Summary of the Third Joint GSICS/IVOS Lunar Calibration Workshop

16-19 November 2020

Virtual meeting

The third Joint GSICS/IVOS Lunar Calibration Workshop was initially planned to be hosted by EUMETSAT in Darmstadt, Germany, between Monday 16 and Thursday 19 November 2020. Due to the Covid-19 situation, the physical meeting has been postponed to 2021, to a date still to be defined. However, in order to ensure that the Lunar Calibration Community is aware of the latest developments on the projects undertaken by its numerous members, it was decided to organise a series of web meetings in place of the real meeting.

Those meetings were limited to a few hours to account for the time difference between the various participants.

A total of 22 presentations addressed almost all topics initially targeted by the workshop:

- Measurements and Moon observations: towards SI traceability (Monday and Thursday)
- Lunar calibration and model development (Monday)
- Instrument monitoring using lunar calibration (Tuesday and Thursday)
- Thermal Infrared and microwave remote sensing and lunar observation (Wednesday)
- Alternative applications of lunar observation, including geometric and MTF post-launch characterisation (Thursday)

Each session included some time for discussing the activities in order to identify ways forward as required.

Between 70 and 80 attendees participated to the web meetings, which demonstrate if needed the interest in lunar calibration and its applications to instruments in space.

Lunar model development:

T. Kouyama (AIST) provided an overview of the status of the SP lunar radiance model, which is currently the only radiance model publicly available in the community. Three new lunar irradiance models were also presented: SLIMED (H. Kieffer), LIME (NPL, VITO and University of Valladolid, under ESA contract) and LESSSR (Earth Space Solutions, under EUMETSAT contract).

SLIMED is a new lunar irradiance model empirically tuned to blend observations from a variety of instrument. It is based on an iterative process to derive relative gains for each instrument band. It assumes that instrumental parameters such as oversampling are properly estimated

and accounted for in the measured moon signal. It also uses uncertainties on the measurements as stated by the data providers.

LIME is based on CIMEL measurements acquired at the Pico Teide in Tenerife. The model uses a similar parametrisation to the ROLO model, with some additional spectral dependencies in the model terms. A large effort was done to ensure the SI-traceable calibration of the sensors, with an in-depth characterisation of the uncertainties.

Finally, LESSR is a model inferred from both SCIAMACHY lunar measurements and RELAB spectra retrieve from the analysis of lunar soil samples. It takes advantage of the latest improvements for SCIAMACHY Level 1 data and allows a broader coverage of the solar spectrum, going from about 250nm to 2600nm. However, the range of lunar phases for the observations used for deriving the model parameters is narrower ([-80, 20] degrees).

Those models are taking part to an inter-comparison exercise with other models such as the GIRO. This activity is on-going and results are expected to be presented at the next GSICS Research and Data Working Group Annual Meeting in 2021.

As part of the discussion, the Lunar Calibration Community recommended to revise the current mechanism for sharing the GIRO model so that it is more easily accessible to the community.

Lunar measurement and SI-traceability:

The status of the following projects was presented:

- Air-LUSI
- ARCSTONE
- Mauna Loa-LUSI

Those projects target to provide high accuracy measurements of the Moon so that lunar models could be tied up to an absolute scale.

Air-LUSI provides very high altitude airborne highly-resolved hyperspectral measurements of the Moon in a set of phases ranging from +10 to +59 degrees. The spectral interval is about [415,1000] nm. Those measurements allow removing a large part of the uncertainties related to the atmosphere. Instrument calibration is assessed before and after flights, and the measurements are provided with their uncertainties budget. The demonstration flight campaign was a success and data will benefit the adjustment of lunar models on an absolute scale. However, more flights are subjects to the availability of funding.

A complementary activity also led by NIST is taking place at Mauna Loa Observatory: the Mauna-Loa – LUSI project. It uses a similar measurement principle to the Air-LUSI project but from the ground. Conditions at Mauna Loa Observatory are similar to the ones at Pico Teide in the Canarias Islands. Deployment is foreseen in March 2021 for a period of 6 months, also depending on the current Covid-19 situation. Interactions with ESA (LIME project), Air-LUSI and ARCSTONE are in place.

Finally, an update on the status of the ARCSTONE project was given by C. Lukashin (NASA). On top of addressing the calibration needs for traditional LEO and GEO Earth Observing missions, ARCSTONE mission would allow the calibration / inter-calibration of instruments aboard fleets of CubeSat platforms, as soon as they would observe the Moon. An important aspect of this mission is that it covers an extended part of the spectral range of interest for reflective solar bands ([350,2300] nm). Two of the key performance goals of the mission are i) to achieve 0.5% (k=1) reflectance accuracy with a 1% threshold, and ii) to achieve a stability of 0.15% (k=1) per decade with a threshold of 0.1%.

Those projects are clearly of interest for GSICS and the Lunar Calibration Community. The possibility to provide supporting letters from GSICS was discussed and is addressed in the list of actions.

Instrument monitoring using lunar observations:

This session was split in two days, with a block of presentations on Low Earth Orbit Missions, including microsatellites (presented by M. Imai - AIST), and another one on the latest generation of geostationary imagers. Those presentations demonstrate further, if needed, the added value of lunar observations for monitoring the radiometric performances of reflective solar bands available on imagers in space.

However, detailed analysis such as showed by T. Hashiguchi (RESTEC) for GCOM-C showed the need for lunar models to address accurately phase and libration effects when the instruments observe the moon under different geometrical and illumination conditions. Even for limited phase and libration variations, residual dependencies may impact bias monitoring by several percent starting from wavelengths around 800nm.

On the other hand, an accurate determination of parameters such as oversampling factors and solid angles remains a key element when monitoring the biases with respect to the models, as errors in their estimates would lead to artefacts in the biases. Additionally, it is important to account properly for the deep space offsets and potential stray light artefacts. All those aspects were discussed for instance for LEO imagers such as OLCI or SLSTR and for GEO radiometers such as ABI, AHI or AMI.

That session raised also the question of the range of applicability of the current lunar irradiance models for instruments on board geostationary platform, whose viewing geometrical conditions extend beyond the initial range of ground observations from which are derived those models.

Usage of the Moon for microwave and thermal infrared instruments:

In 2017, at the 2nd Joint GSICS/IVOS Lunar Calibration Workshop, a session on alternative usage of lunar imagery was organised to address additional topics that are aside lunar calibration as discussed by GSICS or IVOS. That session had some interesting presentations on activities related to microwave imagers. In order to enhance further the interactions on microwave and thermal infrared observations of the moon, a dedicated session was organised on Wednesday 18th November.

Four topics about lunar microwave calibration were presented by scientists from EUMETSAT, University of Hamburg and University of Maryland. The topics cover the following study works currently in progress:

1. Lunar contamination correction method for microwave imager and sounding instruments, as presented by Francesco De Angelis from EUMETSAT.
2. Channel co-registration, pointing error identification, and antenna beam width characterization, as presented by Roberto Bonsignori and Martin Burgdorf.
3. Lunar disk-averaged microwave brightness temperature spectrum from satellite observations and model simulations, as presented by Martin Burgdorf and Tiger Yang.

These topics reflect the most recent progress for lunar microwave calibration in GSICS community. According to the reported research results and the related publications, it is confident to say that some of the research work are pretty mutual and the methods can be recommended to the GSICS community, such as antenna characterization and pointing error identification by using lunar observations from instrument space view. While some work has made encouraging progress, there is still challenging work to be done.

A proposal for future activities in the context of the GSICS and Microwave community was discussed and is addressed in the list of recommendations.

On the side of thermal infrared, CNES (L. Le Barbier) is investigating the possible use of lunar acquisitions by IASI to perform inter-calibration with other sensors and to have an additional mean to monitor over time the instrument radiometric stability. CNES is also looking at the potential use of those observations for absolute calibration. The first phase of the project has been closed. A new phase will start in 2021 with monthly observations of the Moon using IASI-B and IASI-C over a year.

Lunar observations from infrared sensors is being considered by more agencies, such as NOAA or EUMETSAT, for their future thermal infrared sensors.

Alternative usage of lunar imagery – Post launch assessment of co-registration and MTF using lunar imagery:

T. Choi (NOAA) presented the status of the activities at NOAA to monitor the on-orbit band-to-band registration and the modulation transfer functions for NOAA-20 VIIRS using regular lunar observations.

Lunar imagery offers additional post-launch assessment or monitoring capabilities, which are useful to consider for CAL/VAL activities and for long term monitoring. The initiative led by NOAA to compare the methods to assess in orbit the instrument MTF using the Moon was recalled and is supported by the Lunar Calibration Community. NOAA has been encouraged to pursue this effort in collaboration with the participating agencies.

As part of the general discussions that took place during the four days of the virtual meeting, a series of points to be further discussed have been listed and circulated by email to the members of the Lunar Calibration Community. This list is summarised hereafter:

1. How to best integrate of observed irradiance? This point includes the proper definition of the image area which the observed irradiance is integrated, and the need to estimate as accurately as possible the pixel solid angles and the oversampling factors. It requires access to instrument information by the science teams.
2. Definition of an unambiguous terminology for "observed irradiance", which would correspond to an irradiance based on the same DN-to-radiance processing as science products. However, it shall specify any time-based corrections included in this processing and that are based on on-board diffuser, "vicarious" (Earth surface targets) or lunar calibration, etc. So that it would prevent submitting to a lunar calibration dataset that already includes some “hidden” use of some lunar calibration results.
3. Solar irradiance model
4. Need for including lunar data from geostationary instruments in lunar models in order to expand the range of selenographic sub-viewer location (Vlat and Vlon) outside the surface observatory or LEO range.
5. Separation of steps in lunar calibration, each of which should be separately accessible:
    i. System-level relative spectral response to lunar effective wavelength
    ii. Time and location to angles and distance factor
    iii. Solar model and variations to solar irradiance (this may be challenging)
    iv. Geometric angles and effective wavelength to lunar disk-equivalent reflectance (using a named lunar model)
    v. Output formatting
6. Agreed terminology to describe individual detector elements, arrays, focal planes, etc.
7. Definition of a convention to trace lunar model versions and reflect those versions in the model’s name.
8. Need to include polarization in lunar models.
9. Estimate Earth-shine variation effect on lunar irradiance as a function of (absolute) phase angle.

10. Revise the benchmark proposed at the 2nd Joint GSICS/IVOS Lunar Calibration Workshop and propose a standard grid of angles to be used in lunar model comparisons.
11. Agreed terminology for describing accuracy, uncertainties, etc. in the context of lunar calibration and lunar modelling.

In total, 8 actions and 8 recommendations were listed. Following the GSICS convention, they are referenced according to the meeting (LCWS, Lunar Calibration Workshop), the year (2020), 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/LunarCalibrationWS2020 .

List of actions:

- **A.LCWS.2020.16f.1**: EUMETSAT (S. Wagner) to liaise with USGS (T. Stone) to realign the GIRO with respect to the last version of the ROLO model.
- **A.LCWS.2020.16f.2**: EUMETSAT (S. Wagner) to propose letter of recommendation by GSICS to NASA to highlight the benefits to continue the Air-LUSI campaigns to lunar calibration.
- **A.LCWS.2020.16f.3**: EUMETSAT (S. Wagner) to report on the Model Inter-Comparison Exercise at the next GSICS annual meeting + Lunar Calibration Community.
- **A.LCWS.2020.16f.4:** EUMETSAT (S. Wagner) to check possibilities to create a distribution list for the Lunar Calibration Community.
- **A.LCWS.2020.18g.1**: UMD (Hu Tiger Yang) to coordinate with EUMETSAT (Vinia Mattioli) to draft a note outlining possible further collaborations on microwave and thermal infrared lunar calibration activities.
- **A.LCWS.2020.19g.1**: S. Wagner (EUMETSAT) to circulate the list of topics to be addressed by the Lunar Calibration Community and to solicit interest from its members.
- **A.LCWS.2020.19g.2**: EUMETSAT (S. Wagner) to liaise with the participants to the Lunar Calibration Workshop to ensure a follow-on on the actions / recommendations
- **A.LCWS.2020.19g.3**: EUMETSAT (S. Wagner) to propose letter of recommendation by GSICS to NASA to highlight the benefits of ARCSTONE project for GSICS activities and its members.

List of recommendations:

- **R.LCWS.2020.16f.1:** Model developers to consider how their models' inputs can be decoupled from the observations to allow inter-comparison and benchmarking on the various steps of lunar calibration.
- **R.LCWS.2020.16f.2:** EUMETSAT (S. Wagner) to investigate the possibility to revisit the mechanism to share the GIRO model, whilst respecting the existing license agreement.
- **R.LCWS.2020.16f.3:** Satellite operators to consider providing data to Hugh Kieffer for further processing with the SLIMED model.
- **R.LCWS.2020.17c.1**: the solar irradiance spectrum used in the lunar irradiance models or for the instrument calibration should be documented and referenced when discussing lunar calibration results.
- **R.LCWS.2020.18f.1**: CMA is invited to share in upcoming GSICS and/or Lunar Calibration meetings its experience on the use of lunar observations acquired by their IR sounders.
- **R.LCWS.2020.18g.1 :** the Microwave + Infrared group is encouraged to pursue current effort and report within the context of GSICS regular meetings.
- **R.LCWS.2020.18g.2 :** Microwave + Infrared group to liaise with CMA to foster collaborations.
- **R.LCWS.2020.19d.1:** NOAA is encouraged to pursue its initiative on comparing approaches for post-launch assessment of MTF using lunar imagery. This initiative, in collaboration with other agencies would lead to the definition of best practices for MTF assessment using the Moon.