Calibration Anomaly for GOES-17 ABI Infrared Images before Local Midnight

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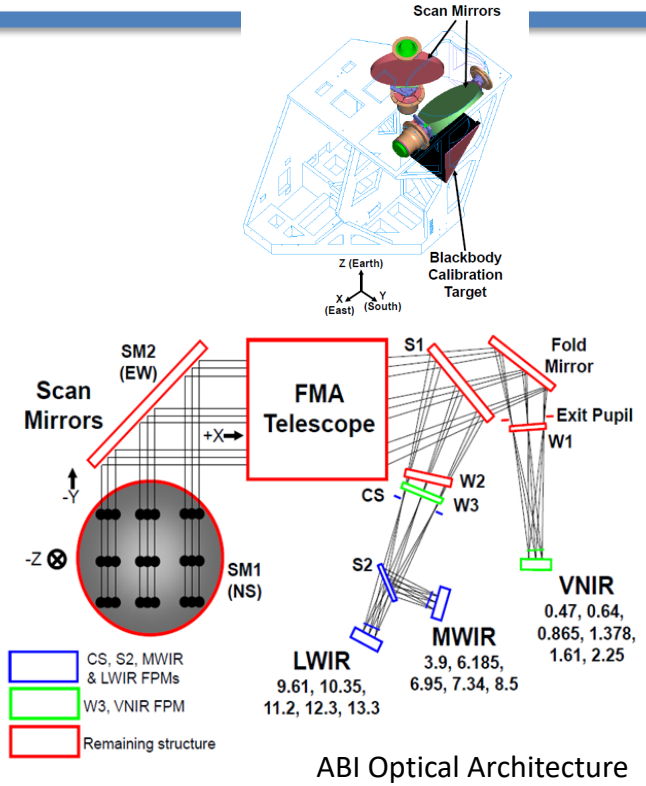
Advanced Baseline Imager (ABI)

- Primary weather instrument on board the NOAA GOES-R series satellites
- Consisting of 16 bands, six visible and near-infrared (VNIR) and 10 infrared(IR) channels for accurate weather forecasting and environmental monitoring
  - Each channel has hundreds to thousands of detector rows with one best detector selected downlinked for ground operational processing
  - Detectors are located at three focal plane modules (FPM)
  - All calibrated with on-board calibration devices
    - VNIR: solar diffusor + space
    - IR: blackbody (Internal Calibration Target) + space
  - Collected with two independent scan-mirrors
- Configurable instrument designs and calibration algorithms



ABI Optical Architecture

ABI key parameters

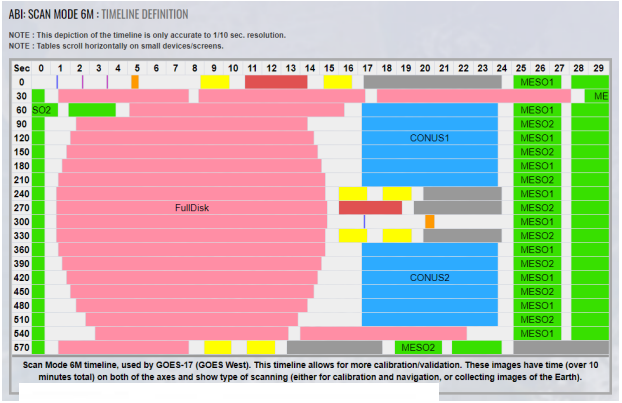
FPM Name	Band No.	Nominal Central Wavelength (μm)	Detector Rows	SNR/ NEdT@300K SPEC	Nadir Pixel Size (km)	Band Descriptive Name
VNIR	1	0.47	676	300	1	Blue
	2	0.64	1460	300	0.5	Red
	3	0.86	676	300	1	Vegetation
	4	1.37	372	300	2	Cirrus
	5	1.6	676	300	1	Snow/Ice
	6	2.2	372	300	2	Cloud particle size
MWIR	7	3.9	332	0.1K	2	Shortwave window
	8	6.2	332	0.1K	2	Upper-level water vapor
	9	6.9	332	0.1K	2	Mid-level water vapor
	10	7.3	332	0.1K	2	Lower/middle level water vapor
	11	8.4	332	0.1K	2	Cloud-top phase
LWIR	12	9.6	332	0.1K*	2	Ozone
	13	10.3	408	0.1K	2	Clean Longwave window
	14	11.2	408	0.1K	2	Longwave window
	15	12.3	408	0.1K	2	Dirty longwave window
	16	13.3	408	0.3K*	2	CO_2

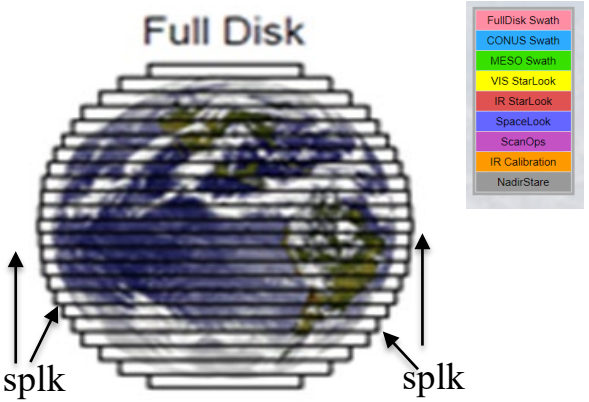
ABI Earth Scans and Spacelook Locations

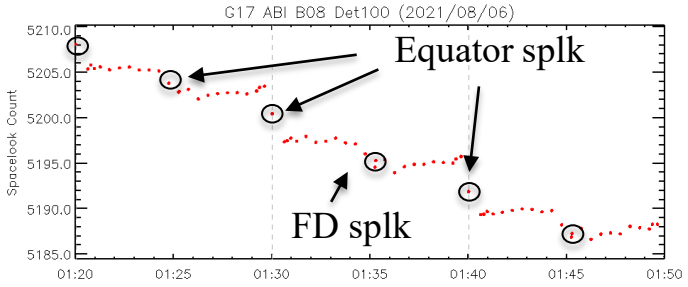
- One timeline = Earth scans + radiometric calibration target scans (space look and ICT look) + geometric calibration target scans (star)

- Earth scans = one full-disk (FD, 22 swaths) + CONUS (6 swaths) + MESO (2 swaths)

- Radiometric Cal Targets
  - Fixed location for the ICT look
  - Varied spacelook (spl) locations
    - Space at far end of each FD swath or Equator
    - Switch positions at noon and midnight time to minimize the possible straylight impact
      - East side to the Earth: noon->midnight
      - West side to the Earth: midnight-> noon
  - SPL count varies at different scan mirror locations, on top of the thermal condition





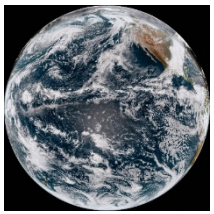


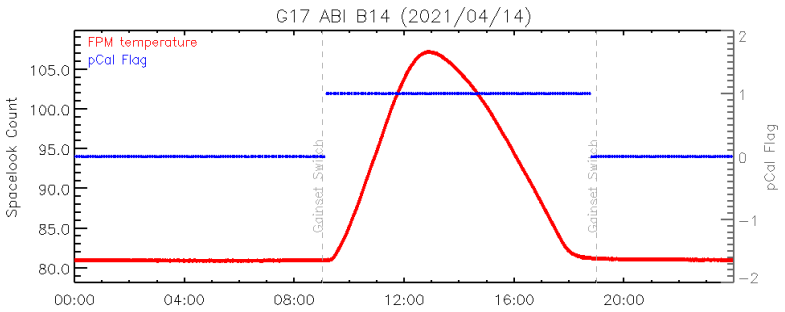
GOES-17 ABI & Cooling System Anomaly

- GOES-17 is the 2nd satellite in the GOES-R series.
  - Launched on 1 March 2018, has been operational as the GOES-West at 137.2°W since 12 February 2019

- Loop heat pipe (LHP) anomaly detected in late April 2018 causes the malfunction of the cooling system
  - Degraded data quality at all IR channels
  - Geometric calibration of good images is not appreciably affected by the anomaly.

- To optimize the instrument performance, G17 ABI is being operated at many different calibration configurations and calibration algorithms from the original designs.
  - *Elevated operational FPM temperature*
  - *Controlled vs. uncontrolled IR FPM time in a day*
  - *Different detector biases from the designed*
  - *Different gain-set configurations in a day*
  - *Higher frequency of blackbody (internal calibration target, ICT) calibration at every 5 minutes*
  - *Predictive Calibration algorithm (pCal) at drifting FPM time*
  - *Yaw-flip maneuvers semi-annually*
  - *Updates of many calibration look-up-tables (LUTs)*
  - *Flexible cooling timeline in eclipse seasons.*
  - *…*



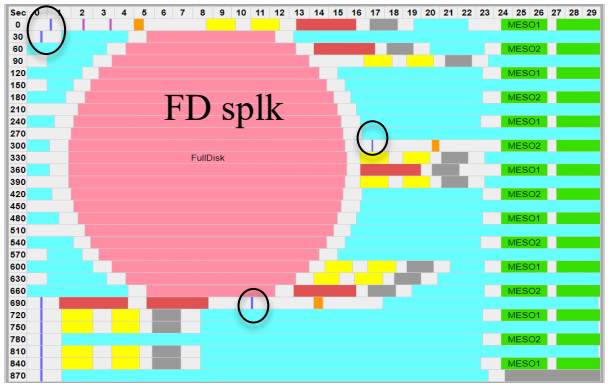


G17 ABI IR Normal Calibration

$$L_{ev} = \frac{m\Delta C_{ev} + q\Delta C_{ev}^2 - \left(L_{NS@ev}^{eff} - L_{NS@spl}^{eff}\right) - \left(L_{EW@ev}^{eff} - L_{EW@spl}^{eff}\right)}{\rho_{EW}^{ev}\rho_{NS}^{ev}}$$

IR calibration targets

- Blackbody (Internal Calibration Target, ICT)
  - Interval: ~5 minutes
- Space-look (SPL) for the dark current offset
  - Interval: few to ~30 seconds
- Detector responsivity and dark current are stable within the neighboring calibration events



Flexible Mode 3 Time-Time Diagram (GOES-West). Time interval: 15 minutes

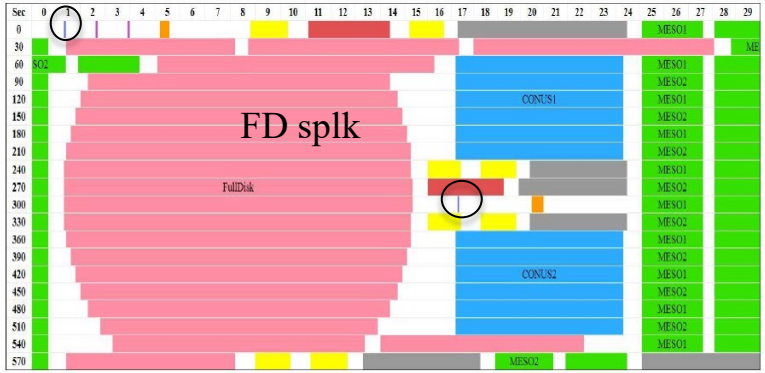
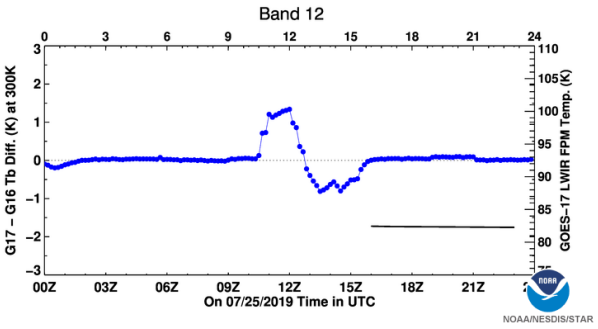
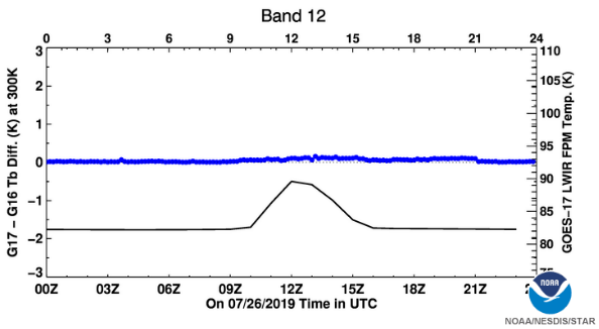


Figure 3-22B. Scan Mode 6 Time-Time Diagram (GOES-West)
Time interval: 10 minutes

Predictive Calibration (pCal)

- Detector responsivity (gain) and dark current (spl count) may change dramatically at floating FPM temperature, and should be accurately estimated for each image sample
- Predictive Calibration (pCal), delivered by the vendor, is to alleviate the calibration bias when FPM temperature is drifting
- pCal can be turned on/off in operation
- When pCal is enabled, both spl count and gain value are linearly extrapolated to the scanning time of each sample
  - Applicable to B08 – B16
  - Operationally implemented since 07/26/2019
  - Greatly improved the calibration accuracy at the thermal stress time





https://www.star.nesdis.noaa.gov/GOESCal/G16G17_ABI_GEO_GEO_IR_daily.php Courtesy of H. Yoo et al.

Normal Calibration vs. pCal

$$L_{ev} = \frac{m\Delta C_{ev} + q\Delta C_{ev}^2 - \left(L_{NS@ev}^{eff} - L_{NS@spl}^{eff}\right) - \left(L_{EW@ev}^{eff} - L_{EW@spl}^{eff}\right)}{\rho_{EW}^{ev}\rho_{NS}^{ev}}$$

$$\Delta C_{ev} = C_{spc} - C_{splk}^{i}$$

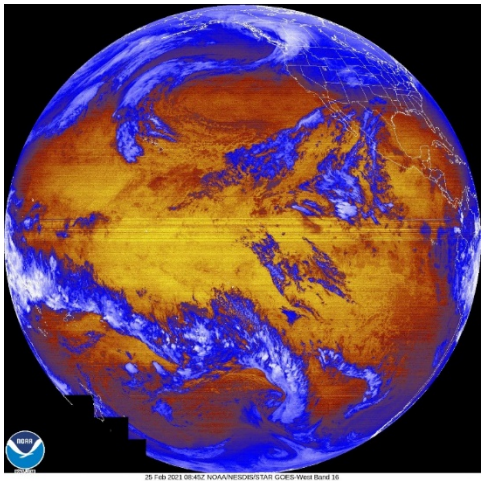
C_{spc}: sample count

	Normal Calibration	pCal
SPL count	$C_{spc} = C_{spl}^{i}$ for t=[0, 30 seconds]	$C_{spc} = C_{spl}^{i} + \frac{C_{spl}^{i} - C_{spl}^{i-1}}{\Delta t}\delta t$
Gain (m)	$m_{spc} = m_{ict}^{i}$ for t = [0,5minutes]	$m_{spc} = m_{ict}^{i*} + \frac{m_{ict}^{i*} - m_{ict}^{i-1}}{\Delta t}\delta t$

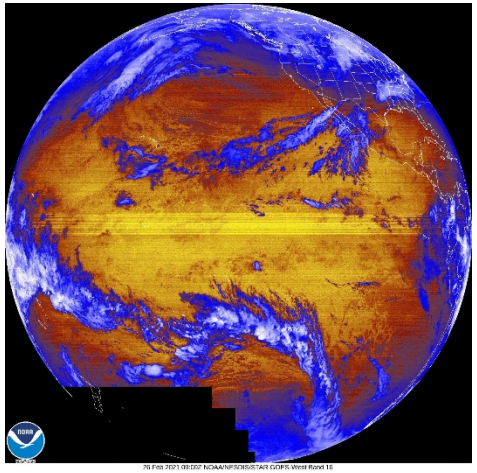
m_{spc}^{i*}: dark current is extrapolated to the ICT event time

Calibration Anomaly near the Equator

- A reported striping feature at B15 and B16 near the Equator in the 08:45Z and 09:00Z images on 02/25/2021



B16 08:45Z

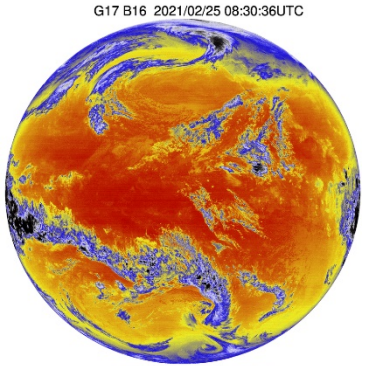


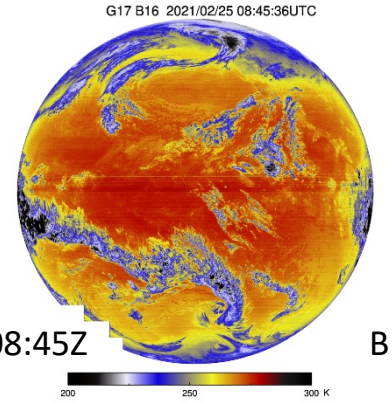
B16 09:00Z

Courtesy NOAA/STAR

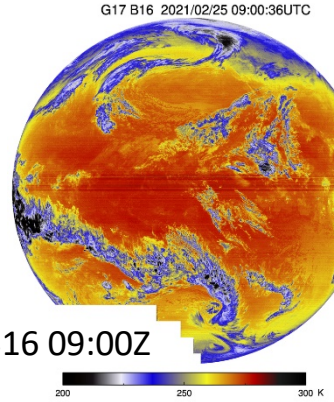
Calibration Anomaly near the Equator

Time	SPL Side	pCal	Image
0830	East	Off	Normal
0845	East	On	Striping
0900	East	On	Striping
0915	West	On	Normal

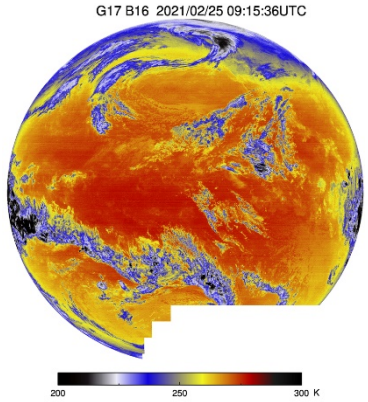




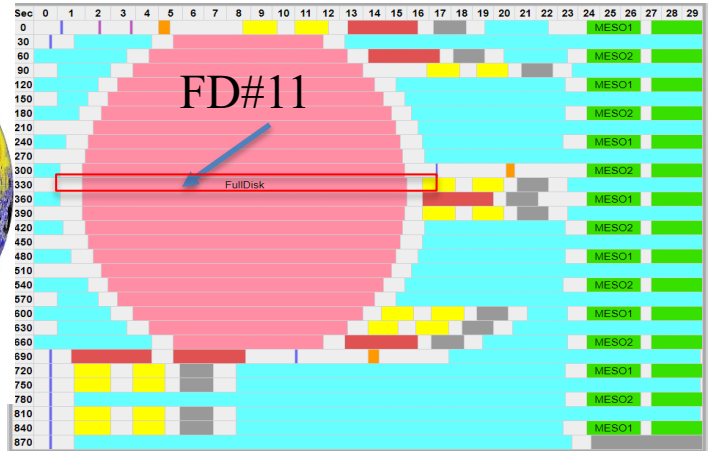
B16 08:45Z



B16 09:00Z



M3 Timeline



- Normal images at 08:30z and after 09:15Z
- Anomaly located at FD Swath #11, after the ICT event
- Anomaly occurred at multiple IR channels

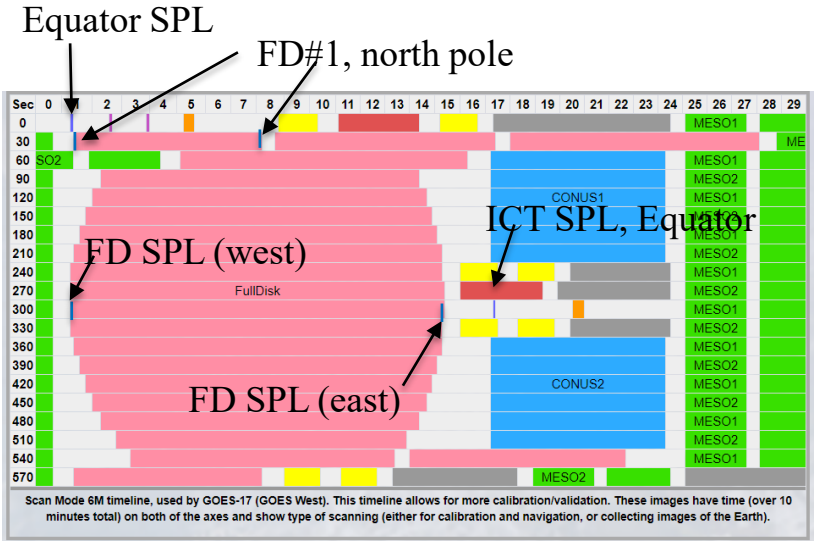
pCal Issue in the Dark Current Prediction

- Dark current is determined by: (1) change of the previous two SPL events, (2) time between the last two SPL events Δt, and (3) time from the last SPL event δt

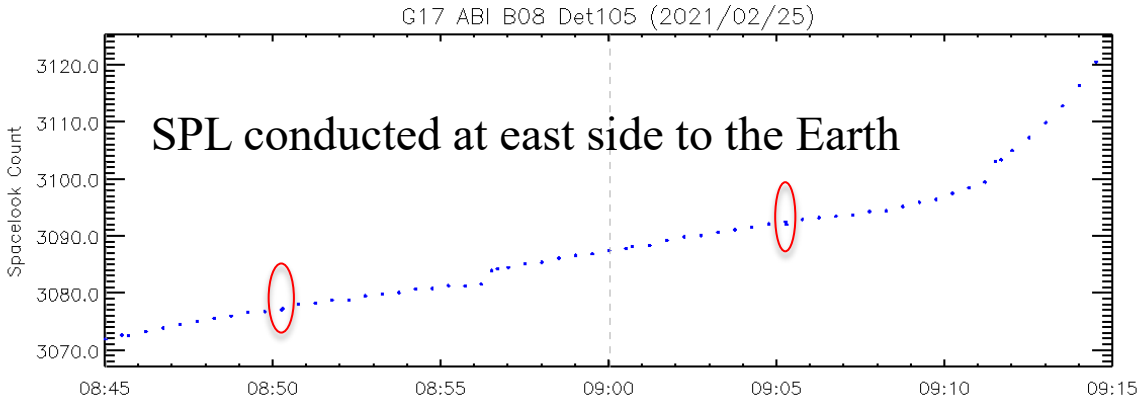
$$C_{spc} = C_{spl}^{i} + \frac{C_{spl}^{i} - C_{spl}^{i-1}}{\Delta t}\delta t$$

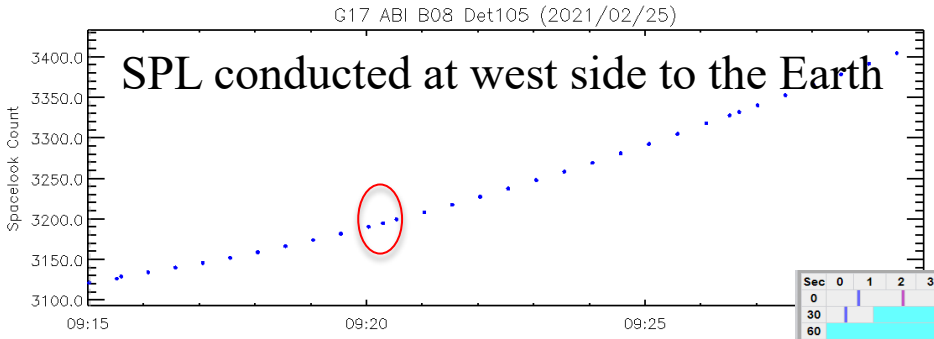
- Error sources in the SPL change ($C_{spl}^{i} - C_{spl}^{i-1}$)
  - Change in SPL locations
  - Detector noise

- Impact of the errors and SPL locations
  - Shorter Δt
    - East (right) side: Time between FD and ICT SPL, Δt < 3 seconds
    - West (left) side: Time between ICT SPL and FD, Δt >15 seconds
  - Longer δt
    - Time between equator and north pole (NP, at FD#1) SPLs, δt (east side) > δt (west side)
  - $\delta t / \Delta t$
    - Magnify the uncertainty caused by SPL variations when the SPL is conducted at the east (right) side to the Earth



FD SPL around Local Midnight: Mode 3

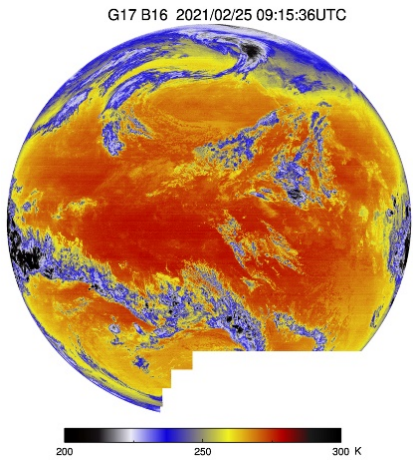




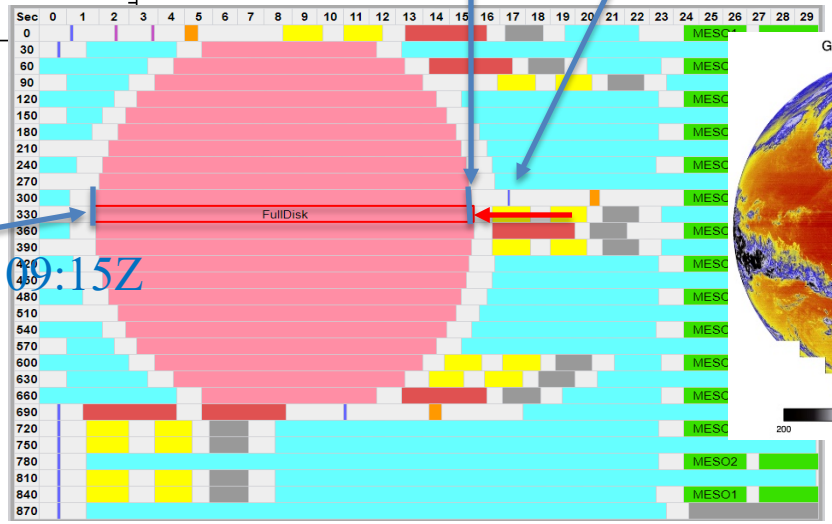
- SPL was conducted at the eastern side before 09:15Z and then switched to the western side.
- Only few seconds in between FD SPLK and 2nd ICT SPLK before the switch

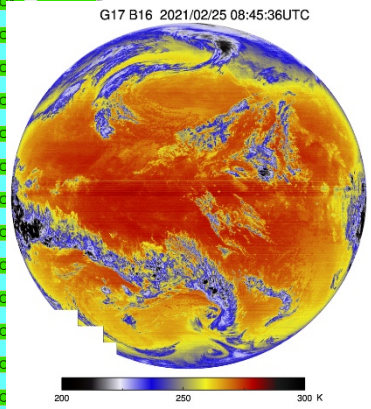
FD SPLK before 09:15Z

ICT SPL

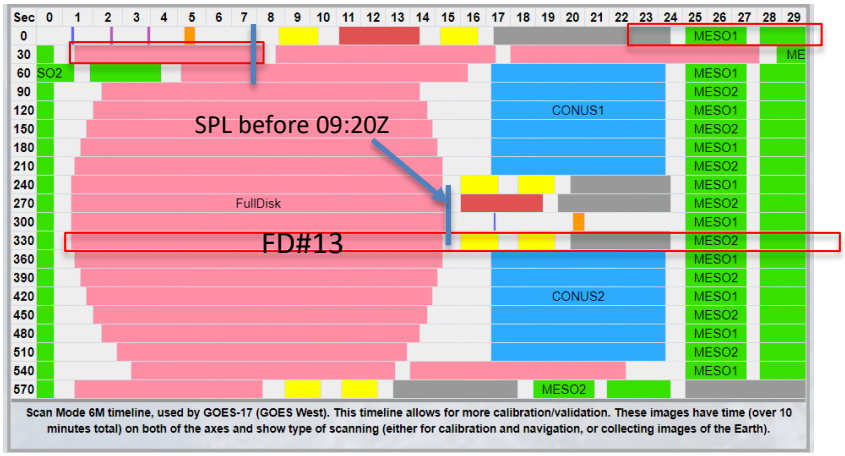


FD SPLK after 09:15Z

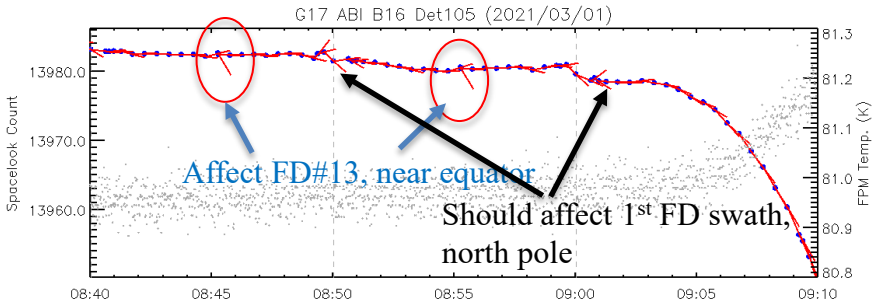




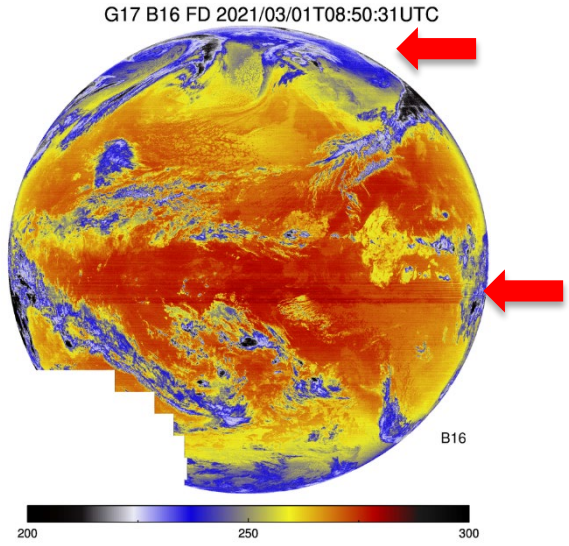
Calibration Anomaly around Midnight: Mode 6



Red lines: Estimated dark current



When the FPM temperature starts to change rapidly, the rapid change in dark current overwhelms the variations caused by sudden change in SPL locations/positions



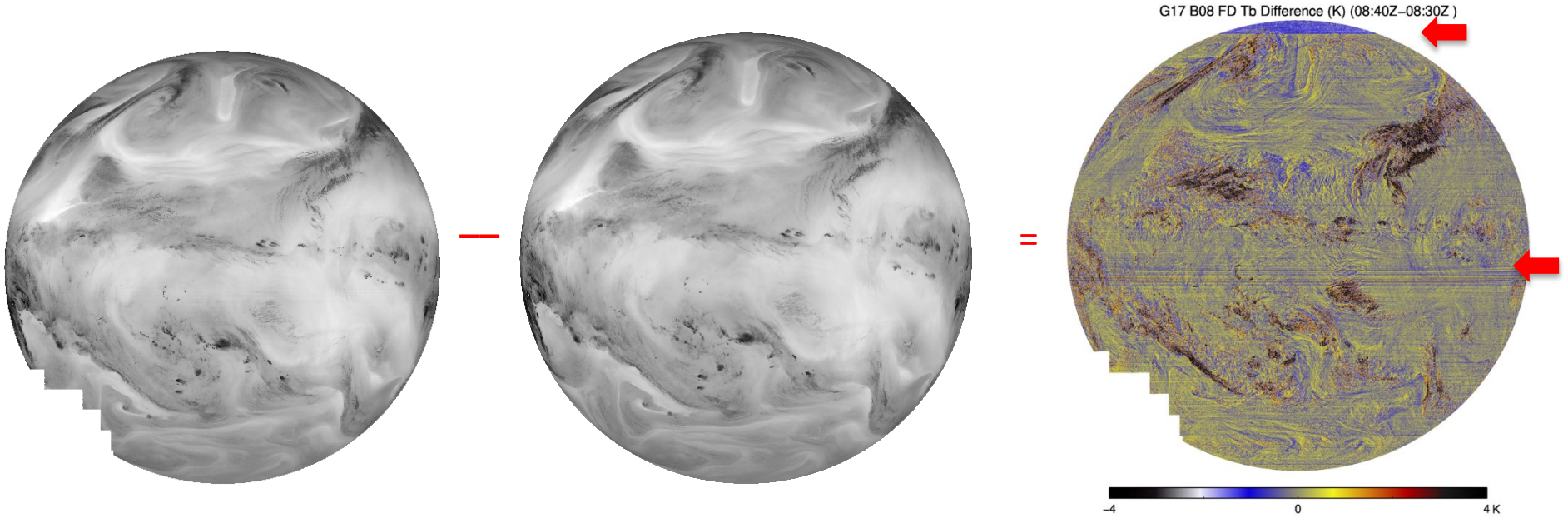
In addition to the near Equator, the 1st FD swath scanning over the North Pole region should be affected

Impact Assessment: Method

B08 08:40UTC

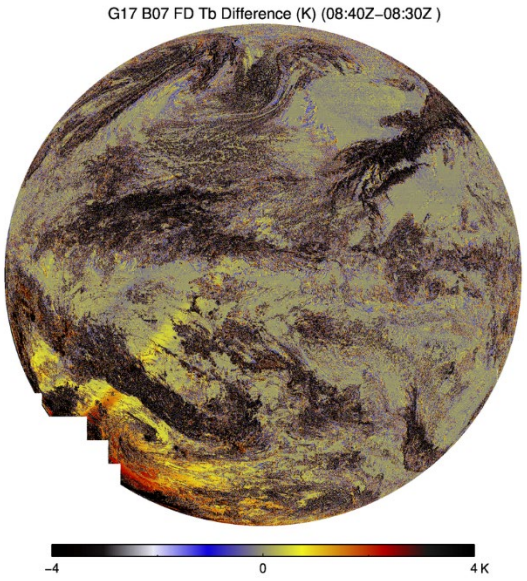
B08 08:30UTC

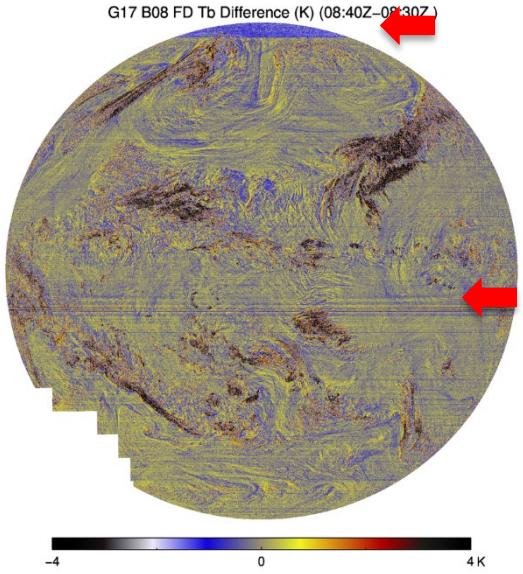
Result

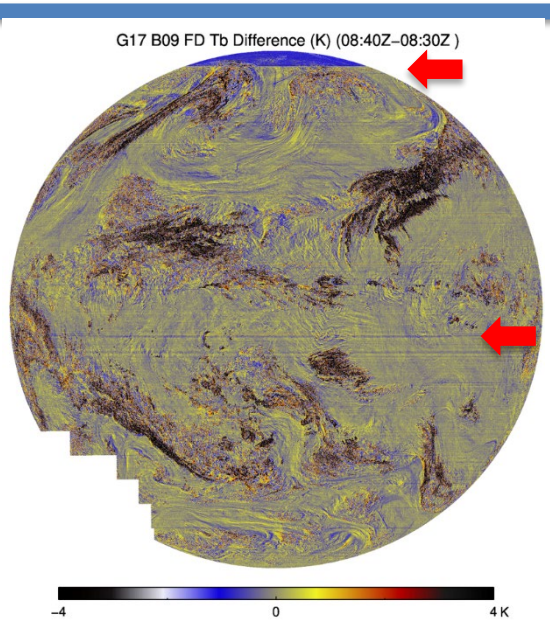


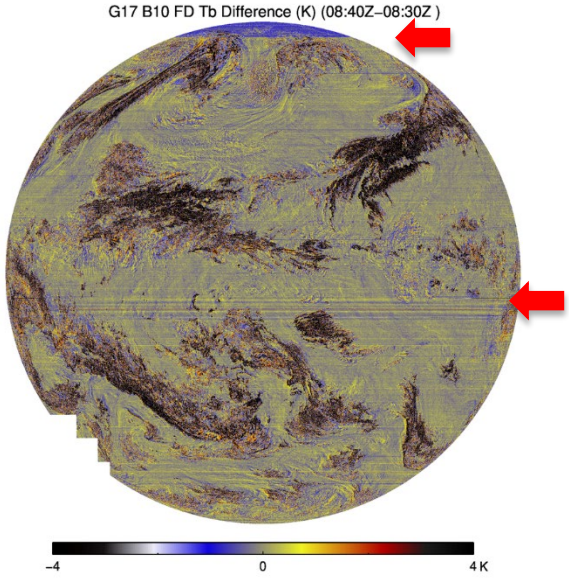
GEO-GEO Difference: 08:40 Z (pCal ON) – 08:30 Z (pCal OFF) on 03/01/2021

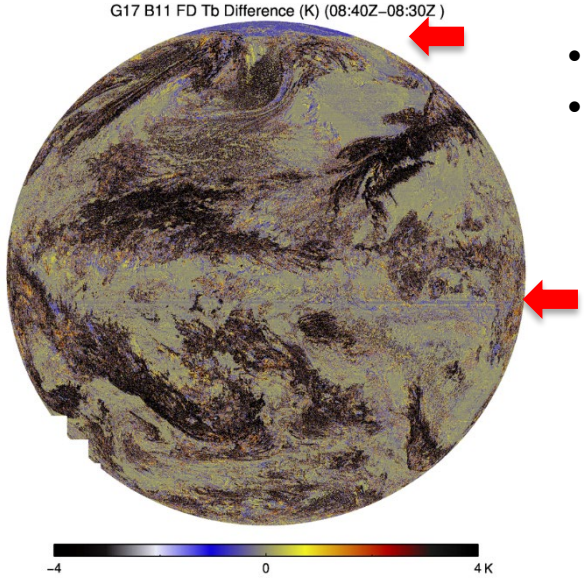
Tb Difference (08:40 – 08:30Z): B07 – B11





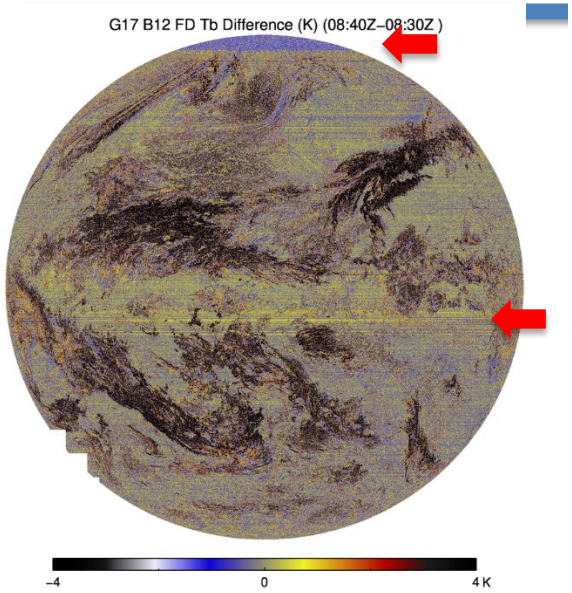


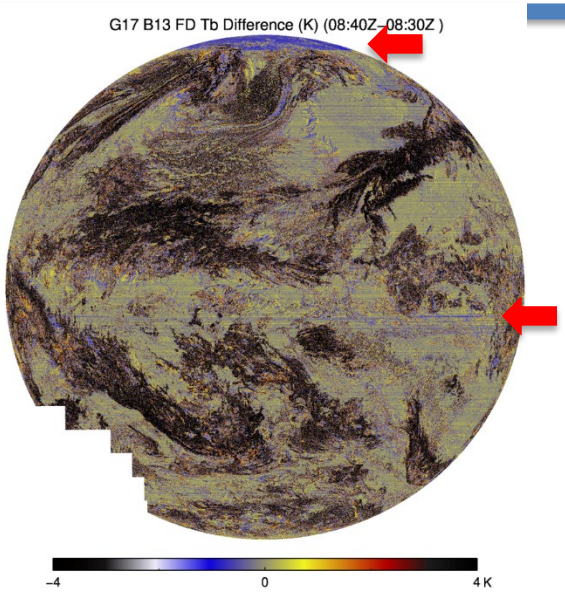


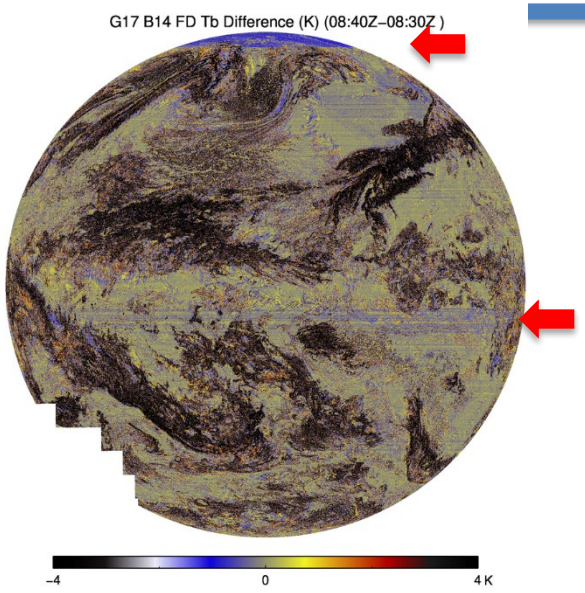


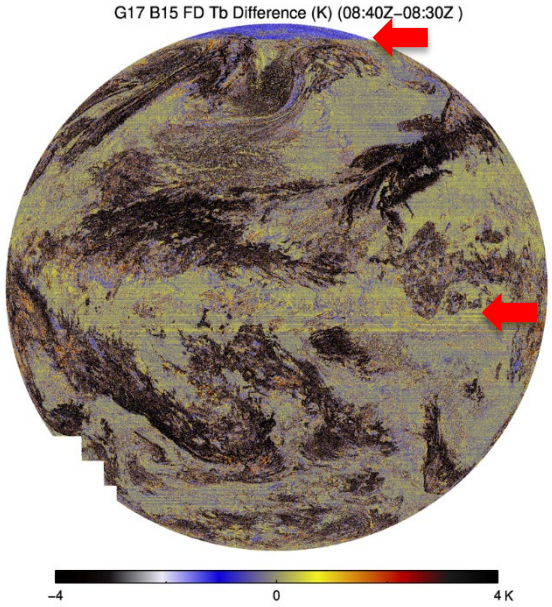
- No impact on B07
- B08-B11:
  - Anomaly shown at FD #1 and #13.
  - Impact increases from west to east

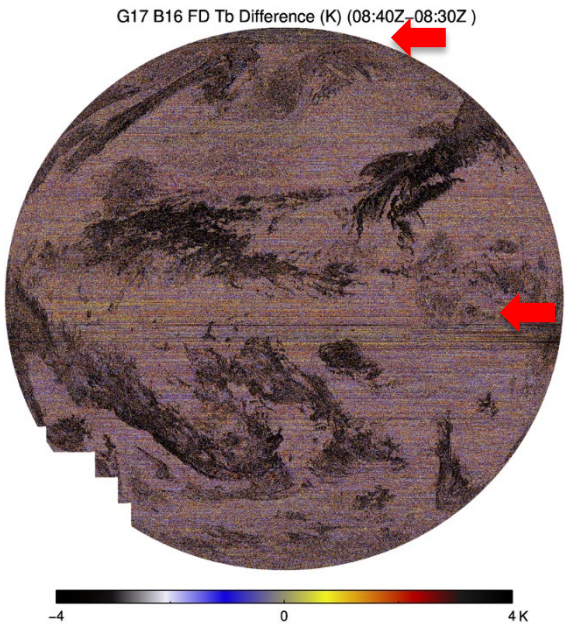
Tb Difference (08:40 – 08:30Z): B12 – B16





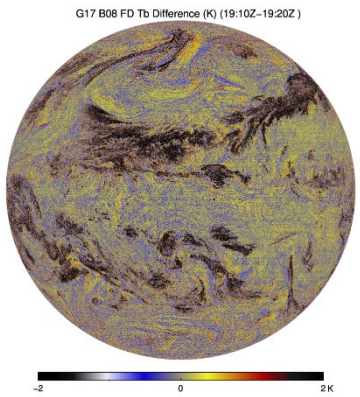


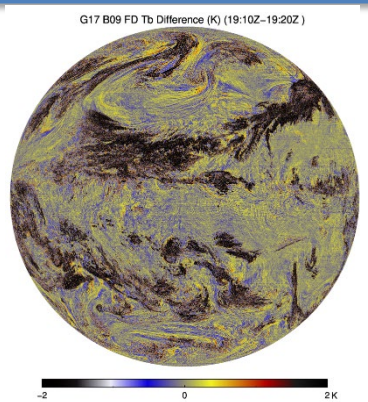


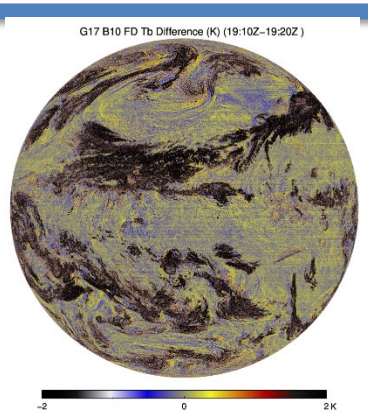


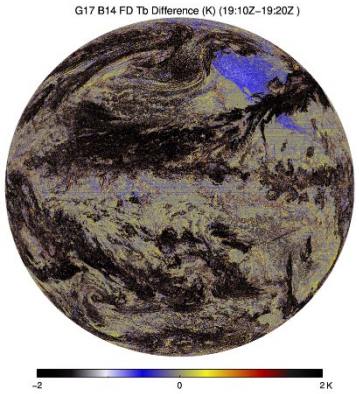
Shown at all the LWIR bands

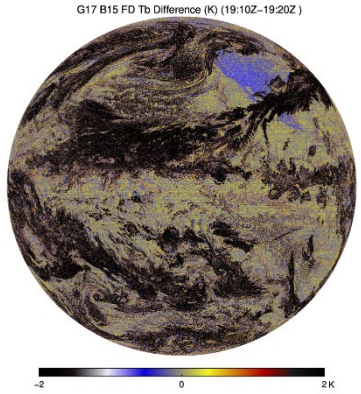
B08-B16 at 19:10 – 19:20Z

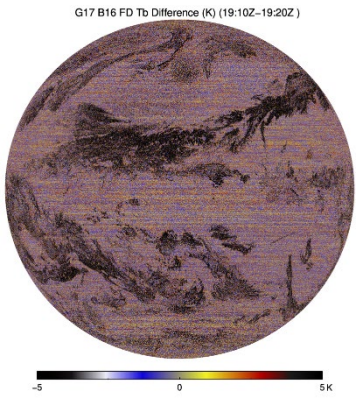










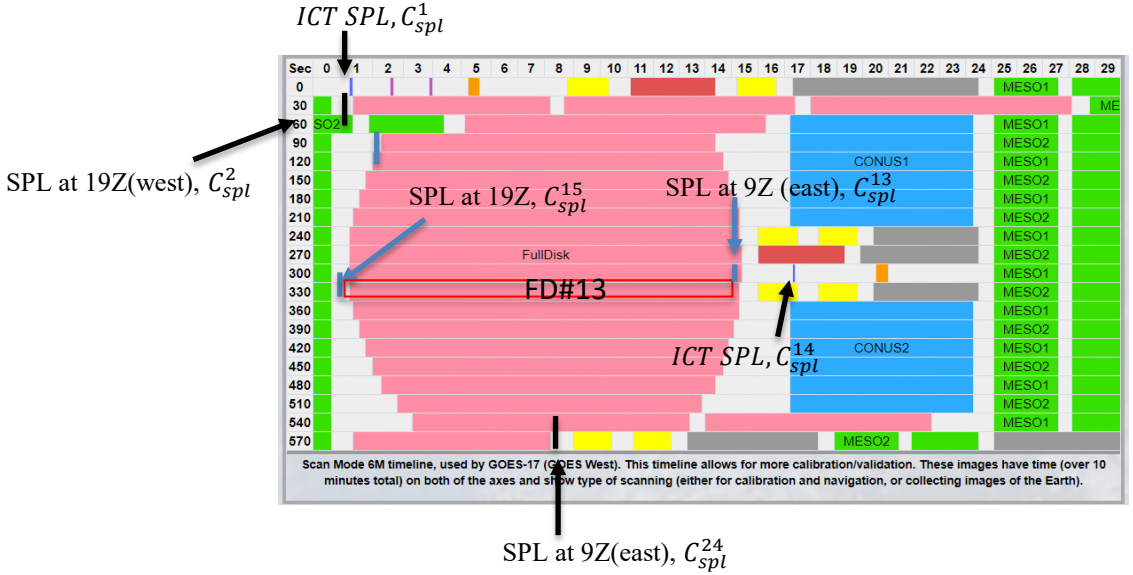


Much less magnitudes of anomaly, compared to those at ~09Z

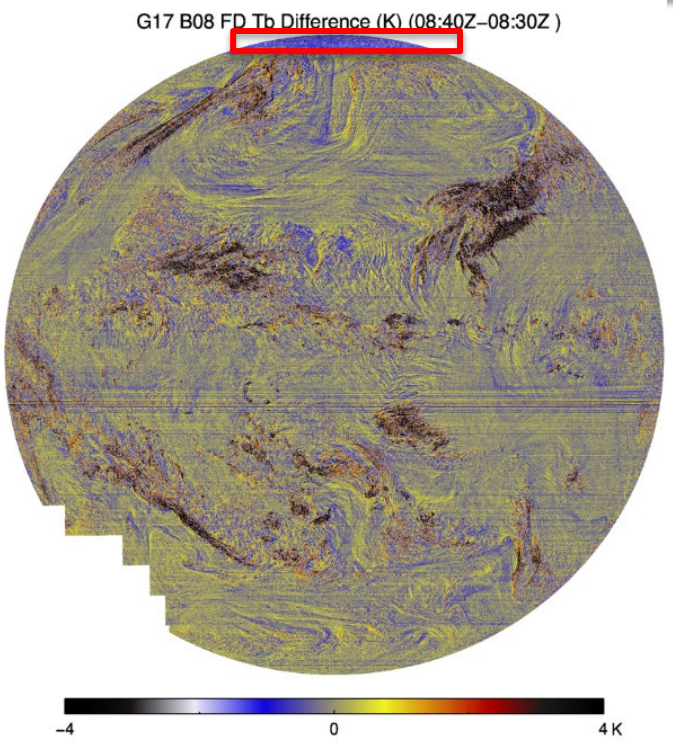
Different Performances at 9Z vs. 19Z

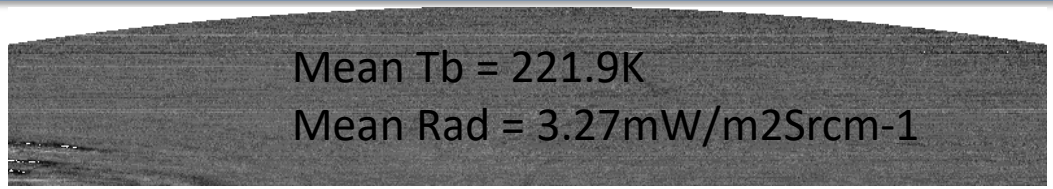
$$C_{spc} = C_{spl}^{i} + \frac{C_{spl}^{i} - C_{spl}^{i-1}}{\Delta t}\delta t$$

- FD #1 (north pole):
  - East side (~09Z)
    - $C_{spc} = C_{spl}^{1} + \frac{C_{spl}^{1} - C_{spl}^{24}}{\Delta t}\delta t$
    - δt: time from C_{spl}^{1}
  - west side (~19Z)
    - $C_{spc} = \delta t C_{spl}^{2} + \frac{C_{spl}^{2} - C_{spl}^{1}}{\Delta t}$
    - δt: time from C_{spl}^{2}
  - δt (east, ~09Z) > δt (west, ~19Z)
    - $\frac{\delta t}{\Delta t}$ (west, ~19Z) = 0 – 0.3
    - $\frac{\delta t}{\Delta t}$ (east, ~9Z) = 1.5 – 2
- FD #13 (near Equator):
  - East side (~09Z)
    - $C_{spc} = C_{spl}^{14} + \frac{C_{spl}^{14} - C_{spl}^{13}}{\Delta t}\delta t$
    - Δt = 2-3 seconds
    - *δt : time from* C_{spl}^{14}, 13 – 28 seconds
  - West side (~19Z)
    - $C_{spc} = C_{spl}^{15} + \frac{C_{spl}^{15} - C_{spl}^{14}}{\Delta t}\delta t$
    - Δt > 15 seconds
    - *δt : time from* C_{spl}^{15}, 0 – 15 seconds
  - *δt/Δt*:
    - (West, ~19z) = 0 – 1
    - (East, ~9z) = 0 - 13



Impact at the North Pole Swath

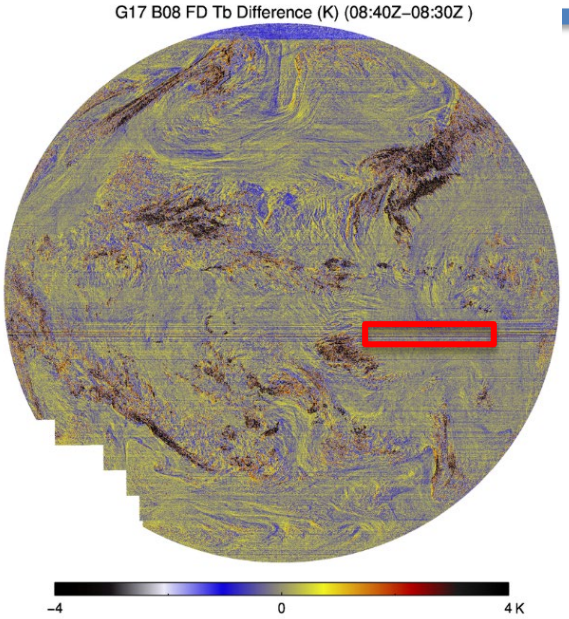


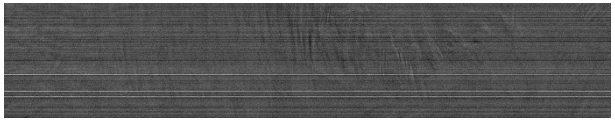


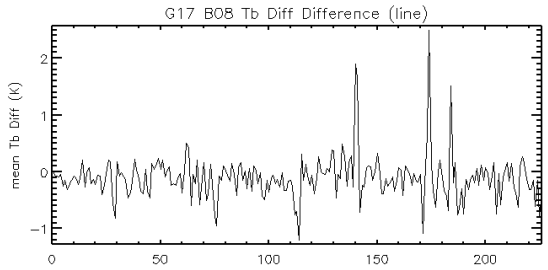
	Mean Tb Diff @ 300K
B08	-0.14 (±0.07)
B09	-0.17 (±0.10)
B10	-0.17 (±0.17)
B11	-0.17 (±0.30)
B12	-0.32 (±0.28)
B13	-0.28 (±0.42)
B14	-0.36 (±0.47)
B15	-0.64 (±0.58)
B16	-1.08 (±1.62)

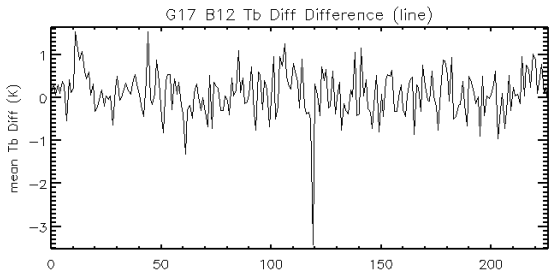
Mean Tb Difference = -1.20 (±0.65)K
Mean Radiance Difference = -0.079(±0.042) mW/Srm2cm-1
Tb difference @ 300K = -0.14K

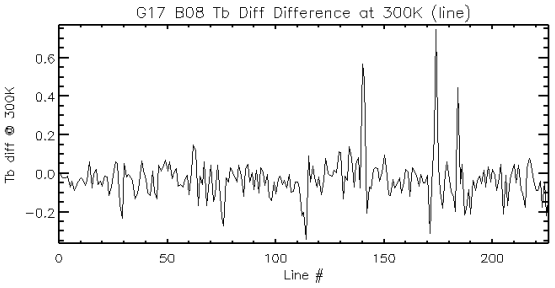
Impact at Near Equator Swath

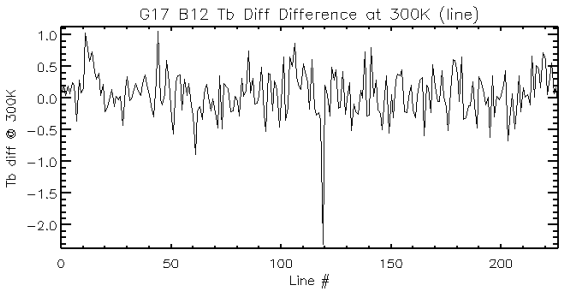












$$\overline{R\_Diff_{iline}} = mean(R\_Diff_{iline,ielem})$$

Some IR bands sometimes may display strong striping > 1K

Summary

- The midnight calibration anomaly, when displayed with FD images, occurs at two FD swaths - one at North Pole and the other near the Equator
  - The North pole anomaly is showed as calibration bias, while the near Equator swath may be dominated with striping
  - B08 – B16 are affected
- The anomaly is caused by an inherent deficiency of the pCal algorithm, and only appears when the pCal is enabled at stable FPM time and the spacelook is conducted at the east side to the Earth
  - Need to meet three conditions: (1) pCal is turned on, (2) IR FPM temperature is stable, and (3) spacelook is conducted at the east side to the Earth
- Ongoing effort to mitigate the anomaly operationally

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- The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the authors and do not necessarily reflect those of NOAA or the Department of Commerce