Third Lunar Calibration Workshop 16-19 November 2020

Minutes of meeting – Webex sessions

1-18-2021

16/11 Item	Lunar model development Chair: Tom Stone / Sebastien Wagner		
16	**T. Stone / S. Wagner**	**USGS / EUMETSAT**	**Introduction to the workshop and to the session**

Seb welcomed participants to these lunar calibration mini-sessions, which are intended to bridge the gap until we can again run a full Lunar Calibration Workshop - which is now hoped to take place in 2021.

An Lingping (XIOPM)
Arata Okuyama (JMA)
Berit Ahlers (ESA-ESTEC)
Bertrand Fougnie (EUMETSAT)
Chris (?)
Constantine Lukashin (NASA)
Emma Woolliams (NPL)
Erin Lynch (?)
Fangfang Yu (NOAA)
Fred Wu (NOAA)
Greg Kopp (UCAR)
Haifeng Qian (NOAA)
Hideaki Tanaka (JMA)
Hirokazu Yamamoto (AIST / GSJ)
Hugh Kieffer (Celestial Reasonings)
John Woodward (NIST)
Kazuki Kodera (JMA)
Kevin Turpie (UMBC/NASA)
Kurihara Junichi (Hokkaido University)
Lawrence Ong (NASA)
Maciej Neneman (ESA)
Marc Bouvet (ESA)
Marcel Dobber (EUMETSAT)
Martin Burgdorf (Uni Hamburg)
Masataka Imai (AIST)
Matthew Kowalewski (NASA)
Matthijs Krijger (ESS)
Minju Gu (KMA)
Mireye Etxaluze (RAL)
Morven Sinclair (NPL)
Nicolas Lamquin (ACRI)
Pepe Philipps (EUMETSAT)
Sarah Taylor (NPL)
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Tae-Hyeong Oh (KMA)
Taeyoung Choi (NOAA)
Taichiro Hashiguchi (RESTEC, Japan)
Thierry Marbach (EUMETSAT)
Thomas Müller (MPE)
Tim Hewison (EUMETSAT)
Tom Stone (USGS)
Toru Kouyama (AIST)
Tiger Yang (UMD)
Xiaoxiong Xiong (NASA)
Xu Geng (NASA)
Yu Can (XIOPM)

Yuan Li (CMA)
Yu Zhang (?)
Zhipeng Ben Wang (NOAA)

16a	**Toru Kouyama**	**AIST**	**Lunar Calibration Activities at AIST - An update on SP Lunar Model**

Toru introduced the SP lunar radiance model, based on the Spectral Profiler onboard Selene (Kagayu), which has been used to derive a hyperspectral radiance map of the Moon's surface from 516-1600nm. This has been used to generate a reflectance map and can also be integrated to model the lunar irradiance for comparison with ROLO.

SP model has been applied to monitor the degradation of a small sat sensor and Hayabusa-2 asteroid explorer
For temporal trending, the accuracy is similar to the ROLO.
Performances for the SP model = similar to the ROLO (within 1 or 2%). However, there is an issue when accounting for the reddening effect. The model has been corrected with the ROLO model.

SP model cube will be released via JAXA website – maybe in 2021 – also available from Toru directly.
Also developing application to take inputs of observation time, position, SRF, spatial resolution to drive SP model

Toru expressed an interest in the SP model joining the GIRO lunar irradiance model inter-comparison, which was warmly welcome.

Pixel-to-pixel comparison of modelled and observed radiances show some large biases (~20%) near the terminator.

16b	**Sarah Taylor**	**NPL**	**The Lunar Irradiance Model of ESA (LIME)**

LIME derived using SI-traceable ground-based measurements with CIMEL photometer in Tenerife.
Based on ROLO model – with additions of a spectral dependency on the c-coefficients.

Instrument bands range = 340-1640nm – including polarisation capabilities
Non-linearity <0.1% - considered negligible
Temperature sensitivity of detectors characterisation needed as no thermal stabilisation
Irradiance responsivity characterised with standard uncertainty ~1%
Lunar Phases -90° to +90°,
Tracked using Langley Plot over Airmass 2.0-5.0 in 2hr – phase variations corrected – how?
Iterative atmospheric correction to TOA radiance
Uncertainty Analysis accounts for correlation within Langley plot.
Now updating model with 2.5years new observations
95% uncertainty ~2% (k=2) on absolute irradiance

To fill the spectral gaps between the CIMEL bands, the Thuillier solar irradiance spectrum is used.

~7/8% brighter than GIRO in VIS/NIR - also compared with VITO/CNES implementation of ROLO
- Highlight differences between different implementations of ROLO

Plan to update spectral interpolation (using Pandora) - and revising the uncertainty associated with this + polarisation

Q: Calibration frequency?
- Planning recalibration in 2021 – after ~3yr + in-situ monitoring

Q: Public availability?
- Already published on WGCV Cal/Val Portal including model coefficients

Q: Experience of high-frequency atmospheric variations during Langley Plots?

- Site chosen for stability + uncertainty in Langley plots carefully monitored = key!

2% accurate with 95% confidence on the absolute scale. To reproduce a trend it would be less than 1%

Q: Detectors?

- Silicon + InGaSi

16c	Matthijs Krijger	ESS	A new lunar irradiance model based on SCIAMACHY and RELAB data

Derived Lunar Extended Satellite Spectral Reflectance model (LESSSR) to fit SCIAMACHY observations

- Very similar to ROLO, but with different phase-dependence
- 250-2600nm with 5nm resolution
- -80° to +20° phase angle validated
- Accuracy <1.5% over 500-1600nm (5% beyond)
- Available from EUMETSAT? - TBC

One source of problem with SCIA acquisitions was the degradation in time and the loss of throughput. Another issue is polarisation sensitivity.

Validation against GOME-2 observations reveals wavelength-dependent bias ~±1%

- May be due to different solar longitude sampled by SCIAMACHY and GOME-2?

Apollo samples = disturbed samples. Could be an issue for modelling the soil reflectance when considering information as provided by RELAB data.

16d	Hugh Kieffer	Celestial Reasonings	SLIMED: a continuous lunar model algorithm using many instruments

Difficult to characterise variation with libration angle using single instrument. Global albedo maps from lunar orbiters can be used to model libration effect.

Mean residuals ~0.75%, comparable to ROLO.
Iterative – adjusted gain for each instrument to bring them to a common scale – until convergence
“Adding rigorous uncertainty analysis increases the workload by a factor of ~3”

Libration is treated in 4D in SLIMED, only in 2D in ROLO.

Substantial differences between ROLO and SLIMED at 0 libration for different phases (slide 14).

An uncertainty coefficient is added to each instrument dataset. It is based on available information from data provider or on Hugh’s own estimates and judgement (which would need to be confirmed by data owners or updated as required) ➔ this coeff avoids giving an unrealistic weight to a specific instrument in the mix.

Q: Will model, code and data be shared?

- That’s the plan – to publish it all. A publication is under preparation. Hugh is looking for an US agency to host the SLIMED model.

Q: How do you handle oversampling?

- Relies on instrument teams, who have dealt with this.

16e	Kevin Turpie	University of Maryland	Update on the air-LUSI project to achieve absolute calibration with lunar models

Aim: high-accuracy Moon observations from high-altitude aircraft
Currently <1% (k=1) 415-1000nm (targeting <0.5%) with 3.7nm resolution
Small atmospheric correction max 3% from molecular scattering
NASA ER-2 @21km – above 90% of atmosphere (and almost all water), but below most ozone

Engineering flight campaign carried out with two ~2-hours flights
Demo flight campaign carried out with 5 consecutive nights (= 5 different phases) with ~2 hours flights.

Air LUSI lunar irradiance measurement: below 1% uncertainty between ~400nm and ~970nm

Jason from NOAA: any plan to release the data?
Kevin: yes. Timescale is to be confirmed (~1 month).

Q: Plans to extend into SWIR?

- Would need additional focal plane – e.g. part of Air-LUSI-2?

16f	All participants	Discussion

Use of Reference Spectrum to benchmark model comparisons

- Potential use of Air-LUSI observations to provide a Reference Spectrum

How well can we retrieve lunar irradiance from Moon observations?
Modellers shall provide the focus of their models:

- Absolute Calibration
- Calibration trending
- Inter-channel calibration

Need for modellers to provide details on how the model handles:

- Moon reddening
- Libration

Hugh: Lunar Calibration Community should aim to replace ROLO model v3.11g with consensus-agreed reference model

Matthijs: Would be helpful to be able to provide viewing geometry as input to GIRO (and other models) - to disconnect the model from the viewing geometry

- **R.LCWS.2020.16f.1:** Model developers to consider how their models' inputs can be decoupled from the observations to allow inter-comparison and benchmarking on the various steps of lunar calibration.

Could also create a fake instrument, but all models should be able to consider specific observation geometry – e.g. one air-LUSI case

- **A.LCWS.2020.16f.1**: EUMETSAT (S. Wagner) to liaise with USGS (T. Stone) to realign the GIRO with respect to the last version of the ROLO model.

Kevin Turpie proposed that potential users of the Air-LUSI observations should let NASA know how relevant these are to the development of lunar calibration activities.

- **A.LCWS.2020.16f.2**: EUMETSAT (S. Wagner) to propose letter of recommendation by GSICS to NASA to highlight the benefits to continue the Air-LUSI campaigns to lunar calibration.

Model Inter-Comparison Exercise:

- Seb is planning web meeting for participants in first 2 weeks of December
- Will presents results of inter-comparison at future public meeting

- **A.LCWS.2020.16f.3**: EUMETSAT (S. Wagner) to report on the Model Inter-Comparison Exercise at the next GSICS annual meeting + Lunar Calibration Community.

Q: Possibility to establish public mailing list for lunar calibration community?

- e.g. list of participants

- **A.LCWS.2020.16f.4**: EUMETSAT (S. Wagner) to check possibilities to create a distribution list for the Lunar Calibration Community.

Participants to let us know if they don't want email or presentations shared

- **R.LCWS.2020.16f.2:** EUMETSAT (S. Wagner) to investigate the possibility to revisit the mechanism to share the GIRO model, whilst respecting the existing license agreement.

Q: NOAA progress on lunar radiance modelling?
A: on hold for the time being

- **R.LCWS.2020.16f.3:** Satellite operators to consider providing data to Hugh Kieffer for further processing with the SLIMED model.

- Could also be pursued through GSICS – to be followed-up offline

17/11 Item	**Mission monitoring using Lunar Calibration Chair: Sebastien Wagner**		
17	**Sebastien Wagner**	**EUMETSAT**	**Introduction to the session**

Attendees – bold – present today – others copied from previous days

Ali Mousivand (EUMETSAT)
Alessandro Burini (EUMETSAT)
An Lingping (XIOPM)
Arata Okuyama (JMA)
Berit Ahlers (ESA-ESTEC)
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Woordward (?)
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17a	**Taichiro Hashiguchi**	**RESTEC**	**Monitoring GCOM-C Radiometric Performances Using Lunar Calibration**

Mission: 3 years of continuous observations.
SGLI lunar calibration: achieved with a pitch manoeuver.
For IRS sensor, a reconstruction method is needed.

Resulting Calibration coefficients show trends consistent with on-board reference within 1%?

Phase angle dependency is corrected through a parametrisation. The phase angle dependence is small for short wavelengths and gets larger for longer wavelengths (see slide 13).

Also compared results with AHI:
- SGLI was 15-20% darker (solid angle calculation issues?)
- Derived phase-angle correction from AHI & compared with SGLI – approx 3% in SWIR band

Q: how to reconstruct image?

- Use precise geometric model based on ground test data

17b	Masataka Imai	AIST	Lunar Calibration Activities at AIST - Lunar calibration and micro satellites

SP model developed to allow compensation for satellite instruments' degradation – especially small satellites.
Observe Moon with RISESAT + OOC about once a month with abs phase ~ 10°±2.5°
Also checked inter-band ratio between OOC bands – consistent trend - validated with Railroad Valley
The impact of temperature was analysed to check potential correlations. After correction, OOC sensitivity degradation < 1%
Observed negative trend in OBS/SIM in 405nm, but positive at 869nm

Q: Phase angle range? - see above

Q: Are radiometric calibration trends explained by temperature variations?
- Depends on instrument design
- Could also be spectral effects (D. Smith)
- Pre-launch tests confirmed 50°C change ==> 1nm shift

17c	Maciej Neneman	ESTEC	Lunar Calibration and Sentinel-3 OLCI

Maciej introduced the OLCI instrument and its calibration mechanism (dark shutter + solar diffusers) and SLSTR.
Nice animations showing S-3 roll manoeuvre
OLCI stray-light correction – iteratively tuned, to optimise Moon views – will be introduced in Instrument Processing Facility – see Remote Sensing paper by Neneman et al., 2020
Missing GIRO results for OLCI-A observation
OLCI-A+B Observations consistent with LIME – mostly within ±2% uncertainty – except at Oa21
Residual Stray Light = Total Irradiance/Disk Irradiance –1 – Oa21 very sensitive

Recommendation from OLCI Quality Working Group are to perform further manoeuvres – e.g. with other cameras or/and more regularly.

SLSTR: VNIR-SWIR need to address dark levels, radiometry + nonlinearity

Q: Microwave observations of Moon include smearing due to sampling – similar to stray-light correction?
- No smearing in OLCI (already corrected), some electronic cross-talk, but mostly optical straylight

Q: How to explain sudden change in GIRO+LIME in Oa21 channel?
- Not sure – under investigation
- Critical to use consistent solar spectra – re-sampled Wehrli spectrum for GIRO and LIME, as OLCI radiances are obtained after applying another solar irradiance spectrum (Thuillier).
- D. Smith recommends comparing reflectance spectra, rather than irradiance

- **R.LCWS.2020.17c.1**: the solar irradiance spectrum used in the lunar irradiance models or for the instrument calibration should be documented and referenced when discussing lunar calibration results.

17d	Mireya Etxaluze Azkonaga	RAL	Deriving lunar irradiances from SLSTR lunar acquisition

Preliminary results

SLSTR VISCAL reflectance characterized on-ground pre-launch.
VISCAL signal used from previous orbit.
Compared SLSTR observed irradiance with and without vicarious calibration (mostly PICS desert sites).

S3B VIS channels within 2% of LIME model without vicarious calibration (4% with vicarious calibration).
S4 channel – S3B agree with LIME within 1.5%
S5 – agrees with LIME within 0.5%
S6 is ~10% lower than LIME, but vicarious calibration improves it

Q: How to handle different detectors?

- Only processed 1 image/detector so far – can repeat for each detector and compare.
- Moon reconstruction and the interpolation method to reconstruct the moon is still work in progress.

Q: how to integrate irradiance from images?

- Differed to discussion section

17e	Jason Choi	NOAA	S-NPP and NOAA-20 VIIRS Instrument Trending using Lunar and Solar Diffuser Calibrations

Compare results from VIIRS on-board calibration – Solar Diffuser (SD) and Solar Diffuser Stability Monitor (SDSM) - with lunar calibration

Introduced F-factor as ratio of modelled/observed solar radiance

- can also be derived from lunar observations
- and H-factor to account for the solar diffuser degradation and its change in BRDF.

The F factor corrects for some effects of the lunar phase (cosine function)

Trends produced by lunar calibration (GIRO) and the solar diffuser are very consistent except for some points are the beginning of the mission.

For NOAA-20, even though lunar calibration and solar diffuser are within 1-2% the behaviour is quite different in time. So DCC and SNOx (between SNPP and N20) methods were applied to cross-check.

For recalibration, a Kalman filter has been implemented to account for a set of various methods, including the lunar calibration.

Moon views not available to VIIRS during summer months

Q: Cause of seasonal oscillations in F-factors (slide 8)?

- From screen of solar diffuser – has not been corrected in operations yet – in discussion

17f	Fangfang Yu	NOAA	ABI lunar radiometric calibration

ABI can scan the Moon whenever is appears in the FOR

- With 0.14 to 2.2 million samples per image
- Can retrieve very small biases in sample solid angle, oversampling factor, lunar irradiance

Broad interested of using Moon for GOES: solar calibration validation, degradation trending, RVS, MTF, detector response uniformity, …

GOES-17 ABI cannot control focal plane temperature consistently

Oversampling factor calculated as described in 2nd Lunar Calibration Workshop:

- Scan rate is very stable – so oversampling factors are very consistent & normalised with respect to the first observation

Phase angle dependence increases with wavelength – up to 12% at 90° phase in the SWIR (slide 13)

Spacelook contamination correction <0.015% - but systematically detectable
Earth-shine correction – impact very small

- After corrections E-W RVS<1%

Q: fuzzy edges of B04 Moon image?

- Due to detector selection not being compensated in processing of lunar images

Q: solid angle calculation?

- Use Angular Separation Distance value provided by instrument vendor
- Should be included in assessment of uncertainties

17g	**All participants**	**Discussion**

Hugh has 10 topics for discussion

- to be circulated by email via Seb to participants
- with request for proposals for how to follow-up (e.g. at GSICS WG meeting in March 2021)
- e.g. ask who is planning to work on each topic in the coming year:
- List can already be revisited in Thursday discussion session

1. How to do irradiance integration & impact of cut-off? (sensitive to cosmic rays) - LEO/GEO diffs.
2. Calibration – extent to which lunar calibration is included in operational
3. Agreement on solar model & Account for solar variability
4. GEO sensitivity to view angle
5. Need to separate the satellite position and time from the input parameters to the lunar models themselves.
6. If participants send Hugh data, he will provide model simulations, but not share results further
7. Need for consistent terminology for detectors to avoid confusion when comparing sensors
8. Need for naming convention for model versions as they evolve
9. Need to include polarisation in Moon radiance/irradiance models
10. Effect of Earth-shine – accounting for variable cloud situation (needed for <0.1%)

Seb: Consistent terminology and approach on Uncertainty analysis

Lawrence: any attempt to account for instantaneous solid angle variations in SLSTR observations?
Mireya: Yes – but little impact when the Moon is in the centre of the swath

Seb: Use of lunar imagery to characterise MTF post-launch being led by Fred Wu (NOAA) and IVOS

- See recommendation **R.LCWS.2020.19d.1**.

N.b. Some participants have suggested using the LIME model instead of the GIRO as LIME has a different absolute calibration – tied to observations it is based on. LIME is expected to continue to evolve as additional observations become available. LIME currently only has 2.5yr observations, so does not cover full phase/libration space. GIRO was established as a common reference, using one implementation of ROLO and the drivers needed to apply it – could be replaced as reference

EUMETSAT need to resolve outstanding issues with GIRO licence, so that US agencies and CMA have access.
GLOD could be used in Hugh Kieffer consensus model.

18/11 Item	Microwave mini-session Chair: Vinia Mattioli		
18	**Vinia Mattioli**	**EUMETSAT**	**Introduction to the session and discussion**

Attendees: - **Names in bold attended this session.** Other names attended previous sessions:

Ali Mousivand (EUMETSAT)
Alessandro Burini (EUMETSAT)
An Lingping (XIOPM)
Arata Okuyama (JMA)
Berit Ahlers (ESA-ESTEC)
Bertrand Fougnie (EUMETSAT)
Chris (?)
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Frank Borde (?)
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Vinia introduced the microwave mini-session and outlined the presentation planned.

18a	**Roberto Bonsignori**	**EUMETSAT**	**In-Orbit Verification of MHS Spectral Channels Co-Registration Using the Moon**

Roberto introduced the Microwave Humidity Sounder (MHS), which is operational on Metop-A/B/C and NOAA-18/19. He explained how Moon intrusions occur regularly in the space views, depending on the orbital geometry.

Two time periods were used for the analysis of the co-registration post-launch: Jan 2015 and Nov 2016 He performed a Gaussian fit of the observed radiance curves to derive the relative position of the Moon between different channels.

Concept is applicable to IR and MW scanners where a space view port is available. In-flight co-alignment of MHS channels in the along-track direction could be verified with moon observation to an accuracy of a small fraction of the beam width.

Q: Channel H1 (89GHz) offset wrt other channels – could check misalignment with coastlines?

- Possible in principle wrt H2 or H5
- However, checking the result for channel H1 with ground landmarks to the accuracy achieved with lunar observations would be impossible, due to the poor sampling scheme (1.1 deg spacing, 1.1 degrees FWHM). The moon is oversampled because the space port position is close to the orbital axis and the moon moves slowly, thus providing the wanted oversampling although only in the along-track direction. Oversampling in the across-track direction would only be obtained by changing the scan profile or performing roll manoeuvres

Q: Do multiple intrusions during mission lifetime help reduce uncertainties?

- Not investigated further – but could be possible effects which could bias the measurement
- Jan 2015 and Nov 2016 are perfectly consistent
- Martin Burgdorf has analysed 20 Moon intrusions – with consistent results

Martin also remarked that he was able to derive co-alignment information also in the across-track direction without oversampling, thanks to his analysis based on a larger data set

Q: Which channels of MHS share common optics (feedhorns, etc)? Would you expect the same pointing error for H3 and H4? And H5 too?

H3 and H4 share the feedhorn and front-end electronics (central frequency 183.311 GHz). H5 has a different feedhorn and central frequency (as well as the other two channels) unlike for AMSU-B, ATMS or MWS.

18b	**Martin Burgdorf**	**Universität Hamburg**	**Calibration and characterisation of microwave sounders with the Moon**

Martin extended the analysis presented by Roberto light curves, applied to all MHS and AMSU-B to retrieve pointing error in 2-D. L1B files give the pointing direction. This is compared with what comes out of the lunar intrusion data analysis. These were not consistent with requirements in 1/3 of cases.

He went on to show analysis of the beam size from the width of light curves during the Moon intrusions into space views. This showed unexpected results with >1.12° for all MHS and AMSU-B (except N17 and Metop-B).

The moon is smaller than the beam. Therefore, we have an integrated measurement of the Moon BT. Compared to reference models, (Liu and Jin, 2020, or Keihm - 1984) MHS measurements seem not to always agree, with a difference up to 5% for NOAA18 MHS for instance. The measurements were adjusted to allow for the varying distances between Sun-Moon-Satellite.

Liu and Jin could be used a radiometric reference after some adjustment (in order to match measurements that are regarded to be fully accurate, the model had to be “shifted” upwards by a constant factor.

Hence the photometric calibration of microwave sounders can be characterised post launch using the moon.

More than 20 moon intrusions were used to produce the results.

Q: How to derive pointing error in along-track direction?
Slightly different view from Roberto – although 4 space view pixels are >1° apart, multiple Moon intrusions can be averaged, with focus on those where the signal is exactly the same from 2 pixels, which pinpoints the moon's position in the middle between them.

Q: Could you quantify the uncertainty of the fit between the observed BT and model (after 5.5% scaling)?
Post-meeting answer: I have calculated the difference between the measured TB of the Moon and the prediction by Liu's model for all points I got with channel 1 of MHS on NOAA-18. Then I calculated the standard deviation of these values with MATLAB. The result was 2.01 K. If I do not scale the model, then it is 2.02 K (but then mean is of course quite different). If I fit a fifth order polynomial to the measured points and use this as my new model, I get also an std of 2.02 K. If I use Keihm's model, I get std = 3.52 K. This shows me that Liu's model fits the measured brightness temperature of the Moon as a function of phase angle very well. The difference between Liu's model and observation is mainly due to the random scatter of the measured values, whereas Keihm's model has a considerable, systematic error.

18c	**Yang Hu (Tiger)**	**University of Maryland**	**Lunar Disk Integrated Microwave Brightness Temperature from 23 to 183 GHz**

Tiger introduced the ATMS. The NOAA-20 ATMS current noise performances are well within requirements for all 22 channels.
He explained the pitch-over manoeuvre performed on NOAA-20, which provided very good Moon scans in the nominal Earth views.
In the channels with oversampling (achieved by instrument design), uncertainties are lower on the lunar measurements. Those uncertainties are higher in the channels where oversampling is less.
Tiger fitted the observations to a Gaussian response function and derived disk-average microwave antenna temperature (Ta) and brightness temperature (Tb) spectra, accounting for the different channels’ different beamwidths.

Although it is possible to model the impact of Moon phase, satellites in very stable orbits can always observe the Moon in the same phase – unlike the older NOAA satellites

18d	Francesco De Angelis	EUMETSAT	Future EUMETSAT Microwave Missions and Plans for Making Use of Lunar Observations

Francesco introduced the MWI and ICI instruments (conical scanning radiometers) which will operate on the next generation EUMETSAT Polar System (EPS-SG).

First he described the geometry of the cold space view observations for these two instruments. During a small angular section of the scan, the rotating feed horns point at a fixed dedicated reflector, which collects energy from the cold space at temperature around 2.73K. 352 and 52 samples are acquired during the cold space view for MWI and ICI, respectively, but only a portion of them is considered for the calibration.

Occasionally the presence of the Moon can contaminate the cold counts degrading the calibration. Possible contaminations by the Moon are first detected using an angle threshold and, then may be corrected. The algorithm by Mo and Kigawa 2007 has been analysed. This method has been already used operationally for several microwave sounders but cannot be directly applicable for a conical scanning radiometer. This because the antenna pattern gain in the space view reflector reference frame varies along the angular section dedicated to the space view observations. The Mo and Kigawa 2007 method has been customized to be suitable for conical scanning radiometers. Advantages and disadvantages of this customized method have been presented and discussed.

Q: How to select Space Views from 352/52 available for MWI/ICI?
- Only part of the space view is free from boundary effects

Comment: Need to be very careful about model parameters - especially solar angle subtended by Moon – might be necessary to adjust post-launch

Comment by Tiger Yang: The model planned for the EPS-SG algorithms does not account for the phase lag between full moon and maximum brightness temperature. This should be addressed.

18e	Laura Le Barbier	CNES	Moon study for IASI instruments inter-comparisons and absolute calibration

Further activities on lunar acquisitions using IASI will be undertaken by CNES next year. The presentation by Laura is about the first part of the activities.

Only 5 external calibrations dedicated to Moon acquisitions in 2019 between IASI-B & C – to minimise outages

IASI imager (IIS) used to check alignment of Moon wrt IASI FoV – imperfect alignments result in problematic interferograms
Moon has a smooth radiance spectral ==> can average several wavelengths to minimise noise
A model for moon radiances in the TIR domain was developed by NOVELTIS for CNES.
CNES analysed sensitivity of model to different factors, based on comparisons with IASI observations.
Highlight issue with high “geolocation” uncertainty for analysis of Moon observations

Q: IASI pixel is larger than the Moon – so no saturation – so what impact of PSF on BT?
- Uncertainty ~2K based on analysis of IASI observations and model

Q: Spectral features in model or observations?
- None detected in observations – hence co-averaging multiple channels

Q: Why so few samples?
- Looking for simultaneous observations from IASI-B and –C
- Planned for End Of Life for IASI-A? Still difficult to coordinate timing with IASI-B and –C

Q:What is the lowest wavelength covered by model?
- Focus on IASI spectral band

Q: Will CNES share model?
- Planning to publish in June 2021

<table>
<tr><td colspan="4">Q: Planning Moon acquisitions for IASI-NG?
Yes - Depending on outcome of ongoing studies</td></tr>
<tr><td>18f</td><td>Flavio Iturbide-Sanchez</td><td>NOAA</td><td>Potential lunar cal/val activities for next-generation GEO IR sounder</td></tr>
<tr><td colspan="4">Flavio gave an overview of current and planned geostationary hyperspectral IR sounders, including the potential NOAA GEO-HyIRS and potential of lunar observations to support Cal/Val

Comment: importance of CNES’ model development work
Comment: Would be interesting to know CMA’s experience with the lunar observations – particularly from FY-4/GIIRS
R.LCWS.2020.18f.1: CMA is invited to share in upcoming GSICS and/or Lunar Calibration meetings its experience on the use of lunar observations acquired by their IR sounders.</td></tr>
<tr><td>18g</td><td colspan="2">All participants</td><td>Discussion</td></tr>
<tr><td colspan="4">Topics for further cooperation:
Algorithms for geolocation, antenna pattern / FOV characterisation and
Radiance Modelling – initially full-disc
Inter-comparisons of algorithms, observations and models could be coordinated through GSICS, following the example of the reflected solar band.

Community should promote the use of lunar observations for MW and IR instruments, based on encouraging initial results presented here.
R.LCWS.2020.18g.1 : the Microwave + Infrared group is encouraged to pursue current effort and report within the context of GSICS regular meetings.
R.LCWS.2020.18g.2 : Microwave + Infrared group to liaise with CMA to foster collaborations.
A.LCWS.2020.18g.1: UMD (Hu Tiger Yang) to coordinate with EUMETSAT (Vinia Mattioli) to draft a note outlining possible further collaborations on microwave and thermal infrared lunar calibration activities.</td></tr>
</table>

19/11 Item	Mission monitoring using Lunar Calibration / Alternative usage of lunar imagery Chair: Sebastien Wagner		
19	**Sebastien Wagner**	**EUMETSAT**	**Introduction to the session and discussion**

Attendees: - **Names in bold attended this session.** Other names attended previous sessions:

Ali Mousivand (EUMETSAT)
Alessandro Burini (EUMETSAT)
An Lingping (XIOPM)
Arata Okuyama (JMA)
Berit Ahlers (ESA-ESTEC)
Bertrand Fougnie (EUMETSAT)
Chris (?)
Constantine Lukashin (NASA)
Constanze Seibert (University of Hamburg)
Dave Smith (RAL)
David (?)
Emma Woolliams (NPL)
Erin Lynch (?)
Fangfang Yu (NOAA)
Flavio Iturbide-Sanchez (NOAA)
Francesco De Angelis (EUMETSAT)
Frank Borde (?)
Fred Wu (NOAA)
Greg Kopp (UCAR)
Haifeng Qian (NOAA)
Hideaki Tanaka (JMA)
Hirokazu Yamamoto (AIST / GSJ)
Hugh Kieffer (Celestial Reasonings)
Hu Tiger Yang (UMD)
Hyelim Yoo (NOAA)
Imke Krizek (EUMETSAT)
ISRO Pradeep Thapliyal (ISRO)
Johannes Frerick (ESA)
John Woodward (NIST)
Kazuki Kodera (JMA)
Kurihara Junichi (Hokkaido University)
Kevin Turpie (UMBC/NASA)
Lawrence Ong (NASA)
Laura Le Barbier (CNES)
Maciej Neneman (ESA)
Marc Bouvet (ESA)
Marcel Dobber (EUMETSAT)
Mario Papa (University of Rome Sapienza)
Mario Montopoli (CNR)
Martin Burgdorf (Uni Hamburg)
Masataka Imai (AIST)
Matthew Kowalewski (NASA)
Matthijs Krijger (ESS)
Mireye Etxaluze (RAL)
Morven Sinclair (NPL)
Nicolas Lamquin (ACRI)
Pepe Philipps (EUMETSAT)
Rakshith Shanbhag (EUMETSAT/TPZ)
Roberto Colombo (University of Milano Bicocca)
Roberto Bonsignori (EUMETSAT)
Robin Ekelund (EUMETSAT)
Sarah Taylor (NPL)
Sebastien Wagner (EUMETSAT)

Stefan Adriaensen (VITO)
Stephen Maxwell (NIST)
Steven Brown (NIST)
Steven Miller (CSU)
Tae-Hyeong Oh (KMA)
Minju Gu (KMA)
Taeyoung Choi (NOAA)
Taichiro Hashiguchi (RESTEC, Japan)
Thierry Marbach (EUMETSAT)
Thomas Müller (MPE)
Tim Hewison (EUMETSAT)
Tom Stone (USGS)
Toru Kouyama (AIST)
Vincent Debaeker (EUMETSAT)
Vinia Mattioli (EUMETSAT)
Woordward (?)
Xiaoxiong Xiong (NASA)
Xu Geng (NASA)
Yu Can (XIOPM)
Yuan Li (CMA)
Yu Zhang (?)
Zhipeng Ben Wang (NOAA)

19a	**Arata Okuyama**	**JMA**	**Lunar Calibration and Himawari-8 AHI monitoring**

An update on the status of Himawari-8 and 9 was presented.
Schedule to move H9 to prime satellite is being discussed at JMA

A correction for Bands 4,5 and 6 is applied to the lunar data to remove phase dependency.
Monitoring methods include SD, RTM, ray-matching and DCC.

More than 100 images can be acquired for moon chasing configuration. Used for RVS monitoring.
Non-uniformity of space count can affect constant term of calibration equation – can include N-S variation

- This can include stray-light - esp in B01 and B02

The discrepancy in the DS may come from the fact there is no DS look before and after lunar observation.
Need to account for Out of Field Anomalous Response (OFAR) - ghosting – in B01-B03

Q: Looks like a spectacular dataset to improve modelling of lunar irradiance. Is it available?

- Some AHI data have been provided as part of the GSICS Lunar Observation Dataset (GLOD).

Q: What magnitude of RVS is expected? E.g. based on ground characterisation

- Good question – Solar Diffusor is viewed 2x per month, but includes seasonal variation, which may be explained by RVS ~0.5% - is this achievable with GIRO? Believed to be more stable in Moon-chasing events
- Fangfang commented that although these issues are very small per pixel, they are resolving in lunar irradiance – also, the stray light is not always present – and is not corrected in ABI data NOAA provided to Hugh

Q: Which is the solar diffusor in Slide 6? Does it have a different trend?

- Yes in B02 and B03, but trends still within 0.1%/yr

Q: Is operational calibration still based on solar diffusor?

- Yes – calibration coefficients stored in L1 data and updated annually
- Would be a good example for a GSICS correction – e.g. in a blended approach
- Arata explained that DCC and Ray-matching would be first candidates for such an approach, as they are already implemented

19b	**Tae-Hyeong Oh**	**KMA**	**GK2A AMI Mission Monitoring Using Lunar Calibration**

Tae-Hyeong introduced Korea's geostationary satellite, KOMSAT-2A, which carries the AMI imager, similar to ABI and AHI
KMA have implemented vicarious calibration using ocean, desert, water cloud and lunar calibration to monitor the solar band channels
He explained that some Moon observations are contaminated by Earth straylight
Oversampling factors are estimated using the method proposed by NOAA in 2nd lunar calibration workshop. Value is about 1.005

The analysis of the results over >1yr shows seasonal variations up to ~10%, depending on channel

- Related to phase angle dependence – not yet corrected?
- But also seen in GSICS DCC and Ray-matching methods

Q: Impact of Moon shape fitting?

- Not used to reject contamination from cases near the Earth limb
- Is it necessary? Could be instrument-dependent

Comment from Hugh:

- Could GEO operators agree a consensus on how to characterise and correct for scan angle dependence?

Q: Did you also plot how the background varies in time? Could this influence seasonality in Slide 13?

- Will check!

Q: Residuals in B03 are unusually large and should be investigated
Q: Has the phase angle dependence been corrected in the time series – e.g. in slide 13?

- Could contribute to observed seasonal variation – as could the solar diffusor
- Not yet (would be helpful to isolate the different factors)

19c	**All participants**		**Discussion**

Deferred to 19g

19d	**Jason Choi**	**NOAA**	**NOAA-20 VIIRS Initial On-orbit BBR and MTF Estimations Using the Scheduled Lunar Images**

Jason explained how VIIRS can view the Moon in the regularly in the space view on a monthly basis (except the summer months) - and also in dedicated manoeuvres
Band-to-Band Registration is estimated by comparing the Moon's centroid relative to a reference band (M1).
Then MTF is analysed, based on sharp edge over all lines cutting the Moon disc
BBR very stable in time but there are some slight differences band-to-band causing potential artefacts in L2 products making use of band registrations (NDVI for instance).

Seb noted that this activity was identified at previous LCWs, and that NOAA had hoped to make more progress on this topic also for GEO imagers.

Q: Was the BBR analysis also done for S-NPP/VIIRS? This had very strong light leaks which caused spatial effects.
See paper by Zhipeng Wang *et al.* (2015, IEEE TGRS, "Update of VIIRS On-Orbit Spatial Parameters Characterized With the Moon").

Q: any indication that VIIRS MTF changes with time in a systematic way & why?

- Focal length changes – e.g. due to deformation in optics (e.g. thermal?)
- But mainly during launch process – due to mechanical stresses
- Most sensors don't change too much during mission life
- BBR is also sensitive to similar factors
- (Kevin Turpie): S-NPP/VIIRS light leak sensitive to changing contamination levels on optics

19e	Constantine Lukashin	NASA	ARCSTONE: Calibration of Lunar Spectral Reflectance from Space

Costy introduced the ARCSTONE project, which is coordinated with Mauna Loa LUSI and Air-LUSI teams.
ARCSTONE project would allow the calibration of fleets of CubeSat satellites to be accurately calibrated as soon as they would regularly view the moon.
Goal Spectral range of ARCSTONE = [350nm, 2300nm] at 4nm resolution. (min 380-900@8nm)
One single pixel FOV of about 0.7 degrees (no scanning)
Targeting combined uncertainty on lunar spectral irradiance <0.5% (k=1) <1.0% threshold at 70° phase
Stability <0.1%/decade (0.15% threshold)
On CubeSat, but well stabilised with 2 star trackers

Moon observed at all phases (requirements established for a phase at 75 degrees)

Lunar observation sequence every 12 hours.

- Built and characterised two sensors – UVVNIR + SWIR
- Now working on integrated MCT detector covering 350-2300nm - now fabricated – SNR>100

Mission lifetime: 1 year (mimimum), goal = 3 years

Due to availability of newer detector systems, a redesign of the instrument was done in the last 2 years to take on-board latest available technology.

Q: Technical design details

Q: Earliest launch?

- 2022/23 - still not

Q: Solar irradiance observed?

- TSIS is used or successor (TSIS-II). Those instruments are part of a long-term NASA program. So the mission continuity should not be an issue.

19f	Stephen Maxwell	NIST	Some update on the Mauna Loa LUSI project

Context: project fits into the development of an accurate lunar irradiance reference model.
Based on same measurement principle as air-LUSI: refractor telescope + image + polarisation scramblers
Expect uncertainty ~0.5%, but Mt Hopkins too instable
Mauna Loa site = similar conditions at Canarian Islands (Pico Teide).

Q: potential cooperation with ESA?

- Already in touch – through Air-LUSI + ARCSTONE
- Aiming to establish absolute lunar irradiance scale

Q: Will only new model come out or also data?

- Aiming to produce and share TOA radiances

Q: COVID issues?

- Planned to deploy in March 2021 for 6 months – maybe delayed 1 month

19g	All participants	Discussion and concluding remarks

Sebastien reviewed the topics discussed this week:

- Lunar model development
- Measurement campaigns and future dedicated missions
- Mission monitoring – for the RSB
- Microwave + TIR lunar imagery applications – including calibration monitoring
- MTF post-launch characterisation

- **A.LCWS.2020.19g.1**: S. Wagner (EUMETSAT) to circulate the list of topics to be addressed by the Lunar Calibration Community and to solicit interest from its members.

- **R.LCWS.2020.19d.1:** NOAA is encouraged to pursue its initiative on comparing approaches for post-launch assessment of MTF using lunar imagery. This initiative, in collaboration with other agencies would lead to the definition of best practices for MTF assessment using the Moon.

Mission Monitoring

- How to calculate observed lunar irradiance:
    - Pixel solid angle/oversampling factors
    - Integration of irradiance – definition of cutoff radiance + sensitivity to cosmic rays
        - Costy suggested using PSFs to define annulus (planned for ARCSTONE)
        - Kevin Turpie pointed out that PSFs are difficult to characterise on-orbit
        - Typically characterised PSFs don't extend more than a couple of pixels – need more
        - Tom: PSF also characterises solid angle, needed for oversampling factor
        - Hugh: need to examine integrated energy curves to define annulus down to ppm
        - Need to be aware of stray-light – esp for GEO
        - How to remove background – especially when it varies – e.g. RVS?
        - Need to ensure dark side of Moon (lit by Earthshine) is included – small impact
        - OLI experience – very low stray light levels - Removing stars has little impact
        - Uncertainty estimates need for each instrument's observations
        -
    - - e.g. define circle + annulus to encompass lunar energy and estimate dark level
    - Avoid including results based on lunar calibration

Recurring theme: defining standard terminology

- Need alignment
- Including detector terminology
- And uncertainties
- To discuss by email?

Lunar Models

- Solar irradiance spectrum
    - Model must be specified!
    - Solar variability becoming significant as algorithms & instruments improve
    - Need a consensus model – which could evolve in time
- Benefit of including GEO observations in developing/validating lunar models?
    - e.g. ROLO is limited to observations within 8° of Moon centre
    - Need to ensure full range of libration space observed from GEO orbit is included
- Increased modularity in algorithm – in calc "reference" lunar signal
    -
- Model version traceability and naming convention
    - e.g. as Included in GIRO
- Inclusion of polarisation
    - Need to specify polarisation of observations used to derive model
    - LIME includes specification of degree of linear polarisation, but ongoing development
    - Tom: Impact on lunar irradiance depends on polarisation sensitivity of instrument
    - Kevin: modern grating spectrometers have a DOLP 2-4% - critical for ocean colour
    - Tom: TRUTHS will also have polarisation sensitivity – Air-LUSI not
    - Fred: Some instruments can have much higher DOLP
    - Also beneficial for polarimeters!
    - Moon's DOL Polarisation varies with phase angle (zero at 24°) and wavelength
- Model uncertainties
    - Earth-shine variation effect on lunar irradiance as a function of phase angle
- Benchmarking

- Cover the space of observables
  - e.g. is GEO worst case? High inclination?
  - Potential benefit of stepping through each variable of observation space – to isolate the dependencies
  - Not to include SRFs? But need to account for fact that some models have different spectral resolution
  - Could also define an effective wavelength for most channels (not panchromatic)
  -
- Allow systematic model assessment + traceability to a “reference” model
- Needs to be accompanied by efforts to validate the reference model against accurate observations – even at a few points

* Could extend model fitting based on ANN
  - Matthijs, Hugh and Costy are interested in this
* Shift to Reflectance model

Reviewed list of actions and Recommendations

All accepted as written, except:

- Letter of recommendation to NASA to include MLO-LUSI + ARCSTONE (in addition to **A.LCWS.2020.16f.2** for Air-LUSI)

- **A.LCWS.2020.19g.2**: EUMETSAT (S. Wagner) to liaise with the participants to the Lunar Calibration Workshop to ensure a follow-on on the actions / recommendations

- **A.LCWS.2020.19g.3**: EUMETSAT (S. Wagner) to propose letter of recommendation by GSICS to NASA to highlight the benefits of ARCSTONE project for GSICS activities and its members.