A summary of the joint GSICS –CEOS/IVOS lunar calibration workshop: moving towards intercalibration using the Moon as a transfer target

S. C. Wagner*[a], T. Hewison[a], T. Stone[b], S. Lachérade[c], B. Fougnie[c], X. Xiong[d]
[a]EUMETSAT, Eumetsat Allee 1, Darmstadt, 64295, Germany; [b]US Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ USA 86001; [c]CNES, 18 Avenue E. Belin, 31401 Toulouse, France; [d]NASA GSFC, Code 618.0, Greenbelt, MD USA 20771

ABSTRACT

In December 2014 experts from 14 different agencies and departments attended the joint GSICS – CEOS/IVOS Lunar Calibration Workshop meeting organised by EUMETSAT in collaboration with USGS, CNES and NASA. Altogether, this represents potentially more than 25 instruments capable of observing the Moon.

The main objectives of the workshop were i) to work across agencies with the GSICS Implementation of the ROLO model (GIRO) - a common and validated implementation of the USGS lunar radiometric reference, ii) to share knowledge and expertise on lunar calibration and iii) to generate for the first time a reference dataset that could be used for validation and comparisons. This lunar calibration community endorsed the GIRO to be the established publicly available reference for lunar calibration, directly traceable to the USGS ROLO model. However, further effort is required to reach inter-calibration between instruments, in particular for each instrument team to accurately estimate the over-sampling factor for their images of the Moon.

A way to develop a cross-calibration algorithm and GSICS inter-calibration products is proposed. This includes key issues of fixing the GIRO calibration to an absolute scale, addressing spectral differences between instruments, and improving the existing calibration reference, which translates into future updates of the GIRO. The availability of extensive Moon observation datasets will help to further improve this reference and is expected to grow with the availability of additional lunar observations from past, current and future missions. All participants agreed on EUMETSAT pursuing its efforts in developing and maintaining the GIRO in collaboration with USGS to ensure traceability to the reference ROLO model.

Keywords: Lunar calibration, ROLO, GIRO, GSICS, CEOS IVOS, calibration reference, traceability.

1. INTRODUCTION

In the recent years, space and meteorological agencies operating Earth Observing satellites have shown an increasing interest in lunar calibration for monitoring the temporal stability of their instruments. Both GSICS and CEOS IVOS recommend lunar calibration as a calibration and inter-calibration method for VIS/NIR bands that should be implemented for instruments that have the capability to sense the Moon. The current reference model for lunar calibration (the so-called ROLO model) has been developed and is being maintained by the United States Geological Survey (USGS). A few agencies have implemented their own version of this model. However, experience has shown that there could be differences between some of these independent implementations and the official USGS version of the ROLO model.

During the GSICS Research and Data Working Group annual meeting in Darmstadt (24-28 March 2014), the GSICS community, together with the CEOS-IVOS chairman (Nigel Fox, from NPL) recommended harmonising the version of the ROLO model that is used for lunar calibration of VIS/NIR satellite instruments by more and more operators. Indeed, in the context of instrument inter-calibration, the use of the same transfer reference should be ensured.

The main outcome of the joint GISCS – CEOS/IVOS Lunar Calibration Workshop are presented in Section 2. The collaborative framework defined to develop the GSICS Implementation of the ROLO model is described in Section 3

Sensors, Systems, and Next-Generation Satellites XIX, edited by Roland Meynart, Steven P. Neeck, Haruhisa Shimoda
Proc. of SPIE Vol. 9639, 96390Z · © 2015 SPIE · CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2193161

together with the infrastructure that is envisaged to host a reference implementation of the ROLO model. Finally, Section 4 focuses on the on-going effort to achieve inter-calibration of instruments using the Moon as a transfer target. The purpose is to complement corrections or gains inferred by using other methods such as the GSICS Deep Convective Cloud method in order to derive blended GSICS products for reflective solar bands.

2. ACHIEVEMENTS OF THE LUNAR CALIBRATION WORKSHOP

The first joint GSICS – CEOS/IVOS Lunar Calibration Workshop was organised by EUMETSAT in collaboration with USGS, CNES and NASA in December 2014 in order to initiate an activity to share knowledge on lunar calibration and to promote the use of a common reference across participating groups. Experts from 14 agencies and departments attended the event. This represents potentially more than 25 instruments capable of observing the Moon. The relevant spectral bands of these instruments (listed in Table 1) cover a range from about 0.4µm to 2.3µm.

The workshop addressed the following objectives: i) to work across agencies with the GSICS Implementation of the ROLO model (GIRO) - a common and validated implementation of the USGS lunar radiometric reference, ii) to share knowledge and expertise on lunar calibration and iii) to generate for the first time a reference dataset, the GSICS Lunar Observation Dataset (GLOD), which could be used for validation and cross-comparisons. This dataset is meant to be a sample of typical lunar acquisitions from each registered instrument.

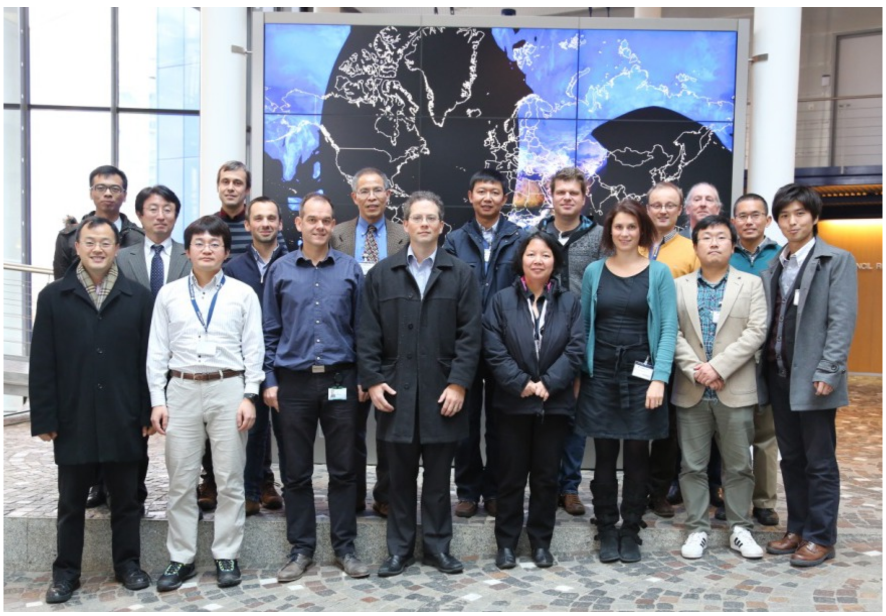

Figure 1: 14 agencies were represented (including remote participations) at the Lunar Calibration Workshop organised in Darmstadt (1-4 December 2014)

The workshop addressed various aspects of the data preparation that are critical to lunar calibration. In particular estimating accurately the oversampling factor, whose value is specific to each instrument, can be constant or vary in time and space. Additionally, the difficulty of estimating deep space count offsets and removing potential artefacts from the images (such as stray light) were also discussed. The large variety of scanning mechanisms and acquisition configurations, as illustrated by Figure 2, adds to the difficulty of identifying potential deficiencies in the image processing and the lunar data preparation. A set of actions and recommendations [1] was agreed with the participants to review the various aspects of their image processing with a special focus on the estimation of the oversampling factors.

Most of the groups had prepared data for the instruments they presented at the workshop, and processed them with the GIRO application as provided by EUMETSAT. These data were collected to establish the first version of the GLOD, a reference lunar calibration dataset.

Team	Satellite	Sensor	G/L	Dates	Number of obs (GSICSdataset)	Phase angle range (°)
CMA	FY-3C	MERSI	LEO	2013-2014	9	[43 57]
CMA	FY-2D	VISSR	GEO	2007-2014		
CMA	FY-2E	VISSR	GEO	2010-2014		
CMA	FY-2F	VISSR	GEO	2012-2014		
JMA	MTSAT-2	IMAGER	GEO	2010-2013	62	[-138,147]
JMA	GMS5	VISSR	GEO	1995-2003	50	[-94,96]
JMA	Himawari-8	AHI	GEO	2014-	-	
EUMETSAT	MSG1	SEVIRI	GEO	2003-2014	380/43	[-150,152]
EUMETSAT	MSG2	SEVIRI	GEO	2006-2014	312/54	[-147,150]
EUMETSAT	MSG3	SEVIRI	GEO	2013-2014	45/7	[-144,143]
EUMETSAT	MET7	MVIRI	GEO	1998-2014	128	[-147,144]
CNES	Pleiades-1A	PHR	LEO	2012	10	[+/-40]
CNES	Pleiades-1B	PHR	LEO	2013-2014	10	[+/-40]
NASA-MODIS	Terra	MODIS	LEO	2000-2014	136	[54,56]
NASA-MODIS	Aqua	MODIS	LEO	2002-2014	117	[-54,-56]
NASA-VIIRS	NPP	VIIRS	LEO	2012-2014	20	[50,52]
NASA-OBPG	SeaStar	SeaWiFS	LEO	1997-2010	204	(<10 , [27-66])
NASA/USGS	Landsat-8	OLI	LEO	2013-2014	3	[-7]
NASA	OCO-2	OCO	LEO	2014		
NOAA-STAR	NPP	VIIRS	LEO	2011-2014	19	[-52,-50]
NOAA	GOES-10	IMAGER	GEO	1998-2006	33	[-66, 81]
NOAA	GOES-11	IMAGER	GEO	2006-2007	10	[-62, 57]
NOAA	GOES-12	IMAGER	GEO	2003-2010	49	[-83, 66]
NOAA	GOES-13	IMAGER	GEO	2006	11	
NOAA	GOES-15	IMAGER	GEO	2012-2013	28	[-52, 69]
VITO	Proba-V	VGT-P	LEO	2013-2014	25	[-7]
KMA	COMS	MI	GEO	2010-2014	60	
AIST	Terra	ASTER	LEO	1999-2014	1	-27.7
ISRO	OceanSat2	OCM-2	LEO	2009-2014	2	
ISRO	INSAT-3D	IMAGER	GEO	2013-2014	2	

Table 1: Instruments with lunar observation capabilities, with the minimum number of Moon observations expected to be provided to the Lunar Calibration Dataset (more observations may be available). Negative phase angles denote waxing Moon (before full Moon).

The participants of the lunar calibration workshop endorsed the GIRO to be the established publicly available reference for lunar calibration, directly traceable to the USGS ROLO model. A process to formalise this traceability was discussed and will be implemented in the coming months.

The important aspects of error budget and uncertainty assessment were also addressed during a full-day practical session using the existing lunar calibration dataset. This assessment needs to be continued by each data provider but participants agreed to prepare instrument cross-comparisons and inter-calibration products as defined by GSICS.

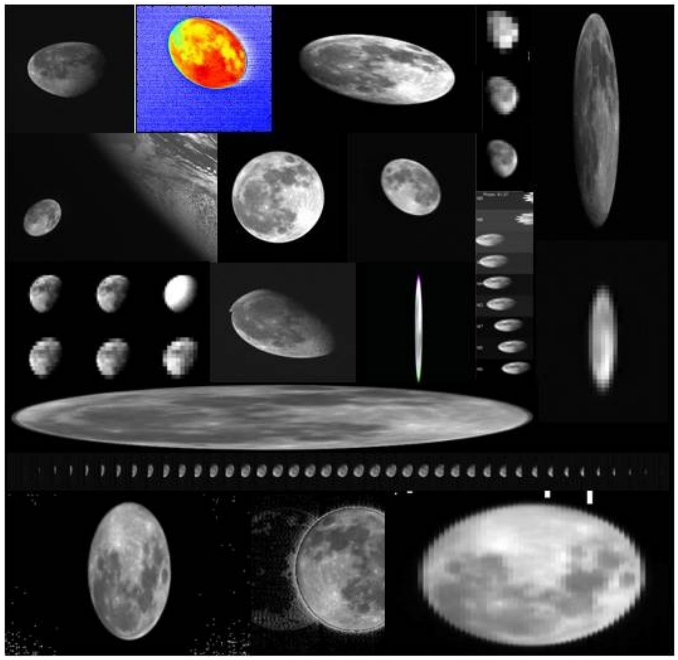

Figure 2: Examples of Moon observations from the participating instruments, illustrating the variety of acquisition mechanisms.

3. COLLABORATIVE FRAMEWORK AND INFRASTRUCTURE FOR THE GIRO AND THE GLOD

Following the decisions made during the workshop [1], a GIRO and GLOD Usage Policy was established and presented at the GSICS Executive Panel in May 2015 [4]. It lists the conditions of being granted access to the GIRO and the GLOD and how it should be used. Additionally, a collaborative framework was defined to maintain and improve further the current international reference. This framework is illustrated in Figure 3. The US Geological Survey is responsible for the maintenance and the further improvement of the ROLO model. Once in the public domain (i.e. through scientific publications), improvements to the ROLO are implemented in the GIRO by the GIRO Implementing Agency (currently EUMETSAT) and fully validated against the updated ROLO model. This validation is part of the process to ensure full traceability of the GIRO to the ROLO model. The traceability is essential to ensure the validity of cross-comparisons and inter-calibration between instruments. The newly validated GIRO version is successively released to become the official international reference for lunar calibration. It can be used for instrument monitoring and/or for instrument inter-calibration as shown in Figure 3.

In order to support the access to the GIRO and the GLOD, EUMETSAT will put in place an infrastructure where the GIRO and the GLOD are stored. An access point will be defined i.e. on the EUMETSAT GSICS Processing and Research Centre webpage (accessible for instance from http://gsics.wmo.int/).

The current GSICS Lunar Observation Dataset is expected to grow with the availability of additional observations from past, current and future missions. All participants to the Lunar Calibration Workshop agreed on EUMETSAT pursuing its efforts in developing and maintaining the GIRO in collaboration with USGS to ensure traceability to the reference ROLO model [2].

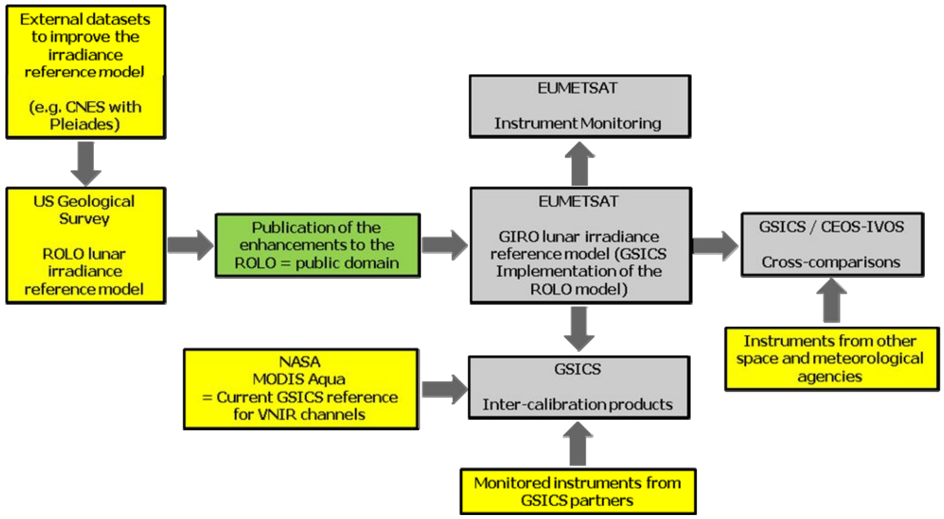

Figure 3: The collaborative framework defined to maintain and further improve the GIRO.

4. MOVING FORWARD INTER-CALIBRATION

Looking at the future, further effort is required to achieve inter-calibration between instruments. Oversampling factor determination is currently a major source of uncertainty in the evaluation of the observed lunar irradiance. Second, drift in the instruments' calibration should be corrected in order to use the irradiance as the quantity for comparison or inter-calibration. Third, *Spectral Band Adjustment Factors* must be derived from GIRO and validated. Finally, the lunar calibration reference needs to be tied to an absolute scale that is SI traceable.

In order to use the Moon as an absolute calibration source, the uncertainties in the lunar reference should be less than1% over the entire reflected solar spectral range, with assured traceability to SI. The current best lunar radiometric reference, the ROLO irradiance model, does not meet these standards. To meet this objective requires acquiring a new lunar measurement database. However such a project would imply a few years of acquisitions before a new model can be derived. Therefore, various additional projects have been initiated in the mean time by individual agencies or within the framework of GSICS to investigate for instance the possibility to achieve inter-calibration using Aqua MODIS as a reference instrument and the GIRO as a calibration transfer. The goal is to infer corrections/gains for the target instruments in the lower part of their dynamic range in order to complement similar products derived over targets with a different brightness (e.g. deep convective clouds). Similarly to Aqua MODIS, the VIIRS instrument on-board the Suomi-NPP satellite could be used as an alternative reference instrument for inter-calibration purposes using lunar observations and other transfer targets such as deep convective clouds.

5. CONCLUSION

The Lunar Calibration Workshop successfully brought together the GSICS and CEOS/IVOS communities. It involved not only teams with existing lunar data but also scientists and engineers preparing for future missions. The level of participation and discussion show the increasing interest to use lunar calibration for instrument performance monitoring, cross-comparisons and inter-calibration. A list of decisions, actions and recommendations [1] was established to pursue this international collaboration. The most obvious sign of interest in continuing this activity was that all participants agreed on the need to organise at a suitable date another Lunar Calibration Workshop.

Additionally, a collaborative framework has been put in place in order to coordinate the development and the maintenance of the GIRO and the GLOD, but also in order to foster interactions between groups working on lunar calibration. The purpose is to converge at international level towards an absolute reference for lunar calibration. Such a system would allow the calibration and the monitoring of present and future missions. But it would also allow the recalibration of past satellite data. Before absolute calibration can be achieved, some important aspects must be carefully addressed such as oversampling factor determination and drift correction. The next GSICS Research and Data Group annual meeting in Tsukuba, Japan, in February/March 2016 will be the next milestone for presenting the progress made by the members of the GSICS and CEOS/IVOS community.

REFERENCES

[1] GSICS/CEOS-IVOS Lunar Calibration Workshop Summary, https://gsics.nesdis.noaa.gov/pub/Development/LunarCalibrationWorkshop/SummaryoftheLunarCalibrationWorkshop.pdf

[2] Kieffer, H., H., Stone, T. C., *The Spectral Irradiance of the Moon,* The Astronomical Journal, **129**, 2887-2901 (2005)

[3] GSICS Lunar Calibration wiki page, https://gsics.nesdis.noaa.gov/wiki/Development/LunarWorkArea

[4] GIRO and GSICS Lunar Observation Dataset Usage Policy, Global Space-based Inter-Calibration System Executive Panel, GSICS-EP/Doc.13, http://www.wmo.int/pages/prog/sat/meetings/GSICS-EP-16.php (May 2015)