Implementation of Revised DCC Calibration ATBD for GEO Imager VIS and NIR Bands

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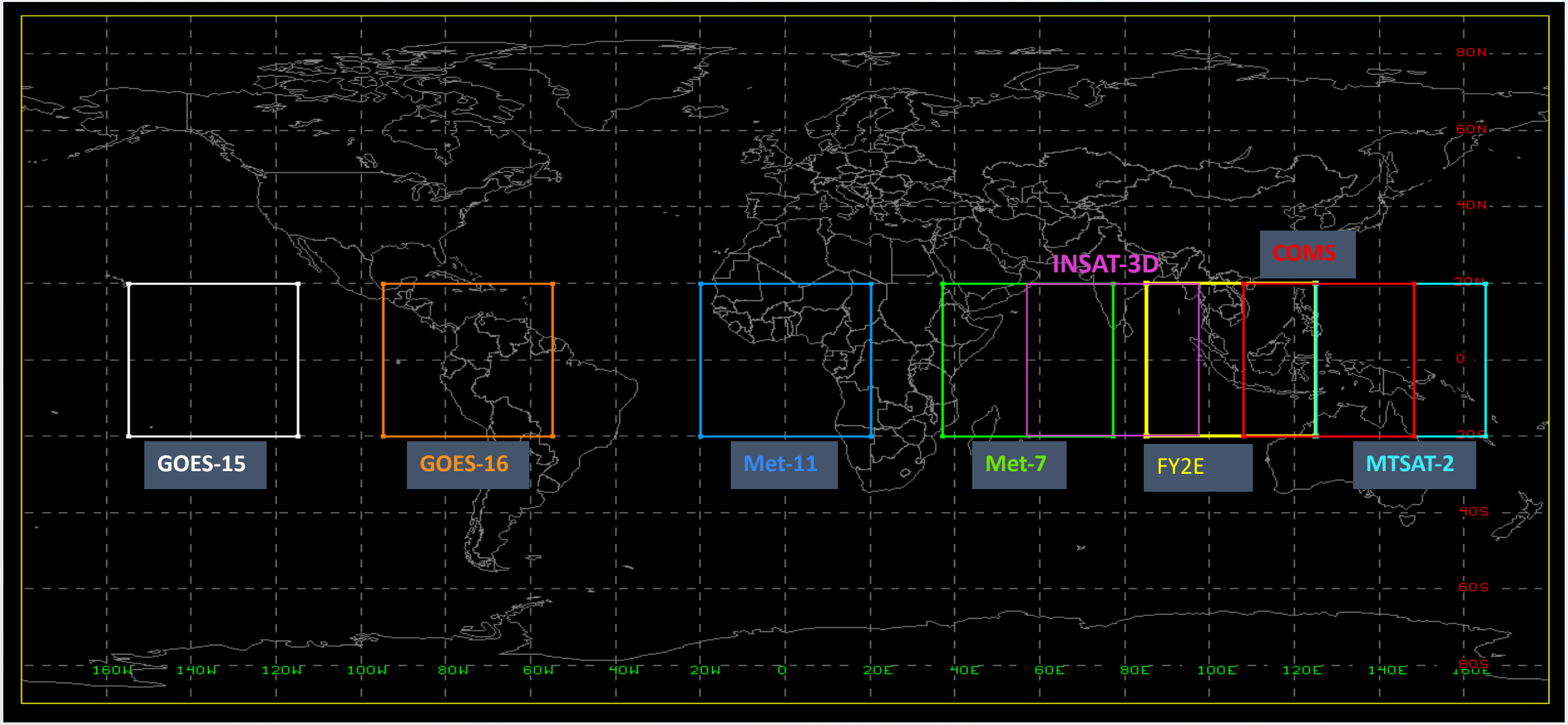
Objectives

- *Characterize tropical DCC response at the top-of-atmosphere using the latest dataset (Collection 2.1) of NOAA-20 VIIRS L1b radiances from NASA Land SIPS*
- *Provide regional-dependent reference DCC mode and mean values based on reflective solar bands measurements from VIIRS to facilitate consistent radiometric scaling of GEO imagers using DCC-IT (no need for agencies to download or process VIIRS data)*
- *Provide guidance on consistent implementation of DCC-IT algorithm across agencies and sharing of best practices*
- *Support effort for publishing a joint agency peer-reviewed article on DCC-IT based calibration*
  - *include agency-specific implementation and validation results*

Revised DCC-IT Calibration ATBD highlights

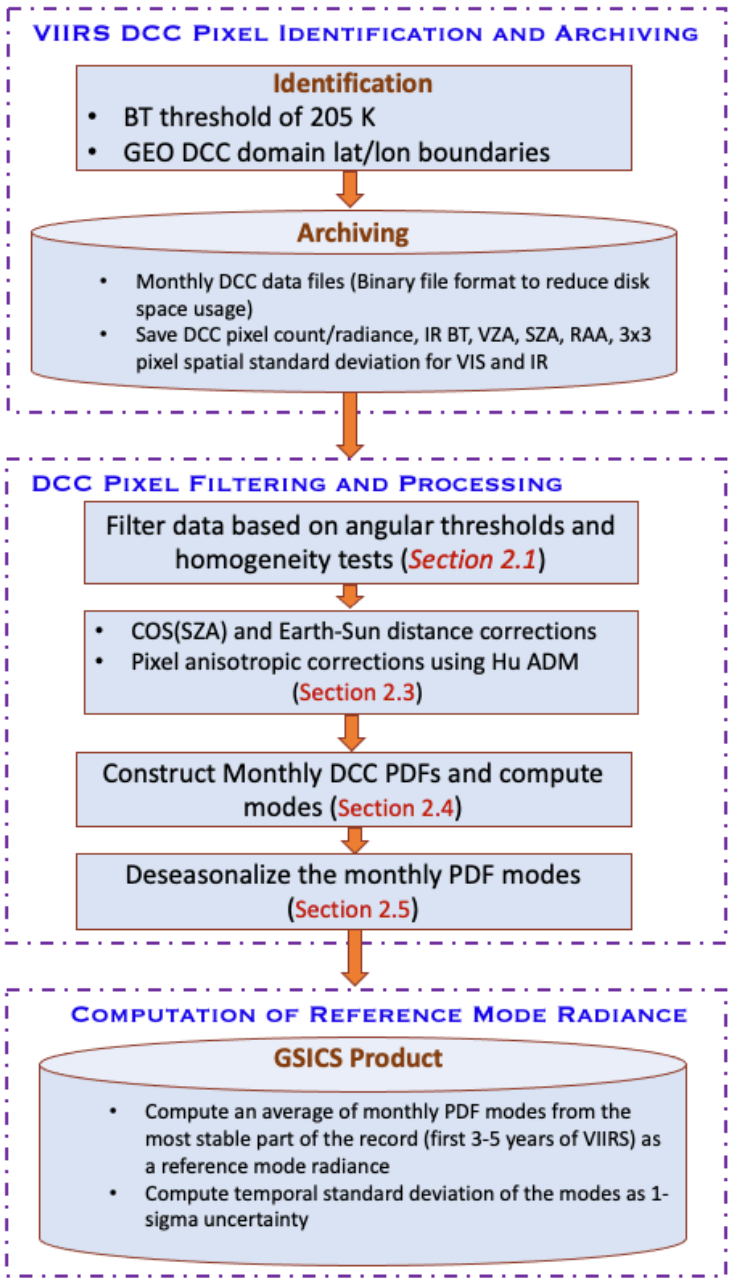
- *Significant improvement upon the 2011 DCC ATBD*
- *Extends the methodology to all spectral channels between 0.4-1.0 µm*
- *Uses the most recent and well-calibrated NOAA-20 VIIRS sensor as a reference instrument for DCC characterization*
- *IR BT threshold normalization between GEO and VIIRS for consistent DCC sampling and response*
- *Seasonal corrections of GEO imager monthly DCC response*
- *Spectral corrections using NASA Langley's robust online SBAF computation tool (https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SBAF)*
- *PDF bin optimization (0.2-0.4% of Mode)*

GEO Imagers DCC Identification Domains



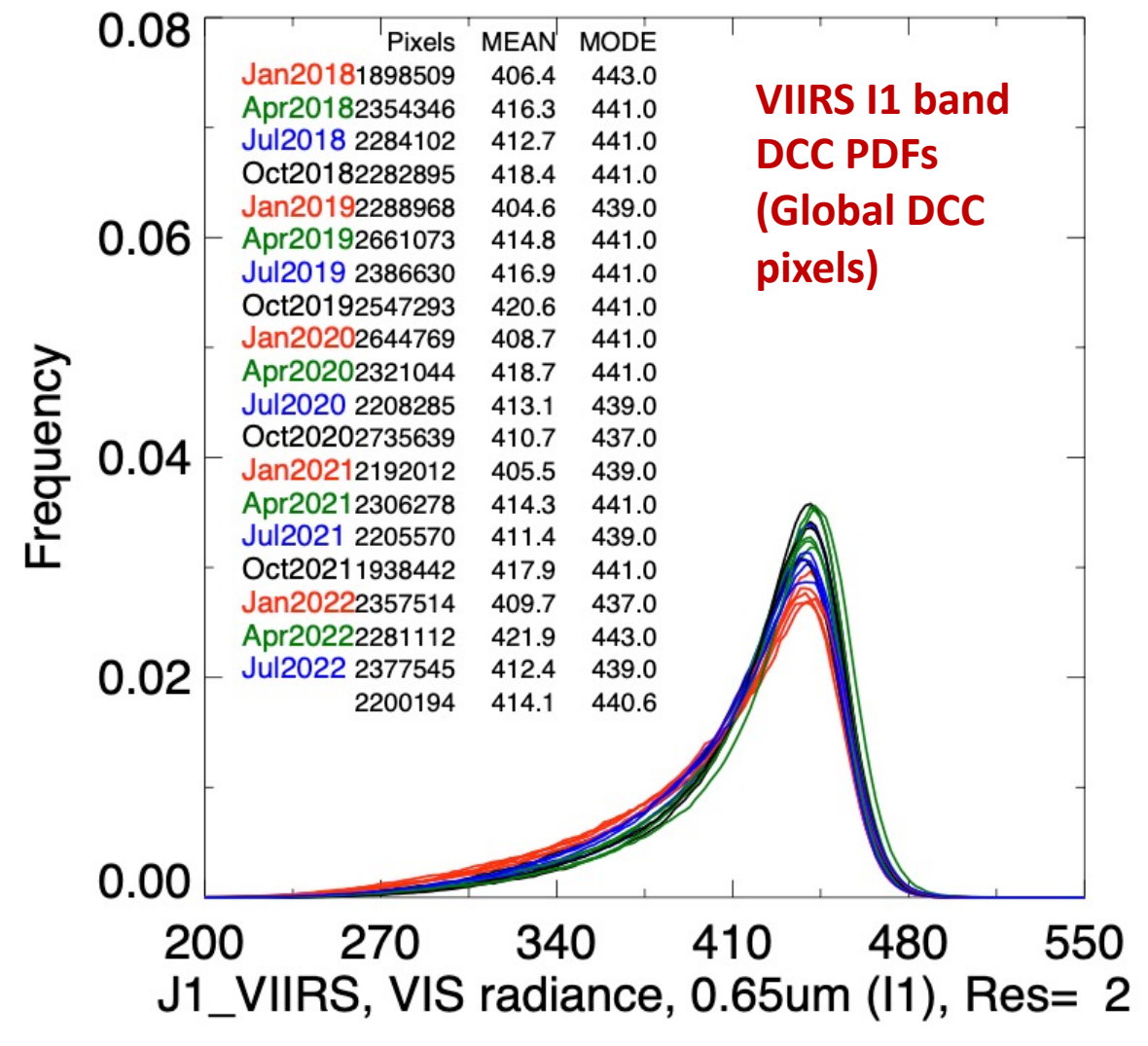
±20° Lat/Lon from the GEO sub-satellite point

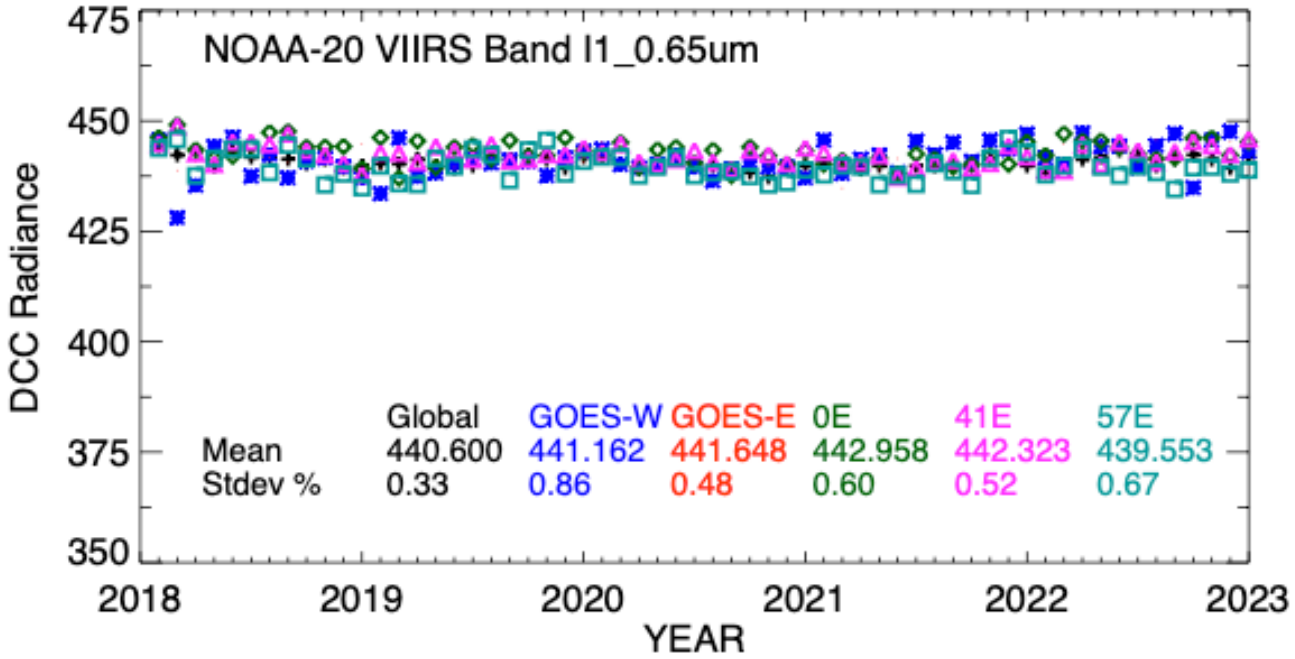
DCC Characterization using NOAA-20 VIIRS

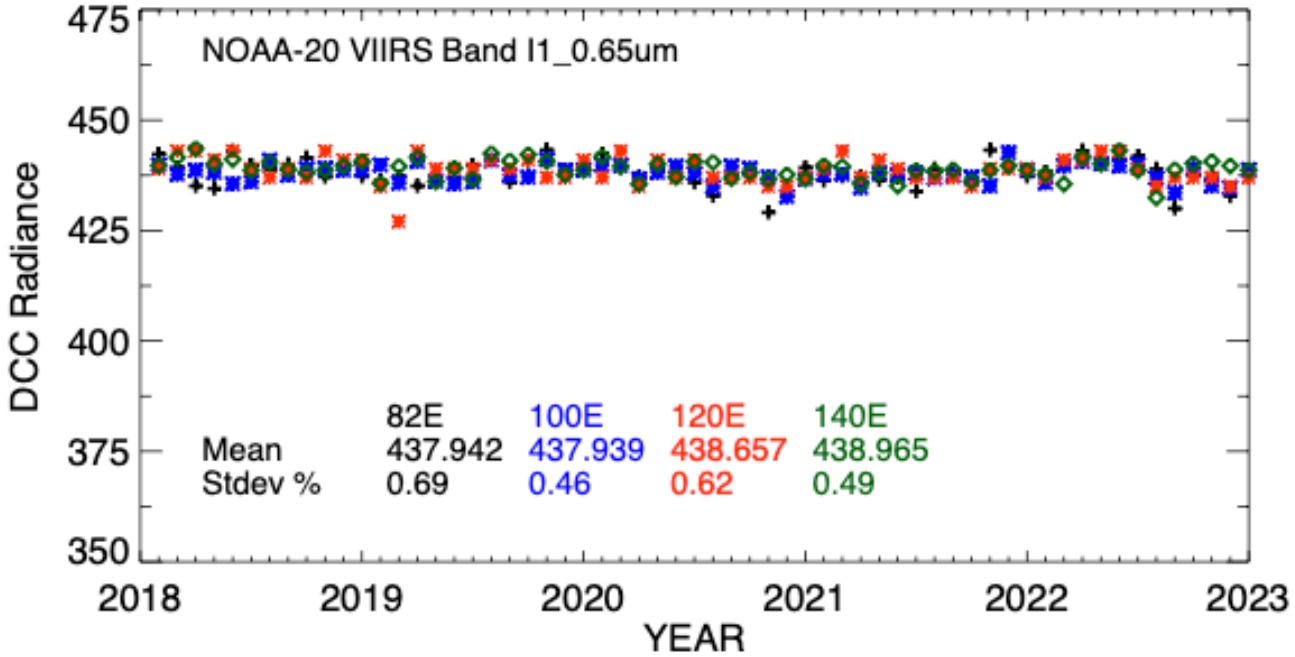


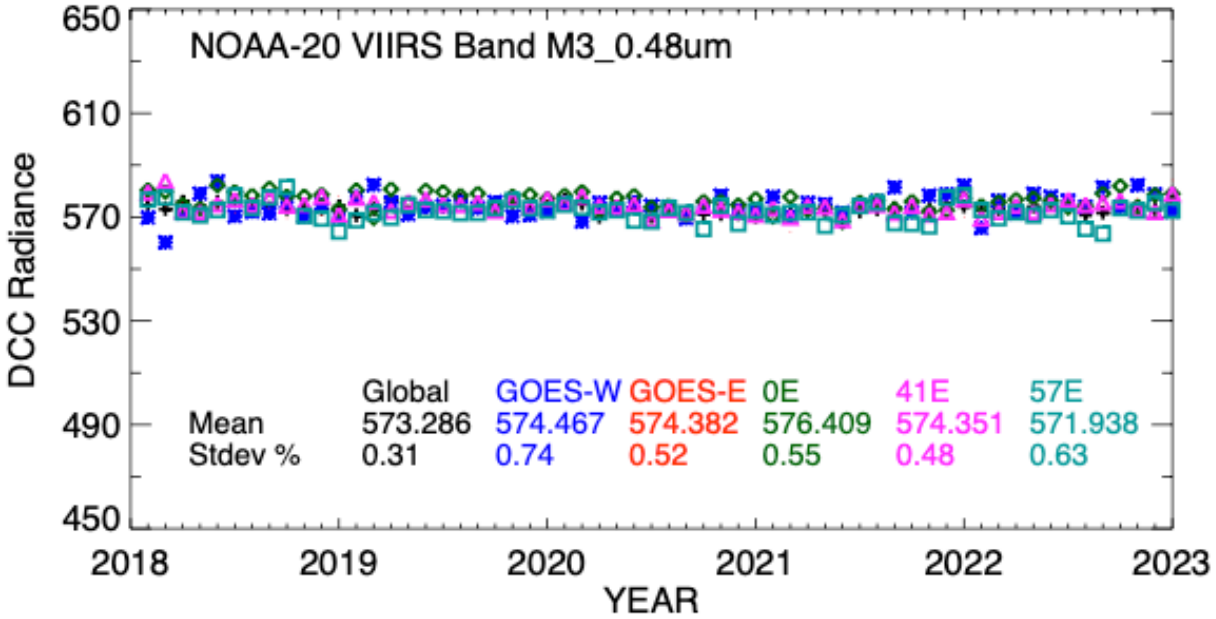
- Identify DCC pixels within GEO domain using M15 (10.8 µm) BT < 205 K
- Filtering
  - *Spatial homogeneity tests for filtering DCC edges*
    - $\sigma_{VIS} < 3\%$ *and* $\sigma_{BT} < 1K$ *for the* 3x3 pixel block surrounding a DCC pixel
  - *Angular thresholds for capturing the most Lambertian part 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 (wavelengths < 1 µm) to a common set of solar and viewing conditions*
  - *Compile DCC pixels into monthly probability distribution functions (PDFs) and compute their statistical mean and mode values*
- Derive mean and standard deviation of monthly DCC mode timeseries after deseasonalization
- ***Update:*** *Uses NOAA-20 VIIRS C2.1 L1b product from NASA Land SIPS*
- *Full first 5 years of VIIRS record used*

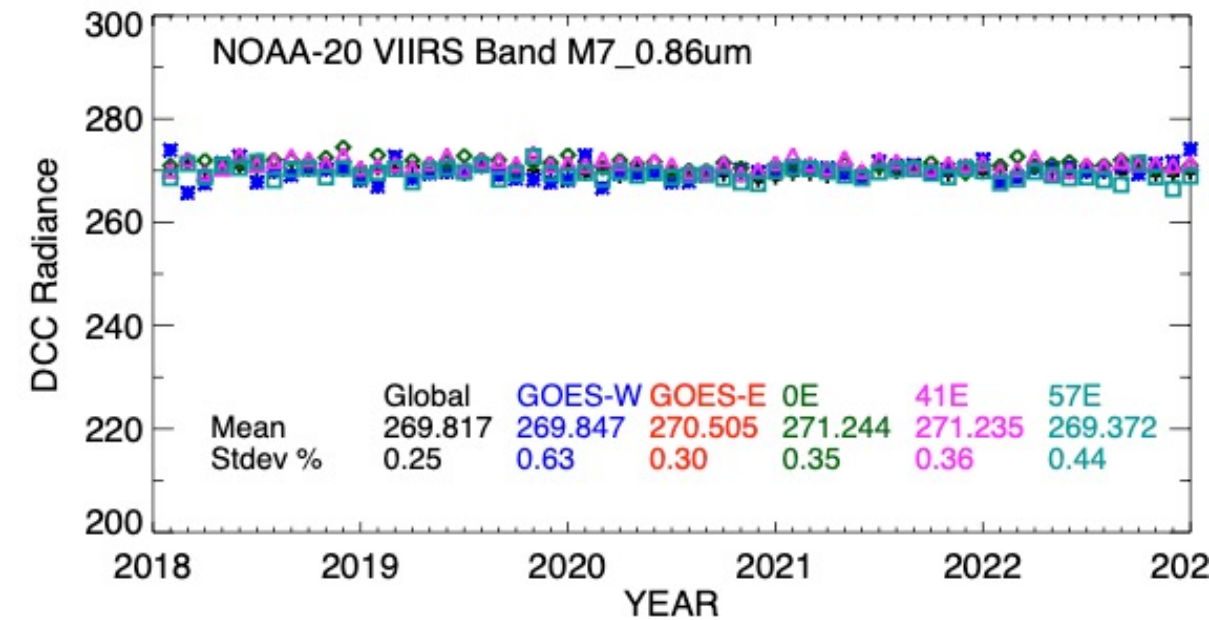
Reference DCC mode values

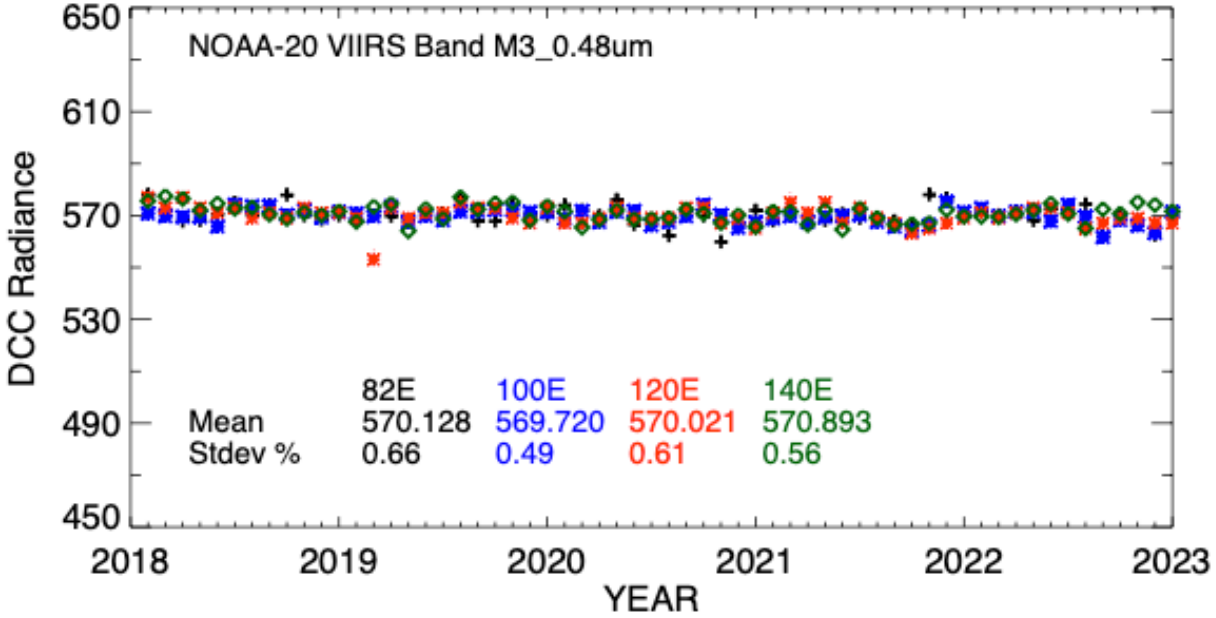


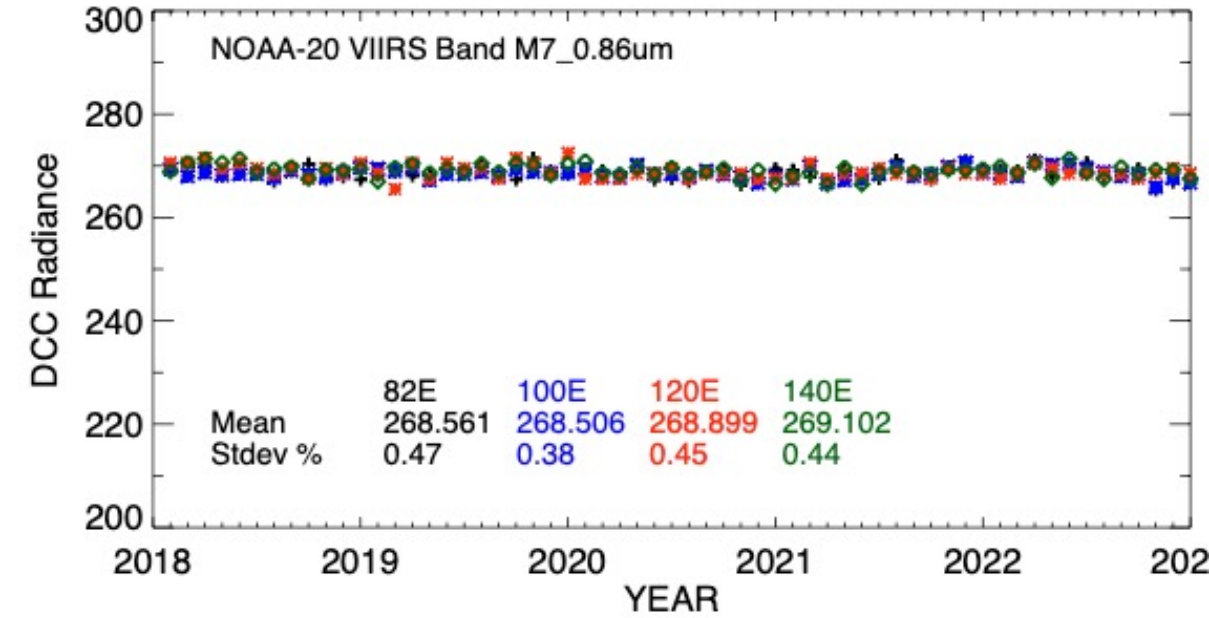





NOAA-20 VIIRS Band M3_0.48um
DCC Radiance
YEAR
Global GOES-W GOES-E 0E 41E 57E
Mean 573.286 574.467 574.382 576.409 574.351 571.938
Stdev % 0.31 0.74 0.52 0.55 0.48 0.63


NOAA-20 VIIRS Band M7_0.86um
DCC Radiance
YEAR
Global GOES-W GOES-E 0E 41E 57E
Mean 269.817 269.847 270.505 271.244 271.235 269.372
Stdev % 0.25 0.63 0.30 0.35 0.36 0.44


NOAA-20 VIIRS Band M3_0.48um
DCC Radiance
YEAR
82E 100E 120E 140E
Mean 570.128 569.720 570.021 570.893
Stdev % 0.66 0.49 0.61 0.56


NOAA-20 VIIRS Band M7_0.86um
DCC Radiance
YEAR
82E 100E 120E 140E
Mean 268.561 268.506 268.899 269.102
Stdev % 0.47 0.38 0.45 0.44

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

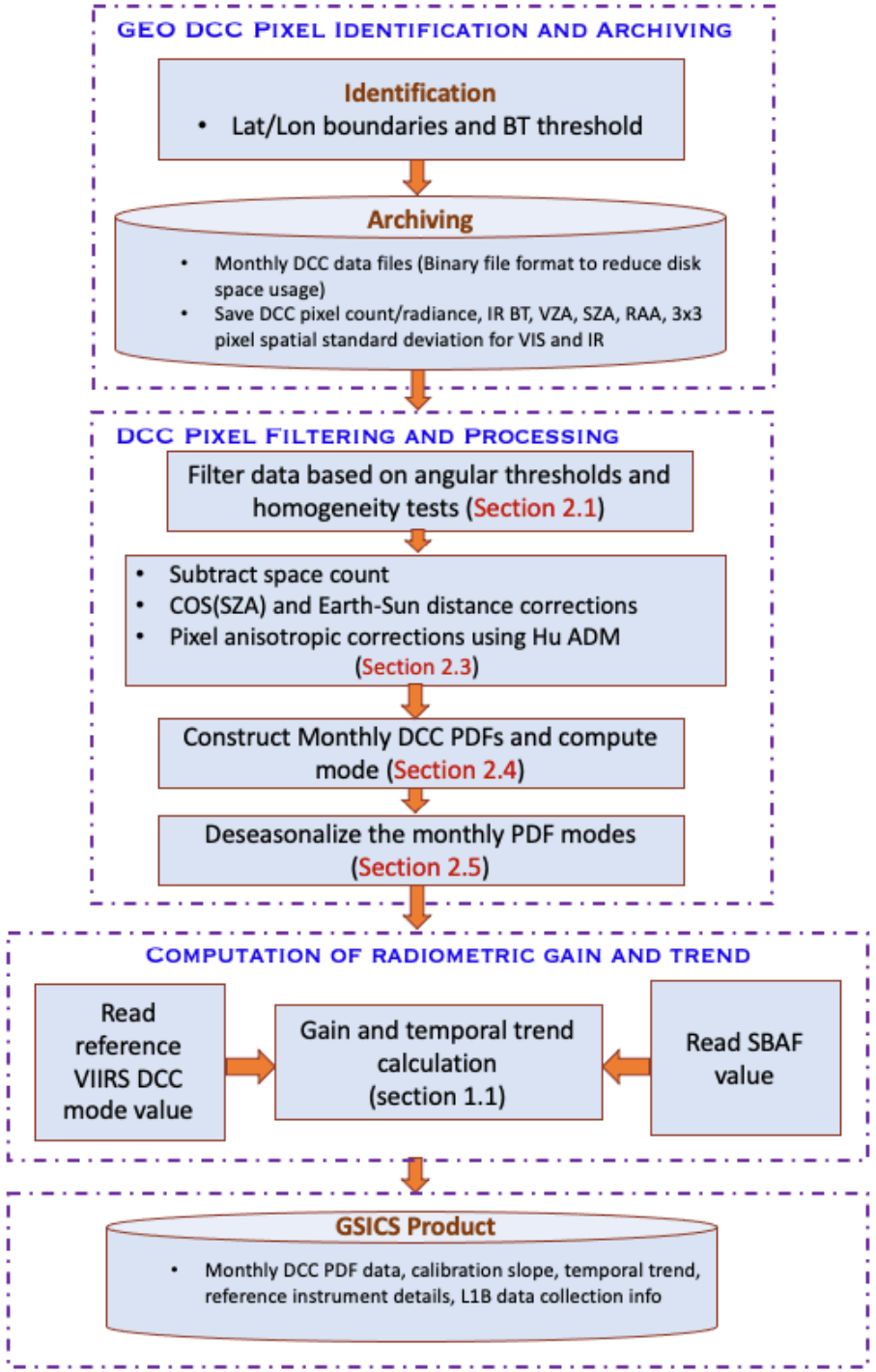
NOAA-20 VIIRS based reference DCC radiance for GEO domains (based on ~5 years of observation)										
Band	**Global**	**GOES-W**	**GOES-E**	**0E**	**41E**	**57E**	**82E**	**100E**	**120E**	**140E**
M3_0.48um	573.3106	574.2886	574.1561	576.2417	574.4566	571.7466	570.5536	569.9536	570.099	570.7167
M4_0.55um	506.1241	507.2404	507.3154	509.054	507.582	504.6942	503.8166	503.6269	503.9973	505.1976
M5_0.67um	431.1717	432.3336	431.6643	433.5389	432.783	430.4023	429.1947	429.1932	429.7318	430.409
M7_0.86um	269.8475	269.7048	270.5088	271.2723	271.2081	269.4268	268.7202	268.6634	268.8952	269.1443
M8_1.24um	97.5102	97.4311	99.0111	99.9722	99.7063	97.6039	96.8815	96.8926	96.707	96.5699
M9_1.38um	68.5258	68.9824	71.2152	72.1015	71.7712	68.4424	67.3299	67.204	67.2569	67.2638
M10_1.6um	18.2495	17.826	18.598	19.2765	19.1919	18.2991	18.0388	18.1599	18.0086	17.8656
M11_2.25um	8.8133	8.6687	8.9759	9.216	9.1906	8.8266	8.7207	8.7579	8.7153	8.6702
I1_0.65um	440.6533	440.868	441.5347	442.7679	442.2879	439.5295	438.2284	438.0925	438.8077	438.9072
I3_1.6um	17.9934	17.5606	18.3323	18.9992	18.9191	18.0429	17.7872	17.9074	17.7608	17.6196
Temporal standard deviation (%)										
Band	**Global**	**GOES-W**	**GOES-E**	**0E**	**41E**	**57E**	**82E**	**100E**	**120E**	**140E**
M3_0.48um	0.3224	0.7362	0.4648	0.5545	0.4794	0.6457	0.6529	0.4954	0.6257	0.5707
M4_0.55um	0.3828	0.8147	0.539	0.55	0.5102	0.812	0.7524	0.5202	0.7637	0.5621
M5_0.67um	0.3014	0.7365	0.4421	0.4593	0.3891	0.6223	0.5968	0.445	0.6345	0.5113
M7_0.86um	0.2532	0.6018	0.2988	0.3525	0.3681	0.4237	0.4422	0.3526	0.4553	0.4666
M8_1.24um	0.323	0.884	0.2876	0.4206	0.8008	0.6556	0.529	0.5354	0.5533	0.5497
M9_1.38um	0.768	1.9258	0.6587	1.0579	1.8741	1.5701	1.3559	1.2823	1.3041	1.2425
M10_1.6um	0.6682	2.3391	0.8873	1.1625	1.8501	1.5523	1.2395	1.0369	0.9909	0.9824
M11_2.25um	0.5209	1.765	0.6386	0.8359	1.5041	1.1304	0.9324	0.8365	0.8199	0.8054
I1_0.65um	0.3432	0.8554	0.4763	0.6018	0.5274	0.6881	0.7027	0.453	0.6328	0.5237
I3_1.6um	0.7027	2.215	0.854	1.1647	1.8416	1.5651	1.2669	1.0557	0.9961	0.9982

SWIR bands

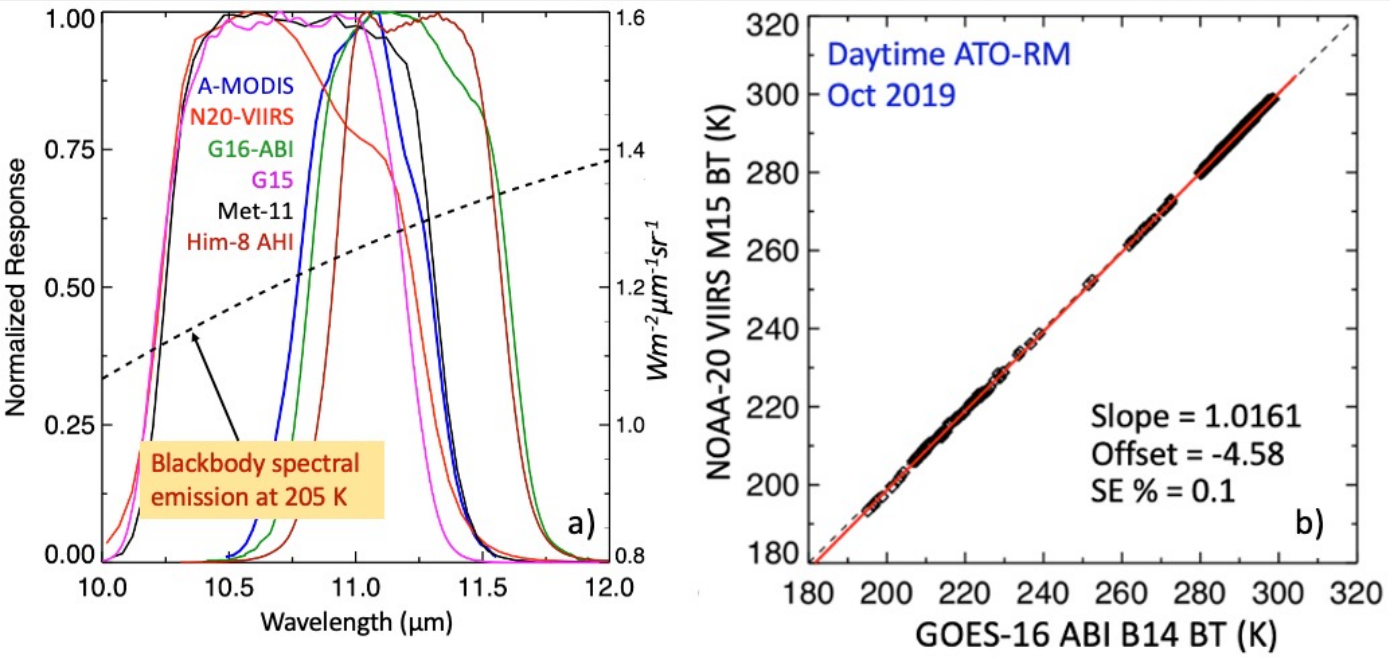
- ***For visible channel (0.65 µm), two sets of reference mode values are provided (M5 and I1)***
- ***Units of these mode radiances are*** $Wm^{-2}\mu m^{-1}sr^{-1}$

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



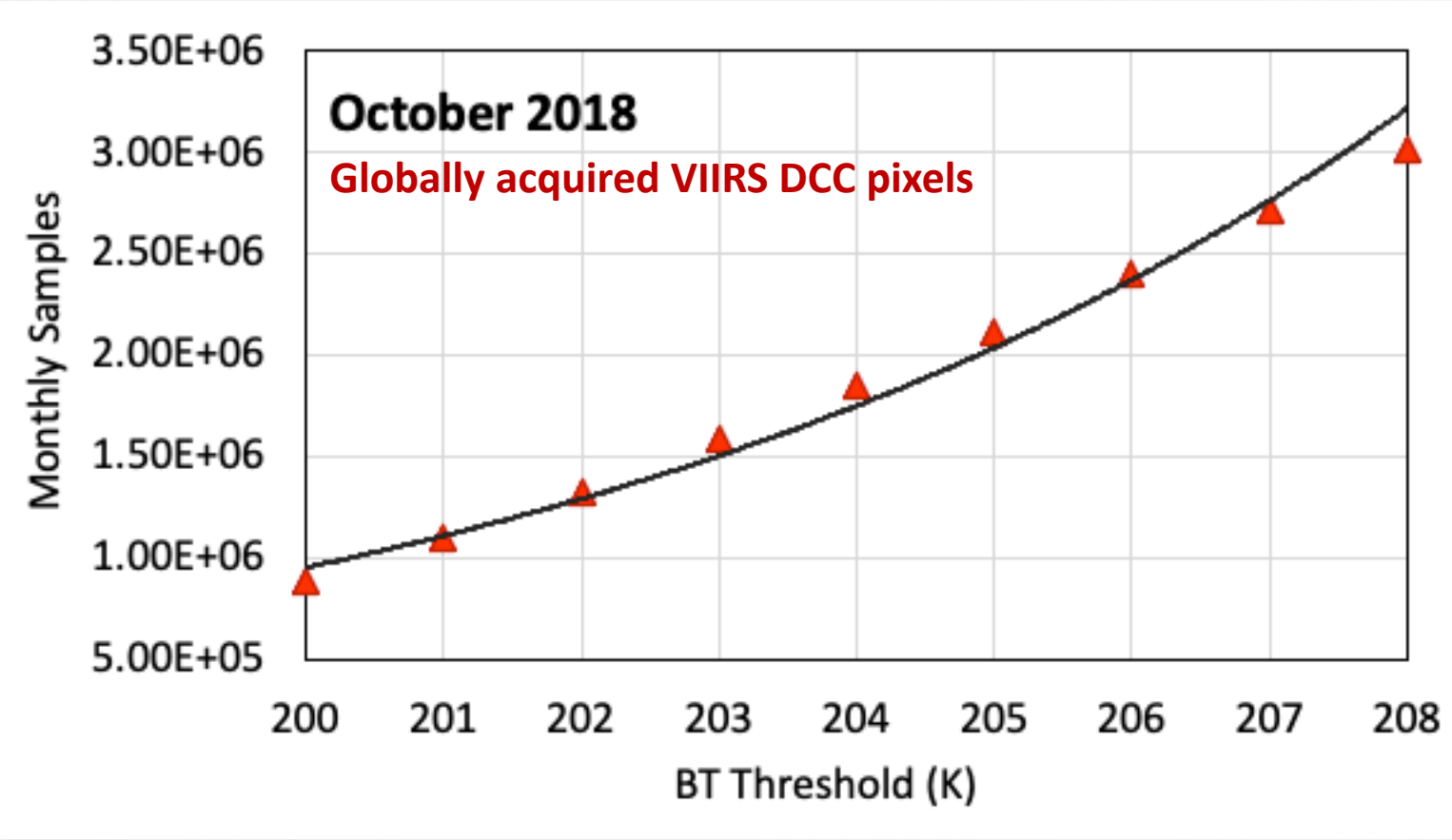
IR BT threshold normalization



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 14 (11.2 μm)	205.4
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

Implementation: Computation of monthly GEO calibration slope

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

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

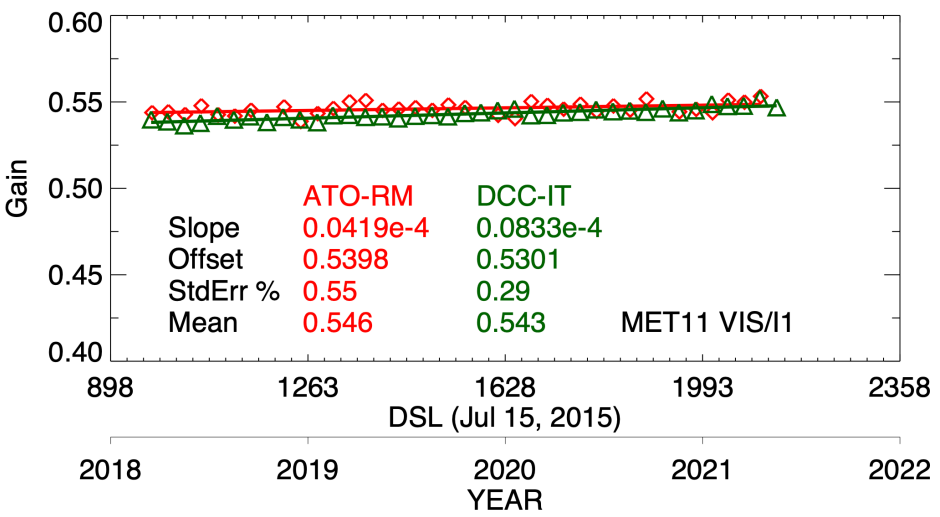
Eqn. 3 $$\gamma_{GEO,cal-slope} = \frac{L_{GEO,Mode,reference}}{C_{GEO,Mode,observed}} \ (Wm^{-2}\mu m^{-1}sr^{-1}/Count)$$

From Table in slide 8
Constant in time, as long as reference instrument and data collection stay same

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***



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*
- Only random uncertainties based on natural variability are considered
- 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

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

- *Other sources of uncertainty could be from BT normalization, SCIAMACHY relative calibration inconsistency between channels, SRF changes in orbit, PDF bin sizes, etc. Not addressed in current ATBD*

GSICS Products

- Two sets of netCDF files
  1. N20_VIIRS_DCC_Mode_VIS_NIR_v1.nc
     - **Contains reference sensor details:** band information, DCC mode information for specific GEO domain and units, standard deviation, uncertainty, L1B collection info, NASA or NOAA dataset, etc.

  2. GOES16_ABI_DCC_PDF_2020_01_v1.nc
     - **Contains GEO sensor details:** space count, channel information, linear/squared count, scaled radiance or count bit resolution, BT threshold, homogeneity test parameters, ADM, etc.
     - Monthly GEO imager DCC PDF data and statistics

Timeframe

- *First draft of revised DCC ATBD was presented in June 2021*
- *Discussed and addressed reviewers' feedback in March 2022*
- *Earlier target for final ATBD release was July 2022*
- *New targeted date for ATBD completion and reference DCC mode and uncertainty tables delivery is May 2023*
- *Joint DCC implementation paper*

Summary

- DCC are an excellent invariant target for post-launch radiometric calibration of satellite sensors.
- DCC can be referenced to a well-calibrated sensor (MODIS or VIIRS) for transferring absolute calibration to other GEO and LEO sensors.
- The 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 based on stable 5 years NOAA-20 VIIRS record, SBAF computation, uncertainty analysis, GSICS DCC products
- In future, a dedicated ATBD will be presented for calibrating SWIR bands using DCC

Backup slides

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