Estimation of VIIRS On-Orbit TEB Response Versus Scan (RVS) and Calibration Offsets Using Pitch Maneuver Data

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- Evaluation Results for Method2021
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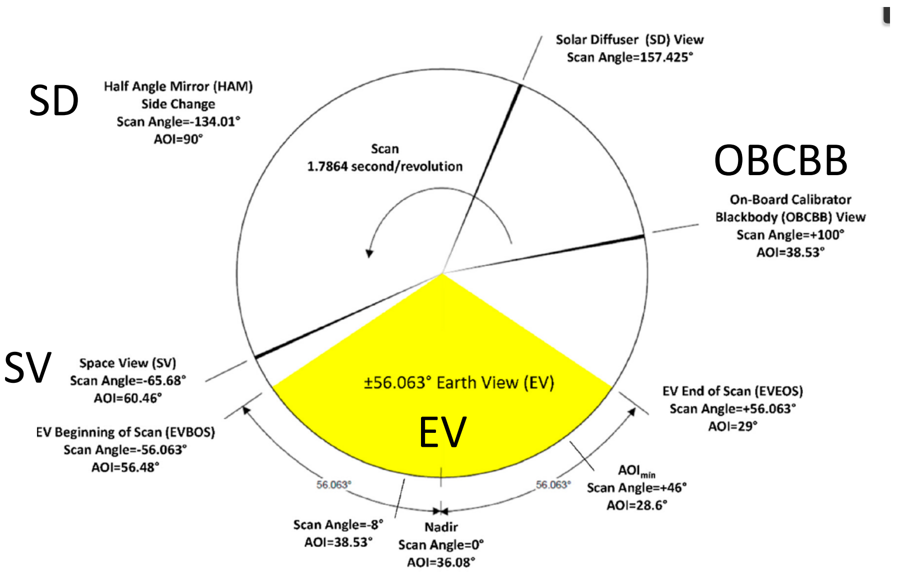
- Summary

Background

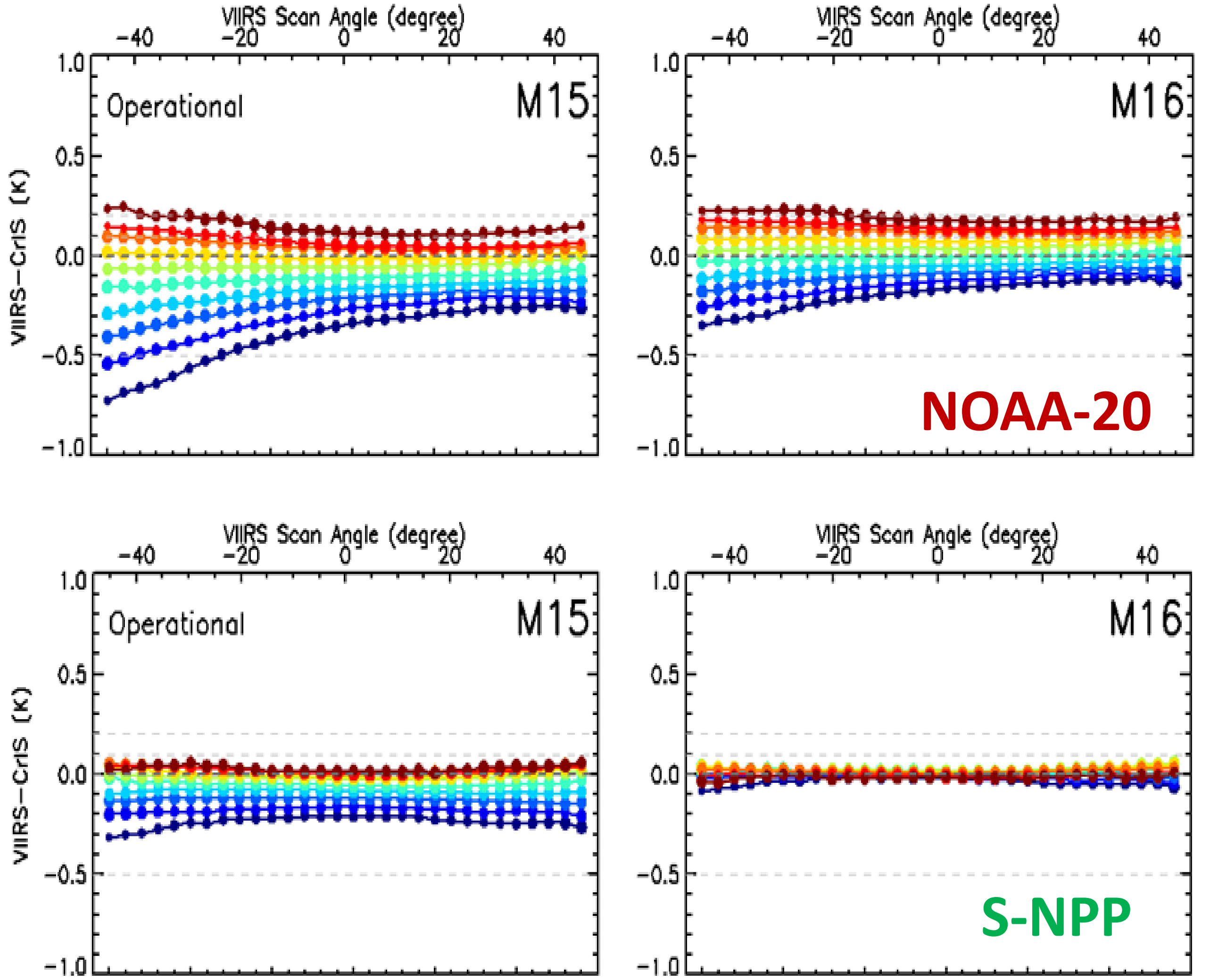
- The Visible Infrared Imaging Radiometer Suite (VIIRS) is onboard NOAA-20 and Suomi NPP (S-NPP) satellites.
  - **NOAA-20**: launched on Nov. 18, 2017 **S-NPP**: launched on Oct. 28, 2012.
- There are 7 Thermal Emissive Bands (TEB) on VIIRS:
  - MWIR: I4 and M12-M13
  - LWIR: I5 and M14-M16
- VIIRS TEBs are calibrated scan-by-scan, using Onboard Calibrator Blackbody (OBCBB), Space View (SV), and prelaunch calibration parameters.



		Center Wavelength (µm)		Ttyp (K)	NEdT Spec (K)	On-Orbit NEdT	
		NPP	N20			NPP	N20
MWIR	M12	3.697	3.700	270	0.396	0.12	0.12
	I4	3.753	3.753	270	2.5	0.40	0.42
	M13	4.067	4.070	300 (HG) 380 (LG)	0.107 0.423	0.04 -	0.04 -
LWIR	M14	8.578	8.583	270	0.091	0.06	0.05
	M15	10.729	10.703	300	0.07	0.03	0.02
	I5	11.469	11.450	210	1.5	0.40	0.42
	M16	11.845	11.869	300	0.072	0.03	0.03

Background

- NOAA-20 and S-NPP VIIRS TEB on-orbit calibration has been generally stable during nominal operations.
  - NOAA-20 TEB LWIR degradation was resolved by the March 2018 MMOG.
  - On-orbit responsivity degradations are small after the MMOG.
- However, persistent larger than expected scan angle/scene temperature dependent biases (relative to CrIS) have been observed in the NOAA-20 LWIR bands, e.g.
  - M15: up to 1 K
  - M16: up to 0.6 K
- The scan angle and scene temperature dependent biases in S-NPP are much smaller.
  - M15 exhibits some cold biases (~0.3 K), mostly constant.
- Our analyses indicate that NOAA-20 and S-NPP TEB biases during nominal operations haven't changed much over time.



March 18, 2019 (randomly selected)

Background

- VIIRS TEB calibration algorithm:

$$L_{ev} = \frac{F \cdot (c_0 + c_1 \cdot dn_{ev} + c_2 \cdot dn_{ev}{}^2) - (RVS_{ev} - RVS_{sv}) \cdot L_{mirror}}{RVS_{ev}}$$

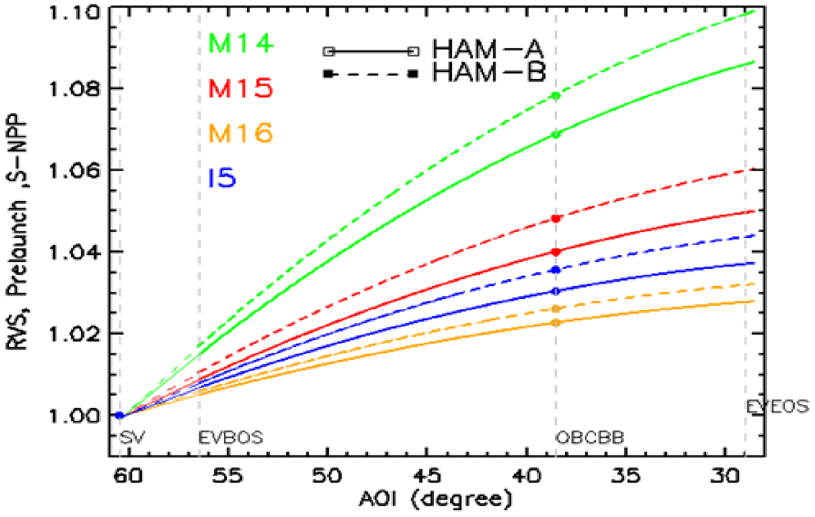
$$L_{mirror} = \frac{(1-\rho_{RTA}) \cdot L_{RTA} - L_{HAM}}{\rho_{RTA}}$$

$$F = \frac{RVS_{bb} \cdot L_{bb\_emitted+reflected} + (RVS_{bb} - RVS_{sv}) \cdot L_{mirror}}{(c_0 + c_1 \cdot dn_{bb} + c_2 \cdot dn_{bb}{}^2)}$$

F -- On-orbit degradation factor (F-factor)

c_0, c_1, c_2: C-Coefficients

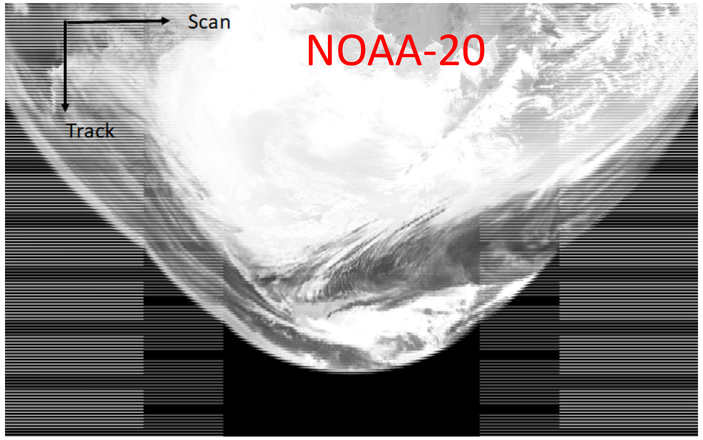
S-NPP (LWIR)

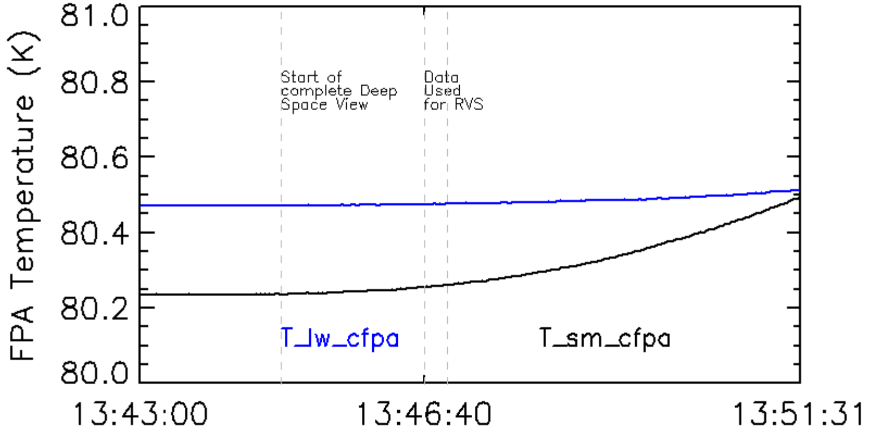


- Response Versus Scan (RVS) is used to characterize the variation of instrument reflectance of source radiance with scan angles.
  - Represented as functions of angle of incidence (AOI) on the half-angle mirror (HAM).
  - LWIR: up to 10%   MWIR: ~0.5% or lower.
  - The only calibration parameter that varies with scan angles.
- Prelaunch RVS have been used in the operational processing to date, for both NOAA-20 and S-NPP.
  - 2nd order polynomials are used to model/predict RVS variations at SV, EV, OBCBB AOIs.
  - RVS at EV and BB view AOIs are normalized to SV (RVS_{sv}=1).

VIIRS On-Orbit Pitch Maneuver Data

- On-orbit spacecraft pitch maneuver was performed during the Post-Launch Test (PLT) period for verifying prelaunch TEB RVS *(Wu et al. 2012;2017;2018, Wang et al. 2019)* and for estimating DNB dark offsets.
  - NOAA-20: Jan 31, 2018 13:42 – 13:48 UTC
  - S-NPP: Feb 20, 2012 18:26-18:27 UTC
  - It provides complete view of deep space.
- Estimation VIIRS TEB RVS using pitch maneuver data:
  - Using scans away from Earth influence, when cold FPA temperatures are close to the nominal operating temperatures.
  - SV & BB DNs in these scans are in good quality, comparable to nominal operations.
- Pitch maneuver data are also potentially useful for improving TEB calibration offsets (c0).
  - Observing deep space, EV signals are very low.
  - Ranges of SV DN subtracted EV DNs:
    - LWIR: 70 – 80 counts
    - MWIR: 5 – 20 counts





This study presents an improved method for estimating VIIRS TEB RVS and calibration offset (c0) using pitch maneuver data, to mitigate the scan angle and scene temperature dependent biases

Method2019 for Estimating On-Orbit TEB RVS

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- Method2019 estimates TEB EV RVS using pitch maneuver data *(Wang et al. 2019)*
  - Using TEB on-orbit calibration equation directly (different from *Wu et al. 2012;2017;2018*)
  - RVSsv is set to unity (RVSsv=1)
  - Prelaunch C-coefficients and RVS_{BB} are used as first guess.

Eq. 1-1: $$L_{ev} = \frac{F \cdot \left(c_0 + c_1 \cdot dn_{ev} + c_2 \cdot dn_{ev}{}^2\right) - (RVS_{ev} - RVS_{sv}) \cdot L_{mirror}}{RVS_{ev}}$$

Eq. 1-2: $$F \cdot \left(c_0 + c_1 \cdot dn_{ev} + c_2 \cdot dn_{ev}{}^2\right) = (RVS_{ev} - 1) \cdot L_{mirror}$$

L_{ev}=0 during pitch maneuver

Eq. 1-3: $$RVS_{ev} = 1 + \frac{F \cdot \left(c_0 + c_1 \cdot dn_{ev} + c_2 \cdot dn_{ev}{}^2\right)}{L_{mirror}}$$

Insensitive to errors in F

Eq. 1-4: $$RVS_{ev} = a_0 + a_1 AOI + \ a_2 AOI^2$$

2nd order polynomial fit is used to smooth the EV RVS only.

- "Limitations":
  - Derived EV RVS is affected by errors in prelaunch calibration offsets (c0).
  - As a result, the 2nd order polynomials fitted by EV RVS may not converge to unity at SV AOI.

W. Wang, C. Cao, and S. Blonski, "A New Method for Characterizing NOAA-20/S-NPP VIIRS Thermal Emissive Bands Response Versus Scan Using On-Orbit Pitch Maneuver Data," Remote Sensing, vol. 11, no. 13, p. 1624, 2019.

Improved Method for Estimating TEB RVS & C0 Using On-Orbit Pitch Maneuver Data (Method2021)

- Detector/HAM-side dependent raw EV RVS is estimated using Eq. 2-1.
  - Using prelaunch C-coefficients & RVS_{BB} as first guess.
  - Similar to the Method2019

Eq. 2-1: $$RVS_{ev} = 1 + \frac{F\cdot(c_0+c_1\cdot dn_{ev})}{L_{mirror}}$$

Nonlinear term is insignificant, removed

- 2^{nd} order polynomial models are fitted using raw EV RVS.
  - RVS at SV AOI is predicted using the models.
  - RVS at all AOIs are normalized by $RVS_{sv,predicted}$

Eq. 2-2 $$RVS = a_0 + a_1 AOI + a_2 AOI^2$$

Used for prediction at all AOIs

Eq. 2-3 $$RVS_{sv,predicted} = a_0 + a_1 AOI_{sv} + a_2 AOI_{sv}^2$$

- Estimate errors in prelaunch calibration offsets (c0), using the differences between the model predicted SV RVS and unity.

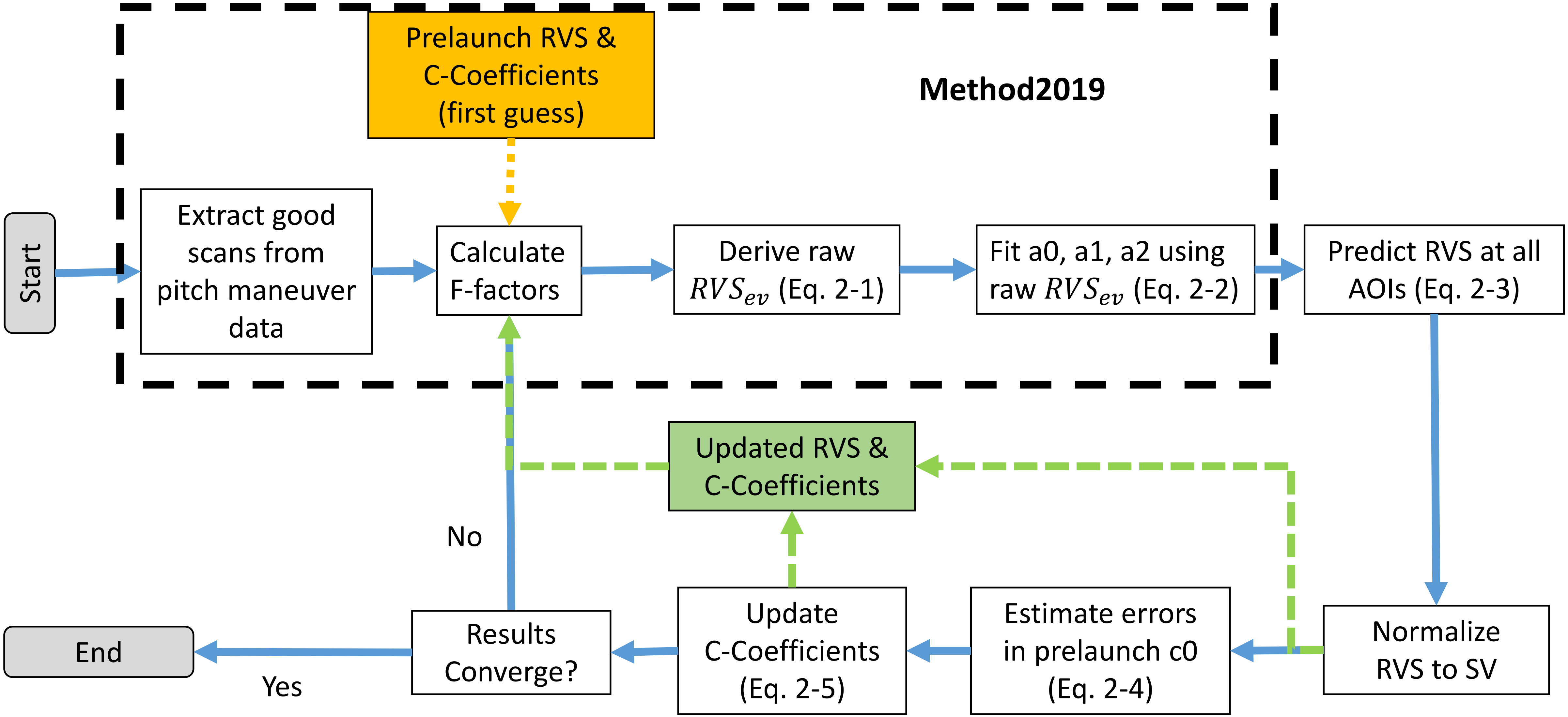
Eq. 2-4 $$c_{0,corr} = (1.0 - \mathrm{RVS}_{sv,predicted}) \cdot L_{mirror}/\mathrm{F}$$

Eq. 2-5 $$c_{0,updated} = c_{0,prelaunch} + c_{0,corr}$$

- Repeat previous steps using the updated RVS and C-coefficients, until results converge.

- The on-orbit TEB EV RVS derived by this method converge at SV.
- TEB calibration offsets are also updated.

Flowchart of the Method for Estimating TEB RVS & C0 Using On-Orbit Pitch Maneuver Data (Method2021)

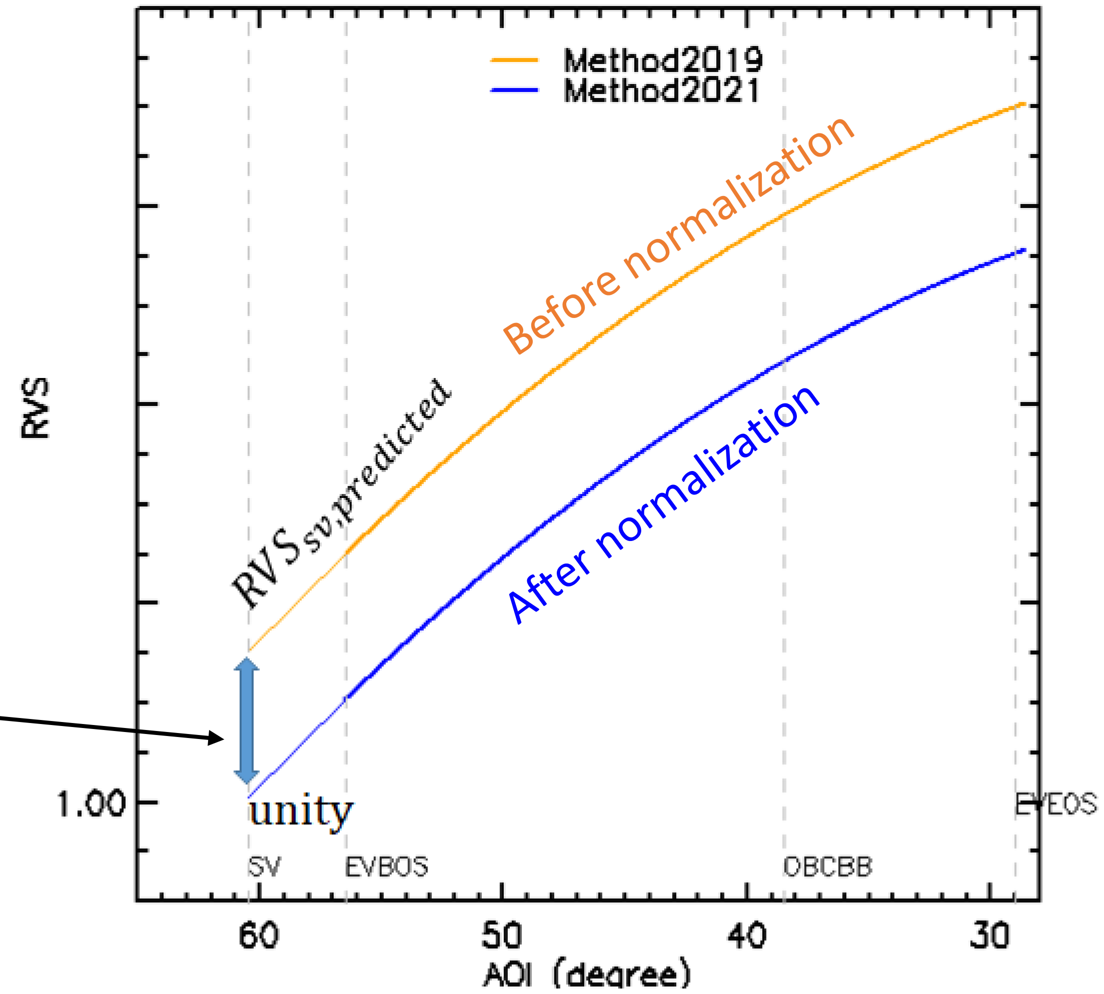


Estimating Errors in Calibration Offset (*c0*)

Errors in prelaunch calibration offsets (c_0) are estimated using the differences between the model predicted SV RVS and unity, and modulated by L_{mirror}/F.

Eq. 2-4 $c_{0,corr} = (1.0 - \mathrm{RVS}_{sv,predicted}) \cdot L_{mirror}/\mathrm{F}$

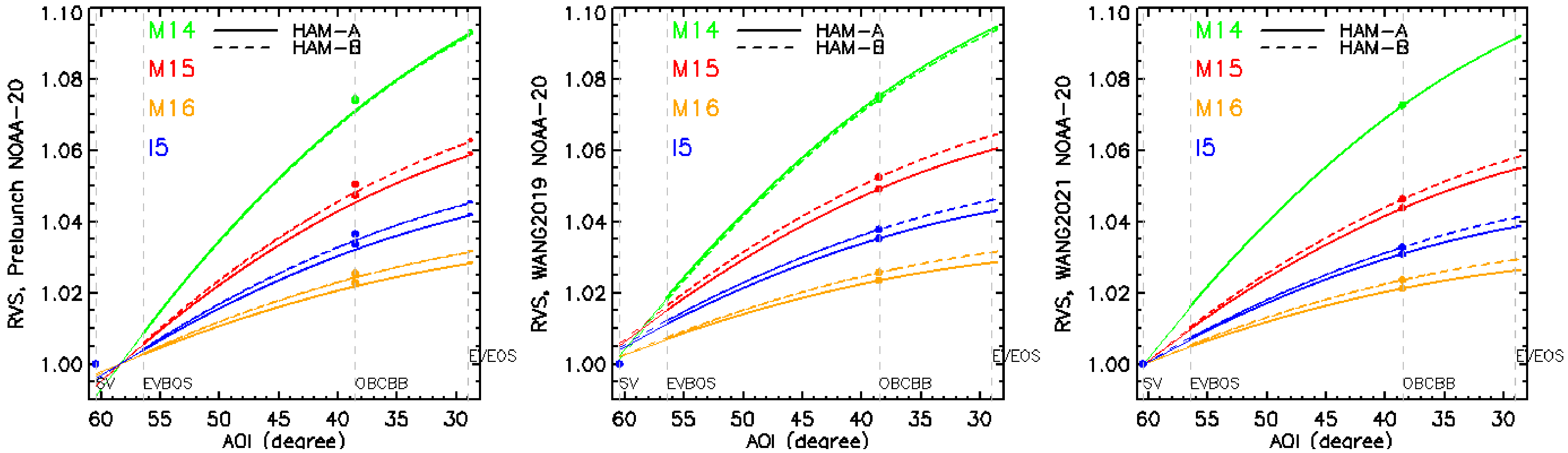
Eq. 2-5 $c_{0,updated} = c_{0,prelaunch} + c_{0,corr}$



Comparison of Prelaunch and On-Orbit TEB RVS (NOAA-20, LWIR)

- Differences between pitch maneuver data derived RVS and the operational (prelaunch) RVS:
  - Method 2019: Up to 1% (M14-M15), near the beginning of EV scans
  - Method 2021: up to 0.85% (M14) and 0.5% (M15), near the beginning of EV scans

  Note: additional differences go to the calibration offsets.



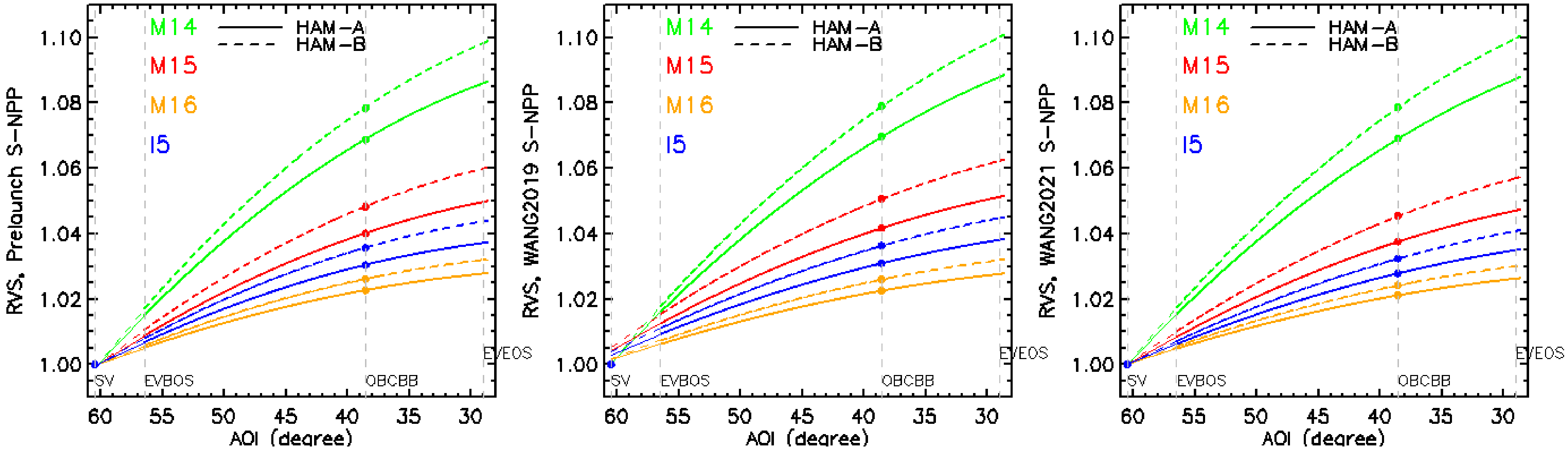
Operational
Discrepancies reported
(Wang et al. 2019)

Method2019
RVS may not converge at SV AOI

Method2021
RVS converges at SV

Comparison of Prelaunch and On-Orbit TEB RVS (S-NPP,LWIR)

- Differences between prelaunch and pitch maneuver data derived RVS are much smaller compared with NOAA-20.
  - M15 shows relatively larger differences, but mostly constant across the EV scan.
    ~+0.2% (Method2019)   ~ -0.2% (Method2021).

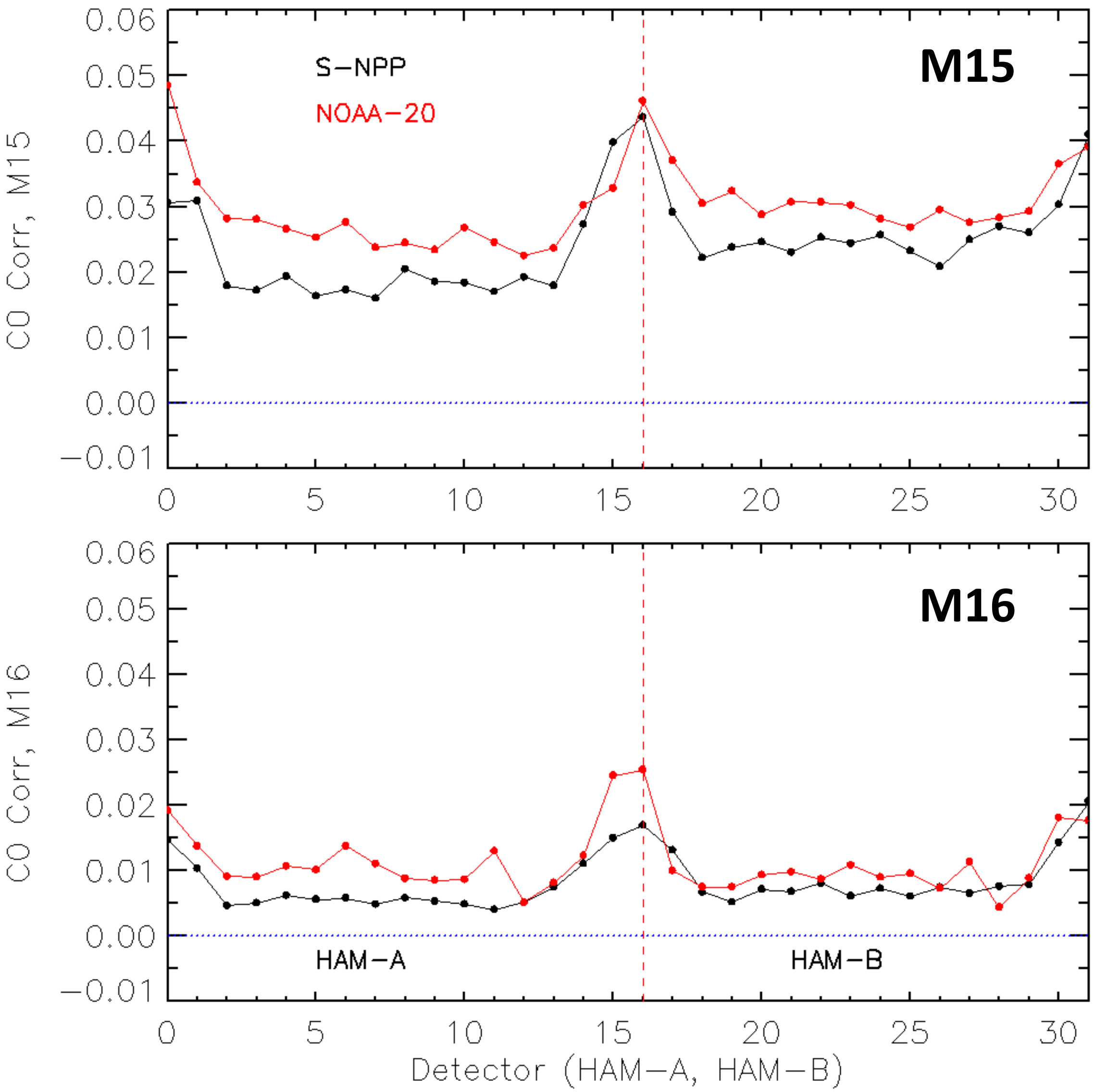


Operational (Prelaunch)

Method2019
May not converge at SV AOI

Method2021
Converge at SV AOI

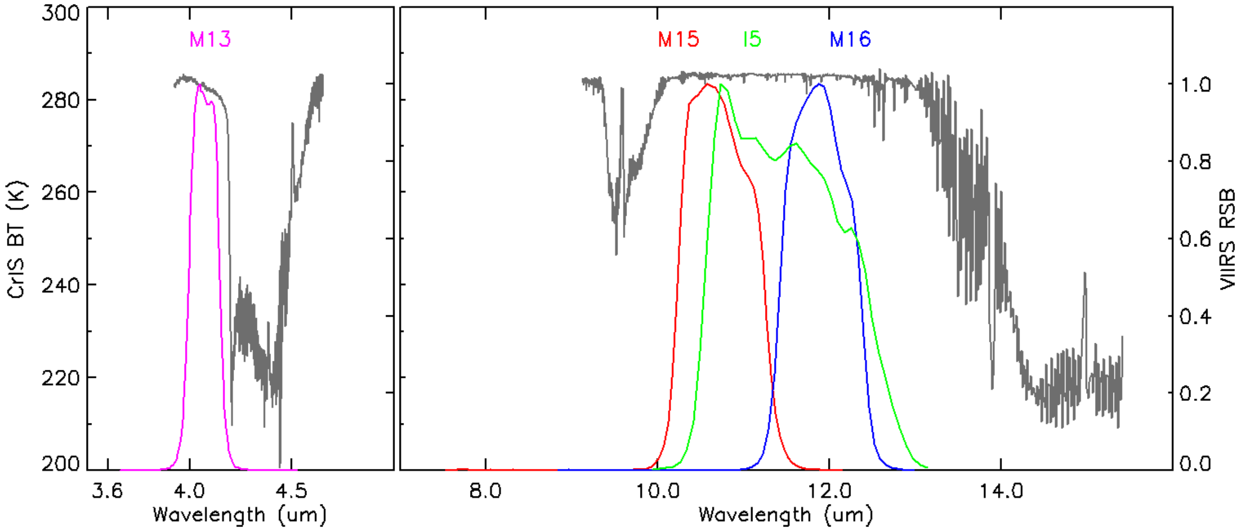
Methd2021: Corrections to c_0



- NOAA-20 LWIR bands show larger c_0 corrections compared to S-NPP, consistent with the larger cold biases observed in NOAA-20.
- c_0 corrections estimated are nearly constant for non-edge detectors
- Relatively larger corrections for edge detectors.
  - Larger uncertainty may exist for the edge detectors.
  - Limited data near SV AOI, due to the VIIRS onboard bowtie deletion scheme.

Evaluation of VIIRS Scan Angle and Scene Temperature Dependent Biases Using Co-Located CrIS Data

- VIIRS and the Cross-track Infrared Sounder (CrIS) are both onboard NOAA-20 and S-NPP satellites.
- There are plenty of co-located VIIRS-CrIS observations for independent evaluation of VIIRS TEB radiometric calibration.
- VIIRS bands M13, M15-M16 and I5 are covered by CrIS spectra.



VIIRS

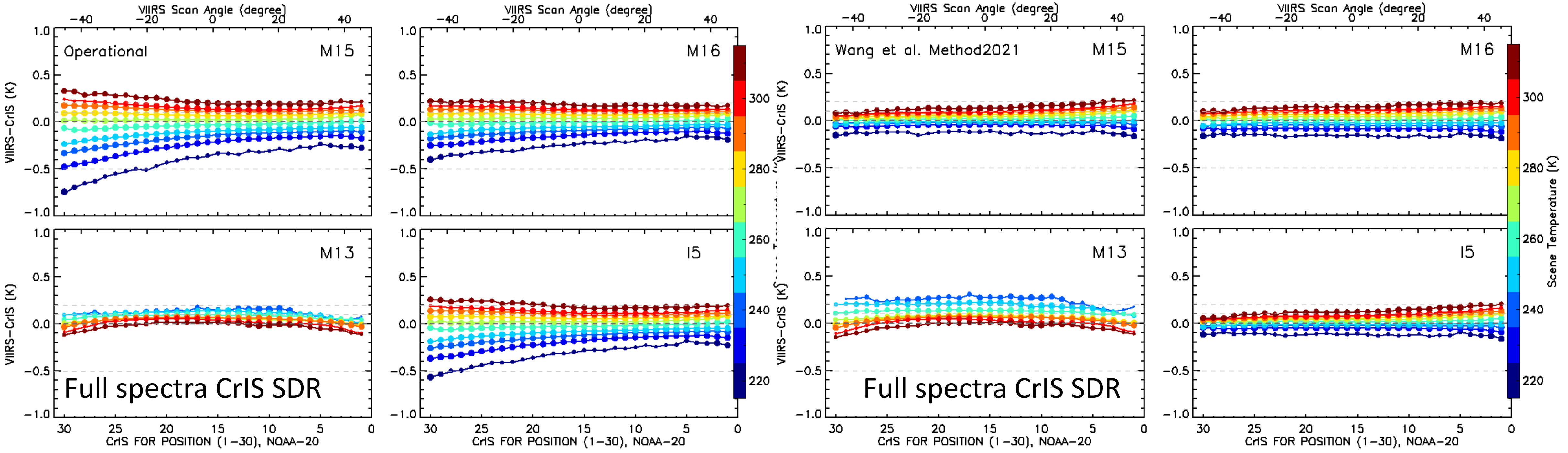
- 14 Reflective Solar Bands (RSB): I1-I3 & M1-M11
- **7 Thermal Emissive Bands (TEB):**
  I4-I5 (0.375 km at nadir)
  M12-M16 (0.750 km at nadir)
- 1 Day/Night Band.
- **EV view scan angles: ±56.063°**

CrIS

- **Normal Spectral Resolution SDR**: 1305 channels, terminated on June 24, 2020.
- **Full Spectral Resolution SDR**: 2211 channels
- 30 field of regards (FOR, 1 – 30); Each FOR has 9 field of views (FOV, 13.5 km at nadir).
- **EV scan angles: ±48.3°**

VIIRS-CrIS BT Biases (NOAA-20)

- Scan angle and scene temperature dependent biases in LWIR bands (M15-M16, I5) are effectively reduced.
- M13 shows increased scene temperature dependent biases, but may be due to full spectral CrIS SDR.
- Biases patterns in other days are similar.

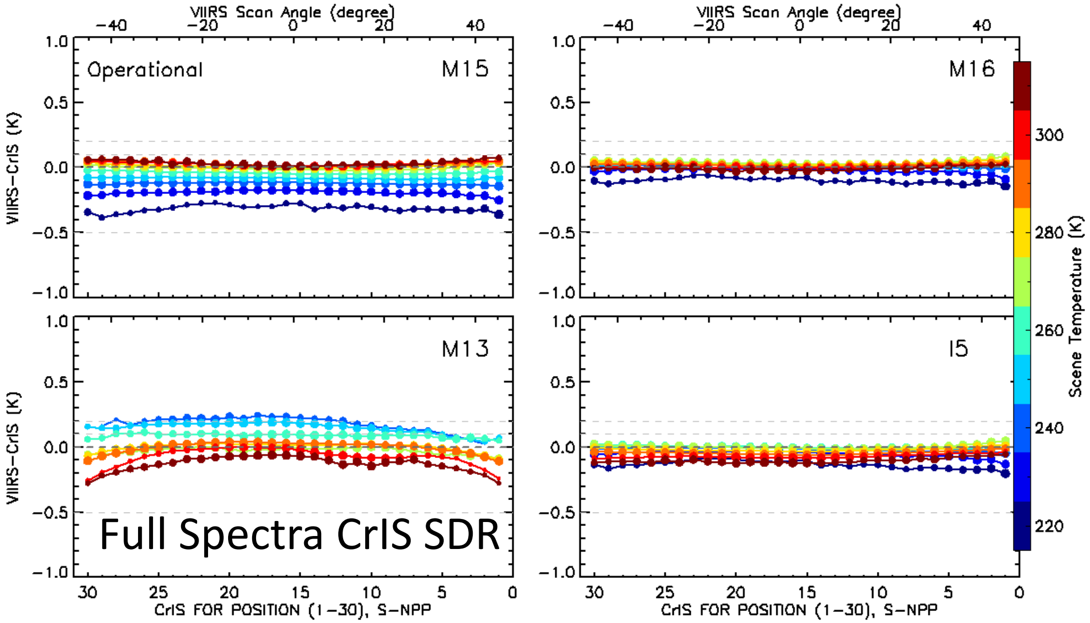


NOAA Operational, 2020/01/27

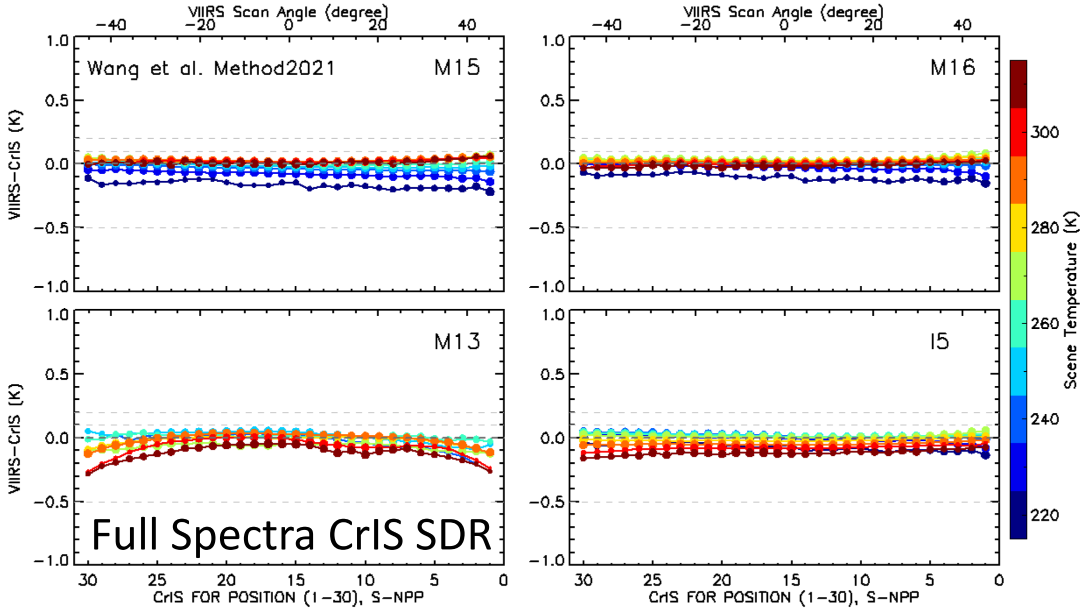
Reprocessed (Method2021), 2020/01/27

VIIRS-CrIS BT Biases (S-NPP)

- The scan angle and scene temperature dependent biases in S-NPP LWIR bands are much smaller than NOAA-20 in the operational processing.
  - M15 shows ~0.3 K scene temperature dependent biases, reduced to ~0.15 K after applying Method2021.
- M13: scene temperature dependent biases and scan angle dependent biases at colder scene temperatures were also reduced, for the CrIS full spectral SDR.
  - Scan angle dependent biases at warmer scene temperatures are mostly unchanged.
- Biases patterns during other days are similar.

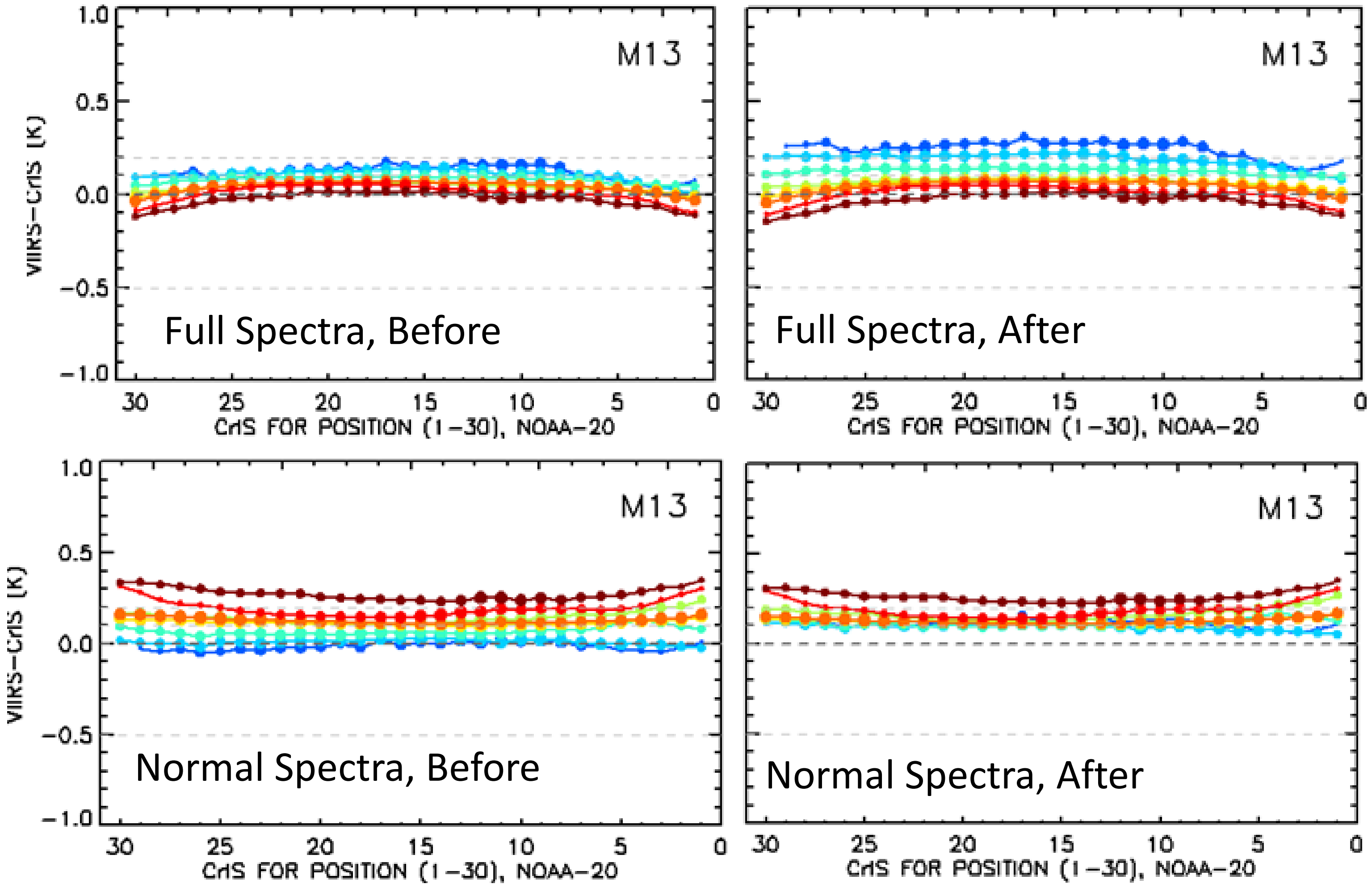


NOAA Operational, 2020/01/27



Reprocessed (Method2021), 2020/01/27

VIIRS-CrIS BT Biases for M13



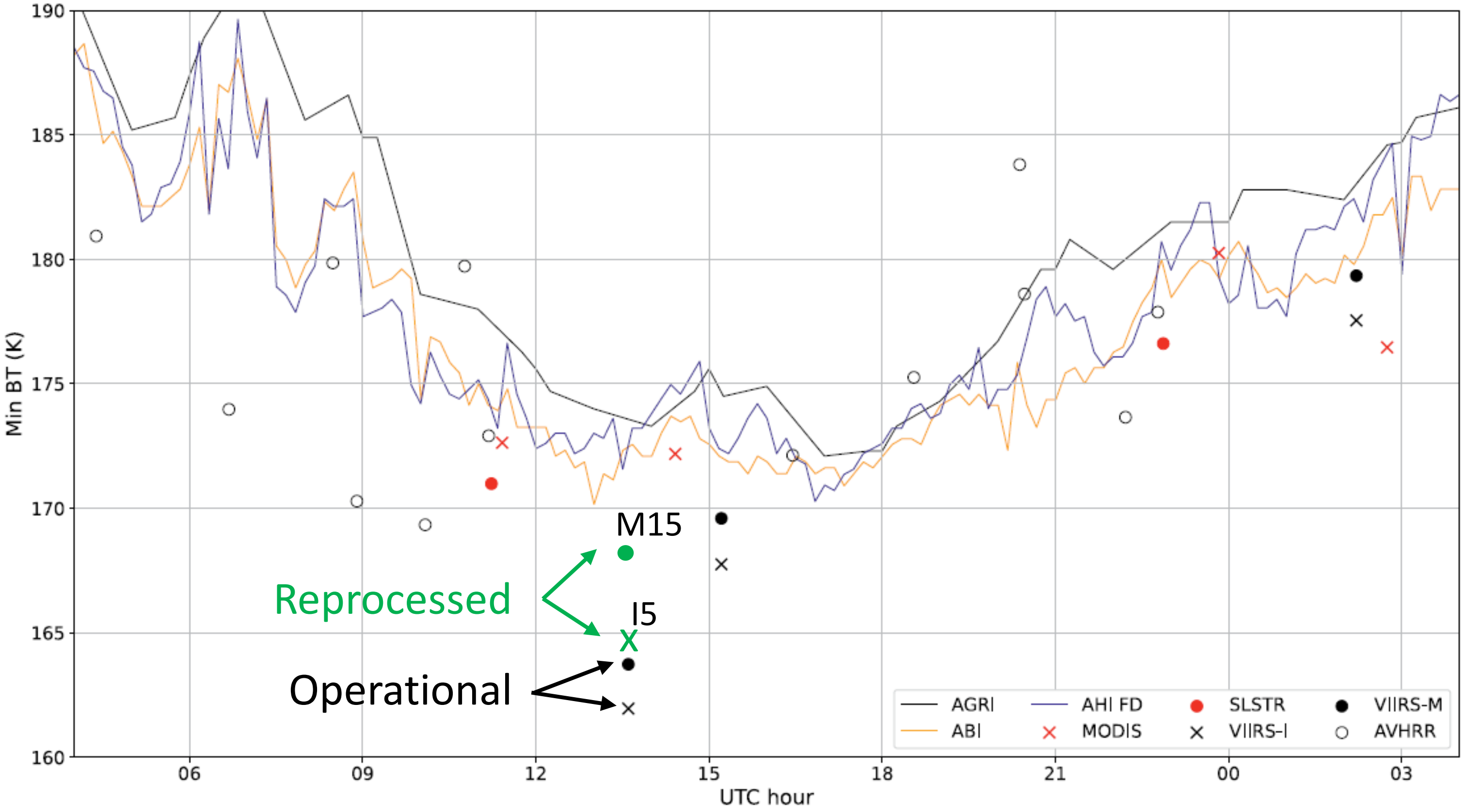
NOAA-20, M13, 2020/01/27

- Mixed results were observed for both NOAA-20 and S-NPP M13.
- NOAA-20:
  - Full spectral SDR: scene temperature dependent biases increased by ~0.2 K.
  - Normal spectral SDR: decreased by ~0.2 K.
- S-NPP:
  - Biases decreased for full spectral SDR.
  - But increased for normal spectral SDR.
  - See backup slide.
- Potential causes:
  - CrIS calibration.
  - Uncertainty in the pitch maneuver data derived RVS and c0.

Case Study: NOAA-20 VIIRS Measured Record-Low Cloud Temperatures on Dec. 29, 2018

- NOAA-20 VIIRS operational SDRs measured record-low temperatures over the tropical West Pacific.
  - Granule: d20181229_t1336
  - **I5: 161.96 K M15: 163.73 K**
  - Both occurs near the beginning of scan.

- After applying the Method2021, I5/M15 become more in-family with other sensors.
  - **I5: 164.89 K → ~3 K warmer than the operational processing.**
  - **M15: 167.87 K→ ~4 K warmer than the operational processing.**

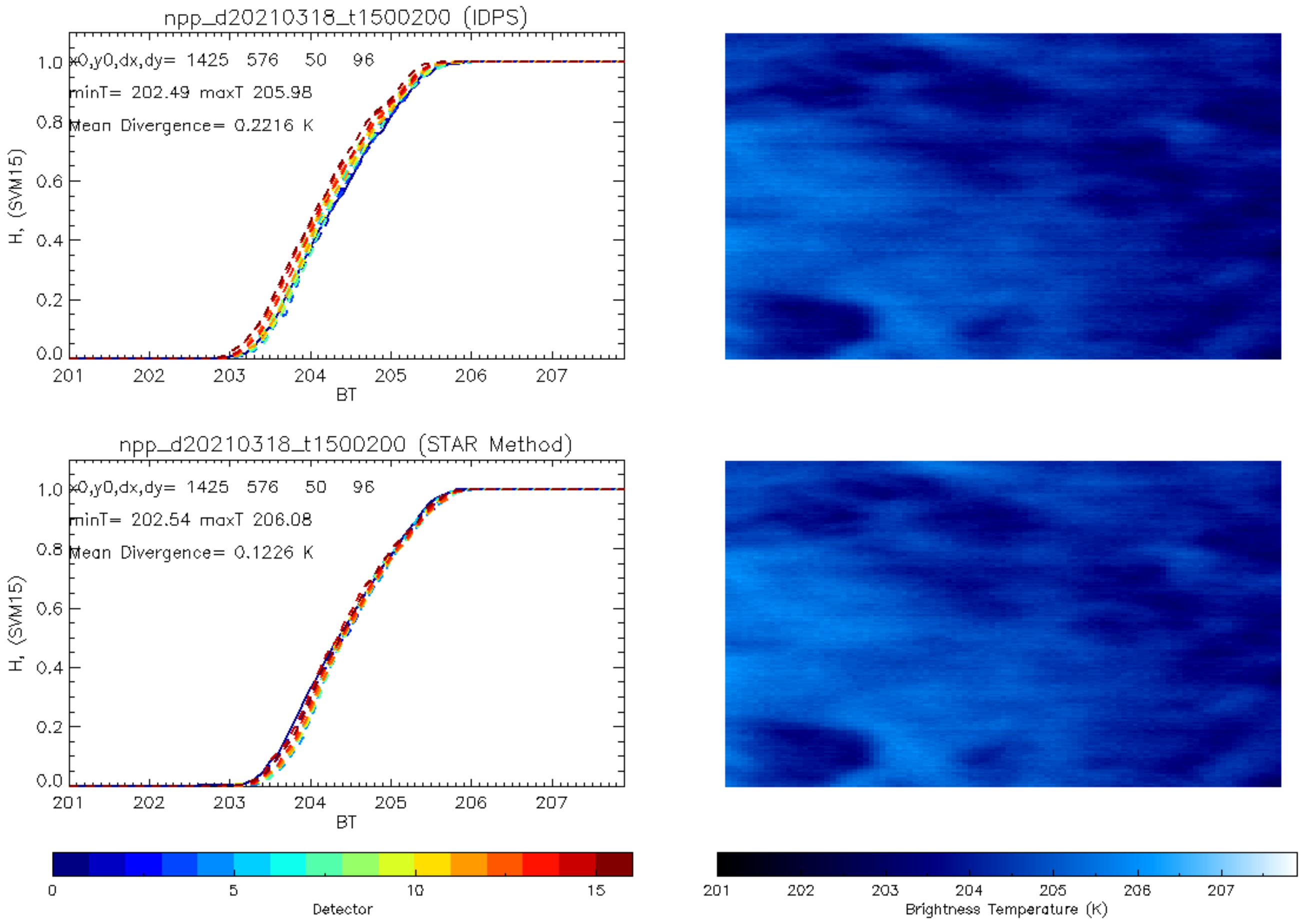


S. R. Proud and S. Bachmeier, "Record-Low Cloud Temperatures Associated With a Tropical Deep Convective Event," *Geophysical Research Letters*, https://doi.org/10.1029/2020GL092261 vol. 48, no. 6, p. e2020GL092261, 2021/03/28 2021.

Impacts of Method2021 on SDR Striping

- S-NPP: relatively larger striping was observed in the operational processing at cold scene temperatures.
  - Preliminary results show M15 & M16 striping at cold scene temperatures is reduced by ~40% after applying Method2021.
  - Striping in I5 is also reduced.
  - No significant change of striping at warmer scene temperatures.

- NOAA-20: striping is small in the operational processing.
  - Striping doesn't change significantly after applying Methd2021.



M15, S-NPP
(Dome-C, March 18, 2021)

Summary

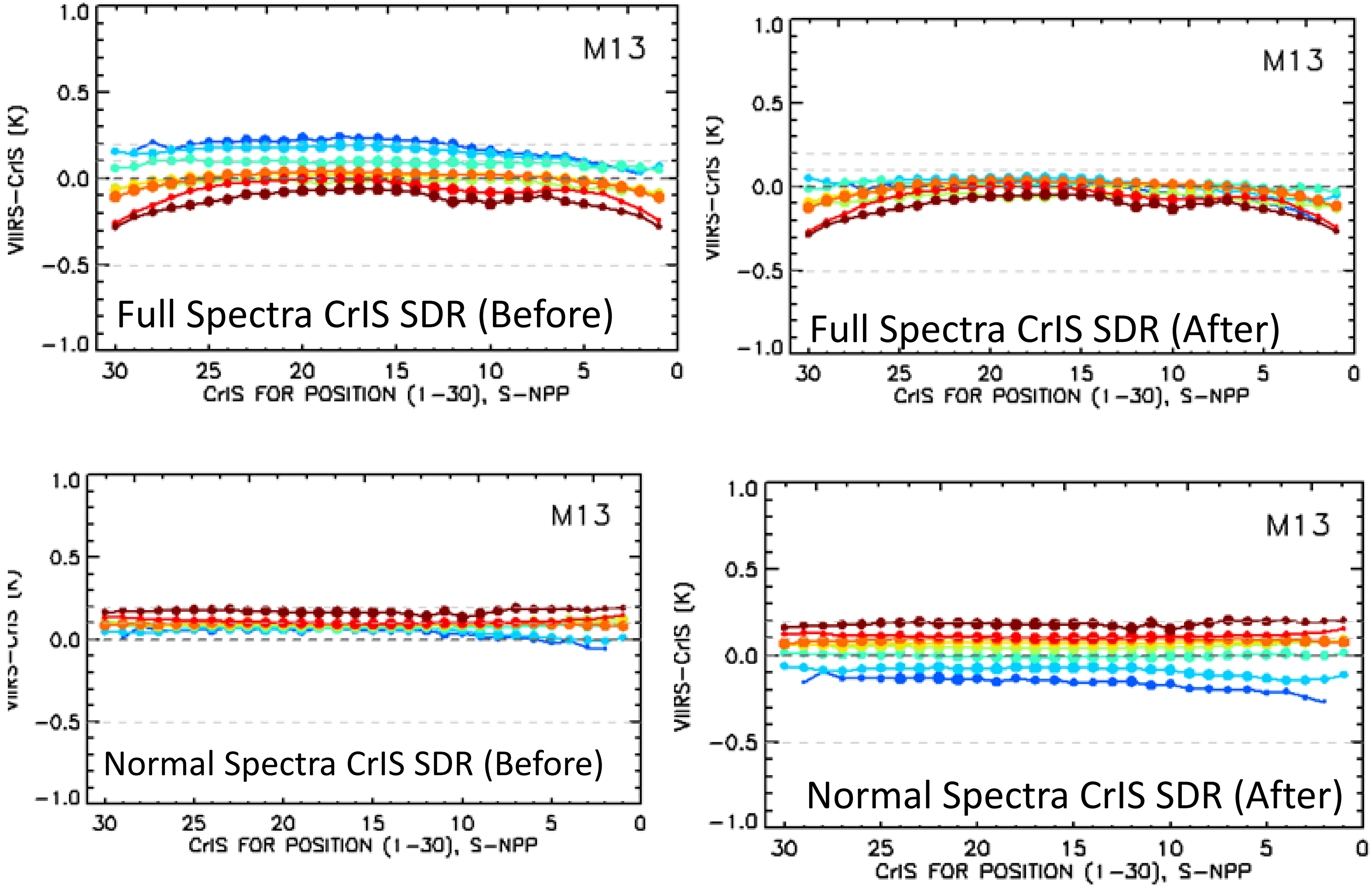
- An improved method (Method2021) was developed for estimating VIIRS TEB RVS and c_0 using on-orbit pitch maneuver data.
  - Derived RVS complies with the prelaunch data based 2nd polynomial assumption, different from the existing Method2019.
  - TEB calibration offsets (c_0) can also be updated.

- The impacts on NOAA-20 and S-NPP VIIRS TEB scan angle and scene temperature dependent biases were evaluated using co-located CrIS observations.
  - NOAA-20 LWIR scan angle and scene temperature dependent biases are significantly reduced.
  - S-NPP M15 cold bias is also effectively reduced.
  - M13: mixed results were observed for the full and normal spectral CrIS SDRs, require further study.

- The impacts on VIIRS TEB SDR striping were evaluated at cold scene temperatures.
  - S-NPP pitch maneuver data derived RVS and c0 can reduce striping in LWIR bands.
  - No significant change in striping was observed for NOAA-20.

Backups

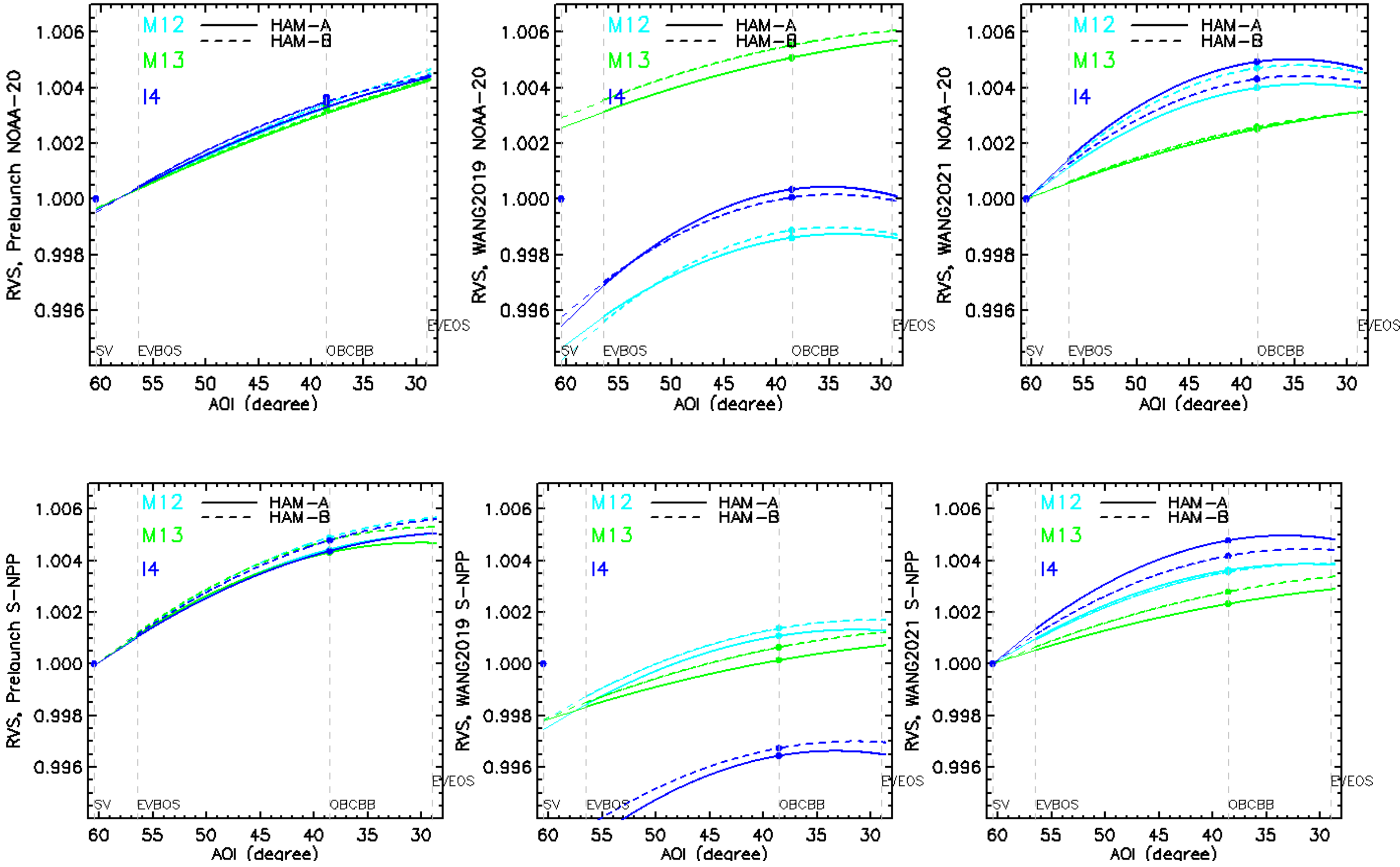
S-NPP M13



- ➢ CrIS full spectra SDR: the scan-angle an scene temperature dependent biases decreased after applying the Method2021.
- ➢ CrIS normal spectral SDR:
  - No significant scan-angel dependent biases before & after the correction
  - Scene temperature dependent biases increased slightly after the correction.
- ➢ The ranges of EV dns for S-NPP MWIR are similar to NOAA-20 (M13: ~5 counts)
- ➢ This topic will be further studied.

Comparison of MWIR RVS (NOAA-20 & S-NPP)

- VIIRS MWIR RVS effects are ~0.5% or less, much smaller than LWIR bands.
- Differences between Pitch Maneuver Data derived and prelaunch RVS are generally smaller compared to LWIR bands.



Prelaunch Wang2019 WANG2021