FIRST LUNAR PHOTOMETRY WORKSHOP
Notes on the meeting and recommendations

Rationale

A number of studies using the data acquired at high latitudes demonstrate the value of having highly resolved spectral Aerosol Optical Depth (AOD) data. One concern is the expansion of oil and gas extraction in the Arctic and associated increase in shipping activity, which is expected to contribute to pollution and the amount of black carbon (BC) deposited on sea ice.

Data from several satellite programs have been used to study characteristics of aerosols on a global scale. The use of Earth-observation data in Polar Regions is increasing steadily, despite the fact that the retrieval of Arctic aerosol properties using satellite data is challenging. There remain deficiencies in Arctic AOD climatologies due to a lack of validation data needed to improve retrieval algorithms, especially during winter when traditional Sun photometry cannot be employed.

Long polar nights represent a major obstacle to completing an AOD climatology and to improve understanding of processes that impact the surface radiation budget in Polar Regions. For example, at Ny-Ålesund the sun is below 5° of elevation from 10 October to 4 March, clearly limiting the period with sufficient sunlight for making conventional photometric observations.

Lidar observations have the capability of detecting atmospheric column aerosols at night. However, Lidar systems are located in very few sites in the Arctic, which are subjected to harsh environmental conditions. Retrievals usually provide limited spectral information if passive AOD observations are not available to constrain the extinction solution from the backscattering measurements.

To fill gaps in the Arctic AOD climatology, measuring irradiance emitted by stars or reflected Moonlight has been proposed. The difference between star-photometry and moon-photometry relies on simplicity, costs and maintenance of the instruments: the moon, or lunar photometer can be developed as an adaptation of a sun-photometer or sky radiometer, while star-photometers are more complicated, relying on the use of a light source several orders of magnitude weaker than the sun or moon, thus requiring the use of astronomical instruments, more sophisticated apparatus, weather protection, and personnel dedicated to their routine operation.

Previously, researchers abandoned lunar measurements in favour of Star photometry because of the uncertainty in determining exo-atmospheric lunar irradiance (EAI). Today, however, high-precision EAIs are available through the U.S.G.S. ROLO project and lunar photometry is an emerging technology, with successful results at high as well as at lower latitudes.

At Ny Alesund and at Barrow winter campaigns were successfully performed using prototype PFR and SP02, proven feasability of wintertime observation with this technique.

On the basis of above remarks, the workshop was organized with the following objectives in mind:

1 - Connect ongoing activities and facilitate establishment of a network for Lunar Photometer measurements, strengthening POLAR-AOD activities.

2 - Offer an opportunity to bring together the lunar photometric community and promote dialogue and exchange of experience on issues pertaining to calibration and data processing methodologies and protocols.

3 - Promote further development of instrumentation, sharing experiences of those who have operated prototype lunar photometers at different sites, including the Arctic.

4 - Develop collaboration and joint research actions aimed to assess accuracy and uncertainties of different methodologies, instrumentation, and data processing procedures.

5 - Promote dialogue with potential stakeholders, in particular with the satellite community

Scientific questions and motivation

In order to reduce uncertainties of the impact of aerosols on polar climate, the overarching scientific objective is:

to obtain a better and comprehensive picture of polar AOD and vertical distributions of aerosols for climatologies (process understanding), satellite validations, and model evaluations

Taking into account that the major impact of aerosols may be through indirect and semi-direct effects and aerosol-cloud interactions (e.g., change of microphysical characteristics, cloud coverage and vertical stratification), specific scientific questions to address are:

- better locate and improve the quantitative understanding of source regions of Arctic aerosols. as well as relevance of long-range transport processes with respect to local sources.
- improve knowledge about vertical structure of aerosol layers and their spatial (horizontal) and temporal (seasonal) variability.
- Assess aerosol-induced direct radiative effects and influence of surface reflectance characteristics on both the surface and TOA aerosol radiative forcing in the polar regions.

Plenary sessions: exchange of information and discussions

<u>First day (see final agenda attached)</u>

Presentations and discussions during the first day were aimed at deepening scientific relevance of aerosol measurements in the Arctic throughout the annual cycle, describing instrument developments thus far, identifying gaps in knowledge

and observations in the Arctic, and identifying needed improvements to lunar photometer prototypes and the analysis of data collected using these systems.
Specifically, discussions focused on use of lunar prototype systems developed using a Middleton SP02, a PMOD PFR, and a CIMEL Sun photometer, and first tests using a Prede Sky-Radiometer to observe the Moon. Common needs for improvements follow:

a) better sensors and/or improved signal to noise ratios for wavelengths lower than 500 nm and greater than 862 nm

b) need to routinely measure variable, zero-offset voltages to correct signals biased by electronics. Mechanical shuttering during sampling is the recommended solution.

c) the need to extend dynamic range of sensitivity and electronics to improve overall signal/noise ratio and extend measurement period beyond the current quarter Moon phase

Regarding knowledge gaps, it will be necessary to:

a) improve observational systems in ways to allow meaningful "closure" experiments and arrive at a more accurate assessment of the Arctic aerosol budget and impacts

b) improve our knowledge of aerosol distribution and characteristics at different vertical heights to better understand role and impact of aerosols on climate system.

As a consequence of limitation in retrieval algorithms, mainly in clean conditions, satellite measurements tend to be biased. Therefore, there is need for validation of satellite retrieved AOD using ground-based measurements. Night observations will serve best in this regard, thus the need for lunar and stellar observations.

Finally, with respect to evaluation of extra-terrestrial lunar irradiance and data analysis, presented results and discussion have raised the following points:

a) the importance of having a unique reference model for lunar irradiance, so to maintain coherence within analysis procedures, namely the USGS ROLO spectral output specific to instrument filter functions.

b) the possibility to have at disposal for all potential users a web-procedure to retrieve extra-terrestrial lunar irradiances thanks to an agreement and joint efforts of USGS and AERONET

c) the need to work together to identify standard procedures and reach the operational level necessary to realize a network for polar regions and connect it to measurements at lower latitudes.

d) the need to assess the absolute uncertainty of computed ROLO model outputs, or the more properly called error - the difference between ROLO-generated data and the true exo-atmospheric irradiance (EAI) of the Moon. With no supplemental reference for the EAI, the only option is a Type-B uncertainty analysis, i.e. an approach that relies on external information rather than statistical interpretation of measurements (i.e. a Type-A analysis, which has been done with ROLO and has led to the quoted ~1% relative precision).

Second day

First sessions were devoted to collecting information on activities and comparisons performed using different active-passive techniques, and discussions related to lessons learned during field campaigns. Following was a discussion on synergies and potential integration of measurements to better answer scientific questions raised earlier. Discussions included both ground-based lunar and Star systems and satellite systems.

The presentations and discussion highlighted:

a) the analysis performed in the past year in implementing at Ny Alesund and Eureka star photometry and integration with sun-photometry and lidar vertical profiles, to demonstrate the potential of measuring AOD over the annual cycle, filling the gap during the Arctic night.

b) the relevant work by AERONET to integrate sun-photometric and lunar measurements and explore possibilities of obtaining other parameters besides AOD

c) the possibility that planned activities inside ACTRIS-2 EU project could support further developments with respect to integration of solar-lunar and active-passive techniques and also offer opportunity to partly support inter-comparison campaigns in the frame of Trans-national access program to infrastructures

d) the work made in developing unified algorithms, like GRASP (Generalized Retrieval of Aerosol and Surface Properties - http://www.researchgate.net/publication/266081435), for retrieving a variety of atmospheric properties from integration and simultaneous synergic analysis of measurements provided by remote sensing observations from ground, space, and aircraft.

e) the potential for satellite validation activities if a few "super" sites are established with co-located lunar-star-sun photometers and lidar.

f) the need to reinforce communication with satellite community to fully develop this potential as well as to develop a better integration of ground and space observations.

From this point of view, the discussion emphasized need for integrated systems to achieve identified scientific goals, with a target of developing a unified observing system in the Arctic.

Break out sessions

Second part of the day was devoted to developing a vision for the future, as well as identifying needs and recommendations for improving observing systems, instruments and analysis procedures.

Two break-out sections were held, the first to address:

Perspective and Strategy for Observing Systems

Instruments and ETI issues

Both sessions were asked to discuss and address their specific theme with respect to three topics:
(1) **Status,**
(2) **Gaps**,
(3) **Needs** and further to
formulate Recommendations, propose Actions
Break-out groups had about two hours to develop discussion during the second day, and another hour beginning third day to refine and write up reports for presentation during the final session of the workshop.

Reports and recommendations/actions formulated by the two working groups are provided in Annexes to these notes.

General Discussion: identification of priorities

The last session of the workshop was devoted to share results of break-out groups and to identify priorities through which to address future work and develop the overarching goal to continue and reinforce action of the existing POLAR-AOD network.

Below is a list of priorities identified by participants:

- Complete analysis and improve climatology with data set that we have at disposal
- Work to formulate and sign a statement agreement in relation to POLAR-AOD network

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메모 포함[b2]: could mention here the Tomasi et al. data set that exisits and was used for publication and is to be including in the IASOA web site

- Develop actions to secure/improve the observations: secure star-photometry continuity, establishing key sites lunar operations,
- Work for a CALIOP climatology validation
- Secure implementation of ROLO web-based procedures
- Promote/work for a 2016 intercomparison/calibration campaign