The NIR- and SWIR-based On-orbit Vicarious Calibrations for VIIRS

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Wang, M., W. Shi, L. Jiang, and K. Voss, "NIR- and SWIR-based on-orbit vicarious calibrations for satellite ocean color sensors," *Opt. Express*, **24**, 20437–20453, 2016.

VIIRS Spectral Bands for Ocean Color

VIIRS (Visible Infrared Imaging Radiometer Suite) on
Suomi National Polar-orbiting Partnership **(SNPP)**
VIIRS-**SNPP**, Oct. 28, **2011**, VIIRS-Joint Polar Satellite System (**JPSS**) **J1**, **2017**, VIIR-**J2**,
2021, and J3 & J4 (up to ~2038)

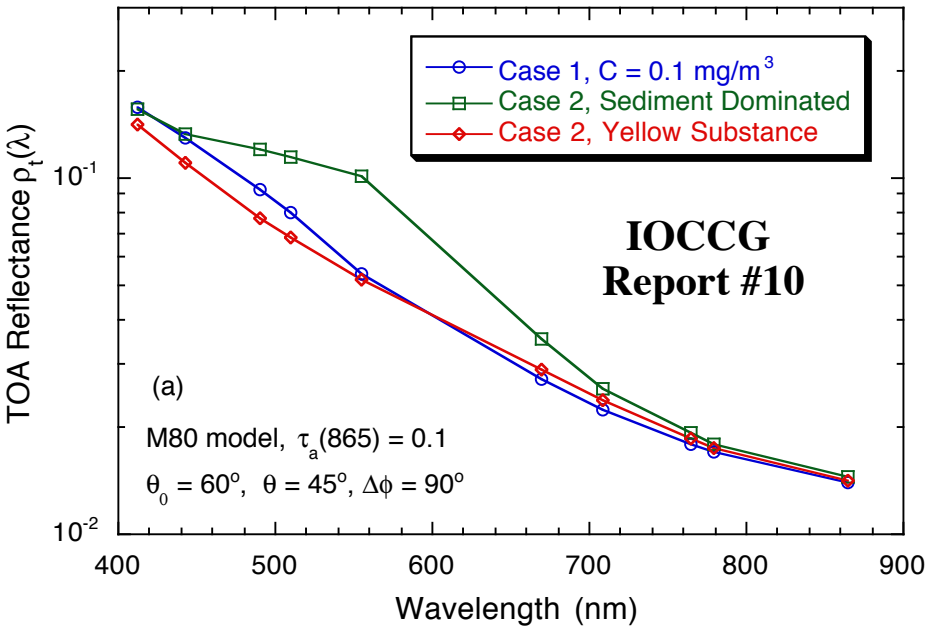
VIIRS†		MODIS		SeaWiFS
Ocean Bands (nm)	Other Bands (nm)	Ocean Bands (nm)	Other Bands (nm)	Ocean Band (nm)
410 (M1)	638 (I1)	412	645	412
443 (M2)	862 (I2)	443	859	443
486 (M3)	1600 (I3)	488	469	490
—		531	555	510
551 (M4)	***SWIR Bands***	551	***SWIR Bands***	555
671 (M5)	1238 (M8)	667, 678	1240	670
745 (M6)	1601 (M10)	748	1640	765
862 (M7)	2257 (M11)	869	2130	865

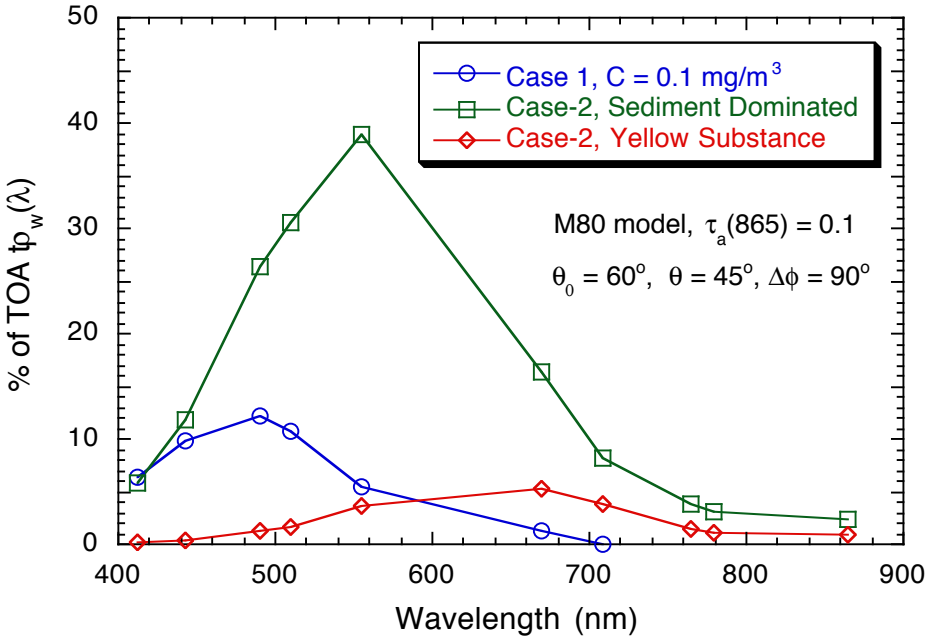
†VIIRS-SNPP nominal center wavelength

Spatial resolution for VIIRS M-band: 750 m, I-band: 375 m

Background

- **At satellite altitude ~90% sensor-measured signal over ocean comes from the atmosphere & surface**
  - Require accurate **atmospheric correction** and **calibration.**
  - **0.5%** error in the TOA radiance corresponds to possible of **~5%** in the derived ocean water-leaving radiance.
  - We need **~0.1%** sensor calibration accuracy.
- **Atmospheric correction algorithm**
  - Using the near-infrared (**NIR**) bands, e.g., Gordon & Wang (1994) for SeaWiFS/MODIS/VIIRS (open oceans).
  - Using the shortwave infrared (**SWIR**) bands (Wang, 2007), e.g., VIIRS 1238 and 1601 nm bands or 1601 and 2257 nm bands (turbid waters).
  - **NIR-SWIR** combined algorithm (Wang & Shi, 2007) for open oceans (**NIR**) and costal/inland turbid waters (**SWIR**).





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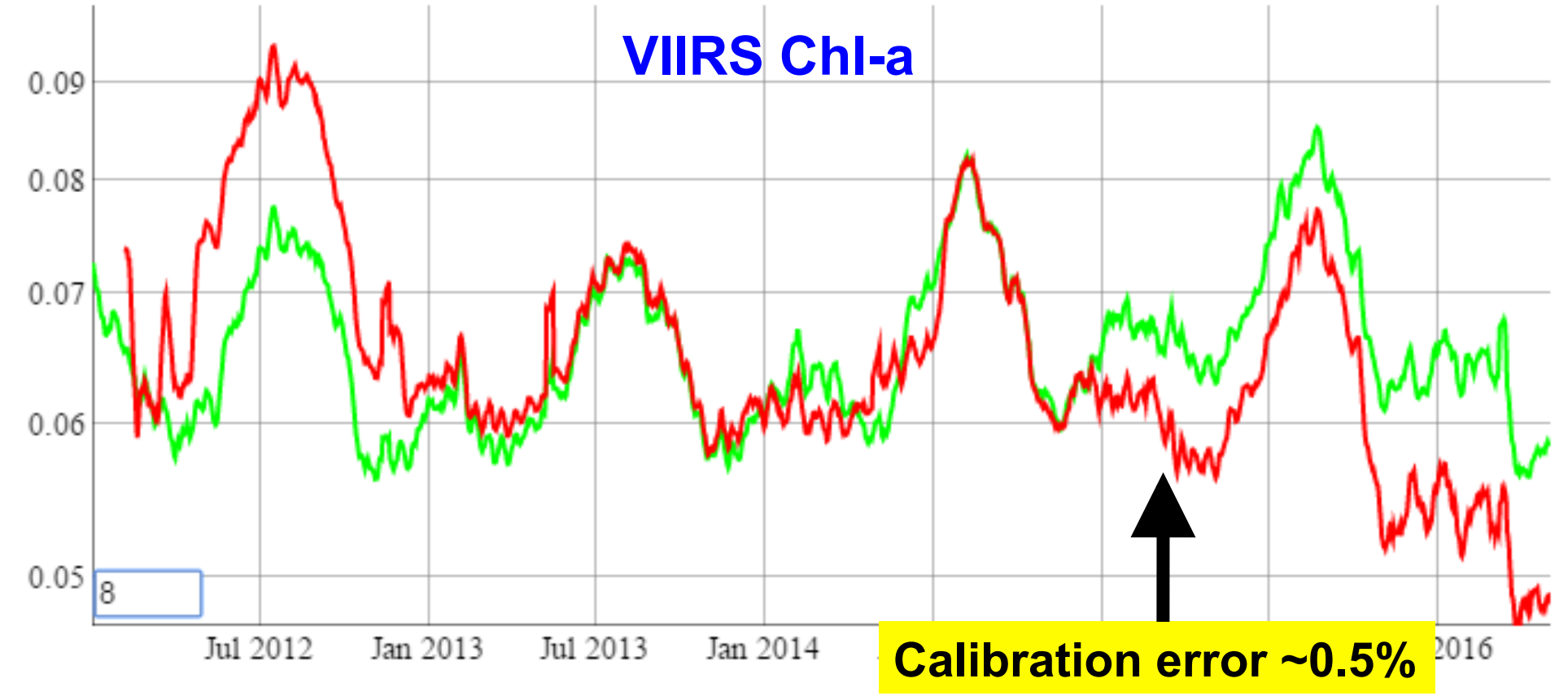
Global Oligotrophic Waters



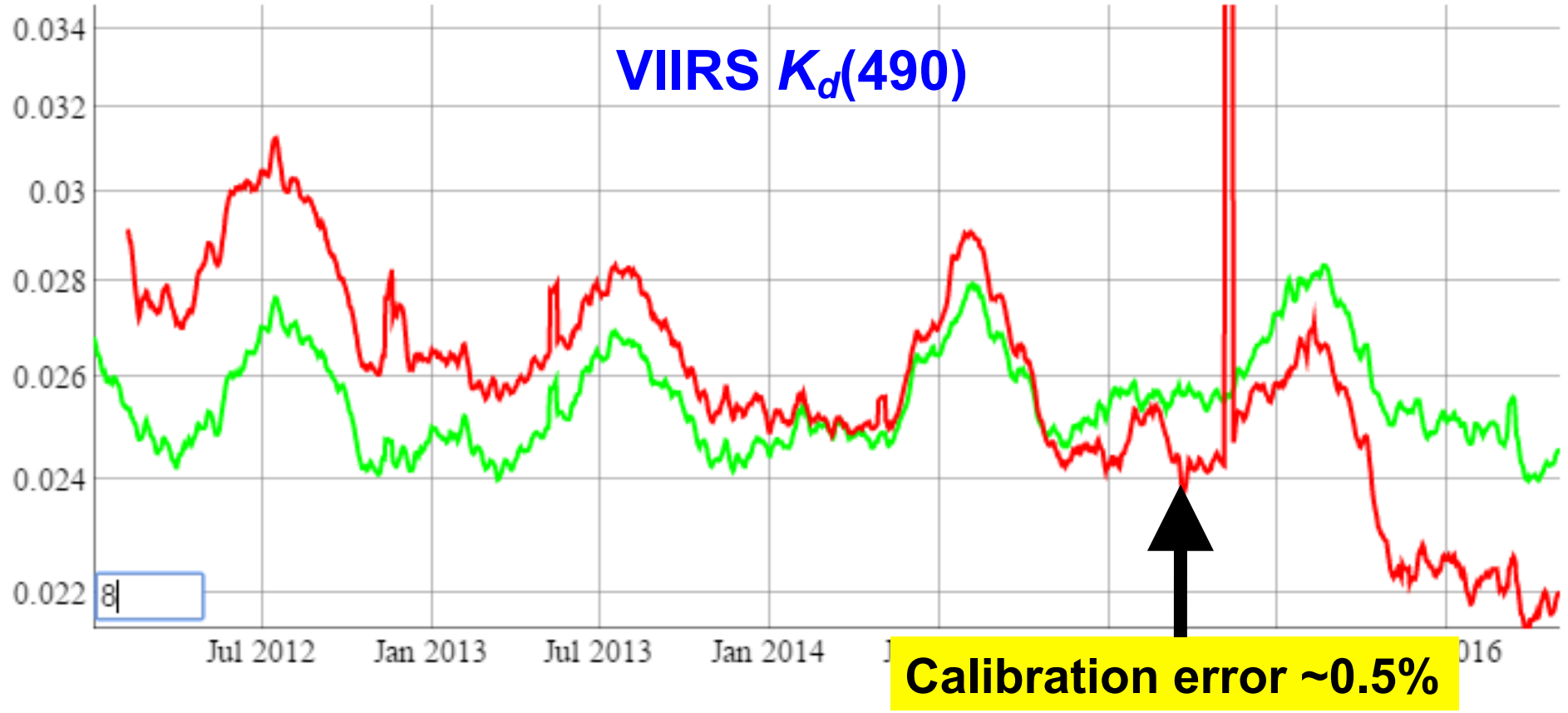
Red: VIIRS **IDPS-SDR**
Near-real-time data

Green: VIIRS **OC-SDR**
Science quality data

Both data are reprocessed using the same MSL12!

Wang, M., W. Shi, L. Jiang, X. Liu, S. Son, and K. Voss, "Technique for monitoring performance of VIIRS reflective solar bands for ocean color data processing," *Opt. Express*, **23**, 14446–14460, 2015. http://dx.doi.org/10.1364/OE.23.014446

Global Oligotrophic Waters



Red: VIIRS **IDPS-SDR**
Near-real-time data

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Science quality data

Both data are reprocessed using the same MSL12!

Vicarious Calibration (VC)

For ocean color remote sensing, post-launch vicarious calibration is necessary for visible bands.

VC: Calibration of the entire system: Sensor + Algorithms

- Account for (by direct measurement or prediction) all of the components of the TOA radiance and
- Compare the computed results with the sensor-measured radiance.

Sensor-measured reflectance:

$$\rho_t^{(Meas)}(\lambda) = [1 + a(\lambda)]\rho_t(\lambda), \quad a(\lambda) - \text{calibration error}$$

Computed reflectance:

$$\rho_t^{(Computed)}(\lambda) = \underbrace{\rho_r(\lambda)}_{\text{Computed}} + \underbrace{\rho_a(\lambda) + \rho_{ra}(\lambda)}_{\text{Predicted Using Models}} + \underbrace{t\rho_{wc}(\lambda)}_{\text{Computed}} + \underbrace{t\rho_w(\lambda)}_{\text{Measured}}$$

H. R. Gordon, "In-orbit calibration strategy for ocean color sensors," *Remote Sens. Environ.*, **63**, 265-278, 1998.

Calibration Site, e.g., MOBY

Vicarious Calibration (Cont.)

Corrected reflectance after vicarious calibration (VC):

$$\rho_t^{(Corrected)}(\lambda) = G^{(VC)}(\lambda)\rho_t^{(Meas)}(\lambda) = [1 + a'(\lambda)]\rho_t(\lambda)$$

where for a given calibration site (solar and viewing geometry)

$$a'(\lambda) = G^{(VC)}(\lambda)[1 + a(\lambda)] - 1 = \left[\rho_t^{(Computed)}(\lambda)\right]^{(VC)} \Big/ \rho_t(\lambda) - 1$$

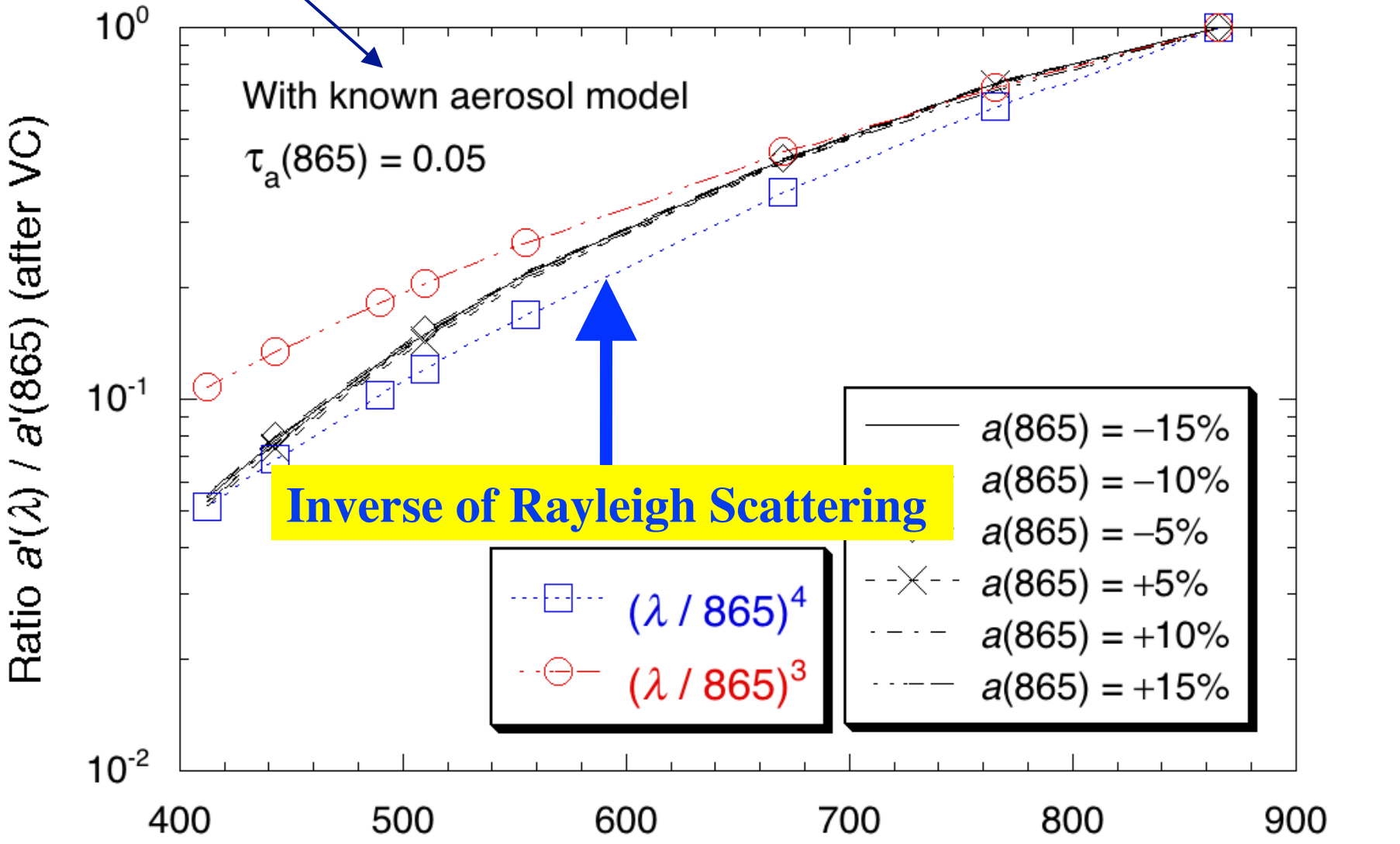
For $a'(\lambda)$ with $\lambda < 865$ nm only dependent on $a(865)$ (or at the SWIR band), but not on $a(\lambda)$.

Results of VC are independent of the sensor pre-launch calibration for $\lambda < 865$ nm (or < SWIR bands if the SWIR band is used as a reference wavelength)!!

Wang, M. and H. R. Gordon, "Calibration of ocean color scanners: How much error is acceptable in the near-infrared," *Remote Sens. Environ.*, **82**, 497-504, 2002.

Used correct aerosol model

***a'*(865) = *a*(865)**



It is really a relative *spectral* vicarious calibration approach!

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VC Approach for VIIRS

Assumption: The VIIRS NIR 862 nm on-orbit calibration is accurate, i.e., gain = 1.

1. Set initial VC gains at the SWIR bands 1238 nm (M8) and 1601 nm (M10) to be 1.
2. Using selected aerosol models, the SWIR-based VC procedure can be carried out to derive the VC gain for VIIRS SWIR band M8 (1238 nm) in the South Pacific Gyre (SPG) region.
3. Using the derived VC gains at the SWIR 1238 and 1601 nm bands from the SPG region, the SWIR-based ocean color data processing can be carried out to derive VC gains for the VIIRS two NIR bands 745 and 862 nm (M6 and M7) at the **MOBY** site.
4. Iterate steps 2–3, adjusting of the VC gains at the VIIRS 1238 and 1601 nm bands at the SPG site until the derived gain at the NIR 862 nm band is 1.
5. With the derived two **NIR** VC gains, the NIR-based ocean color data processing (inverse processing in the MSL12) can be carried out to derive VC gains for all visible bands M1–M5. It is noted that, except for the VC gains at the two NIR bands, the SWIR1-derived and NIR-derived VC gains at the VIIRS visible bands (M1–M5) are independently derived using the MSL12.
6. Repeat step 4 to adjust the VIIRS SWIR band at 2257 nm using the SWIR band at 1238 nm to make the gain of the VIIRS NIR 862 nm band equal to 1 at the **MOBY** site. Note that the two SWIR bands at 1238 and 2257 nm are used for the data processing and only VC gain at the SWIR 2257 nm is adjusted (no gain changes for other two SWIR bands).

VC Gain Results for the NIR-, SWIR1-, and SWIR2-based Ocean Color Data Processing using the Multi-Sensor Level-1 to Level-2 (MSL12) for VIIRS over MOBY Site

Reminder:

NIR uses VIIRS 745 and 862 nm bands

SWIR1 uses VIIRS 1238 and 1601 nm bands

SWIR2 uses VIIRS 1238 and 2257 nm bands

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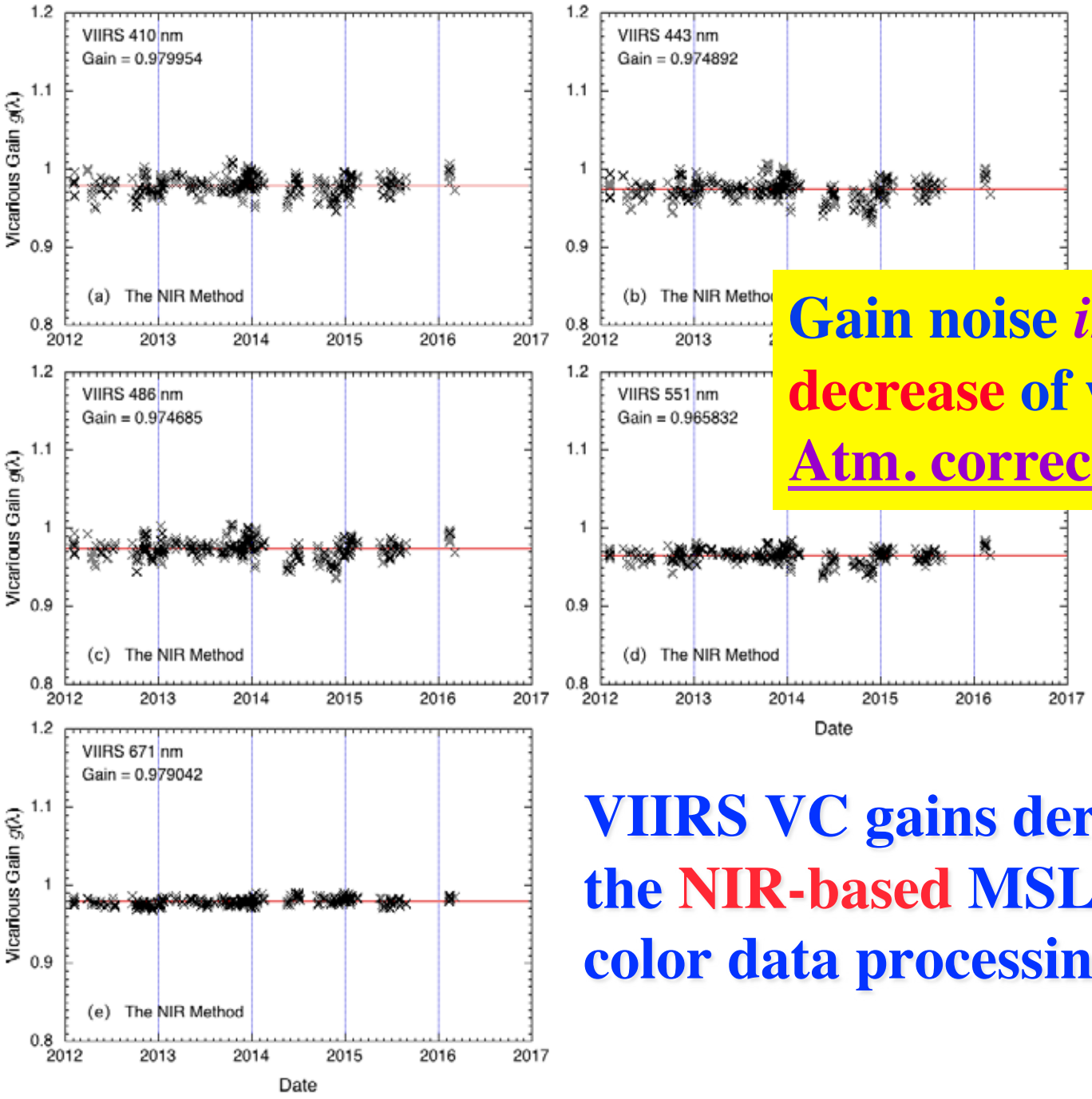
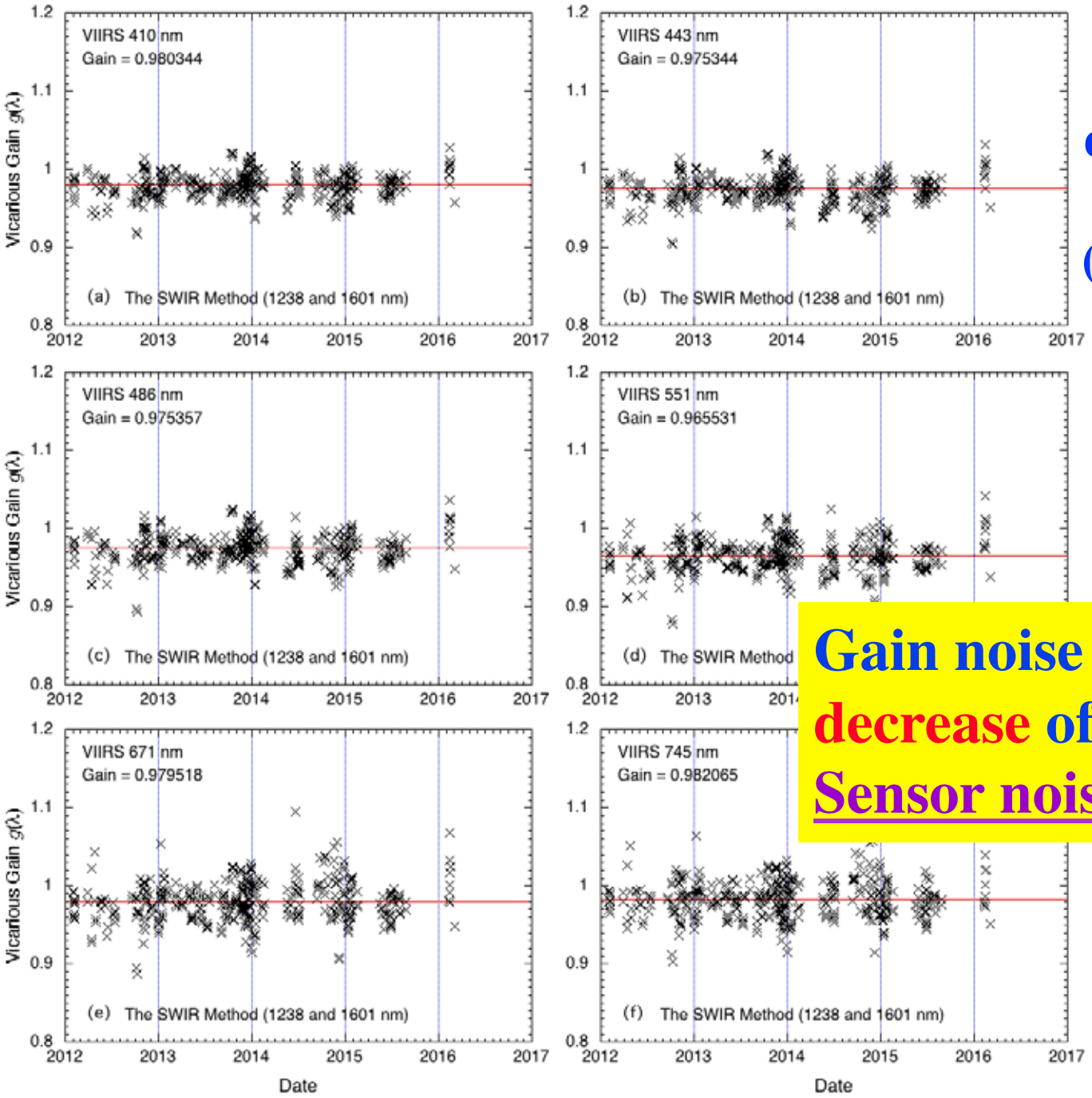


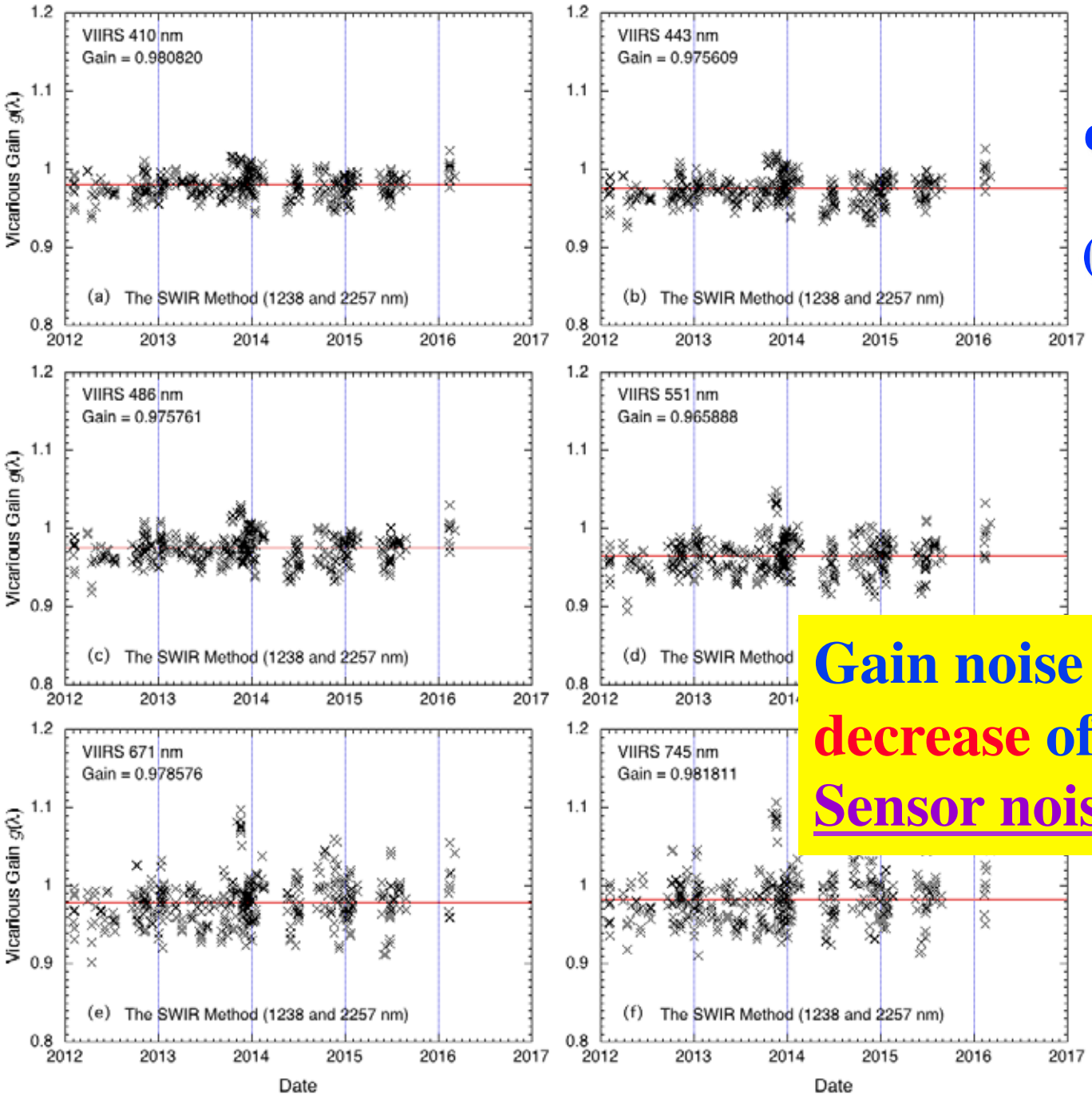
Gain noise *increase* with decrease of wavelengths: Atm. correction errors

VIIRS VC gains derived using the NIR-based MSL12 ocean color data processing



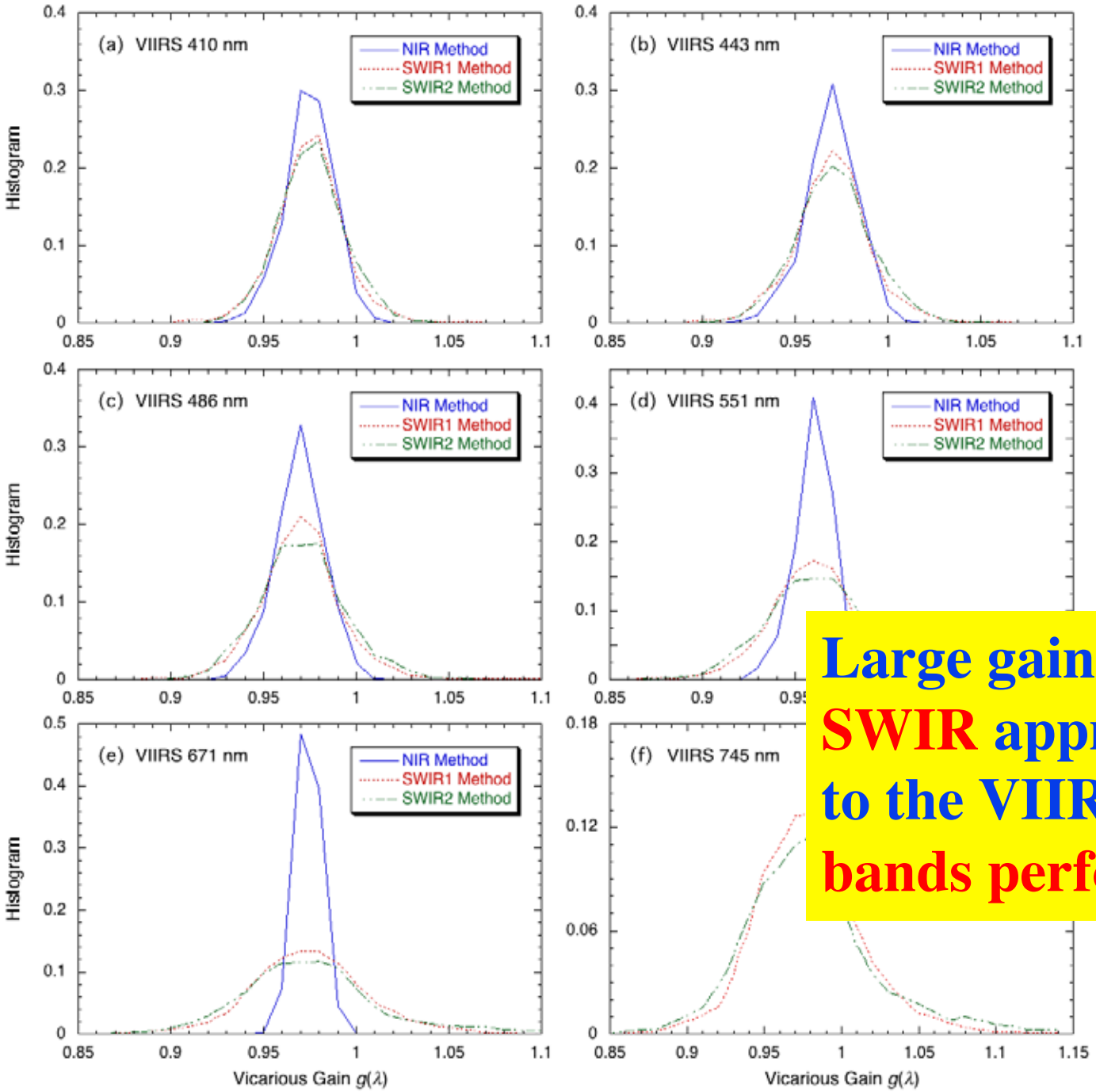
VIIRS VC gains derived using the SWIR1-based (1238 & 1601 nm) MSL12 ocean color data processing

Gain noise *decrease* with decrease of wavelengths: Sensor noise errors



VIIRS VC gains derived using the SWIR2-based (1238 & 2257 nm) MSL12 ocean color data processing

Gain noise *decrease* with decrease of wavelengths: Sensor noise errors



Histogram results: VIIRS VC gains derived using the NIR-, SWIR1-, and SWIR2-based MSL12 ocean color data processing

Large gain noises in the SWIR approaches due to the VIIRS poor SWIR bands performance

VIIRS NIR- and SWIR1, SWIR2-based Vicarious Gains

VIIRS Band (nm)	NIR-Method		SWIR1-Method		SWIR2-Method		Difference (%)	
	Gains	STD	Gains	STD	Gains	STD	SWIR1 vs. NIR	SWIR2 vs. NIR
410 (M1)	0.979954	0.0129	0.980344	0.0190	0.980820	0.0181	0.040	0.088
443 (M2)	0.974892	0.0142	0.975344	0.0219	0.975609	0.0212	0.046	0.074
486 (M3)	0.974685	0.0131	0.975357	0.0246	0.975761	0.0240	0.069	0.110
551 (M4)	0.965832	0.0100	0.965531	0.0299	0.965888	0.0314	–0.031	0.006
671 (M5)	0.979042	0.0064	0.979518	0.0356	0.978576	0.0445	0.049	–0.048
745 (M6)	0.982065	—	0.982065	0.0379	0.981811	0.0476	0.000	–0.026
862 (M7)	1.00000	—	1.00001	0.0423	1.00000	0.0490	0.001	0.000
1238 (M8)	—	—	1.01812	—	1.01812	—	—	—
1601 (M10)	—	—	0.994676	—	—	—	—	—
2257 (M11)	—	—	—	—	1.20252	—	—	—

STD values ***increase*** with **decrease** of wavelengths

STD values ***decrease*** with **decrease** of wavelengths

STD values ***decrease*** with **decrease** of wavelengths

Gain **differences** between the **NIR** and **SWIR** methods are mostly within **~0.05%**!

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Unified NIR and SWIR Vicarious Gains for VIIRS Ocean Color Data Processing

VIIRS Spectral Band (nm)	**Vicarious Gains**
410 (M1)	0.979954
443 (M2)	0.974892
486 (M3)	0.974685
551 (M4)	0.965832
671 (M5)	0.979042
745 (M6)	0.982065
862 (M7)	1.00000
1238 (M8)	1.01812
1601 (M10)	0.994676
2257 (M11)	1.20252

The unified VC gains have been used in **MSL12** to reprocess VIIRS mission-long ocean color data products.

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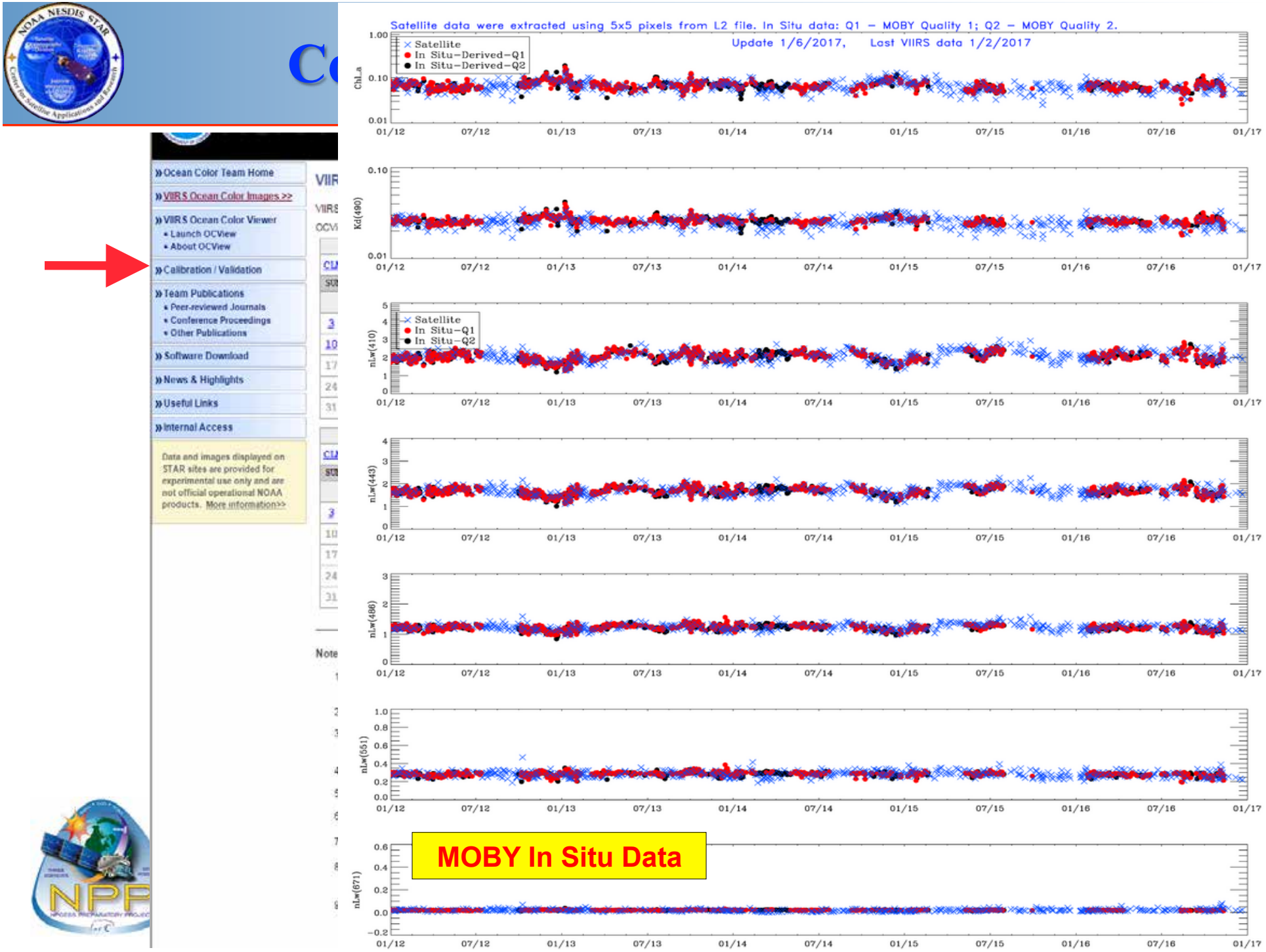
Satellite data were extracted using 5x5 pixels from L2 file. In Situ data: Q1 – MOBY Quality 1; Q2 – MOBY Quality 2.
Update 1/6/2017, Last VIIRS data 1/2/2017
Satellite
In Situ-Derived-Q1
In Situ-Derived-Q2
ChLa
Kd(490)
nLw(410)
nLw(443)
nLw(486)
nLw(551)
nLw(671)
01/12
07/12
01/13
07/13
01/14
07/14
01/15
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07/16
01/17
Ocean Color Team Home
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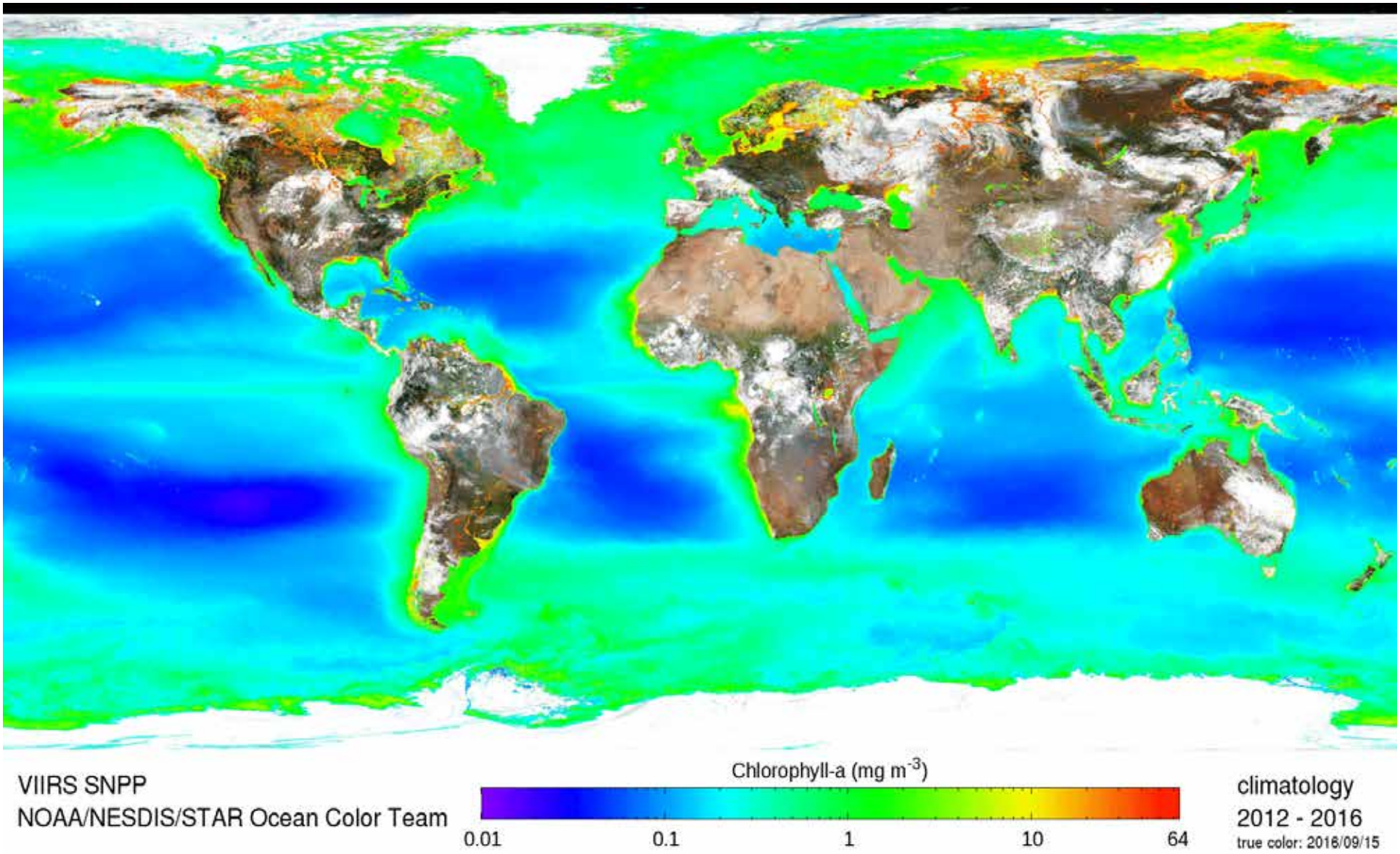
VIIRS Climatology Ocean Color Product Image (2012–2016)



Conclusions

- The sensor on-orbit vicarious calibration is a key calibration procedure necessary for satellite ocean color remote sensing. The VC methodology outlined by *Gordon* (1998) and used for various satellite ocean color sensors, e.g., SeaWiFS, MODIS, MERIS, VIIRS, is really a relative spectral VC approach utilizing the power of Rayleigh scattering.
- We developed a VC approach for deriving consistent vicarious gains for the NIR- and SWIR-based ocean color data processing. Specifically, using the in situ MOBY optics observations between 2012 and 2016, VC gain coefficients for VIIRS-SNPP with the NIR and SWIR VC approaches are derived. The VC gain differences between the NIR- and SWIR-based approaches are mostly within ~**0.05**%.
- It is required to have in situ vicarious calibration facility for satellite ocean color sensors, such as MOBY, to provide accurate $nL_w(\lambda)$ spectra data.
- VIIRS mission-long ocean color data have been reprocessed using the MSL12 with the unified VC gains. VIIRS ocean color validation results show consistent and improved ocean color data from the NIR- and SWIR-base approaches.
- VIIRS global ocean color data have been routinely produced using the NIR-, SWIR-, and NIR-SWIR-based ocean color data processing.

Website:

https://www.star.nesdis.noaa.gov/sod/mecb/color/