Name of research institute or organization:

Federal Office of Meteorology and Climatology MeteoSwiss, Payerne

Title of project:

Global Atmosphere Watch Radiation Measurements

Project leader and team:

Dr. Laurent Vuilleumier, project leader
Dr. Daniel Walker

Project description:

In 2009, radiation measurements at the Jungfraujoch were performed satisfactorily, except for direct solar irradiance measurements. Part of the problems affecting direct irradiance measurements were similar to those mentioned in the 2008 report of the Global Atmosphere Watch radiation measurements program to the International Foundation HFSJG (data acquisition system problem for solar photometry). These problems were solved in spring 2009. Unfortunately, the astronomical cupola that protects the sun trackers for direct irradiance measurements had recurrent failures that required a complete update of the cupola control system that was achieved end of 2009. The data availability for radiation parameters reached 90.2% at the Jungfraujoch in 2009 (01.11.2008 –31.10.2009), even when including the problematic direct solar irradiance measurements.

The quality control and analysis procedures that were in development in 2008 were completed in 2009. This system is an automatic end-to-end quality control (QC) system that verifies all steps of data transmission, and estimate the plausibility of the data based on physical limits, built-in redundancies, links between measured parameters, and instruments housekeeping values (power consumption, instrument temperature, etc.). This system has a simple web interface available within MeteoSwiss intranet (not accessible from addresses outside MeteoSwiss network) that allows the operator to quickly assess the performance of the system (see Fig. 1). This system will allow a quicker detection of problems and failures, as well as lead to an improved data quality.

Run description

begin	●	Mon Dec 28 05:12:00 MET 2009
date check	●	QC tests from 20091227 to 20091227
Exist file/dir	●	All necessary files exist
QC group	●	Starting QC group SWLW
create mat proc	●	creating /proj/pay/CHARM/D_ged_qual_eval/run_ged_qc_shrt_trm_alrm.m
QC test	●	No problems detected by QC
matlab	●	executing QC test matlab procedure
matlab	●	output file check: ged_qual_plot('/proj/pay/CHARM/D_ged_qual_eval/D_day/D_SWLW_chk/qc_chk_20091227.mat')
QC group	●	Starting QC group UV
create mat proc	●	creating /proj/pay/CHARM/D_ged_qual_eval/run_ged_qc_shrt_trm_alrm.m
QC test	●	JUN_UVAglo (UVAglo); 1440x QC set as invalid, hklm, JUN UVAglo TUVAglo;
QC test	●	PAY_UVBdif (UVBdif); 1293x Flagged as invalid;
matlab	●	executing QC test matlab procedure
matlab	●	output file check: ged_qual_plot('/proj/pay/CHARM/D_ged_qual_eval/D_day/D_UVB_chk/qc_chk_20091227.mat')
QC group	●	Starting QC group PFR
create mat proc	●	creating /proj/pay/CHARM/D_ged_qual_eval/run_ged_qc_shrt_trm_alrm.m
QC test	●	JUN_pfr_wl_o2 (wl311); 69x Flagged as invalid;
matlab	●	executing QC test matlab procedure
matlab	●	output file check: ged_qual_plot('/proj/pay/CHARM/D_ged_qual_eval/D_day/D_PFR_chk/qc_chk_20091227.mat')
exit	●	Mon Dec 28 05:31:06 MET 2009

Figure 1. Interface of the automatic QC system used for the GAW-CH radiation measurement program.

Within the framework of the European Science Foundation COST Action 726 (Long term changes and climatology of UV radiation over Europe), the radiation monitoring program conducted a study of the applicability of erythemal ultraviolet (UV) reconstruction techniques in Switzerland. Such techniques are used to infer the UV irradiance at time when, or location where this measurement is not performed. This project resulted in a PhD thesis whose main results are summarized below.

Since the amount of solar UV radiation reaching the top of the atmosphere is relatively well-known, estimating the amount of UV radiation at the ground implies being able to quantify how the most influential parameters for the transfer of UV radiation in the atmosphere evolve. These parameters are the total atmospheric ozone column, the cloudiness, the ground surface reflectance and the atmospheric turbidity. The ozone atmospheric column is monitored since many years, and is relatively well understood. In Switzerland, the complex topography and the quickly varying meteorological conditions result in the cloudiness and the surface reflectance as being the most challenging parameters to evaluate.

Particular attention has been focused on these two parameters and methods have been devised for estimating their influence on UV radiation on the ground. An effective surface reflectance was derived from the amount of snow cover and used in model simulation of clear-sky UV radiation transfer. Concerning cloudiness, an empirical method was developed for inferring the effect of clouds on UV radiation based on measurements of the total solar short-wave (SW) irradiance. This method was developed because of the difficulty of theoretically modeling the influence of cloud on radiation transfer, and because SW irradiance has been measured at many locations in Switzerland since the 1980’s.

The results of the project are based on measurements from four stations in Switzerland, where UV irradiance is measured operationally by the Federal Office of Meteorology and Climatology MeteoSwiss (Payerne, Davos, Jungfraujoch, and Locarno-Monti). These stations are representative of different climate regions in Switzerland such as high mountain, alpine valley, Swiss Plateau, and low elevation location south of the Alps.

The core of the project was the study of cloud effects in the UV based on the atmospheric transmission of SW radiation. These cloud effects were investigated by assessing the relationship between cloud modification factors (CMFs) in the SW and UV. The cloud modification factor is the ratio between a real observed irradiance and the theoretical estimate of the irradiance that would be observed if all conditions were identical to the observed situation except that the cloud would be absent (clear-sky situation). The link between CMF-SW and CMF-UV was parameterized separately for scattered clouds and for strong cloud attenuation, which is usually linked to overcast conditions. The following findings were obtained:

- Observed cloud effects on UV and SW radiation show the same characteristics at all studied stations in Switzerland.
- The relationship between CMF-SW and CMF-UV mainly depends on the solar zenith angle (SZA), while other local conditions, such as total ozone, surface reflectance, and the topography are only of minor importance.
- Observed cloud effects on UV radiation are smaller compared to SW radiation. In other words, for a given cloud situation, CMF-UV is closer to unity (no cloud effect) than CMF-SW. This observation confirms theoretical considerations and previous modeling results also at the same four studied stations.

- The relationship between UV and SW cloud effects changes for different cloud situations: a given change in the cloud optical depth for strong cloud attenuation (overcast conditions) results in larger CMF changes for UV than for SW radiation. The opposite is true for scattered cloud conditions, when direct sunlight often passes through the broken cloud cover.
- As a consequence, the CMF relationship was separated into light and strong cloud cover situation by our regression analysis using an iterative procedure on observed CMF data. The location of the separation point as determined by our analysis agrees well with an independent sorting of the CMF data into overcast and scattered situations by a cloud detection tool based on infrared radiation.
- Our empirically determined relationship between CMF-SW and CMF-UV shows strong similarities with results of another fully model-based approach. However, the locations where the relationships have their strongest bends clearly differ between the two methods for large SZAs. These differences are most likely related to the fact that the modeling approach uses exclusively stratiform clouds, while our method is based on a wide range of real cloud situations, including scattered clouds.

Our empirically-derived relationship between CMF-SW and CMF-UV can be applied generally since the most important influence comes from SZA, which can be derived for any location.

The results of the study of cloud effects allowed developing a semi-empirical all-sky model for deriving erythemal UV, wherever SW radiation is observed and information on total ozone and surface reflectance is available. In validations with measured UV irradiance independent of those used for developing the model,

- estimated UV radiation showed RMS errors to observations smaller than 7 mW/m2 (< 11.9%) at the four studied stations and a time resolution of 10 minutes;
- the performance of the model improved (RMS 8.4–9.7%) for situations with small SZAs (<42°); and
- the aggregation in daily doses led at all four stations to a good agreement with observations with RMS between 5.4 and 8.0%.

These validation results confirm that the derived method successfully describes the short-term variability of UV radiation due to clouds (see Fig. 2). Furthermore, UV can satisfyingly be estimated at all four stations covering climate conditions ranging from the Swiss lowlands to the high-alpine environment. The validation showed especially good results for small SZAs corresponding to periods with higher UV doses, which are more relevant for public health.

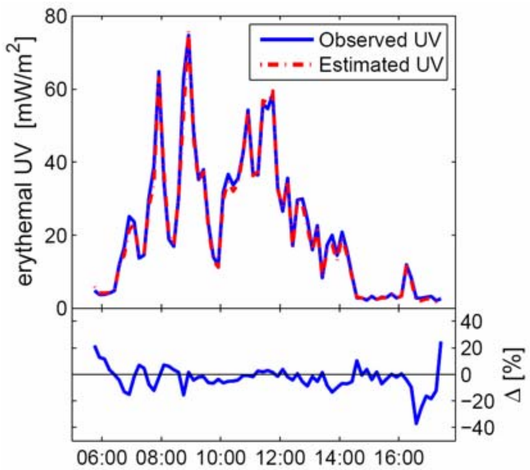

Figure 2. Example of agreement between UV erythemal irradiance estimation and observations for a typical day with varying cloud coverage (25/06/2007).

The semi-empirical all-sky model

mentioned above was used for reconstructing UV radiation at the four stations for the time period between 1981 and 2007. The reconstructed UV time-series and the used proxy-data were analyzed for monthly trends using non-parametric Mann-Kendall tests and Sen's slope estimations.

- Positive decadal trends for the median daily UV values between 5.6 and 11.5% were found for the months of the first half of the year (January-June). The trend analysis revealed largest relative UV changes for March with a decadal increase ranging from 8.6 to 11.5%. In May and June, the UV-index increased by 0.54-0.85 units over the last 27 years.
- The analysis of observed total ozone showed generally negative trends for the months of the first half year, which are significant for May and June. Afterward, the trends for the months July to December are smaller and statistically non-significant. For the months May and June, negative decadal trends of 2.8 and 1.9% were found.
- Most trends for SW radiation are found to be non-significant by Mann-Kendall test. However, the trends of the first half year tend to be positive and a significant increase is found for February and March at Jungfraujoch and Locarno-Monti (6.5 to 6.9% dec-1).
- The derived trends for the annual data are often significant, especially for UV and total ozone, but the monthly trends are quite inhomogeneous and therefore reduce the actual significance of the annual trends.

The temporal changes of UV radiation at the four stations in Switzerland are comparable with results of previous studies and at other locations. The impact of an increased in UV Index of 0.54-0.85 (close to 1 UV index unit) for May/June can be illustrated by the reduction of the sunburn-time: when the UV-Index is increased by 1 unit at Jungfraujoch for May and clear-sky conditions, the sunburn time is reduced by 3 to 6 minutes (~20%).

The temporal evolution of observed SW radiation and total ozone was identified as being statistically non-significant for most stations and months. Thus, the significant increase of UV radiation found at most stations in January–June results from the combination of mainly non-significant increases of SW radiation and reductions of ozone. On the other hand, a statistically significant decrease in regional snow cover counteracts the effects from SW and ozone changes.

The reflectivity of the ground directly affects the down-welling irradiance by multiple reflections at the surface and back-scattering in the atmosphere above. Surface reflectivity is thus an important parameter for this project, and it is strongly determined by the presence and absence of snow. This required the development of a scheme for estimating the regional snow distribution in the surrounding of any location in Switzerland on a daily basis. This scheme is based on observed snow-depths and is consequently independent of satellite data.

- The temporal evolution of the regional snow distribution was studied using a method based on observed snow depth in combination with a digital elevation model.
- Time-series of snow distribution in Switzerland were reconstructed back to 1980 and validated against snow observations and satellite snow masks. In the cross-validation during winter periods (November–April), a probability of detection of

0.96 and a false alarm rate (FAR) of 0.15 were obtained. The validation of modeled snow coverage against satellite observations yielded an agreement between 69 and 97%.

- The trend analysis of reconstructed time-series using Mann-Kendall tests showed a decrease of the snow cover between -10 and -15% in the lowlands north of the Alps. The negative trends in the more elevated alpine regions are smaller (1–8%) and statistically non-significant ($p > 0.1$).

This confirms that the regional snow cover can successfully be derived over the last 28 years in Switzerland, providing valuable information for describing the seasonal variability in surface reflectivity on a larger spatial scale. Nevertheless, it is still difficult to achieve good modeling results in the lowlands, since not only the occurrence of snow is infrequent, compared to alpine regions but also the amount of snow is lower. Therefore both, the occurrence and the persistence of snow at these low altitudes depend stronger on local effects, which are difficult to assess with this method.

Key words:

Solar irradiance, ultraviolet, visible, infrared, spectral irradiance, precision filter radiometer (PFR), pyranometer, pyrheliometer, UV biometer, total aerosol optical depth (AOD), integrated water vapor (IWV).

Internet data bases:

http://wrdc.mgo.rssi.ru/ (World Radiation Data Centre – WRDC)
http://www.iapmw.unibe.ch/research/projects/STARTWAVE/startwave_dbs.html (IWV STARWAVE data)

Collaborating partners/networks:

- Radiation data submitted to the World Radiation Data Centre (WRDC, St. Petersburg, Russian Federation) within the framework of the Global Atmosphere Watch.
- European Science Foundation COST Action 726: “Long term changes and climatology of UV radiation over Europe” http://www.cost726.org/
- Study of solar photometry (aerosol optical depth) and longwave infrared radiative forcing in collaboration with the "Physikalisch-Meteorologisches Observatorium Davos" (PMOD) World Radiation Center (WRC).

Scientific publications and public outreach 2009:

Refereed journal articles and their internet access

Gröbner, J., S. Wacker, L. Vuilleumier and N. Kämpfer. Effective atmospheric boundary layer temperature from longwave radiation measurements, *J. Geophys. Res.*, **114**, (2009), D19116,

http://dx.doi.org/10.1029/2009JD012274.

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Gröbner, J., S. Wacker, and L. Vuilleumier, Effective boundary layer temperature from atmospheric water vapour emission. *Geophys. Res. Abstr.*, Vol. 11, EGU2009-10014-1. European Geosciences Union General Assembly 2009, Vienna, Austria, 19 – 24 April 2009.

Walker D., L. Vuilleumier, C. Marty, S. Broennimann and U. Lohmann, Distribution and Evolution of Surface Reflectivity and Regional Snow Cover in Switzerland between 1980 and 2008. MOCA-09 Joint Assembly IAMAS-IAPSO-IACS, 19.-29. July 2009, Montréal, Canada.

Walker D., L. Vuilleumier and S. Broennimann, All-sky Model for Erythemal Ultraviolet Radiation (UV) in Switzerland. MOCA-09 Joint Assembly IAMAS-IAPSO-IACS, 19.-29. July 2009, Montréal, Canada.

Theses

Walker, D., (2009) Cloud effects on erythemal UV radiation in a complex topography. PhD thesis. Dissertation no. 18415, ETH Zurich.

Data books and reports

"Ozone, rayonnement et aérosols (GAW)" in Annalen 2008 MeteoSchweiz, Zürich SZ ISSN 0080-7338 pp. 111–124.

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