Summary of the Second Joint GSICS/IVOS Lunar Calibration Workshop

1316 November 2017 Xi'an, China

More than 60 people representing 22 agencies or research institutes attended the Second Joint GSICS/IVOS Lunar Calibration Workshop either physically in Xi'an or remotely through Webex sessions. The workshop was co-organized by CMA, EUMETSAT, NOAA and NASA and hosted by the Xi'an Institute of Optics and Precision Mechanics (XIOPM), which is part of the Chinese Academy of Sciences (CAS).

The main objectives of the workshop were:

a) To share knowledge and expertise on the latest dedicated ground-based lunar observation campaigns, and also space-based lunar datasets, that can help with refining the current lunar calibration reference.
b) To share knowledge and expertise in the preparation of lunar irradiance measurements from observations by the instruments to be monitored.
c) To work jointly on algorithms to compare and inter-calibrate instruments with lunar observation capabilities, even from different eras, supporting the generation of Fundamental Climate Data Records.
d) To explore further alternative applications of lunar observations for calibration purposes or post-launch assessments, such as geometric and MTF characterization.

The workshop lasted four days (13-16 November 2017) with the following agenda:

- **Monday**: Measurements and Moon Observations (chaired by X. Hu - CMA)
- **Tuesday:** Using the ROLO and the GIRO and Lunar Model Developments (chaired by T. Stone - USGS)
- **Wednesday:** Inter-calibration and Inter-band Calibration (chaired by S. Wagner - EUMETSAT) and Alternative uses of lunar measurements (MTF post-launch characterisation, chaired by F. Yu - NOAA)
- **Thursday**: Alternative uses of lunar measurements (ghost, cross-talk, infrared, microwave, etc. – chaired by X. Xiong - NASA) and Discussions, Review of actions/recommendation/way forward and Conclusions of the workshop (chaired by S. Wagner - EUMETSAT).

Measurements and Moon Observations

CMA is leading an important activity in collaboration with other institutes from the Chinese Academy of Science on the development of new instruments and dedicated ground-based lunar measurement campaigns. The objectives are to develop new lunar calibration models both in irradiance and in radiance with a significantly reduced level of uncertainties and to achieve traceability to SI standards. Several campaigns took place in 2015, in 2016 and more recently in 2017. The current outcome of those campaigns were presented together with the

foreseen future activities. New measurement campaigns are planned, with greater capabilities (automated acquisitions, broader spectral coverage and long time series for instance). Measurements from space are also part of CMA's future developments.
Other organisations are also investing resources in model development, processing of new lunar datasets from instruments in space and in acquiring new measurements from ground.

Finally, the discussions on Moon Measurements addressed the possibility to constitute a database for all the measurements currently available (satellites and ground-based). This database would support the development of new irradiance and radiance lunar models. There is a clear interest of the Lunar Calibration Community to see the GSICS Lunar Observation Dataset (GLOD) as an evolving dataset in order to i) allow more systematic cross-comparisons and inter-calibration, ii) support model development.

Using the ROLO and the GIRO and Lunar Model Developments

Following the effort initiated at the First Lunar Calibration Workshop, the participants presented the current status of their lunar image processing to prepare their irradiance input to the GIRO. Discussions addressed the estimation of the oversampling factor, which was already a concern at the first workshop. Some recommendations on how to estimate this factor were made in order to reduce the uncertainties on the results. In particular, it is recommended to use the sampling and scan rates to determine oversampling, and not spatial analysis of images. New datasets were also presented, in particular hyperspectral observations from GOME-2 aboard Metop-A and –B, and SCIAMACHY.
Regarding the evolutions of the ROLO, a three-year NASA-funded project will start in early 2018 at USGS to work on the original ROLO telescope data. This project will refine the irradiance measurements from ROLO images, reformat and recalibrate the images, and provide public access to the data to the Lunar Calibration Community and to the research community in general. This work is expected to reduce the uncertainties on the modelled irradiance.
As part of improving the traceability of the GIRO to the ROLO, the details of a benchmark dataset developed at EUMETSAT, in collaboration with JMA and USGS was presented. This benchmark is to be used to demonstrate the traceability of the GIRO to the ROLO model. The outcome of a first comparison are expected for the next GSICS annual meeting, in March 2018 in Shanghai.
Finally the session addressed the development of new models. As part of those developments, NOAA, CMA and JMA are investing efforts into the development of radiance models. The Lunar Calibration Community is also interested by working further on the development of a model accounting for the moon light polarisation.

Inter-calibration and inter-band calibration

Currently, the inter-calibration using the Moon faces two major issues: first is the residual phase dependence in the GIRO (as in the ROLO) which causes the transfer of the calibration from a reference instrument to a target instrument difficult if those instruments are not observing the Moon in the same phase. The second issue is to move from MODIS Aqua, which is the current GSICS instrument reference for reflective solar bands, to Suomi NPP VIIRS as a new inter-calibration reference, in particular because have more bands in the reflective part of the solar spectrum. However, some of the bands available on MODIS Aqua and that are needed to monitor the reflective solar bands available on the new generations of geostationary satellites cannot be used. The SWIR bands for instance have cross-talk issues that need to be corrected, making their usage with lunar inter-calibration problematic.

Additionally, in the context of GSICS activities, the lunar inter-calibration is foreseen to complement the inter-calibration using deep convective clouds (DCC) **Error! Reference source not found.**. The fact that MODIS Aqua saturates over DCC in some bands required for the inter-calibration prevent their use in that context. The Lunar Calibration Community will continue investigating how to move forward on the topic.
As part of this session, some preliminary work was also presented and discussed on inter-band calibration using the spectral behaviour of the Moon irradiance. It was agreed that more work is needed on this topic.

Alternative uses of lunar measurements

A large part of this session was dedicated to the post-launch estimation of the Modulation Transfer Functions (MTF), using Moon imagery. NOAA is leading an activity on algorithm comparison. They tested their method on the datasets provided by the participating agencies (NOAA, JMA, KMA, CMA and EUMETSAT). The participating agencies presented their results using their own algorithms. Several issues were raised from the discussion on the technical aspects of processing Moon imagery to infer MTF curves: interpolation methods, selection of the region of interest for transition Moon/deep space, frequency to represent the MTF, accuracy of the oversampling factor estimation, etc. Those issues are also discussed by the CEOS WGCV IVOS group, and NOAA was invited to liaise with CEOS to benefit from IVOS experience. NOAA will coordinate the next steps of this activity, which is expected to lead to a GSICS/IVOS recommended approach.
The remaining part of the session addressed the use of lunar imagery to characterise artefacts such as optical and electronic cross-talk. CMA also presented their plan to calibrate MWHS, a microwave instrument aboard FY-3 series, using the moon.

Conclusion and Outlook

Looking at the future, the Lunar Calibration Community will continue its current efforts in improving the current ROLO and GIRO irradiance model references and developing and implementing inter-calibration schemas. New measurement campaigns are planned and are expected to lead to significant improvements in bringing lunar calibration to an absolute SI traceable scale. Those measurements will support the on-going effort to develop new radiance models for instance or to improve further the irradiance models.

The Second Lunar Calibration Workshop successfully brought together again the GSICS and CEOS/IVOS communities. New topics of interest such as MTF inference using Moon imagery could strengthen the exchange between the two groups. Many CAS institutes working on the development of new instruments (including instrumentation dedicated to lunar observations) participated for the first time to the workshop. The increasing level of participation and discussion show the broad interest to use lunar calibration for instrument performance monitoring, cross-comparisons, inter-calibration but also for absolute calibration when available. A list of decisions, actions and recommendations **Error! Reference source not found.** was established to pursue this international collaboration. After the success of the first and second Lunar Calibration Workshop, all participants agreed on the need to organize within the next two years another Lunar Calibration Workshop.

The detailed minutes of the meeting are available on:
http://gsics.atmos.umd.edu/bin/view/Development/20171106

In total, 8 actions and 22 recommendations were listed. Following the GSICS action tracker standards, they are reference according to the meeting (LCWS, Lunar Calibration Workshop), the

year (2017), the presentation number (number + letter, for instance "1t"), the action/recommendation number taken during the course of the discussions raised by the presentation (starting at 1). For more information about the background discussions please refer to the corresponding presentation and the minutes of the meeting as available on http://gsics.atmos.umd.edu/bin/view/Development/20171106 .

List of actions:

1. LCWS.2017.1t.1: EUMETSAT to contact the participants to get updates on the lunar data for the GLOD.
2. LCWS.2017.1t.2: CMA to send the data survey form for FY-4A and Chinese MOST ground measurements to NOAA (Point of contact: Fangfang Yu).
3. LCWS.2017.1t.3: CMA to consider a similar plan to ESA to schedule ground measurements in the future (e.g. instruments, calibration, sites, measurement strategy).
4. LCWS.2017.2l.1: Agencies operating geostationary instruments to check the semi-annual phase angle patterns as observed in COMS data.
5. LCWS.2017.2p.1: S. Wagner (EUMETSAT) to clarify with ESA the possibility of sharing SCIAMACHY lunar observation data (as processed for EUMETSAT) within the lunar calibration community.
6. LCWS.2017.2p.1: EUMETSAT/USGS to report at the next GSICS annual meeting on the traceability of the GIRO to the ROLO using the benchmark.
7. LCWS.2017.5h.1: MTF post-launch estimation using lunar imagery. Points of Contact to coordinate and provide details about the algorithm implemented in their agency as listed in EUMETSAT's presentation on MTF (slide 30, point 4).
8. LCWS.2017.5h.2: JMA and NOAA to interact on the oversampling and MTF for AHI and ABI.

List of recommendations

1. LCWS.2017.2c.1: NASA and NOAA to compare their results on lunar calibration (calculation and trending) and report at 2018 GSICS Annual Meeting.
2. LCWS.2017.2c.2: NASA and NOAA to compare their lunar f-factor and to report at the next GSICS annual meeting (NASA VCST, NOAA Ocean Colour and NOAA SDR).
3. LCWS.2017.2f.1: CMA to investigate further the calculation of the irradiance for MERSI as the irradiance signal seems to vary too much.
4. LCWS.2017.2f.2: CMA to investigate alternative method for estimating the oversampling for Tansat/CAPI.

5. LCWS.2017.2h.1: JAXA to share SGLI lunar observation data, particularly polarization bands with the lunar calibration community.
6. LCWS.2017.2h.2: JAXA to report on GCOM-C lunar observation data (in particular on the polarised measurements) either at a GSICS annual meeting or a lunar calibration meeting.
7. LCWS.2017.2j.1: CMA to investigate the impact of the offset cause by the quadratic calibration equation on the lunar calibration results.
8. LCWS.2017.2k.1: Agencies operating geostationary instruments to work together to investigate the possible non-linearity impact on the phase angle dependence of the ratio between measured irradiance and the modeled irradiance.
9. LCWS.2017.2m.1: NOAA and JMA to consider revisit the oversampling factor calculation.
10. LCWS.2017.2o.1: agencies to investigate further their calculation of the oversampling factors and to make use of the operational scan rate and corresponding time when available.
11. LCWS.2017.2o.1: all the agencies to examine the impact of dark count on the phase angle dependency.
12. LCWS.2017.4b.1: CNES to report on the current status of their work on lunar calibration, in particular on the corrections using Pleiades, at the next GSICS annual meeting.
13. LCWS.2017.4d.1: NOAA/NASA to interact on calibration dataset (VIIRS) and report back at the next GSICS annual meeting to provide advice on what to use for inter-calibration
14. LCWS.2017.6a.1: in the preparation of the data for the GIRO and in particular the calculation of the oversampling factor, it is recommended to use the operational parameters from the instrument instead of the apparent size of the Moon.
15. LCWS.2017.6a.2: the Lunar Calibration Community is invited to contribute to the development of a polarisation model for the Moon light. This model would complement the ROLO/GIRO and could be a separate model.
16. LCWS.2017.6a.3: CMA is encouraged to report on lunar model development based on the new ground-based lunar observations.
17. LCWS.2017.6b.1: ESA is invited to present the status of their initiative with the CIMEL lunar photometers in a future meeting (possibly at the next GSICS annual meeting or at a web meeting).
18. LCWS.2017.6c.1: agencies are invited to report on their progress on inter-calibration and/or inter-band calibration at the next GSICS annual meeting.

19. LCWS.2017.6d.1: NOAA is invited to report on their progress on their radiance model development at the next GSICS annual meeting or at a lunar calibration web meeting.
20. LCWS.2017.6d.2: NOAA to circulate a questionnaire to the agencies POC for MTF in order to collect information about the algorithms in place to estimate the MTF using the Moon.
21. LCWS.2017.6d.3: NOAA to liaise with IVOS regarding MTF estimation (contacts: Francoise Viallefont - Francoise.Viallefont - AT - onera.fr , or Dennis Helder - Dennis.Helder - AT - sdstate.edu).
22. LCWS.2017.6d.4: agencies participating to the MTF activity to communicate to NOAA (Xi Shao / Fangfang Yu) the details of the Point Of Contact for their MTF algorithm.