UV Intercomparison and Integration in a High Arctic Environment (UV-ICARE)

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Final Report

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Scientific background and motivation

Solar UV radiation reaching the Earth's surface and total ozone column are important parameters in geophysical research, and usually they are jointly studied because their behaviour is bound to each other. The fraction of the solar UV-B irradiance observed at the ground (from about 300 to 315 nm) is significantly affected by the ozone column content and, together with the UV-A spectral band (315 – 400 nm) it has an impact on chemical reactions in the troposphere, as well as on all biological cycles [*Wolff et al., 1994; Bischof et al. 1998; Cadet et al., 2005*]. Ozone is also an atmospheric component that strongly influences the thermal regime of the stratosphere [*Brasseur and Solomon 2005*] and acts, on the other hand, as a reliable shield for all life on the Earth, protecting the organisms from harmful UV-C (100 – 280 nm) and UV-B (280 – 315 nm) irradiance [*Björn 2002*]. Moreover, the variations in ozone column can be considered as an important indicator of stratospheric dynamical processes. Although there is clearly much less interest in the ozone layer and UV radiation nowadays than in the late 20th century, it is important to continue the long-term programs of ozone and UV monitoring, because a full recovery cannot be expected before the middle of this century and occasionally (and as a consequence of climate change), extreme stratospheric conditions can occur, producing ozone-hole-like conditions also in the Arctic. This occurred, for example, in the winter 2010/11, when a total ozone reduction of close to 40% was recorded (e.g., Manney et al., 2011). As long as these conditions can occur, Arctic ozone depletion and UV enhancement will affect not only Arctic and Antarctic biota, but also the densely populated mid- and lower latitude regions of the Northern hemisphere [*Hansen and Chipperfield, 1999; Dahlback, 2002; Pommereau et al., 2013; Petkov et al., 2014*].

Historical, current, and new observations in Svalbard

Observations of ozone column have been performed, in periods, in Svalbard since 1950 (either Longyearbyen or Ny-Ålesund) and continuously since 1991 in Ny-Ålesund. Most of the historical ozone observations by means of Dobson spectrophotometer #8 between 1950 and 1968 were re-evaluated and published only in the recent past (Vogler et al., 2006). The 1985-1993 Dobson measurements in Longyearbyen are not usable for long-term trend studies due to insufficient quality-control routines, and only in 1995, the Dobson was moved to Ny-Ålesund and observations restarted under controlled conditions at the Sverdrup Station; they continued until 2005. In 1991, a SAOZ UV/Vis spectrometer, based on the differential optical absorption technique, was taken into operation in Ny-Ålesund. With this technique total ozone can be derived from zenith sky observations of the Chappuis band absorption (450 – 550 nm) by ozone at large solar zenith angles, thus providing ozone data during sunrise and sunset from mid-February until early May and from August to end of October. It excellently complements the standard total ozone observation techniques (Dobson, Brewer photo-spectrometers, multi-wavelength filter instruments) which rely on solar zenith angles typically less than 80 degrees and is especially suited to detect stratospheric ozone destruction in later winter/early spring at high latitudes (e.g., *Pommereau et al., 2013*). From 1995, NILU has operated a 5-channel filter instrument of type GUV from Biospherical Instr., mainly to monitor UV, but it also provides total ozone with high temporal resolution at solar zenith angles < 75 degrees. Ozone profile measurements were started in Ny-Ålesund by Alfred Wegener Institute in 1988 and are still continuing on a weekly basis. CNR-ISAC started combined UV/ozone measurements by means of the UV-RAD spectrometer in 2008. Measurements have been quasi-continuous, with two major gaps in 2011 and 2013. The instrument has 8 narrow-band channels (1 nm FWHM) in the 300-to-400 nm spectral range. In 2013, Italian researchers also started operation of a Brewer spectrometer. The instrument was calibrated in 2015, while regular observations supervised by CNR-ISAC only commenced in spring 2017. The UV-RAD and the Brewer spectrometers provide both total ozone and UV irradiance; results are published in e.g. *Petkov et al. (2016)*. Moreover, the Brewer is now used to derive ozone vertical distributions by means of the Umkehr method.

Continuous UV measurements were started up in 1995 in Ny-Ålesund by NILU, applying the already mentioned GUV instrument as part of the Norwegian UV monitoring network. Quasi-continuous UV irradiance data are available for all years except 2005, when the instrument participated in an inter-comparison campaign. Annual reports on the state of the ozone layer and UV irradiance are published by NILU via the Norwegian Environment Agency/Miljødirektoratet (e.g., *Svendby et al., 2017*).

At the Polish Polar Station in Hornsund, irradiance measurements, including UV, were started in 1996, using a Robertson Berge-type UV meter, and continued until 2002. In 2005, it was replaced with a Kipp&Zonen UVS-AE-T UV radiometer, supplied by a CM11 pyranometer; these instrument have continued observations until present. Results are presented in *Krzyścin and Sobolewski (2001)* and *Sobolewski and Krzyścin (2004-2005)*. In 2017, a new K&Z UVS-E-T UV radiometer was taken into operation (prior to this project), and this instrument will continue the measurement series after parallel operation of both UV meters. The new instrument is also participating in the UV-ICARE inter-comparison campaign.

In the frame of this project, a new UV monitoring instrument was purchased and put into operation by the University of Southern Bohemia at the new Czech Research Station (Julius Payer House) in Longyearbyen. After consultations with the project consortium, a Kipp & Zonen UVS-E-T UV radiometer was purchased and set up on the roof of the station. Measurements started in August 2017.

Figure 1. The geographic position of the stations measuring both solar UV irradiance and ozone column, or one of them.

At the Russian station in Barentsburg, a filter ozonometer M-124, operated by a research team from GGO, St. Petersburg, Russia, carries out ozone column measurements. To our knowledge, it is also planned to establish a UFOS spectro-radiometer providing the solar UV spectral irradiance. Unfortunately, the responsible research group did not have the possibility to join the inter-comparison campaign, despite offers with external resources from the UV-ICARE consortium. However, we intend to strengthen this cooperation on a longer-term perspective.

In summary, we now have a chain of instruments along the Western coast of Spitzbergen with a special concentration in Ny-Ålesund, where both UV irradiance, total ozone and ozone vertical distribution are measured continuously and in the frame of national and international monitoring networks. We, therefore, decided to take a new effort to homogenize all ongoing, and - if possible – historical UV and total ozone measurements by means of an inter-comparison campaign and also a retrospective homogenization of historical measurements. An additional aim of the UV-ICARE project is to establish a one-stop access point to measurements from this network via the SIOS Data Management System (SDMS), which is currently under development.

The UV-ICARE intercomparison campaign

An intercomparison campaign was already performed in Ny-Ålesund in 2009 [*Gröbner et al., 2010*] which showed a good quality of the participating radiometers. However, successive activities to homogenise these instruments were not made.

For this reason, a main purpose of the UV-ICARE project was to include all operational total ozone and UV irradiance monitoring instruments in a dedicated inter-comparison campaign limited to about one week duration. The natural choice for the location of the campaign was again Ny-Ålesund, as this site hosts most of the instruments and has excellent infrastructure for this kind of activities. Initially, it was intended to have the campaign at the beginning of the project in the first half of 2017, but due to the slightly delayed start (May 2017), combined with the necessary preparation time for a campaign (3-4 months) including obligatory formalities and most favourable weather and geophysical conditions to be expected, it was postponed until April 2018. The final decision was a one-week campaign from 16 to 23 April, 2018, and the location chosen was Sverdrup Station. The NILU instrumentation is mounted there on a long-term basis, together with CNR's UV-RAD instrument. The Brewer spectrometer is installed on the roof of the neighbouring building, the AWIPEV Station. For the purpose of the campaign, the two UVS-E-T UV meters from IGF-PAS and the University of South Bohemia were mounted on a platform in the immediate vicinity of the GUV and UV-RAD instruments. Figure 2 shows the instrument set-up after mounting on 17 April, 2018.

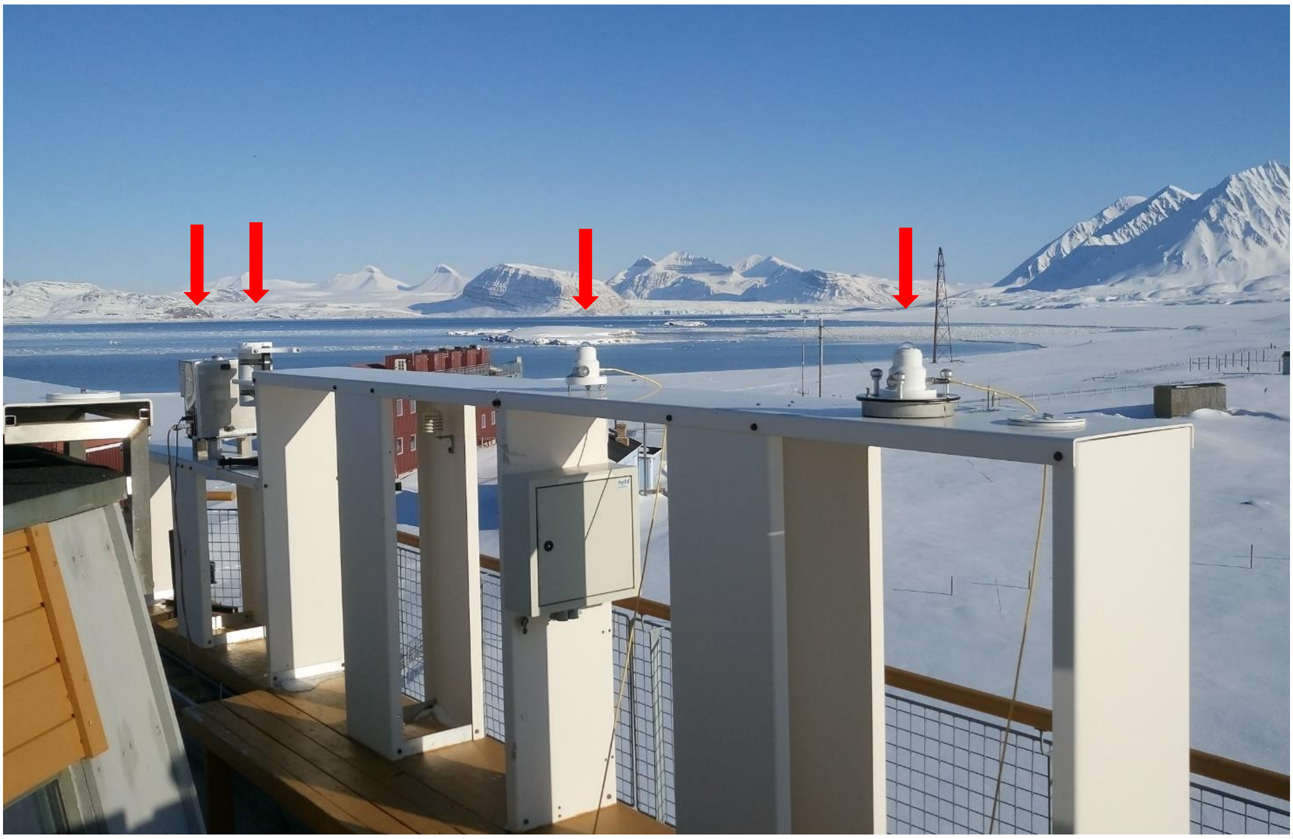

Figure 2. Mounting of instruments participating in the UV-ICARE inter-comparison campaign. Instruments marked by red arrows (from left to right): UV-RAD, GUV, UVS-E-T IGF-PAS, UVS-E-T Univ. South Bohemia.

Measurements with all four instruments started on 17 April, at 14:58 UT. Data from the UVS-E-T instruments were stored in the same logger and had to be read out regularly to be stored on a PC. For unknown reasons, the data sequence from 17 April, 19:28 UT until 18 April, 07:48 UT, was lost. On April 20, from 18:00 to 18:15 UT, both UVS-E-T sensors were covered to make a dark current measurement. While the IGF instrument displayed a rather constant dark signal of -0.65 mV, the dark signal of the USB instrument varied between -1 mV and +1 mV with a period of approximately 45 sec. Weather conditions varied a lot throughout the campaign. On 17, 18, and the first half of 19 April, long periods of clear sky prevailed. In the afternoon of 19 April, clouds came in. 20 April displayed both cloudy and partially sunny and overcast periods with snow, which continued through most of 21 April, causing partial icing of both UVS domes and the UV-RAD dome. At 17:15 LST (15:15 UT) the icing on the UVS domes was removed, followed by de-icing of the UV-RAD few minutes later. Inter-comparison measurements were terminated on 23 April, 2018, at 11:00 LST (09:00 UT).

Figure 3. "Dark signal calibration " of the UVS-E-T instruments during snow episode. The domes were covered with leather gloves and caps.

Total ozone was measured and calculated from the Brewer spectrophotometer (direct-sum, zenith-sky), the GUV, the UV-RAD and the SAOZ spectrometer. The standard method is Brewer direct-sun measurements. Previous comparisons have revealed that GUV values should be corrected by -2% for optimum agreement with Brewer-ds. Figure 4 shows all total ozone measurements 6-day period of the inter-comparison campaign. There is an excellent agreement between the corrected GUV and the Brewer ds-data. Brewer-zs better agree with GUV over a wider range of solar zenith angles, but also have an positive offset of about 2% compared to ds values. The two values derived from SAOZ in the late evening and early morning each day generally follow the other measurements, but have an offset of 2-3% compared to Brewer-ds and GUV. The UV-Rad data have negative offset of about -2% at the smallest SZA value and rapidly increasing negative offsets at larger solar zenith angles.

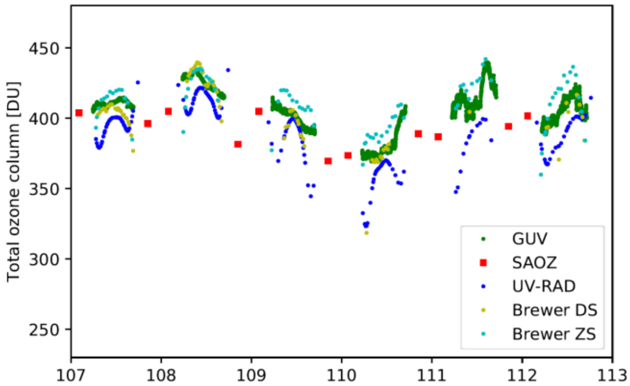

Figure 4. Total ozone measurements during the UV-ICARE inter-comparison campaign, derived from Brewer(ds, zs), GUV, UV-RAD and SAOZ measurements.

Comparison, analysis and homogenisation of historical data

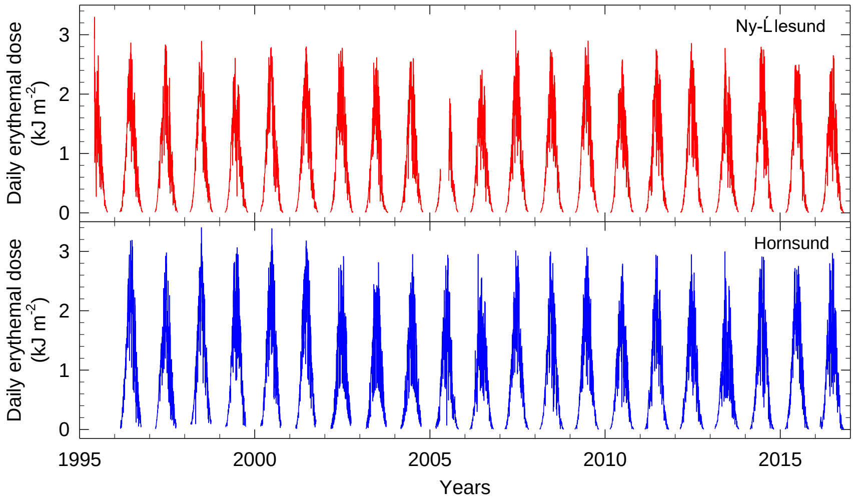

Fig. 3. GUV Erythemal doses at Ny-Ålesund (upper panel) and Robertson Berger UV meter (1996 – 2004)/UVAE-T Kipp & Zonen radiometer (2004 – 2016) from Hornsund (lower panel).

There are two comparably long UV data series from Ny-Ålesund (GUV) and Hornsund (RB + K&Z UV meters) of more than twenty years. Assuming that the two partial series from Hornsund are optimally homogenized, this offers the opportunity for a statistical long-term comparison. Figure 3 shows the two time series for the time period 1996 – 2016. While the annual maximum levels appear comparable at first sight, for a meaningful quantitative comparison the data series were split up into a long-period component (P > 120 days), containing the three major modes of variability in both data sets, and a short-period component (P < 120 days). Figure 4 depicts the correlation of the total datasets, of the long-period component and of the short-period component. While the correlation between the two data sets is good (and highly significant, which is not surprising given the dominant role of the annual cycle), it is almost perfect for the long-period component, yielding an axis offset of about 1% and a slope of 0.99. The short period component reveals a markedly larger variability at Hornsund than at Ny-Ålesund.

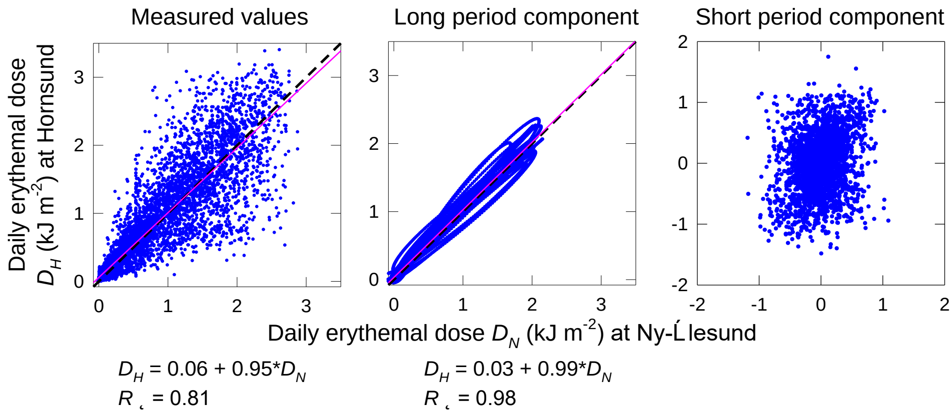

Fig. 5. Comparison of daily erythemal doses (left panel) and their long, and short period components (middle and right panels, respectively) observed at Hornsund (D_H) and Ny-Ålesund (D_N). Diagonals (black dashed lines) and regression lines (in pink) are shown for measured and long period values; analytical regression dependencies with the coefficient of determinations R^2 below.

Description of the work, logistics and implementation plan

The establishment of a network is an activity that requires several steps:

- The most important point is the availability of reliable instrumentation that imposes the necessity of an intercomparison campaign, which will provide information about the capability of the devices to produce data of sufficient quality.

- The next step is the elaboration of the common data format protocol and procedures for the initial data processing in order to achieve an acceptable homogeneity of data set provided by the network. It is envisaged that the format will be compatible with those used in the international community (WOUDC).
- Another important activity is to establish common products and perform joint analysis of the data collected until now so that a climatology and an integrated set of products could be created in a form allowing to be used by other scientists in their studies.

Firstly, we will focus on the organisation of a campaign aiming to compare the instruments that work at the stations under consideration. Taking into account that Ny-Ålesund offers the most appropriate logistic conditions among these stations, the plan is to perform such an inter-comparison campaign there. The campaign, and new facilities at disposal at Ny-Ålesund will give us the opportunity not only to check the quality of the instrumentation, but also to co-locate a workshop and start a discussion on (i) harmonisation of the data analysis procedures, (ii) potential users in the interested scientific community, (iii) need for upgrades of systems and new measurements, and (iv) actions to strengthen the cooperation between the groups working on these topics in the Svalbard Archipelago and enlarge it to surrounding areas.
The inter-comparison campaign will be carried out during the late spring 2017, in order to guarantee the highest values of solar radiation and hopefully minimum cloud coverage and low aerosol load conditions. Discussion and dialogue about common analysis procedures for the elaboration of measurements performed by the different stations will start with the beginning of the project. Also the work to collect historical records and harmonize them in a common format will be started then in order to assure that during the intercomparison campaign the issue about common procedures could be finalised, and the main elements for a common software for the network could be collected/fixed. The intercomparison campaign in Ny-Ålesund will also serve as an opportunity to have discussions with the biology community operating on site and then collect their needs in terms of parameters/products. This will enable us to address in the best way the third step of the process to establish a network in relation to UV fluxes and total ozone column.
With respect to common procedures for analysis and products to release, if necessary a second workshop will be organized co-located with an SSF and NySMAC planned event at beginning of fall 2017.
Results achieved during the field campaign and associated workshop will enable us to start the common analysis of the available data during summer 2017, which then will go ahead until the end of the project. This will enable us on one side to test durability to established a network several-months and from the other hand, working on historical records, to develop a better climatology, better investigate trends for both UV surface radiation and ozone columnar content, better assess seasonal and inter-annual variability and dependence from atmospheric conditions, perform better comparison between surface and satellite evaluations.
As a result of the work plan above described, in the final stage of the project it is expected to have an integrated data-set containing both the previous measurement results collected at different stations and those obtained after the campaign.

Deliveries:

D1 An estimate of the quality of the instruments measuring the solar UV irradiance and ozone column at Svalbard.
D2 A set of procedures, used for elaboration of the measurements
D3 An integrated data set containing harmonized data for the surface solar irradiance and ozone column that concern a large area of Svalbard. An analysis of historical records, comparison between ground based and satellite measurements.
D4 Publication of the main results achieved during the work in the frame of the project.

Distribution of responsibilities between the partner:

NILU will be responsible for overall project management, as well as together with ISAC-CNR to organize intercomparison campaign and workshop at Ny-Ålesund. Moreover, NILU will operate the GUV and SAOZ instruments, will contribute to collecting historical data and will also contribute to analysis of data sets at disposal. **ISAC-CNR,** together with NILU and IG-PAS, will perform an examination of the available data and will assure connection with Barensburg and GGO group. It will work to harmonize collected data sets in a common format for anlysis. Moreover, CNR-ISAC will assure operation of UV-RAD, take efforts to restart the operation of the BREWER instrument, and cooperate with NILU to organize the intercomparison campign and joint workshop. Finally ISAC-CNR will also cooperate with NILU to implement common procedures and data analysis. **IG-PAS** will contribute to collect and analyse historical data as well as to determine trends and climatologies for Hornsund. The institute will also assure the operation of instruments at the Polish station and participation in the intercomparison campaign and workshop. The **University of South Bohemia** team, together with colleagues from Masaryk University, will work on the equipment of their observational station at Longyearbyen, and will assure participation in the inter-comparison campaign and related workshop.

Compliance with the SSF's strategic objectives and the Ny-Ålesund flagship programmes

Three of the four partners (NILU, ISAC-CNR, and IGF-PAS) are actively involved in the SIOS project. The coordination activities between researchers linked to Ny-Ålesund and Hornsund, and the research proposed here, is in line with the SIOS vision to establish a cooperative, transparent research infrastructure, which will give better estimates of the future environmental and climate changes in the Arctic. In particular, the proposal can be seen as a contribution to filling gaps outlined in the SIOS Gap Analysis and to establish the core observation programme as identified by SIOS infrastructure optimization report (for details and documents see SIOS web page www.sios-svalbard.org/). In this respect, the work to establish a new measurements site in Longyearbyen as well as to integrate Barentsburg will be relevant.

This proposal is strongly connected with the atmospheric Flagship Programme (AFP) which includes now a specific working group on UV radiation and ozone. Goals are motivated by results achieved during the last atmospheric flagship workshop held at NILU, Kjeller, at beginning of October, and the work plan of this proposal will try to give concrete form to several recommendations arising from this workshop.

Considering the relevance for biology of UV measurement activities and target of this project could represent a nucleus for a future cross-cutting activity connecting AFP with at least other two Flagships: Terrestrial and Kongsfjorden system.

Data handling and sharing plan

All data obtained in the framework of the project will be quality assured and be made publically available. The dissemination of data will be through the CNR IADC platforms (http://arcticnode.dta.cnr.it/cnr/), the SSF webpage and those of the all participant institutions.

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