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The Norwegian UV-monitoring Network: QC and Results for the Period 1996-2011

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Abstract. The Norwegian UV-monitoring network, implemented in 1995, has provided up to 16 years measurement data from currently 9 stations located from 59º N to 79ºN. The intention is to provide measurements of high scientific quality for the spatial and temporal variability of UV and for information to the public about solar exposure. The stations are equipped with GUV multiband filter radiometers from Biospherical Instruments Inc. The irradiance scale is maintained with a travelling reference instrument, traceable to the QASUME European reference spectroradiometer. Blind test intercomparisons of UV index measurements at the local sites have shown close agreement with the QASUME unit. Changes in yearly UV doses for two of the coastal stations have shown an upward trend for the period 1999-2011. Changes in cloudiness had the largest influence on UV doses in this period.

Keywords: UV index, GUV, UV network, Multiband filter radiometer.
PACS: 07.60.Dq

INTRODUCTION

Ultraviolet radiation has effects on human health, terrestrial and aquatic ecosystems, biogeochemical cycles, air quality and materials [1]. Assessment of UV effects requires UV measurements, which may come from satellite-borne observations providing a global coverage, or ground-based instrumentation representing the local UV climate. Ground-based measurements are the most direct and reliable way of assessing the local UV climate [2]. Implemented as networks of quality controlled UV-monitoring stations, the ground-based data sets provide a basis for satellite- and model validations, required for e.g. UV-effects studies on the population. UV-monitoring networks are currently operating on several continents. International co-operation has resulted in great improvements in measurement accuracy and harmonization of irradiance scales. However, the maintenance of a stable and homogenous irradiance scale is still challenging. This paper gives an overview of the Norwegian UV-monitoring network and how the quality control system is implemented.

NETWORK LOCATIONS AND INSTRUMENTS

The Norwegian UV-monitoring network was implemented in 1995. Locations were selected in order to represent different climate zones (arctic, alpine, coastal and inland) and recreation areas, where technical personell and suitable infrastructure were available. A map of the network locations is shown in figure 1. The stations are equipped with multiband filter radiometers (MBFR) of model GUV541 and GUV511 from Biospherical Instruments Inc. [3], providing 1-minute averaging intervals over 5 spectral bands with nominal peak responsivity at respectively 305 nm, 313 nm, 320 nm, 340 nm and 380 nm. A number of data products are available, using an inversion algorithm suggested by Dahlback [4]: UV Index, erythemally weighted daily UV doses, cloud modification factors and total ozone. UVI and UV doses for the period after 1995 are displayed on the internet, http://www.nrpa.no/uvnett/default_en.aspx. The data set has also been used for RT model validations in the COST-726 action.

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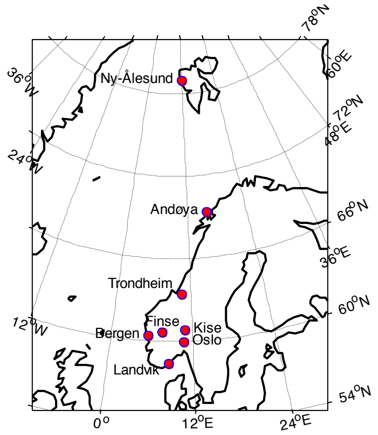

FIGURE 1. Location of multiband filter radiometers in the Norwegian UV-monitoring network.

UV IRRADIANCE SCALE

The maintenance of a homogenous and stable irradiance scale for the different stations, has been accomplished using the network's travelling reference instrument (TRI) and by taking part in national and international intercomparison campaigns.

The relative, long term changes in responsivity of TRI's detector channels is based on a group of in total 14 1000 W quartz tungsten halogen (QTH) lamps introduced in the period from 1995 and a validation of which of the lamp measurements that give the most consistent results. The validation includes different steps: 1. Measurements 3-4 times per year of the TRI and 2-3 of the GUVs permanently installed at NRPA, in order to assess consistency of results from different lamps and different GUVs. 2. The lamp current is monitored in order to detect anomalous performance of the lamps. 3. Two UV-optical feedback regulated QTH lamp systems purchased in 1999 from OmTec GmbH serves as a reference for the validation of long term stability of lamps. The OmTec lamp housings incorporate a thermoelectrically cooled, unfiltered SiC-photodiode. SiC is currently one of the most stable photo detector materials, with peak responsivity near 300 nm and being insensitive to radiation above 400 nm. Over the period 1999-2011 the OmTec lamps have given consistent results within ±0.5 % for the relative change in responsivity for the 5 detector channels of the TRI. 4. Annual lamp and solar measurements of the TRI, provided by the manufacturer Biospherical Instruments Inc. in San Diego, in order to have an independent assessment of long term stability of the TRI.

The absolute calibration for the period 1995-2011 is based on the European travelling reference spectroradiometer QASUME [5] during the FARIN international solar intercomparison in Oslo in 2005 [6] and the long term evaluation of drift factors based on annual visits with the TRI. Formerly, prior to the campaign in 2005, the absolute calibration of the TRI was based on clear sky spectroradiometer measurements in 2000, obtained with the Bentham DM150 spectroradiometer operating at the platform of the NRPA building (http://www.nrpa.no/dav/7dc81f9181.pdf). The absolute spectral responsivity factors and coefficients needed for UVI measurements with the station GUVs were then based on the TRI and individual characterizations of cosine and spectral responsivity in the optical laboratorium at NRPA. During the FARIN campaign in Oslo, all instruments were co-located with the reference spectroradiometer and characterized in the lab, enabling a homogenization of the time series at the different station locations. No further cosine and spectral responsivity measurements have been done since 2005. However, annual solar intercomparisons of the TRI and Bentham spectroradiometer at NRPA indicate unchanged performance as function of the solar zenith angle (SZA). Additionally, blind test intercomparisons of the TRI against the QASUME spectroradiometer visiting Ny-Ålesund in 2009 and Oslo in 2010 showed average agreement within ±1 % for the two campaigns ([7] and http://www.pmodwrc.ch/euvc/euvc.php?topic=qasume_audit).

ASSESSING LONG TERM DRIFT OF NETWORK INSTRUMENTS

The maintenance of a stable calibration scale is based on the TRI operating at every network location during the summer period. The method include 3 steps, combining observations with model simulations: First, the dark-current corrected raw signal of each of the 5 detector channels of the local instrument is divided by the corresponding drift-corrected signals of the TRI. Secondly, the observed ratios are simulated for clear sky conditions, total ozone amount and SZA at each sampling interval, applying look-up tables (LUTs) of response-convoluted spectra for each pair of instruments. The third step simulates the influence of real sky conditions when the cosine responses for the two instruments are different. Clear sky, overcast and radiation-enhanced sky conditions are treated separately, using the 380 nm output of the TRI and a LUTs for the quantification of the direct and diffuse components of global radiation at the measurement moments. Combining observed and simulated spectral ratios, i.e. dividing cosine corrected ratios for the real sky situation with the clear sky simulated ratios, the dependency on SZA, total ozone and sky conditions are equally reflected in observed and simulated ratios. The only discrepancy left in the ratios is a possible azimuthal dependency, which for most of the network instruments is small provided the two instruments have the same orientation. Hence, the ratios for station instruments having different response functions from the TRI become almost flat, reflecting the long term changes in absolute responsivity factors for the station instrument. Generally, the drift has been within ±5 % to ±20 % for most network instruments in the period 1995-2011. Figure 2 shows typical drift factors for one of the instruments.

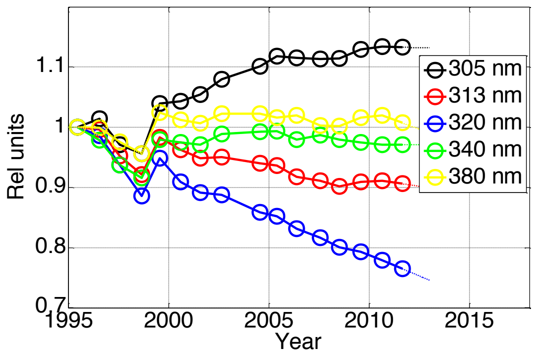

FIGURE 2. Typical long term change in absolute spectral responsivity for one of the MBFRs operating in the network. Step change between 1998 and 1999 is due to a water leakage inside the instrument.

COMPLEMENTATION OF GAPS IN MEASUREMENT SERIES

Gaps in measurements are nearly unavoidable for a network operating over many years and rough weather conditions. Generally, with exception of 2005 where all instruments were moved to Oslo for the intercomparison campaign, and during the initial period 1995-1998, the gaps accounted less than 3 % of the annual CIE-effective UV doses for the rest of the monitoring period. In order to bridge missing data and to evaluate measurements of UVI and daily UV doses, we applied the libRadTran RT-model [8] fitted to the climatological mean clear sky UVI observations, with ozone data from NASA's ozone mapping spectroradiometer instruments (TOMS and OMI), and UV cloud modification factors based on synoptic cloud octa observations recorded in the eKLIMA database of the Norwegian Meteorological Institute.

YEARLY UV DOSES FOR TWO COASTAL UV-STATIONS

Changes in yearly UV doses for the coastal stations in Bergen and Andøya are shown in Figure 3. The influence of the Gulf-Stream causes a relatively mild climate, with few days of snow conditions. Hence, changes in the surface albedo play a minor role compared with the influences from changes in total ozone amount and cloudiness. For both stations, changes in cloudiness have a much stronger influence on yearly doses than changes in total ozone amount, and the yearly variations are larger in the north.

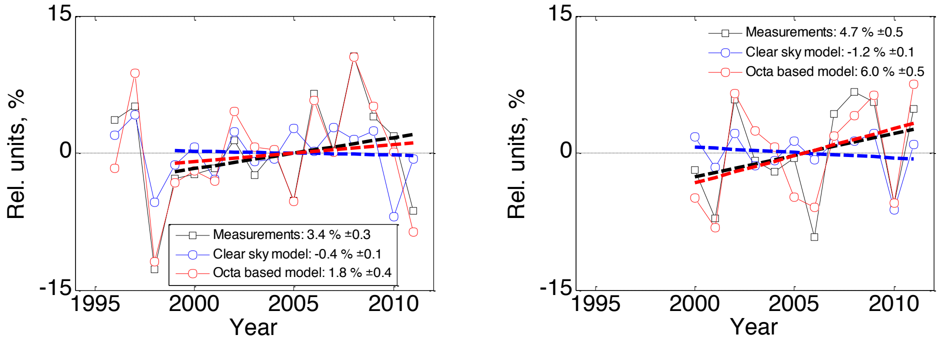

FIGURE 3. Relative changes in measured and modelled yearly UV doses for the instrument in Bergen (left panel) and Andøya (right panel). Numbers are decadal trends for the period 1999-2011.

SUMMARY

The use of the TRI has provided a homogenous and stable irradiance scale for the Norwegian network locations, traceable to the European reference spectroradiometer QASUME. Long term changes in absolute responsivity for local instruments were retrieved using a method of combining ratios of spectral measurements and model simulations. Changes in instrument responses were typically within ±5 % to ±20 % for the period 1995-2011. Blind test intercomparisons in Ny-Ålesund in 2009 and Oslo in 2010 revealed excellent agreement with the QASUME unit. RT-modelling based on cloud octa observations as proxy for cloud effects and NASA's total ozone observations correlate well with the variations in measured yearly UV doses. The two coastal stations in Bergen and Andøya show upward decadal trends for the period 1999-2011. Changes in cloudiness had a much larger influence than total ozone. The almost 16 year series of quality controlled UV-measurements provide a basis for satellite and model validations, validation of UV forecasting, climate trend analyses, information to the public, risk assessments and several other applications.

ACKNOWLEDGMENTS

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