Name of research institute or organization:

Institut d'Astrophysique et de Géophysique, Université de Liège

Title of project:

High resolution, solar infrared Fourier Transform spectrometry. Application to the study of the Earth atmosphere.

Project leader and team:

Whitney Bader, Benoît Bovy, Philippe Demoulin, Bernard Lejeune, Emmanuel Mahieu, Ginette Roland (em.), Christian Servais (project leader), Rodolphe Zander (em.), Olivier Flock, Vincent Van De Weerdt, Diane Zander.

Project description:

Contribution to the long-term monitoring of the Earth's atmosphere has remained the central activity of the Liège group. Regular observations carried out at the Jungfraujoch with high-performance Fourier-transform infrared (FTIR) spectrometers allow to derive abundances of more than 25 constituents affecting our climate and monitored in the frame of the Kyoto protocol (N_2O, CH_4, CO_2, SF_6, CF_4…); related to the erosion of the ozone layer in the stratosphere and therefore linked to the Montreal Protocol (HCl, $ClONO_2$, HNO_3, NO, NO_2, HF, COF_2, O_3, CCl_2F_2, $CHClF_2$, CCl_3F, CCl_4…); or altering the oxidization processes in the troposphere (CO, C_2H_2, C_2H_6, OCS, HCN, H_2CO, H_2CO_2…). The resulting databases allow the precise determination of the short-term variability, seasonal modulations, inter-annual as well as long-term changes affecting most of these species.

During 2012, Liège observers were present during 245 days at the Jungfraujoch and recorded 2115 high-resolution FTIR solar spectra on 116 different days, including 20 days with remote operation from Liège. Here is a selection of key 2012 results derived by our team from Jungfraujoch infrared spectra:

Ethane (C_2H_6)

Ethane is the most abundant non-methane hydrocarbon of the Earth's atmosphere, with a life-time of approximately 2 months. C_2H_6 has both anthropogenic and natural emission sources such as biomass burning, natural gas loss and bio-fuel consumption.

Thanks to new spectroscopic parameters (Harrison *et al.*, 2010), ethane retrievals have been significantly improved and two partial columns (lower troposphere and upper-troposphere/lower-stratosphere UTLS) can now be derived from Jungfraujoch FTIR spectra. Figure 1 displays the retrieved C_2H_6 total and partial columns above the Jungfraujoch from Septembre 1994 onwards. Overall decrease of ethane since 1994 amounts to -14 %, -9 % and -39 %, respectively for total, lower troposphere and UTLS columns. A strong seasonal variation is observed, with a maximum in February and peak-to-peak amplitude of 50 % for the total columns. See Bader *et al.* [1] for more details.

Carbonyl sulfide (OCS)

Carbonyl sulfide is the most abundant sulfur-containing trace gas in the atmosphere and is believed to account for a substantial portion of the sulfur in the stratospheric aerosol layer which influences the Earth's radiation budget and stratospheric ozone chemistry. The major identified OCS sources are oceans and anthropogenic emissions, while atmospheric loss and uptake by vegetation and soils constitute the main OCS sinks. The uptake by vegetation strongly influences the distribution and seasonality of OCS throughout most of the Northern Hemisphere.

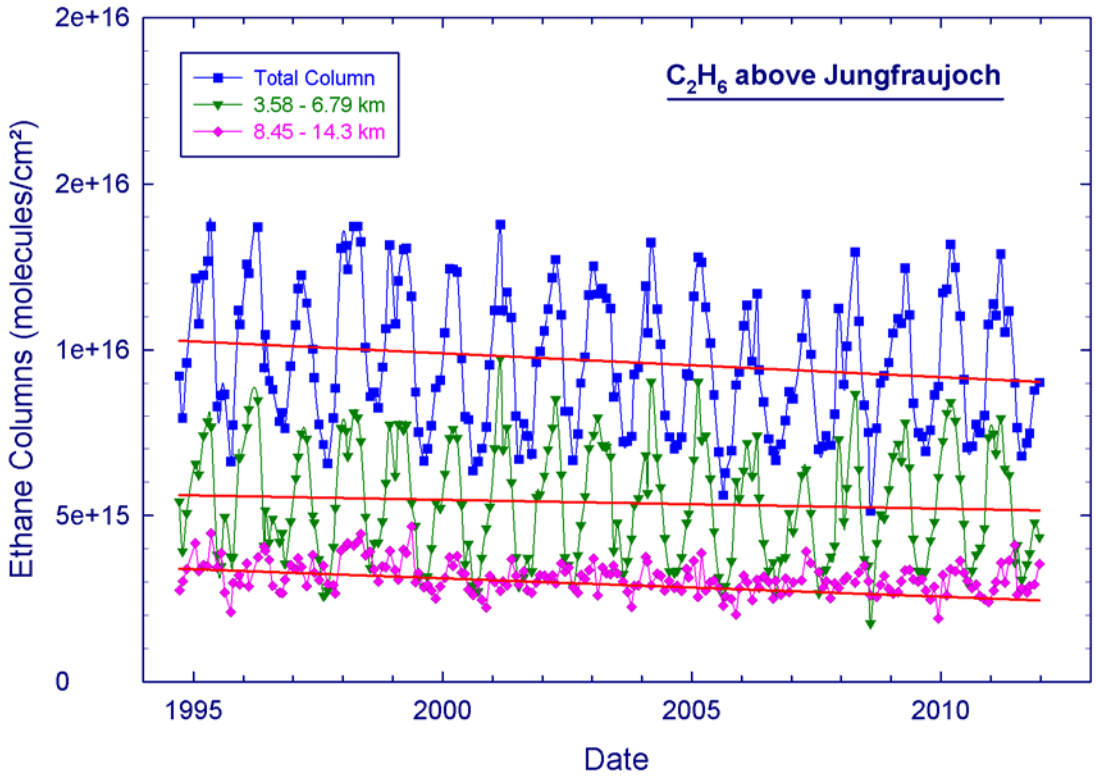

Figure 1: Time series of C_2H_6 monthly mean total (in blue), low-tropospheric (3.58-6.79 km, in green) and UTLS (8.45-14.3 km, in pink) columns above the Jungfraujoch. Red lines are linear trends.

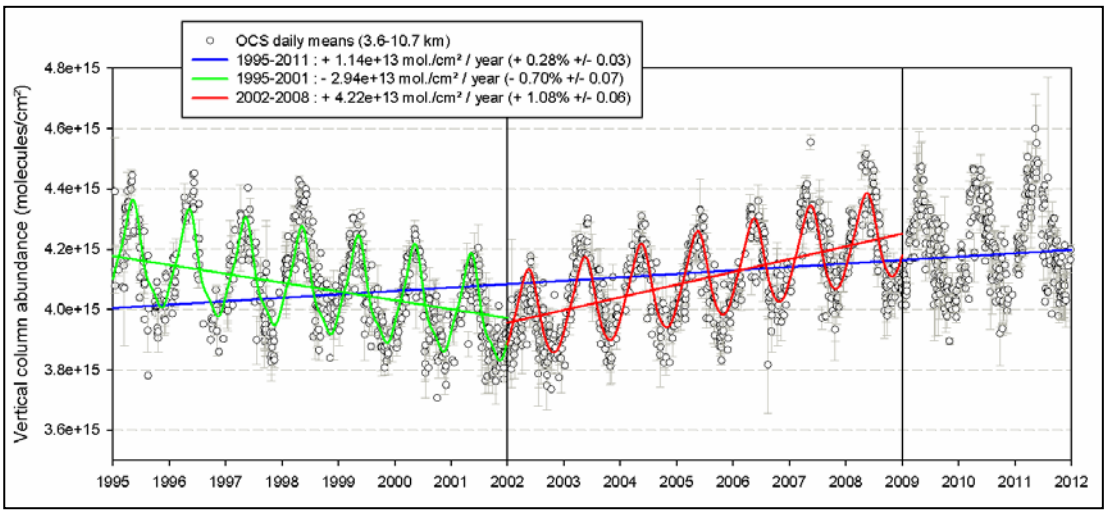

Figure 2: Time series of OCS tropospheric columns above the Jungfraujoch (daily means values). From 1995 to 2001, carbonyl sulfide decreased at a rate of 0.70 ± 0.07 % per year; from 2002 to 2009, it increased at 1.08 ± 0.06 %/year.

There is still a lack of understanding of the strength of some components in the atmospheric OCS budget. It seems that uptake by plants has been strongly underestimated, suggesting that additional significant OCS sources still have to be identified. The study of this gas is thus important and it will help improving our current estimates of OCS budget. Furthermore, recent works suggest that OCS could provide a valuable constraint on photosynthesis and so improve studies of carbon cycle processes.

A new retrieval strategy has been developed to retrieve OCS from Jungfraujoch FTIR spectra: it uses 4 micro-windows in the 2047-2055 cm^{-1} spectral domain (ν_3 band), and the

information analysis for this retrieval indicates a degree of freedom of about 2.6, meaning that we can derive at least 2 significant partial columns from the spectra.

Figure 2 shows the tropospheric OCS columns above the Jungfraujoch: after a few years of decrease, these columns have been increasing since 2002. Reasons of this increase have been investigated, with possible sources being the intensification of emissions from coal combustion and from aluminium production (respectively 30 % and 65 % of the estimated anthropogenic direct OCS emissions). See Lejeune *et al.* [4] for more information.

Carbon tetrachloride CCl_4

The carbon tetrachloride gas, emitted at the ground, has been and remains a key component of the stratospheric chlorine budget, still contributing over 10% to the total chlorine loading, and to the stratospheric ozone depletion by a similar percentage. It is also a potent greenhouse gas with a global warming potential relative to CO_2 of 1400, on a 100-year horizon. Monitoring its atmospheric evolution remains, therefore, of relevance to both the Kyoto and the Montreal Protocol.

The long-term trend of the atmospheric CCl_4 burden has been retrieved from FTIR spectra recorded at the Jungfraujoch between January 1999 and June 2011 (Figure 3). Total columns were derived from spectrometric analysis of the strong CCl_4 ν_3 band at 794 cm^{-1}. A significant improvement in the fitting residuals and in the retrieved CCl_4 columns was obtained by taking into account line-mixing in a strong interfering CO_2 Q-branch. A fit to the CCl_4 daily mean total column time series returns a statistically-significant (2σ) long-term trend of $-1.49 \pm 0.08 \times 10^{13}$ mol/cm^2 per year. This corresponds to an annual decrease of -1.31 ± 0.07) pptv for the mean free tropospheric volume mixing ratio. Furthermore, the total column data set reveals a weak seasonal cycle with a peak-to-peak amplitude of 4.5 %, with minimum and maximum values occurring in mid-February and mid-September, respectively. This small seasonal modulation is attributed primarily to the residual influence of tropopause height changes throughout the year. The negative trend of the CCl_4 loading reflects the continued impact of the regulations implemented by the Montreal Protocol and its strengthening amendments and adjustments. See Rinsland *et al.* [2] for details.

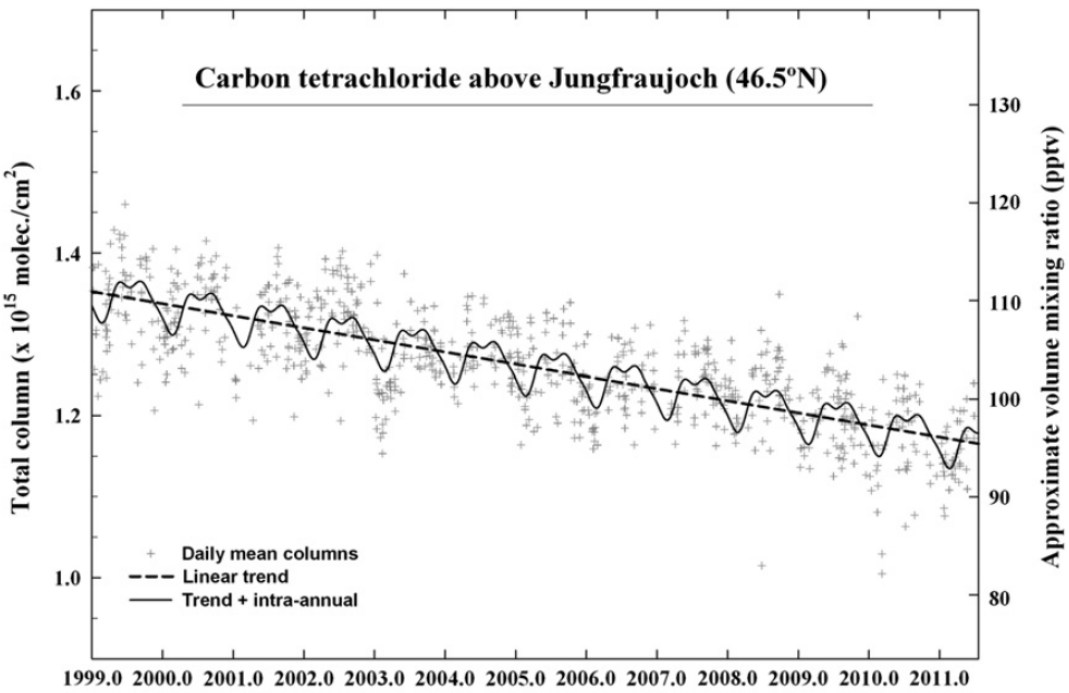

Figure 3: Daily mean CCl_4 total columns above the Jungfraujoch station are shown as plus symbols. The dashed line shows the linear component of the function fitted to all available daily means. The solid curve reproduces the derived seasonal modulation.

Total reactive nitrogen NO_y

The NO_y family of gases, defined as $NO + NO_2 + NO_3 + 2\times N_2O_5 + HNO_3 + HNO_4 + ClONO_2 + BrONO_2$, plays an important role in the ozone depletion (NO catalytic cycle, Crutzen 1970). At the Jungfraujoch observatory, FTIR spectrometers measure since 1984 the four most abundant members of NO_y i.e. NO, NO_2, HNO_3 and $ClONO_2$. Their sum is a good proxy for NO_y (the most important missing gas being N_2O_5). The trends of these four gases have been derived with a multiple regression model that includes linear trend, seasonal variation, stratospheric aerosol optical depth, solar flux… The apparent discrepancy between the NO_y trend and the trend of its source gas N_2O probably arises, according to the models, from the strengthening of the Brewer-Dobson circulation, the stratospheric cooling and the changes in stratospheric chlorine loading. Figures 4 to 7 show some results derived from this study. See Demoulin *et al.* [3] and Hendrick *et al.* [5] for more details.

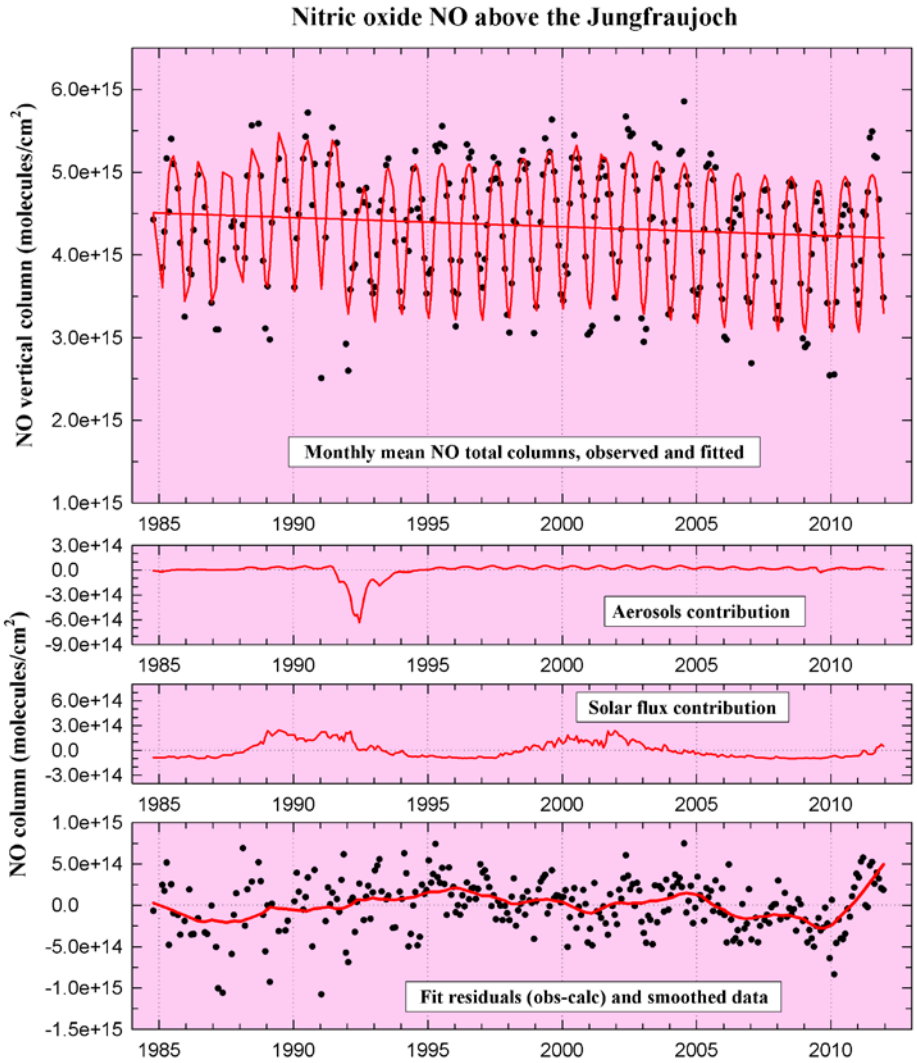

Figure 4: Upper frame: monthly mean NO total columns derived from Jungfraujoch FTIR spectra (black dots), together with best fit of the regression model and linear trend (red lines). A mean NO decrease of -0.25 ± 0.12 %/yr has been derived for the 1985-2012 time period. Middle frames give the contribution of the aerosol optical depth and of the solar flux to the NO total columns. The large aerosol perturbation from the Mt. Pinatubo eruption on June 15, 1991, is clearly visible. The eleven-year solar cycle influences NO total columns by a few percents. Lower frames show the residuals of the fit (measured - model) (black dots) together with a smoothed curve (red lines) of these residuals.

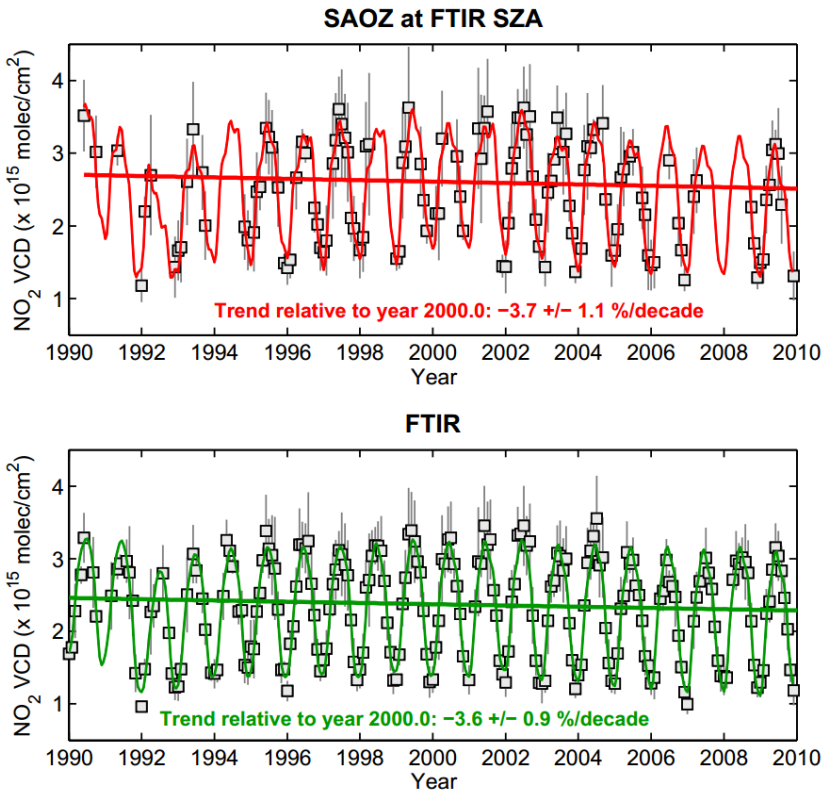

Figure 5: This figure shows the NO_2 vertical column time series of 2 co-located NDACC instruments: the ULg FTIR solar spectrometer and the BIRA-IASB SAOZ UV-vis instrument, both operating at the Jungfraujoch observatory. As NO_2 is varying during the day, twilight SAOZ measurements have been reported, for this comparison exercise, to the solar zenith angles of FTIR observations. Colored lines correspond to the linear trend (thick line) and to the NO_2 columns recalculated using the multiple linear regression model (thin ligne). Trends derived from both datasets, -3.7 ± 1.1 and -3.6 ± 0.9 %/decade, respectively for FTIR and SAOZ instruments, are in very good agreement.

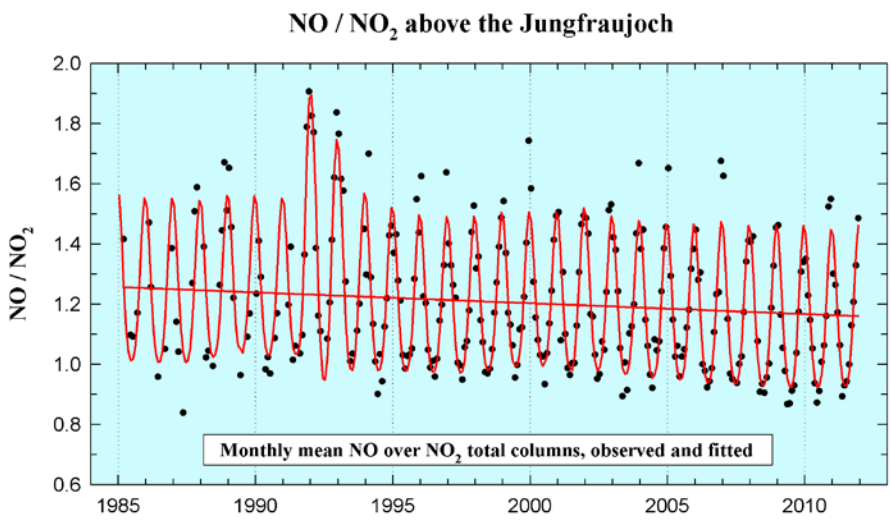

Figure 6: The NO/NO_2 ratio is slowly decreasing above the Jungfraujoch, at a rate of -0.29 ± 0.12 %/year. This decrease is due to increased chlorine loading in the atmosphere, which increases the rate of the reaction [$NO + ClO \rightarrow NO_2 + Cl$]. The NO/NO_2 ratio is expected to increase in the 21st century, as a result of the decreasing chlorine loading and of CO_2-induced stratospheric cooling, which slows the temperature-dependent reaction [$NO + O_3 \rightarrow NO_2 + O_2$] (Revell 2012).

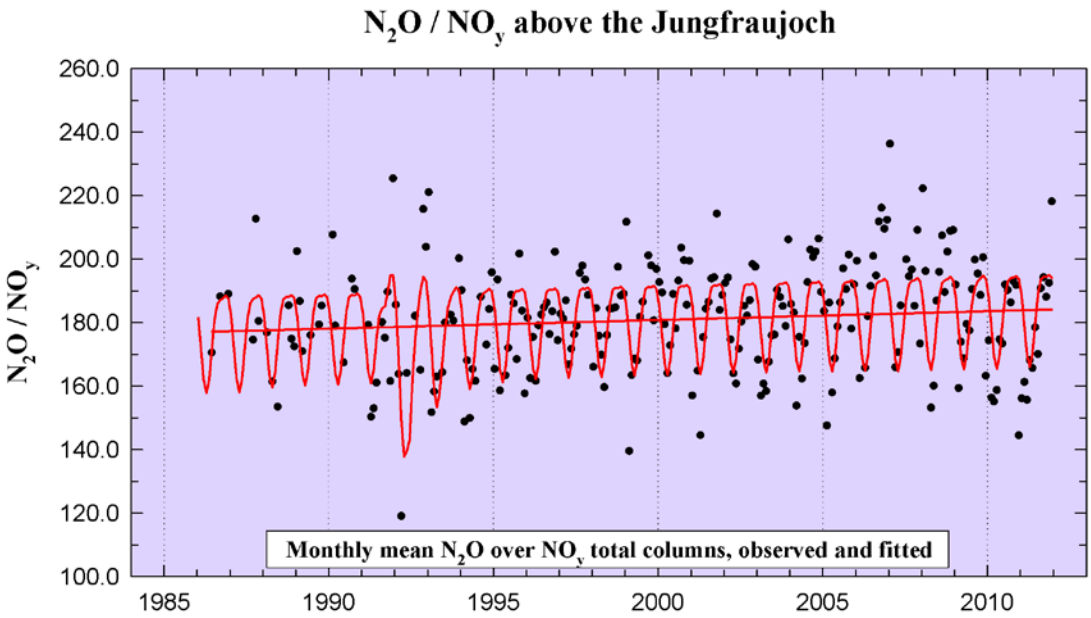

Figure 7: Although N_2O is the source of NO_y, NO_y is not increasing at the same rate (0.31 ± 0.02 %/year for N_2O, 0.11 ± 0.13 %/year for NO_y). This difference is probably due to increasing CO_2 concentrations cooling the stratosphere (Rosenfield and Douglass 1998) and to ozone and halogens changes in the stratosphere (McLinden 2001).

Varia

Results derived from the Jungfraujoch FTIR spectra are regularly archived at the NDACC data center (ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/jungfrau/), usually within less than one year. However, our group is now involved in the NORS project, where we will store a first evaluation of our data at ftp://ftp.cpc.ncep.noaa.gov/ndacc/RD/jungfrau/ (« Rapid Data Delivery », i.e. typically within less than 1 month).

In June 2012, our group organized at Wengen the annual infrared working group of the NDACC network. This meeting was attended by about 50 scientists from around the world, specialists in Fourier transform infrared spectroscopy applied to the long term study of the Earth atmosphere. It was followed by a visit to the Jungfraujoch laboratories.

References

Crutzen P.J., The influence of nitrogen oxides on the atmospheric ozone content, Q.J.R. Meteorol. Soc., **96**, 320-325, 1970.

Harrison, J.J., N.D.C. Allen, and P.F. Bernath, Infrared absorption cross sections for ethane (C_2H_6) in the 3 µm region, J. Quant. Spectrosc. Radiat. Transfer, **111**, 357-363, 2010.

McLinden C. A. Understanding trends in stratospheric NO_y and NO_2, J. Geophys. Res., 106(D21), **27**, 787–27 793, 2001.

Revell, L., Bodeker, G., Smale, D., Lehmann, R. , Huck, P., Williamson, B., Rozanov, E. and Struthers, H., The effectiveness of N_2O in depleting stratospheric ozone. Geophys. Res. Lett., **39**, L15806-L15806, 2012.

Rosenfield J.E. and Douglass, Doubled CO_2 effects on NO_y in a coupled 2D model, Geophys. Res. Lett., **25**, 4381-4384, 1998.

Key words:
Earth atmosphere, climate change, greenhouse gases, ozone layer, long-term monitoring, infrared spectroscopy

Internet data bases:

ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/jungfrau/, http://www.nilu.no/nadir/
ftp://ftp.cpc.ncep.noaa.gov/ndacc/RD/jungfrau/

Collaborating partners/networks:

Main collaborations: IASB (Institut d'Aéronomie Spatiale de Belgique) / NDACC (Network for the Detection of Atmospheric Composition Change, previously NDSC; http://www.ndacc.org/) / GAW-CH / partners of the EC-project NORS (http://nors.aeronomie.be) / NASA Langley Research Center / ACE-FTS science team / NASA JPL / University of Oslo / EMPA / University of Leeds / IMK (Forschungszentrum Karlsruhe) / satellite experiments: IASI, AURA, OMI, ACE-FTS, ENVISAT / …

Scientific publications and public outreach 2012:

The complete list of GIRPAS publications can be found at
http://girpas.astro.ulg.ac.be/girpas/publi03e.htm and
http://girpas.astro.ulg.ac.be/girpas/Communic.htm

Refereed journal articles and their internet access

Duflot, V., D. Hurtmans, L. Clarisse, Y. R'honi, C. Vigouroux, M. De Mazière, E. Mahieu, C. Servais, C. Clerbaux, and P.-F. Coheur, Measurements of hydrogen cyanide (HCN) and acetylene (C_2H_2) from the Infrared Atmospheric Sounding Interferometer (IASI), Atmos. Meas. Tech. Discuss., **5**, 7567-7586, 2012.
http://www.atmos-meas-tech-discuss.net/5/7567/2012/amtd-5-7567-2012.html

[5] Hendrick, F., E. Mahieu, G. Bodeker, K.F. Boersma, M.P. Chipperfield, M. De Mazière, I. De Smedt, P. Demoulin, C. Fayt, C. Hermans, K. Kreher, B. Lejeune, G. Pinardi, C. Servais, R. van der A, J.-P. Vernier, and M. Van Roozendael, Analysis of stratospheric NO_2 trends above Jungfraujoch using ground-based UV-visible, FTIR, and satellite nadir observations, Atmos. Chem. Phys., **12**, 8851-8864, 2012.
http://hdl.handle.net/2268/121603

Kerzenmacher, T., B. Dils, N. Kumps, T. Blumenstock, C. Clerbaux, P.-F. Coheur, P. Demoulin, O. García, M. George, D.W.T Griffith, F. Hase, J. Hadji-Lazaro, D. Hurtmans, N. Jones, E. Mahieu, J. Notholt, C. Paton-Walsh, U. Raffalski, T. Ridder, M. Schneider, C. Servais, and M. De Mazière, Validation of IASI FORLI carbon monoxide retrievals using FTIR data from NDACC, Atmos. Meas. Tech., **5**, 2751-2761, 2012.
http://orbi.ulg.ac.be/handle/2268/124179

Kohlhepp, R., R. Ruhnke, M.P. Chipperfield, M. De Mazière, J. Notholt, S. Barthlott, R.L. Batchelor, R.D. Blatherwick, Th. Blumenstock, M.T. Coffey, P. Demoulin, H. Fast, W. Feng, A. Goldman, D.W.T. Griffith, K. Hamann, J.W. Hannigan, F. Hase, N.B. Jones, A. Kagawa, I. Kaiser, Y. Kasai, O. Kirner, W. Kouker, R. Lindenmaier, E. Mahieu, R.L. Mittermeier, B. Monge-Sanz, I. Morino, I. Murata, H. Nakajima, M. Palm, C. Paton-Walsh, U. Raffalski, Th. Reddmann, M. Rettinger, C.P. Rinsland, E. Rozanov, M. Schneider, C. Senten, C. Servais, B.-M. Sinnhuber, D. Smale, K. Strong, R. Sussmann, J.R. Taylor, G. Vanhaelewyn, T. Warneke, C. Whaley, M. Wiehle, and S.W. Wood, Observed and simulated time evolution of HCl, $ClONO_2$, and HF total column abundances, Atmos. Chem. Phys., **12**, 3527-3556, 2012.
http://hdl.handle.net/2268/117940

[2] Rinsland, C.P., E. Mahieu, P. Demoulin, R.Zander, C. Servais, and J.-M. Hartmann, Decrease of the Carbon Tetrachloride (CCl_4) Loading above Jungfraujoch, based on High Resolution Infrared Solar Spectra recorded between 1999 and 2011, J. Quant. Spectrosc. Radiat. Transfer, **113**, 1322-1329, doi: 10.1016/j.jqsrt.2012.02.016, 2012.
http://hdl.handle.net/2268/121150

Risi, C., D. Noone, J. Worden, C. Frankenberg, G. Stiller, M. Kiefer, B. Funke, K. Walker, P. Bernath, M. Schneider, D. Wunch, V. Sherlock, N. Deutscher, D. Griffith, P.O. Wennberg, K. Strong, D. Smale, E. Mahieu, S. Barthlott, F. Hase, O. García, J. Notholt, T. Warneke, G.C. Toon, D. Sayres, S. Bony, J. Lee, D. Brown, R. Uemura, and C. Sturm, Process-evaluation of tropospheric humidity simulated by general circulation models using water vapor isotopologues: 1. Comparison between models and observations, J. Geophys. Res., **117**, D05303, doi: 10.1029/2011JD016621, 2012.
http://hdl.handle.net/2268/123815

Schneider, M., S. Barthlott, F. Hase, Y. González, K. Yoshimura, O.E. García, E. Sepúlveda, A. Gomez-Pelaez, M. Gisi, R. Kohlepp, S. Dohe, T. Blumenstock, K. Strong, D. Weaver, M. Palm, N.M. Deutscher, T. Warneke, J. Notholt, B. Lejeune, P. Demoulin, N. Jones, D.W.T. Griffith, D. Smale, and J. Robinson, Ground-based remote sensing of tropospheric water vapor isotopologues within the project MUSICA, Atmos. Meas. Tech., **5**, 3007-3027, doi:10.5194/amt-5-3007-2012, 2012.
http://hdl.handle.net/2268/135828

Conference papers

Bader, W., E. Mahieu, B. Bovy, B. Lejeune, P. Demoulin, and C. Servais, First retrievals of methanol (CH_3OH) above Jungfraujoch (46.5ºN): Optimization of the retrieval strategy and information content, poster presentation at the "Journée des doctorants UNITER", Université Libre de Bruxelles, Belgique, December 10, 2012.
http://hdl.handle.net/2268/135878

[1] Bader, W., A. Perrin, D. Jacquemart, J.J. Harrison, G.C. Toon, K. Sudo, O.A. Søvde, P. Demoulin, C. Servais, and E. Mahieu, Retrievals of ethane from ground-based high-resolution FTIR solar observations with updated line parameters: determination of the optimum strategy for the Jungfraujoch station, poster presentation at the "11th Atmospheric Spectroscopy Applications" meeting (ASA 2012), united with the "12th HITRAN Conference", Reims, France, August 29-31, 2012.
http://hdl.handle.net/2268/129289

Bader, W., A. Perrin, D. Jacquemart, K. Sudo, H. Yashiro, M. Gauss, P. Demoulin, C. Servais, and E. Mahieu, Retrievals of ethane from ground-based high-resolution FTIR solar observations with updated line parameters: determination of the optimum strategy for the Jungfraujoch station, poster presentation at the "EGU 2012 General Assembly", Vienna, Austria, April 22-27, 2012 and at the 4th Symposium on METEOrology and CLIMatology for PhD students - MeteoClim2012, 2012.
http://hdl.handle.net/2268/117067

Bader, W., A. Perrin, D. Jacquemart, K. Sudo, H. Yashiro, O.E. Søvde, P. Demoulin, C. Servais, and E. Mahieu, Retrievals of ethane from ground-based high-resolution FTIR solar observations with updated line parameters: determination of the optimum strategy for the Jungfraujoch station, poster presentation at the "NDACC-IRWG Annual Meeting", Wengen, Switzerland, June 11-15, 2012.
http://hdl.handle.net/2268/124230

De Mazière, M, K. Hocke, A. Richter, S. Godin-Beekmann, S. Henne, T. Blumenstock, S. Niemeijer, and E. Mahieu, NORS: Demonstration Network Of ground-based Remote Sensing Observations in support of the GMES Atmospheric Service, poster presentation at the 12th International Global Atmospheric Chemistry (IGAC) Science Conference, Beijing, China, September 17-212012.
http://hdl.handle.net/2268/131119

[3] Demoulin, P., E. Mahieu, C. Servais, B. Lejeune, W. Bader, G. Roland, R. Zander, K.A. Walker, P.F. Bernath, M. Van Roozendael, and F. Hendrick, Long-term trends of NO_y above northern mid-latitudes as inferred from Jungfraujoch, HALOE and ACE-FTS infrared solar observations, poster presentation at the Quadrennial Ozone Symposium QOS 2012, Toronto, Canada, August 27–31, 2012.
http://larss.science.yorku.ca/QOS2012pdf/5997.pdf

Kolonjari, F., E. Mahieu, K.A. Walker, Y. Kasai, A. Kagawa, R. Lindenmaier, R.L. Batchelor, K. Strong, C.D. Boone, and P.F. Bernath, Validation of ACE-FTS using ground-based FTIR measurements of CFC-11, CFC-12 and HCFC-22, poster presentation at the 2012 Summer School in Arctic Atmospheric Science, Alliston, Canada, July 23-27, 2012.
http://hdl.handle.net/2268/130119

[4] Lejeune, B., E. Mahieu, P. Demoulin, C. Servais, W. Bader, B. Bovy, O. Flock, R. Zander, and G. Roland, Trend evolution of carbonyl sulfide above Jungfraujoch deduced from ground-based FTIR and ACE-FTS satellite observations, oral presentation at the *"ACE Science Team Meeting"*, University of Waterloo, Waterloo, ON, Canada, May 23-24, 2012.
http://hdl.handle.net/2268/123804

Lejeune, B., E. Mahieu, M. Schneider, F. Hase, C. Servais, and P. Demoulin, Long-term series of tropospheric water vapour amounts and HDO/H_2O ratio profiles above Jungfraujoch, poster presentation at the "EGU 2012 General Assembly", Vienna, Austria, April 22-27, 2012.
http://hdl.handle.net/2268/117439

Mahieu, E., the GIRPAS- and the ACE-teams, Post-peak trend in inorganic chlorine (Cl_y) from Jungfraujoch, ACE-FTS and HALOE infrared solar observations, oral presentation at the "ACE / SAGE III-ISS International Workshop", Old Dominion University, Norfolk, VA, USA, October 15-17, 2012.
http://hdl.handle.net/2268/132600

Mahieu, E., W. Bader, B. Bovy, B. Lejeune, C. Vigouroux, P. Demoulin, C. Servais, G. Roland, and R. Zander, Retrieval of methanol (CH_3OH) from the high-altitude Jungfraujoch station (46.5ºN): preliminary total column time series, long-term trend and seasonal modulation, poster presentation at the "NDACC-IRWG Annual Meeting", Wengen, Switzerland, June 11-15, 2012.
http://hdl.handle.net/2268/124069

Mahieu, E., W. Bader, B. Lejeune, C. Vigouroux, P. Demoulin, C. Servais, G. Roland, and R. Zander, Seeking for the optimum retrieval strategy of methanol (CH_3OH) using ground-based high-resolution FTIR solar observations recorded at the high-altitude Jungfraujoch station (46.5ºN), poster presentation at the "EGU 2012 General Assembly", 22-27 April 2012, Vienna, Austria, April 22-27, 2012.
http://hdl.handle.net/2268/116957

Pastel, M., S. Godin-Beekmann, E. Mahieu, P. Demoulin, and K. Hocke, A new methodology for integrating ground-based ozone profile data, poster presentation at the Quadrennial Ozone Symposium QOS 2012, Toronto, Canada, August 27–31, 2012.
http://larss.science.yorku.ca/QOS2012pdf/6009.pdf

Servais C. and Roland G., Soixante ans de spectroscopie solaire et atmosphérique depuis le Jungfraujoch, Swiss Academy of Sciences, Les chercheurs de l'extrême, Interlaken, October 25-26, 2012.
http://kongress12.scnat.ch/f/jahreskongress/praesentationen/

Vigouroux, C., M. De Mazière, P. Demoulin, C. Servais, F. Hase, T. Blumenstock, R. Kohlhepp, S. Barthlott, O. García, M. Schneider, J. Mellqvist, G. Personn, M. Palm, J. Notholt, J. Hannigan, and M. Coffey, Ozone tropospheric and stratospheric trends (1995-2011) at six ground-based FTIR stations (28ºN to 79ºN), poster presentation at the Quadrennial Ozone Symposium QOS 2012, Toronto, Canada, August 27–31, 2012.
http://larss.science.yorku.ca/QOS2012pdf/6018.pdf

Edited books

Schneider, M., P. Demoulin, R. Sussmann, and J. Notholt, Fourier Transform Infrared Spectrometry, Chapter 6 in Monitoring Atmospheric Water Vapor: Ground-Based Remote Sensing and In-Situ Methods, ISSI Scientific Report Series, **vol. 10**, ISBN 978-1-4614-3908-0, Springer New York, 2012.
http://link.springer.com/book/10.1007/978-1-4614-3909-7/page/1

Theses

Palumbo Adrien, Étude de faisabilité d'une caméra IP destinée au contrôle d'expérience en haute altitude et basée sur un système embarqué dans un FGPA, Travail de fin d'étude présenté en vue de l'obtention du grade de bachelier en informatique et systèmes finalité réseaux et télécommunications, Haute Ecole de la Province de Liège, Seraing, Année académique 2011-2012.

Van Laeken Lionel and Boileau Quentin, La station de recherche du Jungfraujoch. Étude de la composition chimique de l'atmosphère terrestre par la spectroscopie infrarouge à transformée de Fourier, Mémoire de fin d'études secondaires, Ecole Sainte-Marie, Huy, January 2012.

Magazine and Newspapers articles

Atmosphère ? Atmosphère ! Interview of E. Mahieu in Athena, **277**, 38-41, January, 2012.
http://recherche-technologie.wallonie.be/servlet/Repository/athena-277.pdf?IDR=11102&EXT=PDF

Radio and television

Solar and atmospheric spectroscopy research conducted since 1950 at the Jungfraujoch by the researchers of the University of Liège, permanent video showing to the Jungfraujoch visitors the principle and purpose of work done by Liège researchers, Jungfraujoch 2012.

Address:

Institut d'Astrophysique et de Géophysique - Université de Liège
allée du VI août, 17 - Bâtiment B5a
B-4000 Sart Tilman (Liège, Belgique)

Contacts:

Whitney Bader	Tel. +32 4 366 9789	e-mail: bader@astro.ulg.ac.be
Benoît Bovy	Tel. +32 4 366 9789	e-mail: bovy@astro.ulg.ac.be
Philippe Demoulin	Tel. +32 4 366 9785	e-mail: demoulin@astro.ulg.ac.be
Bernard Lejeune	Tel. +32 4 366 9788	e-mail: lejeune@astro.ulg.ac.be
Emmanuel Mahieu	Tel. +32 4 366 9786	e-mail: mahieu@astro.ulg.ac.be
Ginette Roland	Tel. +32 4 342 2594	e-mail: roland@astro.ulg.ac.be
Christian Servais	Tel. +32 4 366 9784	e-mail: servais@astro.ulg.ac.be
Rodolphe Zander	Tel. +32 4 366 9786	e-mail: zander@astro.ulg.ac.be

URL: http://girpas.astro.ulg.ac.be/