The newly revised GSICS DCC Calibration ATBD for Geostationary Visible imagers

Raj Bhatt, David Doelling, Conor Haney, Benjamin Scarino, and Arun Gopalan

CERES Imager and Geostationary Calibration Group (IGCG)

NASA Langley Research Center

GSICS VIS/NIR Sub-group meeting
June 10, 2021

Motivation and objectives

- *Need a comprehensive ATBD to assist GSICS agencies in delivering GSICS DCC calibration products*
  - *an improvement upon the 2011 DCC ATBD*
- *Provide a reference template and guidelines for agencies to document GSICS operational DCC products and calibration activities*
- *Facilitate the consistent implementation of the algorithm across agencies and sharing of best practices*
- Ultimately, the ATBD will serve as a key document for writing a joint agency paper on DCC calibration
  - *include agency-specific implementation and validation results*

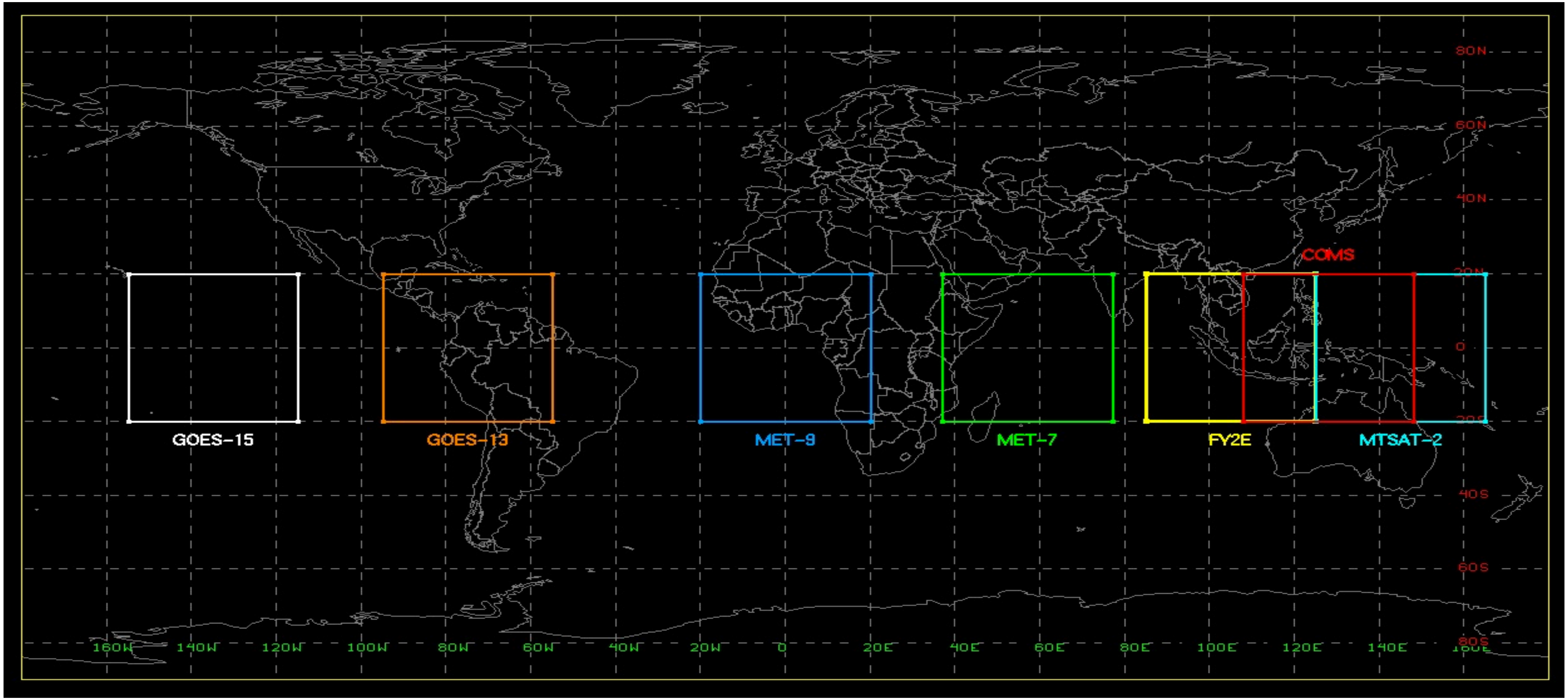
Outline

- **Background**
  - ***Key changes in the revised DCC Calibration ATBD***
- **DCC Calibration ATBD**
  - ***DCC identification, Filtering, Angular/Statistical transformations***
  - ***DCC Characterization using NOAA-20 VIIRS as a reference instrument***
  - ***Derivation of reference DCC mode radiances for GEO domains***
  - ***IR Brightness Temperature (BT) threshold normalization between GEO and VIIRS***
  - ***Spectral Band Adjustment Factors (SBAF)***
  - ***Seasonal correction of DCC responses***
  - ***Transfer of VIIRS Calibration to GEO imagers using DCC modes***
  - ***Uncertainty Analysis***
- **Summary**

Background

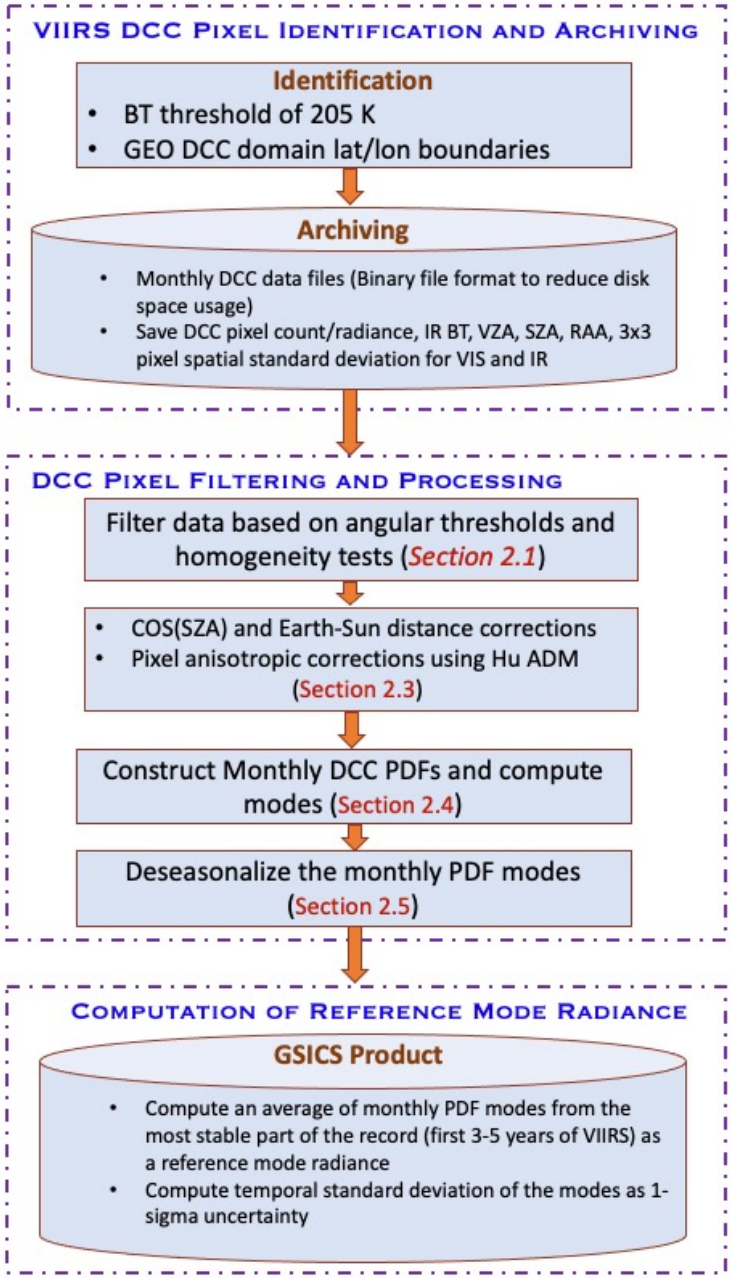
- First GSICS DCC Calibration ATBD was published in 2011
  - Focused on calibrating GEO visible channel (0.65 μm)
  - Described algorithm for temporal trending and radiometric scaling of GEO imager to Aqua-MODIS Band 1 using non-coincident DCC measurements
- **Key highlights** of this revised DCC ATBD
  - *Improved uncertainty (IR BT threshold normalization, seasonal corrections)*
  - *Uses NOAA-20 VIIRS as a reference instrument for DCC characterization*
  - *Provides more comprehensive details on the formulation and implementation of DCC method*
    - *Reference DCC modes for multiple GEO domains, SBAF computation, uncertainty analysis, GSICS DCC products*
  - *Applies to all spectral channels with wavelengths up to 1 μm*

GEO Imagers DCC Identification Domains

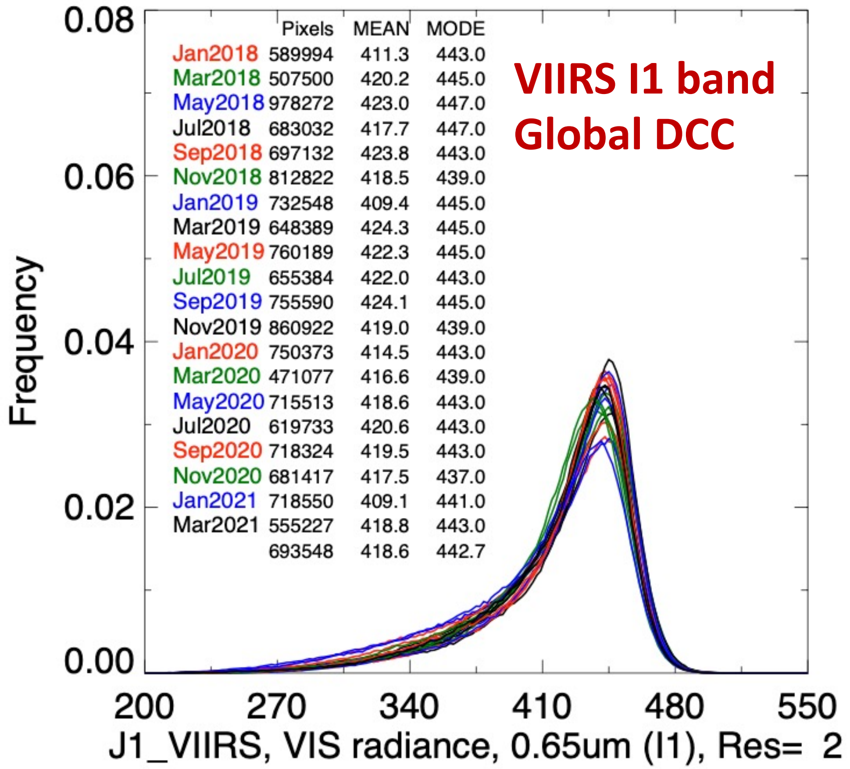


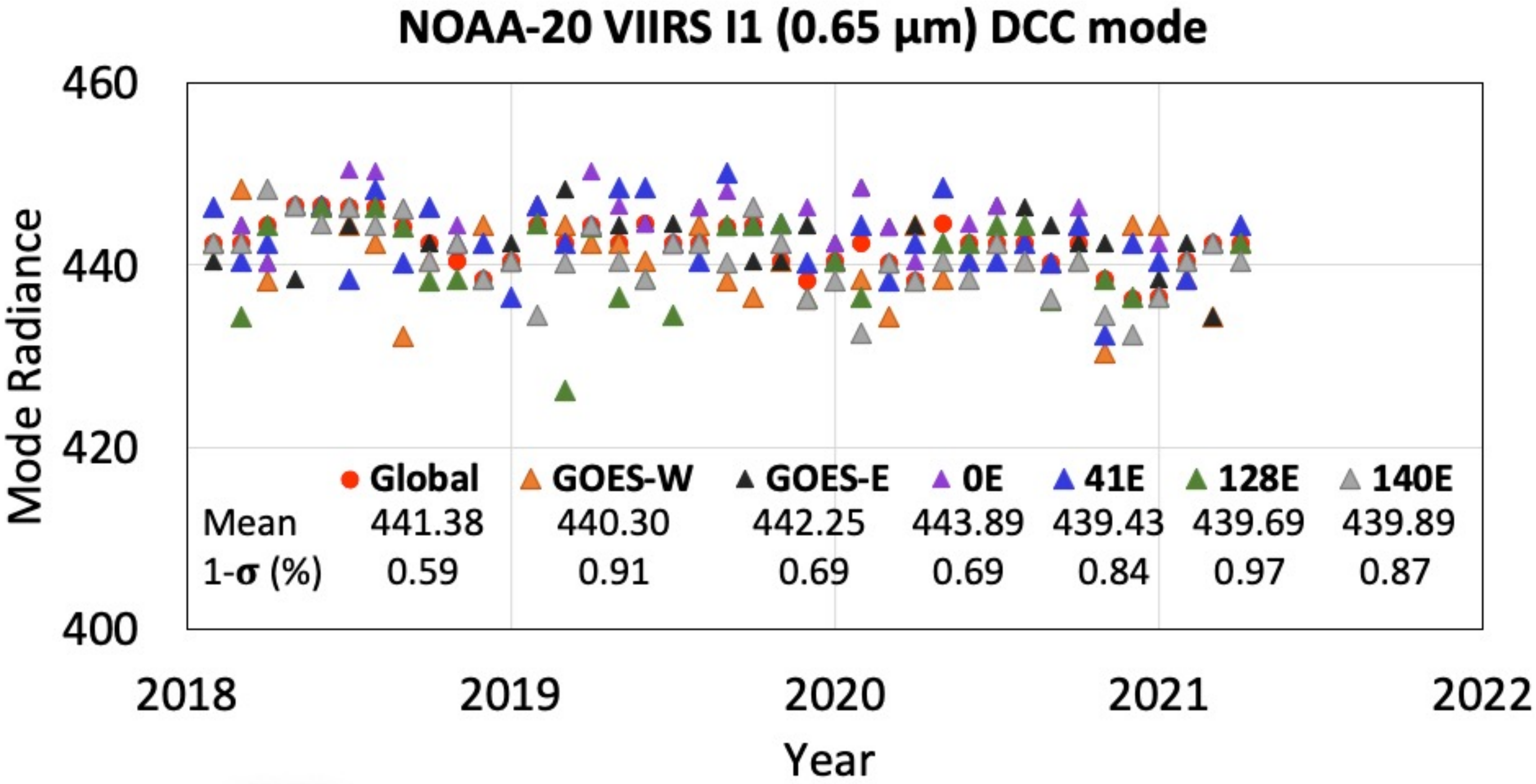
- ±20° Lat/Lon from the GEO sub-satellite point

DCC Characterization using NOAA-20 VIIRS



- Identify DCC pixels within GEO domain using M15 (10.8 µm) BT < 205 K
- Filtering
  - *Spatial homogeneity tests for filtering DCC edges*
    - $\sigma_{VIS} < 3\%$ *and* $\sigma_{BT} < 1K$ *for the* 3x3 pixel block surrounding a DCC pixel
  - *Angular thresholds for capturing the most Lambertian part of DCC*
    - SZA < 40°, VZA < 40°, 10° < RAA < 170°
- Anisotropic Corrections
  - *Apply COS(SZA) and Earth-Sun distance corrections*
  - *Apply Hu Angular Direction Model (ADM) to scale all DCC pixel radiances to a common set of solar and viewing conditions*
  - *Compile DCC pixels into monthly probability distribution functions (PDFs) and compute their modes*
- Derive mean and standard deviation of monthly DCC mode timeseries
  - Use the most stable record of the reference instrument (first 3-5 years)





This study uses NOAA-20 VIIRS L1B Collection 2 products from NASA Land SIPS

- ***Regional variation of DCC mode is ~1%***
  - ***brightest over 0°E longitude***
  - ***TWP DCC radiances are lower***

Reference DCC Mode Radiances ($L_{VIIRS,Mode}$) for GEO Domains

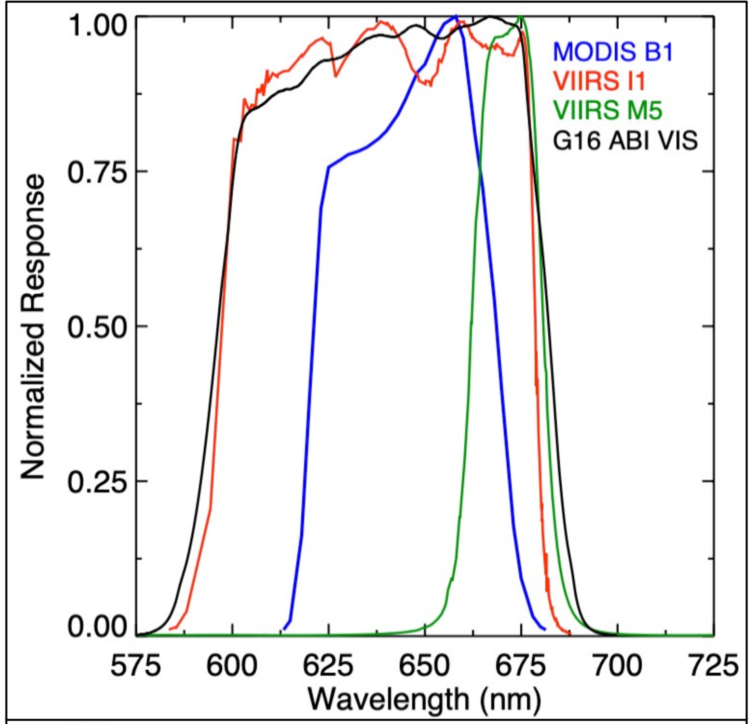
NOAA-20 VIIRS Band	Global		GOES-W (e.g., GOES-15, 11)		GOES-E (e.g., GOES-12, 16)		0°E (e.g., Met-11, 10)		41°E (e.g., Met-8)		57°E (e.g., Met-7)	
	Mean	1-σ %	Mean	1-σ %	Mean	1-σ %	Mean	1-σ %	Mean	1-σ %	Mean	1-σ %
M3 (0.48 µm)	572.75	0.50	571.98	1.27	573.78	0.79	576.54	0.86	570.60	0.91	572.80	0.92
M4 (0.55 µm)	508.55	0.60	508.24	0.96	509.47	0.76	511.11	0.86	506.40	1.27	508.50	0.93
M5 (0.67 µm)	431.49	0.53	430.82	1.03	431.85	0.68	434.30	0.78	430.26	1.11	432.05	0.81
M7 (0.86 µm)	268.39	0.42	267.55	0.65	269.29	0.41	270.31	0.62	267.67	0.67	269.62	0.62
I1 (0.65 µm)	441.38	0.59	440.35	0.91	442.25	0.69	443.89	0.69	442.84	0.84	442.09	1.24

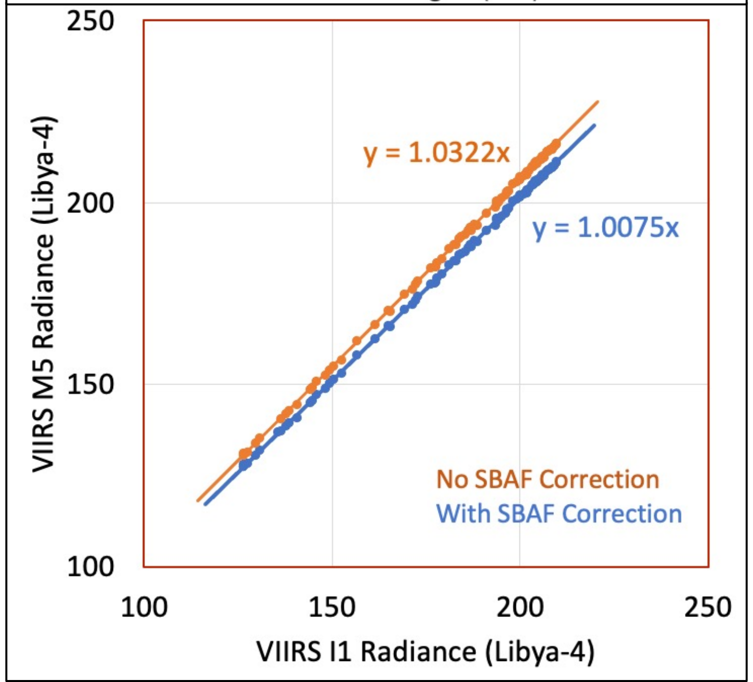
NOAA-20 VIIRS Band	82°E (e.g., INSAT-3D)		100°E (e.g., FY2G)		128°E (e.g., COMS)		140°E (e.g., MTSAT-2, Him-8)	
	Mean	1-σ %	Mean	1-σ %	Mean	1-σ %	Mean	1-σ %
M3 (0.48 µm)	570.60	1.24	569.37	0.93	571.72	1.06	570.81	0.87
M4 (0.55 µm)	505.63	1.34	504.91	1.16	507.06	1.05	506.55	1.03
M5 (0.67 µm)	430.30	1.00	429.43	0.93	430.92	0.98	429.90	0.86
M7 (0.86 µm)	267.36	0.68	267.83	0.66	267.93	0.72	267.57	0.62
I1 (0.65 µm)	439.32	1.22	438.09	1.11	439.69	0.97	439.89	0.87

- ***For visible channel (0.65 µm), two sets of reference mode values are provided based on M5 and I1 bands***
- ***Units of these mode radiances are*** $Wm^{-2}\mu m^{-1}sr^{-1}$

VIIRS M5 vs I1

- Both are calibrated using the same solar diffuser onboard
- I1 band has higher spatial resolution than M5
- I1 SRF has a better spectral match with MODIS band 1 and visible channels in new generation GEO imagers
- *Do you get the same GEO calibration slope using M5 and I1 as reference???*
  - ***M5 is brighter (0.75%) than I1***
  - ***GEO calibrations referenced to I1 and M5 bands should exhibit the same magnitude of difference***

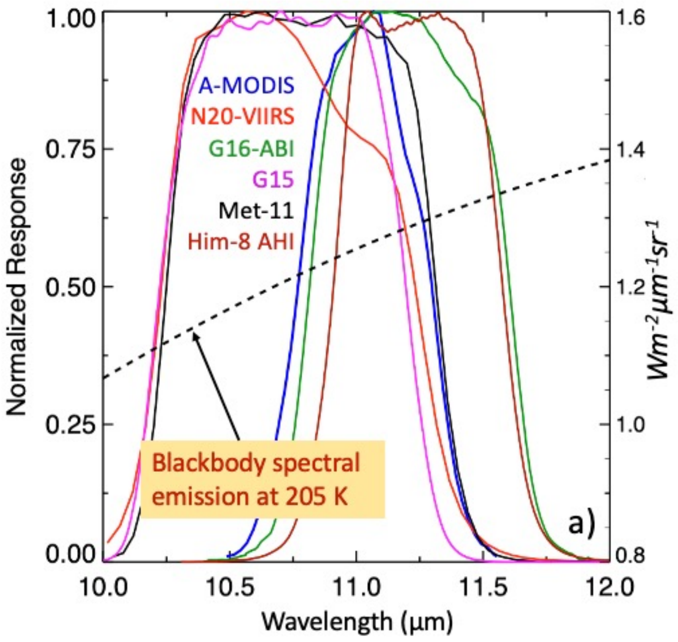


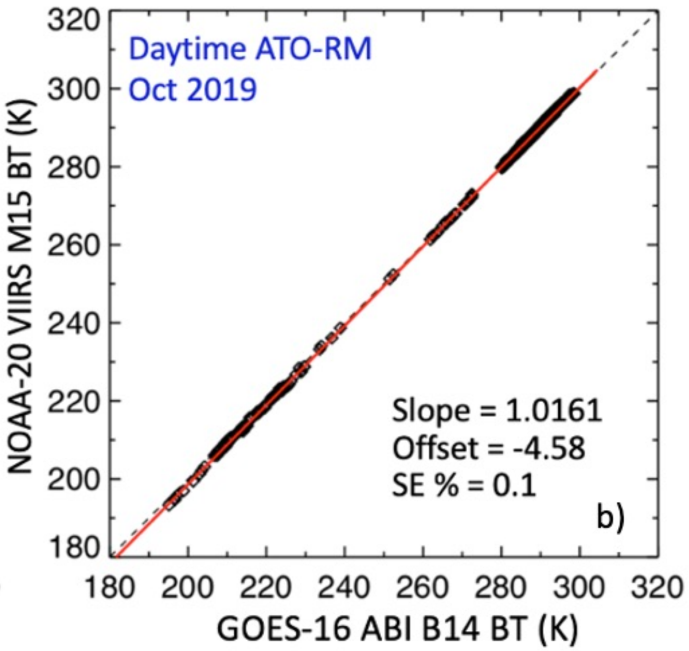


GEO Imager DCC pixel identification and Processing

- DCC method does not require coincident measurements between GEO and VIIRS
- Five GEO images per day surrounding the 1:30 PM local time (equator crossing time of NOAA-20) are used for DCC sampling
- Angular thresholds and spatial homogeneity tests are the same as that used for the VIIRS DCC samples
- IR BT threshold may need to be adjusted for GEO
  - **to account for any differences in SRFs and calibration of the IR channels between GEO and VIIRS**
- VIIRS based reference mode radiances must be adjusted to account for the SRF differences (apply **SBAF**) between the GEO and VIIRS visible channels

IR BT threshold normalization

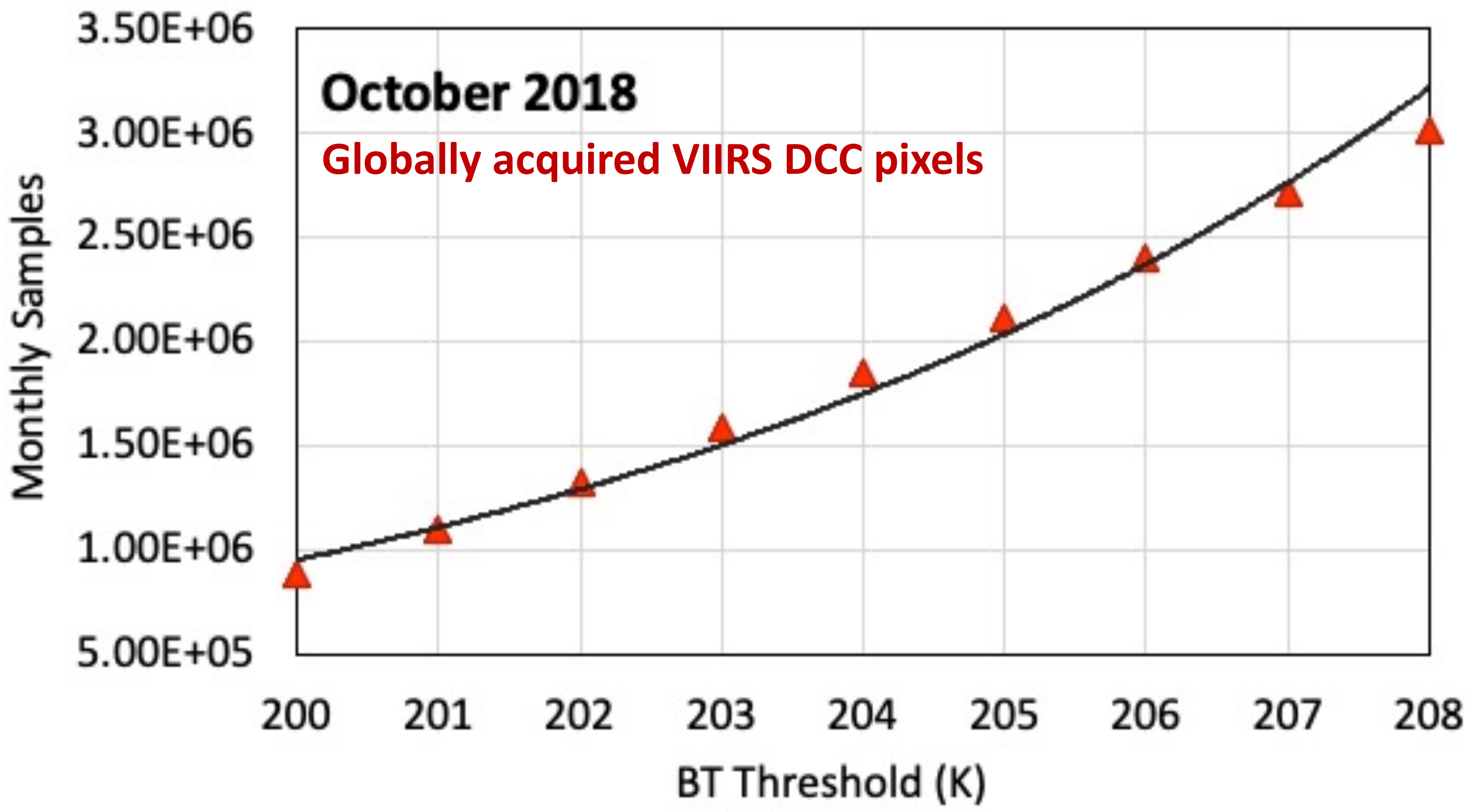




GEO Imager IR Channel	*BT threshold equivalent to VIIRS M15 205 K*
Met-8 Band 9 (10.8 μm)	206.0
Met-11 Band 9 (10.8 μm)	205.9
GOES-16 Band 14 (11.2 μm)	206.1
Him-08 Band 13 (10.8 μm)	206.8
FY2G Band 2 (10.8 μm)	203.5
COMS Band 4 (10.8 μm)	206.7

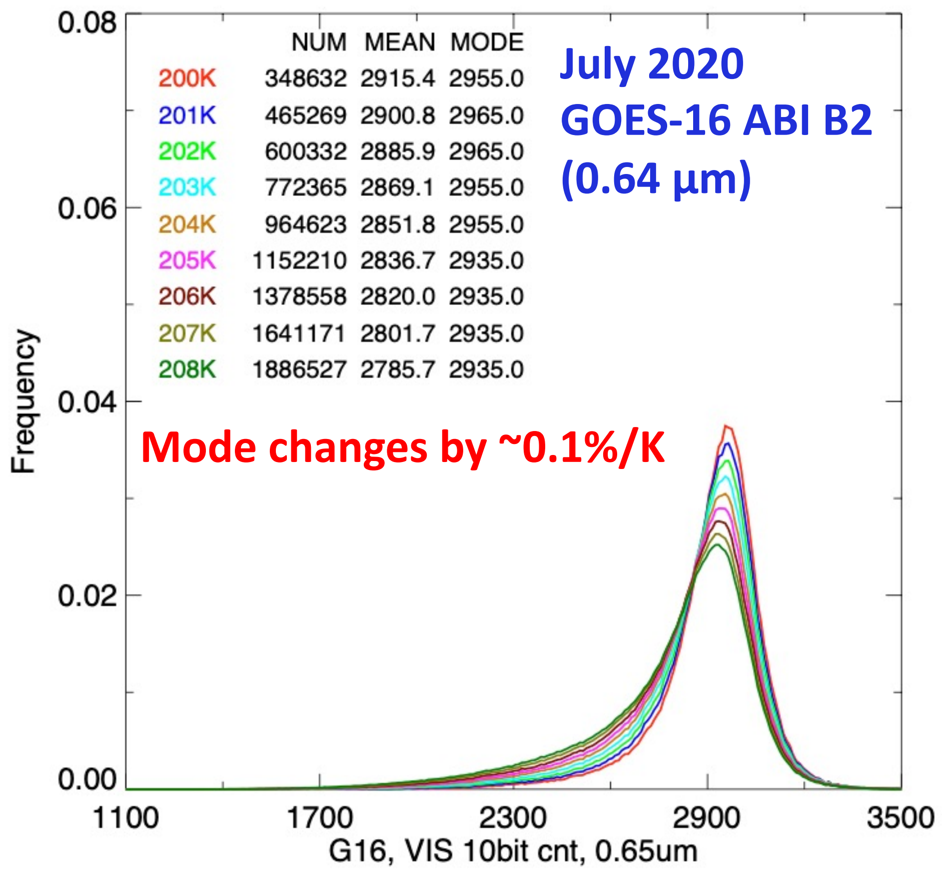
- GOES-16 ABI and Himawari-8 AHI IR channels would measure DCC BT slightly warmer than NOAA-20 VIIRS M15, provided they are all consistently calibrated
- *A DCC pixel with a BT of 205 K measured by VIIRS M15 is recorded as 206.1 K by GOES-16 ABI B14*
- *For consistent DCC sampling between GEO and VIIRS, the GEO IR BT threshold must be adjusted to equivalent VIIRS BT*
- *The magnitude of BT adjustment might change over time depending upon the temporal stability of the IR calibration onboard GEO and VIIRS*

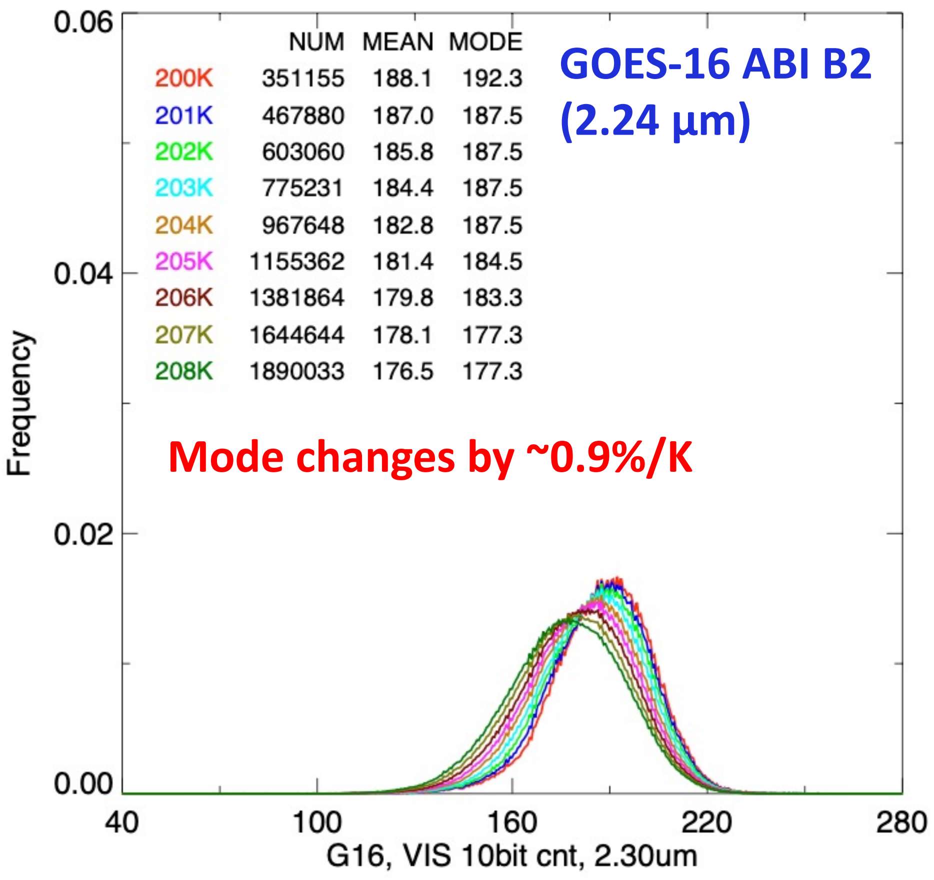
IR BT threshold vs DCC Samples



- IR BT threshold affects sample size
- Exponential relationship between sample size and BT threshold
- Adequate and consistent sampling is a key to the success of DCC method

IR BT threshold vs PDF mode



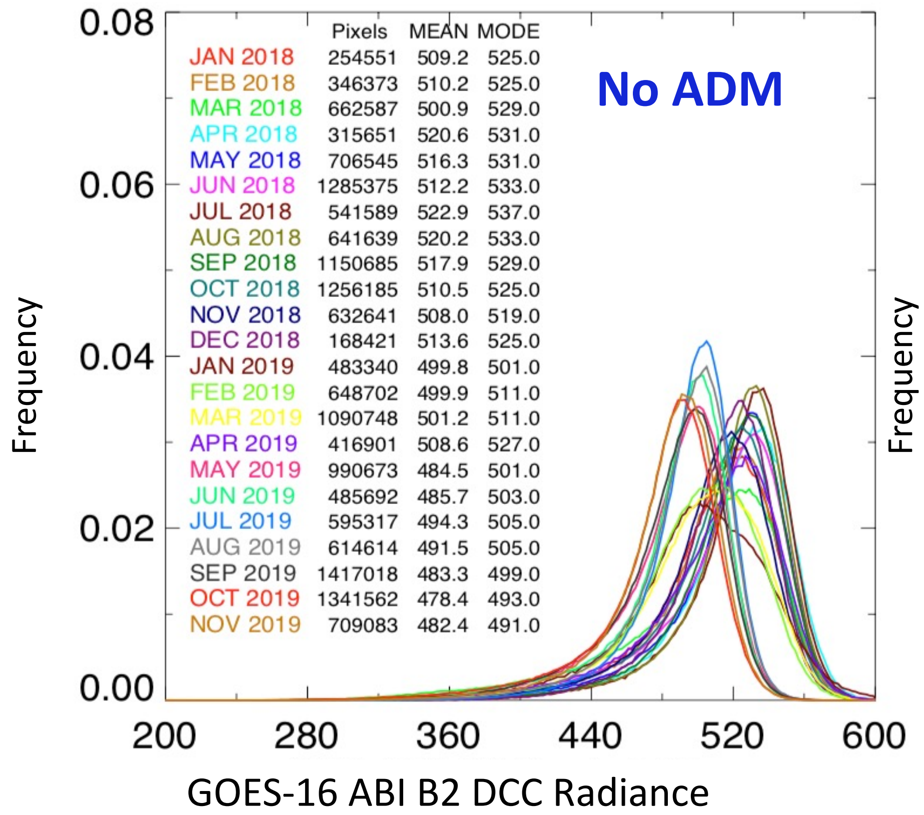


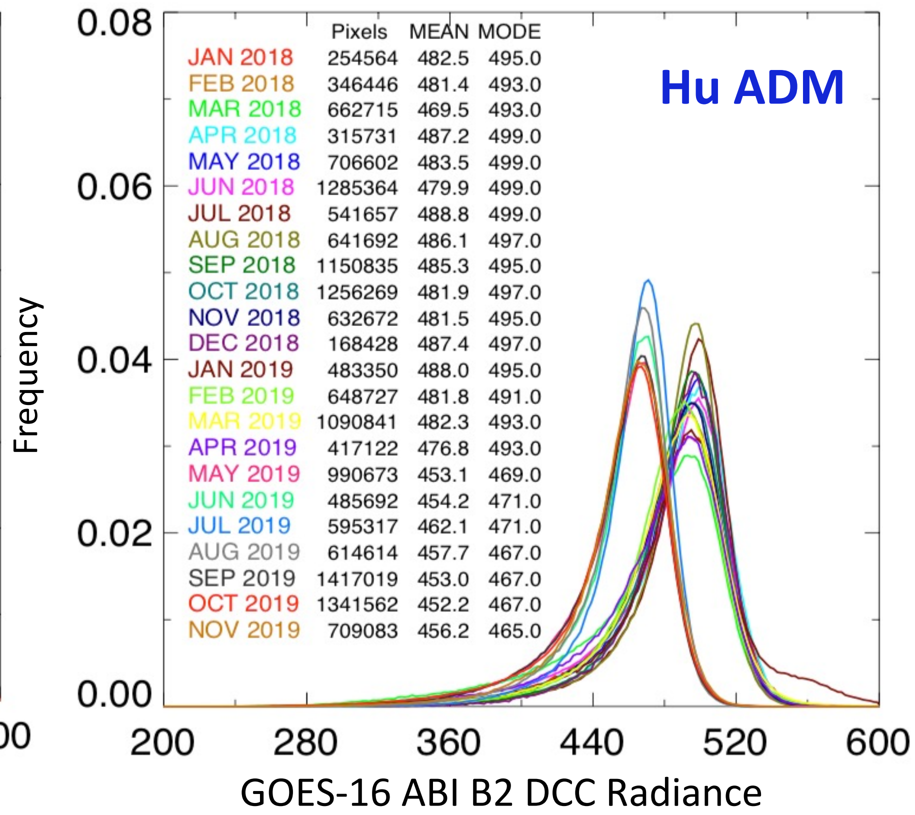
- BT threshold affects DCC PDF mode
  - Lower BT threshold results in a higher mode value
  - ***VIS/NIR bands PDF modes are more stable (~0.1%/K) compared to SWIR bands (~0.9%/K)***

Advantages of IR BT threshold normalization

- Normalizing the GEO IR BT to that of the VIIRS IR channel
  - *mitigates any dependency of the DCC PDF mode on BT threshold, thereby improves the inter-calibration accuracy*
  - *ensures consistent DCC sampling between the reference VIIRS and target GEO imagers*

Angular Transformations



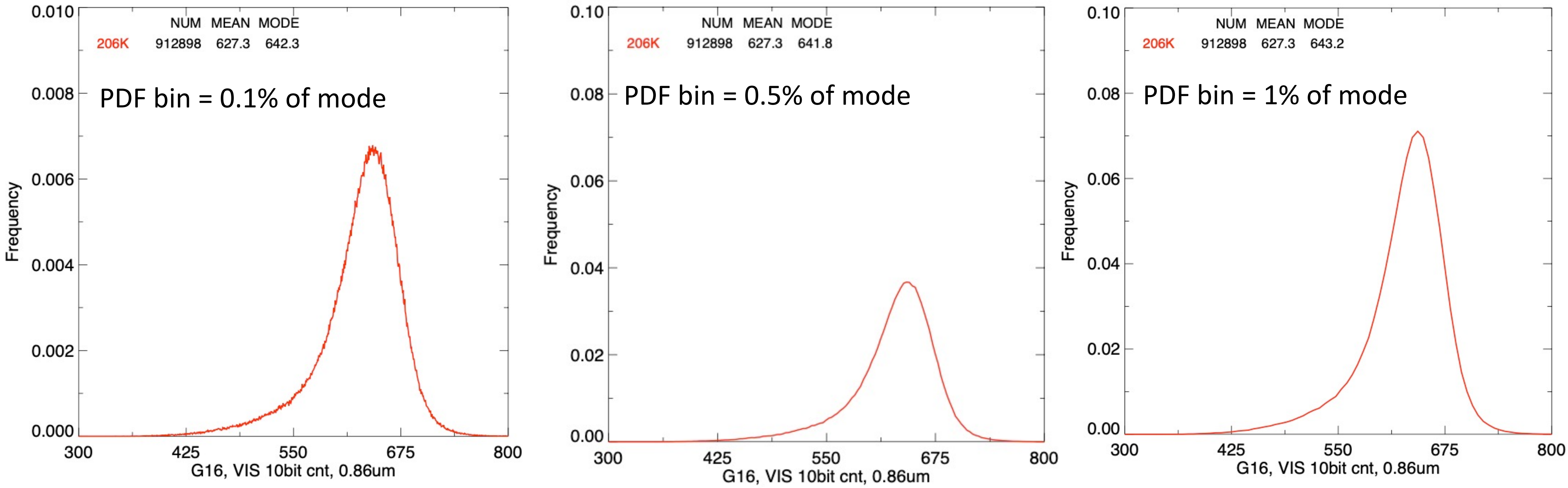


- Prior to PDF formulation, DCC pixel radiances are corrected for anisotropy using Hu ADM
- Hu ADM reduces the temporal variability in the DCC mode response by more than 30% in VIS/NIR bands

$$L_{corrected} = \frac{L_{observed}}{d^2 \times \cos(SZA) \times BRF(SZA, VZA, RAA)}$$

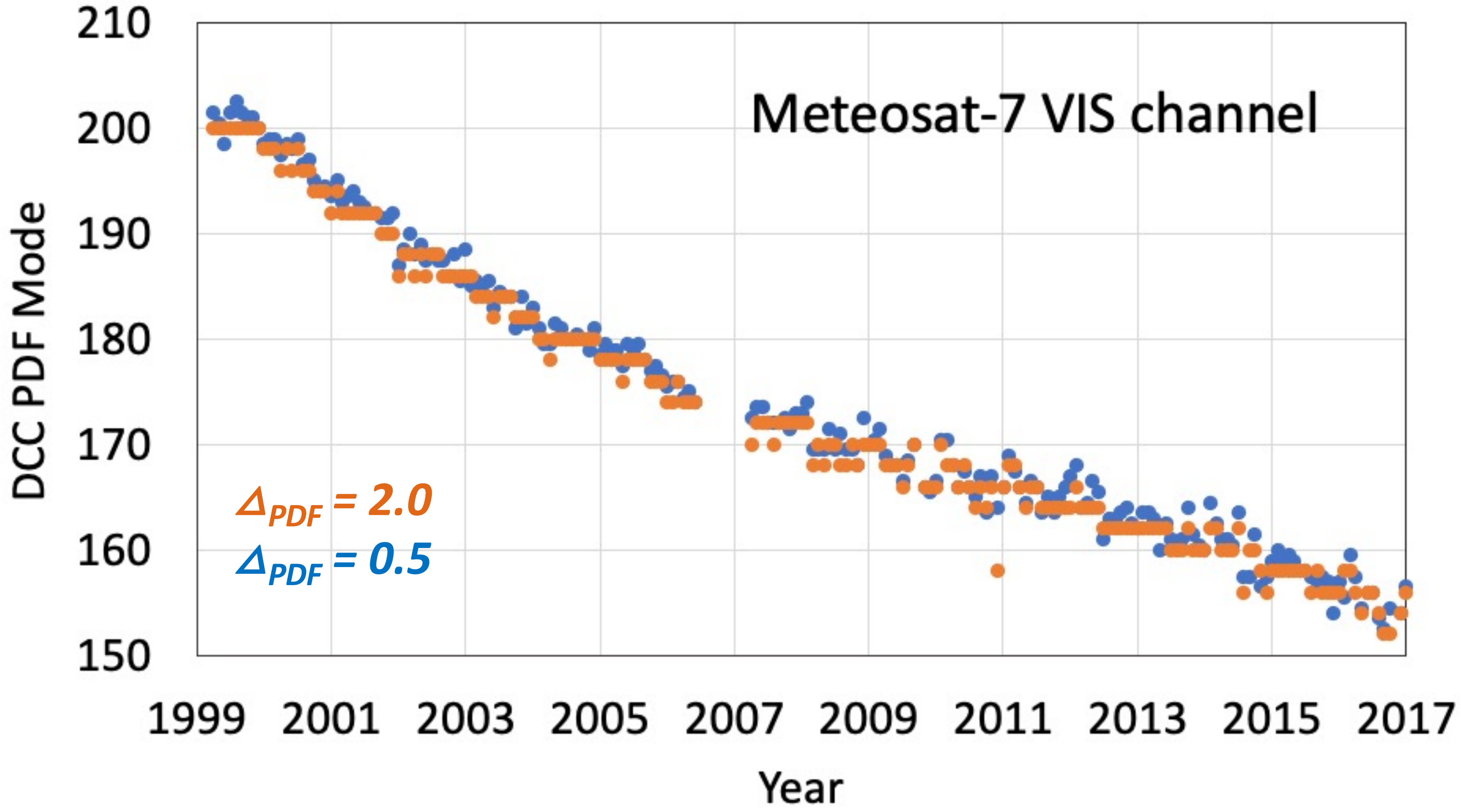
BRF is a bidirectional reflectance factor from Hu ADM LUT

PDF bin size (Δ_{PDF}) optimization



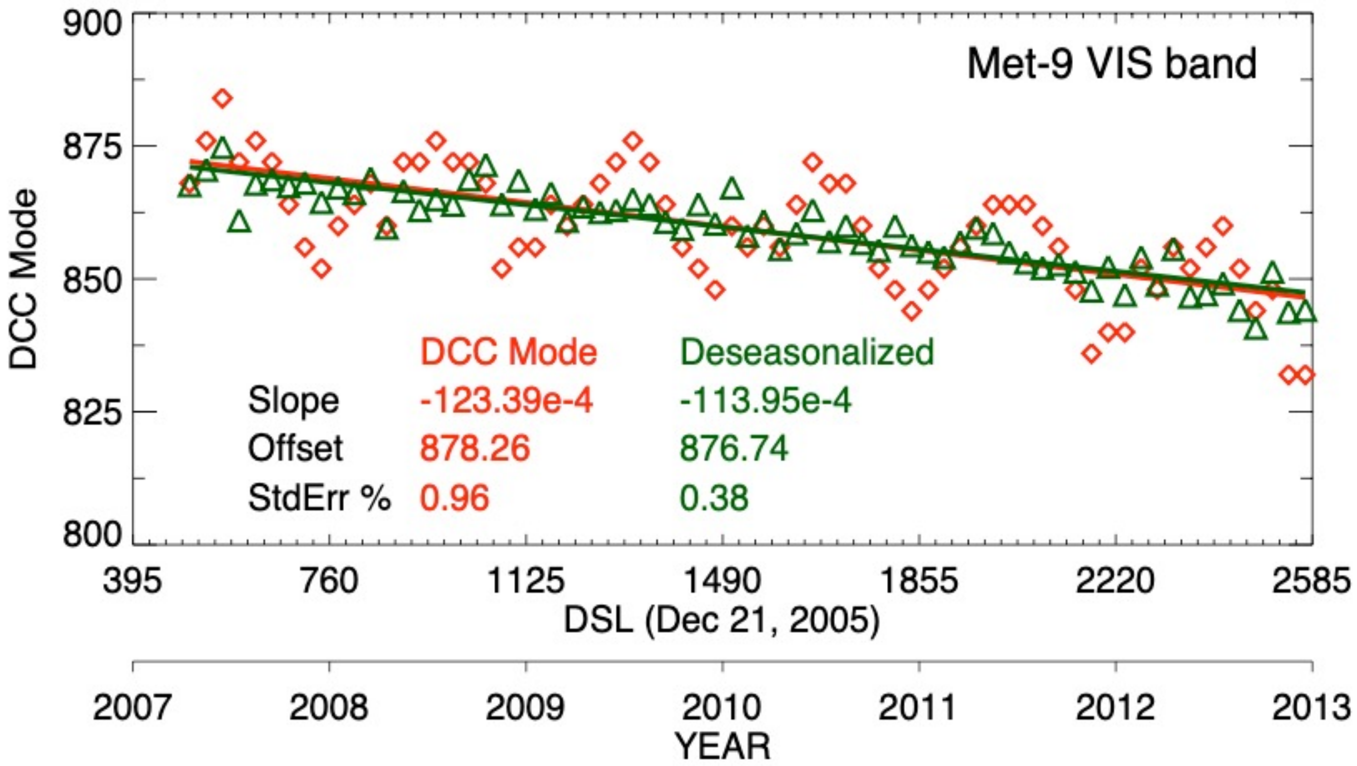
- Smaller Δ_{PDF} results in spiky PDFs (with multiple peaks) and may result in noisier DCC time series
- Larger Δ_{PDF} gives smoother PDFs, but may not detect small magnitude drifts

PDF bin size and drift detection



- DCC can detect calibration drifts greater than PDF bin size
- ***Δ_{PDF} equal to 0.2-0.4% of mode is optimal***
- ***Magnitude of Δ_{PDF} may need to be changed over time as sensor degrades***

Deseasonalization



- Some GEO domains (e.g., Meteosats at 0°E) exhibit noticeable seasonality in DCC time series
- **Ratio-to-moving-average method** for seasonal correction
  - ***only seasonal components are removed***
  - ***absolute mode values and temporal trends are preserved***
- Temporal variability is reduced significantly

Computation of monthly GEO calibration slope

Eqn. 1 $$L_{GEO,Mode,reference} = SBAF \times L_{VIIRS,Mode}\ (Wm^{-2}\mu m^{-1}sr^{-1})$$

From Table in slide 8
Constant in time

Eqn. 2 $$\gamma_{cross-cal} = \frac{L_{GEO,Mode,reference}}{L_{GEO,Mode,observed}}\ \text{(unitless)}$$

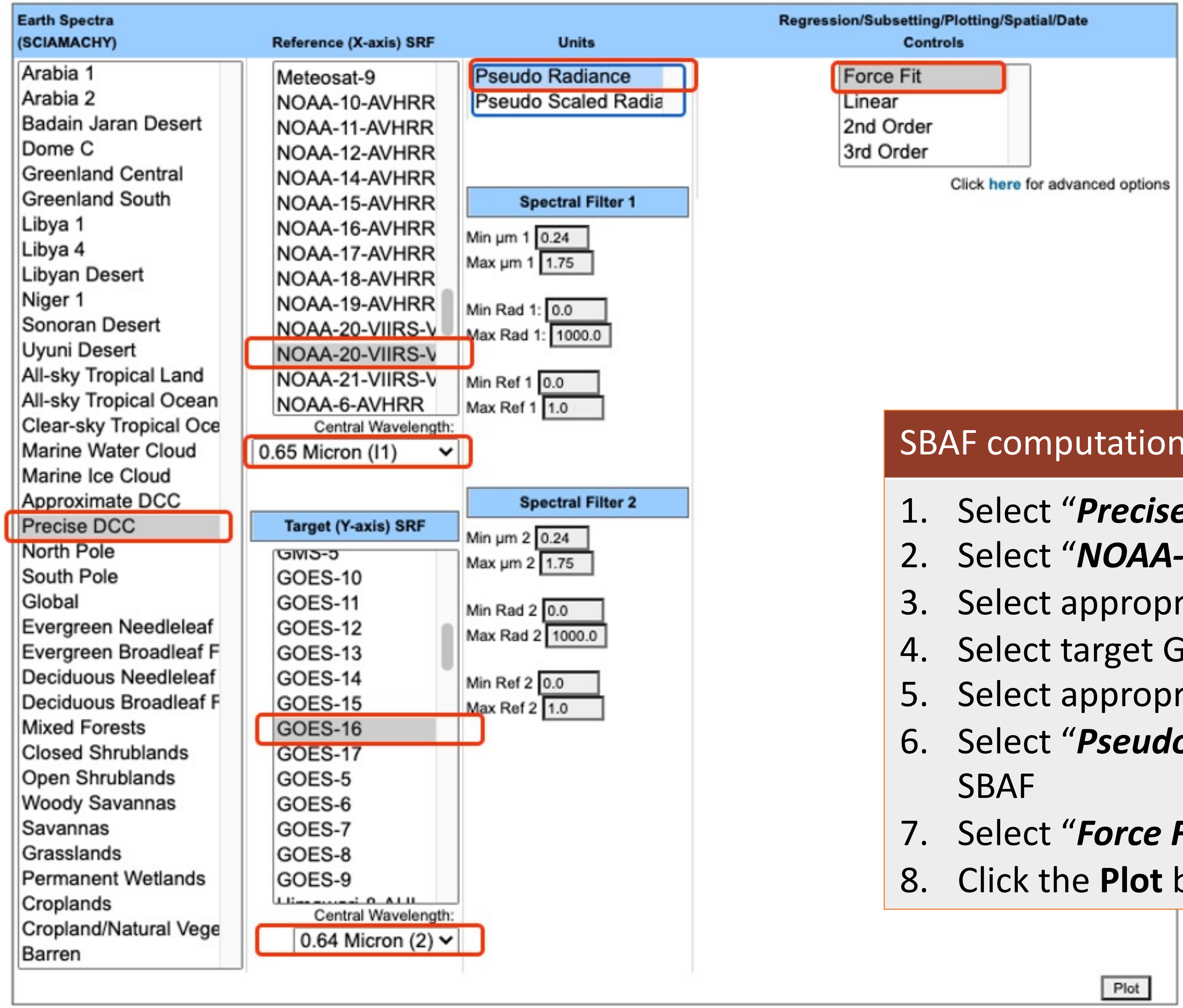
Eqn. 3 $$\gamma_{GEO,cal-slope} = \frac{L_{GEO,Mode,predicted}}{C_{GEO,Mode,observed}}\ (Wm^{-2}\mu m^{-1}sr^{-1}/Count)$$

L stands for Radiance
C represents Counts

$L_{VIIRS,Mode}$ is the reference DCC mode radiance derived from VIIRS measurements
$L_{GEO,Mode,reference}$ is the estimated mode radiance for a GEO after adjusting $L_{VIIRS,Mode}$ for spectral differences
$C_{GEO,Mode,observed}$ is the observed GEO DCC mode count (***Space count is subtracted from GEO counts before computing the mode***)

- Inter-comparison between GEO and VIIRS spectral channels can be performed by comparing their monthly mode values
- If both imagers DCC modes are in radiance units, their ratio provides the cross-calibration coefficient ($\gamma_{cross-cal}$)
- If GEO DCC modes are in counts, the ratio of VIIRS mode radiances over GEO mode counts estimates the monthly calibration slope for the GEO imager ($\gamma_{GEO,cal-slope}$)
- Prior to these operations,
  - ***VIIRS mode radiance must be corrected for spectral differences using SBAF***
  - ***Space count or sensor offset must be subtracted from the GEO counts***

Computation of SBAF

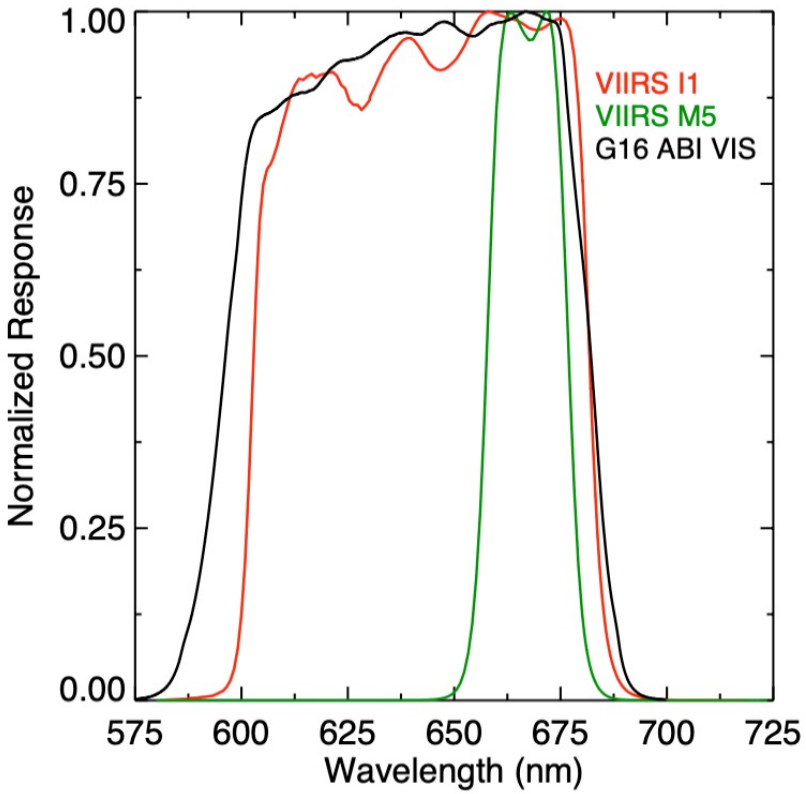


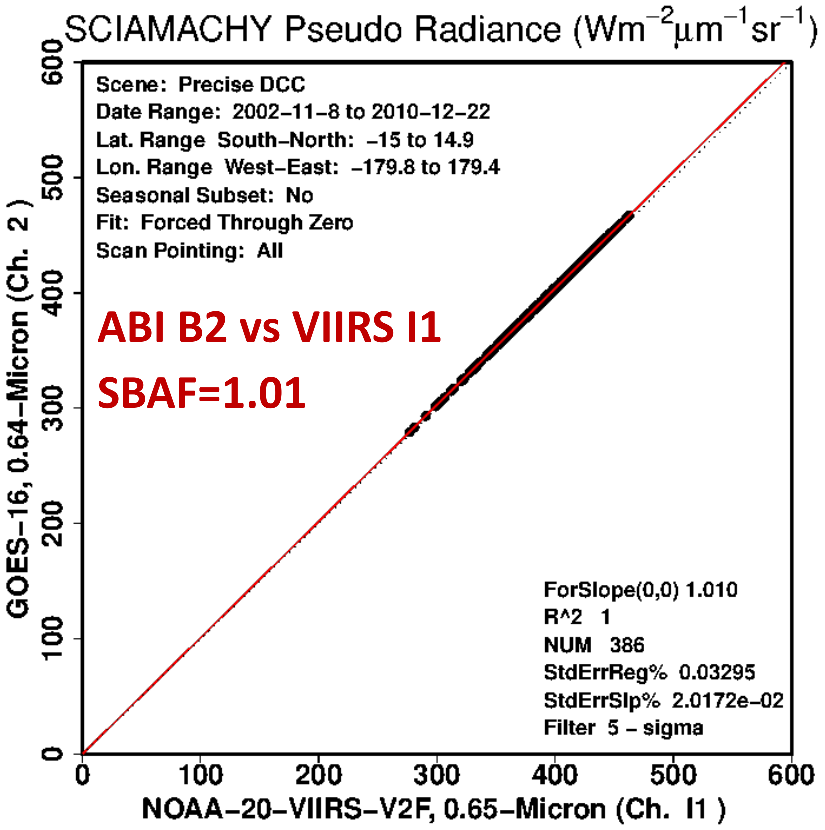
- CERES IGCG provides an online SBAF computation tool based on SCIAMACHY hyperspectral datasets over Earth targets

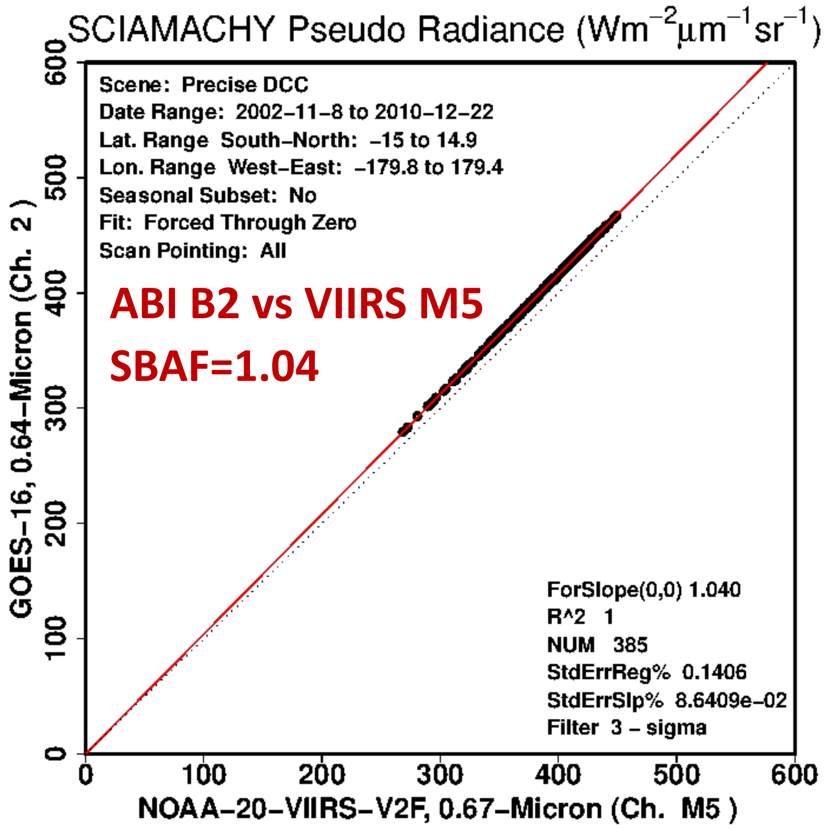
https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SBAF

SBAF computation steps
1. Select "***Precise DCC***" from the Earth Spectra column
2. Select "***NOAA-20-VIIRS-V2F***" for **Reference (X-axis) SRF**
3. Select appropriate **Central Wavelength** for reference VIIRS SRF
4. Select target GEO imager for **Target (Y-axis) SRF**
5. Select appropriate **Central Wavelength** for target GEO SRF
6. Select "***Pseudo Radiance***" from **Units** column for radiance SBAF
7. Select "***Force Fit***" for Regression analysis
8. Click the **Plot** button

DCC SBAF examples

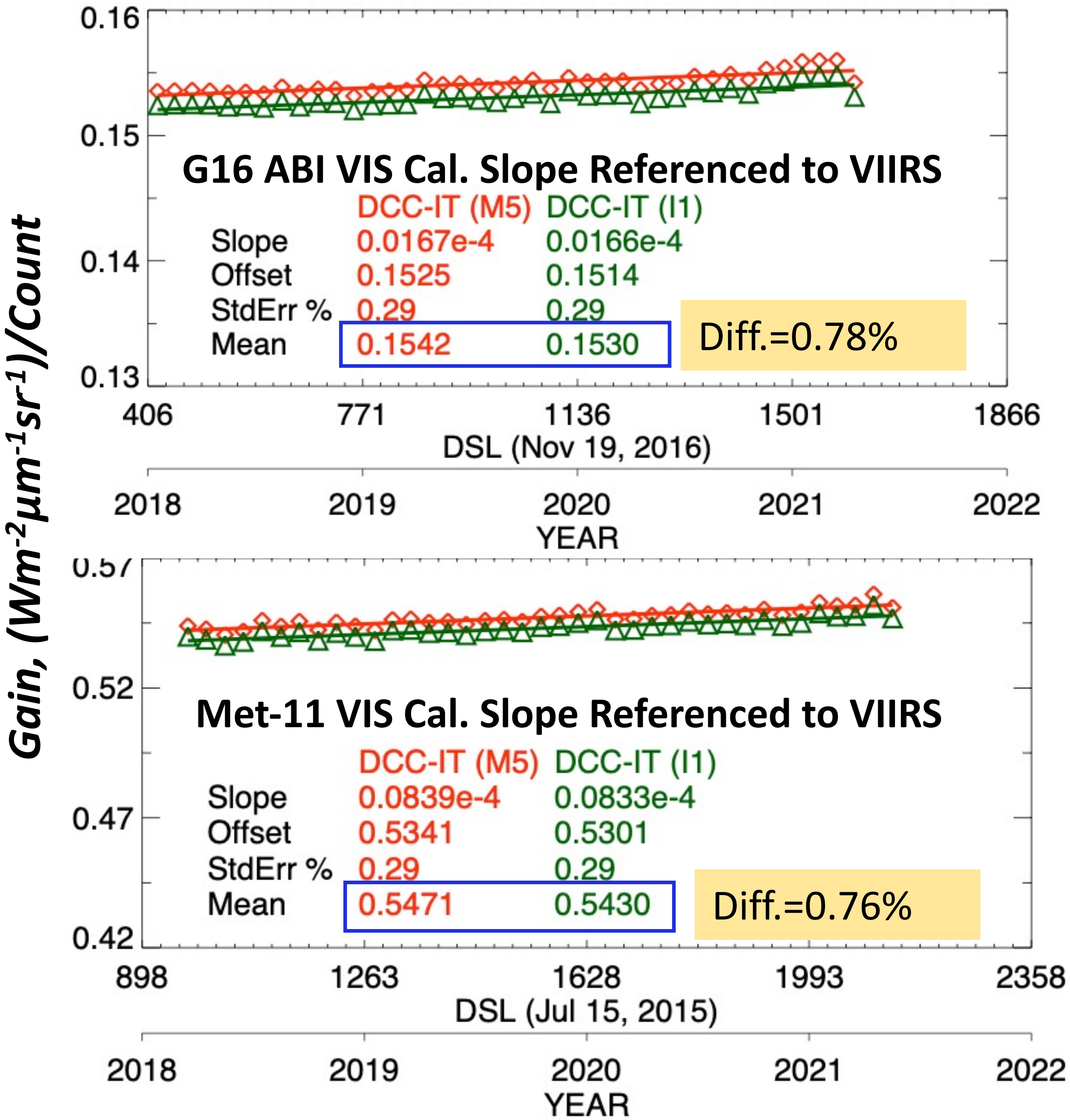




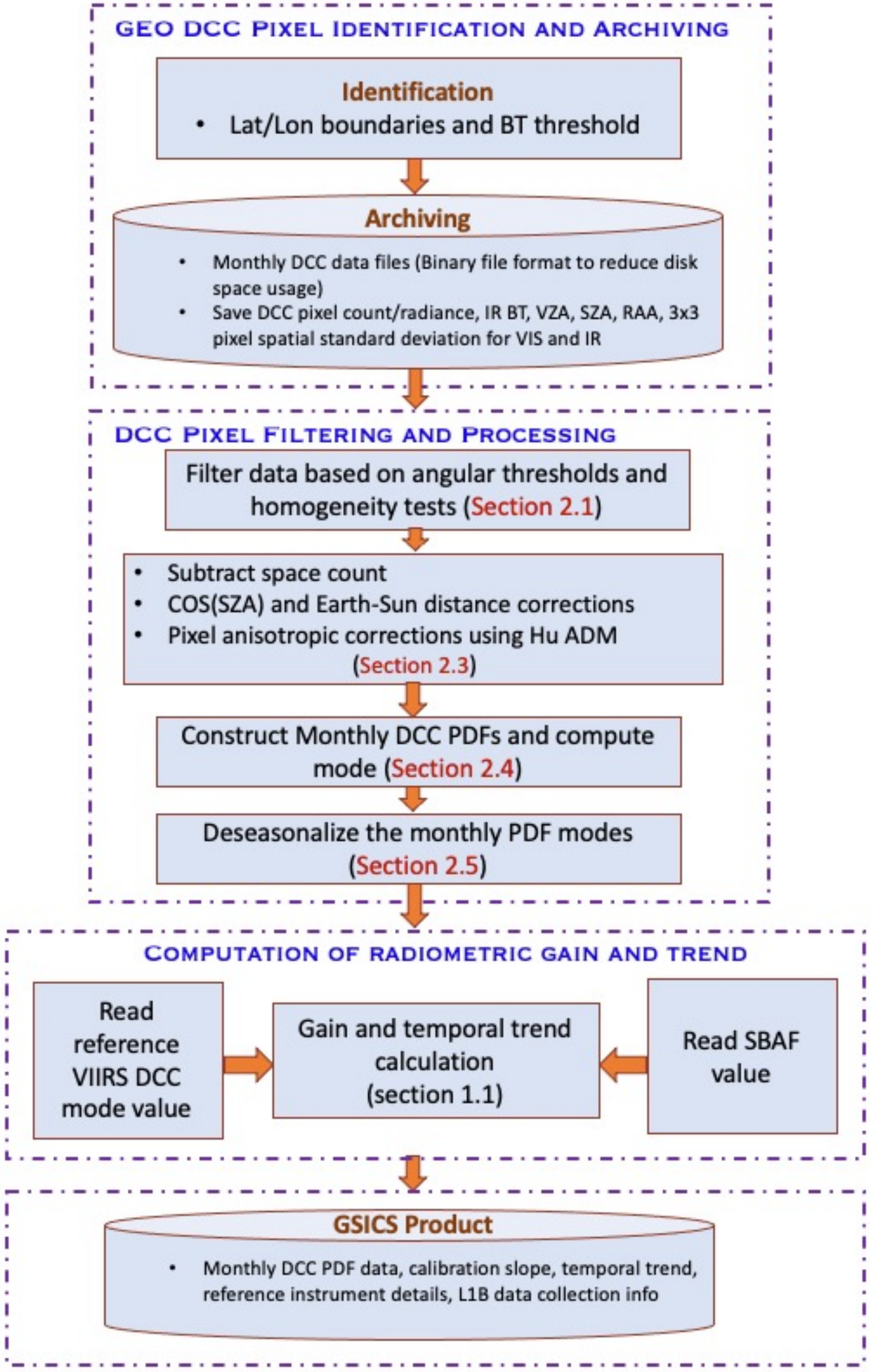


- VIIRS I1 SRF matches very well with GOES-16 ABI band 2 SRF
- Spectral corrections between VIIRS I1 and GOES-16 ABI band 2 is only 1%
- DCC SBAF between VIIRS M5 and ABI band 2 is 4%

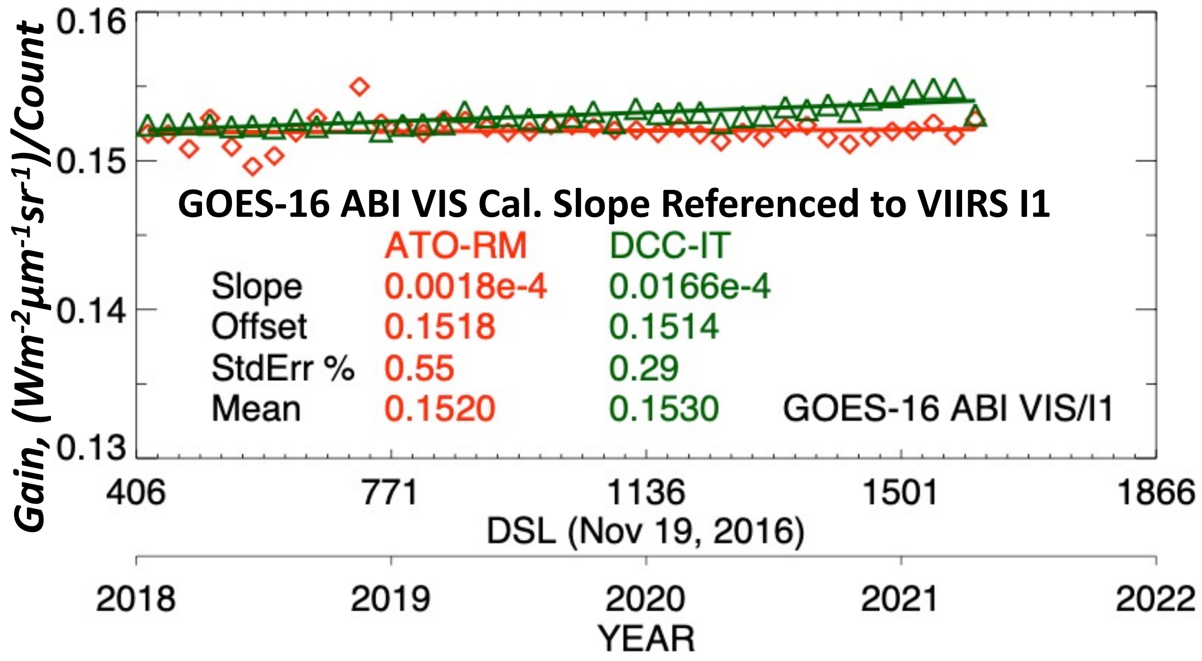
Computation of $\gamma_{GEO,cal-gain}$

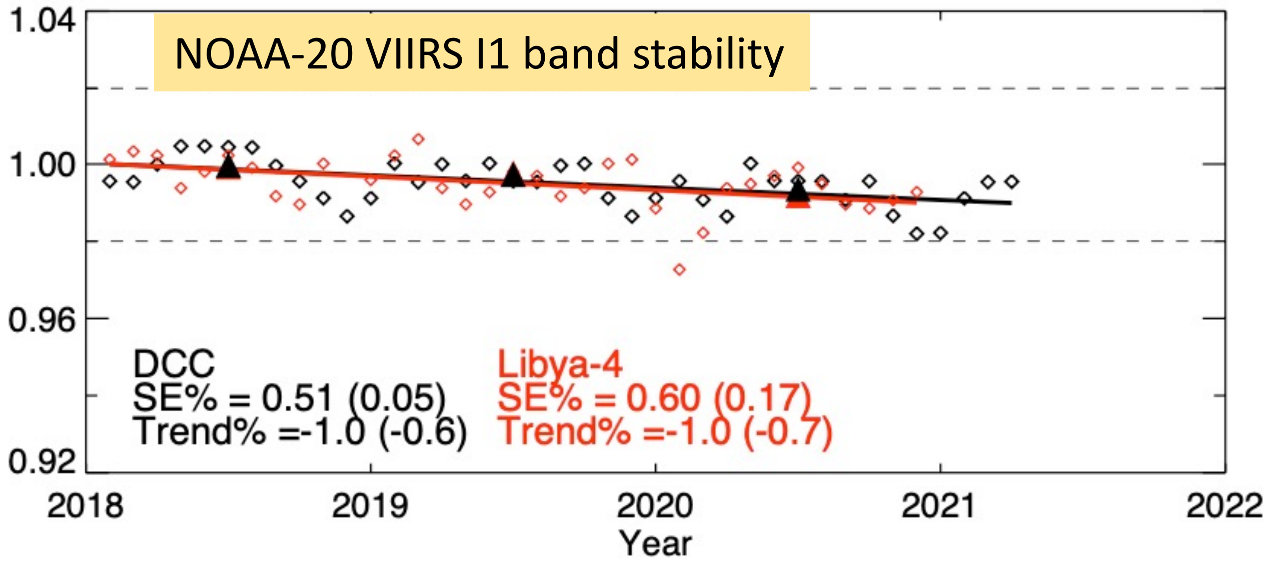


Difference is due to VIIRS M5 vs I1 calibration bias (see slide 9)



Comparison between DCC-IT and ATO-RM

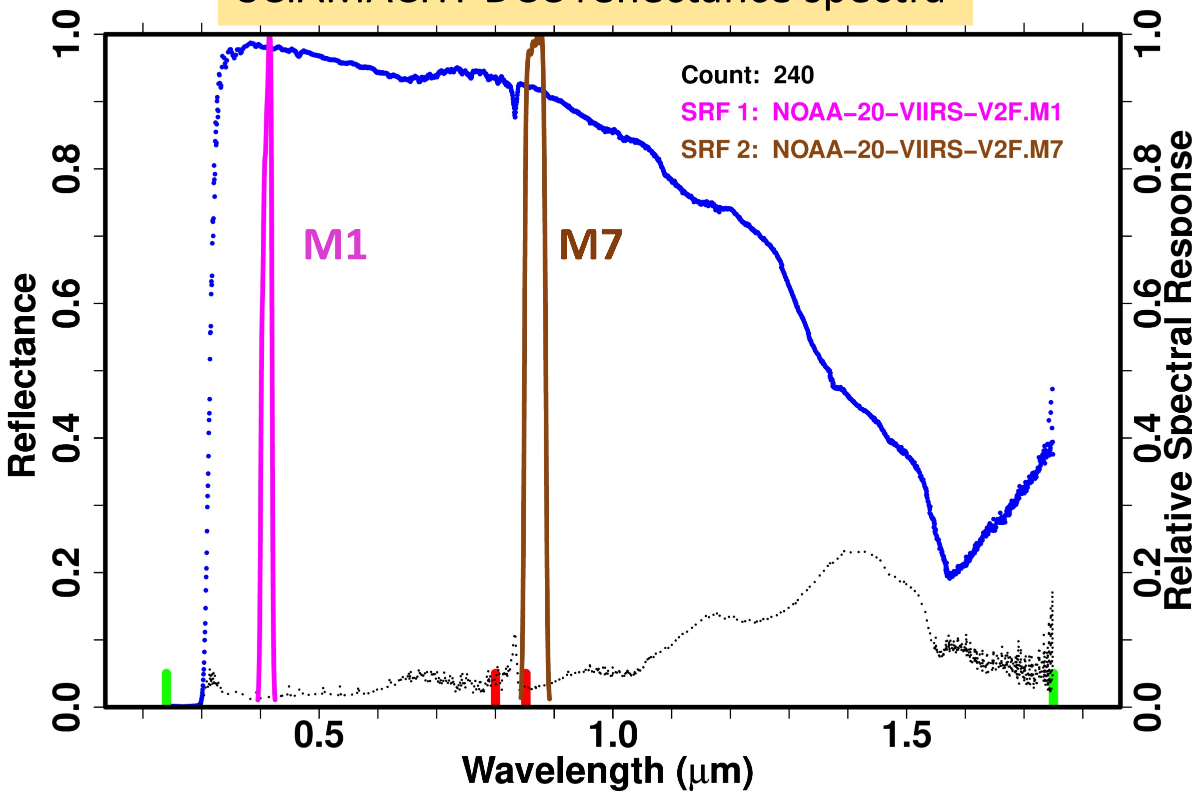


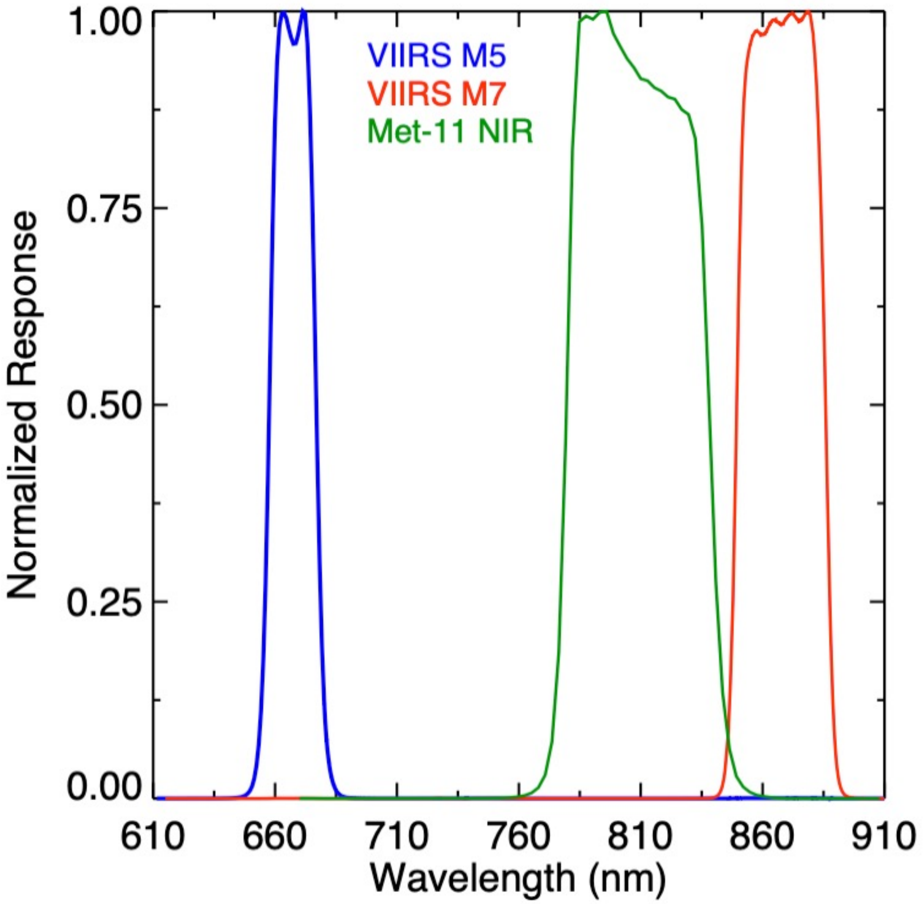


- ATO-RM and DCC-IT trends show excellent agreement in estimating calibration slope for GOES-16 ABI VIS band
- Temporal trends disagree between the two methods
- Likely caused by a small drift observed in NOAA-20 VIIRS I1 band calibration in Collection 2
  - ***DCC-IT is not impacted by reference sensor calibration drifts, thereby revealing the true GEO degradation over time***
  - ***ATO-RM may be influenced by any short-term calibration drifts in the reference VIIRS instrument***

DCC-IT for inter-band calibration

SCIAMACHY DCC reflectance spectra

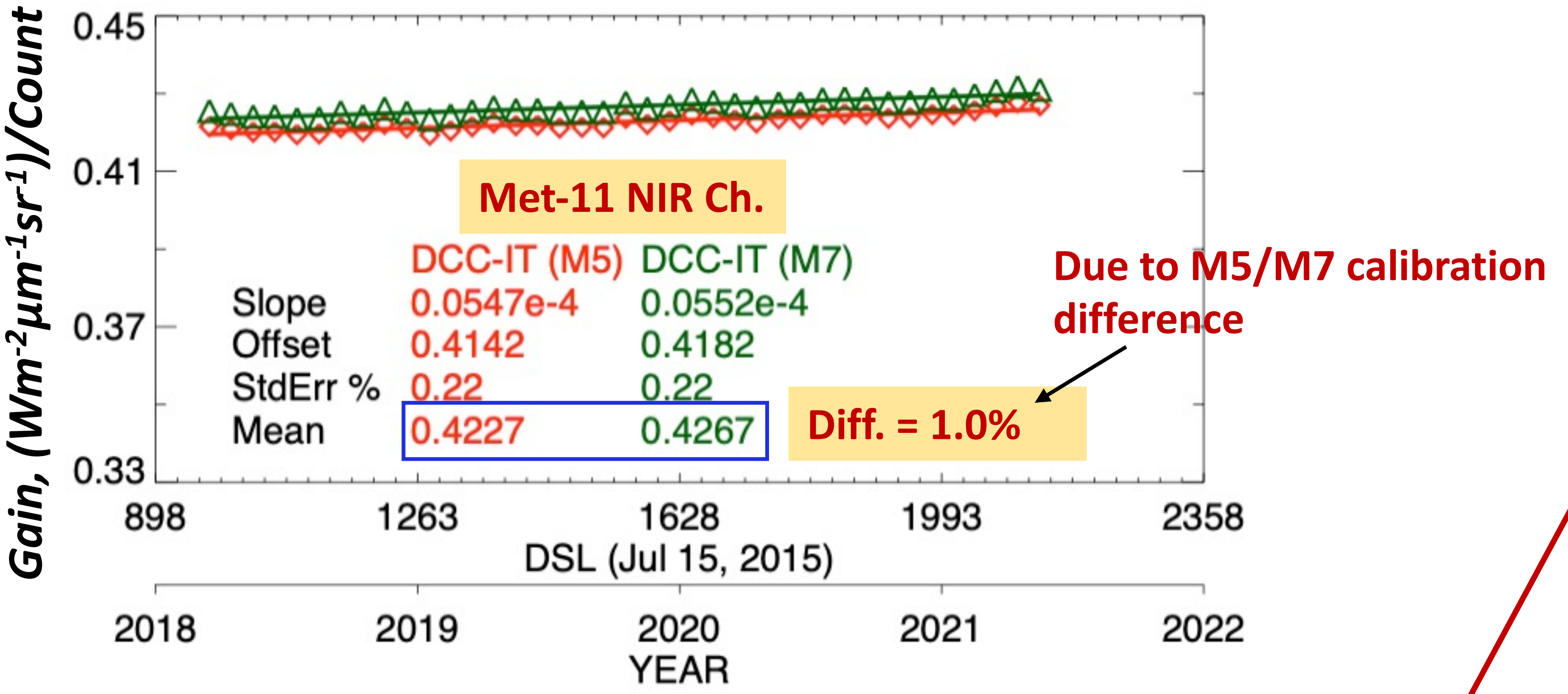


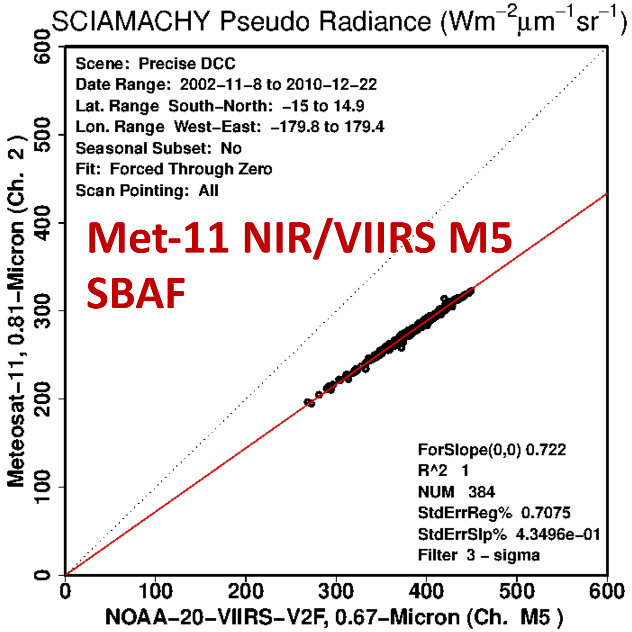


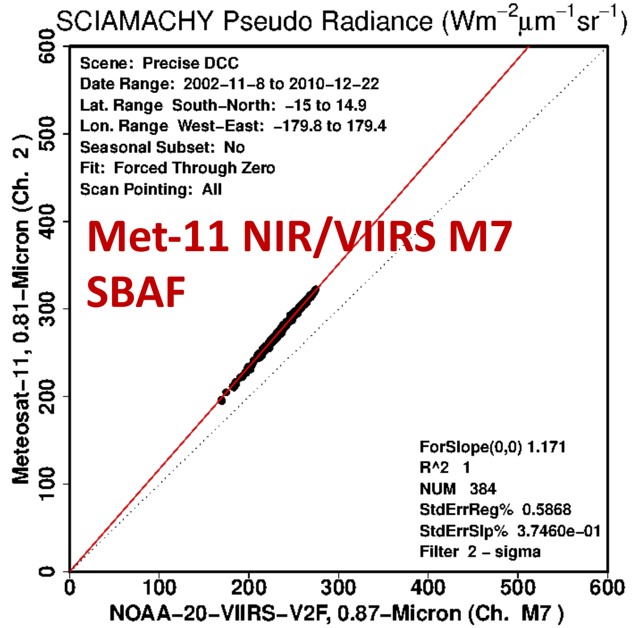
- Very low atmospheric absorption over DCC
- Nearly flat reflectance spectra at VIS/NIR wavelengths (M1-M7 channels, <1.0 μm)
- Allows inter-band calibration between non-overlapping spectral channels

- Met-11 Ch 2 (0.81 μm) has a minimal overlap with VIIRS M7
- Met-11 Ch 2 can be intercalibrated with both VIIRS M5 or M7

DCC-IT for inter-band calibration (contd.)







- Inter-calibration of Met-11 NIR channel reveals 1% relative radiometric bias between M5 and M7 bands of VIIRS
- Direct inter-comparison of DCC modes between M5 and M7 (slide 8) also estimates a 0.9% bias between these two channels
- Very robust and well-behaved SBAF regressions (no absorption and Lambertian reflectance)
- Not feasible to achieve this level of inter-band calibration with ground targets (atmospheric effects)

DCC Calibration in Reflectance

- **Scenario 1:** Using **L1B reflectance** data for both VIIRS and GEO
  - *Most preferred method* (no dependency on reference solar spectra)
  - e.g., VIIRS, GOES-16 ABI, and SCIAMACHY are all reflectance-based calibration

$$\gamma_{cross-cal,reflectance} = \frac{\rho_{VIIRS,Mode} \times SBAF_{reflectance}}{\rho_{GEO,Mode}} \text{ (unitless)}$$

- ρ is reflectance
- $\rho_{VIIRS,Mode}$ is the reference VIIRS mode reflectance which can be derived from VIIRS DCC PDFs in reflectance, or from mode radiance (slide 8) as follows:

$$\rho_{VIIRS,Mode} = L_{VIIRS,Mode}/E_{SUN}$$

- $\rho_{GEO,Mode}$ is a monthly GEO DCC mode in reflectance unit
- $SBAF_{reflectance}$ is the spectral correction in reflectance (Select "***Pseudo Scaled Radiance***" from **Units** column on the SBAF tool)

VIIRS E_{SUN} values using Thuillier 2003 Spectra

NOAA-20 VIIRS band	E_{SUN} (W m^{-2} µm^{-1} sr^{-1})
M3 (0.48 µm)	629.313
M4 (0.55 µm)	581.771
M5 (0.67 µm)	481.029
M7 (0.86 µm)	302.320
I1 (0.65 µm)	505.409

NASA Langley's E_{SUN} computation tool

https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SOLAR-CONSTANT-COMPARISONS

NOAA-20 VIIRS uses Thuillier 2003 solar spectra for computing E_{SUN} values

DCC Calibration in Reflectance (contd.)

- **Scenario 2: Using GEO L1B radiances**
  - *Convert GEO Mode radiance to reflectance using* E_{SUN}
  - Apply the solar spectra (**Thuillier 2003**) used by the reference NOAA-20 VIIRS instrument to compute GEO E_{SUN} values

$$\gamma_{cross-cal,reflectance} = \frac{\rho_{VIIRS,Mode} \times SBAF_{reflectance}}{\rho_{GEO,Mode}} \text{ (unitless)}$$

ABI E_{SUN} values using Thuillier 2003 Spectra

GOES-16 ABI band	E_{SUN} (W m^{-2} µm^{-1} sr^{-1})
B1 (0.47 µm)	648.717
B2 (0.64 µm)	509.719
B3 (0.87 µm)	303.909

NASA Langley's E_{SUN} computation tool

https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SOLAR-CONSTANT-COMPARISONS

Uncertainty Analysis

- **Major sources of uncertainty for GEO-VIIRS intercalibration**
  - *Uncertainty in the reference mode value from VIIRS (U_{Ref})*
    - *Temporal standard deviation (1-Sigma) of DCC time series (DCC reflectance natural variability over the GEO domain)*
  - *SBAF uncertainty (U_{SBAF})*
    - *Standard error of Regression Slope from SBAF tool*
  - *Temporal regression uncertainty (U_{RegFit})*
    - *Standard error (1-Sigma) of GEO calibration slopes temporal regression*
- Absolute radiometric uncertainty of NOAA-20 VIIRS (±2% for RSB) is not considered
- Total uncertainty (U_{Total}) is computed by summing individual uncertainties in quadrature to

$$U_{Total} = \sqrt{U_{Ref}^2 + U_{SBAF}^2 + U_{RegFit}^2}$$

GOES-16 ABI Band 2/VIIRS I1 Calibration Uncertainty	
Source	Value (%)
U_{Ref}	0.69
U_{SBAF}	0.02
U_{RegFit}	0.54
U_{Total}	**0.88**

Other sources of uncertainty could be from BT normalization, SCIAMACHY relative calibration inconsistency between channels, SRF changes in orbit, etc.

GSICS Products

- Monthly netCDF files containing
  - GEO imager DCC PDF data and statistics
  - Attributes:
    - **GEO sensor details:** space count, channel information, linear/squared count, scaled radiance or count bit resolution, BT threshold, homogeneity test parameters, ADM, etc.
    - **Reference sensor details:** band information, reference mode value and units, L1B collection, NASA or NOAA dataset, etc.

Summary

- The newly revised GSICS DCC ATBD offers several improvements:
  - *Extends the methodology to all spectral channels between 0.4-1.0 µm*
  - *Inter-calibration uncertainty is reduced by applying*
    - *IR BT threshold normalization between GEO and VIIRS*
    - *deseasonalization of monthly DCC responses*
  - *Uses the most recent and well-calibrated NOAA-20 VIIRS sensor as a reference instrument for DCC characterization*
  - *Provides more comprehensive details on the formulation and implementation of DCC method*
    - *Reference DCC modes for multiple GEO domains, SBAF computation, uncertainty analysis, GSICS DCC products*
  - *In future, a dedicated ATBD will be presented for calibrating SWIR bands using DCC*

Future activities

- ATBD will be ready by July of 2021
- Future monthly meetings will discuss the agency-specific GSICS DCC product implementation and paper (fall of 2021)