Lunar Calibration Workshop Minutes

4-8 December 2023
EUMETSAT, Darmstadt, Germany

Attendees

Stefan Adraensen (VITO), Biskash Basnet (NOAA), Bojan Bojkov (EUMETSAT), Martin Burgdorf (U. Hamburg), Monica Campanelli (CNR/ISAC), Lars Chapsky (JPL), Vincent Debaecker (Telespazio), Vance Haemmerle (JPL), Scott Hu (CMA), Tiger Hu (UMD), Hugh Kieffer, Natalia Kouremeti (PMOD), Matthijs Kriijger (ESS), Mounir Lekouara (EUMETSAT), Thierry Marbach (EUMETSAT), Stephen Maxwell (NIST), Gerhard Meister (NASA), Ali Mousivand (EUMETSAT), Maciej Neneman (EUMETSAT) , Thomas Müller (MPG/MPE), Rob Rosenberg (JPL), Aki Sato (RESTEC/JAXA), Dave Smith (RAL), Tom Stone (USGS), Masaya Takahashi (JMA), Sebastien Wagner (EUMETSAT), Fangfang Yu (UMD/NOAA), Bojan Sic (Noveltis), Diogo Rio Fernandes (OroraTech)

Remote attendees

Greg Kopp (LASP), HB Lee, Maya Nasr (Harvard U.), Pieter De Vis (NPL), Wei Cai, Hiroshi Murakami (JAXA), Zhenhua Jing (NUAA), Toru Kouyama (AIST), Marc Bouvet (ESA), Jason Choi (NOAA), Kevin Alonso Gonzalez, Fred Wu (NOAA), Truman Wilson (NASA), Hashiguchi Taichiro, Agnieska Bialek (NPL), Hanbyul Lee (KMA), Amit Angal (NASA), Constantine Lukashin (NASA), Clemens Rammeloo, Julian Gröbner (PMOD), Shihyan Lee (NASA), John Woodwood (NIST), Gaurav, Javier Gatón Herguedas (U. Valladolid), Manik Bali (NOAA), Josh Mann (USGS), Bernd Husemann, Thomas Honig, Thomas August

Minutes

Mon am - 4/12	Opening the 4th Joint GSICS/IVOS Lunar calibration Workshop

09:00	Sebastien Wagner / Tom Stone	EUMETSAT / USGS	Opening	1a

Seb welcomed participants, and reviewed the history of previous lunar calibration workshops. This meeting will provide a focal point for lunar irradiance model “derivators” and “applicators”. He reviewed actions from the 2020 Lunar Calibration Workshop, as detailed in the slides.

09:20	Bojan Bojkov / Mounir Lekouara	EUMETSAT	Welcome	1b

Bojan provided an introduction to EUMETSAT and its operational satellite missions, stressing the importance of inter-calibration to enable interoperability. He encouraged further efforts to put the lunar models to use for operational mission monitoring, which is coordinated through GSICS. He suggested setting up a dedicated GSICS web page to act as a focal point to share activities and resources on lunar calibration. This would increase visibility of what we are doing, which can help managers direct funding.

Hugh Kieffer: found it difficult to access GIRO due to previous restrictions, and stressed the importance of data sharing to develop lunar models.

Bojan suggested adding DOIs to tag lunar observations, as a method to provide traceability and ownership of the data, noting that a similar approach could apply to models.

Mounir then introduced the work of the INRC group, who are responsible for radiometric calibration and navigation of EUMETSAT's operational imagers. He presented initial lunar calibration results from several missions, including the Flexible Combined Imager and Lightning Imager on the first Meteosat Third Generation satellite, which are currently undergoing commissioning tests.

Decision D.LCWS.2023.1b.1: SLIMED model to be officially known as SLIM from now on!

09:40	Sebastien Wagner / Tom Stone	EUMETSAT / USGS	Agenda, announcements	1c

Tom welcomed participants and EUMETSAT and started a round of introductions.
Hugh mentioned the need for converging on the Moon's true near-side spectral irradiance.

Mon 4/12	**MEASUREMENTS and MOON OBSERVATIONS** **Chair: Kevin Turpie ⇒ Stephen Maxwell**

09:50	Kevin Turpie	UMBC / NASA	Introduction to the session	1d

Introduced by Seb, due to Kevin's absence.

10:00	Matthijs Krijger	Earth Space Solutions	The New SCIAMACHY Lunar Dataset	1e

Matthijs introduced SCIAMACHY, a spectrometer on Envisat, which has both nadir and limb viewing modes, thanks to its two scanning mirrors. It acquired dedicated Moon observations in

2006 and 2010, but also had regular lunar measurements during its lifetime (between 2002 and 2012). This dataset covers a broad range of the phase/libration angle space. He reviewed an issue identified based on analysis of measurements at the same Moon phase, which has now been corrected (except just around 350nm). The polarisation of the measurements can now be compensated. There remains a potential residual bias due to the coupling of the lunar phase and secondary mirror angle due to orbital mechanics, which could impact the phase angle dependence - e.g. unless polarisation correction is 100% accurate. He reviewed the uncertainties, which are within 1.3-2% absolute lunar reflectance and 1.5-2.2% for radiance, with a relative uncertainty of 0.2-0.5% for radiance and 1.4-1.9% for reflectance (k=1).
In collaboration with DLR, Matthijs is currently reprocessing the SCIAMACHY lunar observation dataset v10.1 in the context of a study funded by ESA.

Q: Why larger dispersion in NIR/SWIR?
- Different detector, which requires active cooling, and higher noise

Q: Which wavelength does polarisation dependence apply to?
- 380nm, but well-characterised wavelength-dependence

Q: How is polarisation sensitivity corrected?
- Polarisation sensitivity measured on-ground and modelled, as a function of mirror angles
- Perpendicular polarisation measurement devices on-board would also allow correction, but instrument is also sensitive to 45° polarisation.
- Difficult to do polarisation at high mirror angles, and drifts in time - but can monitor polarisation correction efficiency.

Q (Greg Kopp): is the noise pattern shortward of 400 nm due to polarisation of moonlight?
- No

Q (Jack Xiong): please elaborate on the impact of polarisation on moon measurements.
- Sensitivity to polarisation was measured pre-launch
- Instrument has on-board DoP measuring capability

Q (Marc Bouvet): please elaborate on the plot showing correlation between lunar phase angle and mirror angle
- The effect is due to orbital mechanics and different sensitivity to polarisation for different mirror positions. It is a known effect, and users of SCIAMACHY data need to be aware of it.

10:25	Kevin Turpie	UMBC / NASA	Update on Air-LUSI project	1f

Stephen Maxwell gave the presentation, due to Kevin’s absence.

Since the last Lunar Calibration Workshop in 2020, Air-LUSI has undergone a number of design improvements and 4 additional flights were conducted in March 2022.
Calibration performance is checked in hangar pre-flight., which works well above 400nm, except around 930nm due to water vapour absorption.

Observations will be published - with DOI.

Uncertainty budget has been revised due to improved temperature control of integrating sphere - now ~0.8% (k=1) over 400-1000 nm.
Stephen highlighted a funding issue and presented a list of recommendations - can be copied here.

Next campaign foreseen in Fall/Winter 2025
Funding is an issue.

Q: Bump in uncertainty budget around 780nm?
- Due to stronger O2 atmospheric transmission
- Not seen in STD plot, as it was consistent

Q: Possible ways to encourage funding - including raising the profile of lunar calibration.
- To be addressed in other discussion sessions - e.g. Friday.

Q: GitHub + Jupyter Notebooks will provide public access to review calibration.

Recommendation R.LCWS.2023.1f.1: Lunar Calibration Community to investigate in coordination with the GSICS Research Working Group how to raise visibility of the lunar (measurement) activities, and how to show the usefulness of those activities for climate monitoring.

11:10	Stephen Maxwell	NIST	Update on Mauna Loa-LUSI project	1g

Stephen introduced this ground-based counterpart of the Air-LUSI instrument and provided a history of its operations on Mauna Loa - in the face of a series of challenges, culminating in a volcanic eruption in November 2022, which resulted in loss of power connection.

Q: Outlook for eruption activity and recovery?
- ~1 year from now
- Considering participating in stellar calibration campaign at ESO site.

Q: What observations are available?
- Informal comparison with Aeronet - saw a change in our data of about ~2% about 45 minutes after sunset
- Need to recover spectrograph from site to confirm calibration

Q: In ROLO model component approach, instead of doing simple Langley plot, divided sky into sectors and fitted quadratic curve to each. Found irreducible limit in atmospheric variations ~1 hour.

11:35	Xiuqing (Scott) Hu	CMA	Latest update of ground-based Lunar measurement and model validation in Lijiang, China	1h

Scott described the series of lunar observations at the Lijiang site, which have continued since 2015 using a series of instruments. The design of those instruments has been improved over time. In Lijiang, conditions are better between October and December, with lower aerosol levels (AOD~0.04).
Found degradation ~3% over 2017-2023 in calibration wrt GIRO

Scott also introduced the JiLin-1 small satellite with high manoeuvrability and spatial resolution, which has provided lunar observations since April 2019 in 19 bands VIS-NIR.
And the FY-3G/HAOC (High Accuracy On-board Calibrator) which includes a VIS-NIR Offner grating spectrometer. Initial results show good consistency with GIRO but with a spectral dependence.

Considering developing purely data-driven irradiance model.

Q: Data access?

- HAOC currently undergoing quality control - expected timescale ~1 year

Q: what aperture size showed to be the most suitable for radiance measurements?

- Still testing

12:00	Agnieszka Bialek	NPL	Latest update of the lunar measurement campaign done for the LIME model development	1i

Agnieskza introduced the ground-based observations used to derive the LIME model. Those measurements are evolving from multispectral to hyperspectral instrumentation from sites on Tenerife at 3555m in summer and Izana at 2401m in winter. Langley plots are used for atmospheric correction with stability <<1%.

CIMEL 318-TP9 Sun Photometer provides observations from 340 to 1640 nm - however, the signal in the 340 and 380 nm channels was too weak - so these channels were replaced in favour of 2 new filters at 550 nm and 780 nm.

SI-traceability is provided by lab calibration of the instrument, ~1% (k=1) for lunar observations.

- Also tested linearity and temperature stability in lab to derive corrections

Hyperspectral measurements have been acquired on an experimental basis for a few months, covering using the ASD FieldSpec spectrometer, covering 350-2500 nm, installed on sun-tracker, with modified front optics, with a scrambler to provide more uniform sampling of the Moon disc - although VNIR FOV still quite "peaky". Spectral resolution goes from 10nm (standard) to 6nm.
Detector installed in thermally-stabilised box. Compared results to CIMEL irradiance observations, but currently limited to 1.6μm. Planning another 3 month campaign - with extended CIMEL spectral range.

Q: Is Atmospheric Correction based on Sun or Moon measurements?
- Both are run continuously, accounting for lunar irradiances changes iteratively

Q: Documentation only covers multispectral observations - when will hyperspectral be published?
- Toolbox for hyperspectral LIME model will be published in a few weeks!

Sharing observations?
- So far only a few nights' multispectral measurements through GLOD. More will be shared through ESA project. Condensed observations are shared through toolbox.
- ESA could consider sharing more if mechanisms are agreed at Lunar Calibration Community.

12:25	All	All	Discussion	1j

Recommendation R.LCWS.2023.1j.1: Agencies acquiring lunar observations to share data with documentation and uncertainties as far as possible.
Recommendation R.LCWS.2023.1j.2: GSICS to define a mechanism to share observations (jointly with IVOS) - e.g. assigning a DOI, linked to a URL.
Can share recommendation with WGCV via Jack Xiong

Is there a need to make a distinction between observations acquired from operational and research systems?
- Could be covered by QA flags, to identify maturity of calibration, including validation by comparison with other observations?
- Could also be covered by commonly-coordinated inter-comparisons, which require involvement of all dataset providers.

Considering whether it would be possible to develop a system of inter-comparisons of lunar observations - in a similar way that LSICS provides a mechanism to compare lunar irradiance models derived from the observations. But this requires the use of a model to transfer the observations to common conditions.

Hugh highlighted the need to ensure observations are independent of the lunar irradiance models that are derived from them. So datasets should be clearly labelled as whether they include any use of lunar models - with full traceability.
Does recommendation on sharing data refer to all data, or only those used to derive models?

- E.g. to include a subset, to ensure independent validation

What about lunar radiance models?

- To be considered while reviewing lunar radiance observations

13:55	Natalia Kouremeti	PMOD	Traceability of Lunar Direct Irradiances Measured with Precision Filter Radiometer	1k

From project on Metrology for Optical Depth measurements

Solar observations gave good agreement with TSIS reference solar spectrum
Lunar-PFR

- 4 detectors - 861.75nm, 501.39nm, 411.95nm, 675.39nm. Spectral responsivity uncertainty: < 0.3%
- Characterised at PTB TUnable Lasers In Photometry (TULIP)
- Uncertainty in responsivity ~0.2-0.3%.
    - Expanded relative uncertainty of lunar irradiance U<0.5%
- Compared with RIMO (Barreto et al., 2018), ROLO and ROLO* irradiance models (the last is an experimental version, with bias corrections provided by Tom Stone)
    - ROLO* version gives excellent agreement within 0.5% for 862nm, and 2-4% for others - with an uncertainty of 1% (k=2)

Q: does the filter off-axis wavelength shift account for the size of the Moon disk?
- it can be corrected, but the uncertainty is high

Q: Data availability?

- following peer review publication

14:20	Constantine Lukashin	NASA	ARCSTONE InVEST: Calibration of Lunar Spectral Reflectance from Space	1l

Costy provided an update on the ARCSTONE InVEST project to fly on cubesat for 6 months in a sun-sync orbit, in support of a full ARCSTONE mission, covering 3 years.
Planning to measure daily from -90° to +90° (nominal) with additional goal to extend to +/-135° (demonstration, not part of the mission requirements)
UV/VNIR prototype reflectance Uncertainty - 0.15% (k=1) - see Courrier et al, JARS 2023
Launch - Summer 2025

Q: Online Lunar Calibration Service? How is this different from LSICS?
- Still to be defined - depending on outcome of LSICS, ARCSTONE could become part of LSICS
- Does this impose any requirements on LSICS?
- Implications for maintenance? And interface to LIME-toolbox?

Q: CubeSat pointing control?
- COTS solution - provides accuracy 0.002° in 3-axis based on 2 star trackers + stability of 1 arc-second over 1 sec - once cryocooler has stabilised.

Q: What limits flight-time to 6-months?
- Mission funding, and battery life for cryocooler. It is foreseen to be 6 months +/- 2 months

14:45	Greg Kopp	CU/LASP	Improving Calibrations of Lunar Spectral Measurements	1m

Greg showed how the Total Solar Irradiance can be used to scale SSI - this forms the basis of the ARCSTONE lunar observations, and compared its specs to those of CLARREO-Pathfinder. Different aperture sizes and integration times are used to cover full dynamic range to allow the instrument to view the Earth, Moon or Sun.
He reviewed the ARCSTONE prototype characterisation, including non-linearity, noise (read-out, dark-current and shot) and polarisation, showing the importance of dark measurements, which dominates overall uncertainty. Polarisation correction is needed, otherwise, it will dominate uncertainty to 0.6-0.8%, which can be achieved with a model (e.g. LIME) or comparison of lunar observations in orthogonal orientation.
He reviewed the uncertainty budget, which should meet threshold <0.5% (k=1)

Q: Timeline for CLARREO-Pathfinder?
- Complete testing Spring 2024
- Launch to ISS late 2025 - early 2026

Q: TRUTHS?
- Contrast to TRUTHS (launch ~2030) - which will carry a cryogenic radiometer, so will not rely on inter-comparisons with solar irradiance to provide traceability of lunar irradiances.
- Motivation to keep CLARREO-Pathfinder running until then!

Q: Constraints from ISS operations?
- Aware of many issues, as a result of TSIS-1 experience
- 2-axis pointing system, but still limited opportunities to observe the Moon
- CLARREO Pathfinder mission has a well-developed Science Planning System that includes ability to predict when Moon is visible

Q: Plans to update uncertainty model?

- Yes - with further characterisation on-ground and in-orbit
- Flatfielding is the largest contributor to the uncertainty budget

15:10	All	All	Discussion	1n

Q: Concerns about retro-fitting models into the data analysis, on data sets used to derive new models. What about LIME's use of ROLO model for atmospheric correction?

- Only used to account for lunar irradiance variations during Langley plot
- Importance to include characterisation of uncertainty contributed by the model used
- Distance correction known very accurately
- Phase-angle correction introduces more uncertainty
- ARCSTONE will use a polarisation model to derive polarisation correction
- All lunar observations rely on a solar irradiance model (except TRUTHS)

Q: Do we need more polarisation measurements of the Moon?

- Would need detailed knowledge of instrument's polarisation response
- CO2M/MAP will provide polarisation diverse observations of the Moon
- E.g. ongoing analysis of SCIAMACHY
- Also possible using ground-based observations

Recommendation R.LCWS.2023.1n.1: Encourage more observations of lunar polarisation to allow development of improved lunar polarisation model

Mon 4/12	**LUNAR CALIBRATION SYSTEMS and MODEL DEVELOPMENT** **Chair: Tom Stone Minutes: Stephen Maxell + Bikash Basnet**

16:00	Tom Stone	USGS	Introduction to the session	1o

Tom introduced the session on lunar modelling and calibration systems.

16:10	Marc Bouvet	ESA	Status of the development of LIME: the Lunar Irradiance Model of ESA	1p

Presented by Stefan Adriaensen, online.

LIME model is based on 5+ years of continuous lunar measurements with ongoing new measurements.

Relies on CSPICE-NAIF library *[bookmark for discussion: which kernel you use matters]*. Conversion to reflectance uses TSIS-1

Polynomial fit to the phase angle was done. After the fit removed the upper Langley uncertainty values. Relative difference in irradiance wrt CIMEL measurement was performed.

There is a split between the inferred reflectance from negative phase angles vs positive. Is this an indication of an issue? They've included correlations in monte carlo simulations to develop uncertainty. CoMet toolkit used.

ASD spectroradiometer data taken over 3 months are used to interpolate between bands rather than original ROLO Apollo mixture

Javier Herguedas presented LIME Toolbox.

NetCDF file can be used in the toolbox. It can perform comparison of irradiance per time.

SRF files were used as GLOD format.

The toolbox (TBX) architecture was shown with many features like simulation, filedata etc.

Simple visualisation shows simplified form of TBX architecture.

Degree Of Linear Polarisation: there is no model yet, but only a regression on data. LIME has band/by/band coefficients in the model. DOLP Measurements show high scatter. 4th order Chebyshev polynomial was used for linear polarization fitting.

Treats positive and negative phase angles separately.

Parameters of degree of polarisation are published.

calvalportal.ceos.org/lime is the official website for the project and the toolbox.

LIME TBX will propagate uncertainties.

Q: for ASD measurements, does the linear assumption hold for adjusting the spectrum to account for phase change and reddening?

Answer: Not really. Overall it seems linear. Variability within the bin is also observed.

Variability in phase angle can be due to sensitivity of the instrument w.r.t view angle.

Not relying on absolute uncertainty of measurement but rather to relative uncertainty of measurements.

Q: Jack: Slide 5: how did you convert Irradiance to reflectance conversion using TSIS-1?

A: divide irradiance from LIME instrument by TSIS irradiance.

Q: Thijs: How do you combine ASD measurements to CIMEL measurements?

A: Regression process to do the interpolation.

Tom: Concern with ASD measurement uncertainty, very much relying on ASD spectra.

Waxing and Waning difference in reflectance captured in slide 6. Hugh and Tom: this is expected, it is modelled with the b terms.

Tom: is the spectral shape change with phase angle more than just well-known reddening? So perhaps the spread in the plot could be modelled with a linear function?

Seb: Is toolbox or code shared?

A: Can be both. The code is in python.

Two different versions of the toolbox are present currently.

Action A.LCWS.2023.1p.1: ESA/VITO to check on the uncertainty in the lower phase angle of the model and report back to GSICS.

Matthijs: Reported uncertainty seems higher here than previously reported. Marc will check.

Recommendation R.LCWS.2023.1p.2: a detailed documentation on all lunar models and their implementation should be provided for review by the Lunar Calibration Community

16:35	Matthijs Krijger	Earth Space Solutions	The New SCIAMACHY Lunar Model (LESSR)	1q

LESSSR uses fits of linear mix of RELAB to SCIAMACHY data. Slightly different than ROLO model formulation.
Fit is split into a linear and a non-linear part. Model fit residuals are “pretty much within a percent”
Uncertainty analysis done via Monte Carlo bootstrap. Uncertainty higher in low phase angles – ranges from ~3% range at 6 degrees to sub ½ % at 30 degrees. Claimed accuracy for v 1.1: “1.5% 500 nm to 2600 nm” and it’s complete without “post-model spectral fits.” Users need to be careful with very small phase angles due to higher uncertainty.
Version 1.0 was shared for Tom’s GSICS comparison due to some issues with another version.
Later versions will include other lunar datasets.

Tom comment: you haven’t used a cross term between solar longitude and observer lon/lat - the impact will be addressed tomorrow.

Seb: Where is risk from small angle while using LESSSR?
A: Under 7 degrees.

Jack: 1.5-2% accuracy is tied to SCIAMACHY measurements?
A: Yes. Relative accuracy <1.5% between 350 and 2600nm; <2% below 350nm

Tom:
A: This model accuracy reported is relative accuracy, not absolute.

Fred: When will the data or model be available?
Seb: Spring of next year version 1.1

Stefan: Did you already compare to other sensors
A: Yes. Tom will show tomorrow.
Bojan: RELAB reflectance spectra are mixed to generate spectra. Do you use the same mix for each spectrum?
Answer: Every individual measurement is re-fit with a mix of 20 RELAB spectra

Tom: The community would appreciate seeing those mixes
Thijs: This is approved and it will be released.
Thijs: Does not see interesting variation in the mixtures.

Seb: Is the group asking for detailed documentation on models? We had similar comments on LIME about how specifically some elements were chosen/derived
A: Tom – yes it's a good idea. Seb – if we are going to use the model for referencing, we need deep documentation. Hugh – need open publication. Getting good reviewers is a challenge and should not rely only on the normal peer review process (use GSICS colleagues – at least 2).

Action A.LCWS.2023.1q.1: Detailed description of model derivation is required for each model

Recommendation R.LCWS.2023.1q.1: GSICS community should review and validate the methodology. Peer review process is secondary.

17:00	Hugh Kieffer	Celestial Reasonings	Converging on the Moon's true near-side spectral irradiance	1r

Talk requires reading a particular paper from JARS written by Hugh two years ago to comprehend.
Hugh H. Kieffer, "Multiple-instrument-based spectral irradiance of the Moon," J. Appl. Rem. Sens. 16(3) 038502 (13 August 2022) https://doi.org/10.1117/1.JRS.16.038502
https://www.spiedigitallibrary.org/journals/journal-of-applied-remote-sensing/volume-16/issue-03/038502/Multiple-instrument-based-spectral-irradiance-of-the-Moon/10.1117/1.JRS.16.038502.full?SSO=1

Redesign motivated by the 40 year history of code that went into SLIM written by a single individual. Unmaintainable by anyone else.

New version: Separation of functions. Removal of idiosyncratic code. Standard files NetCDF or text. 14 major routines go into the code. Used 32 sources (29 instruments + 3 models) and put 14 in the model.

Only ROLO and PLEIADES data came with uncertainties. For PLEIADES, uncertainties off by 8 orders of magnitude. For the other sources, Hugh used judgement to decide what uncertainty on each source is and it is described in paper.

Most of the new code will go into LSICS in Python.

Hugh would like to have input from the community on "heft" coefficients that weigh different instruments going into the model.

Last fit uses SVD to provide uncertainty with the fit.
Hugh can share IDL code and there are visualization tools.

Bikash: What version of SLIM are you now describing?

Hugh: The part which is LSICS will not change much. The original model was one 3000 line program that pointed to other programs. Expect to get this down to 50 routines and is eager for someone to take it over. Will make it as public as possible. Expect to have a redesign running in a couple of months. Licence will not allow commercial use. Wants a long-term curator for this software. This will be required.

Bikash: Have you done any comparison with version 2.1, is there a difference.
Hugh: **No**. “My archaic style of programming is ‘everything can evolve at the same time.’” Everything is under slow evolution. Because the current software under development is not finished, no comparisons are possible.

Tim: GNU Data Language is an option as a public language alternative to IDL.

17:25	All	All	Discussion	1s

Marc: What do we want to achieve as a group w.r.t. diversity of models?
Tom: “We need reliable absolute lunar irradiance measurements…with realistic uncertainties…when we have that, then all of the models need to be consistent with those measurements.” This will be discussed on Tuesday.

Fred: LSICS is intended to address this question. LSICS will facilitate model development by enabling comparisons of models.
Tom: Model development tools and model implementations and interfaces are not the same. Deriving lunar models is a research task and developers can do it any way they like.

Seb: LSICS is a framework to apply models (“applicator”).

Hugh: Encourage everyone to develop models independently, but to be useful to the community provide an LSICS interface. LSICS is a tool to minimize work for model developers to make the model useful.

Fangfang: each model relies on data. How do we include/give-access-to data?
A: data format is topic of discussion tomorrow.

Seb: Original goal with the GLOD was to require people who use the GIRO to submit data. Would be good to have this
Steve: Should we recommend that agencies release data officially?
Jack: agencies don’t want to get legal obligation to process more data. Data are publicly available but won’t commit.
Seb: Some agencies don’t want to release level 1 data that tells too much about the instrument.
Fred: NASA similar to NOAA.

Thijs: Should address LIME-TBX v. LSICS issue.
Tom: what magnitude of changes to LIME-TBX would be required to plug it into LSICS?

Hugh: How do we protect the meaning of "I used LSICS" or "LSICS endorsed"?
Seb: The system requires providing the full traceability of what is used. What has been done, what version?

Seb: Last comment – SCIAMACHY, GOME2, EnMAP, OCO, all hyperspectral. Keep in the back of our mind the hyperspectral dimension.
Hugh: Too many parameters if you're trying to get a global minimum

Tue 5/12	LUNAR CALIBRATION SYSTEMS and MODEL DEVELOPMENT Chair: Tom Stone

Models need to be validated.
Still lacking absolute measurements.

Compare model outputs generated for a common set of inputs:
- Phases +/- 3-90, viewer lon +/- 0-12, viewer lat +/- 0-8 (not all 700 points are possible)
- 8 spectral bands with 20nm FWHM spanning 442-2350
- Sent to community Apr 2023, model Points of Contact are NOT the model developers

Review of models:
- ROLO:
  - ROLO telescopes active 1995-2003
- CLIMES:
  - developed from Lane & Irvine 1973 "but they're good measurements"
  - Designed to say how much moonlight illuminates the dark side of the Earth
- SP model from SELENE lunar orbiter:
  - spatially resolved radiance, tested vs ASTER (6 bands)
- GIRO:
  - ROLO with different post-processing +/- 2-92˚
- SLIM:
  - Continuous in geometry and wavelength, makes a big difference, human assessment of every point, 24 coefficient MapLib from lunar orbiter decreases work done by main fit
- LIME:
  - Reformulation of ROLO, coefficients are wavelength dependent,
  - ~450 CIMEL irradiances,
  - Polarimetric measurements are a significant advance
- LESSSR: based on SCIAMACHY observations

Model comparison: 2D and 3D plots inadequate for 20-dimensional space
Comments and suggestions welcome - will be presented again
Need to compare to something - chose ROLO despite a fairly significant low bias (4-8%) better agreement with Natalia's ground results ("ROLO*") after correcting for it - validation.
Irradiance ratios -10 to +15 % at smallest phase angle +/- 3˚, "straighten out" at higher phases but still quite a spread

LIME notable transition at shorter wavelengths
True should be near +6%, SLIM above the cluster, motivation for SLIM at the core of LSICS
Very little change with librations at low phases
MT2009 large excursions at longer wavelengths for higher phases (acknowledged by S.Miller)
Contributors need to explicitly consent to release of data from this study to answer limited requests
No uncertainties in this exercise - can these differences be used as uncertainty estimates - how significant are the differences?

Q: Why does GIRO differ from ROLO, in particular in the SWIR?
XX: remember smaller differences in SWIR from initial GIRO validation exercise
ROLO has changed since GIRO was developed
Seb Wagner: need to realign the two models. It has to do with the post-processing.

The GSICS reference will need uncertainties
Monte Carlo (LIME), SVD will directly provide uncertainties - best to generate the full covariance matrix
Criteria for selecting reference model? For this study, TS made the plots so arbitrarily chose ROLO - emphasise this is ROLO, not ROLO* (it is still experimental)

Built correction into ROLO that "sort of mimics" using TSIS-1 HSRS instead of Wehrli 1985, this correction was used for this model comparison exercise

Not sure if all models in this study used the same solar spectrum (model results were provided without specifying)
SW: Using TSIS-1 HSRS will help highlight the underlying mathematics of applicators. It could be part of the next iteration on the model inter-comparison

Legacy instruments like MODIS need a consistent time series
HK: SLIM accounts for solar variations (1 day resolution)
Tom Stone: Do you need to look up what the solar spectrum was at the time the Moon was viewed
Solar variability (day to day) very small compared to spread in models - esp in NIR
Jack Xiong: solar model differences can be quite large in the SWIR
Greg Kopp: confirm few percent differences from previous models at wavelengths longer than 1600 nm

Higher phases, longer wavelengths, GIRO bias from different methods for fitting lunar reflectance spectrum.

LESSSR has no post-processing - magnitude of difference is surprising, especially considering that LIME does it in a very similar way

ROLO raw model outputs are noisy, need to smooth by fitting reflectance spectrum
Fit to absolute phase or signed phase? ROLO uses signed.
SW: should future comparisons use more spectral bands?

Recommendation R.LCWS.2023.2a.1: Additional spectral bands should be added to the existing SRF dataset available for the inter-comparison exercise, in particular in spectral domains subject to gaseous absorption.

Lots of atmospheric absorption bands
Doesn't really matter that long-wavelength bands are far apart after the fit
SM: not too surprised by issues at long wavelengths (pointed out in the paper that linear extrapolations are used - clearly wrong)
SLIM "probably best representation of the real moon that we have today"
Have the primary measurements been compared? Can help assess methods. Was data collected close in time? Are there common elements?

Phase (at zero libration) per spectral band - waxing vs waning differences stand out
SLIM highest until lowest phase angles when LIME is highest (3˚ very different from 5˚)
Models with terms for the opposition effect stand out from those that don't
Very large differences between ROLO & GIRO at long wavelengths, with curve at phases
Waxing/waning vs. phase angle plot looks wrong. TS took the action to revisit the plotting procedure.

- Corrected waxing/waning plots in revised presentation slides

Libration: how do the models handle the different angles? (MT excluded here)
ROLO is the black curve, not divided out from the others (ratios are to zero libration)
Qualitatively similar, differences in slope at negative phase angles
Not monotonic at positive phase angles
Not trying to judge models at this stage, just show data "it is curious"
Latitude dependence not in LESSSR
Longitude dependence vs phase - "interesting pattern", not monotonic
MB: Suggest to label that some parameters are zero instead of not showing

- Suggestion implemented in plots in revised presentation slides

Hugh Kieffer: concern that all models are not continuous across 0˚ phase, related to different approaches for modelling opposition. The representation of the opposition effect is not accurate enough.

Tom Stone: in the case of ROLO, there were not many measurements for small phases.
Marc Bouvet: do we need exponential (etc) instead of polynomials?

In the LIME model the regression is not using the same sampling for each and every band because of the filtering on the Langley plots.

Tom Stone: ROLO dataset is sparse at lowest phases, agree that this is clearly a numerical effect, we have to do something for small phases

Fred Wu: is this a forward-scatter vs backscatter issue?

Matthijs Krijger: viewer lat is showing solar longitude - cross terms with phase (Thijs needs to explain in more detail - will write out the whiteboard later)

SM: trying to make things operational - how does this translate to sensor trends vs time? Does this help us choose which model to choose for trending? This is fully another exercise

Seb Wagner: Meteosat time series shows seasonality in signal (20 years MSG1 but limited spectrally)

Tom Stone: VIIRS especially has libration dependence that is probably in the model, any study of time dependence needs a particular satellite

SM: sample parameter space with even time grid (instead of even in the model params), compare each model to the first point in time

Greg Kopp: very useful for instrument teams choosing models for relative trends - better matches uses LIME and LESSSR notable for wavelength-dependent libration - especially LIME not monotonic - might be real, given the difficulties with fitting periodic libration function to VIIRS time variations.
Tom: Different parts of the moon have different reflectance spectra - librations change what you see
Matthijs Krijger: but shouldn't this be smooth?

Hugh Kieffer: Clementine 10 bands

Marc Bouvet: different # of obs per wavelength (separate Langley rejections per band, not all meet quality filter) ~10% differences
RR: would there still be enough data if you required all channels to pass filters to use a LIME night? A: Would not have worked well earlier, but there should be enough data now.
TS: Poles are difficult due to shadows, SP had some issues there
Seb Wagner: what else beyond the solar spectrum could cause models to be different?
GK: data from CLARREO Pathfinder may come before model synthesis

MB: feed models with same input data to understand model analytical formulation differences
TS: would be great but need absolute truth
Core module of LSICS needs to be based on something - should someone write one for LSICS?
TS: "feel free to"
MB: should I give HK the LIME data for him to generate SLIM coefficients - this allows us to compare fitting
RR: would coincidences in training datasets for different models help?
TS: you still need to use a model (moving satellite vs ground sensor, not in the same place, …)
Matthijs Krijger: remove post-processing steps?
Air-LUSI as a good starting point? (unc ~ 1%) just up to 1um right now
Matthijs Krijger: only need one point if you trust it enough to re-normalize the models
TS: need to repeat Air-LUSI flights at previous phases to make sure it's consistent

Recommendation R.LCWS.2023.2a.2: NIST to share fully processed Air-LUSI data with lunar calibration community. This will support the understanding of model differences.

Hugh Kieffer: will want to regenerate SLIM after Air-LUSI data made available

GK: improve absolute accuracy, improve time dependence, improve spectral content accuracy - which do users care about most? Absolute accuracy can be improved quickly, time dependence takes a longer mission, spectral accuracy is very instrument dependent. The group should give priorities

TH/SM: where to put the observer for synthetic time series? Center of earth (0,0,0)? on surface? ISS? Etc.

SM: could help instruments choose which phases etc where models agree best to minimise impact

Recommendation R.LCWS.2023.2a.3: Tom Stone to iterate with the Lunar Calibration Community on the need to generate time series of model lunar irradiance differences for a synthetic instrument

09:00 -> 11:30	Hugh Kieffer	Celestial Reasonings	Redesign of the SLIM lunar model development system	2a

Rational functions to avoid non-physical infinity at 0˚ phase that's in every model
Difficulties from eclipses under 1.6˚
Mix Reference spectra: mare, highlands, then pyroxenes (variability within highlands)

1% absolute by 2025, 0.1% absolute by 2050 (there are no stoppers to 1:10000, at least as good as the Sun) for long term mindset, ignore the issues highlighted in the past session for now - don't omit the things you "could do" that are too hard

4 independent angles & wavelength, two more dimensions for polarizations, will make eval/comparison even more challenging

Counterpoint to emphasising time series analysis: the Moon is effectively invariant - time is the one thing you don't have to worry about
How do we get to one reference model?

"Size of source effect" All real instruments have response outside "edge" of FOV - often more than people realise

Lab calibrations do not simulate real scenes (oceans/clouds) - estimate during commissioning
Scan across moon in both directions as far as you can
Landsat 8 OLI mapped ppm response

Image to irradiance transform: far more pitfalls than people realise - talk to ops & dev teams
Techniques will improve

We will reach the era of absolute lunar cal - not quite there yet

No dictator but unofficial preferred "Lunar Disk Reflectance" model - if LSICS done well, plugging in will be easy

Challenges to free exchange of information - GSICS action item?
People who make data available get more votes?!?

Uncertainties - a large topic - many data sources - community input on "Heft" desired

How to adjudicate differences when "absolute" measurements disagree? Reach the reality of only one Moon

TH: metrology community adds uncertainty terms for unknown contributions until they match within uncertainties and define a community consensus as a weighted average = compromise

Start uncertainty analysis now! Many open source tools for propagating
Email guidance to Seb

Needs to start with input data uncertainties - it's a lot of work! (at least 3X harder than a system that doesn't track unc)

RR: will prelaunch cal & spacecraft telemetry lag behind model dev and limit how well models can be used?

SW: CEOS preflight cal workshop in 2024!

HK: absolutely plan for lunar measurements very early (prelaunch & commissioning) - missions become rigid.
Examples: measuring far off-axis is hard in the lab and easy in space (but need time). So such measurements from space should be attempted during commissioning.
It is also recommended to watch integrating spheres when they are turn off slowly. Those measurements can be done at no additional cost!

Seb Wagner: exploit additional flexibility at decommissioning & end of life - be creative
Jack Xiong: very interesting to plan end of mission tests

Hugh Kieffer: wants data from Jack Xiong at less unusual scan angles
Jack Xiong: tie recommendations to science benefits, RVS changes with time
Reasons for constrained phase angles, e.g. orbital mechanics, but constraint helps VIIRS see libration variations

Greg Kopp: More about time: models will disagree vs time
Hugh Kieffer: LSICS should provide for mission needs

09:25	Tom Stone	USGS	Results of the GSICS Lunar Model Comparison Exercise	2b

See above

Action A.LCWS.2023.2b.1: T. Stone to coordinate with the group involved in the first lunar model inter-comparison to define a way forward for the next iteration on the model inter-comparison.

10:10	All	All	Discussion	2c

See above

11:00 -> 13:15	Tom Stone	USGS	Introduction to the LSICS development	2d

Tom presentation LSICS development: what is it, what is going to do and why do we need LSICS. It is foreseen to replace the current GIRO

ROLO Limitations: absolute, phase/wavelength/libration variations, will be addressed by LSICS
Increasing recognition that intercalibration consistency is essential for climate - the Moon can provide this as the source is ultra-stable and models predict changes in Moon's brightness
In: Date, Time. SRF -> Out: Spectral irradiance ("applicator")
Modular to allow different models to plug in (standard interface) including LIME
SW: LSICS is a framework where different models can be run, distinguishing it from GIRO
SLIM will be first but the infrastructure will be flexible

Where will it be hosted, how is access controlled?

Need: following 2005 paper, different groups had replicated ROLO and claimed they were using ROLO results

The question of the code distribution was discussed but access/distribution mechanism still to be addressed.

SLIM needs to be converted to a public language
Access to other models unclear

11:10	All	All	Discussion	2e

Discussion items were covered in the previous time slots, during the presentations.

13:10	Fred Wu	NOAA	NOAA Support for Lunar Spectral Irradiance Calibration System (LSICS)	2f

Fred Wu: Focusing on administrative support (BB will cover implementation)

Preparing measured irradiance is non-trivial, focusing here on model part of effort
Known ROLO biases hinders use for absolute cal
Trending and "double difference" cross-calibration also very important, but phase/libr makes it more difficult (model error changes with time)
HK 2022 paper won JARS award - represents significant improvement over ROLO/GIRO
Framework proposed in Annual Meeting Mar 2023
NOAA advocates for open source, modular design, TS & FY as co-leads
Additional uses for moonlight-based remote sensing? (as with MT model), GeoXO will have a DnB similar to VIIRS. VIIRS experience will be very useful.
Who are the developers? Will they make LIME & LESSR compatible? What about standalone models from Lijiang or LUSI? - models from both are expected
Python because user-friendly and portable, archived and distributed via GitHub (not final)
Implement from pseudocode (done for LOAS), or translate existing (as with SLIMpy)

What about existing Python for LIME etc? It may not be compatible with LSICS framework -

What will be the responsibilities of implementers? What about licensing?

SW: EUMETSAT needed to define usage and remove liability
TS: release under GSICS umbrella (still open question)

Marc Bouvet: LIME toolbox (GUI & command line) is in Python, not sure about compatibility with LSICS, currently no budget to integrate into LSICS.
ESA will kick-off an activity in 2024 to give visibility to their lunar calibration activities.

Fred Wu: can LIME code be shared with developers?

Marc Bouvet: hopefully yes. Documentation/release of toolbox need to be finished, and then it will go to the CEOS Cal/Val portal first early 2024.

The LIME toolbox could serve as a starting point for LSICS.

GLOD inputs, disk refl ingest module will have a formal interface even if just a few parameters
SM: choice of consistent SPICE kernels is important
SM: use agency standard software disclaimers instead of making something new

Action A.LCWS.2023.2f.1: Teams involved in software development to liaise with LSICS development group on what are the typical disclaimers for distributing software.

CMA can join with Lijiang data and the CMA model in collaboration with EUMETSAT.

13:35 -> 14:15	Bikash Basnet	NOAA	Implementation of Lunar Spectral Irradiance Calibration System (LSICS)	2g

LSICS is still being developed, one module and one model prototype implemented
Algorithm to pseudocode to opensource

EX: USGS Photometric Geometry -> TS Pseudocode -> NOAA STAR open source Python
Confirmed agreement with SLIM IDL and ROLO within machine roundoff

Pseudocode also preferable vs line-to-line (clarity) when starting from shared code
SLIM v0 to v2.1 to SLIMpy1.0 in 13 months including testing and full validation

G16 ABI normalised irradiances match within machine roundoff

TOML 0.10.2 for config files, SpicePy (Annex 2020), all files NetCDF4 1.6.2, NumPy, …

Considerably better precision for GOES-R ABI B5 trending vs SLIM than vs GIRO
Standard wavelength set or native set?
NOAA will continue to support lunar model integration

VH: do you need a spacecraft SPICE kernel or can it come from somewhere else?
OCO-3 has its own telemetry (attitude & ephemeris vectors)
TS: No, spacecraft kernel not needed, "it's on users" to provide s/c positions
BB: Position & time inputs, 5-angular state output
JC: do other ABI bands look similar to B5? Is it normalised? (Yes) Very exciting result
Seb Wagner: there's still some phase dependence (a colour plot would show this)
Toru Kouyama: also interested in incorporating SP

Marc Bouvet: Integrate *all* current and future Lunar models? One framework, declare which to use, can be used for model output comparisons
Hugh Kieffer: switch with default model, allow user to request, same interface to each
Seb Wagner: MICMICS experience is relevant
Manik Bali: can list GSICS deliverables

Can LSICS be structured to allow the implementation of lunar model in the IR and MW in the future? Needs are similar to VNIR. Should not be a problem.

14:00 -> 15:10	Hugh Kieffer	Celestial Reasonings	Discussion on the draft specs of LSICS system	2h

Spec should have been written by someone without biases toward SLIM or any other model
Submit GSICS VISNIR action items
Distribute by Mar 2024 GSICS Annual
Table of irradiance terminology:
Observed: after correcting anything unique to a specific instrument
GSICS standard conditions not defined but LSICS will guarantee it's done consistently
Observed/predicted ratio should be exactly the same as reported/model ratio
SM: what is the relevance of #1 "Image"? Agree that you need same DN -> Radiance
BB: is 2->5 or 3->4 the desired path forward?
HK: anything common should be in LSICS superstructure, 4 is the "real task"
Wavelength concepts & interfaces:
Files are external, DataGroups are internal, otherwise same
Inputs: time, location, band definition
Band indexes or full SRFs? What is the disk reflectance model using internally?
SW: interfaces are for interoperability, compatibility with GIRO desired
JW: people providing models (need to improve definition in this Spec) and people providing images & SC data (already defined through GIRO)
"Shell" Framework uses one effective wavelength for each band

Most instruments are not having spectral response changes on-orbit or at least don't know it
SM: moving to one nominal wavelength makes it harder to use uncertainties
Need "standard sun" and "standard moon" spectra to compute eff wvl - need to quantify uncertainty even if it's likely safe to ignore
Intentional deviation from GIRO: names and dates on every LSICS module (version for each subsystem) - a change to one subsystem increments the version of all GIRO at once
TK: don't have a few lunar experts reinvent version control - agree that it's important to implement
SW: LSICS version needs to be recorded in output files
TS: are we following the standards that come with making an official GSICS tool?
Consensus: yes
Masaya: there are GSICS conventions for data versioning
TK: reprocessed SCIAMACHY data awaiting LSICS definition to be used with LSICS development
SM: see no need for standard wavelength set in LSICS, computation time for full spectral resolution is trivial now
HK: standard wavelengths used in SLIM development for efficiency - it still matters because of how many operations are done on the large body of training data
TS: this is mixing the "derivator" with the "applicator"
FW: if no penalty, then more efficient method should be used
TK: there is a penalty, best to ignore efficiency issue, applicator can be slow because it only gets operated periodically. But in future might encounter very high-res SRFs
SW: better to make it flexible
TS: Need to convolve lunar spectrum, solar spectrum, and SRF on same wavelength grid
BB: everyone should agree before start coding
Sandy Preaux (online): request disk reflectance as output
Discussion:

- reflectance can be output in intermediate file
- issue with potential misuse, but could be useful for downstream processing, e.g. uncert
- disk reflectance not a GSICS product

SM: Flag for if LSICS was run as intended (action to TK: implementation)
Hash in the product matching the version to indicate authentic LSICS output
Infrared model: just say Moon is a uniform emitter? Analytic functions related to isothermal contours?
Microwave: most sensors don't have much resolution, curves for signed phase & libration should still apply
HK: Emission model architecture should be extremely similar to reflectance model
SRFs have no issues with panchromatic bands
Discussion of Specs
What to include as specs?

- Define required vs. "nice to have" ← action: to evaluate
- TS: e.g. no need for launch date in file spec because this system is not doing trending

SW: name changes for variables in GIRO files ← action: need to weigh whether this is worth it, and provide assessment to group
Register unique acronyms with GSICS?
TK: 3 concerns about licensing: someone sells LSICS, someone changes LSICS and claims to have run the original, someone using LSICS without properly crediting its creator (will the license actually prevent these?)
A closed "valid user list" would not be true open source

16:00	All	All	Summary of the discussion / actions / decisions / recommendations	2i

Decision D.LCWS.2023.2i.1: GSICS LSICS model will be developed as a GSICS deliverable tool.

Action A.LCWS.2023.2i.1: Tom to report the scope of LSICS to EP in the 2024 annual meeting. The GSICS LSICS will be modularly implemented with open source code of Python and accessible to the public pending on Github.

Action A.LCWS.2023.2i.2: GDWG (Masaya T.) to seek the corresponding information from WMO and GDWG members to provide guidance on the version control of the GSICS LSICS deliverable. Report at the 2024 annual meeting.

R.LCWS.2023.2i.1: LSICS should maintain GIRO compatibility for input and output files

R.LCWS.2023.2i.2: LSICS should implement a capability to account for the solar spectral irradiance variability.

R.LCWS.2023.2i.3: The LSICS lunar disk reflectance module should consider generating the lunar disk reflectance spectrum as an intermediate product.

R.LCWS.2023.2i.4: LSICS should implement the GSICS-endorsed solar spectrum

Hugh Kieffer: Who takes over? Do not intend to continue working on Spec.

Action A.LCWS.2023.2i.3: EUMETSAT & NOAA to continue to develop spec & circulate, then iterate with group. Seb Wagner needs to check with EUMETSAT.(due: 2024 annual meeting)

Action A.LCWS.2023.2i.4: Within the context of LSICS development and interface definition, revise variable naming conventions, provide the documentation for review (due: 2024 annual meeting)

Wed 6/12	**INSTRUMENT MONITORING USING LUNAR CALIBRATION** **Chair: Sebastien Wagner**

08:30	Sebastien Wagner	EUMETSAT	Introduction to the session	3a

Goal for session: Can we come up with best practices to derive observed lunar irradiance? This is a recurrent goal, but it is very important to provide guidance on how to estimate the oversampling factors, how to estimate the lunar irradiance from the measurements, etc.

08:40	Toru Kouyama	National Institute of Advanced Industrial Science and Technology	Application of a disk-resolved lunar brightness model: flat-field calibration for a pushbroom sensor with cross-track scan	3b

SP has vis 500-1000, NIR1: 900-1700, NIR2 1700-2600 nm
SP Model and code release discussed first. SP model is providing hyperspectral maps.

Flat field calibration of GOSAT-2/CAI-2 using model discussed second.
SP Model is disk resolved and uses an approximate BRDF based on Yokota *et al* 2011. 512 nm to 1650 nm with 1 deg x 1 deg and 0.5 deg x 0.5 degree resolution.
Model has product of the spatially resolved lunar reflectance and a BRDF term.
Toru showed a simulated moon observation compared to ASTER. It has issues at the limb.
SP and ROLO are within 1% of each other when evaluating ASTER degradation
Map of reflectance available on Jaxa site, parameters are in a publication
Sample code on github.com/TKouyama/SP_LunarCal_example
Written in IDL, but has been tested on GDL and works.
Would like to discuss how to collaborate with LSICS

CAI-2 gets the Moon in 20 pixels and they use SP to flat field. Swath required on Earth would be 1000 km and it's hard to find a uniform target on Earth.
To compare with SP, the SP output is degraded by "MTF effect".
Lunar calibration results are consistent with ground calibration.
Demonstrates that SP, plus cross track scan, is an effective method for flat fielding.
Challenge is determining the slit position in the Moon from the 1-D profile. This is modelled as an offset to the Moon centre and an angle to a reference direction, e.g. East-West. Then select parameters with the highest correlation coefficient.

Seb Wagner: in the plots you showed comparisons to ROLO, which version of ROLO was it?
A: ROLO, not GIRO

Jack Xiong: You showed video of cross track scan. How long did it take?
A: 1 minute

Jack Xiong: Will present a result using SP and MTF

Tom Stone: it seems that the technique would take a straight line.In one minute of observation, the curvature of the path could be significant. Have you accounted for this?
A: Yes and CAI-2 has no nadir FOV and they have to care about spacecraft motion.

Bojan Sic: Can you provide details on BRDF
A: it's an approximation that has incident, emission, and phase angle as parameters.

Hugh Kieffer: Moon darkens over time mostly in the blue and over millions of years. An absolute azimuth parameter might be good. Discuss offline. This is "nowhere else in the literature"

SP model can be used for multiple purposes (radiometric calibration, MTF, etc.).

9:20	Zhenhua Jing	Nanjing University of Aeronautics and Astronautics	Jilin-1 space-borne Lunar irradiance measurement and calibration usage	3I

JiLin1 is a commercial satellite with no on-board calibration. Has panchromatic multispectral sensor. 20 bands from 415 nm to 1014 nm. Those bands are similar to S3-OLCI.

Integration time T = IFOV / (f_os * w) where f_os is oversampling and w is scan angular velocity
Use lunar data for image registration (paper, 2023 in TGRS)
Errors in PMS bands on the scale of 5-15 km (often less).
There are 8 sites on the Moon that can be used for radiance calibration. They are listed as M1-M8.
Use ellipse fitting rather than threshold for including pixels in irradiance measurements.
Machine learning being explored. Consistency with GIRO reflectances at 10% level. Trying to add constraints.
Good agreement between irradiance and radiance calibration methods.

Tom Stone: Have you checked the shape of the spectra in Machine Learning Application slide against known laboratory reflectance spectra. Are there other lab spectra that more closely match?
A: Our model will output a reflectance.
Tom: The question is, does the generated spectrum look like a "realistic spectrum of the moon"

Fred Wu: Clarification request, slide 19 – is the degradation really 0.032%/year? Is the decimal in the right place?
A: will check

09:50	Stefan Adriaensen	VITO	Overview of the PROBA-V Lunar Calibration	3d

Comparisons between PROBA-V measured lunar irradiance and LIME simulations show a good agreement.
Some phase dependent differences observed – different at negative and positive phase.
Processing might be to blame.
Red band shows negative degradation
Since 11/2021 only images of the Moon are acquired
PROBA-V will stop images of moon next year, but Belgium has launched a cubesat with the spare PROBA-V instrument – PROBA-V-CC
Will do simultaneous viewings with PROBA-V

Seb: Do you have an approach for the oversampling that isn't detailed here? Will you do something similar to OLCI?
A: This is planned.

Jack: Do direct comparison with ground measurement

Tom: in time series plots, red shows annual oscillations in residuals – you're missing something.
Fangfang: is phase dependence from instrument or model?
A: instrument, perhaps requires an offset correction

Stefan is the only person left to program the satellite

Jack: are acquisitions limited to Europe and Africa related to cost?
A: Yes.

10:15	Sebastien Wagner	EUMETSAT	Status of the S3-OLCI missions using lunar calibration	3e

Maximum negative roll angle allowed is -165 degrees to make sure not all star trackers are pointing at earth
Need to restabilize instrument drives where in orbit measurement is taken.
The purpose of the very first manoeuver in 2018 was to validate the performances of the straylight correction algorithm, using lunar images. A series of acquisitions was done for both OLCI-A and OLCI-B with all cameras. Since September 2022, a monthly inter-leaved manoeuver is done with S3A and S3B to look at the Moon with OLCI Camera #4.
Those acquisitions are done for phases around 6.5 deg phase. They are also used within the SL correction assessment by the OLCI Mission Performance Centre (ACRI). Then, similar phases are kept to continue with the radiometric monitoring.

To see with camera 5, switched to positive phase (due to limited amount of opportunities with negative phases).
Processor is done offline – breaks main processing chain, so the data are not available online anywhere.
Use flight dynamics info to estimate pointing at the moon to better understand IFOV to get oversampling factor, by estimating the pointing rate over the moon.

Model comparisons — LIME, LESSR, GIRO
Pixel selection by threshold - results from ellipse fitting (by contractor) worse
Results: Larger Biases with respect to the GIRO than to lime. OLCI-A and OLCI-B consistent.
GIRO results more stable than LIME
Larger variability and biases for LESSR

Need to review the LESSR implementation and change GIRO to use TSIS HSRS

EUMETSAT has regular meetings with OPT-MPC and ESA to discuss lunar work.

Hugh: Ellipse fitting is a good thing to do. Will share routine. .

Thijs: The latest version of LESSR (developed as part of a contract with EUMETSAT) already uses TSIS in Applicator. Not done in Derivator because the input data already are reflectance.

Ali Mousivand.: scatter in some spectral regions - what is the impact?
Tom: need to fit with smooth reflectance spectrum to get rid of messy features in the spectrum - no impact from these features after smoothing.

Thomas A.: three different models show same relative difference between OLCI instruments. Need to correct S3A and S3B to agree but don't know which way to make the correction - need to find out.

Bikash: Can you elaborate on what room for improvement there is in the applicator.
A: For LESSR – the model gives the reflectance, and then Seb implemented something to convert this to band irradiances.
Matthijs Krijger: this is why we need LSICS!

10:40	All	All	Discussion	3f

Covered by the discussions in the presentations.

11:00	Robert Rosenberg	JPL	Integrating Lunar Irradiance Trends with OCO-2/3 Calibration	3g

Last two OCO-2 processing versions rely on lunar trending.
OCO-3 has sparse coverage.
Lunar to be added to OCO-3 processing later.
Science mode reads 8 summed footprints, pixel mode reads 1/28 frames (every 90 seconds?)
Can also bring another 20 columns back at full resolution
Pointing mirror on OCO-3 allows more scans per orbit than OCO-2.
Pixel mode data doesn't make it to the data center.
SRFs have been using a Gaussian model.
Both instruments keep only one polarization, so OCO-2 has DOLP parameter.
Have done 3 co-observations (+/- 1 hour) in 2021 and one intentional observation in 2023 with the two instruments.

Hugh: size of pixel response does not matter as much as the spacing in the moving frame

Discussion of acceptance angles and PSFs and what solid angle you use when summing pixels.
Tom mentioned Steve Maxwell's plans for ground-based intercalibration campaign. SM mentioned opportunity to use SP for a modelling study.

Polarisation is important for OCO, and the development of lunar models accounting for polarisation is needed.

11:25	Lars Chapsky	JPL	OCO-2 Lunar Calibration	3h

OCO-2 makes "ratty" images of the moon
Unusual scan – orbital motion sweeps instrument across moon with instrument pointing fixed in inertial space.
Instrument moves very far over the course of the scan, and this complicates things. 7.5 to 9 minute scan, and spacecraft travels 3000 to 4000 km, which changes viewing geometry and scan rate. Distance to Moon changes by ½ % during scan. Phase angle changes by a couple 10ths of a percent. Sub-spacecraft lat changes by ½ deg. One frame every 9 seconds. Readout every 28th frame - undersamples by a factor of 2.

Pointing jitter is an issue.
Lars showed the impact of the jitter on the lunar irradiance estimated from the observations
What about using the SP model to assess the uncertainties of the pointing stability?
Do frame weighted average of model predictions to get an average (see slide 7).

Resample radiance profile in elevation space onto a regular grid
Apply empirical polarization correction based on polarization angle on homebrew ROLO-based implementation.
LOCO model – simplified, linearized rolo-like model w/ polarization and time corrections
Sub spacecraft longitude explains almost none of the variance

Polarization extracted agrees well with LIME.

Tom: When you said you stare at inertial point in space, is the orientation of the slit also fixed in inertial space?
A: yes, fixed
Tom: Can you read out more than every 28th frame, or is this an operational constraint?
A: not with the higher spatial resolution. Capabilities are high spectral, high spatial, high temporal resolutions, but only two can be done at once.
Tom: Why not drop the spectral resolution? - it's not needed for lunar cal.
Rob: History. They were concerned about the differences between the slits of the various channels. We came to a similar conclusion as what you have come to. OCO-2 has now 10 observations taking a single spectral column

Tom: why is scan jerky?
Lars: Reaction wheels keeping the inertial hold.

Tom: Maybe you could benefit from SP model to fill in the undersampling, instead of interpolating.
Tom: what is attitude sampling frequency and where is it from:
A: Telemetry and 1 Hz.

Scott: Could it be temperature variations?
A: Bench is well controlled.

11:50	Vance Haemmerle	JPL	OCO-3 Lunar Calibration	3i

OCO-3 mounted on ISS, JEM
Moon acquisition uses color slices 19 useable wavelengths
External and internal context cameras available. Internal used to calibrate pointing mirror assembly. Observations started in 3/2020 testing context camera and with instrument in 9/2020, 12 observations acquired to date.
Curvy transit through the slit. Up to 1min30s for the transit.

Also point to Moon and hold in inertial space.
Oversampled, with varying oversampling.
Scan duration = 50 seconds.
Using uncalibrated region of the pointing mirror.
For phase "we get what we get"
Defocus is wavelength dependent
Polarization 80 degrees to 50 degrees.
Sometimes angle of attack is so low that not the whole moon is seen.
Coordinate system twist effect – changes image roundness. Required going back to TVAC data.

Tom: Twist effect means ellipse fitting will not work - the bright limb edge is not an ellipse.

Lunar phase for the 12 observations varies between 30 an 145 degrees (in absolute value).
Only half of them are within the range [-92,92] degrees
Oversampling estimated to be between 1.4 and 4. Needs to be accounted when estimating the observed lunar irradiance.

Home-brew implementation of ROLO model - ratios to model ~70%
Tom: Ratios to homebrew are not valid.

12:15	All	All	Discussion	3j

Covered within the presentations before.

13:50	Aki Sato	Remote Sensing Technology Center of Japan	GOSAT-2 Lunar Calibration for FTS-2 and CAI-2	3k

Moon underfills FTS FOV, correction factor is ratio of FOV to Moon disk size.
ROLO model reflectance spectral resolution is kept, FTS spectrum down-sampled to it.
Hope that phase angle dependence around 7-8 degrees can be corrected more accurately, waiting for LSICS.
Can share high res spectral lunar data.
FTS-2 and CAI-2 data about 7% uncertainty.
Band 1, 0.7 micron, shows 20% offset to giro w/ Wehrli in FTS-2.
GOSAT-3 to launch in JFY2024.

Matthijs Krijger: How confident are you in the 7% uncertainty, because 20% disagreement with model is too far out?
A: Reference info only. Needs further investigation
Tom: then providing these data needs to come with a warning

Fred Wu: Do you have evidence that FOV is a circle? Maybe knowledge of FOV is part of the disagreement.
Tom Stone: You may need to correct the lunar disk diameter for distance

Mounir Lekouara: can lunar models be improved with high spectral resolution data, e.g. FTS-2?

Tom: No, models cannot be improved by high-res input data alone, but existing models can be operated at high spectral resolution - need to smooth the reference reflectance spectrum, then it can be interpolated to high resolution (up to limit of solar spectrum spectral resolution)

Discussion of whether we can get this hyperspectral data for the dataset

14:30	Taeyoung Choi	NOAA	Operational Radiometric Calibration of NOAA-20 VIIRS using lunar and Solar Diffuser observations	3c

Jason mentioned recent changes (since late 2022) in the H-factor (Solar Diffuser degradation). Also observed on S-NPP.
Even though all results are within +/- 1%, lunar results show a small trend for some bands in the F-factor.

Matthijs Krijger: Please explain again the connection between the reverse degradation and solar activity
A: Microstructure of solar diffuser is smoothed by solar activity (assumption, but unknown)

Matthijs Krijger: The shape of the solar activity curve doesn't match the shape of the reverse degradation. Was there any change in the thermal status or the mechanics of the instrument?
A: not aware.

Jack Xiong: This happened to Terra MODIS, Aqua MODIS, SNPP VIIRS instruments, simultaneously — indicates it is space weather
Gerhard: but not J2 VIIRS - perhaps because it has not had time to degrade yet.

Fred Wu: how do you determine "effective number of pixels" in radiance averages?
A: Somewhat vague – threshold of 5% of moon brightness

Fred Wu: slide 12, is seasonal variation due to sun earth distance?
A: No. Offline calibration coefficients shown here don't affect calibration

Fred Wu: what else can it be?
A: VIIRS has attenuation screens and a large source of uncertainty is the screen function

Hugh Kieffer: The phase term in the denominator needs to be removed from your F-factor equation [(1+cos Phi)/2]

Tom Stone: the "effective number of pixels" in the average radiance term offsets this phase term. But the uncertainty in determining this number is carried through the calculation.
Jason: we will look into this

Seb Wagner: please report back on what you find with issues with F-factor at the annual meeting

Action A.LCWS.2023.3c.1: Jason to report at a future Lunar Calibration sub-group web meeting about the issues with the F-factor (due: by 2025 annual meeting).

14:25	All	All	Discussion	3m

Discussions took place during the presentations.

15:05	Masaya Takahashi	JMA	Radiometric Performance of Himawari-8/-9 AHI VNIR Bands using Lunar Calibration	3n

AHI captures the Moon in one scan. The range of phases covered by AHI ranges from -180 to 180 degrees.
An impressive set of ~17000 obs for Himawari-8, ~12000 obs for Himawari-9. Images used for lunar cal: 30000 for Himawari-8, 4000 Himawari-9
Threshold method for pixel selection. Oversampling = image_size / physical_size
~1% phase angle dependence seen in Himawari-8, ~2% in Himawari-9, consistent over time

Martin: You said you had good agreement with trends that were found with other methods. There was an analysis for Himawari-8 using stars that found a 10% change over ~5 years.
A: –

Q: How do you know the oversampling factor?
A: We are still thinking about what is the best oversampling value

Martin: In one image, you showed a Moon image on the Earth limb. Have you removed observations that go through the atmosphere?
A: yes

Tom: Phase angle dependence patterns are beautiful, with uniform slopes. This suggests high correlation with disk illuminated fraction. So pixel selection method by thresholding likely is causing the phase angle dependence.

Fred: Slide 14, regression does not remove seasonal variation. Partial years will introduce bias.
A: yes

Fred: Martin discussed a 10% cal difference in Himawari-8 to Himawari-9. Can this be presented at a GSICS VisNir web meeting?

Martin: this is not my work. Will contact colleague and request to present star result at VISNIR submeeting

Action A.LCWS.2023.3n.1: Martin Burgdorf to coordinate a presentation on using stars to monitor Himawari-8 and 9 at a future Lunar Calibration sub-group web meeting (due: by 2025 annual meeting).

15:30	Sebastien Wagner	EUMETSAT	MSG/SEVIRI radiometric performance monitoring and end-of-life tests using lunar calibration	3o

Meteosat-8 End of Life tests offered possibilities for testing new instrument configurations, and for acquiring the moon about 8 hours in an attempt to validate the requirement on medium term radiometric stability for SEVIRI (less than 0.5% variability over 24h). The tests also offered the possibility of acquiring unsaturated images in TIR channels.

More accurate solid angles and oversampling calculation for SEVIRI and GEO imagers in general could reduce further the uncertainties.

Masaya: Second lunar calibration meeting…do you have updates for intercal?
Seb: Lunar intercalibration is a work in progress

Masaya: do you plan to use MODIS or VIIRS
Seb: Should be VIIRS for GSICS, but conceptually it doesn't matter. System will allow intercalibration easily.

Fangfang: Is the offset correction for the whole image reprocessing or for the lunar image correction only.
Seb: Only for the lunar images, discussed in the first LCWS.

Hugh: Gap in data in results slide is encouraging. You have done a good job with background correction.
Seb strongly recommend again to take the opportunity of end-of-life test to perform new types of measurements, in particular lunar acquisitions.

15:55	Vincent Debaecker / Sebastien Wagner	Telespazio / EUMETSAT	MTG/FCI and LI and the challenges of performing lunar calibration for radiometric assessments	3p

Disclaimer: this did not use the final radiometric calibration, results shown here are to demonstrate functionality of the tools.
Moon does not fit in one FCI scan, will appear in 2-3 scans.
Whiskbroom south-north scan pattern every 10 minutes

Moon is in different positions in different channels, but the shift is static and known.
There's a "moon stitching algorithm"

Hugh: Scan pattern is called Boustrophedonic – as the ox ploughs

Tom: from GEO the moon moves against the background of stars, so the Moon sampling rate will be different for scans in the different directions, so different oversampling factors for different scan directions. This should be visible in edges of the stitched images. If processing all pixels in imagette then this doesn't matter.

Fangfang: time differences probably don't matter when you catch the moon in two scans not three.
Seb: the time between scans is 30 seconds at the equator.

Lightning Imager: Moon captured in corners of rectangular frames. Stray signals found to come from the previous image.

Hugh: If you can reproject the image into a coordinate system that is defined by the vector from the spacecraft to the centre of the moon, then you can derive a grid of pixel solid angles in that coordinate system that should lead to a proper irradiance calculation. But a weight needs to be assigned to each pixel.
Tom: how does this solve all the issues?
A: -

16:20	Xiuqing Hu	CMA	Calibration monitoring of FY-4A/AGRI using Moon	3q

AGRI: Advanced Geostationary Radiation Imager
Phase angle correction is done in one step and libration correction is done in another step using linear regression. Oversampling calculated with a tensor to the Moon.
Compared DCC results to lunar.

Mounir: How are the relative trends from Moon determined? How do you interpret a positive trend in channel 4?
Scott: Will check

Thijs: degradation should have been corrected before computing the residuals shown on slide 7. Residuals cannot be 50% because this is higher than the libration effects.

Fangfang: What do you use to fit the coefficients
Scott: Own data

Thijs: how do you fit libration separately?
SM: is it because libration is fast?
Hugh: The plot showing the libration effect looks like it's too large

Fred: You have built a new lunar model - why? Why aren't you using GIRO? Has the new lunar model been compared to GIRO?
Scott: We want to use our own data to make corrections. We will use LSICS later
Fred: What did you want to learn, and what was learned?
A: -

Matthijs recommended looking into your libration effect plot.

16:45	All	All	Discussion	3r

Discussions took place during the presentations.

17:40	Gerhard Meister	NASA	Lunar measurements with OCI during the PACE mission	3s

Rotating telescope with half-angle mirror.
IFOV gives 1.2 km pixels, Moon diameter 7-8 pixels.
Two manoeuvres per month, for a lunar phase angle +/- 7 degrees.

Moon acquisitions using roll and pitch manoeuvres, scan Moon then reverse and scan again. So each manoeuvre produces 2 measurements

Expect after 2 years to be able to use lunar data for correction of trends
Also point to the Moon and stare for 30 seconds, to get a high quality single frame.
Oversampling is equal to 4 (and remains constant through the set of observations)
Used GLAMR to calibrated spectral responses
Data below 340 nm isn't great.
Blue FPA has constant band spacing
Red has some dense sections where the ocean color community cares.
There's some spectral ghosting

Thijs: When can we expect the first lunar spectrum?
Gerhard: During commissioning we'll take one within first two months, not sure when it will be released. But taken before March.

Steve M.: are there enough GLAMR data to implement a stray light algorithm?
A: we will check whether a stray light correction is needed, if yes then apply it.

SM: That is spatial stray light correction - will you do spectral stray light corrections?
Gerhard: The scientists said no.

Thijs: during commissioning will any other lunar phase angles be acquired?
A: no, only 7 degrees

Fred: You said absolute calibration uncertainty is about 1% - is it also for lunar measurements?
Gerhard: no, it is for TOA radiances over ocean, for lunar irradiances it will be higher.

Jason: is there a plan to track solar diffuser degradation?
A: there are 2 solar diffusers, one used daily the other infrequently

18:00	Truman Wilson	SSAI/NASA GSFC	Orbital Drift Impacts on the MODIS Lunar Calibration	3t

Presentation on MODIS end of mission activities.

Orbital corrections stopped in 2022
Did a deliberate orbit exiting manoeuvre on TERRA. Maybe another one will be done in 2026 for AQUA.
Orbital drift will mean no more 55 degree observations by 2024 to 2025.
Shifting accessible phase angle range down about 5 degrees per year (not uniform and more in 2026)
Will backcorrect to older observations at lower phases
Expect a few percent correction required. 3.5% at short wavelengths for terra. No real dependence at longer wavelengths.

Discussion: Tom: does Hugh have unscheduled observation dataset?
A: Jack has passed unscheduled observations to Hugh
Tom: Do you see the same phase trend in the results produced by SLIM?
Truman: need to do the analysis

Tom: the phase correction derived by tying to selenographic longitude reproduces the trend seen in the higher phase unscheduled dataset - do you expect this trend to hold for the smaller phases (that will come from the orbital drifting)?
A: keeping track of it, seems to hold for Aqua, not so well for Terra

17:55	All	All	Discussion	3u

Done.

Thu 7/12	THERMAL INFRARED and MICROWAVE Chair: Tim Hewison

09:00	Tim Hewison	EUMETSAT	Introduction to the session	4a

Tim pointed at the topics of particular interest for the session:

- Status of the models
- Possible counterparts to the GIRO/LSICS model/framework for IR/MW
- Other apps: pointing, FOV mapping, lunar eclipse?
- Similar questions for planets and stars
- What about data sharing?

Hugh: if you change from BT to irradiance, LSICS could be used

09:10	Martin Burgdorf	Universität Hamburg	Venus as an Alternative to the Moon for Infrared Imagers	4b

Martin introduced the prospect of using Venus as a third reference for IR imagers, which has the advantage of not saturating many imagers.

Moon and Mercury can be used for IR radiometric assessment. But as for the moon, Mercury would also cause saturation for instruments such as SEVIRI, but does not fill a pixel of most sensors, so requires precise pointing knowledge.

Fulbright et al 2023 analysed Himawari observations of Mercury, covering a broad range of radiances, but with a scatter of ~10K.

Predictability is the question: Moon + Mercury have no atm. What about Venus? Venus has an atm… Knowledge on the absolute flux levels not needed for instrument inter-calibration and stability assessment (in the context of inter-calibration) - which is just as well, as current models of Venus' brightness temperature is pretty unreliable.

Only view Venus in inferior conjunction - only every ~18 months - and then needs to be visible in the image (e.g. SEVIRI corners). Still useful for long-term calibration monitoring.

As for the Moon, L1.0 SEVIRI data are used. Most recent 2 SEVIRI observations from 2 MSGs show consistency of L1.0 counts in the IR12.0 channel within a few percent - but highly variable signals in the WV channels. Similarly, Himawari-8 and -9 agree well in the 9.7μm channel (within 0.5%, 0.3K), but more variable in 13.3μm channel.

Q: No distance correction is needed - only the brightest pixel is selected, which may slightly bias the radiance observations, due to radiometric noise.

Q: Japan has a Venus orbiter since Dec 2015, and has been stable since. Information below provided offline by Toru Kouyama (AIST):

> *Japan has a Venusian orbiter which has observed Venus since December 2015, and it still survives. Unfortunately, NIR sensors (1 um and 2 um) onboard the satellite stopped in 2016, but UV and thermal sensors are still working. Below is a page introducing sensors onboard the satellite: https://akatsuki.isas.jaxa.jp/en/mission/spacecraft/ - The name of satellite is "Akatsuki", meaning dawn in Japanese.*
>
> *In this year, a paper about long-term calibration of the thermal sensor was published: https://earth-planets-space.springeropen.com/articles/10.1186/s40623-023-01803-w*
>
> *We found that the sensor has experienced sensitivity degradation during the mission. In this paper, we successfully corrected the effect from the degradation, and then we confirmed that basically temperature of top of atmosphere of Venus is stable around 230 K in the equator region, while it shows small day-to-day variation and systematic variation mainly due to diurnal component. I think if we see disk-averaged temperature of Venus, which is observable one from the Earth position, should be more stable.*
>
> *You can find whole dataset of this sensor from JAXA's site: https://darts.isas.jaxa.jp/planet/project/akatsuki/lir.html.en*
>
> *Level 2d is the product which provides calibrated brightness temperature of top of atmosphere of Venus. I think this could be comparable to observation from the Earth.*

Q: Applications for LEO satellites? May be limited by small size of Venus - only 1 arcmin, which may not fill a pixel - and limited visibility.

Q: Processing SEVIRI L1.0 data?
- No additional processing has been applied.

09:25	Kay Wohlfarth	TU Dortmund	An advanced thermal roughness model for airless planetary bodies - applications to the Moon and Mercury	4c

Applied thermal roughness model + DEM to Moon and compared with observations from Gaofen at 3.77μm and lunar orbiter Diviner off-nadir observations at 8-25μm, and MERTIS in a flyby en-route to Mercury. Fractal surface model based on Apollo camera images. Thermal isolation is such that large thermal gradients can exist on scales of ~1cm.

With the Sun near zenith (full moon), shadowing at high viewing angles, results in selective visibility of colder areas. So rough models give much higher radiances than smooth models at high solar angles - though less difference at low solar angles.

Computed a map at 2.5μm and extrapolated to 3.77μm using Apollo sample spectra.
Model has one tunable parameter - roughness - allows good match to observations from India orbiter in general - with a few problem areas (Mare and craters). Comparisons with Diviner (on LRO) at 8.25μm and 25-41μm, included a broad range of viewing angles.

Emissivity probably has additional anisotropic effects not well captured in current models.

Application to Mercury:

- Very strong diurnal variations - 150-600K

Q: Can use later data with more EPF configuration post 2015?

- Planning to do after finishing thesis.

Q: Importance of multiple scattering?

- Interaction matrices already include multiple scattering, assuming it is lambertian
- (n.b. These are big matrices ~40k elements)

Q: RMS difference (Obs-Model) in K?

- Given in paper ~3% integrated over the Moon - will confirm by email
- https://doi.org/10.1051/0004-6361/202245343

Q: Do you have enough information to predict different lunar phase angles?

- Current observations have limited phase angles, but already includes

Q: Albedo variations?

- Used directional hemispherical albedo from Moon mineralogy mapper.

Q: Application to microwave? Depth profiles?

- Should be possible, but have not considered details

09:50	Thomas Müller	Max-Planck-Institut für extraterrestrische Physik	Modelling the Microwave Radiation of the Moon	4d

Goal: Find a Thermo-Physical Model (TPM) of disk-integrated flux of the Moon in the microwave between -90° to +90°. Result: abs acc <3% at 157, 183, 190GHz, and <2% at 89GHz.
Details of model given in slides, including references to publication.

Observations from 8 different satellites, AMSU-B and MHS, covering mostly ~180-300K (ma 325K). Obs/Model Tb - strong dependence on phase angle 0.8-1.1 using default Moon model (Müller 2021) - aim to find good emissivity, as function of phase angle. Minimum ~20° before full Moon - a function of frequency - but emissivity curve goes above 1 at high phase angles!

StdDev (Obs/Model) ~2% at 89GHz ~3% at 157/183/190GHz (except NOAA-19) on MHS.

Tried 3 different roughness models - none reproduce the observed phase-angle dependence.

Q: How is emissivity phase angle model derived?
- Fitted to observations

Q: Physical reason for phase-angle dependence on emissivity?
- none!

Q: Meaning of emissivity >1 at phase angle >60°?
- Possibly seeing higher temperatures deeper in lunar soil

Q: (Hugh) - may be related to high slopes in crater walls at limb?
- Already included in TPM for thermal IR

Action A.LCWS.2023.4d.1: Tiger Hu (UMD) to share AMSU and ATMS Moon observations with Thomas Müller

10:15	Hu (Tiger) Yang	University of Maryland	Lunar Microwave Radiative Transfer Model Validation with NOAA-20 and NOAA-21 Two-Dimension Moon Scan Observations	4e

ATMS special 2D scans of Moon during pitch manoeuvre
- at 34° phase angle - to capture maximum signal at low frequencies
- conducted over Pacific to minimise contribution from antenna back-lobe

- data processed and calibrated in MiCalPS system
- Includes reflector correction as a function of polarisation, characterised on deep-space views acquired in manoeuvre
- Can characterise antenna response and correct for beam-pointing error
- Compare observations with model by Keihm (1984) - with modified temperature profile term (published in 2022)
- used observations to calibrate the emissivity model
- Proposed pitch manoeuvre as routine test for future missions
- Data and model available via Github

Q: How to account for smearing effect?
- During 18ms acquisition, the Moon moves through antenna path. It is taken into account by calculating the solid angle and by integrating over the integration time.

Q: Why are weighting functions different at day and night?
- To compensate for temperature being calculated at local solar time

Q: Is there an opposition effect in the microwave?
- Not like in reflected solar band
- Thomas Müller: Some calculations suggest a very small effect due to roughness

Q: non-linearity?

10:40	All	All	Discussion	4f

Covered above

11:30	Thomas Müller	Max-Planck-Institut für extraterrestrische Physik	The Moon at thermal infrared wavelengths: Comparison between NOAA/MetOp-A/MetOp-B, TIROS-N HIRS measurements and thermophysical model predictions	4g

Goal to find a TPM for disk-integrated flux of the Moon in 4-15μm.
Result: better than 8% at 3.7-4.6μm, 5% at 7-15μm in +/-85° phase angle

HIRS observations TIROS-N to Metop-B available in PhD Thesis.
Same model as before
- With small phase-angle correction - which is not needed

Different roughness models tried - very sensitive
- Tried to use lunar sample spectral measurements, but disk-integrated observations very different

Compared observations/model
- There is no remaining phase angle dependence or apparent size, Sun-Moon distance or libration, as these effects are all included in the model.
- Some offset effects - applied corrections to account for
    - FOV in some instruments are different from published values
    - dependence on space view position(!) - esp earlier satellites
    - NOAA-16 was 20% out
- Small opposition effect in 3.7-4.6μm band
- Useful for inter-calibration (assuming adjustments are understood)

Q: Cause of space view position dependence? Straylight?
- Fred Wu: Possible impact of Earth screen reflections - Analysis of Metop-A End of Life manoeuvre by Jörg Ackermann (EUMETSAT) may help understanding

Q: Saturation of high radiance, cause of “missing data”
Q: Spectral shifts?
- Very sensitive to wavelength shifts, as it is a stiff regime for lunar measurements - have taken newer SRFs and AAPP

Q: Inter-calibration with IASI?
- Will cover offline

Q: importance of accurate pointing?
- Could introduce impact due to PSF - especially. The location of the moon in the FOV (which varies from 0.6 to 1.4) is very important.

Thomas Müller looked into the HIRS data to see if there is a signature of the libration in the thermal signal, but the scatter between the various data sets from different satellites is too large. The exercise could be repeated with the availability of IASI data and/or CrIS data.

11:55	Bojan Sic	Noveltis	Potential of the Moon as a calibration target for IASI instruments	4h

CNES adapted ob-board coding tables for cold space to the lunar dynamics
IASI observations acquired by selecting space views in 2019 and 2021-2.
Model includes thermal emissive and solar reflective components

- Surface temperature from LRO/Diviner bolometric temperature L4 product
    - 0.5° spatial resolution, 1h temporal resolution
    - No libration
- Emissivity model
    - Data from Apollo samples, assumed lambertian, distinct soil types (rock abundance from Diviner)
- Sensitivity test
    - Part of uncertainty analysis
    - Emissivity dominant - big differences between different models
- Used IIS (imager with FOV~61 mrad) to locate Moon within IASI iFOV
    - Position can be improved by analysing time series of images
    - Also checked and corrected yaw-steering angle
- Some observations limited by saturation
    - Absolute differences ~2.5K
    - - with strong temporal variations - as function of moon phase, but not radiance
    - Concluded cause is non-lambertian emissivity
    - Inter-band calibration: Standard deviation of Obs-Model
    - Inter-satellite comparisons accuracy 0.5-1K
        - Much worse than other methods - due to pointing errors

Could retrieve emissivity from IASI observations

Share observations?

- CNES and EUM preparing to distribute - by Jan 2024 - Ask Bojan

Q: What is impact of libration?

- Checked with temperature map - less than 0.2K max
- Thomas Müller: IR signal dominated by hot spots - so little impact, MW would
- **Could need to include in LSICS a history of libration angle to account for hysteresis**

Q: Working on spatially-resolved radiance model?

- Yes - already available - results shown are integrated
- Validated phase angle corrections with MODIS measurements
-

Q: What is the primary application for IASI?
- In-flight characterise of geometric parameters - e.g. coregistration with imager
- Stray-light checks

Q: And what could be done with a better model?
- Inter-calibration could be improved

12:20	Martin Burgdorf	Universität Hamburg	Inter-Calibration of CrIS on SNPP and NOAA-20 Using Lunar Observations	4i

CrIS spectra provide by Yong Chen (NOAA)
Compared observed spectral with TPM from Thomas Müller
Averaged 100 spectral elements, then grouped 3 bands
Moon in >25 consecutive orbits. Compared Tb time series - plotted against phase angle
Allows inter-calibration of CrIS on SNPP and N20 - no direct SNOs possible

N20-SNPP=0.42+/-0.03K (SW) - but no MW data!
N20-SNPP=0.14+/-0.06K (LW) - noisier

Systematic uncertainty from diameter of FOV?
4-5K difference between perihelion-aphelion - need to compare at same Earth-Sun distance
Long-term calibration trending
- Need to find cases with similar phase angle and solar distances (<<1%)
- Plot Tb time series v phase angle
- Tb(2020-2015)=-0.52+/-0.07K (LW), -0.46+/-0.07K (MW)

Q: Other factors to explain differences between years?
- E.g. libration
- Need more data to check

Q: Comparison with Thomas Müller's model?
- Difference could also be due to saturation effect

Q: Surprising large difference between SNPP and N20 in SW
- Not seen in AHI double-differences
- GOES-ABI suggests could be differences ~0.1-0.2K in the LW channels

13:45	Diogo Rio Fernandes / Fatima Kahil	OroraTech	Towards a constellation of thermal infrared sensors for wildfire detection: inter-calibration of FOREST-2 with Sentinel-3 SLSTR using the Moon	4j

To support thermal IR imagers - SAFIRE
- GSD~200m, NEdT<50mK
- LWIR=LWIR1+2 = 8-13µm - similar to S3 SLSTR S8, S9
- No onboard BBs

- MWIR vicarious calibration difficult
- Captures Moon in single frame
- Aim to validate calibration based on inter-calibration with SLSTR lunar images
    - By scheduling coincident acquisitions
    - gain=2.27+/-0.03, n
- Evaluating uncertainties following Fiduceo approach
- Using fire channels
- Compensation for difference SRFs
- Validation with VIIRS, confirms correction derived gains from lunar inter-calibration is good (offset set manually)

Q: Comparison of SNO with CrIS?
- Possible - as currently in 13:15asc sun-sync orbit

Q: Impact of size of source effect? (Can be significant for bolometers)
- Moon covers ~25 pixels - so impact is small - also checked radiance at centre of Moon

Q: How to get SLSTR data?
- Through Optical MPC, through Copernicus cooperation data

Action A.LCWS.2023.4j.1: Fangfang Yu (NOAA) to invite Diogo Rio Fernandes (OroraTech) to GSICS annual meeting to present inter-calibration of SAFIRE thermal IR imagers

14:10	Jack Xiong	NASA GSFC	MODIS and VIIRS Thermal Emissive Bands Lunar Calibration and Calibration Inter-comparisons	4k

Use Moon to monitor calibration
- Need to exclude saturated and near-saturated pixels
- Divide remaining pixels into BT bins
- 20+ years data track changes at 5 levels ~1K

Inter-band calibration is possible, as channels are collocated
- Binned in 20K BT bins 210-290K
- Need model as intermediate transfer
- Simple correction of Earth-Sun distance improves comparison

VIIRS and MODIS both have 1 non-saturated channel
- But difficult to transfer to other channels

VIIRS inter-calibration:
- Schedule S-NPP, N-20, N-21 to regularly view Moon at ~same time
- Hoped that no need for model to compare, but different results from different roll angles
- Compare pixel pairs

Spatially-resolved Lunar Model under development
- Based on Diviner

- Need to account for roughness to project to different phase angle

Q: Geostationary imagers can acquire Moon at high phase angles when it is not saturated?
- Would also be interested to use data to constrain (Seb to complete)

Q: Number of saturated pixels can increase over time due to drift?
- Yes - different methods can be more/less sensitive to this effect

MODIS ~7x7 pixels, VIIRS ~10x10 pixels - typically 5-6 saturated pixels - more with MODIS due to higher over-sampling factor

Q: Edge pixels - for less impact on high spatial resolution sensors - but more sensitivity to pointing, FOV, …?

Jack presented 3 methods to monitor the thermal infrared bands using unsaturated co-registered detector measurements of the moon. Phase is critical due to emissivity. So the analysis for MODIS was done on the regular opportunities at |55deg| +/- 1deg. Unplanned measurements were not included as they are happening at a broader range of phases and the number of observations when binning them would probably not be large enough.
Seb commented that similar methods could be tried on geostationary measurements as moon intrusions are many and can be lumped by phase values. Jack is exchanging with NOAA to work on ABI data.

Recommendation R.LCWS.2023.4k.1: Jack Xiong (NASA) to report on the outcome of the analysis of the ABI lunar data in the thermal infrared.

14:35	All	All	Discussion	4l

Q: GOES-R ABI data access using celestial targets?
- Fangfang to provide information to Thomas Müller

Q: Can we make Spectral Band Adjustment Factors for disk-resolved modelled radiances?
- Thomas Müller's model could be used
- Limited only by quality of underlying models - e.g. DEM

Action A.LCWS.2023.4l.1: Jack Xiong (NASA) to report back on result of comparison of comparison of TPMs with MODIS/VIIRS

Thu 7/12	**ALTERNATIVE APPLICATIONS OF LUNAR OBSERVATIONS** **Chair: Fangfang Yu**

15:25	Fangfang Yu	NOAA	Introduction to the session	4m

Brief introduction on the scope of the session, with a focus on straylight and MTF in-flight assessments.
In particular, the group should think of defining best practices.

15:35	Stefan Adriaensen	VITO	In-orbit MTF and Straylight verification for the PROBA-V instrument	4n

Stefan addressed both MTF and straylight assessment.

MTF: method based on slanted edge as presented in the past already.
First, an ellipse fitting is done and the sharpest edge is retrieved. Second a normalisation to the highest value of the transect is done.. Third, the derivative + the FFT gives the MTF. Comparisons with on-ground measurements are done at Nyquist. The regular acquisitions allow time series. Results shown are across track, over about 15 transects. No obvious MTF degradation seen.

Straylight: the lunar imagery is used to check the straylight as characterised on ground. Straylight levels are very low. There is no SL correction at the moment in the data processing

Question: not used for assessing the straylight algo performances?
A: no, it is only to compare with the on-ground characterisation

LSF reconstruction: by using transect along and across track, the LSF is reconstructed. But Stefan does not have the on-ground characterisation. So no comparison with pre-launch is currently possible.

Fangfang: did you try more fitting functions?
A: no
Recommendation R.LCWS.2023.4n.1: EUMETSAT and VITO are invited to test more fitting functions and share results with the Lunar Calibration Community

Fred: how is the oversampling accounted for in the processing?
A: the ellipse procedure is where the oversampling is accounted for.

Jack: if across track, there is no oversampling, correct?
A: ….

Gehrard: a lot of SL along track. Was it expected?
A: no

Hugh: nature of the straylight (electronic?)

A: does not know.

16:00	Christoph Straif	EUMETSAT	Lunar imagery and MTF post launch assessment for MTG/FCI	4o

MTF = imaging system requirement.
For FCI, a template was defined. Characterised on the ground and purpose is as in the previous talk to use the moon to compare with pre-launch.

In Christoph's talk, the analysis goes beyond Nyquist.

The method starts by identifying the edges by applying a mask to separate from the Earth and identifying the fully illuminated side.
The ESF is smoothed and fitted. Smoothing uses a Savitzky-Golay filter. A Fermi function is used for fitting the regularly-spaced ESF. This fit can probably be improved. LSF is the derivative of this, smoothed ESF was used to avoid noisy derivatives.

A bump is observed at 0.1 spatial frequency.
The choice of the fit function has an impact on the retrieval. Work is still on-going to find the most suitable function.
The algorithm was applied to 3 cases (in April, May and September). At Nyquist, values retrieved are in very good agreement with the on-ground characterisation.

A series of identified limitations and mitigations were listed, with respect to the method currently implemented for FCI.

Fred: what is meant by "moon is not a flat radiance field".
A: if you go from outside to inside, there are some issues with the gradients. The padding needs to be done carefully.

Fred: is the heterogeneity impacting more when looking into crescent obs?
A: current results were not so good.

Fangfang: choice of the fitting function might be instrument specific.
A: yes indeed. Now, the purpose was to have a similar approach to the one with SEVIRI.

Fred: reminded about the MTF exercise led by NOAA on MTF retrieval, and the outcome (in particular the discussion on the fitting function). He commented on the possibility to continue the exercise with more recent instruments to see if the fitting function really depends on the instrument. He pointed also to the tests done with ABI on both sides of the moon. Results should be the same, but the results show differences.

R.LCWS.2023.4o.1: as a continuation of **R.GVNIR.2020.19d.1** (see Notes), NOAA is encouraged to coordinate the Lunar Calibration Community efforts to define best practices for post-launch assessment of MTF using lunar imagery.

Bikash mentioned testing with different phase angles.

16:25	Fangfang Yu	NOAA	Straylight Corrections for the Accurate GOES ABI Lunar Irradiance Measurement	4p

ABI collected lunar images for phases between 5 and 60 deg + moon chasing in absolute value to characterise response vs scan angle

The moon is acquired in one swath, with MESO scans (which is 2 swaths, but only one has the moon).

For the RVS study, space looks were acquired at equator and then from north to south and back at the equator. For the different acquisition, there were also some variations of the focal plane temperature.

Uniformity study: RVS is characterised by doing the irradiance ration (obs / model). Model = GIRO. To overcome the uncertainties on the model, a normalisation to the mean value of the ratios is done.
Fangfang mentioned that SL may occur at the spacelook scenes near the polar regions around the satellite noon. In B01(where the largest magnitude of the SL is seen), it can increase the spacelook by 1-2 counts out of 14-bit depth of the ABI calibration data.

Adjustments in the spacelook for B01 to B03 removes the scattered outliers in the long chasing events.
Spilled light could also be identified using lunar imagery. A correction has been implemented After correction RVS is within 0.5% variation for all G16/17 VNIR bands. SL corrections were applied to B01 to B03.

The impact of the irradiance comes from the integration over a very large number of pixels. A small error (in the calibration / offset correction) impacts right away the results by amplifying the effet.

Mounir: is there a SL correction for the Earth sample?
A: no.

Masaya: is there a north-south scan dependence for ABI ? For VNIR, AHI has a dependence.
A: Not for the IR bands. For VNIR bands, need to look into it.

16:50	Truman Wilson	SSAI/NASA GSFC	Surface Corrected Lunar MTF Measurements in MODIS and VIIRS	4q

Idea: use the SP model to remove the moon surface variability when reconstructed the LSF from the lunar transects.
For VIIRS: from 375m to 750m at Earth scenes
MODIS: from 250m to 1km.
So there is quite some difference on how they resolve the Moon surface.
SP is used to reconstruct the instrument bands to be assessed.

However, a reprojection of the SP model is needed to map the instrument grids, of course accounting for the moon orientation when acquired.

The transect used for the MTF is the ratio between observation and the model.

Comparisons with SRCA data were shown for the results in the scan direction. Time series for the track directions were also shown. The average is still above spec for MODIS.

Bikash: asked about the difference shown between centre profiles / expanded profiles and curve corrected.
A: Truman needs to look more into it.

Fangfang: how much does the new approach improve the results?
A: needs to check. The talk was more to present the method and compare with the pre-launch.

Bikash: did you try several methods to address the transition between deep space and moon surface?
A: problem was to automate the process. Using the model was much more straight forward and easier for automation.

17:15	Monica Campanelli	ISAC-CNR	The Skynet network for the retrieval of aerosol properties from the moon irradiance	4r

Skynet network is about looking at the Moon from the ground.
It is a network of sun-sky photometers, dedicated to study columnar aerosol properties. More than 100 sites worldwide, some co-located with AERONET and PMOD photometers.
It is not meant to provide operational data. So, it is possible to test and change configurations.

Skynet instruments are POM, produced by the Japanese PREDE company. The instruments were adjusted by the instrument vendor to allow moon measurement (i.e. with a much lower level of signal than the sun).

For the Moon, good measurements are acquired only after amplification for 340 and 380 nm. Difficult for 1225, 1627 and 2200nm.
Reflectance from ROLO is considered. No transformation in irradiance. ROLO reflectance is interpolated between nearest ROLO bands to POM band wavelengths.

Several types of measurements are done: direct sun, direct moon, almucantar and principal plane sun, and almucantar moon.

AOD retrievals using the ROLO reflectance have some issues with Moon phase dependence. A correction is done based on the paper by Uchiyama (doi.org/10.5194/amt-12-6465-2019):
C = Ac*g + Bc where g is phase angle and Ac and Bc are taken from the Uchiyama paper.

Retrieval are done for Moon illuminations greater than 65%

Continuity between day (AERONET) and the night retrievals (with SKYNET) are good for the few sites analysed so far, which indicates that the measurement sites are characterised adequately.

Still to be done: upgrade the solar calibration constant values every month when available, cloud screening, confirm the validity of the corrections on the ROLO reflectance (Ac and Bc), use other reflectance models. Also, to organise a coordinated measurement campaign.

Thijs: the dataset presented here seems very similar to LIME. Are the Skynet irradiance measurements available?
A: not for free download but yes for collaboration. But the measurements are not calibrated. However, the instrument could be calibrated and the measurements could be repeated.

Stefan: are there sites that are high enough?
A: not yet.

For the moment, the correction on the ROLO is just one set of coefficients, derived from a site in altitude (Uchiyama, 2019). The assumption for now is that they can be applied to the other sites. The correction is widely used in the aerosol community.

Many CIMEL are looking at the moon but they are not calibrated instruments as the one on Pico Teide for LIME.

17:40	All	All	Discussion	4s

This technique for AOD retrieval provides reliable indicators for the correction to a lunar model to make it an accurate exospheric lunar irradiance generator.

In a future iteration on the model inter-comparison, this approach (using the aerosol retrieval as a way to compare the models) could be used for the comparison, i.e. generate model outputs for a specific location and time.

Tom mentioned that he intends to develop a new ROLO model, which will include not only the ROLO dataset but also the measurements from air-LUSI, and lunar irradiance measurements from the ground.

Thijs mentioned that if an adjustment can be derived from the Skynet/lunar CIMEL network, there is nothing that prevents to derive also a libration correction.
Thijs: Why is the LIME not picking up such a correction with the Langley plot? If ROLO is corrected by C, we should get LIME, with some level of uncertainty.
Tom: to derive a libration correction requires many measurements covering a range of librations. The photometer exo-atmospheric irradiances come from lunar Langley analysis, so only one measurement can be acquired per night this way.
Tom: the Uchiyama correction to ROLO was developed for a limited number of bands and from a specific set of observations, so it is not universally applicable. But good nighttime AOD retrievals can be derived using e.g. ROLO or LIME to account for the irradiance variation with phase angle and applying a bias correction such as Uchiyama. Once the nighttime AOD can be made continuous with the daytime AOD, then the photometer measurements extrapolated to zero airmass can provide exo-atmospheric irradiance measurements.

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R.LCWS.2023.4s.1: GDWG to review how to host the new lunar irradiance data such as air-LUSI, skynet lunar irradiance data

Fri 8/12	**Conclusion and way forward** **Chair: Sebastien Wagner and Tom Stone**

09:00	All	All	Data policy / GLOD / LSICS licensing & distribution	5a

Best Practice Guidelines
Hugh Kieffer offered to coordinate Best Practice guidelines, incorporating different spectral bands. He proposed a review committee, where contributions from various experts would be credited to different authors. He foresaw this as a Wiki, rather than a book (initially), and will propose section titles.

E.g. Stephen Maxwell + Hugh Kieffer offered to contribute an article on calculation of pixel solid angle.

How to ensure that best practises are followed? Tom mentioned that agencies stay with their own procedures, even if they are not best practises. Seb commented that we could work on baselines and groups would provide details on their own implementations, similarly to what is done for GSICS products (GSCIS ATBD baseline and agency implementation of the baseline). Agencies would need to document how their procedures follow the best practices. Thijs commented that we will need some way to address disagreements.

Before information is recommended as best practises, we need to make sure that information provided is properly reviewed by the group before it is published.

Action A.LCWS.2023.5a.1: Hugh Kieffer to propose section titles for Best Practice Guideline on lunar calibration by 2024-03-01

This guideline will need to be supplemented with community input.
Identified a need for a lexicon/glossary

- Encouraged participation in existing Terms and Definitions Wiki initiative from CEOS-WGCV: https://calvalportal.ceos.org/t-d_wiki
- And CGMS: https://cgms-info.org/glossary-of-terms/

CEOS/GSICS Workshop on Optical Space Sensor Pre-flight Calibration and Characterisation 19-21 Nov 2024 at ESTEC, NL

Sub-Group Formation and Meetings

Decision D.LCWS.2023.5a.1: To propose formation of a sub-group of the GSICS Research Working Group on lunar calibration - cross-cutting spectral bands, and propose to Executive Panel. (Proposal of chairs to follow EP endorsement)

Decision D.LCWS.2023.5a.2: Agreed to continue joint GSICS/IVOS lunar calibration workshops in person every year or 2 years.

Decision D.LCWS.2023.5a.3: Schedule regular web meeting slots - with the objective of holding a meeting every 2 or 3 months - in coordination with other GSICS sub-groups. With one meeting in person every second year (see above!)

Fangfang: make the lunar calibration sub-group proposal part of the GRWG report to the EP?

Fred: concerned about the level of activities. In order to justify a subgroup, it means that there is enough momentum. Scope of the activities in the lunar group has enlarged since the start of the activity.

Data Exchange
Is EUMETSAT still planning to support the GSICS Lunar Observation Dataset (GLOD)?
To be discussed internally at EUMETSAT. E.g. landing site/catalogue

Action A.LCWS.2023.5a.2: Seb Wagner (EUMETSAT) to propose way forward with GSICS Lunar Observation Dataset (GLOD) by 2024-03-01

09:30	Kevin Turpie	UMBC / NASA	MEASUREMENTS and MOON OBSERVATIONS : summary (including action / decisions/recommendations)	5b

Steve gave a summary of the session with highlights on the session.

POCs and associated agencies to be added to actions - e.g. NASA/NIST for Air-LUSI/Mauna Loa-LUSI, …

Recommendation R.LCWS.2023.5b.1: EP to promote acquisition of SI-traceable observations of the Moon to support further operation of Mauna Loa-LUSI, and to include the aerosol retrieval application to raise visibility of lunar calibration by tying it to a key climate data record

- Seb and Tom to interface with Monica and Natalia to formulate the latter

Recommendation R.LCWS.2023.5b.2: GSICS Exec Panel to support acquisitions of more polarisation-diverse observations of the Moon.

Recommendation R.LCWS.2023.5b.3: GSICS recognises the additional value in disk-resolved lunar observations to support the further development and validation of lunar radiance models.

Greg Kopp: polarimetric measurements can help with advancing lunar calibration.

Actions/recommendations were agreed.

09:45	Tom Stone	USGS	LUNAR CALIBRATION SYSTEMS and MODEL DEVELOPMENT : summary (including action / decisions/recommendations)	5c

Tom reviewed key outcomes of the session:

- Model development is proceeding within several GSICS agencies and other entities
- Comparison of model outputs revealed differences in development approaches
- Progress is being made on LSICS development

Model development to include validation against observations with reliable uncertainties. Need to put uncertainties on model outputs - a big task!

Considered doing comparisons in reflectance space (irradiance is currently the reference)

- would remove dependence on solar spectra
- but irradiance is what sensors detect

Identified need to keep separate the tools for developing and applying lunar irradiance models.

- have been using the terms “derivator” and “applicator”
- Tom suggested these might cross into using jargon, which should be avoided

Discussed comparison of model results as a function of time - although the Moon itself is invariant - this could be beneficial for some users, or closer to what users use.

Importance of constraints beyond linear interpolation, by adding knowledge of smooth-nature of lunar reflectance spectrum - especially when applying hyperspectrally - for Best Practice.

Identified need to capture the differences in the different versions of the ROLO model being used, e.g. the TSIS HSRS correction.

Action A.LCWS.2023.5c.1: Tom Stone (USGS) to document the versions of the ROLO model he supports.

- The adjustment used by PMOD (Natalia) is experimental and not a ROLO model version

LSICS development session - see summary slides for that session

- Convert some decisions and recommendations into requirements on LSICS
- Use TSIS HSRS for solar spectrum, but include ability to load different solar spectra?
- Convert recommendation on outputting disk-reflectance as an intermediate product to a decision? To be addressed offline.

Update on last 3 actions:

- Combine into one action on Hugh Kieffer to coordinate - with inputs from Fangfang Yu (NOAA) and Seb Wagner (EUMETSAT) - with target date 2024-01-31, include priorities

Action A.LCWS.2023.5c.2: Seb Wagner (EUMETSAT) to set up web meeting to agree LSICS input format by 2024-01-31

Actions/recommendations were agreed.

10:00	Sebastien Wagner	EUMETSAT	INSTRUMENT MONITORING USING LUNAR CALIBRATION : summary	5d

			(including action / decisions/recommendations)	

See summary slides for that session

How to establish the observables is the key - and important to have a measurement model in order to generate a comprehensive understanding of the uncertainties.

Recommendation: R.LCWS.5d.1: Agencies are encouraged to take the opportunity of end of life tests to conduct manoeuvres to acquire diverse observations of the Moon for later analysis.

Re: Solar Diffuser recovery on NOAA-20 VIIRS - Request for further reports from NASA on which instruments see what - and share with Space Weather sub-group.

Actions:

- covered above

Actions/recommendations were agreed.

10:35	Tim Hewison	EUMETSAT	THERMAL INFRARED and MICROWAVE : summary (including action / decisions/recommendations)	5e

Tim listed the potential applications for IR / MW lunar observations:

- Inter-calibration transfer target, which requires stability between observations, and observations in the same geometry/phase – or a lunar model - although observation sequences in successive orbits may relax this requirement
- Inter-band calibration, which requires a spectral model
- Long-term calibration tracking, which requires compensation for Earth-Sun distance + Moon Phase and precise navigation
- FOV/Antenna Pattern mapping, which benefits from spacecraft manoeuvres
- Viewing dark-side of Venus in syzygy may provide alternative target

Thermo-Physical Models (TPM) available for Moon (and other celestrial bodies), which can predict radiance maps in thermal IR, based on finite element modelling, accounting for surface roughness - or use observed thermal emissions (e.g. From Gaofen-4 or LRO/Diviner, coupled with emissivity model). These can be integrated to give disk-integrated values for the thermal infrared - and could possibly be extended to microwave by adding temperature profiles - or with addition of empirical emissivity phase angle model. The current status is that uncertainties on absolute radiance ~2-3% in MW 89-183GHz ~3-5%/ ~2.5K in TIR, while relative uncertainties are much better, allowing accurate inter-calibration.

Outstanding issues include the need to account for anisotropy in the emissivity model, checking the influence of libration angle and possible opposition effect, which is small in 3-4μm band, and assumed small in MW - TBC. Validation is key – but currently challenging in 3-4μm band, in MW <89GHz and >183GHz.

On the observation side:

- Spacecraft manoeuvres (including 2-D mapping) highly beneficial for lunar calibration, allowing targeted observations at the same phase angle/distances to allow direct inter-calibration.
- For infrared, managing saturated imagery is an issue. NASA (Jack) showed a showcase with MODIS and VIIRS that could be used for further work with other missions.
- Accurate Pointing/PSF/Antenna Pattern is important, but this can also be a major application of lunar observations.
- Current observations are mostly based on integrating irradiance over the lunar disk, but it is also possible to exploit radiance models on selected pixels.

The session encouraged exchange of observations and models, noting new datasets available:

- IR: CrIS (Yong Chen), IASI (CNES+EUM), Akatsuki Venus Orbiter (JAXA)
- MW: ATMS (Tiger Hu)

Actions are in place to facilitate the sharing of these, which is expected to lead to best practices on observation processing techniques. These should first be developed and documented in contributions to the Best Practice guidelines. This could lead to a collaboratively-written review paper on the status of lunar modelling in thermal infrared and microwave, and their validation with observations.

Application of LSICS applicator to the thermal IR/MW was also discussed. The current inputs are likely to be sufficient, although the potential need was identified to include history of model radiances to account for hysteresis in microwave signal.

Action A.LCWS.2023.5e.1: Thomas Müller to analyse impact of libration on thermal signal using IASI data and/or CrIS data upon availability and report by 2024-12-31

Actions/recommendations were agreed.

Way forward:

- Data sharing is encouraged
- For LSICS inclusion, the only missing element is the history of previous model radiances, which may influence microwave signal
- Regarding the observation processing techniques, first the IR/MW contributors should think of contributing to the best practise effort decided by the group before they consider a collaborative review article on the current status of lunar modelling

Tiger: for current instruments, libration may not impact. But for future missions, it may. But accounting for the sun-moon distance is important and will be addressed. Tiger will iterate with Thomas on the TPM model.

Recommendation R.LCWS.2023.5e.1: Agencies operating microwave instruments observing the Moon are encouraged to compare these with the model presented by Tiger Hu (UMD), which is fitted to ATMS data. This would allow instrument comparison, covering more phase angles.

Thomas Mueller asked about polarisation effects. He believes that the disk-integrated lunar MW signal depends on the orientation of the polarizer. At least at larger phase angles (>45deg?) there should be a measurable difference between the horizontal and the vertical polarized instruments (assuming that the orientation of the polarizers wrt the Moon is known).
The group is invited to investigate further and exchange via a web meeting.

10:50	Fangfang Yu	NOAA	ALTERNATIVE APPLICATIONS OF LUNAR OBSERVATIONS : summary (including action / decisions/recommendations)	5f

Fangfang recapped on the best practice method for MTF to be continued.
She also summarised the outcome of the work of straylight corrections she did on ABI.

Monica Campanelli (ISAC- CNR, IT) introduced the skynet network for aerosol retrieval from the moon irradiance. The moon data is collected with POM-2 instruments. It was recognized that the POM-2 instruments, although not calibrated, could be a good data source for lunar irradiance model development.

Actions/recommendations were agreed.

11:05	All	All	Discussion	5g

FORUM will observe the Moon in the far infrared 5-6 times a year automatically in the deep space view and will consider dedicated manoeuvres during end of life testing.

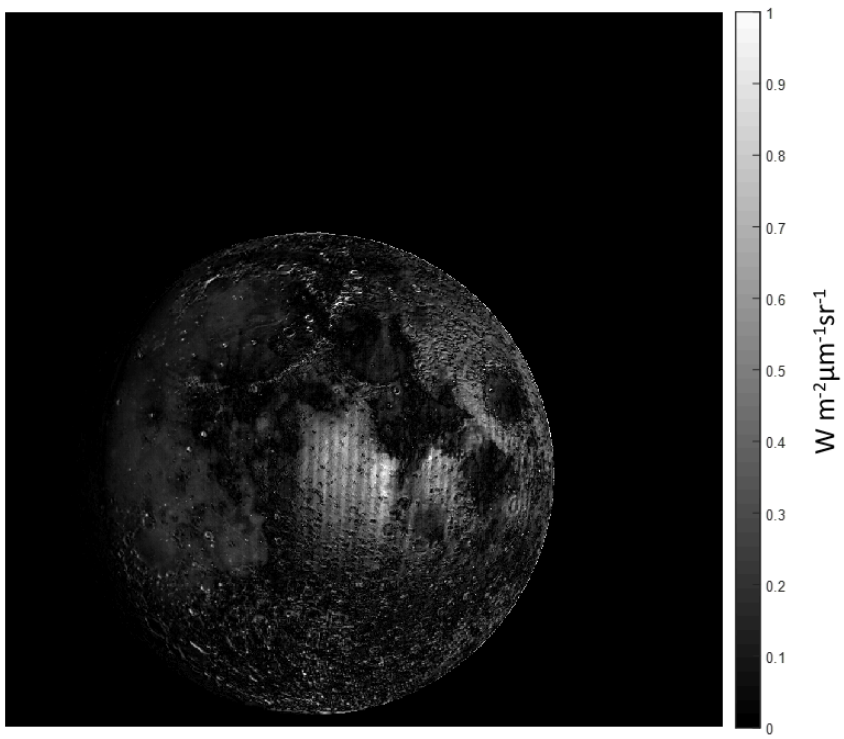
11:50	Sebastien Wagner / Tom Stone	EUMETSAT / USGS	Wrap-up / overall summary / way forward / time line	5h

Need to discuss topic of lunar irradiance extraction from images.

There was no discussion at this point about the next iteration of the lunar workshop. The next milestone is the GSICS Research and Data Working Group annual meeting in 2024 to propose the creation of a lunar calibration subgroup.

Post-meeting note from Kay Wohlfarth 2024-01-18:

I had another look at the disk-resolved and disk-integrated errors of the Gaofen-4 data, calculated the disk-resolved error, and added it to my thesis. So, thank you very much for suggesting this experiment! After chasing some commas and making minor edits, I finally handed in the document and can relax and resume with all correspondence and projects. Attached is the root-mean-squared error between the Gaofen-4 measurements and my model regarding radiance units. The disk-integrated error is 0.1985 Wm^{-2} μm^{-1} sr^{-1}, just 2.5 % of 8 W/m^2/sr/micron (close to the disk's maximum radiance). The error map correlates with composition and generally shows larger values for some highland material, titanium-rich Oceanus Procellarum material, and fresh crater ejecta. I suppose these deviations come from the albedo estimates (see also the discussion part in my paper), which I derived from Moon Mineralogy Mapper data and Apollo samples from very few surface locations. I plan to dig into this in the future, so with better albedo estimates, I might get even better results. The stripes from north to south are likely an artefact from the albedo estimates, too. Unfortunately, the Moon Mineralogy Mapper data has these stripes, which propagated to the model. Cheers Kay



RMSE between model and measurement for July 25, 2018