Progress of the Metop-C AMSU-A Lunar Contamination Correction Algorithm at NOAA/STAR

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Abstract

The European MetOp-C satellite, launched on November 7th, 2018, carries the last one of the Advanced Microwave Sounding Unit (AMSU-A) instruments onboard a series of Polar Orbiting Environmental Satellites (POES), including NOAA-15, 16, 17, 18, 19, MetOp-A, B, C. NOAA/STAR undertakes the major cal/val work for the US instruments onboard MetOp-C, including AMSU-A. The Lunar Contamination Correction is one of the most challenging tasks in the MetOp-C AMSU-A cal/val activities.

Originally, the AMSU-A Lunar Contamination Correction algorithm was developed by Kigawa and Mo (2002), and was implemented in the NOAA AMSU-A L1-B operation system. As a calibration effort for the MetOp-C AMSU-A, the lunar contamination correction algorithm has been revisited and advanced. In this presentation, we will comprehensively review the Lunar Contamination Correction process, the algorithm improvement, and the pre-launch and post launch coefficients estimation. Emphasis will be put on the derivation of the Lunar coefficients in pre-launch phase based on antenna pattern data and in post-launch phase based on time series of deep space cold counts when lunar contamination happens. Corresponding validation and comparison of the Lunar Contamination Correction results between those based on the pre-launch coefficients and the post-launch coefficients demonstarte the big improvement from the post-launch calibration work.

Lunar Contamination in AMSU-A

AMSU-A is a cross-track, step-scan instrument. In every 8 second period, it executes a cross-track scan with 30 Earth Field-of-Views (FOVs) within ±48 degree from the nadir location, one cold space view calibration FOV, and one warm blackbody calibration FOV.

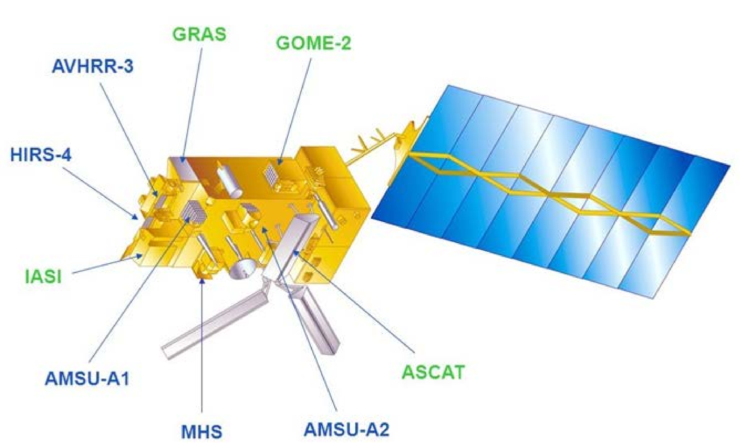

Figure 1. A diagram of MetOp satellites, one of the satellite series that the AMSU-A instrument is onboard.

AMSU-A is a self-calibrating total power radiometer. The on-board calibration is achieved by viewing the cold space and an internal blackbody target. This provides a two point calibration reference.

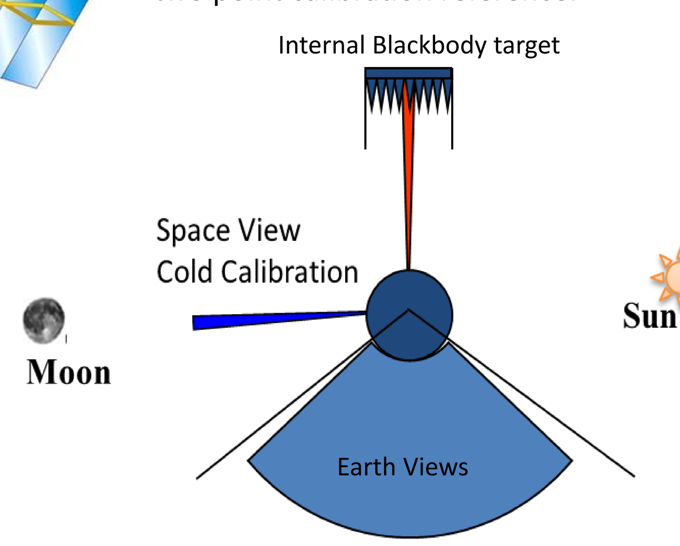

Figure 2. A diagram of the AMSU-A scan process.

- Lunar contamination occurs whenever the Moon moves into the space view FOV.
- It happens several times a year, affecting several successive orbits in each time.
- The impact could be greater than 1K in some AMSU-A channels because that the lunar surface brightness temperature is 120 ~ 380 K, much higher than the deep space background temperature of 2.73 K.

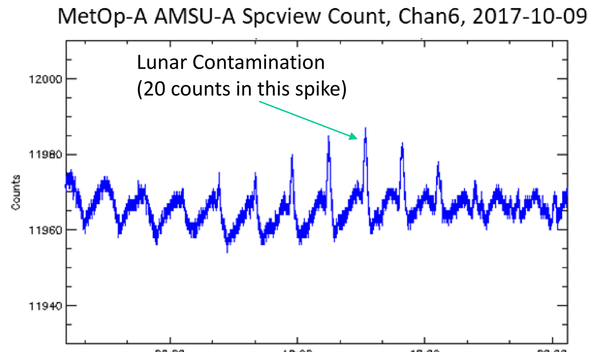

Figure 3. Time series of spaceview counts of MetOp-A AMSU-A channel 6 on Oct 09, 2017.

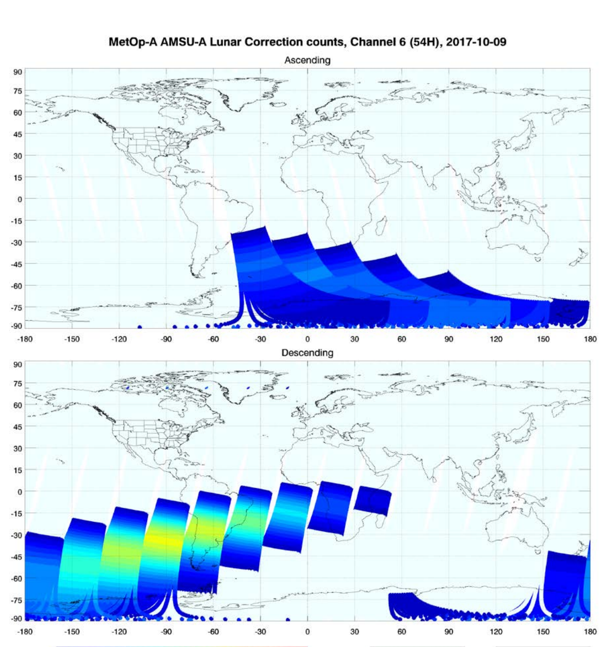

Figure 4. Lunar Contamination area of MetOp-A AMSU-A Channel 6 on Oct 09, 2017

Lunar Contamination Correction algorithm

Space view count lunar contamination correction:

$$\Delta C_c = \left(\frac{C_W - C_C}{T_W - (T_C + \Delta T_c)}\right)\Delta T_c \qquad (1.)$$

Cw: blackbody count;
Tw: blackbody temperature;
Tc: deep space background temperature;
Cc: observed space view counts, including lunar contamination;
ΔT_c: increased cold space temperature caused by lunar contamination;
(Kigawa and Mo, 2002; Mo and Kigawa, 2007)

$$\Delta T_c = G(\alpha,\delta)\beta T_{moon} r \qquad (2.)$$

ΔT_c: increased cold space temperature;
G(α,δ): antenna pattern power function;
β: area ratio of lunar disk to FOV convolved with the antenna pattern powers;
Tmoon: effective lunar surface brightness temperature
r: distance ratio = $(60.3 * 6378/d)^2$, where d is the distance (in km) between the satellite and Moon. The range of r is from 0.94 to 1.06.

$$\beta = \frac{\pi(0.259)^2}{\iint G(\alpha,\delta)\,d\delta\,d\alpha}$$

β: area ratio of lunar disk to FOV convolved with the antenna pattern powers. The 0.259 is the half cone angle that the lunar disk subtends at the satellite at its normal distance;

$$G(\alpha,\delta) = e^{-\frac{(\alpha-\alpha_0)^2}{2\alpha_s^2}} e^{-\frac{(\delta-\delta_0)^2}{2\delta_s^2}} \qquad (3.)$$

α: lunar azimuth angle;
α_0: FOV center azimuth angle;
α_s: azimuth size factor;
δ: lunar elevation angle;
δ_0: FOV center elevation angle;
δ_s: elevation size factor;

$$T_{moon} = 95.21 + 104.63(1 - \cos\theta) + 11.62(1 + \cos 2\theta) \qquad (5.)$$

θ: Sun-Moon separation angle.

Red: constant coefficients to be put into CPIDS.

Blue: instantaneous inputs decided by satellite, moon, sun positions.

AMSU-A Lunar Contamination Correction Tasks and Challenge

- STAR is responsible for delivery of the MetOp-C calibration coefficients (CPIDS) set to OSPO. The Lunar Contamination Coefficients are the most challenging part.
- The Lunar Coefficients can be derived from antenna pattern data in pre-launch phase, and need to be refined based on satellite data in post-launch phase.
- We need to build an in-house Lunar Contamination Correction software package to validate the Lunar Coefficients based on antenna pattern data in pre-launch phase, and to generate necessary information based on satellite data for the post-launch refinement of the Lunar Coefficients.
- The most difficult part of the Lunar package is the astrometry calculation to get the relative positions of sun and moon from the cold space view vector.

Geometry in astrometry calculation

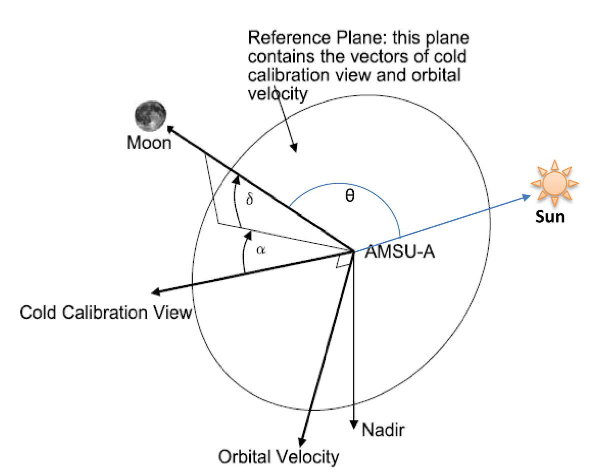

Figure 5. Geometry of the lunar azimuth and elevation angles. From Mo and Kigawa, 2007, modified

In order to get d (moon distance), α (lunar azimuth angle), δ (lunar elevation angle) and θ (Sun-moon separation angle), we need the Nadir vector (or orbital velocity), cold view vector, moon vector and sun vector.

In the operational system, these vectors are calculated based on no-publicly accessible navigation package.

Since we only have L1B data (α, δ available, but not d and θ), we built an in-house Lunar Contamination Correction package referring Kigawa and Mo's method, using Simplified Perturbations Models (SGP4) for satellite position and using Naval Observatory Vector Astrometry Software (NOVAS) for Sun and Moon positions.

In-house Lunar Contamination Correction Package

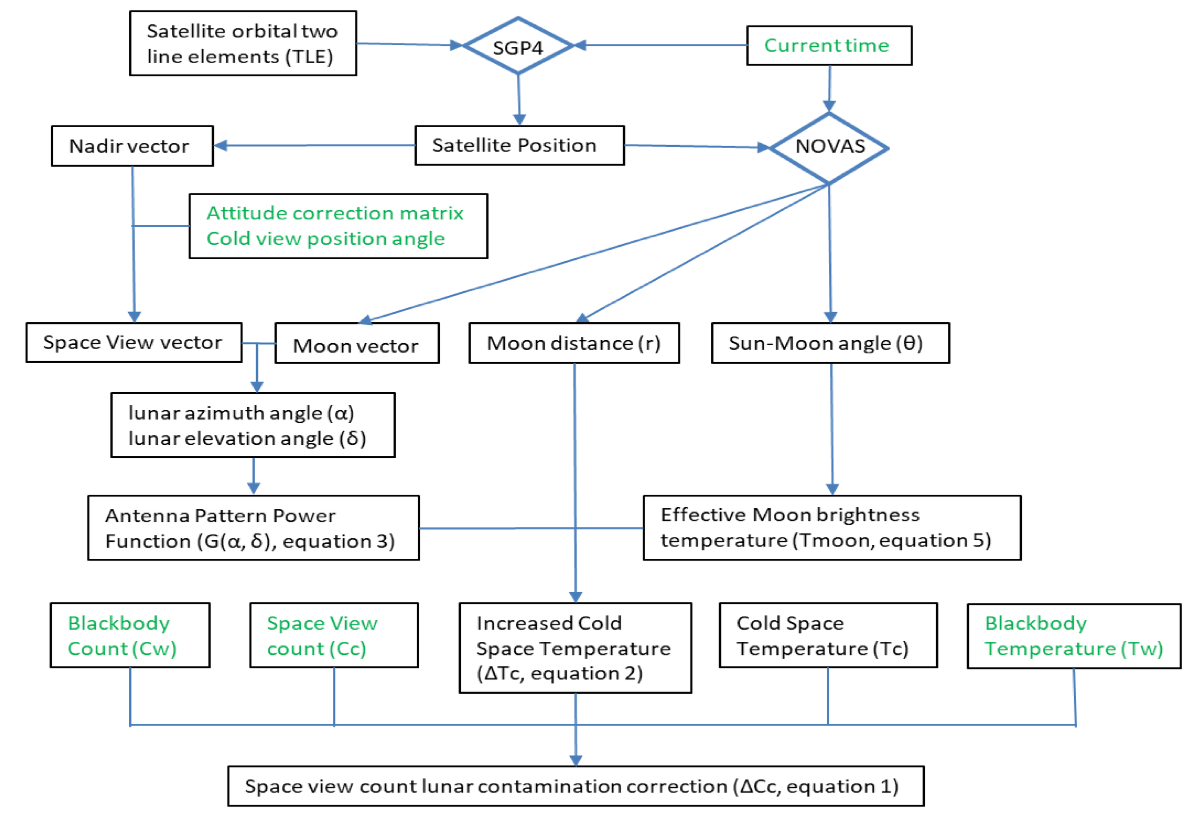

Figure 6. A flowchart of the In-house Lunar Contamination Correction software. Green: input from L1B data

The in-house Lunar Contamination Correction package was constructed. The software works well in removing lunar contamination with operational Lunar Coefficients.

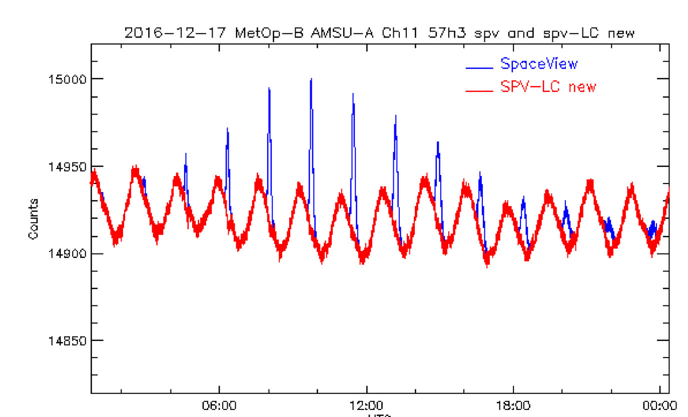

Figure 7. Time series of spaceview counts of MetOp-B AMSU-A channel 11 on Dec 17, 2016, before (blue) and after (red) Lunar Correction with in-house software.

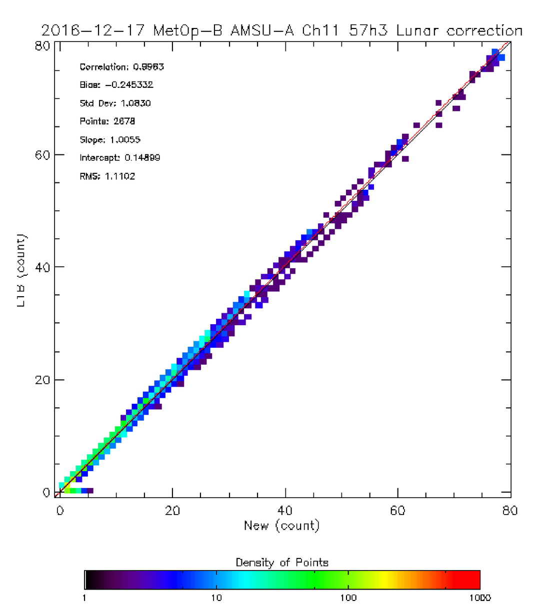

Figure 8. Scatter plot between the Lunar Corrections from operational system and in-house software based on the data of MetOp-B AMSU-A channel 11 on Dec 17, 2016

The Lunar contamination correction result based on the in-house Lunar software with operational coefficients based on MetOp-A and MetOp-B data is pretty close to the operational output in the L1B dataset.

Lunar Coefficients Estimation based on Antenna Pattern Data

In pre-launch phase, the Lunar coefficients could be estimated by fitting the high resolution antenna data with Gaussian function.

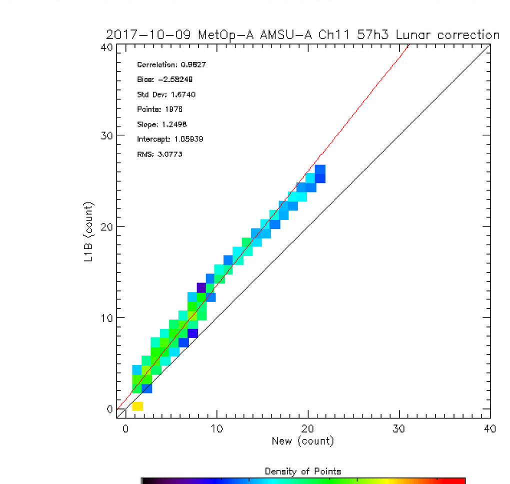

Figure 9. Scatter plot of MetOp-A AMSU-A channel 11 Lunar Corrections on Oct 9, 2017 between those from the operational system and those the in-house software with Lunar coefficients derived from antenna data.

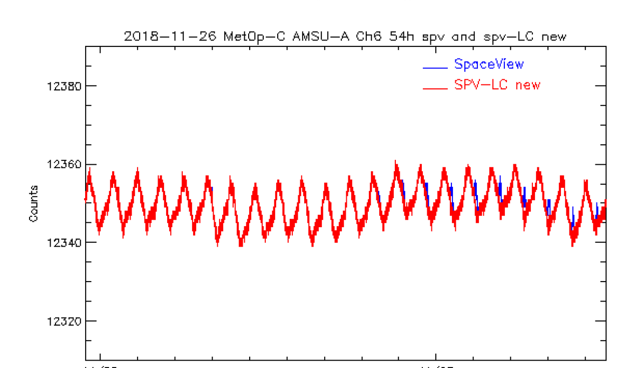

Figure 10. Time series of spaceview counts of MetOp-C AMSU-A channel 6 on Nov 26-27, 2018, before (blue) and after (red) Lunar Correction with in-house software.

Implementation: with the Lunar Coefficients based on the antenna pattern data, both the in-house and operational algorithm successfully caught the Lunar Contamination signal consistently from MetOp-C AMSU-A data in less than two weeks after the instrument was turned on.

Lunar Coefficients Estimation based on post-launch observation

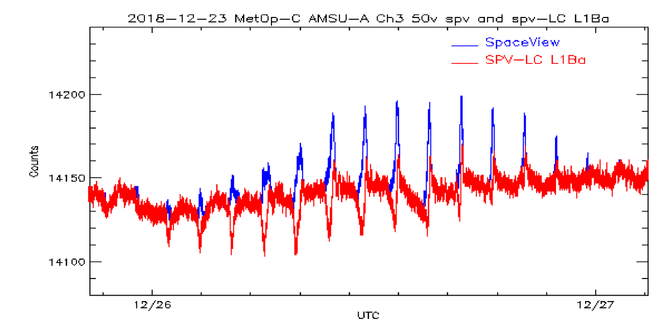

Figure 11. The time series of the MetOp-C AMSU-A Channel 3 spaceview counts before (blue) and after (red) Lunar Correction in the period around Dec 26, 2016 based on the Pre-launch Coefficients.

- Lunar Correction based on the Pre-launch coefficients can largely corrected the spaceview count, but not ideally. This is consistent with our estimation.
- After launch, we produced new version of Lunar Coefficients based on regression method with Lunar signal extracted from the spaceview counts time series in the period of December 25 – 27, 2018, the second Lunar event since the MetOp-C launch (The first Lunar event is relative small, so not being used for regression).
- We validated the post-launch coefficients with the third Lunar event around Jan 24, 2019. It appears that the Lunar correction is largely improved.

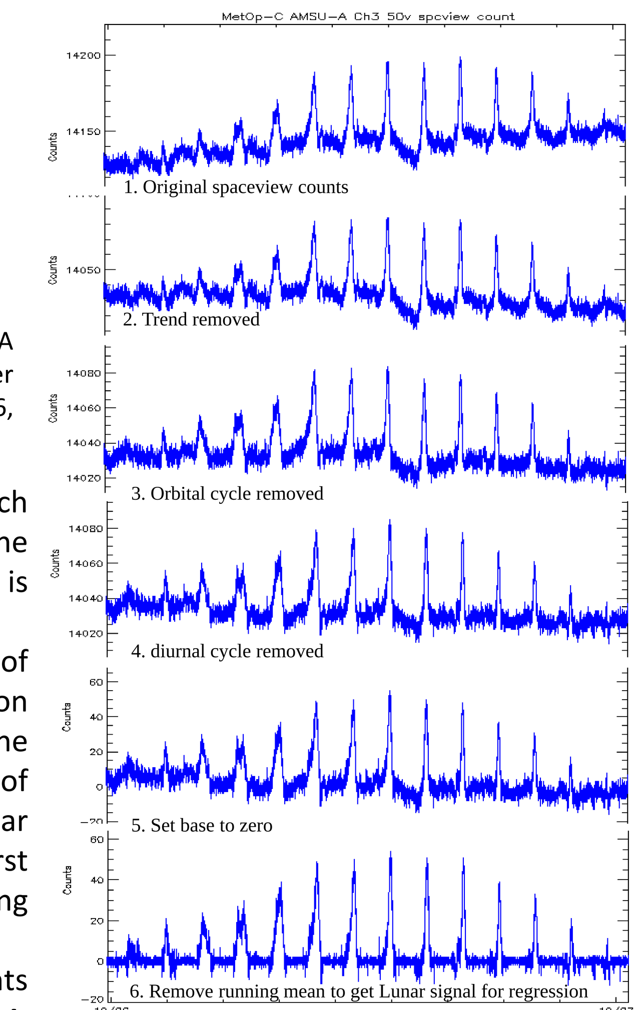

Figure 12. The step by step process to extract Lunar signal from the spaceview counts for the Lunar Coefficients regression.

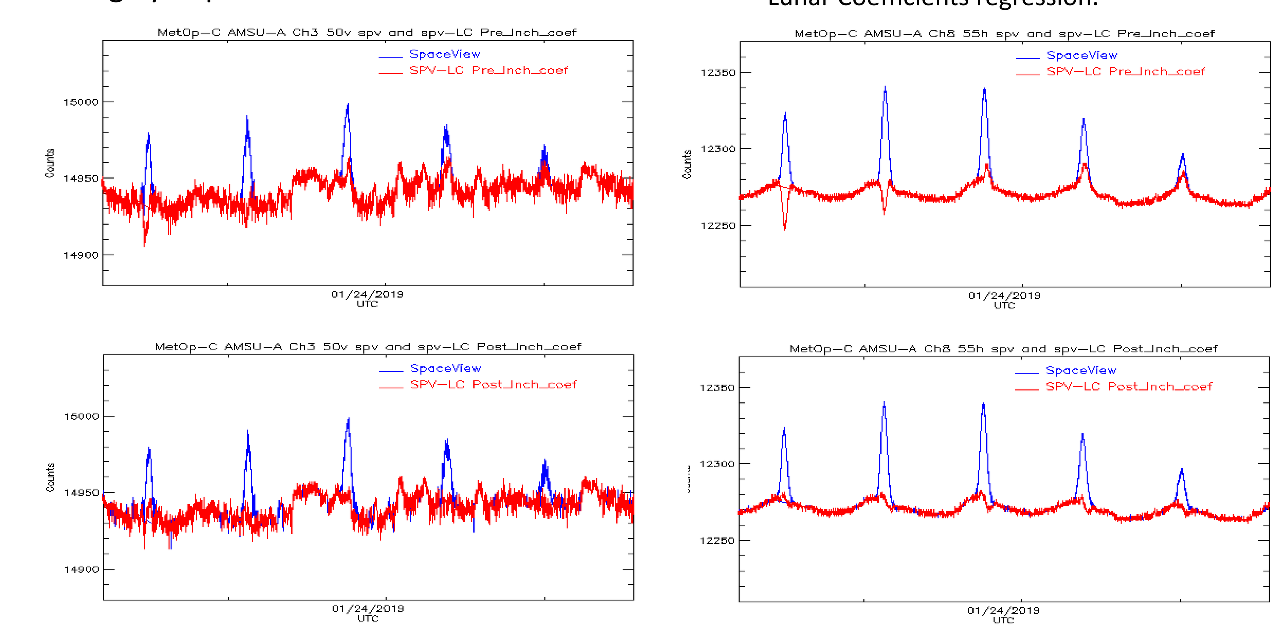

Figure 13. The time series of the MetOp-C AMSU-A spaceview counts before (blue) and after (red) Lunar Correction in the period around Jan 24, 2019. Upper: based on the Pre-launch Coefficients; Lower: based on the Post-launch Coefficients; Left: Channel 3; Right: Channel 8.

Conclusions

- As a part of MetOp-C AMSU-A Cal/Val activity, the lunar contamination correction algorithm for AMSU-A instrument has been revisited and advanced.
- The Lunar Coefficients for MetOp-C AMSU-A are derived based on antenna pattern data in pre-launch period. Lunar Contamination signal was caught and preliminarily corrected on MetOp-C AMSU-A data just after launch.
- The Lunar Coefficients are updated based on real Lunar signal extracted from post-launch spaceview counts during a Lunar event. The Lunar Correction is largely improved based on the Post-launch coefficients than that based on the Pre-launch coefficients.

References and Acknowledgement

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