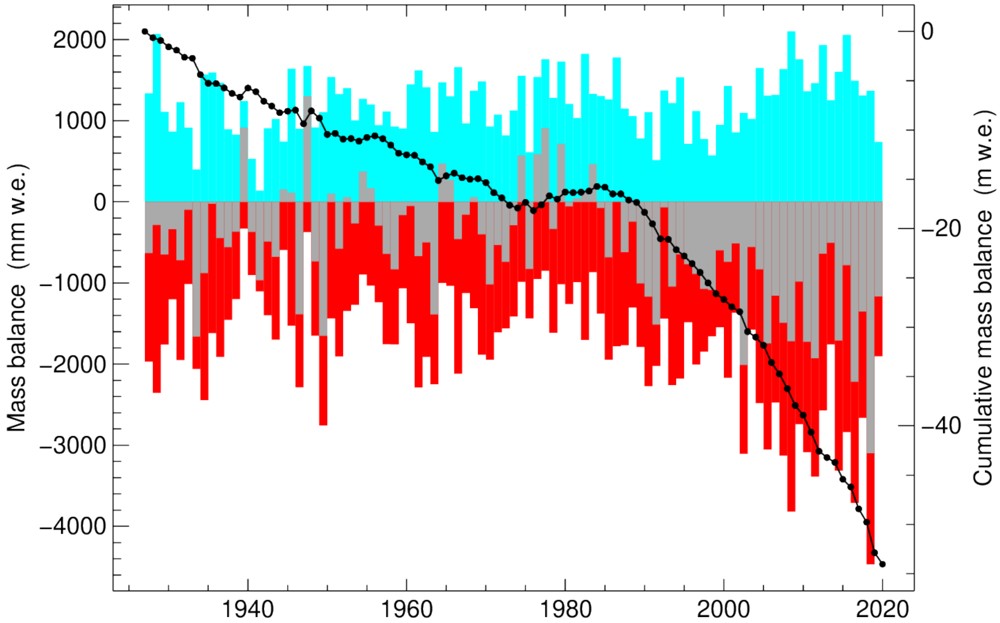

Figure 2. Glacier-wide winter (blue), summer (red) and annual (grey) mass balance (in millimetres water equivalent) of Grosser Aletschgletscher since 1927 and the first detailed mapping of the entire surface topography. Area averaged cumulative mass balance (in meters water equivalent) is given in black.

Internet data bases

http://www.glamos.ch
http://www.glaciology.ethz.ch

Collaborating partners / networks

Laudo Albrecht, Maurus Bamert, Elisabeth Karrer, Pro Natura Zentrum Aletsch , Villa Cassel, Riederalp
Dr. André Streilein, Roberto Artuso, swisstopo, Wabern

Scientific publications and public outreach 2020

Data books and reports

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Kurzböck, C., M. Huss, A. Bauder, L. Geibel, A. Linsbauer, A Best Practice Guide for Long-term Glacier Monitoring in Switzerland, Laboratory of Hydraulics, Hydrology and Glaciology, ETH Zürich, doi: 10.18752/intrep_5., 2020. https://doi.glamos.ch/pubs/intrep/intrep_5.html

Address

Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW)
ETH Zürich
Hönggerbergring 26
CH-8093 Zürich
Switzerland

Contacts

Dr. Andreas Bauder
Tel.: +41 44 632 4112
e-mail: bauder@vaw.baug.ethz.ch

Glacier tunnel closure experiments in the Jungfraujoch ice cap

Martin Lüthi[1], Sarah Morard[1], Andrea Walter[1], Diego Wasser[1], Adrien Wehrlér[1]

[1] Department of Geography, University of Zurich, Zurich, Switzerland

martin.luethi@geo.uzh.ch

Keywords: glaciology; ice dynamics; rheology

1. Project description

The glacier saddle between Jungfraujoch and Jungfrau hosts the access tunnel to the Ostgrat station on the eastern ridge of Jungfrau. This tunnel of 160 meter length, shown in Figure 1, was initially constructed in 1952 as provisional access, but has been in operation ever since. As the tunnel crosses through the glacier at about 30 meters depth, and the glacier is slowly flowing sideways, it has to be adjusted every year. Rails of a tram, power lines and signal cables run through this tunnel, and are protected in a steel cable channel.

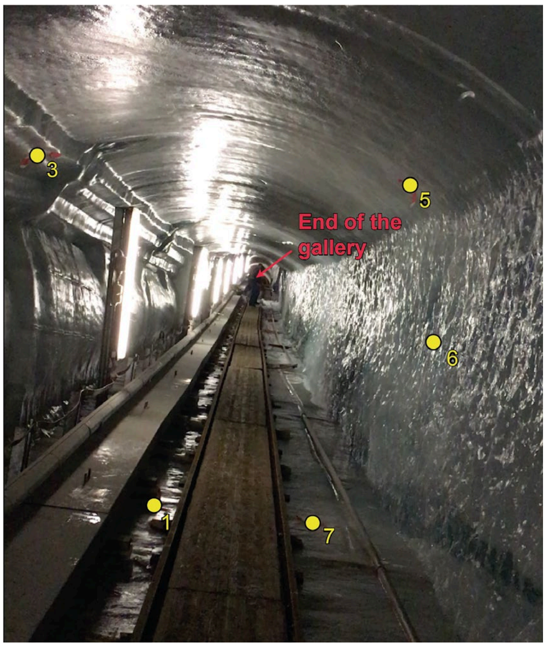

Figure 1. The glacier tunnel through the Jungfraujoch ice cap leading to the Ostgrat station. In the center are the rails of the tram and the utility channel is installed on the left. Yellow dots mark the positions of screws used to measure tunnel closure for two months.

Cavities in the glaciers slowly shrink under the weight of the surrounding ice. Measuring these deformations provides the unique opportunity to determine the rheology of ice under real-world conditions. The deviatoric stress field around a tunnel is spherically symmetric in a first approximation, which has been used to derive flow parameters for glacier ice that are still used today. This approximation, however, is crude and does not take into account horizontal ice motion which is mostly extensional in the glacier saddle geometry of Jungfraujoch.

Detailed measurements of tunnel closure were made in the 1950s in the main access tunnel and in cross tunnels that were specifically excavated for glaciological research. In 2019/20 we measured the closure of the main tunnel at two profiles during 64 days (Fig. 1). For that purpose painted wood screws were drilled into the ice and their respective distances measured with a laser distometer to an accuracy of 2 mm. The biggest displacement was a 40 mm lowering of the ceiling in two months at profile K3 shown in Figure 2. This corresponds to a 9% shortening of the tunnel height in one year. The horizontal distance got reduced by 22 mm. These deformation rates are lower than those measured in the 1950s which can be explained by the smaller current ice thickness and consequently a reduced compressive stress.

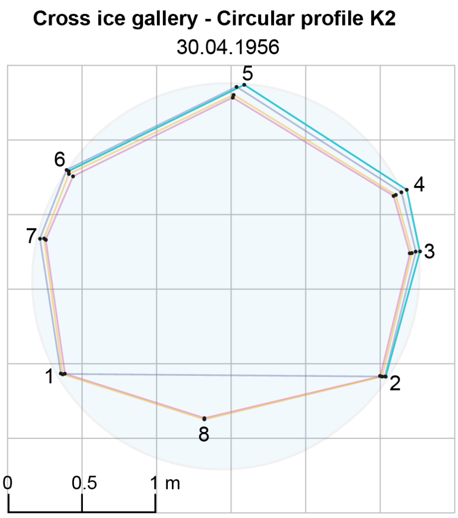

Figure 2. Tunnel closure measurements between 1954 and 1956 (Haefeli, 1957). Vertical deformation was 116 mm or 6.5% of the initial height.

Complementary to the ice deformation measurements we also measured ice temperatures in vertical and horizontal boreholes of 10 m length drilled with a power drill and Kovacs spiral drill bits. The temperatures were below freezing everywhere, with coldest values away from the tunnel between -1 and -2 C. Three data loggers within the tunnel measured temperatures between 0 and -2 C, which are likely strongly disturbed by air flow caused by ventilation of the construction site of the new railway station.

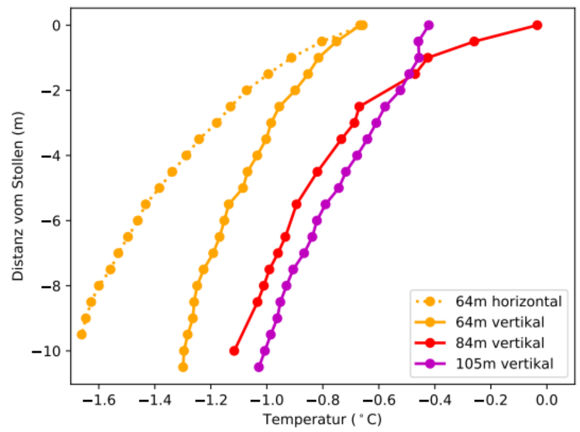

Figure 3: Ice temperatures profiles from vertical and horizontal (towards North) bore holes. The ice temperatures at a distance from the tunnel are throughout between -1 and -2 C.

At the upper end of the tunnel, about 30 meters from the transition into the bedrock of Mathildenspitze, a horizontal borehole of 10.5 m length, drilled for temperature measurements, is connected to a water-filled crevasse. In the course of roughly 5 hours that crevasse emptied 120 m3 of water through the tunnel at a rate of 6.5 L/s. The calculated initial pressure height in the crevasse was 0.6 m which gives a surface of the drained lake of 200 m2. Such a drainage of a water-filled crevasse led to a near-catastrophe during the initial construction of the ice tunnel (two further crevasses were encountered during that excavation work). In our case, we were lucky that the water did not enlarge the 5 cm diameter drill hole as is usually the case if the water temperature is slightly above 0 C. Thankfully, our safety measures recommended to the engineers of the company constructing the new railway station proved to be unnecessary: upon our strong recommendation they moved a running large ventilator away from the side exit into the tunnel ascending towards the railway station. After one hour the tunnel sole and the high-tension power cables were already covered by 10-20 cm of water. If the crevasse would have broken through, or the drill hole would have broached the crevasse at a lower level, a strong water pulse could have rapidly inundated the tunnel and the electric installations.

The tunnel closure measurements were analysed with a numerical Finite Element model that implements visco-elastic-plastic flow. Our preliminary results are not fully conclusive, but most tunnel closure measurement can be well reproduced using the conventional Glen flow law for glacier ice with parameters n=3 and A = 30 MPa^-3 yr^-1. This latter value is considerably lower than would be expected at the measured ice temperatures between -1 and -2 C. Further analysis with other rheologies will be performed in the near future.

Thanks to the unique setting of a long tunnel through a cold glacier, its easy accessibility, and the support of the Jungfraujoch research station this research was possible. The support of the custodians J. and M. Fischer, R. and Ch. Käser, and the engineers of the construction company Frutiger AG is highly appreciated.

Scientific publications and public outreach 2020

Theses

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Address

Department of Geography, 3G
University of Zurich
Winterthurerstrasse 190
CH-8057 Zurich
Switzerland

Contacts

Dr. Martin Lüthi
Phone: +41 44 635 5146
e-mail: martin.luethi@geo.uzh.ch

Long-term permafrost monitoring in the Jungfrau East ridge

Marcia Phillips[1]

[1] WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland

phillips@slf.ch

Part of this programme: PERMOS, GTN-P

Keywords: mountain permafrost; frozen rock walls; thermal regime; long-term permafrost monitoring

1. Project description

The sub-horizontal borehole in the Jungfrau East ridge is located at 3590 m asl (Fig. 1) in the northern flank of the ridge. It is 20 m long and is equipped with 9 thermistors and a data logger. Rock temperatures currently vary between -3.4 and -6°C (Fig. 2). Due to the time lag with depth, the highest rock temperatures are registered in winter and the lowest ones in summer. The high elevation of the borehole and its position in a steep rock wall make it valuable for long-term permafrost monitoring, as there are only eight boreholes in high elevation rock walls in the entire Alps.

Figure 1. White arrow: Position of the borehole in the Northern flank of the Jungfrau East ridge (Photograph: M. Phillips).

The Jungfrau borehole temperature data indicate a clear warming trend at all depths, as do other borehole data measured in steep, ice-poor permafrost rock in the Swiss Alps (Phillips et al. 2020; Huss et al. 2020).

The borehole is part of the Swiss permafrost monitoring network PERMOS and the borehole temperature data can be accessed here: http://newshinypermos.geo.uzh.ch/app/DataBrowser/.

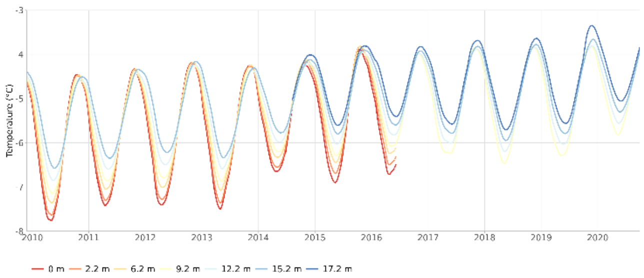

Figure 2. Borehole temperatures (2009-2020) in the Jungfrau borehole (Legend: 0 is located 6 m from the outer surface of the rock wall). Data: SLF/PERMOS

Internet data bases

www.permos.ch; http://newshinypermos.geo.uzh.ch/app/DataBrowser
https://gtnp.arcticportal.org/data/data-download

Collaborating partners / networks

PERMOS (Permafrost Monitoring Switzerland)
GTN-P (Global Terrestrial Network for Permafrost)

Scientific publications and public outreach 2020

Refereed journal articles and their internet access

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Address

WSL Institute for Snow and Avalanche Research SLF
Flüelastrasse 11, 7260 Davos Dorf, Switzerland

Contacts

Dr. Marcia Phillips
Tel.: +41 81 417 0218
e-mail: phillips@slf.ch

Performance of methanol fuel cells in alpine environments

Ronny Lorenzo[1], Orlando Summermatter[1], Mario Clausen[1]

[1] Federal Department of Defence, Civil Protection and Sport, Federal Office of Defence Procurement, armasuisse Science & Technology, Test Centre, Thun, Switzerland

ronny.lorenzo@ar.admin.ch

Keywords: solar panel; methanol fuel cell

1. Project description

The long-term use of scientific measurement or monitoring equipment on remote alpine sites is often confined to the vicinity of permanent installations or to available mobile energy sources. While combinations of solar panels and rechargeable batteries are readily available, their power output is limited by the surface area of the solar panels (larger battery packs provide more energy but need a large array of solar panels to be recharged within a reasonable amount of time). Additionally, during prolonged periods of unfavourable weather, the solar panels may not be able to compensate the energy needs of the equipment resulting in prematurely drained batteries.

Methanol-based fuel cells are not only small and safe to handle but also provide a fair amount of energy. Teaming fuel cells with solar panels and batteries, therefore, seems to be a sensible approach to a fail-safe power supply for unattended measuring campaigns in remote areas. However, available (civilian) commercial fuel cells are not built for alpine environments where they have to cope with bad weather, temperatures below freezing, low atmospheric pressure and very dry air.

2. Trial run

After the 2019 trial run two new fuel cells were ordered and fitted into their weatherproof boxes. Both systems were then tested inside a climate chamber and out on a field in mid-summer, as a

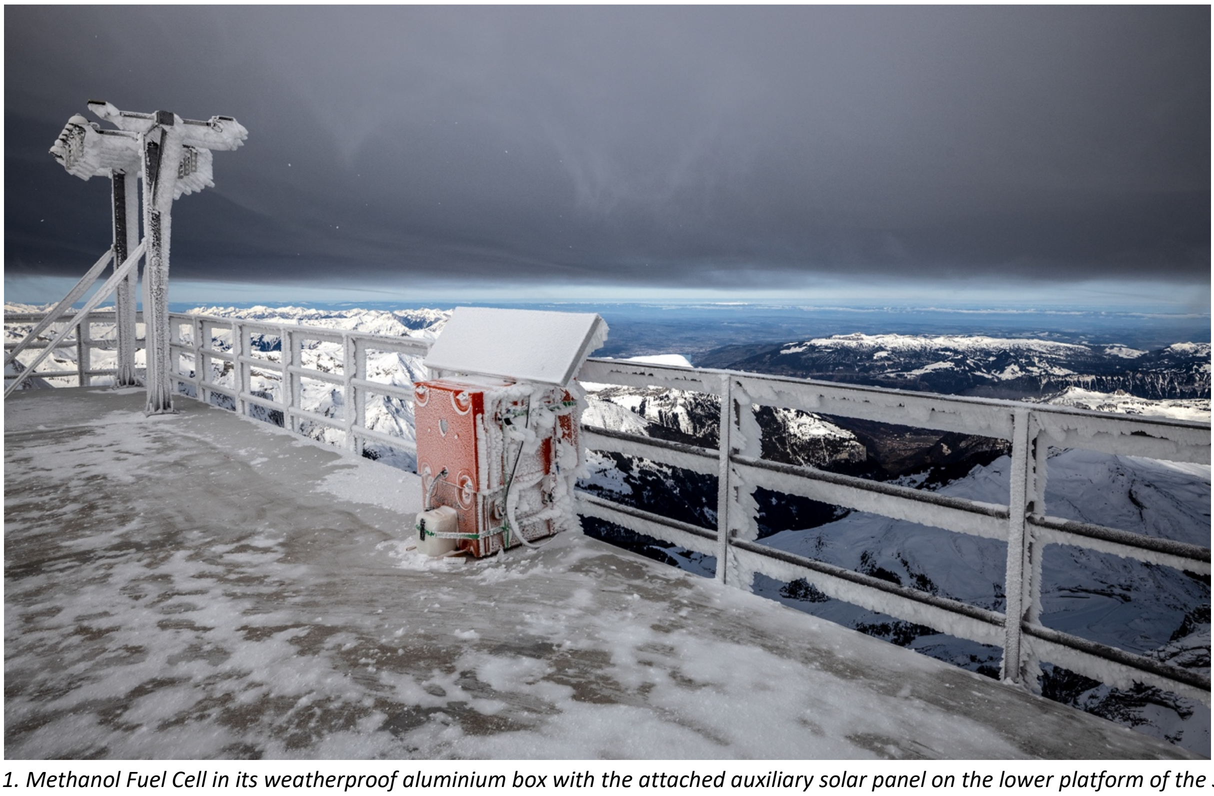

Figure 1. Methanol Fuel Cell in its weatherproof aluminium box with the attached auxiliary solar panel on the lower platform of the Sphinx observatory during the crisp February trials.

final proof of concept before packing one of them for the inaugural trial run in an alpine environment.

As an upgrade to the set-up used in the previous years, the light bulb was replaced by a software controlled electrical load, simulating a worst-case version of the designated primary use of the system. The electrical load was designed to represent the traffic on a radio relay varying power demand between 15 and 100 W over a period of 8 hours, staying at 15 W for 4 hours and restarting the cycle afterwards.

Eventually, the 5-day test run with the military grade methanol-based fuel cell with a nominal (sea level) power output of 130 W in a weatherproofed aluminium box was carried out at the High Altitude Research Station Jungfraujoch in February 2020. The fuel cell in its housing was placed on top of the new electrical load on the lower platform of the Sphinx observatory (Fig. 1). Every 15 minutes a set of 36 operational parameters from the fuel cell was logged. Additionally, the power output of the solar panel, the power demand of the electrical load and the temperature inside and outside of the aluminium box were logged every minute.

3. Results

During the trials, the fuel cell did perform according to specifications but…

The campaign on the Jungfraujoch took place in favourable conditions: Four days of unspoiled sunshine with one full day of snowfall in the middle, temperatures constantly below freezing. As it was February, daytime hours were limited to just over 10 hours resulting in 39 h of (theoretical) sunshine during the 93 h test run. Accordingly, the solar panel delivered 1200 Wh (2019: 1400 Wh) to the battery. The fuel cell on the other hand, produced 3100 Wh, which is considerably more than the 2300 Wh from the previous year.

Already during the first night atop the Jungfraujoch it was becoming obvious, that something wasn't right. Sometime during the second half of the night, the charge controller decided, that it had to disconnect the electrical load. This should not have happened since the electrical load was designed to require less than 25 W on average, which is considerably less than the roughly 95 W the fuel cell is able to provide at this altitude (minus the power requirements of the whole system).

Shortly after sunrise the charge controller reconnected the electrical load. Since everything appeared to be back to normal, we left the experiment running as it was.

However, a few hours after sunset the charge controller disconnected the electrical load once more. As a consequence, and since the fuel cell did perform according to specifications, we decided to disconnect the electrical load for the remainder of the experiment.

A closer inspection of the log files indeed revealed, that after the first eight hours of operation, when the electrical load should have switched to idle mode, it malfunctioned and permanently demanded 97 W from the charge controller, resulting in 3300 Wh in the first 42 h of the experiment. This is too much for the fuel cell alone and, therefore, the battery was completly drained during the night, triggering the disconnection of the electrical load.

4. Conclusions

The numerous campaigns at the High Altitude Research Station Jungfraujoch during the last couple of years showed that commercially available (military grade) fuel cells are capable of performing according to specifications even at high altitudes. The stand-alone solution proved to be perfectly suited for continuous unattended operation in alpine environments. By adding a solar panel, the operating time of the fuel cell on one tank of methanol (10 ℓ) was more than doubled.

In the follow-up campaign in 2021 the new fuel cell in its weatherproofed box will undergo its full-length maiden trial with the improved (and hopefully faultless) software controlled electrical load, simulating the worst-case version of the designated use of the system.

Collaborating partners / networks

SFC Energy AG, Eugen-Sänger-Ring 7, D-85649 Brunnthal

Address

Federal Department of Defence, Civil Protection and Sport DDPS
Federal Office of Defence Procurement
armasuisse Science & Technology
Test Centre
Feuerwerkerstrasse 39
CH-3602 Thun
Switzerland

Contacts

Dr. Ronny Lorenzo
Tel.: +41 58 468 2753
e-mail: ronny.lorenzo@ar.admin.ch

Production loss and degradation of photovoltaic modules induced by damaged front glass

Urs Muntwyler[1], Thomas Schott[1], Maëla Beuzit[2], Franziska Kuonen[1], Jorge Gomes[1]

[1] BFH, Bern University of Applied Sciences, Burgdorf, Switzerland
[2] EPF, Ecole d'Ingenieur-e-s, Sceaux, France

urs.muntwyler@bfh.ch

Keywords: photovoltaics; energy yield; reliability; energy loss due to construction

1. Project description

The reason why, in 1993, the first PV plant by Bern University of Applied Science was installed on the south façade of the research building of HFSJG was to find out how this (at this time) new technology performs in an alpine climate. The measurements showing high energy yield and a high portion of winter PV were exciting results for the PV world. When, in 2014, the second PV plant was realised with PV modules of the newest technology it was still the same motivation as in 1993. As expected, the measured energy yield per m^2 was more than doubled and the cost much lower.
The 20 years of experience in the PV industry brought new module designs, new mechanical constructions, new technology by the photocell production. One difference seems to be on the mechanical side and concerns the new fixation of the modules. The construction holding the modules on the wall is not as stiff as it is on the older modules of 1993. The PV construction in 1993 at Jungfraujoch used mounting material for telecommunication applications, which is very rugged but also very expensive. Compared to the high prices of the PV module then, this was no problem at all. But how are things today? Our research provides new insight.

2. Situation

The 24 PV modules M75 (48Wp) from Siemens from 1993 are much smaller, have a stiff frame construction and are installed on an extensive and costly construction with aluminium tubes (Figure 2). The new 2 x 4 SunPower X 21 modules (345 Wp) are fixed on an iron frame according to a method like it is now often done on mountain cabins (Figure 3). The new SunPower modules are 4-times bigger and about fifteen times cheaper than the M75 in 1993 and have nearly the double efficiency.

Figure 1. Situation of the PV power plants of Bern University of Applied Science BFH at the south façade of the HFSJG research building.

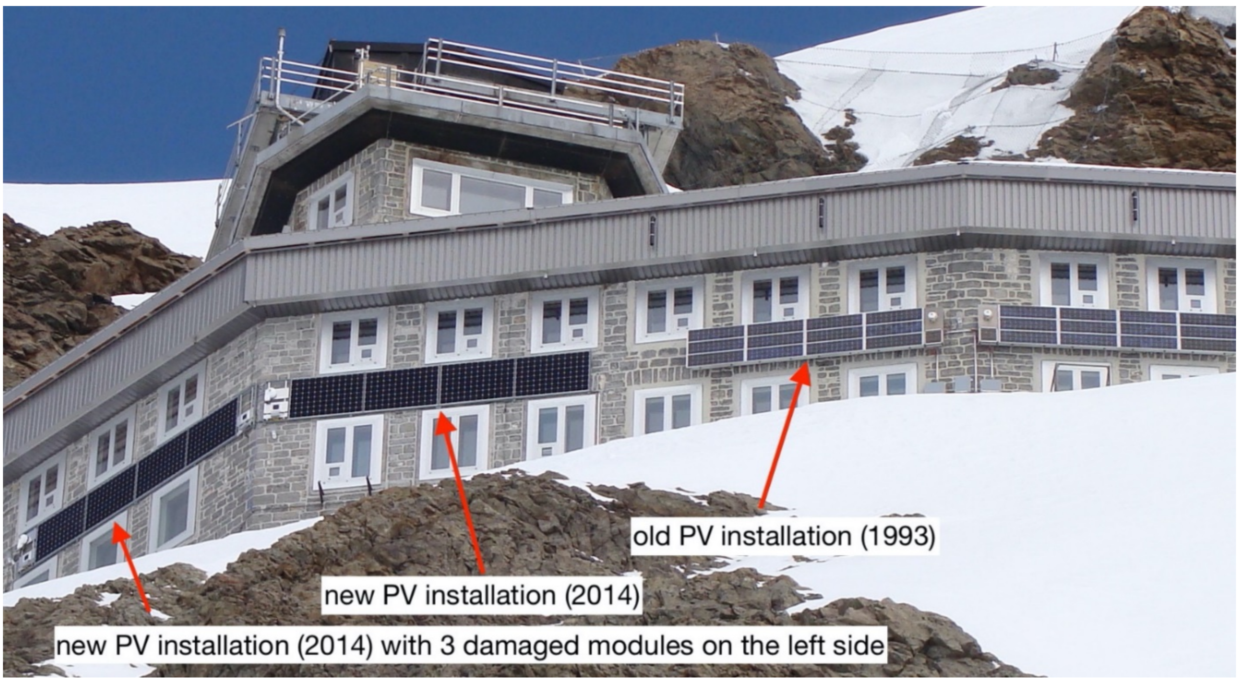

Figure 2. Frame construction of the 1993 installation.

Figure 3. Frame construction of the 2014 installation.

Since 2017 the glass of three modules has cracked, the first one in 2017, the second one in 2018 and the third in 2020. The reason could be the tensions forced by the iron frame, caused by temperature changes or by the high wind load on the modules on the west side. The most likely cause is the wind load as the three modules are mounted on the same wall facing the west. This west side experiences the strongest wind forces. Figure 4 shows the cracked glass of one of the damaged modules.

When the glass of the first module cracked, we planned to exchange the damaged module. Yet, for research reasons, we then decided to maintain all damaged modules to further observe and measure them. The rational was to compare the damaged modules to the undamaged modules on the very south side of the façade and assess their degeneration in relation to the undamaged modules.

3. Question

The objectives of this study are (i) to investigate the reasons underlying the cracked front glass in PV modules at Jungfraujoch and (ii) to quantify the impacts upon the energy yield production.

Figure 4. Cracked front glass of a module installed in 2014.

4. Data harvesting using I-V-Curve measurements

In addition to the PV records available from the long-term Swiss PV monitoring programme operated by the PV LAB/BFH at Jungfraujoch, on-site measurements were carried out to determine the maximum power point. That was realised by using a I-V-curve tracer for PV modules, called PVPM. (Figure 5).

Figure 5. Portable I-V-Curve tracer PVPM 1000CX for PV modules.

This equipment uses the natural sunlight as a reference for its measurement, while the I-V-Curve tracer for laboratories uses a standardised lamp. An irradiation sensor was fixed close to the investigated modules and connected to the PVPM. Also, a temperature sensor was attached on the rear of the module (a difficult task!) and connected to the PVPM.

Since the module temperature is also measured at Jungfraujoch in the long-term Swiss PV monitoring program operated by the PV LAB/BFH, a second measurement is now available.

For the I-V-Curve measurement, the power connections of the PV modules to the PV inverters were changed from the inverters to the PVPM measuring equipment.

5. Results

5.1 I-V-Curve measurement

Figures 6 and 7 show a typical plot of the measurements made with the I-V-Curve tracer PVPM 1000CX. “Joch 21” is the PV installation at Jungfraujoch with undamaged module glass (Figure 6). “Joch 22” is the PV installation at Jungfraujoch with the three PV modules experiencing damaged glass (Figure 7).

The shapes of these I-V-Curves provide information about the quality of the measured modules. The curves of the undamaged PV modules (Figure 6) are smooth and stable. The current is nearly stable up to 200 V and then starts to drop when the power curve reaches its maximum.

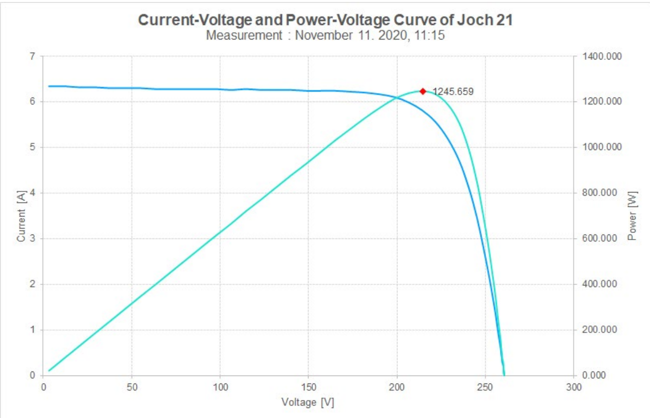

Figure 6. I-V-Curve of the undamaged “Joch 21”.

On the other hand, Figure 7 displays unstable curves with a much lower and wider power curve and a current curve that does not stagnate but decreases almost from the beginning. This wavy characteristic of the curve is the result of the damaged glass on the panels.

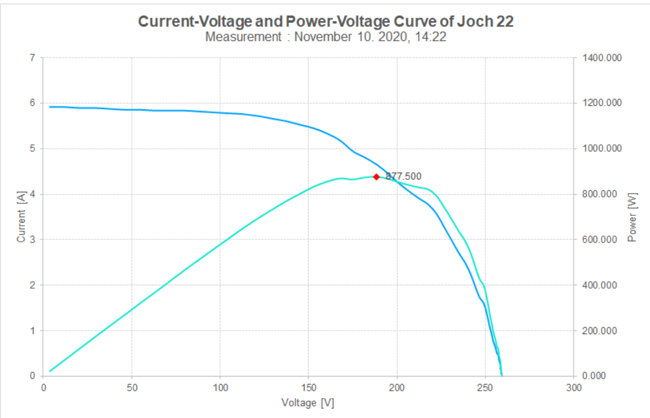

Figure 7. I-V-Curve of the damaged “Joch 22”.

In conclusion, noteworthy differences in the shape of the I-V-Curves between “Joch 21” and “Joch 22” are demonstrated. We interpret the information revealed by the I-V-Curves as evidence for the condition of the PV modules measured, i.e., damaged glasses in PV modules of “Joch 22”. Thanks to the I-V-Curves obtained with the PVPM, the performance of the PV installations “Joch 21” and “Joch 22” could hence be illustrated.

5.2 Power comparison of “Joch 21” and “Joch 22”

In the context of the PVPM measurements, the irradiation was also recorded. The data (Figure 8) indicate that, for the same irradiation values, “Joch 22” produces about 300 Watt less than “Joch 21”, thus making “Joch 22” about 26 % less efficient than “Joch 21”.

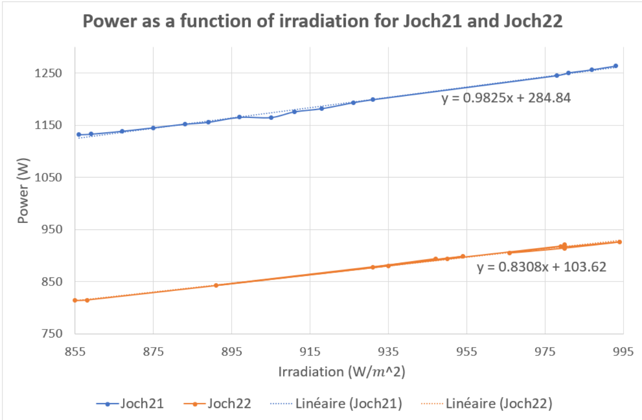

Figure 8. Power vs irradiation for “Joch 21” and “Joch 22”.

6. Analysis of 5-year (2016 - 2020) record to assess degradation

The data available from the long-term Swiss PV monitoring programme operated by the PV LAB/BFH allow to calculate the degradation of the PV installations at Jungfraujoch by using the quotient of the normalised yields ($\boldsymbol{Y_a}$) of the PV modules over the normalised reference yields ($\boldsymbol{Y_r}$) of the pyranometers (see also our Activity Report 2017).

To be more precise:

- Y_r : Time witch the sun must shine with $G_0 = 1\ \mathrm{kW}/m^2$ to irradiate the energy Hg onto the solar generator (h/d)
- Y_a : Time witch the PV plant must operate with its nominal power P_0 to generate array (DC) energy E_A (h/d)
- $\frac{Y_a}{Y_r}$: Measure for the degradation of the PV modules (ø)

Concerning “Joch 21”, the quotient of degradation $\frac{Y_a}{Y_r}$ remains globally stable between 0.9 and 1.10, except for a drop at the end of 2018. However, for “Joch 22”, the quotient dropped from 1.06 to 0.75, which means that “Joch 22” has lost about 30 % of its efficiency over a period of 5 years.

The dates on which the PV modules cracked (2017, 2018 and 2020) can also be identified in the graph (Figure 10), as reflected by a sharp drop in the curve.

Moreover, application of linear curves of the type $y = ax + b$, gives “a”, the steering coefficient, which represent this gradient of degradation per year in per-units.

For “Joch 21”, this gradient is -0.000005 [pu], so about 0.0005 % deterioration each year. For “Joch 22”, the gradient is -0.0001 [pu], so about 0.01 % deterioration each year, which is 20 times bigger than for “Joch 21”.

In summary, the Figures 9 and 10 indicate that the performance loss of the PV installation at Jungfraujoch with damaged glass on the PV modules (“Joch 22”) was about 30 %.

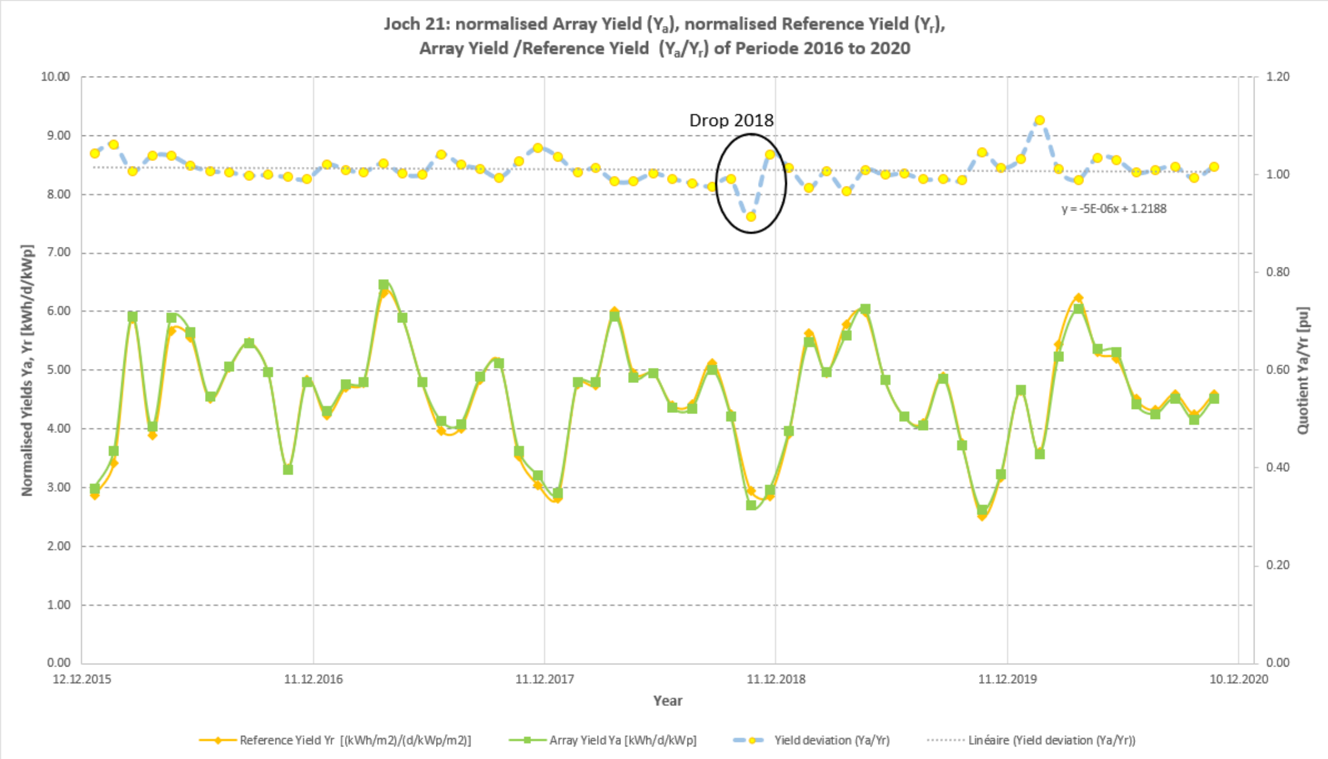

Figure 9. Degradation of the PV modules of "Joch 21" from 2016 to 2020.

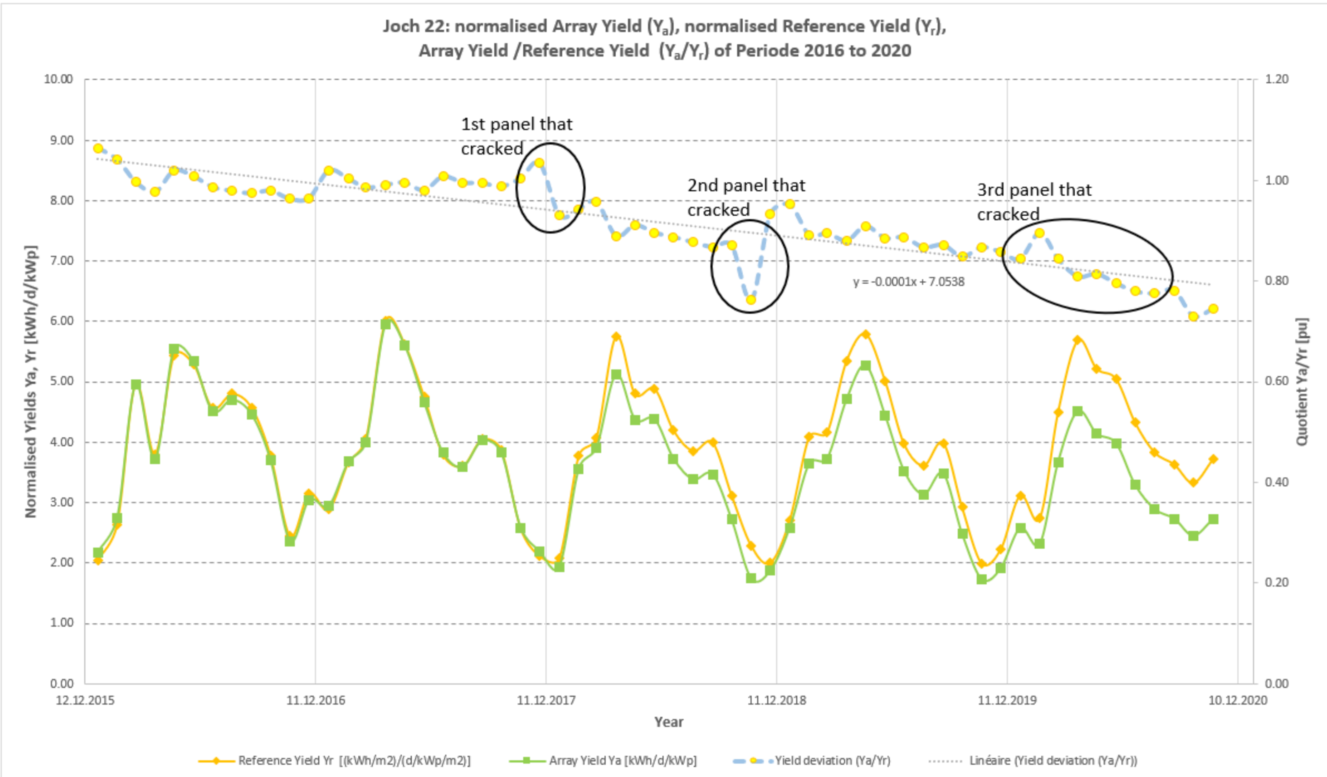

Figure 10. Degradation of the PV modules of "Joch 22" from 2016 to 2020. Glass breaking events of the PV modules are clearly visible.

7. Effect of humidity

It is assumed that - through cracked glass - humidity can enter a PV module and thus induce more damage to the PV cells. Yet, the front glass is not the only shield to the cells as these are additionally encapsulated between an EVA (ethylene vinyl acetate) film on the front and rear side. The schematics in Figure 11 illustrates very nicely the complete composition of a PV module with the double protection on its front (glass plus EVA-film) and rear (back sheet plus EVA-film). If the EVA-film-encapsulation is undamaged, the PV cells remain protected.

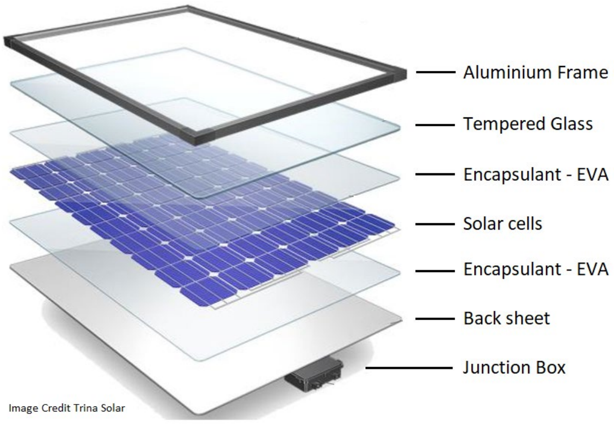

Figure 11. Composition of a PV module (Clean Energy Reviews).

To assess, as a first approximation, whether our damaged modules are affected by humidity, we made an orientational comparison "humidity to PV module performance" between the damaged PV installation "Joch 22" and the undamaged PV installation "Joch 21".

The Figures 12 and 13 show a function of the relative humidity (%) to the performance (W). It is evident that - when air humidity is high, the power is low. This is because humid days are days of rain, mist, or snow, when it is cloudy, and no high irradiation is possible. All this results in a low power production.

In Figure 13, however, the lower performance of the PV installation "Joch 22" is also caused by the damaged front glass.

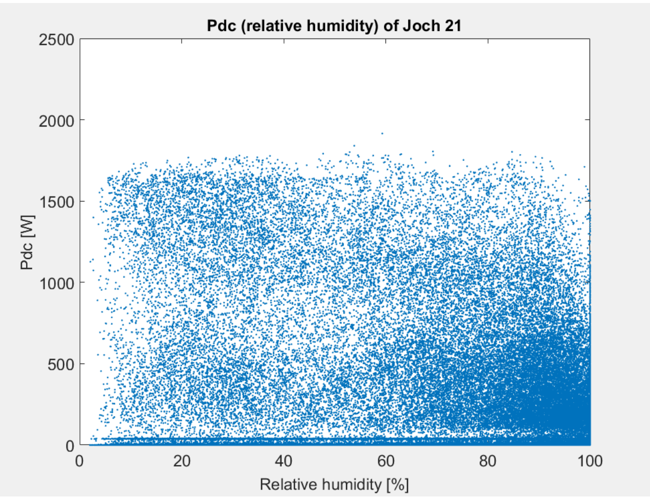

Figure 12. Power as a function of relative humidity for "Joch 21".

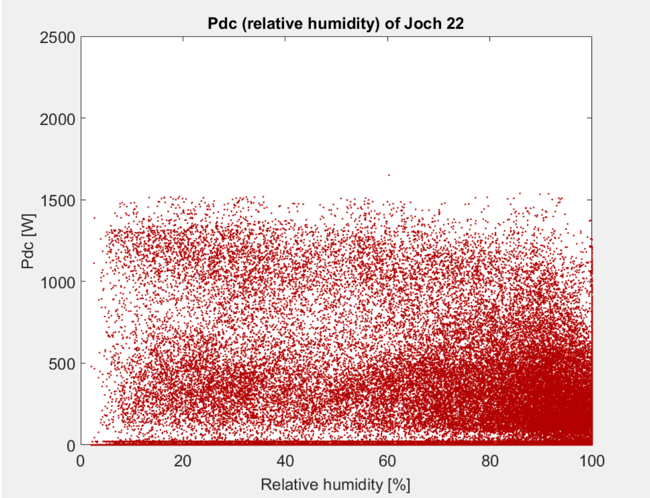

Figure 13. Power as a function of relative humidity for "Joch 22".

8. Conclusion

High-alpine PV installations like the ones at Jungfraujoch produce comparatively high energy yields. Yet, climate-related damage on PV modules (cracked glass) may reduce their performance. Governing factors like strong forces (wind) and humidity must hence be considered when planning PV installations in high-alpine climates. Special expensive robust PV modules and mounting structures are needed. The higher labour costs to maintain PV installations in alpine areas also must be carefully evaluated. In view of implementing the Swiss Energy Strategy 2050, it is thus recommended to increase the number of (cheap) PV installations in the Swiss Basin.

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Internet data bases

http://www.pvtest.ch
http://www.societe-mont-soleil.ch/
http://sccer-furies.epfl.ch

Address

Bern University of Applied Sciences BFH
Dept. Engineering and Information Technology (EIT)
Photovoltaic Laboratory (PV LAB)
CH-3400 Burgdorf
Switzerland

Contact

Prof. Urs Muntwyler
Tel.: +41 34 426 6837
e-mail: urs.muntwyler@bfh.ch

Continuation of the recordings at the research station Jungfraujoch on the activity and migration behaviour of bats

Peter E. Zingg[1], Fabio Bontadina[2,3]

[1] BRCC, Bat Research, Conservation & Consulting, Unterseen, Switzerland
[2] SWILD, Urban Ecology & Wildlife Research, Zürich, Switzerland
[3] Swiss Federal Research Institute WSL, Biodiversity and Conservation Biology, Birmensdorf, Switzerland

peter.zingg@tcmail.ch

Keywords: bats; bioacoustics; migration; high altitude; seasonal patterns

1. Project description

In 2011 (May, Aug, Sept, Oct), using a batlogger, we detected for the first time that bats fly over the Jungfraujoch. A crossing of such high altitudes in the alpine region in connection with seasonal migration was unknown until then (Zingg & Bontadina 2016). Batloggers (www.batlogger.com) are data loggers, which record ultrasound vocalisations (10-150 kHz) of bats in real-time, and store them in a digitised form for later processing on a SD / SDHC memory card. A temperature sensor (range -5°C to +40°C) is integrated in the microphone. With each sound sequence, air temperature, date, time, location etc. are registered on a meta data file. With a batlogger and its microphone, only a small area can be scanned for bats calling in flight. The detection distance (between microphone and bat) ranges from a few metres to almost a hundred metres, depending on the bat species and the range of its calls. For most combinations of bat species passing through, flight direction, wind direction, etc. in relation to the microphone, the effective detection distance should be less than 50 m in most cases.

In 2011 and 2012, a batlogger with autonomous power supply was operated unsystematically not far from the lowest point (3464 m.a.s.l.) on the north-south transition, the so-called plateau (A in Fig. 1), during single nights with air temperatures above zero degrees Celsius (compare Activity Report 2012; https://www.hfsjg.ch/).

In 2018, we operated two to three batloggers simultaneously for two to three nights at the end of April, May, June and July, mostly on the plateau and the research station, and once each on the Sphinx and the Mönchsjoch (Activity Report 2018). In order to reduce the presence and time required at the Jungfraujoch and at the same time to enable continuous monitoring, we installed and operated a batlogger C outside the research station (C in Fig. 1) for the first time from June to the end of October 2019, with electricity supplied from the grid (Activity Report 2019).

Due to restrictions caused by the SARS-CoV-2 pandemic, the batlogger C could not be installed and commissioned at the research station this year until 8 May 2020. We ended the mission for this year on 29 October.

The research station site in a rocky flank, exposed to the south (C in Fig. 1), used in 2019 and 2020, is 370 m ESE of the lowest point of the Jungfraujoch. The data collected at this site C are therefore likely to be different from those collected on the plateau (site A). Additional monitoring on the plateau (A) would be desirable as a supplement to the research station site (C).

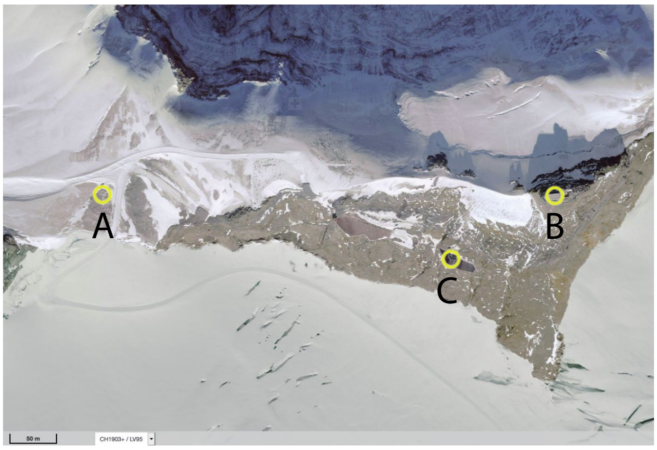

Figure 1. Batlogger locations: A – Plateau, B – Sphinx, C – Research station (Areal photo from https://map.geo.admin.ch).

2. Goals

The Jungfraujoch is an extreme location for most creatures. Therefore, we are interested in which bat species visit the Jungfraujoch or cross it as part of their seasonal migration and when in the year and under which weather conditions these specific visits or crossings happen. Weather patterns vary from year to year and are also influenced by ongoing climate change. Consequently, the presence and activity patterns of the different bat species on the Jungfraujoch are likely to vary from year to year or show medium-term trends. This requires continuous monitoring over the years in order to identify correlations and long-term trends.

3. Main results 2020

From 8 May to 29 October (175 operating nights) a total of 27'250 events were triggered. 99% of the recorded events (sound sequences) were related to wind noise, falling ice and water. Among these 246 sequences concerned the echolocation calls of bats (hereafter simplified as bat call sequences). The distribution of these bat call sequences during the nights and over the months of May to October is shown in Figure 2. The abundances in May (45), August (78) and September (89) are likely to be largely the result of seasonal migration of various bat species.

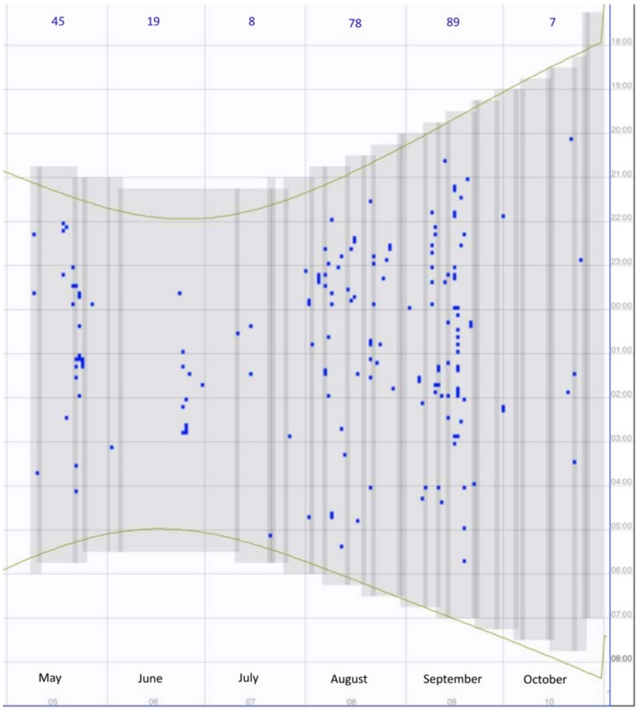

Figure 2. Temporal distribution of bat call sequences recorded by the batlogger C at the research station during the nights from 8 May to 29 October 2020. Horizontal axis: months May to October; vertical axis: nighttime between sunset (upper green line) and sunrise (lower green line). The grey vertical shading shows the nocturnal operating time of the batlogger (overlaps of the grey shading have no meaning). Numbers at the top of the image: Monthly sum of sequences with bat echolocation calls. A blue dot represents all sequences with bat echolocation calls within a 5-minute interval.

The extent to which the bats recorded in June and July were migrating individuals and/or this behaviour belongs to dispersal (roaming) cannot be said with certainty in individual cases. The cold periods towards the end of September and during October with air temperatures well below 0°C (see Fig. 3) brought bat migration over the Jungfraujoch almost to a standstill. Throughout the observation period, temperature often seems to have had an influence on the occurrence of bats at the research station (see Fig. 3). When the air temperature was below 0°C (black dots below the horizontal axis in Fig. 3), most of the bat call sequences were zero (the red dots are on the horizontal 0-line). The quantitative data are shown in Table 1.

Median night temperature	> 0°C	= 0°C	< 0°C
Number of bat call sequences	162 (66%)	37 (15%)	47 (19%)

Table 1. Distribution of bat call sequences in three temperature classes.

The highest number of bat call sequences was recorded when the median air temperatures at night was above 0°C. Comparing the number of bat call sequences per night and the median night air temperature of all the 175 nights the batlogger was in operation, shows a weak but significant correlation between the number of bat call sequences and air temperature (Kendall's rank correlation coefficient $\tau = 0.35$, p=4.40 E-12; n=175).

Even at air temperatures above 0°C, no bat calls were recorded in some nights. Besides air temperature, other weather factors (e.g. wind direction, wind strength) as well as endogenous biological factors control the mobility behaviour of the different bat species.

Ten bat species and one unidentified call (rodent?) could be detected acoustically from May to October 2020. The following records are noteworthy: On 21 July (23:03 h; +3°C), a social sound of a small mammal was recorded in the ultrasonic range 20-55 kHz (see Fig. 4).

On 15 Sept. (21:14 h, +4°C), the batlogger recorded a sequence with two calls of a European Free-tailed bat *(Tadarida teniotis)*. This bat species is one of the largest in Europe and has its main distribution in the Mediterranean region. Regular occurrences in Switzerland are only known from Ticino, Valais and the Geneva Basin. The registration on 15 Sept. on the Jungfraujoch is probably the highest record of this species in Europe. This individual probably made a trip (so-called dispersal) from the Valais to the Jungfraujoch, as seasonal migrations are unknown for this species.

The two last recorded overflights of the whole observation period were remarkable, too: These were two Nathusiu's or Kuhl's Pipistrelle bats *(P. nathusii or kuhlii)* on 24.10.2020 at 22:54 h and an air temperature of minus 5°C! The two small (5 - 10 g body weight) migrating bats still had to fly from the Jungfraujoch more than 20 km over the Aletsch Glacier towards the south!

4. Importance of the High Altitude Research Station Jungfraujoch for biological research

In terms of altitude and weather conditions, the Jungfraujoch in Switzerland is a border zone for many living creatures. The infrastructure of the research station makes it possible to carry out studies on living organisms in this border zone that would otherwise not be possible. Studies on organisms in extreme areas provide information about their plasticity and temporary adaptability. Long-term monitoring at such extreme places contributes valuable information on seasonal variations and the consequences of climate change.

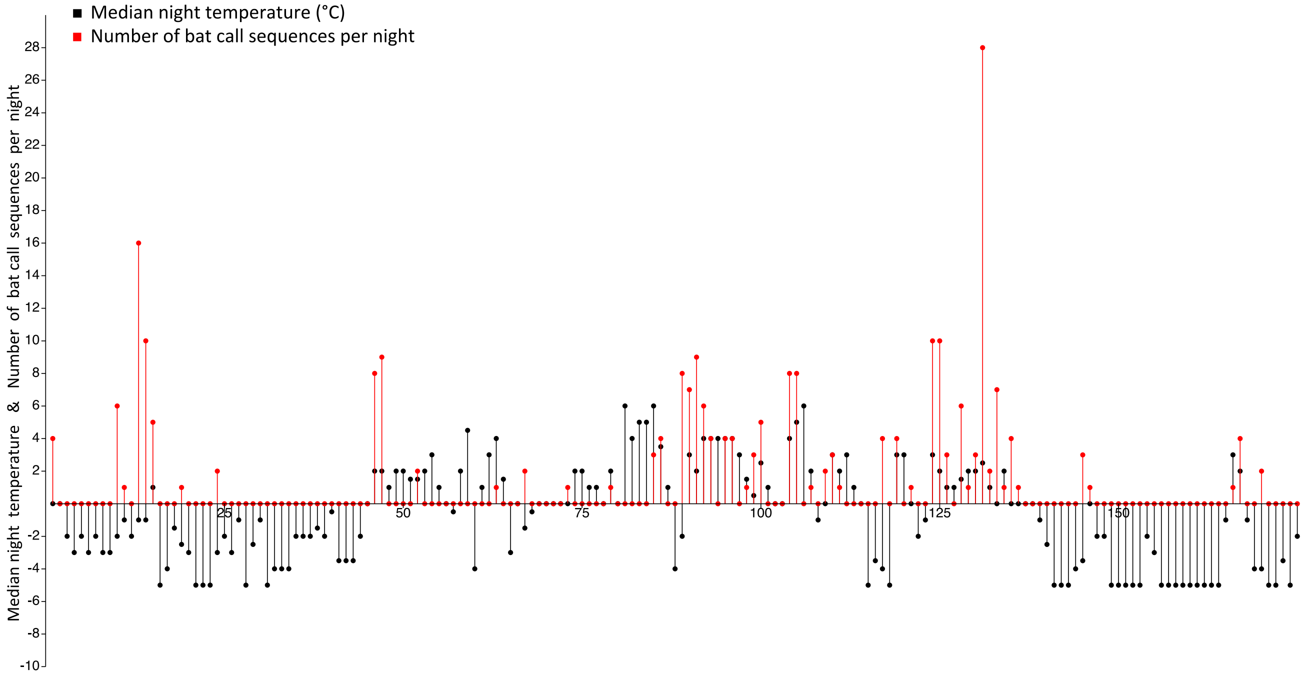

Figure 3. Distribution of bat call sequences (red dots) from 8 May to 29 October 2020 (horizontal time axis) and median night temperature (black dots). On the vertical axis, the same scale is used for temperature (°C) and number of bat call sequences. The vertical lines from the dots to the time axis serve as a visual interpretation aid.

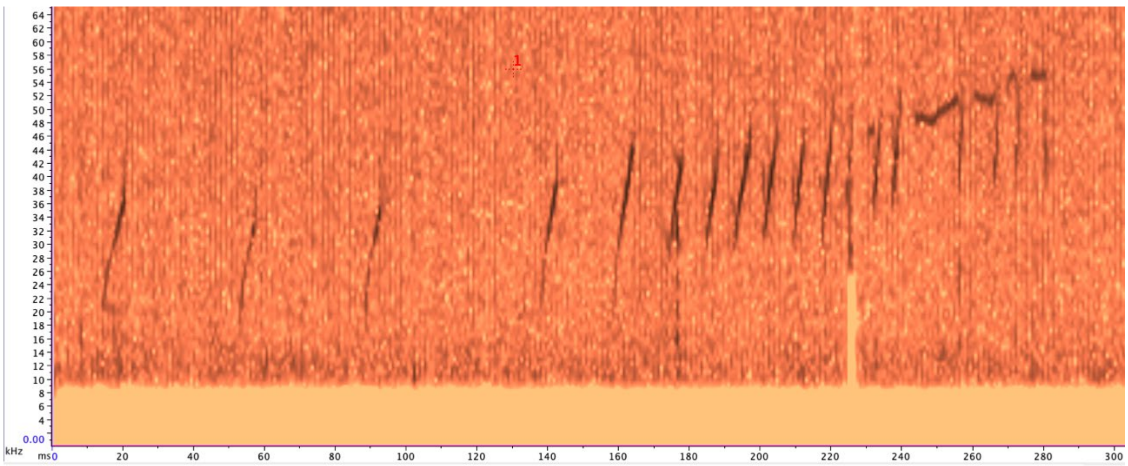

Figure 4. Frequency spectrogram of a vocalisation, most probably of a rodent; 21 July 2020 (23:03 h; +3°C air temperature). Vertical axis: Sound frequency in kHz. Horizontal axes: Time in Milliseconds.

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Address

Bat Research, Conservation & Consulting - BRCC
Spielhölzli 8
CH-3800 Unterseen
Switzerland

Contacts

Dr. Peter E. Zingg
Tel.: +41 33 823 0712
e-mail: peter.zingg@tcmail.ch

Research on Heart Rate Variability in the Prediction of Acute Mountain Sickness

Sophie Rüchardt[1], Prof. Dr. Rainald Fischer[1]

[1] Ludwig-Maximilian University, Munich, Germany

sophie.ruechardt@gmx.de

Keywords: Heart Rate Variability; Acute Mountain Sickness; Autonomous Nervous System

1. Project Description

In autumn 2020 a total of 12 students from the Ludwig-Maximilian-University in Munich visited the research station at the Jungfraujoch in Switzerland in order to investigate the changes in autonomic nervous activity in the human body taking place when going from normoxic to hypoxic conditions. The aim of these investigations was the examination of a possible relationship between those autonomic changes and the occurrence of acute mountain sickness (AMS) during the three day stay at the Jungfraujoch. Results could then possibly become a useful component in prediction of AMS before an actual stay at high altitude.

A series of parameters reflecting the activity of the autonomous nervous system had already been measured under normoxic, as well as normobaric hypoxic conditions back in Munich. For the latter, an altitude generator producing oxygen-deficient air equivalent to an altitude of 4000m had been used. The parameters measured comprised the heart rate, the arterial blood pressure, the peripheral oxygen saturation as well as the heart rate variability (HRV). Focus was put on the heart rate variability since this parameter has lately not only gained centre stage in research on autonomic nervous activity but has also entered the field of high altitude medicine. Broadly speaking, HRV parameters can be divided in such reflecting parasympathetic activity and such showing activity of the sympathetic branch of the autonomous nervous system. The so called "Total Power" (TP) of HRV mirrors the ANS activity as a whole.

The students were between 22 and 35 years old (three female). All of them felt well upon arrival at the lower terminus of the mountain railway in Grindelwald, Switzerland. During the course of the stay at the research station, however, a total of five should develop AMS, which was diagnosed using the Lake Louise Symptom Score.

Results of AMS were collected every day, HRV measurements were done on day one and two in the evening, blood gas analysis on day one in the evening.

The conducted research resulted in the main finding of a higher adaptability of the autonomous nervous system of those subjects staying healthy during the stay at high altitude. This conclusion was drawn from higher differences between the values measured under normoxic and hypoxic conditions with nearly all of the obtained parameters. Most importantly, all of the four main HRV parameters obtained reflected this observation. The assumption behind these findings is that, in order to adapt to the new and unfamiliar hypoxic conditions, the ANS has to alter all of the parameters above. The greater the change, the greater its ability to help the human body adapt to the new conditions.

Due to the small sample size, no assertion can be made regarding the statistical significance of these results. They do, however, possibly constitute an interesting starting point for further research on the relationship between impaired autonomous nervous activity and the development of AMS. The study is ongoing.

2. Figures

All of the differences below were calculated, subtracting the value measured in normoxia from the value measured under hypobaric hypoxic conditions at the Jungfraujoch.

dTP (ms^2)			AMS-	AMS+
	N	Valid	4	5
		Missing	1	0
	Mean		4824	712
	Minimum		574	-3926
	Maximum		6654	8461

Table 1. Difference of Total Power (TP) of HRV between normoxic and hypobaric hypoxic conditions. Differences are greater among those subjects not developing AMS symptoms during the stay at Jungfraujoch suggesting greater adaptability of the ANS.

dHRV_LF (ms^2)			ABK-	ABK+
	N	Valid	4	5
		Missing	1	0
	Mean		2505	-8,40
	Minimum		177	-2991
	Maximum		*4253*	*5089*

Table 2. Difference of Low Frequency Power (LF-Power) of HRV between normoxic and hypobaric hypoxic conditions. The LF-Power is frequently being used as a parameter reflecting the sympathetic branch of the ANS.

dHRV_HF (ms²)			ABK-	ABK+
	N	Valid	4	5
		Missing	1	0
	Mean		1967	640
	Minimum		512	-541
	Maximum		2963	2194

Table 3. Difference of High Frequency Power (HF-Power) of HRV between normoxic and hypobaric hypoxic conditions. The HF-Power is an indicator of parasympathetic activity. There is greater change in parasympathetic activity within the group of healthy individuals.

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Address

Lungenheilkunde München – Pasing
Gleichmannstr. 5
D-81241 München
Germany

Contacts

Prof. Dr. med. Rainald Fischer
Tel.: +49 89 876443
e-mail: rainald.fischer@gmail.com

Trigonometric altitude determination

Patrick Reimann[1]

[1] Amt für Geoinformation BL, Liestal, Switzerland

patrick.reimann@bl.ch

Part of this programme: swisstopo, ETH Zürich

Keywords: altitude calculation and error theory; long distances; refraction; curvature of the earth; gravitational field and -anomaly; context to altitude determination Mount Everest

1. Introduction

The rapport from 2019 covered the theory of trigonometric altitude determination in detail – as well as the fact that George Everest in 1852 determined the altitude of Mount Everest, later named after him, from a distance of 200 km as 8840 m - the value valid today is 8848 m!

According to several press reports in Nov 20, China and Nepal started a project between 2018 and 2019 to re-determine the altitude of Mt. Everest. Both teams were on the summit independently and measured elevation angles to surrounding points known by GPS coordinates. In order to do justice to the geoid (see chapter 2), gravity measurements were also taken there. The new altitude of Mt. Everest thus determined by mutual agreement is 8848.86 m above sea level. With this new scientific result, admiration for the 19th century work of George Everest increases.

George Everest may have read off the decimal places of the elevation angles in a vernier scale, as is necessary for this research work on the Kern repetition theodolite, which was involved in 1909.

Figure 1. Altitude determination Mönch with Kern 1909.

The reading of the elevation angle is done laterally with the additional difficulty of reading the second and third decimal places with a 20-nonius (Figures 2 and 3).

Figure 2. Altitude reading analogous to the procedure of George Everest.

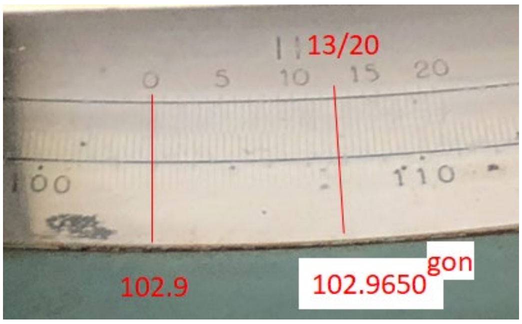

Figure 3. Altitude reading 102.9 + 13/20 = 102.9650 gon.

The vernier scale was introduced in 1631 by the French mathematician Pierre Vernier (1580-1637) and used in historical measuring instruments. With it, the angle sought could be indicated more precisely than the human eye could recognize.

2. Systematic deviations

Geoid and gravity field

The geoid is a selected equipotential surface of the Earth's gravitational field and serves as a reference surface for altitude determination. It can be thought of as an idealised mean sea surface that continues under the continents [1].

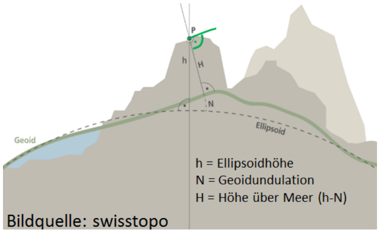

Figure 4. Influence of the geoid on the horizon of the instruments and on the effective altitude above sea level; not shown to scale.

The current geoid model of Switzerland (CHGeo2004) was determined from a combination of astro-geodetic and gravimetric methods and has an accuracy of 1-3 cm over the whole of Switzerland.

The difference to the ellipsoid is called geoidundulation. The lowest value in Switzerland is -4 m in the southern Ticino, the highest value + 4 m in the Engadine.

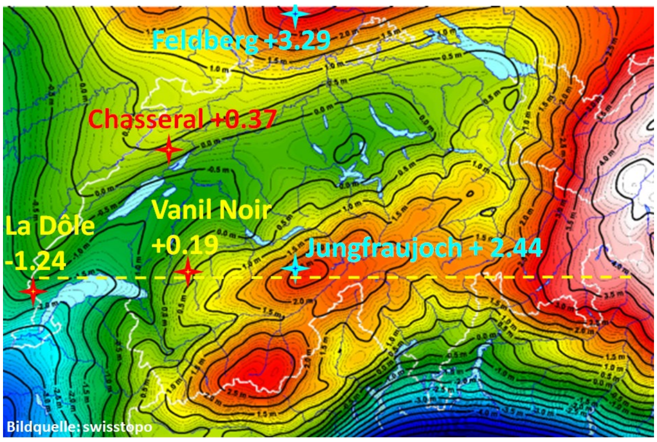

Figure 5. Swiss geoid model (CHGeo2004).

However, the look through the telescope does not take into account the course of the geoidundulation. Thus, the altitude calculation for La Dôle, for example, must be reduced by 3.68 m (Figures 9 and 10).

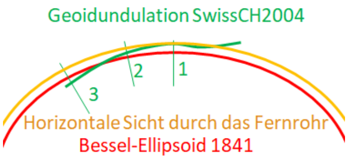

Figure 6. Geoidundulation 1 Jungfraujoch (+2.44), 2 Vanil Noir (+0.19), 3 La Dôle (-1.24).

The connection between the geoidundulation and the perpendicular deviation is not yet clarified, namely whether further systematic reductions have to be applied to the calculated altitude for this reason.

Temperature and refraction

As already shown, the refraction is dependent on the temperature. At low temperatures, a constant refraction value (0.13) should result in higher target altitudes than at higher temperatures. In other words, with two measurements and identical good visibility conditions but different temperatures, the observer receives differently calculated altitudes.

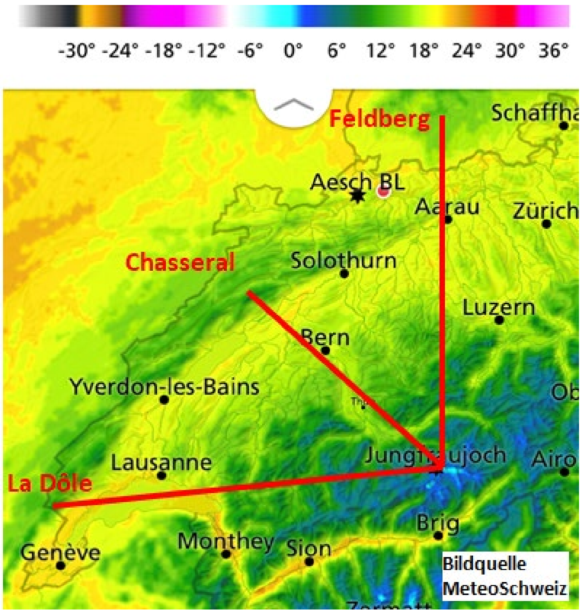

Figure 7. Temperature animation on 26 May 2020 at 1pm.

Whether and how the change in elevation angle is related to the temperature gradient along the sighting will have to be investigated in another context.

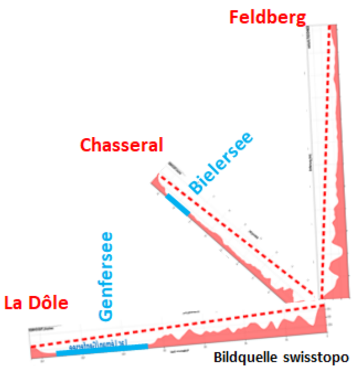

Figure 8. Longitudinal profiles of remote destinations.

Also of interest is whether the size of the clear height below the views plays a role in the refraction and whether lake surfaces reduce or increase the sensitivity of the refraction.

[1]https://www.swisstopo.admin.ch/ ⇨ knowledge and facts ⇨Surveying / Geodesy ⇨ Geoid

3. Measurement program 2020

The 2020 measurements focused primarily on points known by coordinates at far, medium and near distances (Figures 4-6).

The majority of these are triangulation points with a known altitude – or buildings, masts or other features that are directly next to them and are also clearly visible from a distance.

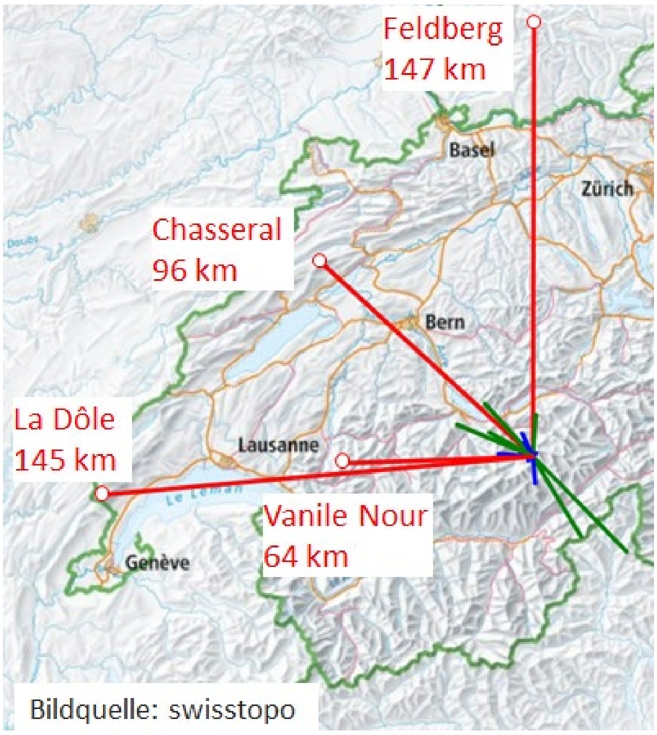

Figure 9. Far distances.

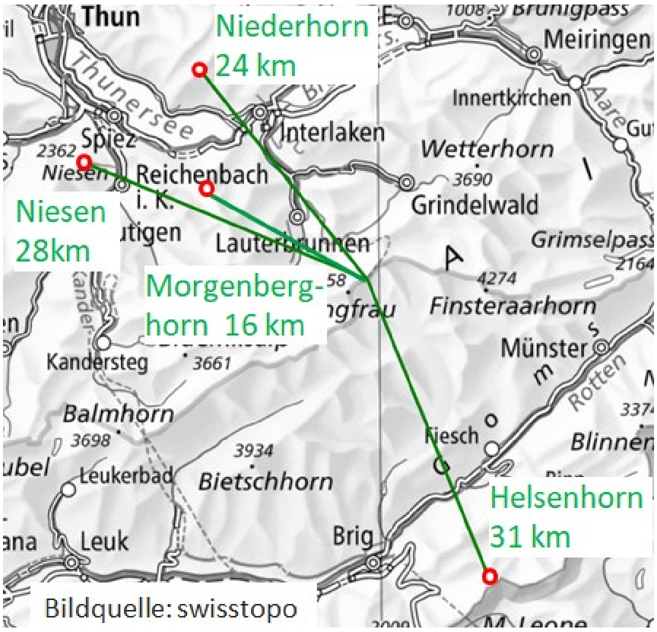

Figure 10. Medium distances.

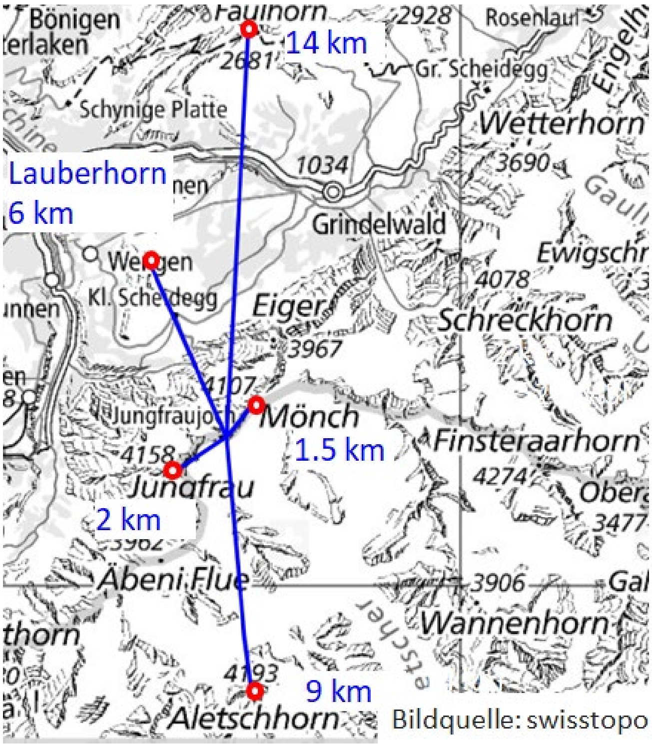

Figure 11. Near distances.

For the Helsenhorn, Mönch, Jungfrau and Aletschhorn, the measured altitudes are compared with the values from the national map.

To confirm the systematic dependence of the refraction on the temperature, the temperature at the site is also recorded for each measurement in addition to the elevation angle.

4. Results 2020

The evaluations of the selected target locations uniformly concern the results from the measurements with the most advanced instrument Leica 1100. However, they are confirmed in a first approximation with samples with the older instruments Wild T2 (1952) and Kern (1909).

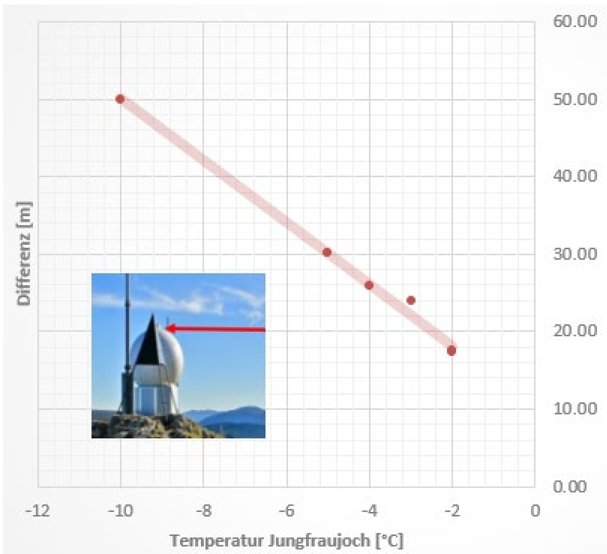

Figure 12. La Dôle, average difference 27 m.

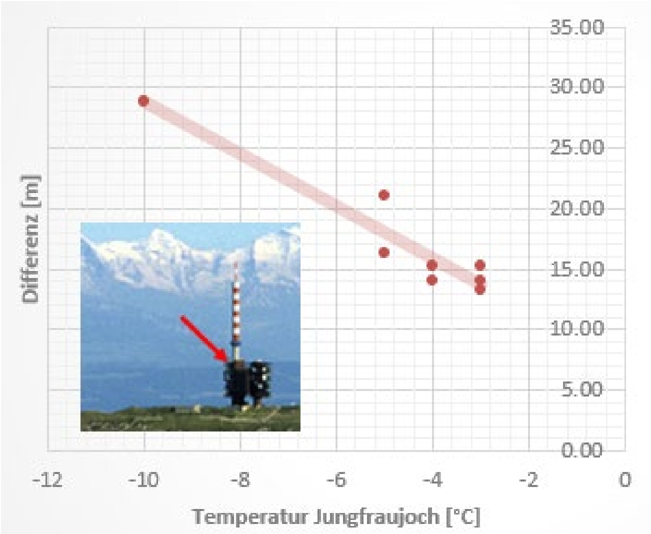

Figure 13. Chasseral, average difference 15 m.

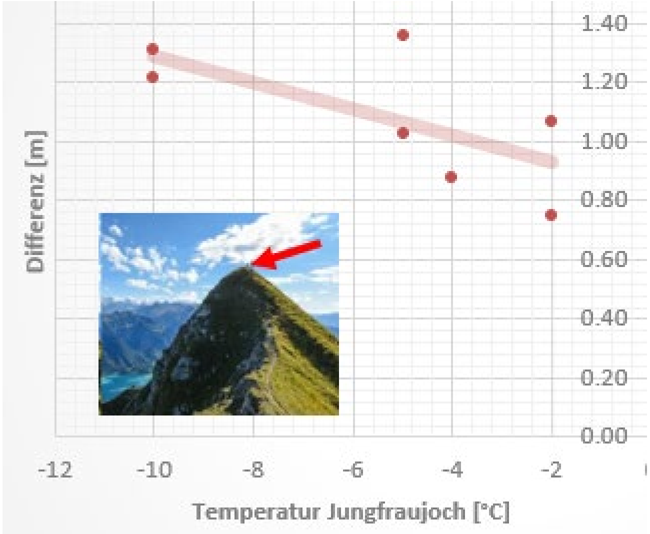

Figure 16. Morgenberghorn, average difference 1.1 m.

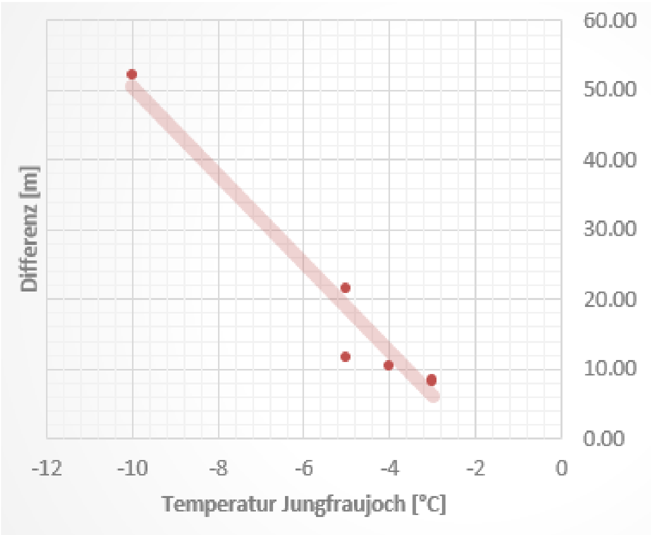

Figure 14. Feldberg, average difference 21 m.

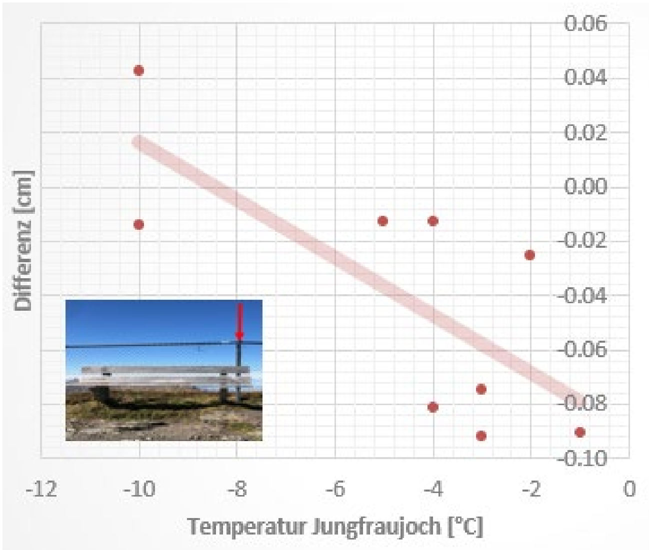

Figure 17. Lauberhorn, average difference -4cm.

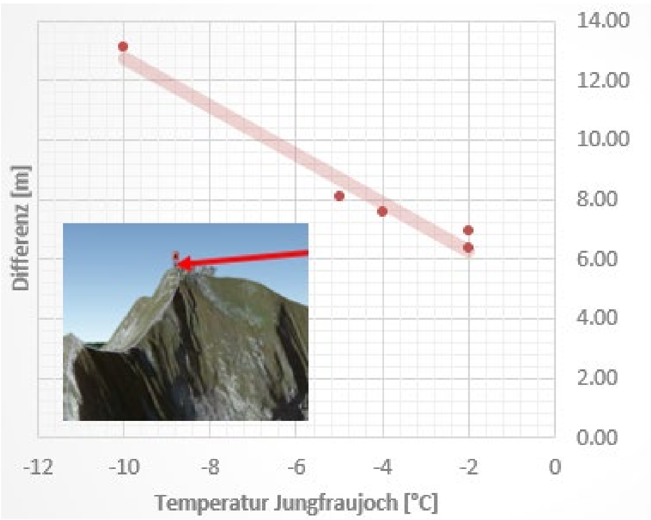

Figure 15. Vanil Noir, average difference 8 m.

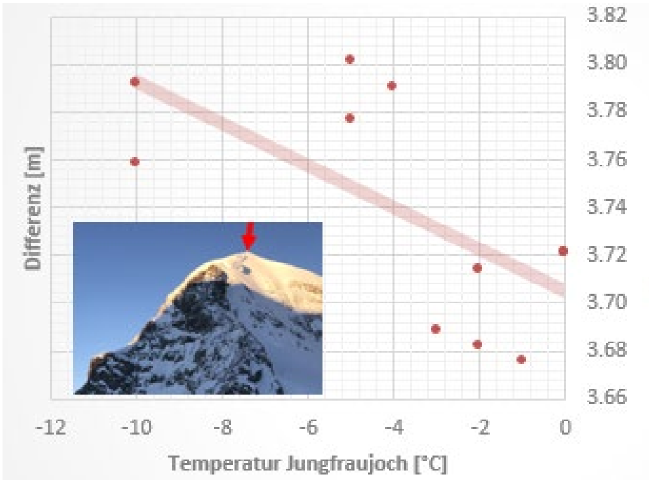

Figure 18. Mönch, average difference 3.7m.

5. Assessment

According to these calculations, the comprehensive measurements from 2020 confirm a linear dependence between the refraction with the temperature at the site as told the theory.

The variance of the individual evaluations results from different visibilities and possibly also from the observer's form of day.

However, it may be noted that these results may be considered representative for the study of refraction.

The averaged values of the differences are considerable at the current stage of this project, especially when considering the longest view to La Dôle (145 km, 27m). This is also due to the fact that the exact altitude of the target is known.

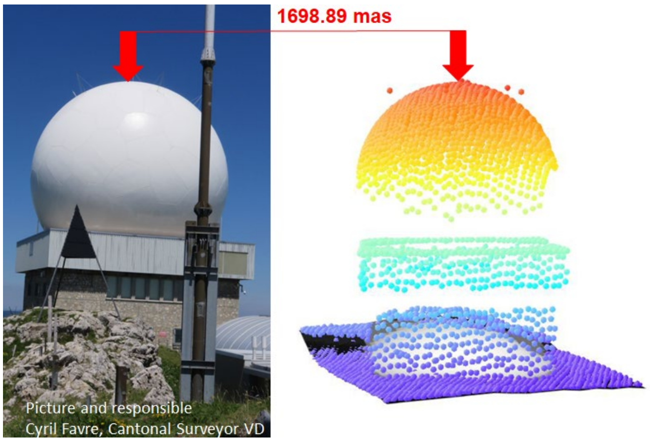

Figure 19. Absolute altitude of La Dôle building from LiDAR data.

The small average difference to the Lauberhorn (6 km, -0.04m) is interesting, although it is close enough to expect such good results.

Even closer than Lauberhorn is Mönch, a four-thousand-metre peak in the Bernese Alps. The average difference of 3.70 metres compared to the national map draws attention. The observer represents his repeatedly determined altitude and swisstopo has already conceded. There will be something to report next year.

Overall, the mean differences cannot yet be summarised in a uniform error theory. The measures in chapter 6 could make this possible.

6. Outlook

Stephen W. Hawking wrote in his book "A Brief History of Time": 'A theory is good if it fulfils two conditions: It must contain **a large number of observations** and thus describe the basis of a model that contains **only a few arbitrary elements**'.

The results from chapter 4 are remarkable, but for a scientific evaluation, a much higher number of measurements under meteorologically clear conditions is necessary. Regarding refraction, studies at ETH Zurich have shown that the absolute temperature at the site does allow statements to be made about the effect of altitude determination. The investigation becomes more accurate if the temperature gradients are recorded over the first 3 meters from the viewpoint.

Finally, the possibility of systematic perpendicular deviation of the site should be investigated. The ETH Zurich and the Federal Office of Topography swisstopo have documents on the Jungfraujoch that should be included in the study.

Furthermore, the results of the altitude difference are of interest if measurements are taken simultaneously on the Jungfraujoch and at one of the target locations. Simultaneous reciprocal measurements mathematically and thus theoretically resolve the influence of refraction.

To be continued.

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Internet data bases

https://www.swisstopo.admin.ch/ ⇨ knowledge and facts ⇨ Surveying / Geodesy ⇨ FAQ ⇨ terrestrial curvature

Collaborating partners / networks

Prof. Dr. Andreas Wieser; Departement Bau, Umwelt und Geomatik, Institut für Geodäsie und Photogrammetrie, ETH Zürich
Dr. Urs Marti, Bundesamt für Landestopografie swisstopo
Julia Wunsch, Assistenz und Photographie
Cyril Favre, Kantonsgeometer VD
Johannes Gerber, Flotron AG, 3860 Meiringen
Ruedi Käser, Vermessungsingenieur HTL und Betriebsleiter HFSJG
Karl Heinz Münch, Studiensammlung Kern AG

Address

Amt für Geoinformation BL
Mühlemattstrasse 36
CH-4410 Liestal
Switzerland

Contacts

Patrick Reimann, Eidg. Pat. Ing.-Geometer
Tel.: +41 61 552 5685
e-mail: patrick.reimann@bl.ch

Research statistics for 2020

High Altitude Research Station Gornergrat

Foundation HFSJG

Institute	Country	Person-working days
High Altitude Research Station Gornergrat	Switzerland	**1**

University of Bern / University of Geneva /

Hochschule für Technik und Architektur Fribourg

Institute	Country	Person-working days
Centre for Space and Habitability, University of Bern	Switzerland	**46**

Stellarium Gornergrat

Timm-Emanuel Riesen[1], Stéphane Gschwind[2], Andreas Müller[2], Simon Ruffieux[3], Jesse Weder[1], Jonas Frey[1], Peter Schlatter[1], Sascha Hohmann[5], Thomas Schildknecht[4], Kevin Heng[1]

[1] University of Bern, Center for Space & Habitability (CSH), Bern, Switzerland
[2] University of Geneva, Geneva, Switzerland
[3] Haute école d'ingénierie et d'architecture Fribourg, Fribourg, Switzerland
[4] University of Bern, Astronomical Institute (AIUB), Bern, Switzerland
[5] Leibniz Institute for Science and Mathematics Education (IPN), Didaktik der Physik, Kiel, Germany

timm.riesen@csh.unibe.ch

Keywords: outreach; robotic telescope; astronomy; space; school; education; pedagogical activity; gornergrat; stellarium

1. Project description

The Stellarium Gornergrat is a long-term project carried out by an on-going collaboration between the Center for Space and Habitability (CSH), the Astronomical Institute (AIUB), the University of Geneva (UoG), and the International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat (HFSJG). Its major focus lies with public outreach and education. The project's main goals are:

- To build bridges between science and society.
- To spark and foster the public's interest in space, space sciences, and astronomy.
- Attract young people to the field and illustrate potential careers in astronomy and space sciences.
- Help people recognize and understand different observable phenomena in the day and night sky and let them appreciate the beauty and delicacy of nature.

To achieve these goals, the partners installed and operate an observatory at the Kulmhotel Gornergrat with different instruments and hardware (see Figure 1). The instrumentation in the south dome has to survive challenging meteorological conditions and is under constant maintenance. Our instrument park currently consists of these 5 different instruments:

1. The Allsky Camera (OMEA 8M) takes around the clock exposures of the day and night sky. This instrument replaces the previous Allsky Camera that was destroyed in the lightning incident. The camera is currently being commissioned in Bern.

2. The RiFast 600mm telescope with a huge Field of View (FOV) is ideal for deep sky objects.

3. The Planet Camera (Takahashi Mewlon-250) is ideal for planetary objects and small targets that require a smaller FOV.

4. The Constellation Camera is ideal to depict complete constellations, asterisms, and group of constellations. It has a customized housing that was developed and built in Bern.

5. The Look-through Telescope (Takahashi TAO-150) for local guests and guided tours at the observatory.

A major way to use the Stellarium Gornergrat is by scheduling observations remotely through a web portal that triggers robotic observing. Teachers, students, and the broad public can browse and pick among different astronomical activities and schedule observations. The Stellarium automatically works through the different scheduled observations and allows a registered user to access the obtained data or status information upon completion of an observation task.

Figure 1. The intermediate spiral galaxy NGC 2403 (Caldwell 7) in filters L, R, G, B with an exposure time of 240s per filter obtained with the Stellarium Gornergrat RiFast 600mm. Distance of the galaxy is roughly 2.5Mpc (8 million light-years) and its diameter roughly 50'000 light-years. Image: Niklaus J. Imfeld.

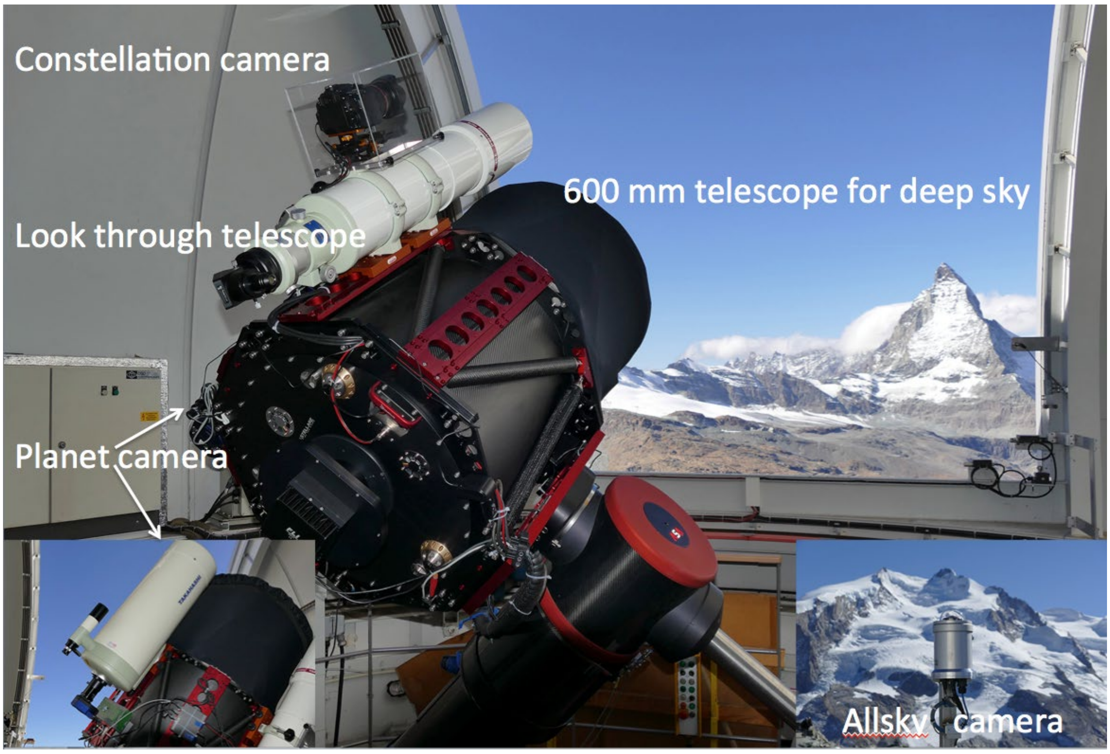

Figure 2. Available instruments at the Stellarium Gornergrat: On the ASA DDM 160 mount (with absolute encoders) inside the south dome are the Officina Stellare RiFast 600mm "Deep sky telescope", the Canon 60Da "Constellation camera", the Takahashi TAO-150 "Look-through telescope", and the Takahashi Mewlon-250 "Planet Camera"(see image inset in the lower left). Mounted on a boom outside the north dome is the Alcor systems "Allsky camera" with a DMK51AG02.AS CCD sensor (see image inset in the lower right).

2. Status of hardware and instruments

Table 1. Instrument/hardware status and performance.

Instrument	Status / Performance
Officina Stellare RiFast 60cm (DeepSky telescope)	The telescope performs very well and shows constant quality over the whole range of instrument attitude in both equatorial orientations. Mirror cleaning is scheduled for 2021.
FLI Proline PL16803 (Main CCD detector)	The on-spec performance of the CCD is unchanged in 2020.
Takahashi Mewlon 250 (Planet camera)	The instrument proves to be difficult for the end user. We are planning steps to mitigate that and/or to redesign the portal use of that telescope.
Takahashi TOA 150 (Looking through telescope)	Telescope and eyepieces are in very good condition.
Canon 60Da (Constellation camera)	The camera is in very good condition and working as expected. We are still exploring options to produce images in an easier format, i.e. debayered and compressed.
ALCOR OMEA 8M (Allsky camera)	The instrument was repaired but not yet re-deployed. We have reasons to believe that the electrical grounding of the Kulmhotel is bad and we wait until work to improve this has been done.
SAIA and weather sensors	Cloud and rain sensors, and SAIA itself worked as expected. The Lambrecht weather sensor still awaits repairs (delayed due to Corona).
ASA DDM160 (Equatorial mount)	Overall, the mount performed very well in all seasons and temperatures. The tracking could be better for some telescope attitudes but this is not a serious issue.
EATON USV (Large UPS in the cellar)	Yearly maintenance showed no problems. Performed as expected.
USB hubs, and active repeaters	All electronic components worked as expected.

Table 1 summarizes the instrument status throughout the reporting period. From the engineering point of view, 2020 has been another stable year for the Stellarium project. The main instruments all worked very reliably and we had regular observations almost every usable night. The Allsky-Camera has not been remounted outside the North Tower as we have cause to believe, that the electrical grounding of the Kulmhotel is not very good anymore. In collaboration with the Burgergemeinde Zermatt, we started a process of investigation and exploration of possible improvements, but the crisis with the pandemic left this at a low priority.

3. Milestones & Achievements regarding robotic abilities and software on site

The automated observing procedure requires constant monitoring and generated error reporting output needs to be reviewed regularly. In addition to these recurring tasks, our collaborators in Fribourg also worked on significant improvements summarized below.

Recover from bad weather: In 2019, the automated observing system has been updated to provide the possibility to pause operations after the detection of unsafe weather and resume them on safe weather. This feature has been used per default in 2020 much to our satisfaction. Additional functionalities have been added and constant validation has been kept up after each deployment of a new feature.

New ConstCam management system: The canon 60Da can get into a bad state dependent on loss of communications with other components of the robotic telescope facility. The added system monitors the camera and detects problems and power cycles the ConstCam when needed to ensure stable operations.

Manage Planet Camera Custom Gain Value: In order to improve the user experience of the planet camera, we added customizable settings for the camera gain (was fixed before). The system now reads the desired gain from the observation plan and can dynamically set the gain for the camera accordingly.

Other relevant system updates and developments

- Resuming Automatic operations: Several additional options have been added to facilitate the configuration of the functionality.
- Dynamically opening the dome according to sunset time.
- Dynamically closing the dome before sunrise time.
- Set up additional mail alarms to warn on relay box and/or dome problems.
- Improved management of Scope UNPARK procedure which was sometimes not succeeding correctly.
- Code rewrite of how the system manages plans for the night in order to allow manual start of operations past midnight without losing observations. This situation typically occurs in nights with local events.
- Improvements to regular monitoring of system operations and error reporting.
- Generation of usage statistics for the system.

4. Local events, remote usage and statistical quantities

Due to the crisis with Covid 19, many of the public events and outreach opportunities were cancelled. Local events as the "Dining with the stars" were successful but the last event of the series was cancelled by lockdown. Throughout the year, a good deal of the scheduled guided tours were cancelled because of the pandemic.

Local: In 2020, a total of 606 people (previous year: 776) visited the Stellarium and got a tour of the facility and/or night-time observing on site. Further key numbers: Total days with crew on site: 26 (last year 36). Total nights with crew on site: 23 (last year 32).

Remote: Remote usage slightly decreased from 2964 generated observing plans in year 2019 to 2735 generated observing plans in the current reporting period. This number is taken from the database on the main server in Bern and differs from the number of plans that were treated on the Gornergrat and monitored by the logging system (2146). The difference can be explained by communication interruptions (which triggers resubmission of new plans (for the same object), failing the initial ones) or monitoring failures such as incomplete log files due to an error condition. The following figures and tables show more details of the usage and are taken from the monitoring and logging system on the Gornergrat.

4.1 System

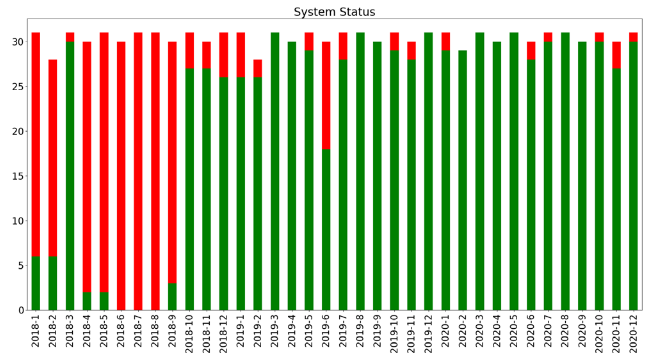

Figure 3. System availability over the last 3 years. Each month is represented with days online (green) and days offline (red). Clearly visible are the problems we had in Q1/18 (mount failure) followed by the lightning incident in Q2/18. In 2019 and 2020, our downtimes were significantly reduced. The majority of offline days in 2020 were due to problems with the internet connection such as interruptions caused by construction work of the Gornergrat railway during Covid closure (i.e. 11/2020).

4.2 Automatic Observations

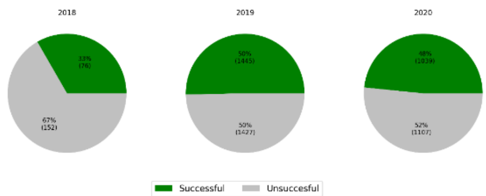

Figure 4. Success vs failure of automatic observations plans. Over the last 2 years, we could improve the success rate to roughly 50% which is what can be expected considering the weather conditions on the Gornergrat. Most reported failures are due to unsafe weather conditions (estimated > 90%) whereas the rest is caused by network interruptions or other problems with hard or software. Users can reschedule an observation that failed, until it is successful.

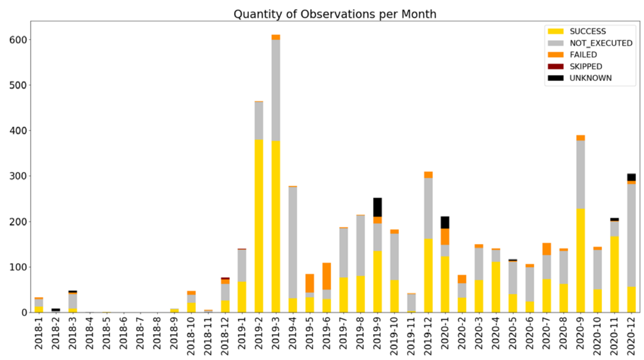

Figure 5. Histograms with observations in days/month over the last 3 years. The final status of the observation is color coded. Yellow: SUCCESS, the observation was successfully performed. Gray: NOT_EXECUTED, the observation could not be executed because of weather conditions or the observatory was used for manual observations. Orange: FAILED, the observation failed because of a problem within the system or because the target was too low. Dark Red: SKIPPED, the observation was skipped because it was behind the scheduled time. Black: UNKNOWN, the information could not be retrieved from monitoring and log files. This can occur in case of a system crash or manual interruption of the automatic procedure (may also occur because of tests performed on the system).

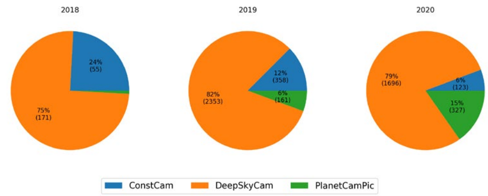

Figure 6. Instrument usage over the last 3 years. While the main telescope (Rifast 600mm / DeepSkyCam) remains clearly the most popular instrument, there has been an increase of more than 100% in the usage of the PlanetCam in 2020.

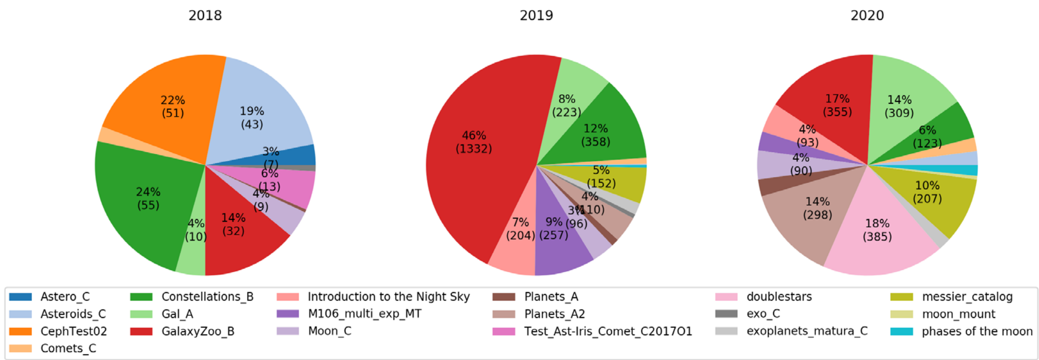

Figure 7. Type of activity requested by portal users over the last 3 years. Activities that were selected less than 3% are omitted in the graphical representation but can be found in Table 2 below.

Table 2. This table lists how often a certain activity was ordered via portal in the last 3 years. Suffixes are used to describe the different target audiences. A: general public adults and children in age range 8-15y. B: Secondary level I, age 13-16y. C: Secondary level I & II, age 16-19y. D: Secondary level II, astronomy courses and special classes, matura theses. Please note that suffixes were introduced at a later time, so not all activities show a correct suffix in their technical name. Also, not every matura thesis has a dedicated activity, many of them sent observing plans by email because of their special interest.

Activity	2018	2019	2020
Asteroids_D	7	1	0
Asteroids_C	43	5	44
CephTest02_D	51	0	0
Comets_C	5	25	43
Constellations_B	55	358	123
Gal_A	10	223	309
GalaxyZoo_B	32	1332	355
Introduction to the Night Sky	0	204	93
M106_multi_exp_MT	0	257	60
Moon_C	9	96	90
Planets_A	1	32	54
Planets_A2	0	110	298
Test_Ast-Iris_Comet_C2017O1_D	13	0	0

Doublestars	0	0	385
exoplanets_C	2	18	0
exoplanets_matura_D	0	49	41
messier_catalog	0	152	207
moon_mount	0	0	11
phases of the moon	0	10	33

4.3 Observing Conditions

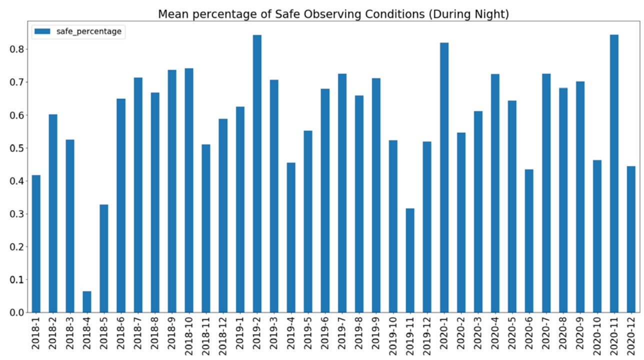

Figure 8. The robotic observatory always evaluates the weather conditions. The software fuses all sensor data and sets a Boolean flag to true when it is safe to observe. The histograms show the average percentage of time per/month when it was safe to observe.

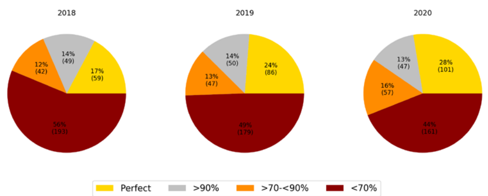

Figure 9. Analysis of night quality over the last 3 years. The indicated percentage describes the proportional amount of time for a given night, for which the fused sensor data indicated that it was safe to observe. Example: In 2020, 44% of all nights had at least bad weather for 30% of the night-time or more.

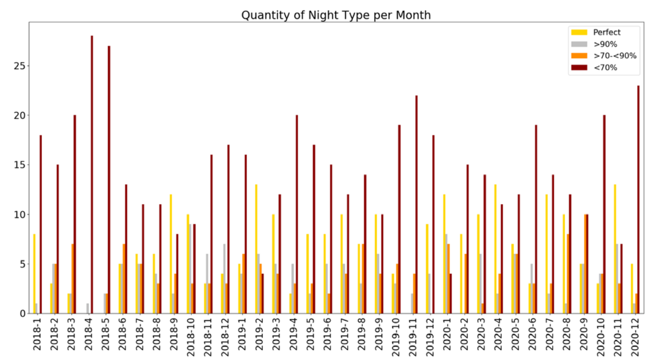

Figure 10. Per month analysis of the night quality as explained in Figure 9.

5. Pedagogical Activities

The Stellarium Gornergrat is aware of at least 8 matura theses, that were supported in 2020 with data, technical council, and in some cases also with topic search or refinement. A new website is being prepared to showcase that work. Especially interesting results were obtained by observing transits of exoplanets for the first time with the Stellarium Gornergrat, see example in Figure 11.

Furthermore, the web portal was improved, and several activities were finished or revised. In the last months, two new activities were uploaded to the web portal and are ready to be booked in German (see Table 3). *Jupiter's Great Red Spot* is basically ready, just a few pictures are missing. The concept of *Exoplanets* is finished, and the analysis of a transit is tested successfully (including instructions for students), but there are some questions about the automation remaining.

Table 3. Developments in 2020.

Name	Level	Status	Comment
Night sky 101	B	Finished	Revised additional documents uploaded
Lunar Mountain Height	C	Finishing working sheets	New version with a revised concept uploaded
The Crab nebula	B / C	Finished	First version uploaded, with available working sheets for levels B and C
Jupiter's Great Red Spot	B / C	Finished*	First version uploaded, with available working sheets for levels B and C
Constellations	A	Finishing documents	Was put on hold, now resumed; still needs a few weeks before upload
Parallax method	C	Finishing documents	Started to collect data
Exoplanets	D	In progress	New activity related to the Nobel Prize 2020. Basis conception is done, remaining work is mostly of technical nature.
Cepheids	C	Basic conception	Can use already available instructions on the portal that explain how to do photometry

* Some images are missing as Jupiter and the great red spot have to be visible and in good weather

Table 4. Presentations and public or organized events, including planned events in 2021.

Name	Type	Place	Date	Activity
DiNAT 11th Forum	Forum of the Swiss Science Education Association	Geneva	23.-24.1.2020	Live commented Powerpoint/Poster
Teacher training GE 2020	Teacher Training	Geneva	4.3.2020	Half-day teacher training
RD Physics	Physics Head-teacher meeting from Geneva	Online	2.6.2020	Talk
Matura thesis presentation	Flyer/emails	Online Collège du Sud, Bulle, Fribourg	8.6.2020	Flyers/emails
Matura thesis presentation	Flyer distribution	Collège Calvin, Geneva	21.9.2020	Flyers
RD Physics	Physics Head-teacher meeting from Geneva	Geisendorf, Geneva	28.09.2020	Talk
DPG-Spring Meeting	Conference of the German Physical Society	Virtual	22.03-24.03.2021	Talk
Teacher training GE 2021	Teacher Training	Geneva	17.03.2021	Half day teacher training
Matura thesis presentation	Flyers, emails, presentations	Secondary Schools, Geneva	After the summer holidays	Flyers, emails, presentations
Nation (GER) wide teacher training in astronomy	Teacher Training	Heidelberg	12.11.2021	Talk with livestream from the Stellarium

Further presentations, teacher professional development courses etc. were planned, but had to be cancelled due to COVID 19 restrictions. These activities will be resumed as soon as the conditions will allow it.

Comment about Matura theses

A physics teacher from the Collège du Sud in Bulle (Fribourg) contacted us because he was interested in proposing a matura thesis with the Stellarium Gornergrat to his students.

Out of a group of over twenty students, six chose to do a matura thesis with the Stellarium Gornergrat after being presented by this opportunity. This is an outstanding number.

Again, we see here the great interest for astronomy by the students.

One could almost say that we are a victim of our own success: Although the students are coached/accompanied by a teacher at their school for the maturity thesis, it also requires a contribution from the members of the Stellarium Gornergrat for the realization of the matura thesis.

It should be noted that teachers who accompany the pupils do not necessarily have the appropriate knowledge of astronomy or are not even persons with a scientific background. As the matura thesis is usually substantial and specific, it is not possible to leave the students by themselves; they must be accompanied. Therefore, it is obvious that members of the Stellarium Gornergrat are and will be called upon at some point to help the student with his or her work.

To reduce our workload, we have started to write small guides (tutorial, How-to's) to help the students with their data analysis. These short guides are not intended to give indications such as: which software to use, which database to use, which specific parameter to pay attention to, ...

Some mini guides are uploaded to the resources section of the stellarium-gornergrat.ch website, others will be made available to students only after contacting us, so we have an additional path to be are aware that someone is starting a matura thesis with data from the Stellarium Gornergrat. They will have access to a shared directory in our Google Drive which contains these guides. In addition, we will also provide in this directory a little more documentation on the chosen subject such as books or scientific articles.

The aim is that the students can be as self-sufficient as possible and to reduce the need to contact us.

Commentary about the teacher training course in Geneva March 2020:

On Wednesday, 4 March, a teacher training course was held at the University of Geneva. We were lucky: two days later, the university closed its buildings due to the COVID 19 lockdown.

Among the teachers registered for this training, we had teachers of all levels: some teach at primary level, others at secondary I and/or II. And among the upper secondary level, there was also a teacher who works in a vocational training school. It may seem surprising at first glance that a teacher from a vocational training school would enrol in such training, as students enrolled in a vocational school do not have physics lessons. But they do have so-called "general culture" courses on their timetable. Of course, an activity in astronomy perfectly aligns with the spirit of these "general knowledge" courses. It is good to see that the Stellarium Gornergrat is not only meant to be used as part of a physics or astronomy course.

Once again, we see there is interest and demand for astronomy in schools. This is even more remarkable since the teacher in question has no scientific background; in addition to teaching "general knowledge", he teaches accounting and marketing. This teacher training course went well, and the participants showed a high level of satisfaction. We had the opportunity to discuss, exchange and get their valuable (and very detailed) feedback (more than a full afternoon online meeting session for one of them).

After the training session, we had multiple contacts with two participants. These two teachers (including the "general knowledge" teacher) contacted us because they wanted to start an astronomy activity with their students during the COVID online school phase.

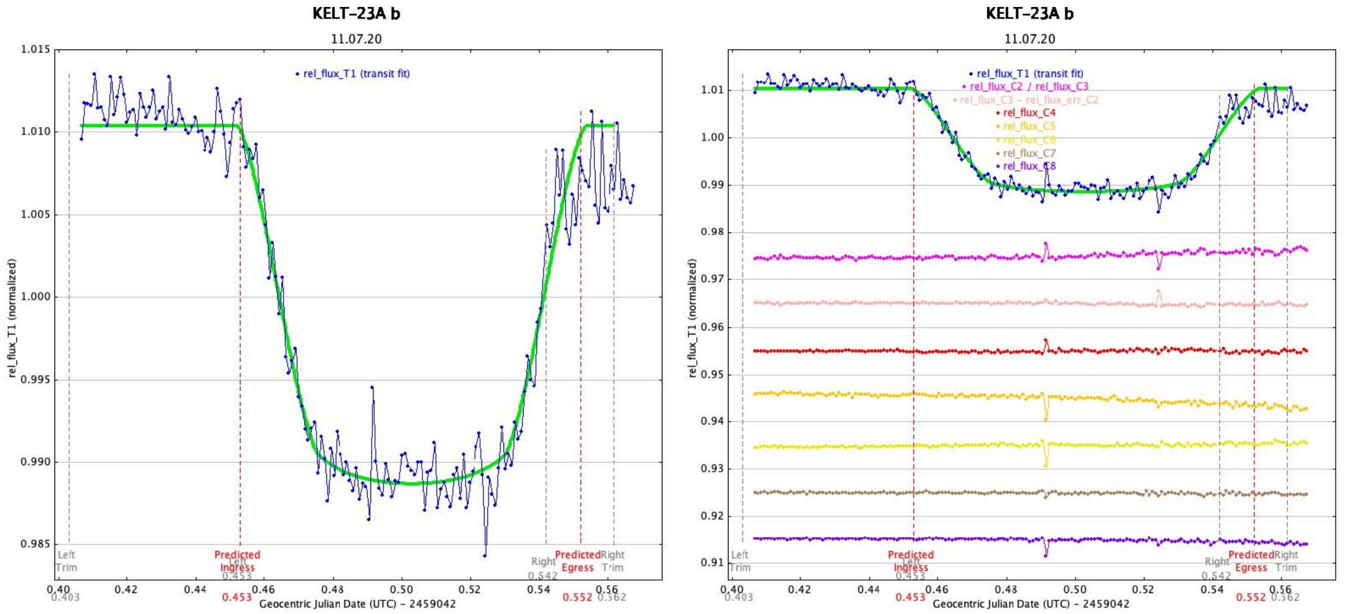

Figure 11. Left panel: Light curve of KELT-23A b during transit on 11.07.2020 with estimated ingress and egress. Right panel: Light curve of KELT-23A b during transit on 11.07.2020 together with light curves from comparison stars. Data was obtained using the Stellarium Gornergrat DeepSky telescope (RiFast 600mm). Data has been reduced and analysed as part of a matura thesis with the title "KELT-23A b – Nachweis eines Exoplaneten mithilfe der Transitmethode" by Panni Widor, Gymnsasium Münchenstein (BL), Schweiz.

Planned talks and workshops 2021

Several talks or trainings are planned in 2021 to increase the reach of the Stellarium Gornergrat, given on scientific conferences and teacher trainings (see Table 4).

Collaborations

We were approached by the Department of Public Education of the Canton of Geneva for collaboration. The aim would be to integrate the Stellarium Gornergrat into one or more activities within the curriculum of a new course in applied sciences which is currently being set up in the canton of Geneva. This means that the Stellarium Gornergrat will be integrated as part of an "official/mandatory" activity of the new applied sciences course in Geneva, a highly welcome development for the project.

After S. Hohmann left to the Institute for Sciences Education (IPN), a new collaboration is discussed (astronomy research & development for the Stellarium, funding proposal).

Internet data bases

http://www.stellarium-gornergrat.ch
http://lists.stellarium-gornergrat.ch

Scientific publications and public outreach 2020

Refereed journal articles and their internet access

Ekström, S., J. Frey, S. Gschwind, S. Hohmann, A. Müller, T. Riesen, S. Ruffieux, P. Schlatter, "Stellarium Gornergrat – A Swiss Robotic Observatory for Education and Citizen Science", in press in: *Communications of the Swiss Physical Society*, no. 63.

Gschwind, S., S. Hohmann, A. Müller, T. Riesen, "Das Stellarium Gornergrat: Ein ferngesteuertes Observatorium für Bildungszwecke", accepted for publication in: *Astronomie & Raumfahrt* (leading journal for astronomy amateurs and education in German).

Magazine and Newspaper articles

"Blick aufs Horu und himmelwärts", Coopzeitung #35, August 25, 2020. https://epaper.coopzeitung.ch/aviator/aviator.php?newspaper=CZ&issue=20200825&edition=CZ23&globalnumber=202035&startpage=10&displaypages=2

Address

Stellarium Gornergrat
University of Bern, Center for Space and Habitability (CSH)
CH-3012 Bern
Switzerland

Contacts

Dr. Timm-Emanuel Riesen
Tel.: +41 31 631 3318
e-mail: timm.riesen@csh.unibe.ch

The International Foundation HFSJG in the News

8 Print media
1 Radio
2 Television
7 Internet

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Publication list

26 Refereed publications
2 Bachelor (), Master (2) and PhD () theses
38 Conference presentations / posters
1 Books / edited books
1 Popular publications and presentations
10 Data books and reports

Refereed publications

Bernet, L., E. Brockmann, T. von Clarmann, N. Kämpfer, E. Mahieu, C. Mazler, G. Stober, K. Hocke, Trends of atmospheric water vapour in Switzerland from ground-based radiometry, FTIR and GNSS data, Atmos. Chem. Phys., **20**, 19, 11223-11244, doi: 10.5194/acp-20-11223-2020, 2020. https://acp.copernicus.org/articles/20/11223/2020/acp-20-11223-2020.pdf

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Morard, S., Re-analysis of ice deformation measurements in cold firn on Jungfraujoch, MSc Thesis, University of Zurich, 2020.

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Bigi, A., M. Collaud Coen, E. Andrews, C. Rose, C. Lund Myhre, M. Fiebig, M. Schulz, J.A. Ogren, J. Gliss, A. Mortier, A. Wiedensohler, M. Pandolfi, T. Petäja, S.-W. Kim, W. Aas, J.-P. Putaud, O. Mayol-Bracero, M. Keywood, L. Labrador, P. Laj, Global variability of aerosol optical properties retrieved from the network of GAW near-surface observatories, EGU 2020, Vienna, Austria, held on-line, May 3-8, 2020.

Brem, B., G. Wehrle, M. Gysel-Beer, Climate relevant optical and microphysical properties of wildfire particulate matter in the free troposphere, 5th VAO Symposium, Bern, Switzerland, February 4-6, 2020.

Brem, B., N. Bukowiecki, G. Wehrle, M. Collaud Coen, M. Steinbacher, S. Henne, U. Baltensperger, M. Gysel-Beer, Optical and microphysical properties of aged wildfire aerosol plumes detected at the Jungfraujoch, European Aerosol Conference - EAC 2020, Aachen, Germany, held on-line, August 31 – September 4, 2020.

Brunner, C. and Z. A. Kanji, A new instrument for continuous monitoring of ice nucleating particles, 5th Virtual Alpine Observatory Symposium, Bern, Switzerland, February 4-6, 2020.

Brunner, C. and Z. A. Kanji, A new instrument for continuous monitoring of ice nucleating particles, European Aerosol Conference, Aachen, Germany, August 31 – September 4, 2020 (virtual conference due to CoViD-19).

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Bütikofer, R., Why Cosmic Ray Monitoring at High Altitude?, 5th VAO Symposium, Bern, Switzerland, February 4-6, 2020.

Bukowiecki, N., B. Brem, M. Hervo, M. Collaud Coen, S. Affolter, G. Wehrle, M. Leuenberger, U. Baltensperger, M. Gysel, Small-scale spatial variability of aerosol parameters around Jungfraujoch, Switzerland (3580 m asl). Parallel aerosol measurements at an adjacent mountain ridge, 5th VAO Symposium, Bern, Switzerland, February 4-6, 2020.

Collaud Coen, M., A. Andrews, B. Brem, H. Flentje, K. Sellegri, A. Marinoni, C. Couret, T. Arsov, Multidecadal trend analysis of aerosol properties at a global scale: characteristic of high altitude stations, 5th VAO Symposium, Bern, Switzerland, February 4-6, 2020.

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Collaborations and networks

Institutions collaborating with research projects at Jungfraujoch and Gornergrat in 2020

Institution / network	Country	Collaborating with project:
Australian Nuclear Science and Technology Organisation (ANSTO) Dr. Alastair Williams, Dr. Alan Griffiths, Dr. Scott Chambers Sydney Australia	Australia	Separating ‘free tropospheric conditions’ from those ‘influenced by the planetary boundary’ Department of Environmental Sciences University of Basel Bernoullistrasse 30 CH-4056 Basel
CSIRO Oceans and Atmosphere	Australia	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Belgian Institute for Space Aeronomy Brussels	Belgium	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
BIRA-IASB Royal Belgian Institute of Space Aeronomy Dr. M. De Mazière Dr. S. Chabrillat and teams Ukkel Belgium	Belgium	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth’s atmosphere Université de Liège Institut d’Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
Université Libre de Bruxelles Prof. P. Coheur	Belgium	Atmospheric composition monitoring at ISSJ Royal Belgian Institute for Space Aeronomy (BIRA-IASB) Ringlaan 3 B-1180 Brussels Belgium
Université de Liège Institut d’Astrophysique et de Géophysique Dr. E. Mahieu	Belgium	Atmospheric composition monitoring at ISSJ Royal Belgian Institute for Space Aeronomy (BIRA-IASB) Ringlaan 3 B-1180 Brussels Belgium
Université de Liège Institut d’Astrophysique et de Géophysique B-4000 Sart Tilman (Liège)	Belgium	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Université de Liège Institut d’Astrophysique et de Géophysique B-4000 Sart Tilman (Liège)	Belgium	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Université Libre de Bruxelles (ULB) Dr. B. Franco Bruxelles Belgium	Belgium	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth’s atmosphere Université de Liège Institut d’Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
Department of Earth Sciences Memorial University of Newfoundland Dr. Michael G. Babechuk St. John’s, Canada	Canada	Evaluating the contribution of Marine Aerosols to the Mo Surface Water Cycle Universität Bern Institut für Geologie Baltzerstrasse 1 + 3 CH-3012 Bern
ACTRIS (Aerosol, Clouds and Trace Gases Research Network)	European network	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution / Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
ACTRIS (Aerosol, Clouds and Trace Gases Research Network)	European network	Quality assurance and quality control of CO2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf

Institution / network	Country	Collaborating with project:
ACTRIS (Aerosol, Clouds and Trace Gases Research Network)	European network	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
ACTRIS (Aerosol, Clouds and Trace Gases Research Network)	European network	Atmospheric composition monitoring at ISSJ Royal Belgian Institute for Space Aeronomy (BIRA-IASB) Ringlaan 3 B-1180 Brussels Belgium
ACTRIS (Aerosol, Clouds and Trace Gases Research Network)	European network	Long-term study of aerosol particle formation in the free troposphere University of Helsinki Institute for Atmospheric and Earth System Research Gustaf Hällströmin katu 2a FI-00560 Helsinki Finland
Collaboration with KNMI and S&T for the CAMS and S5P MPC Validation Server	European network	Atmospheric composition monitoring at ISSJ Royal Belgian Institute for Space Aeronomy (BIRA-IASB) Ringlaan 3 B-1180 Brussels Belgium
Collaboration with CNR (Italy) and ECMWF for the delivery of NDACC data to the C3S	European network	Atmospheric composition monitoring at ISSJ Royal Belgian Institute for Space Aeronomy (BIRA-IASB) Ringlaan 3 B-1180 Brussels Belgium
E-GVAP II (EUMETNET GPS Water Vapour Programme)	European network	Automated GNSS Network Switzerland (AGNES) Swiss Federal Office of Topography swisstopo Seftigenstrasse 264 CH-3084 Wabern
EMEP (European Monitoring and Evaluation Programme)	European network	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
EMEP (European Monitoring and Evaluation Programme)	European network	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
European FP7 Project Real-Time Database for High Resolution Neutron Monitor Measurements (NMDB) http://www.nmdb.eu	European network	Neutron monitors - Study of solar and galactic cosmic rays Universität Bern Physikalisches Institut Sidlerstrasse 5 CH-3012 Bern
GAW-CH	European network	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
ICOS Integrated Carbon Observation System ICOS-RI partners and ICOS-CH partners https://www.icos-ri.eu	European network	Long-term observations of $^{14}CO_2$ at Jungfraujoch Universität Bern Physikalisches Institut Klima- und Umweltphysik Sidlerstrasse 5 CH-3012 Bern
ICOS Integrated Carbon Observation System Research Infrastructure http://www.icos-ri.eu	European network	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
ICOS Integrated Carbon Observation System Research Infrastructure http://www.icos-ri.eu	European network	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
ICOS Integrated Carbon Observation System https://www.icos-ri.eu/	European network	Continuous measurement of stable CO2 isotopes at Jungfraujoch, Switzerland Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf

Institution / network	Country	Collaborating with project:
ICOS Integrated Carbon Observation System https://www.icos-ri.eu/	European network	Separating 'free tropospheric conditions' from those 'influenced by the planetary boundary' Department of Environmental Sciences University of Basel Bernoullistrasse 30 CH-4056 Basel
ICOS Integrated Carbon Observation System ICOS-RI partners and ICOS-CH partners https://www.icos-ri.eu/	European network	Flask comparison on Jungfraujoch Max Planck Institut für Biogeochemie Hans Knöll Str. 10 D-007745 Jena
ICOS Integrated Carbon Observation System partners https://www.icos-ri.eu/	European network	High precision carbon dioxide and oxygen measurements at Jungfraujoch Universität Bern Physikalisches Institut Klima- und Umweltphysik Sidlerstrasse 5 CH-3012 Bern
ICOS-ICOS Flask and Calibration Laboratory	European network	High precision carbon dioxide and oxygen measurements at Jungfraujoch Universität Bern Physikalisches Institut Klima- und Umweltphysik Sidlerstrasse 5 CH-3012 Bern
IG3IS (Integrated Global Greenhouse Gas Information System)	European network	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
RINGO (Readiness of ICOS for Necessities of integrated Global Observations)	European network	Continuous measurement of stable CO_2 isotopes at Jungfraujoch, Switzerland Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
RINGO (Readiness of ICOS for Necessities of integrated Global Observations)	European network	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
University of Helsinki Department of Physics Prof. M. Kulmala, Prof. F. Bianchi Helsinki, Finland	Finland	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen Switzerland
LATMOS Guyancourt, France Dr. A. Pazmino	France	Atmospheric composition monitoring at ISSJ Royal Belgian Institute for Space Aeronomy (BIRA-IASB) Ringlaan 3 B-1180 Brussels Belgium
Université de Strasbourg, CNRS Laboratoire d'Hydrologie et Géochimie de Strasbourg, EOST Prof. Marie-Claire Pierret-Neboit Strasbourg, France	France	Evaluating the contribution of Marine Aerosols to the Mo Surface Water Cycle Universität Bern Institut für Geologie Baltzerstrasse 1 + 3 CH-3012 Bern
ECAC and TROPOS Prof. A. Wiedensohler Dr. T. Müller Dr. S. Henning Leipzig, Germany	Germany	The Global Atmosphere Watch Aerosol Program at the Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen Switzerland
Extraterrestrial Physics Department of the Institute for Experimental and Applied Physics Christian-Albrechts University of Kiel Robert Wimmer-Schweingruber, Bernd Heber, Christian Steigies, Stephan Böttcher	Germany	Neutron monitors - Study of solar and galactic cosmic rays Universität Bern Physikalisches Institut Sidlerstrasse 5 CH-3012 Bern
Heidelberg University Institute of Environmental Physics Dr. S. Hammer	Germany	Radiocarbon measurements of atmospheric methane Department of Chemistry, Biochemistry and Pharmaceutical Sciences University of Bern Freiestrasse 3 CH-3012 Bern
Helmholtz Zentrum München Neuherberg, Germany Vladimir Mares Thomas Brall Werner Rühm	Germany	Neutron monitors - Study of solar and galactic cosmic rays Universität Bern Physikalisches Institut Sidlerstrasse 5 CH-3012 Bern

Institution / network	Country	Collaborating with project:
Institute of Meteorology and Climate Research IMK Karlsruhe Institute of Technology Dr. T. Blumenstock and team Karlsruhe Germany	Germany	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
Max-Planck Institute for Biogeochemistry Hans Knöll Str. 10 D-007745 Jena Germany	Germany	Continuous measurement of stable CO_2 isotopes at Jungfraujoch, Switzerland Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Max-Planck-Institut für Biogeochemie Dr. Armin Jordan and staff members Jena	Germany	High precision carbon dioxide and oxygen measurements at Jungfraujoch Universität Bern Physikalisches Institut Klima- und Umweltphysik Sidlerstrasse 5 CH-3012 Bern
SFC Energy AG Eugen-Sänger-Ring 7 D-85649 Brunnthal	Germany	Performance of Methanol fuel cells in alpine environments armasuisse Science & Technology Test Centre Feuerwerkerstrasse 39 CH-3602 Thun Switzerland
Technologie Center Felsenkeller (TCF) Jena Germany	Germany	High precision carbon dioxide and oxygen measurements at Jungfraujoch Universität Bern Physikalisches Institut Klima- und Umweltphysik Sidlerstrasse 5 CH-3012 Bern
University of Bremen Dr. J. Notholt M. Palm Bremen Germany	Germany	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
ACE-FTS satellite team	International network	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
AGAGE (Advanced Global Atmospheric Gases Experiment) https://agage.mit.edu/	International network	Halogenated Greenhouse Gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf Switzerland
Both the UV-Vis and FTIR observations contribute to the international Network for the Detection of Atmospheric Composition Changes (NDACC)	International network	Atmospheric composition monitoring at ISSJ Royal Belgian Institute for Space Aeronomy (BIRA-IASB) Ringlaan 3 B-1180 Brussels Belgium
Cooperative Global Atmospheric Data Integration Project; (2019): Multi-laboratory compilation of atmospheric carbon dioxide data for the period 1957-2018; obspack_co2_1_GLOBALVIEWplus_v5.0_2019_08_12; NOAA Earth System Research Laboratory, Global Monitoring Division http://dx.doi.org/10.25925/20190812.	International network	High precision carbon dioxide and oxygen measurements at Jungfraujoch Universität Bern Physikalisches Institut Klima- und Umweltphysik Sidlerstrasse 5 CH-3012 Bern
Global Atmosphere Watch (GAW)	International network	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Global Atmosphere Watch (GAW)	International network	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf Switzerland

Institution / network	Country	Collaborating with project:
Global Atmosphere Watch (GAW)	International network	Monitoring of ice cloud forming aerosols at the Jungfraujoch: automation of HINC for continuous INP ETH Zürich Institute for Atmospheric and Climate Science Universitätsstrasse 16 CH-8092 Zürich
Global Atmosphere Watch (GAW)	International network	Aerosol Optical Depth measurements from the GAW-PFR network Physikalisch-Meteorologisches Observatorium Davos PMOD World Radiation Center WRC Dorfstrasse 33 CH-7260 Davos Dorf
Global Atmosphere Watch (GAW)	International network	Continous measurement of stable CO_2 isotopes at Jungfraujoch, Switzerland Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Global Atmosphere Watch (GAW)	International network	High precision carbon dioxide and oxygen measurements at Jungfraujoch Universität Bern Physikalisches Institut Klima- und Umweltphysik Sidlerstrasse 5 CH-3012 Bern
Global Climate Observing System (GCOS)	International networks	Aerosol Optical Depth measurements from the GAW-PFR network Physikalisch-Meteorologisches Observatorium Davos PMOD World Radiation Center WRC Dorfstrasse 33 CH-7260 Davos Dorf
GTN-P (Global Terrestrial Network for Permafrost)	International networks	Long-term permafrost monitoring in the Jungfrau East ridge WSL Institute for Snow and Avalanche Research SLF Flüelastrasse 11 CH-7260 Davos Dorf, Switzerland
Collaboration with the OMI, TROPOMI (S5P), Metop GOME-2 and IASI satellite communities	International networks	Atmospheric composition monitoring at ISSJ Royal Belgian Institute for Space Aeronomy (BIRA-IASB) Ringlaan 3 B-1180 Brussels Belgium
Collaboration with colleagues from the NDACC and TCCON FTIR networks	International networks	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
IG3IS (Integrated Global Greenhouse Gas Information System)	International networks	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
NDACC (Network for the Detection of Atmospheric Composition Change, http://www.ndacc.org)	International network	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
Satellite experiments: IASI (Infrared Atmospheric Sounding Interferometer	International network	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
World Meteorological Organization (WMO)	International network	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
World Meteorological Organization (WMO)	International network	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf

Institution / network	Country	Collaborating with project:
World Meteorological Organization (WMO)	International network	Aerosol Optical Depth measurements from the GAW-PFR network Physikalisch-Meteorologisches Observatorium Davos PMOD World Radiation Center WRC Dorfstrasse 33 CH-7260 Davos Dorf
Korea Polar Research Institute KOPRI	Korea	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
ICOS Carbon Portal Lund University	Sweden	Continuous measurement of stable CO_2 isotopes at Jungfraujoch, Switzerland Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
University of Nova Gorica Centre for Atmospheric Research Grisa Mocnik Ljubljana, Slovenia	Slovenia	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen, Switzerland
Astronomical Institute of the University of Bern (AIUB) Sidlerstrasse 5 CH-3012 Bern	Switzerland	Stellarium Gornergrat Center for Space and Habitability University of Bern Gesellschaftsstrasse 6 CH-3012 Bern
Astronomical Institute of the University of Bern (AIUB) Dr. Rolf Dach Prof. Dr. Adrian Jäggi Sidlerstrasse 5 CH-3012 Bern	Switzerland	Automated GNSS Network Switzerland (AGNES) Swiss Federal Office of Topography swisstopo Seftigenstrasse 264 CH-3084 Wabern
Bundesamt für Landestopografie swisstopo Dr. Urs Marti	Switzerland	Trigonometric height determination Amt für Geoinformation BL Mühlemattstrasse 36 CH-4410 Liestal Switzerland
Bundesamt für Umwelt (BAFU)/ Federal Office for the Environment (FOEN)	Switzerland	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf

Bundesamt für Umwelt (BAFU)/ Federal Office for the Environment (FOEN)	Switzerland	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution/Environmental Technology Ueberlandstrasse 129 CH-8600 Dübendorf
Burgergemeinde Zermatt Bahnhofstrasse 53 CH-3920 Zermatt	Switzerland	Stellarium Gornergrat Center for Space and Habitability University of Bern Gesellschaftsstrasse 6 CH-3012 Bern
Cyril Favre Kantonsgeometer VD	Switzerland	Trigonometric height determination Amt für Geoinformation BL Mühlemattstrasse 36 CH-4410 Liestal Switzerland
Empa Laboratory for Air Pollution/Environmental Technology Ueberlandstrasse 129 CH-8600 Dübendorf	Switzerland	High precision carbon dioxide and oxygen measurements at Jungfraujoch Universität Bern Physikalisches Institut Klima- und Umweltphysik Sidlerstrasse 5 CH-3012 Bern
Empa Laboratory for Air Pollution/Environmental Technology Dr. S. Reimann, Dr. M. Steinbacher, Dr. M.K. Vollmer Überlandstrasse 129 CH-8600 Dübendorf	Switzerland	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
Empa Laboratory for Air Pollution/Environmental Technology Dr. D. Brunner, Dr. S. Henne Überlandstrasse 129 CH-8600 Dübendorf	Switzerland	Radiocarbon measurements of atmospheric methane Department of Chemistry, Biochemistry and Pharmaceutical Sciences University of Bern Freiestrasse 3 CH-3012 Bern
Empa Laboratory for Air Pollution / Environmental Technology Dr. C. Zellweger, Dr. M. Steinbacher, Dr. M. Vollmer, Dr. S. Reimann CH-8600 Dübendorf	Switzerland	Monitoring of ice cloud forming aerosols at the Jungfraujoch: automation of HINC for continuous INP ETH Zürich Institute for Atmospheric and Climate Science Universitätsstrasse 16 CH-8092 Zürich

Institution / network	Country	Collaborating with project:
Empa Laboratory for Air Pollution/Environmental Technology Dr. C. Hüglin, Dr. S. Henne, Dr. S. Reimann, Dr. M. Steinbacher Ueberlandstrasse 129 CH-8600 Dübendorf	Switzerland	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen Switzerland
Empa Laboratory for Air Pollution/Environmental Technology Dr. S. Reimann, Dr. C. Hüglin, Dr. M. Steinbacher, Ms. C. Zellweger-Fäsi, Dr. A. Fischer CH-8600 Dübendorf	Switzerland	Separating 'free tropospheric conditions' from those 'influenced by the planetary boundary' University of Basel Department of Environmental Sciences Bernoullistrasse 30 CH-4056 Basel
Empa Laboratory for Air Pollution/Environmental Technology Dr. S. Reimann, Dr. C. Hüglin, Dr. M. Steinbacher, Ms. C. Zellweger-Fäsi, Dr. A. Fischer CH-8600 Dübendorf	Switzerland	Ice nucleating particles and ice multiplication at moderate supercooling University of Basel Department of Environmental Sciences Bernoullistrasse 30 CH-4056 Basel
ETH Zürich Departement Bau, Umwelt und Geomatik, Institut für Geodäsie und Photogrammetrie Prof. Dr. Andreas Wieser CH-8093 Zürich	Switzerland	Trigonometric height determination Amt für Geoinformation BL Mühlemattstrasse 36 CH-4410 Liestal Switzerland
ETH Zürich Swiss Federal Institute of Technology Institute for Atmospheric and Climate Science Prof. U. Lohmann Prof. T. Peter Universitätstrasse 16 CH-8092 Zürich	Switzerland	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen Switzerland
ETH Zürich Department of Earth Sciences Prof. T. I. Eglinton	Switzerland	Radiocarbon measurements of atmospheric methane Department of Chemistry, Biochemistry and Pharmaceutical Sciences University of Bern Freiestrasse 3 CH-3012 Bern
ETH Zürich Laboratory of Ion Beam Physics Dr. L. Wacker	Switzerland	Radiocarbon measurements of atmospheric methane Department of Chemistry, Biochemistry and Pharmaceutical Sciences University of Bern Freiestrasse 3 CH-3012 Bern
ETH Zürich Swiss Federal Institute of Technology Institute for Atmospheric and Climate Science	Switzerland	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Flotron AG Johannes Gerber CH-3860 Meiringen	Switzerland	Trigonometric height determination Amt für Geoinformation BL Mühlemattstrasse 36 CH-4410 Liestal Switzerland
Haute école d'ingénierie et d'architecture Fribourg Bd de Pérolles 80 CH-1705 Fribourg	Switzerland	Stellarium Gornergrat Center for Space and Habitability University of Bern Gesellschaftsstrasse 6 CH-3012 Bern
Institut für Aerosol- und Sensortechnik, Fachhochschule Nordwestschweiz, Prof. E. Weingartner Windisch	Switzerland	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen Switzerland
Institute of Applied Physics (IAP), University of Berne Dr. Klemens Hocke Dr. Leonie Bernet	Switzerland	Automated GNSS Network Switzerland (AGNES) Swiss Federal Office of Topography swisstopo Seftigenstrasse 264 CH-3084 Wabern
Institute of Geodesy and Photogrammetry ETH Zürich Prof. Alain Geiger, Dr. Karina Wilgan, Dr. Roland Hohensinn, Dr. Endrit Shehaj	Switzerland	Automated GNSS Network Switzerland (AGNES) Swiss Federal Office of Topography swisstopo Seftigenstrasse 264 CH-3084 Wabern
Julia Wunsch https://juliawunsch.ch/	Switzerland	Trigonometric height determination Amt für Geoinformation BL Mühlemattstrasse 36 CH-4410 Liestal Switzerland
3100 Kulmhotel Gornergrat Gornergrat 3100m CH-3920 Zermatt	Switzerland	Stellarium Gornergrat Center for Space and Habitability University of Bern Gesellschaftsstrasse 6 CH-3012 Bern
MeteoSwiss Gilles Durieux Payerne	Switzerland	Aerosol radioactivity monitoring at the Jungfraujoch Bundesamt für Gesundheit Schwarzenburgstrasse 165 CH-3003 Bern

Institution / network	Country	Collaborating with project:
MeteoSwiss	Switzerland	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
MeteoSwiss Dr. L. Vuilleumier Dr. Martine Collaud Payerne	Switzerland	Aerosol Optical Depth measurements from the GAW-PFR network Physikalisch-Meteorologisches Observatorium Davos PMOD World Radiation Center WRC Dorfstrasse 33 CH-7260 Davos Dorf
MeteoSwiss Zurich and Payerne Dr. Philippe Steiner Dr. Daniel Leuenberger Dr. Alexander Haefele Dr. Rolf Rüfenacht	Switzerland	Automated GNSS Network Switzerland (AGNES) Swiss Federal Office of Topography swisstopo Seftigenstrasse 264 CH-3084 Wabern
MeteoSwiss, Payerne Office fédéral de météorologie et de climatologie MétéoSuisse Dr. A. Haefele Dr. J. Klausen Ch. de l'Aérologie 1 CH-1530 Payerne	Switzerland	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen, Switzerland
NABEL (Swiss National Air Pollution Monitoring Network)	Switzerland	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
NABEL (Swiss National Air Pollution Monitoring Network)	Switzerland	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution and Environmental Technology Ueberlandstrasse 129 CH-8600 Dübendorf
Oeschger Centre for Climate Change Research University of Bern Hochschulstrasse 4 CH-3012 Bern	Switzerland	Flask comparison on Jungfraujoch Max Planck Institut für Biogeochemie Hans Knöll Str. 10 D-007745 Jena
Paul Scherrer Institute Laboratory of Atmospheric Chemistry Dr. M. Gysel, Dr. B. Brem CH-5232 Villigen Switzerland	Switzerland	Monitoring of ice cloud forming aerosols at the Jungfraujoch: automation of HINC for continuous INP ETH Zürich Institute for Atmospheric and Climate Science Universitätsstrasse 16 CH-8092 Zürich
Paul Scherrer Institute Laboratory of Atmospheric Chemistry Dr. M. Gysel, CH-5232 Villigen Switzerland	Switzerland	Ice nucleating particles and ice multiplication at moderate supercooling University of Basel Department of Environmental Sciences Bernoullistrasse 30 CH-4056 Basel
Paul Scherrer Institute Laboratory of Atmospheric Chemistry Dr. M. Gysel CH-5232 Villigen Switzerland	Switzerland	Separating 'free tropospheric conditions' from those 'influenced by the planetary boundary' University of Basel Department of Environmental Sciences Bernoullistrasse 30 CH-4056 Basel
Paul Scherrer Institute Laboratory of Atmospheric Chemistry Dr. M. Gysel CH-5232 Villigen Switzerland	Switzerland	Long-term study of aerosol particle formation in the free troposphere University of Helsinki Institute for Atmospheric and Earth System Research Gustaf Hällströmin katu 2a FI-00560 Helsinki Finland
Paul Scherrer Institute Laboratory of Atmospheric Chemistry CH-5232 Villigen Switzerland	Switzerland	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Paul Scherrer Institute Laboratory of Environmental Chemistry Prof. Margit Schwikowski-Gigar CH-5232 Villigen Switzerland	Switzerland	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen Switzerland
PERMOS (Permafrost Monitoring Switzerland) www.permos.ch/	Switzerland	Long-term permafrost monitoring in the Jungfrau East ridge WSL Institute for Snow and Avalanche Research SLF Flüelastrasse 11 CH-7260 Davos Dorf, Switzerland

Institution / network	Country	Collaborating with project:
PMOD/WRC Dr. Julian Gröbner Dr. Christine Aebi Davos Dorf	Switzerland	Automated GNSS Network Switzerland (AGNES) Swiss Federal Office of Topography swisstopo Seftigenstrasse 264 CH-3084 Wabern
Physikalisch-Meteorologisches Observatorium Davos (PMOD), World Radiation Center (WRC) Dr. S. Nyeki, Dr. J. Gröbner Dorfstrasse 33 CH-7260 Davos Dorf	Switzerland	Global Atmosphere Watch Radiation Measurements Federal Office of Meteorology and Climatology MeteoSwiss Station Aérologique Ch. de l'Aérologie 1 CH-1530 Payerne
Pro Natura Zentrum Aletsch Laudo Albrecht, Maurus Bamert, Elisabeth Karrer Villa Cassel Riederalp	Switzerland	Glaciological investigations on Grosser Aletschgletscher ETH Zürich Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW) Hönggerbergring 26 CH-8093 Zürich
Studiensammlung Kern AG Stadtmuseum Aarau Karl Heinz Münch Schlossplatz 23 CH-5000 Aarau	Switzerland	Trigonometric height determination Amt für Geoinformation BL Mühlemattstrasse 36 CH-4410 Liestal Switzerland
Swiss Federal Institute for Forest, Snow and Landscape Research WSL Dr. F. Hagedorn Birmensdorf	Switzerland	Radiocarbon measurements of atmospheric methane Department of Chemistry, Biochemistry and Pharmaceutical Sciences University of Bern Freiestrasse 3 CH-3012 Bern
Swiss GCOS (Roundtables)	Switzerland	High precision carbon dioxide and oxygen measurements at Jungfraujoch Universität Bern Physikalisches Institut Klima- und Umweltphysik Sidlerstrasse 5 CH-3012 Bern
Swiss Glacier Monitoring Network (GLAMOS) http://www.glamos.ch	Switzerland	Glaciological investigations on Grosser Aletschgletscher ETH Zürich Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW) Hönggerbergring 26 CH-8093 Zürich
Swisstopo Dr. André Streilein, Roberto Artuso Wabern	Switzerland	Glaciological investigations on the Grosser Aletschgletscher ETH Zürich Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW) Hönggerbergring 26 CH-8093 Zürich
Tofwerk AG Thun	Switzerland	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution/ Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Unisanté Centre universitaire de médecine générale et santé publique Dr. D. Vernez, Dr. J.-L. Bulliard Lausanne	Switzerland	Global Atmosphere Watch Radiation Measurements Federal Office of Meteorology and Climatology MeteoSwiss Station Aérologique Ch. de l'Aérologie 1 CH-1530 Payerne
Universität Basel Institut für Umweltgeowissenschaften Dr. F. Conen, C. Mignani Bernoullistrasse 30 CH-4056 Basel	Switzerland	Monitoring of ice cloud forming aerosols at the Jungfraujoch: automation of HINC for continuous INP ETH Zürich Institute for Atmospheric and Climate Science Universitätsstrasse 16 CH-8092 Zürich
Universität Basel Institut für Umweltgeowissenschaften Dr. Franz Conen Bernoullistrasse 30 CH-4056 Basel	Switzerland	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen Switzerland
Universität Basel Institut für Umweltgeowissenschaften Dr. Franz Conen Bernoullistrasse 30 CH-4056 Basel	Switzerland	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth’s atmosphere Université de Liège Institut d’Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium

Institution / network	Country	Collaborating with project:
Universität Basel Institut für Umweltgeowissenschaften Bernoullistrasse 30 CH-4056 Basel	Switzerland	Continuous measurement of stable CO_2 isotopes at Jungfraujoch, Switzerland Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
University of Basel Environmental Geosciences	Switzerland	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
University of Bern Physics Institute Climate and Environmental Physics Sidlerstrasse 5 CH-3012 Bern	Switzerland	Quality assurance and quality control of CO_2 observations Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
University of Bern Physics Institute Climate and Environmental Physics Prof. M. Leuenberger Sidlerstrasse 5 CH-3012 Bern	Switzerland	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen Switzerland
University of Bern Physics Institute Climate and Environmental Physics Prof. M. Leuenberger Sidlerstrasse 5 CH-3012 Bern	Switzerland	Radiocarbon measurements of atmospheric methane Department of Chemistry, Biochemistry and Pharmaceutical Sciences University of Bern Freiestrasse 3 CH-3012 Bern
University of Bern Physics Institute Climate and Environmental Physics Prof. M. Leuenberger Sidlerstrasse 5 CH-3012 Bern	Switzerland	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth's atmosphere Université de Liège Institut d'Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium)
University of Bern Physics Institute Climate and Environmental Physics Sidlerstrasse 5 CH-3012 Bern	Switzerland	Continuous measurement of stable CO2 isotopes at Jungfraujoch, Switzerland Empa Laboratory for Air Pollution and Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
University of Bern Physics Institute Climate and Environmental Physics Sidlerstrasse 5 CH-3012 Bern	Switzerland	Flask comparison on Jungfraujoch Max Planck Institut für Biogeochemie Hans Knöll Str. 10 D-007745 Jena
Universität Bern Physikalisches Institut Klima- und Umweltphysik Dr. Roland Purtschert Sidlerstrasse 5 CH-3012 Bern	Switzerland	^{85}Kr Activity Determination in Tropospheric Air Bundesamt für Strahlenschutz Rosastrasse 9 D-79098 Freiburg
University of Geneva Geneva Observatory Astronomy Department 51, Chemin des Maillettes CH-1290 Sauverny	Switzerland	Stellarium Gornergrat Center for Space and Habitability University of Bern Gesellschaftsstrasse 6 CH-3012 Bern
Imperial College London Department of Physics Dr. H. Graven	UK	Radiocarbon measurements of atmospheric methane Department of Chemistry, Biochemistry and Pharmaceutical Sciences University of Bern Freiestrasse 3 CH-3012 Bern
University of Bristol	UK	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution/ Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
University of Leeds School of Earth and Environment Dr. M. Chipperfield Leeds, LS2 9JT United Kingdom	UK	Atmospheric composition monitoring at ISSJ Royal Belgian Institute for Space Aeronomy (BIRA-IASB) Ringlaan 3 B-1180 Brussels Belgium

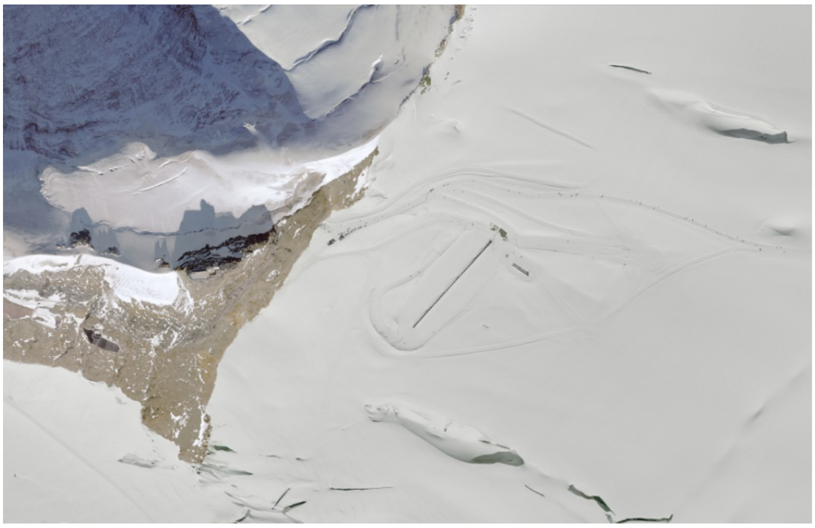
Institution / network	Country	Collaborating with project:
University of Leeds Dr. M.P. Chipperfield and team Leeds United Kingdom	UK	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth’s atmosphere Université de Liège Institut d’Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
Aerodyne Research Inc. Billercia (Ma), USA	USA	Halogenated greenhouse gases at Jungfraujoch Empa Laboratory for Air Pollution/ Environmental Technology Überlandstrasse 129 CH-8600 Dübendorf
Colorado State University Dr. E.V. Fischer Fort Collins, CO, USA	USA	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth’s atmosphere Université de Liège Institut d’Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
NASA JPL California Institute of Technology Dr. G.C. Toon Pasadena, CA USA	USA	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth’s atmosphere Université de Liège Institut d’Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
National Center for Atmospheric Research Mr. J. Hannigan Boulder, CO USA	USA	High resolution, solar infrared Fourier transform spectrometry: application to the study of the Earth’s atmosphere Université de Liège Institut d’Astrophysique et de Géophysique Quartier Agora Allée du six Août, 19 - Bâtiment B5a B-4000 Sart Tilman (Liège), Belgium
NOAA Dr. E. Andrews Boulder, USA	USA	The Global Atmosphere Watch Aerosol Program at Jungfraujoch Paul Scherrer Institute Laboratory of Atmospheric Chemistry Forschungsstrasse 111 CH-5232 Villigen Switzerland

Picture Gallery 2020 from https://www.hfsjg.ch

January: Sunset at Jungfraujoch on a cold winter day. Photo: HFSJG

February: Patrick Reimann, patented federally engineer-geometer, investigates the influence of the earth's curvature and terrestrial refraction in trigonometric altitude determination from mountain summits and triangulation points a few to 150 kilometers away. Interest is also directed towards how Sir George Everest succeeded around 1850 in determining the trigonometric altitude of Mount Everest, later named after him, to an accuracy of 8 metres. The distance between the visures was about 200 kilometres, which, in theory, did not and still does not lead to the conclusion that such a high degree of accuracy was possible. For this reason, the trigonometric measurements on the Jungfraujoch are now also carried out with 'historical' instruments, in this case the repetition theodolite of the Kern company from 1909. For more details see the annual report 2019. Photo by Julia Wunsch

March: NGC 2392 – Eskimo fog
Distance: ca. 3’751 light years (Hipparcos, 1997)
Distance: 6’523 ± 652 light years (Gaia, 2018)
Diameter: ca. 0.34 light years
Exposure time: 8x30s R, 8x30s G, 8x30s B, 16x30s C
Photo: © Stellarium Gornergrat

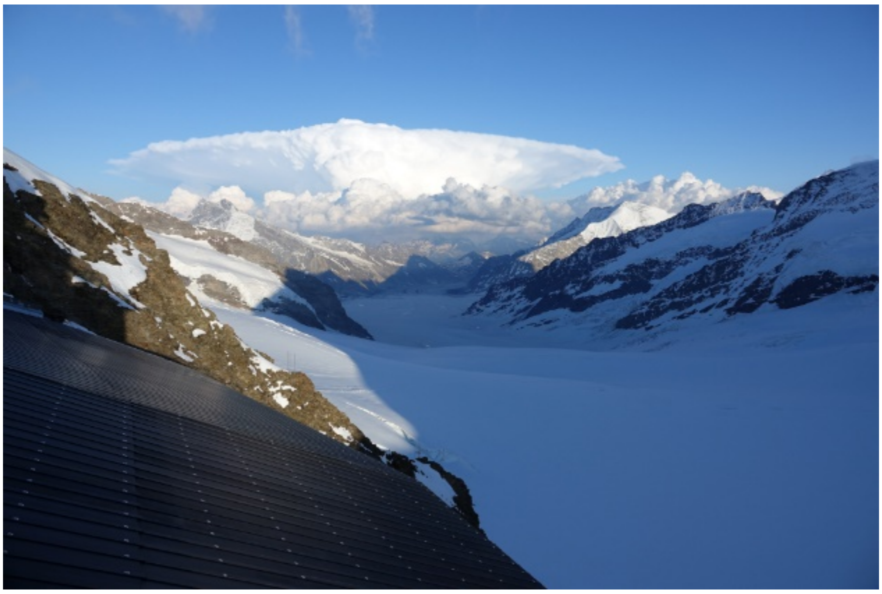


April: The Jungfraujoch from a bird’s eye view.
https://www.swisstopo.admin.ch/en/knowledge-facts/geoinformation/a_birds_eye_view_of_Switzerland/switzerland-pictures.html.
Photo: Geodaten©swisstopo

May: The Jungfrau Railways are closed and the Jungfraujoch is almost deserted. Therefore, after work, the chief facility manager of the research station Jungfraujoch, Ruedi Käser, can play his alphorn at the empty Sphinx-observatory without any interruption. Photo: Christine Käser

June: A new, heated air inlet system was designed and installed at Jungfraujoch by Empa. The bundle of tubing is about 80 meters long and was installed and fixed on the rock from the Sphinx in direction of the Mönch by Rock Tec AG. The tubing is heated, so that the gas flow is guaranteed. This new system shall minimise the contaminations, which arise due to the tourists and the touristic infrastructures. Photos: Martin Vollmer, Empa

July: The air conditioning in the Sphinx-labs has to be renewed. In a first step, three new air conditioners were installed in the labs for cooling (picture on the left). In a separate room there is a heat exchanger with two ventilators, which emits the waste heat of the air conditioners into the air of the room and into the cupola (picture on the right). Photo: Ruedi Käser

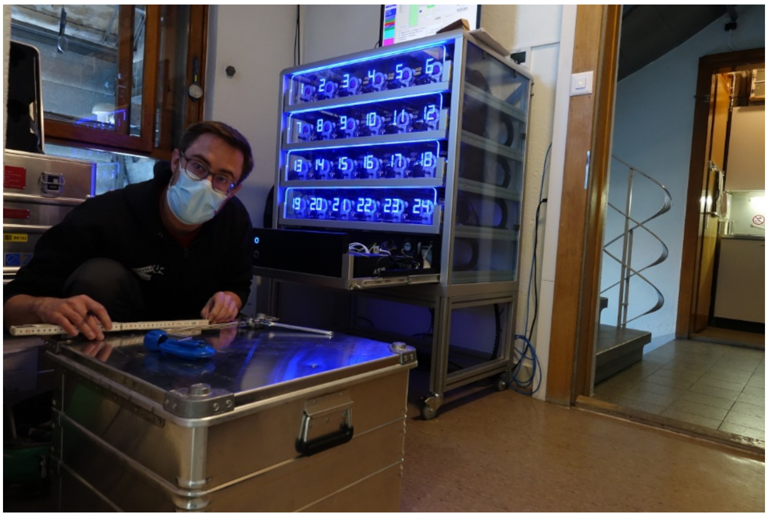


August: A beautiful example of a Cumulonimbus capillatus incus (latin: anvil). The picture was taken at Jungfraujoch by Ruedi Käser.

September: At Jungfraujoch, the entrance doors to the research station and the Sphinx-laboratories have been renewed and updated (new members are now also represented with their logos) by the Pure Polydesign GmbH and the KARGO Kommunikation GmbH. Also, the MeteoSwiss panel at the scientific exhibition has been updated. Next time you are at Jungfraujoch, take a look! Photos: Georg Wyler, Pure Polydesign GmbH

October: View from the Konkordiaplatz on the Aletschglacier, in direction of the Eggishorn. Photo: Ruedi Käser

November: A photo of the Milky Way, taken from the Sphinx-terrace at Jungfraujoch. The picture is the total of 20 shots, in order to give the colours and structures of this phenomenal view even more power. Photo: © Klaus Theiler



December: A short while ago, a new instrument was installed at the Sphinx-observatory at Jungfraujoch. The ICOS flask sampler automatically collects air samples in glass flasks that are sent to the ICOS-CAL (Central Analytical Laboratories) at the Max-Planck-Institute in Jena, Germany. There, the air samples are analysed for CO2, CH4, N2O and CO as a quality control of the in-situ measurements but also for other tracers such as e.g. H2 and SF6 that are not measured in-situ. The picture shows Dr. Michael Schibig from the Climate and Environmental Physics division of the University of Bern with the flask sampler in the background. Picture: Ruedi Käser, HFSJG

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University of Bern
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And our hearty thanks to all the scientists who worked at Jungfraujoch and Gornergrat in this special year 2020 and who contributed to the continuation of top scientific research under difficult conditions and to this report.