The Jungfraujoch Station as part of the Swiss Atmospheric Radiation Monitoring CHARM program

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Introduction

To discern between natural and anthropological influences on the Earth's climate, it is of paramount importance to monitor the main contributors of radiative forcing, the Sun, and the greenhouse effect, in order to determine the magnitude of the changes. The main greenhouse gases are water vapor (the most important contributor), carbon dioxide, methane, nitrous oxide, and (in recent years) halocarbons. A change in the greenhouse effect is amplified by water vapor feedback because of the strong temperature dependence of the water content of the atmosphere. This has important consequences for the greenhouse effect for regions such as the Alps. As the temperature decreases with altitude, water vapor feedback plays a much less important role over elevated terrain. Thus, for the direct monitoring of the greenhouse effect, an elevated observing station is more appropriate because it is much less influenced by radiative feedbacks.

In order to scientifically evaluate the magnitude of these problems, the World Meteorological Organization (WMO) has reacted by creating new, or updating older programs such as the Global Atmosphere Watch program (GAW) and the World Climate Research Program (WCRP) with the Baseline Surface Radiation Network (BSRN). Switzerland has agreed to contribute to those two WMO programs, and this has led to the creation of a Swiss Atmospheric Radiation Monitoring program called CHARM with the participation of the Swiss Meteorological Institute SMI, the Physikalisch- Meteorologisches Observatorium Davos / World Radiation Center PMOD/WRC, the Geographic Institute of the Swiss Federal Institute of Technology GIETHZ, and the Institute of Applied Physics, University of Bern IAP.

The CHARM network represents an ambitious program where the Jungfraujoch station has a very particular and important position as an outstanding reference site. After having dealt with the many teething problems encountered due to the extreme climatic conditions found at this altitude, the whole system has been put in operation on 1.1.1997. Subsequent improvements have been implemented until recently where a more or less final state has been reached.

Measurements facility at Jungfraujoch

In order to achieve optimal protection of the instruments measuring direct radiation needing sun-trackers, the installation of a dome was chosen. The measurement infrastructure includes therefore two main components that can be easily identified on the following pictures:

- a dome of diameter 260 cm mounted on a cylinder of 250 cm diameter. The total height of the system is 300 cm. The management of the dome is fully automated and depends only on meteorological parameters such as outdoor temperature, wind speed and direction, precipitation, temperature of the sky, sunshine duration, etc., and technical parameters such as electrical network state, UPS, etc. A CCD camera is further installed on the Sphinx terrasse and oriented toward the dome, allowing for remote visual control of the state of the equipment through internet (http://sma001.unibe.ch).

- one external measurement bridge (height 300 cm, length 250 cm) located at the north side of the dome, which supports all instruments with a 2π field of view as well as the conventional meteorological instruments mentioned above.


General and detailed pictures of the Jungfraujoch CHARM radiometric measurement facility.

The following measurements are presently being performed:

- within the dome: two sun-tracker units are supporting one absolute cavity radiometer PMO6 (PMOD/WRC) traceable to WRR[1], one pyrheliometer CH1 (Kipp & Zonen), one UVee[2] Biometer (Solar Light Co) mounted in a tube for the measurement of the direct component and one set of Precision Filter Radiometers (PMOD/WRC) measuring at 16 wavelengths for the determination of the aerosol, ozone, and water vapor total content of the atmosphere. The lower tracker is available for calibration activities of the PMOD/WRC.
- on the external bridge: UVee Biometer, UV-A Biometer, pyranometer CM21 (Kipp & Zonen) and pyrgeometer PIR (Eppley) upgraded by PMOD/WRC for more accurate measurements. All these instruments measure hemispherical downward irradiance. Identical sensors have been recently installed on the north side of the bridge with fixed shading systems in order to measure at least at solar noon the diffuse component and to compare directly with the “global” instruments. Meteorological instruments are also installed on the bridge: sunshine duration, precipitation with three present weather detectors, temperature and humidity, ice accretion detection and, located at the west end of the terrasse, wind speed and direction with a Pitot tube and a 3D sonic anemometer. Last but not least, a Global Positioning System GPS antenna has been installed at the west end of the bridge, which should yield information about columnar water vapor content of the atmosphere at this site in the near future (see below).

[1] World Radiometric Reference
[2] Erythemal effective UV irradiance

Preliminary results

As the available measurement period is too short to yield any meteorological information from a statistical point of view, the following results must be considered as a presentation of the information potential available in the future.

A- Long-wave Irradiance LW

Measurements of the downward long-wave irradiance are performed on the external bridge. A major improvement in the calibration accuracy of the pyrgeometers was achieved a few years ago at the PMOD/WRC [1], which allows for an estimated absolute accuracy of those measurements better than 3 W/m2 (~1%) in operational mode.

Figure 1 displays the monthly mean values of the daily mean LW irradiance for the available period. Similar values obtained at the BSRN station Payerne (490 m a.s.l.) are also displayed for comparison purposes [2]. Intensities at intermediate altitudes are measured within the Alpine Surface Radiation Budget ASRB network, which is jointly operated by the PMOD/WRC and SMI: this special network represents an important component of the CHARM program (the Jungfraujoch and Payerne stations are also part of the ASRB network).

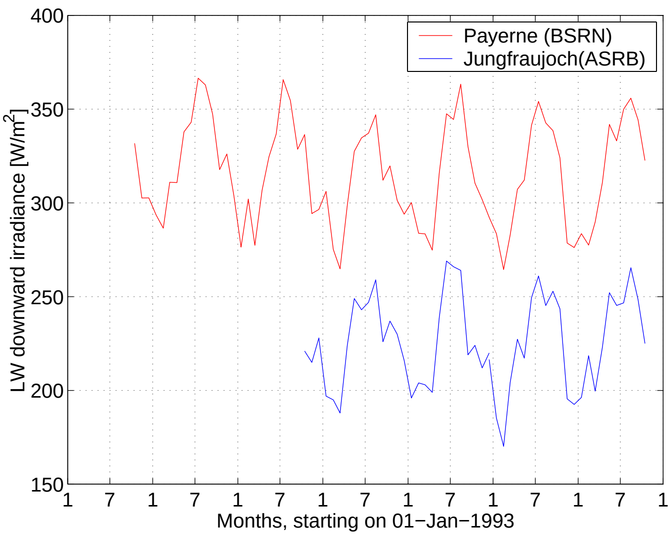

Figure 1: Variation of the LW monthly mean irradiance at Payerne and Jungfraujoch.

The warmer sky temperature seen at Payerne is due to the amount of water vapor in the Planetary Boundary Layer and the amount and/or type of clouds. A major study is presently underway at PMOD/WRC [3] in order to analyze the gradient of the IR irradiance as function of the altitude and of the meteorological conditions. The obtained algorithms and results will represent basic tools for the detection of possible future climatic changes. Another study [4] deals with the longer record already available at the BSRN station Payerne.

B- Short-wave Irradiance SW

Short-wave radiation measurements are performed on the external bridge for the global irradiance and, within the dome, the direct irradiance. This means that the former yields a continuous record, while the latter measurements are available only when the dome is open. The absolute radiometer is used for calibration transfer by comparing it with the pyrheliometer when the intensity is above 400 W/m^2 and the standard deviation of the pyrheliometer intensity remains under 5 W/m^2 during the integration period (2 minutes), in agreement with the BSRN specifications.

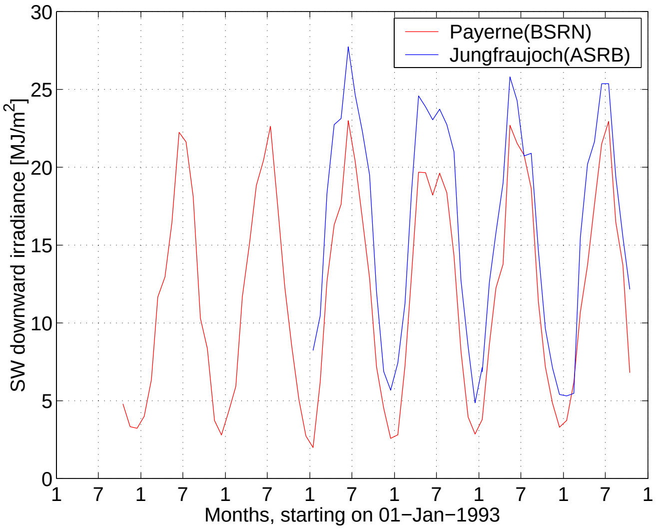

Figure 2.1: Monthly mean values of daily totals of the global irradiance for Jungfraujoch and Payerne.

Figure 2.1 displays the monthly mean values of the daily total of the global irradiance for stations Payerne and Jungfraujoch. It is interesting to note that the irradiance is not much higher at the Jungfraujoch than at Payerne. This is to be related to the different climatic conditions prevailing at both stations. Figure 2.2 displays the daily totals of sunshine duration for both stations: while the mountain station records much more sun at low solar elevation than the low-land site in winter, the situation is reversed in summer due to the regular build-up of convective clouds within the Alps. It must be also kept in mind that for cloudy situations the Jungfraujoch station is usually within the clouds and measures therefore very low irradiance intensities.

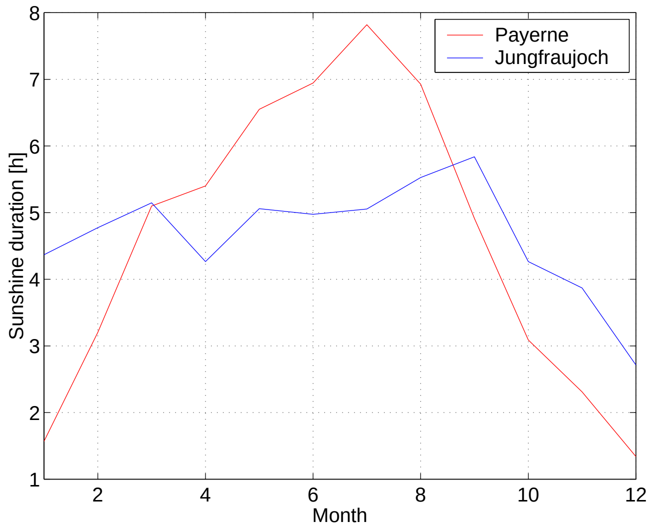

Figure 2.2: Annual variation of the monthly mean of the daily total of sunshine duration for the same station as in Figure 2.1.

C- Ultraviolet range

Measurements in the UVee irradiance are also performed on the external bridge for global irradiance and inside the dome for direct irradiance. Figure 3 displays the monthly mean values of the daily UVee total irradiance for solar zenith angle < 85 degrees for all the stations presently available in Switzerland. The very high values measured at Jungfraujoch in summer are due to the altitude and to the albedo of the surrounding. It must be kept in mind that, in the UVee range, the solar altitude and the diffuse component play a much more significant role than in the visible range due to the very strong Rayleigh scattering at these wavelengths. For clear weather conditions, the four parameters influencing the ultraviolet irradiance are the total ozone amount, the aerosol optical depth, the horizon, and the albedo of the surrounding region, the last two effects influencing the diffuse, and consequently the global components only.

The data collected at Jungfraujoch in 1999 has been analyzed for clear sky conditions. Thanks to the high elevation of the station, atmospheric conditions with extremely low aerosol content have provided a possibility to verify ultraviolet irradiance models under simplified conditions. This fact is essential in order to determine the sources for discrepancies between model and measurements.

The accuracy of the model has been tested using total ozone amounts measured at Jungfraujoch with a Microtops II (Solar Light Co.) and at LKO Arosa[3] with an official Dobson spectrophotometer in winter 1998/1999. In Figure 4, the impact on the model of the two ozone data-sets is displayed: the use of locally measured ozone values increases both the daily stability (shorter error bar length) and the long term stability of the computed ratios (median of the daily results). The quality of the results illustrates both the coherency of the model and the need for local ozone measurements.

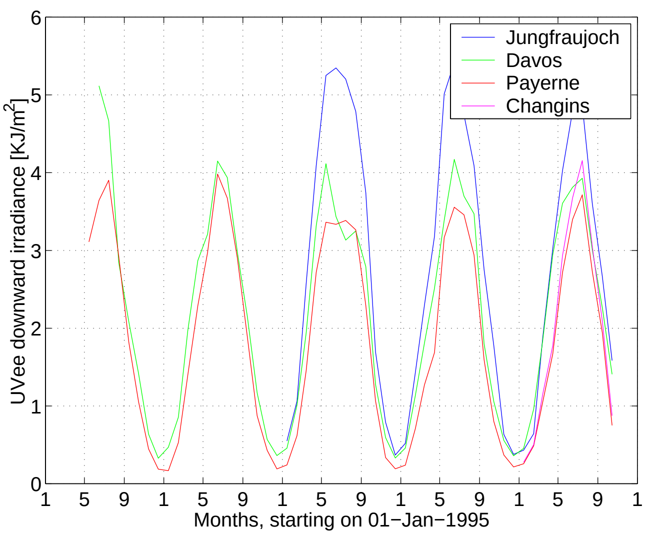

Figure 3: Variation of the monthly means of the daily total UVee global irradiance at stations Jungfraujoch, Davos (1600 m a.s.l.), Payerne, and Changins (430 m a.s.l.).

[3] Licht Klimatisches Obervatorium LKO, Ozone station, Arosa, Switzerland.

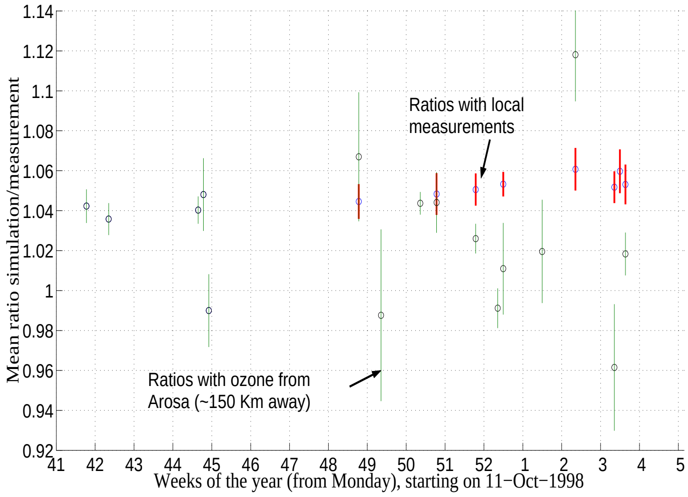

Figure 4 : Ratios between simulation and measurements of UVee mean daily direct irradiances using Arosa (green) and local (red) total columnar ozone values under clear sky conditions.

Based on this result, the total ozone columnar amounts can be computed for the whole available Jungfraujoch data-set and compared with the Arosa measurements as displayed on Figure 5 where the differences between the two locations are clearly illustrated.

The broadband UVee irradiance measurements performed at Jungfraujoch have confirmed the validity of simple models for conditions when aerosols play a minor role in the solar irradiance extinction. Further analyses are presently being performed to provide better determination of the impact of the zonal albedo perceived by the instrument. Comparisons between the Davos and Jungfraujoch measured and computed irradiances should help to characterize the influence of the "strong-or-weak" types of albedo in the UV range (for snow, respectively no-snow landscape coverage) and help to determine with more accuracy which portion of the area surrounding the sensor is important in terms of the albedo effect.

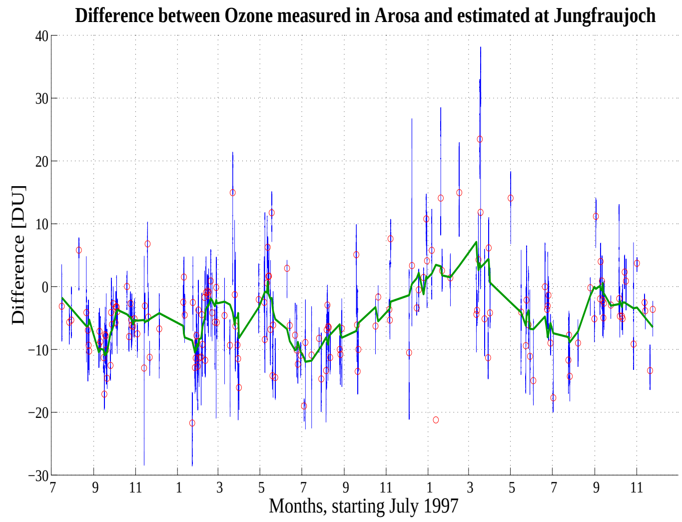

Figure 5 : Running mean of the differences (green curve) between daily means of total ozone measured at Arosa and computed at the Jungfraujoch with the direct UVee irradiance model (blue error bars).

D- Spectral measurements

Spectral optical depth measurements are performed using sun photometers mounted on an automatic tracker within the dome. Operational measurements of Aerosol Optical Depth AOD were started in 1994 using a 3-channel instrument SPM (368, 500, and 778 nm). In March 1999, a set of three new Precision Filter Radiometer PFR designed at PMOD/WRC, was installed. The PFRs have an improved design, including, among other things, shutter mechanism and increased filter stability [5]. These instruments yield the full set of twelve wavelengths recommended by the WMO (368 to 1024 nm). Four additional channels in the UV will be added in the nearfuture, allowing for a second method of total ozone determination (see above).

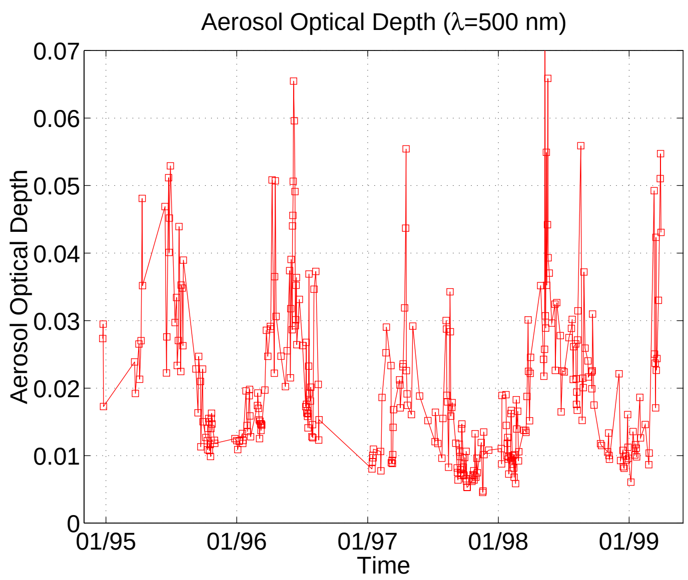

Figure 6: Daily averaged AOD at 500 nm measured between 12/94 and 03/99 at Jungfraujoch.

Because of the station altitude, Jungfraujoch is considered to be prevailingly in the free troposphere during the winter. Thus Jungfraujoch is well suited for studying stratospheric aerosols. Figure 6 shows the variation of daily averaged AOD at 500 nm in the period from 1994 to 1999. The seasonal cycle with higher atmospheric turbidity in summer is characteristic for Jungfraujoch. Such a variation was also found in the epiphaniometer data at the same site [6]. Inspection of AOD values obtained during winter indicates that background aerosols were still affected by the Mt. Pinatubo volcanic eruption until winter 1996/97, which is consistent with AOD time series obtained at Davos.

Besides AODs, the PFRs allow deriving columnar water vapor content CWV from channels inside water vapor absorption bands. Data obtained during the first months of operation have yielded promising results. Figure 7 shows the monthly averaged CWV obtained with SPMs or PFRs at Jungfraujoch, together with similar results recorded at Davos and Bern.

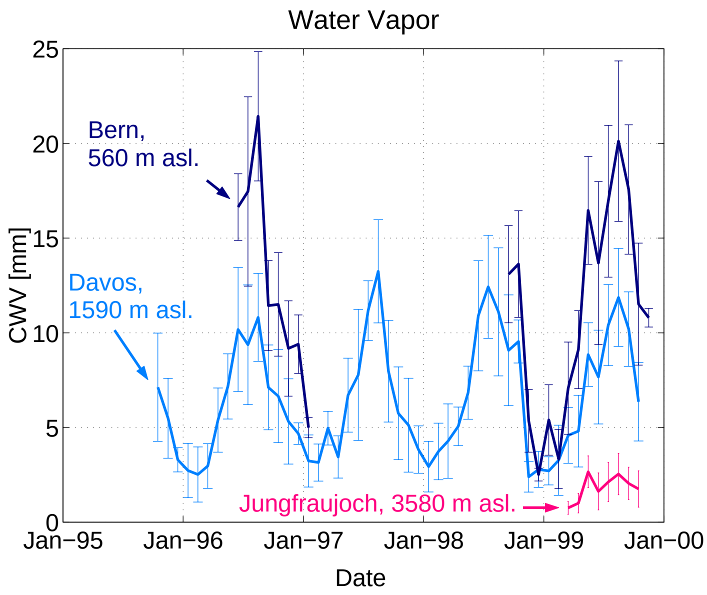

Figure 7: Monthly averaged CWV values obtained at Jungfraujoch, Davos, and Bern. The error-bars represent the standard deviation of CWV within one month indicating a high CWV variability.

For the period between March 1999 and October 1999, CWV was retrieved at Jungfraujoch on 69 days yielding a mean value of 1.78 mm (1σ=1.01 mm). This is considerably lower than the values obtained at Davos and Bern, whereas a similar seasonal variation is observed at all three sites. Low CWV values are normally recorded during wintertime due to a dryer atmosphere as compared to summer. Because the tropospheric water vapor density strongly decreases with increasing altitude, the difference in absolute CWV content reflects the altitude difference of the stations.

However, in order to obtain reliable CWV climatology for Jungfraujoch, more data over an extended period has to be acquired. Furthermore, the GPS antennas installed at all these sites will allow for direct comparisons in the future.

References:

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