Imaging Radiometer Cal/Val for Aerosol and Atmospheric Composition

National Environmental Satellite, Data, and Information Service

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Background

- Global aerosol product generation relies on imaging radiometers such as VIIRS, MODIS, AVHRR, METImage, and others, that need to be well-calibrated radiometrically, spectrally, and spatially for aerosol detection, retrieval, and cloud clearing.

- **Radiometric accuracy and stability** are two major requirements which must be well quantified using a variety of calibration/validation methods, including monthly lunar, DCC, Desert sites, cross calibration with a constellation of satellites with optical sensors (Landsat, Sentinels, ABI, GOSAT, TROPOMI, EMIT, MODIS, AVHRR, etc).

- **Recalibration** is necessary to address shortcomings in operational(24x7) products, which in turn improves the product quality of aerosols as well as all other products.

- Each instrument has its own characteristics in on-orbit performance, VIIRS on NOAA-20 is recognized by GSICS as the most stable, while VIIRS SWIR bands for NOAA-21, and NIR bands for SNPP have faster degradation which must be corrected in reprocessing.

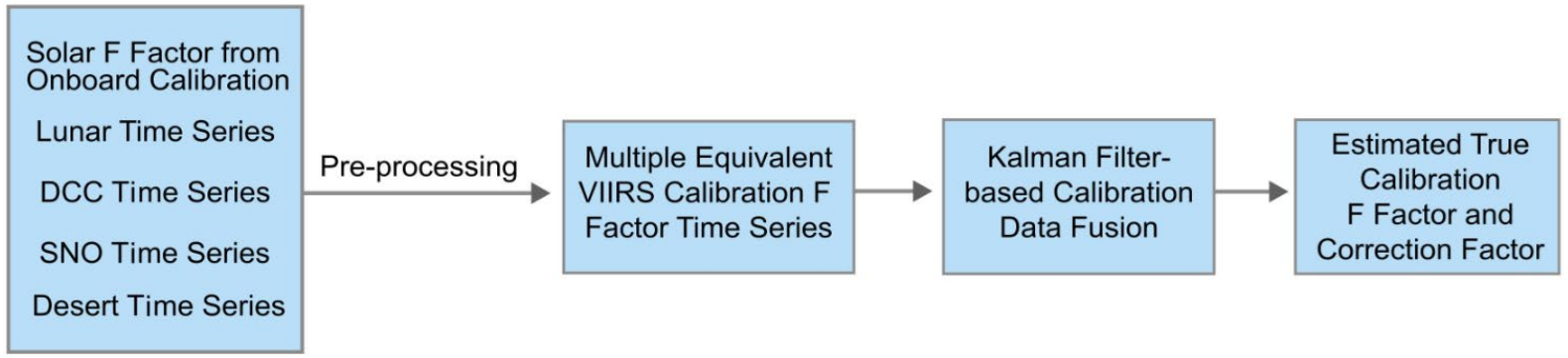
- **Reprocessing** leads to a well calibrated, radiometrically consistent L1b radiance and reflectance products
    - Improved radiometric stability/accuracy and interchannel consistency
    - Improved accuracy of measured aerosol properties to assess air quality
    - Supported NOAA aerosol team for the Covid-19 project through CLOUD based on-demand reprocessing (Kondragunta et al., 2023)
- Intercalibration with **hyperspectral** sensors is also desirable (GOSAT, TROPOMI, EMIT, etc)

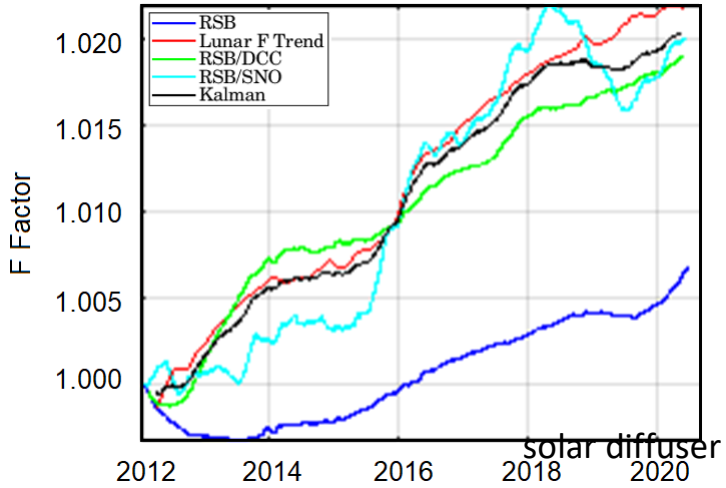
VIIRS Requirements, Performance, and Challenges

- Radiometric Accuracy Requirement for reflective solar bands **2% (absolute)**;
- 2% actually means +/-2% 1 sigma, which can be 4% total (per discussion with NASA MODIS team)
- On-orbit absolute radiometric reference has yet to be established;
  - SNPP agrees better with MODIS (built by the same vendor group)
  - NOAA-20 is lower than SNPP by 2% (same vendor but different group)
  - NOAA-20 interchannel calibration more consistent than SNPP
  - SNPP VIIRS has two channels(M5, M7, I2) consistently higher by ~2%
  - NOAA-21 is more consistent with NOAA-20
- Stability requirement 0.3% between calibration updates; mission life ±1%.
- NOAA Open Data Access (NODD) to VIIRS near real time data: https://ncc.nesdis.noaa.gov/VIIRS/noddviirs.php

S-NPP VIIRS Recalibration Improvements for Reflective Solar Bands (RSB)

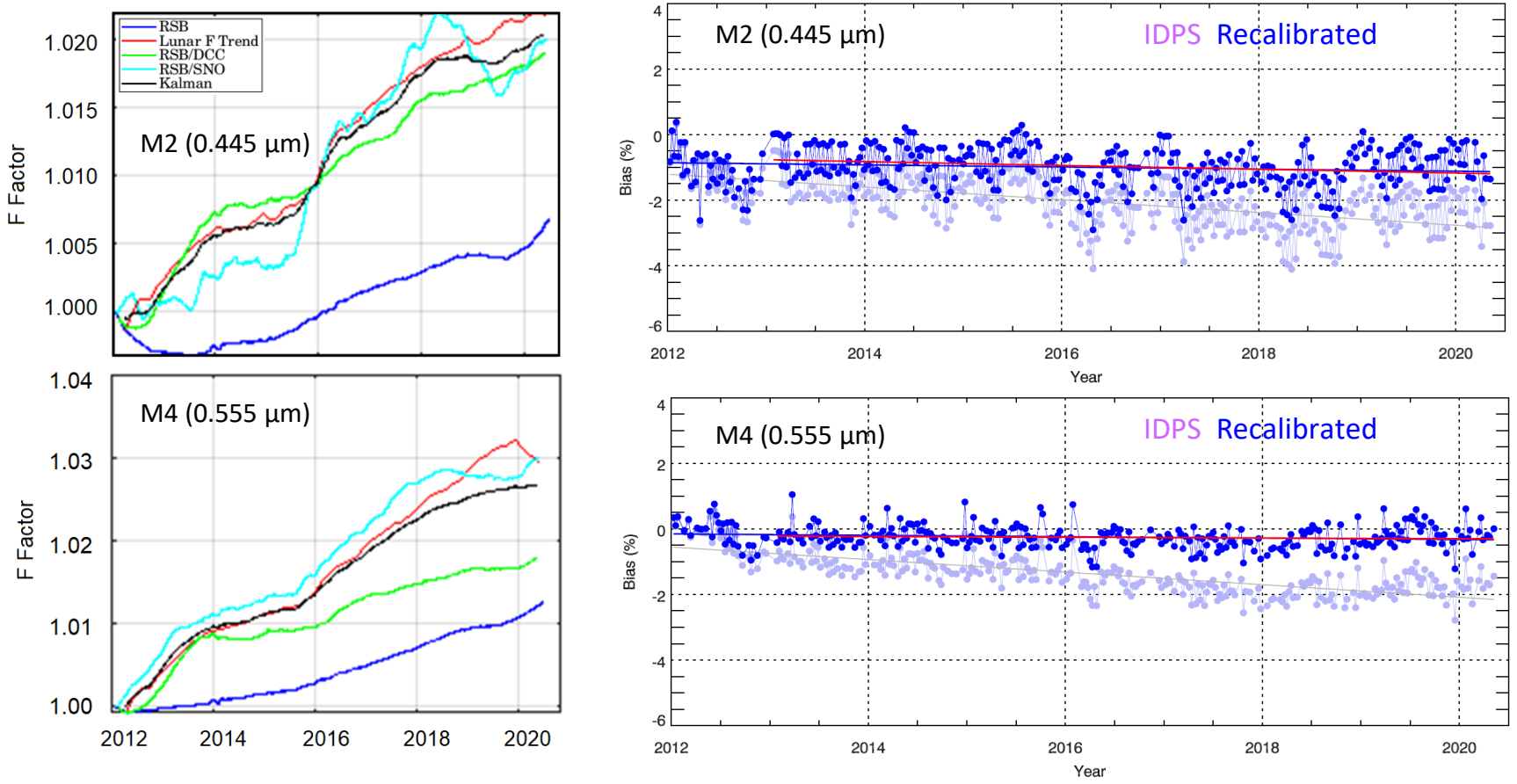
- Recalibration aims to address remaining issues in the mission-long/life-cycle time series.
  - Resolve major issues, such as
    - Residual degradation in reflective solar bands
    - Bias correction for Red (M5) and NIR bands (M7): Address the feedback from cloud and aerosol teams (NOAA and NASA) on larger bias for M5 and M7 .
  - Using Thuillier (2002) solar spectrum, consistent with NOAA-20; makes difference in radiance
  - STAR *Kalman Filter* based bias correction factors based on LunarCal/DCC/SNO for VNIR bands
  - STAR solar diffuser *Surface Roughness-induced Rayleigh Scattering (SRRS)* Model for SWIR bands





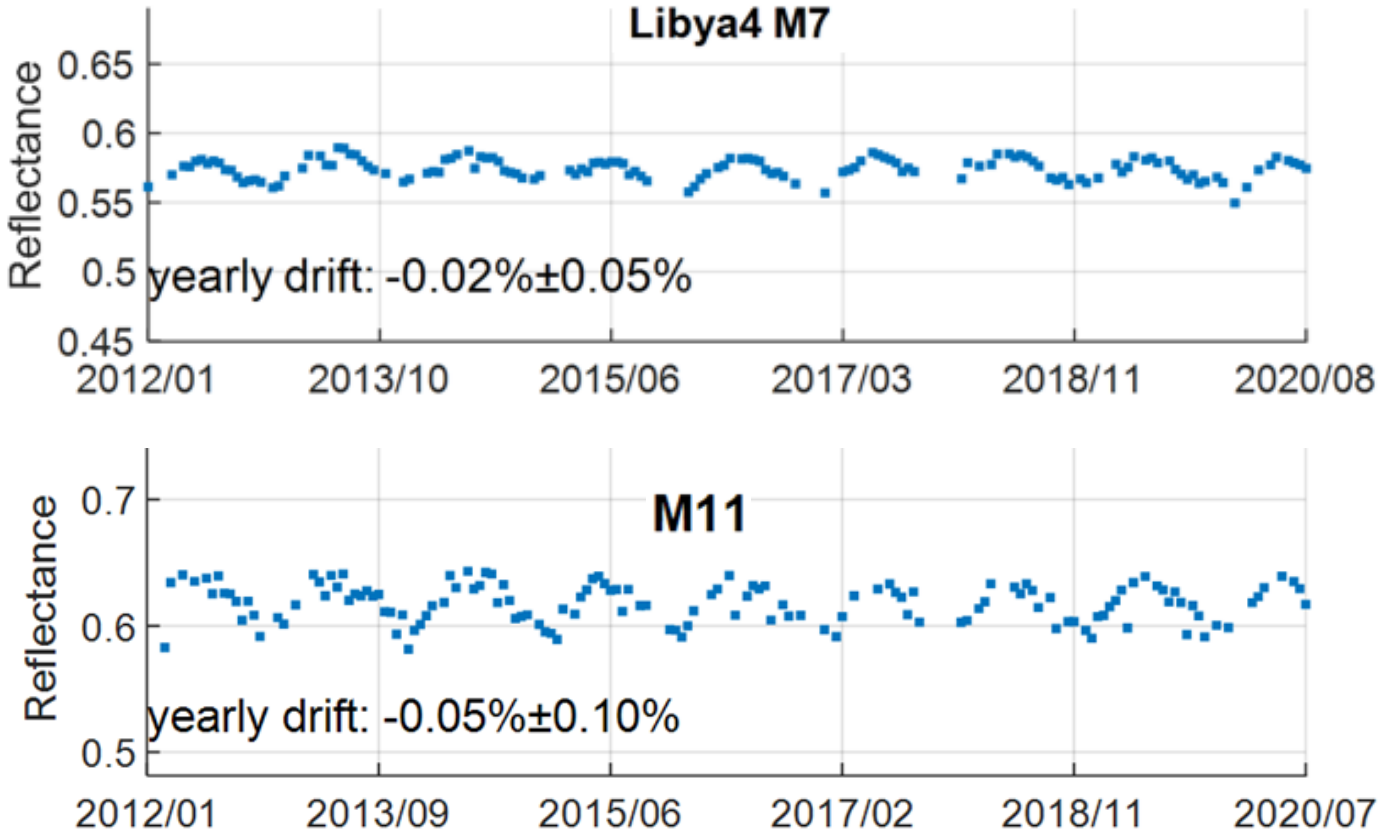
Cao et al. 2021 (https://doi.org/10.3390/rs13061075)

Improved Calibration Stability using Kalman Filter



- After using Kalman Filter, excellent stability achieved in VNIR, <0.3% change in 8 years for most bands

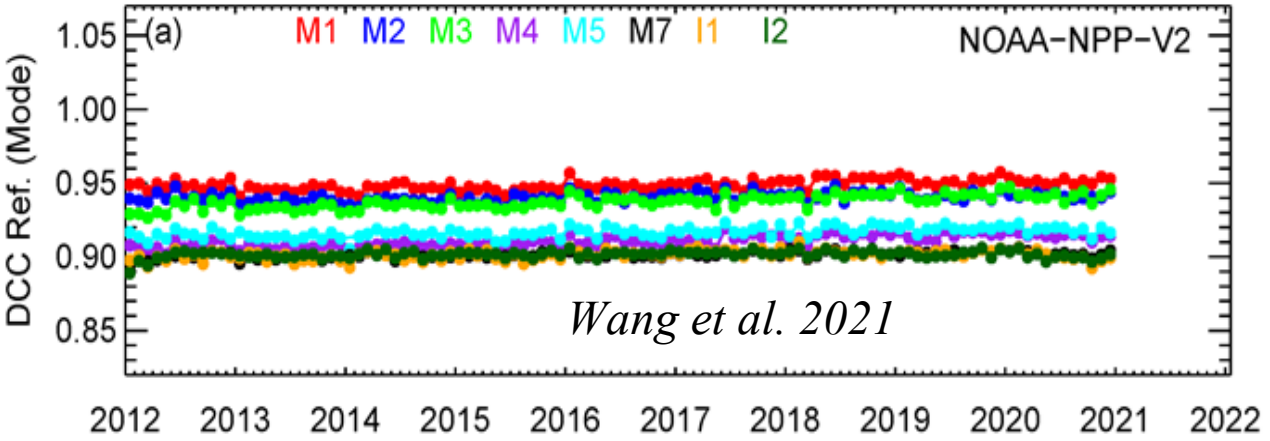
SNPP VIIRS stability over Libya 4 Site (after recalibration)

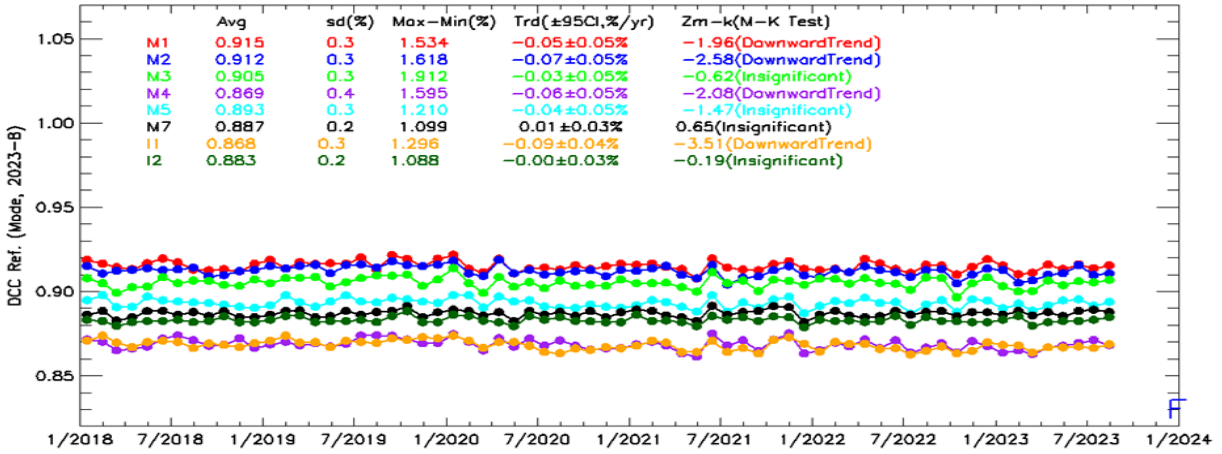


- Reprocessed VIIRS data: **better than 0.1%/yr degradation for all M bands**

SNPP and NOAA-20 VIIRS RSB Calibration Stability over DCCs

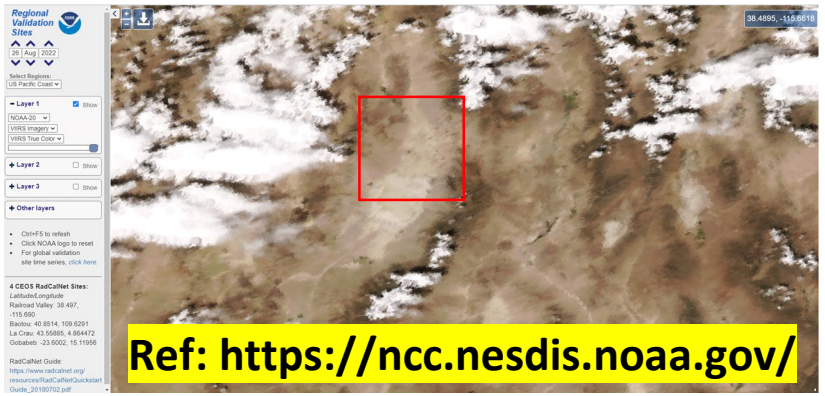
- SNPP VIIRS V2 reprocessed RSB SDRs:
  - Trends <0.1%/year for all RSBs, except M3-M4 (0.14%/year)
- NOAA-20 VIIRS RSB SDRs:
  - On-orbit degradations have been very small.
  - <0.1%/year for all bands since May 2018.
    - Further reduced after reprocessing.
  - Recommended as on-orbit stability reference by GSICS



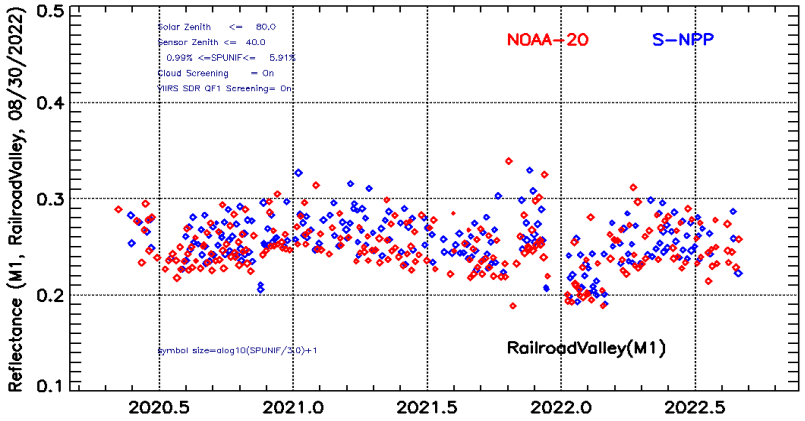


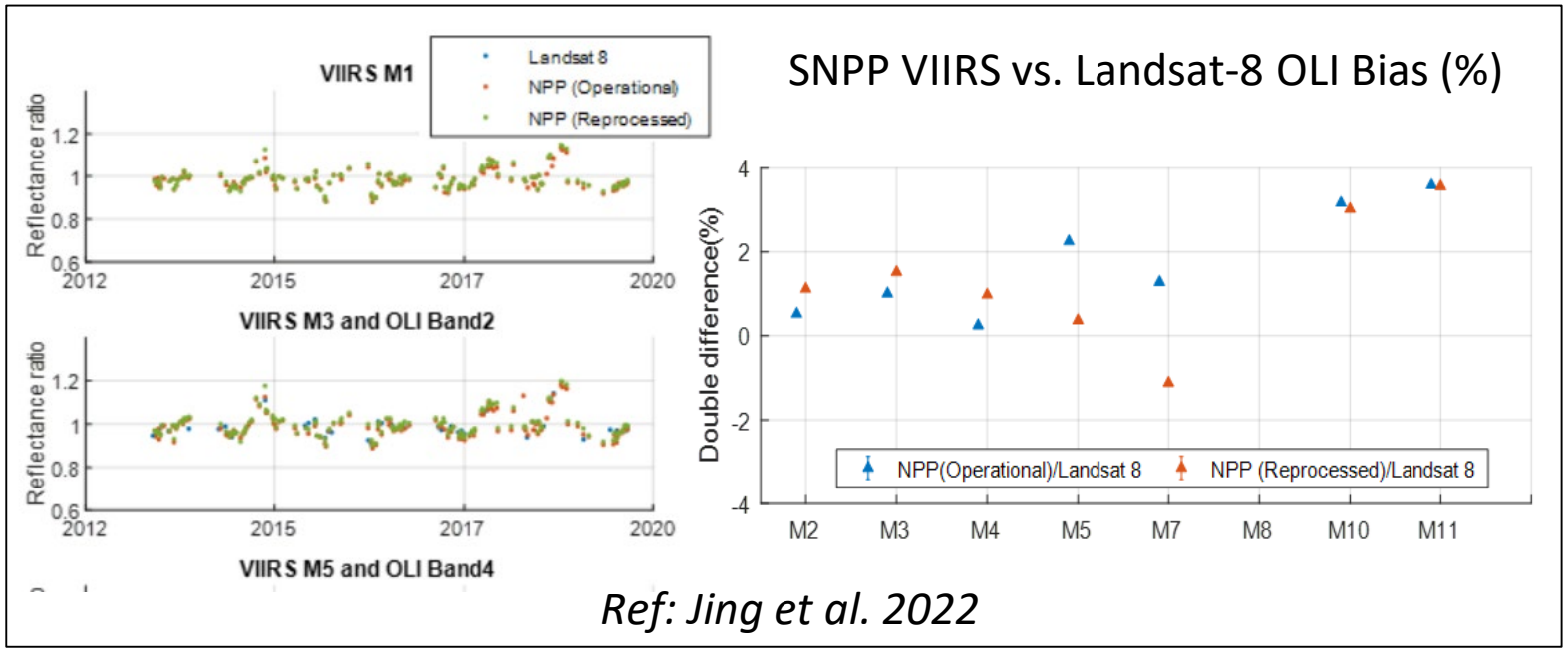
Comparison of SNPP SDRs with Landsat over CEOS Calibration Site (Railroad Valley)

NOAA/STAR Global Regional Validation Sites (GReVS)



VIIRS M1 Reflectance Time Series at RRV



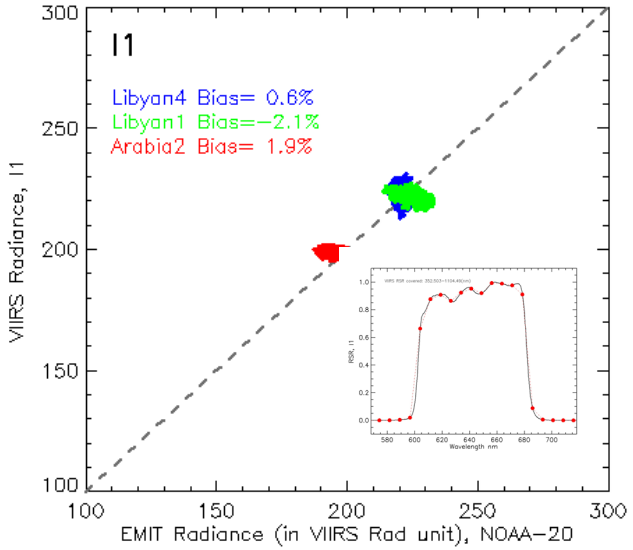


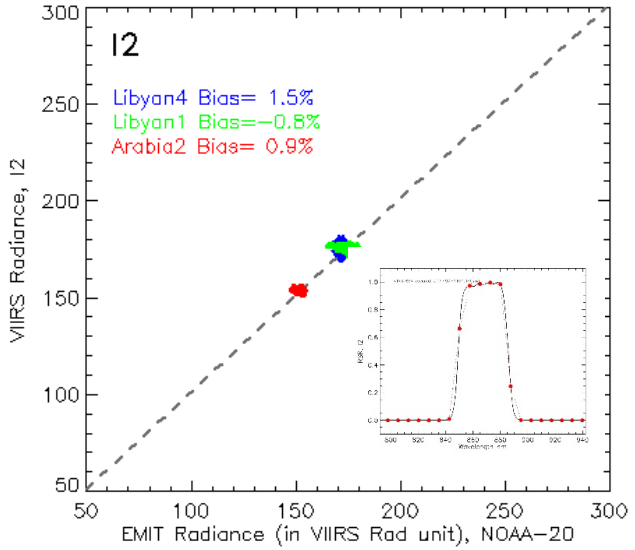
Ref: Jing et al. 2022

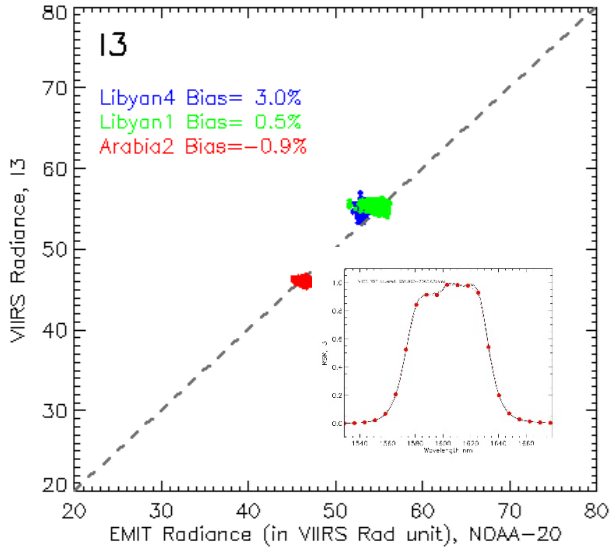
- SNPP VIIRS and Landsat-8 OLI agree but with noticeable variability
- Reprocessed SNPP VIIRS stability is better than 0.1% per year for reflective solar band (RSB) in comparison with Landsat-8
- Supported CEOS IVOS PICSCAR Project on PICS by providing S-NPP VIIRS data over the Libya-4 site from 2014 to 2019

Inter-Comparison of VIIRS with EMIT by JPL (preliminary)

- The NASA JPL EMIT (Earth Surface Mineral Dust Source Investigation) was launched on July 2022.
  - Observes Earth from outside the International Space Station.
  - Designed for map the mineral composition of arid dust source regions via imaging spectroscopy in the visible and short-wave infrared range (285 bands,).
- CEOS desert sites are widely used by the calibration community for solar bands cal/val.
  - VIIRS bands I1-I3 & M10-M11) are well covered by EMIT spectra.
  - NOAA-20 VIIRS agree well with co-located EMIT observations for majority of cases.





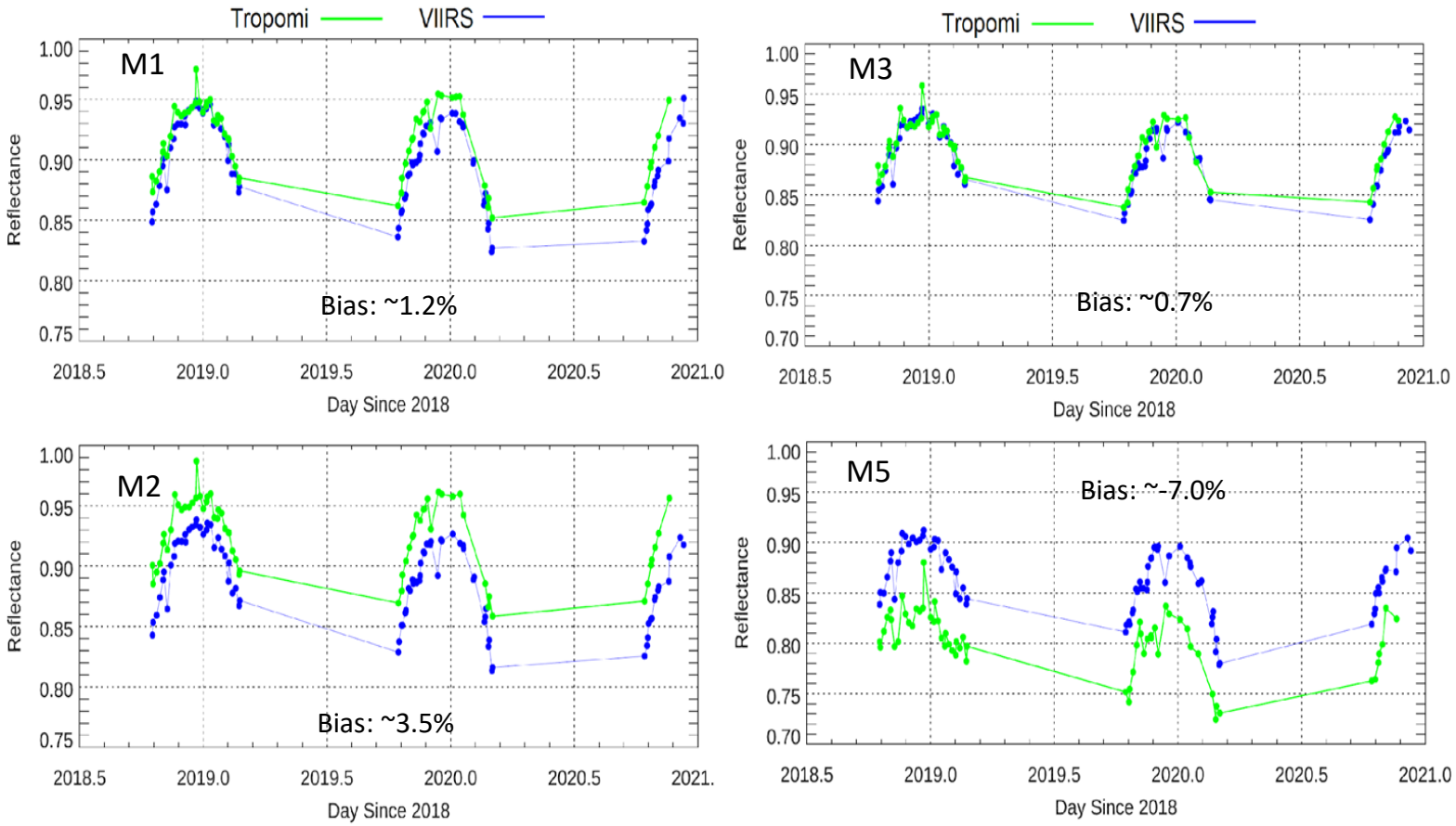


VIIRS/TROPOMI Reflectance Comparison over Dome C

- Tropomi agrees with VIIRS M1, M2, M3 to within 1.2%, 3.5%, and 1% respectively

- Larger bias for M5 (7%) could be due to,
  - Incomplete overlap of Tropomi spectra and VIIRS RSRs that has not been accounted for.
  - VIIRS M5 absolute calibration is ~2% higher *(Ref: Uprety et al., 2013, 2015, 2017)*

*Bias= (Tropomi - VIIRS)*100%/ VIIRS*

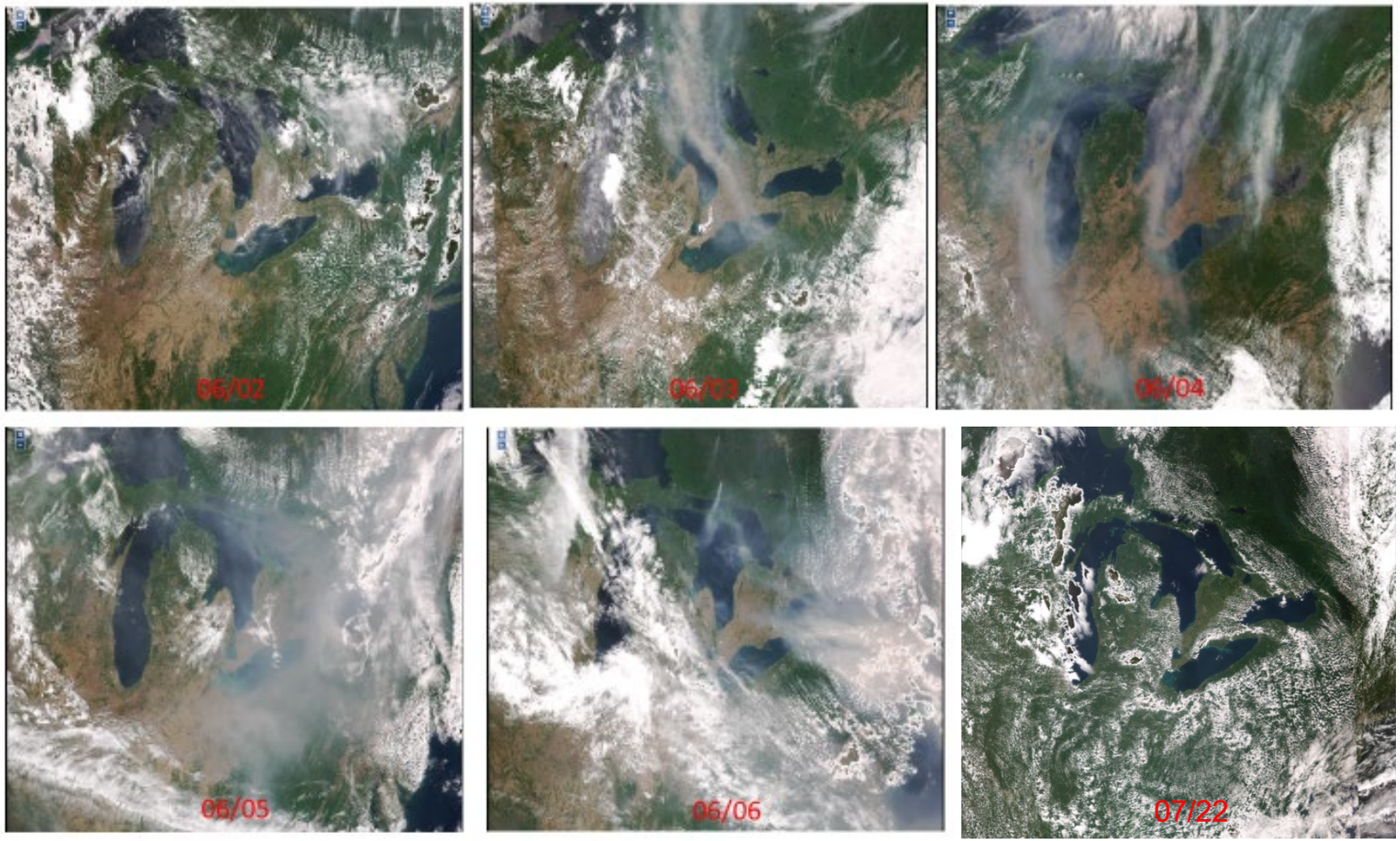


Uprety et al. 2021, AMS

Supported to the TROPOMI Mission

- Sentinel-5P/TROPOMI satellite follows Suomi NPP with ~ 5 minutes in time making the recalibrated science quality VIIRS data very useful for the synergistic use with TROPOMI.
  - Cloud product from VIIRS used for cloud clearing in aerosol and trace gas retrievals using TROPOMI
  - Provides ample opportunities to evaluate the radiometric consistency between the VIIRS and TROPOMI
- Supported ESA TROPOMI Team by providing reprocessed SNPP VIIRS from 04/2018-03/2020
  - Reprocessed SNPP VIIRS SDR and Cloud Masks (using Enterprise Cloud Mask algorithm) per ESA's request on UMD Supercomputer
  - Delivered reprocessed data to EAS Cloud server, through Open Telekom Cloud (OTC) by t-systems using AWS CLI software
- We are preparing to support **Metop-SG Sentinel-5 and METImage** with EUMETSAT on joint cal/val, including global-regional validation sites, and ground based cal/val instruments.

Smoke from Canadian Fire captured by NOAA-21 VIIRS at Regional Validation Sites



https:/ncc.nesdis.noaa.gov/Regional

Summary

- Meeting the mission requirements is easier than meeting application needs for aerosols and atmospheric composition
- Recalibration is necessary to fuse all calibration (Lunar, DCC, SNO, onboard, Desert, CEOS sites) to achieve excellent stability for time series analysis and climate change detection
- Intercalibration with partner missions (both multispectral and hyperspectral) is essential to ensure consistency
- We look forward to comparing with SI traceable missions to further assess absolute accuracy

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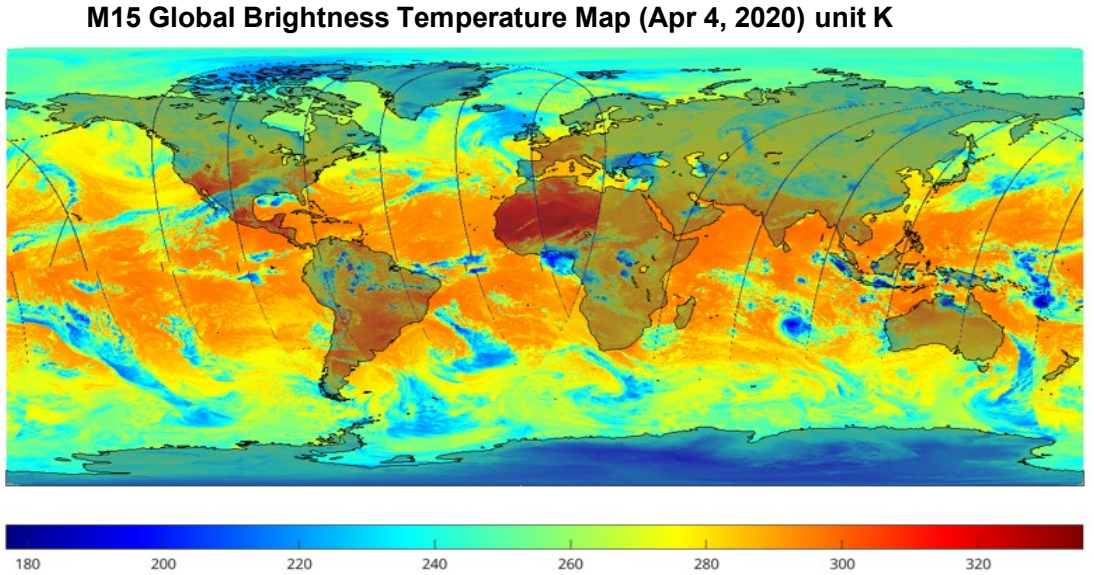
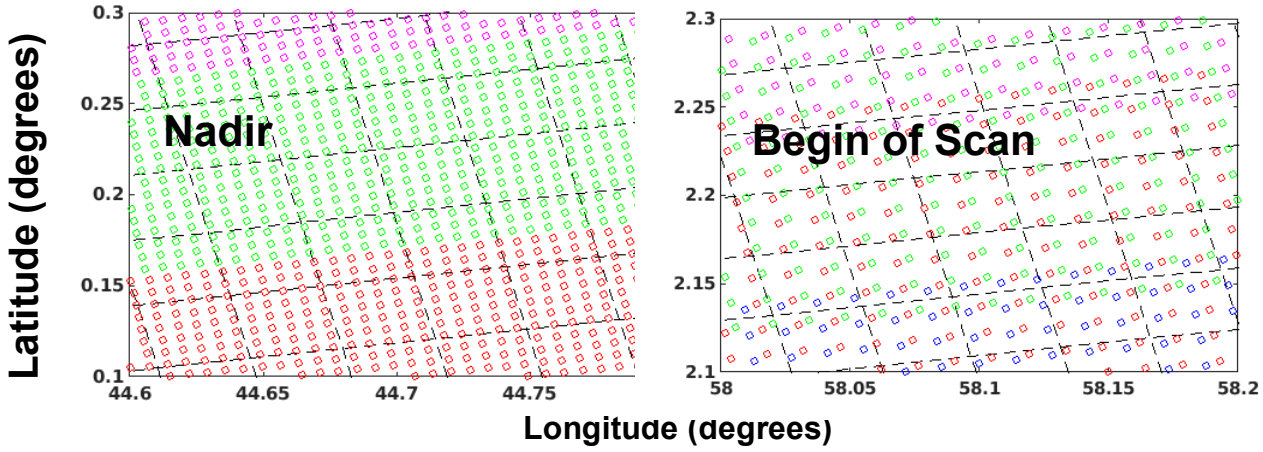
VIIRS Global Area Coverage (VGAC) Data Generation in Collaboration with NECI

- In collaboration with NCEI, NOAA/STAR produced SNPP VGAC data from recalibrated/reprocessed SNPP VIIRS SDR data
- 2012-2020 SNPP VGAC available at ftp://snpp.umd.edu/VGAC/
- Impacts
  - Improved SDR accuracy and stability with recalibration
  - ~30 times reduction in data volume at low spatial resolution for enhanced accessibility, portability and faster processing
  - **Facilitate long term EDR (aerosol, cloud, polar wind) development**
  - Continuation of AVHRR GAC to support climate study
- VGAC: Resampled onto 3.9 km × 3.9 km grid (~30 times reduction compared to the VIIRS SDR data.)



VIIRS vs. VGAC Grid



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