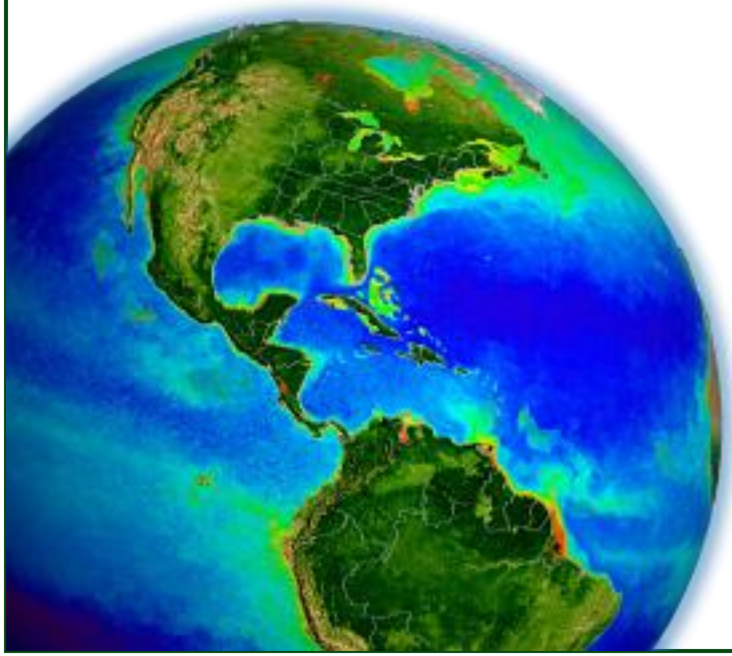
NASA Approach to Vicarious Calibration



Bryan Franz

and the

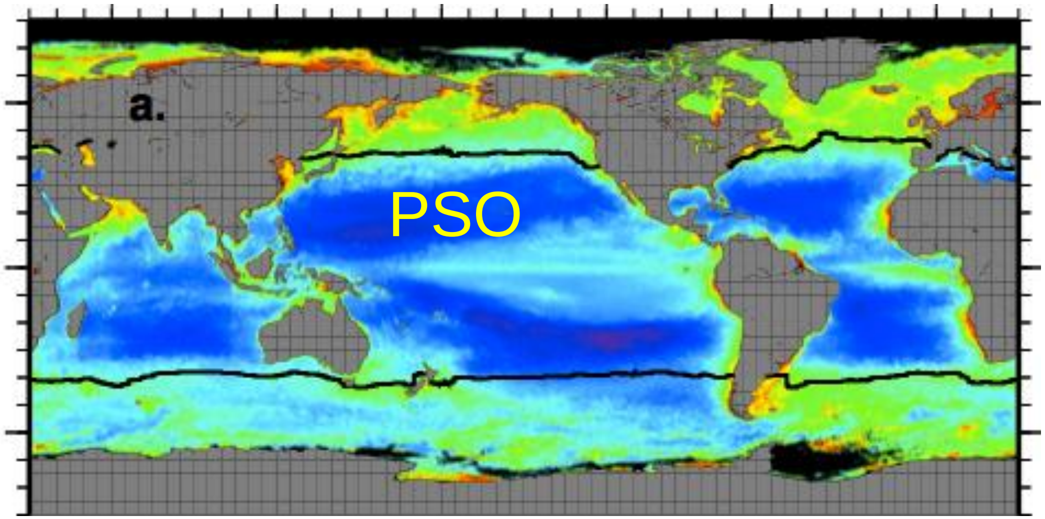
Ocean Biology Processing Group

IOCCG Vicarious Calibration Workshop

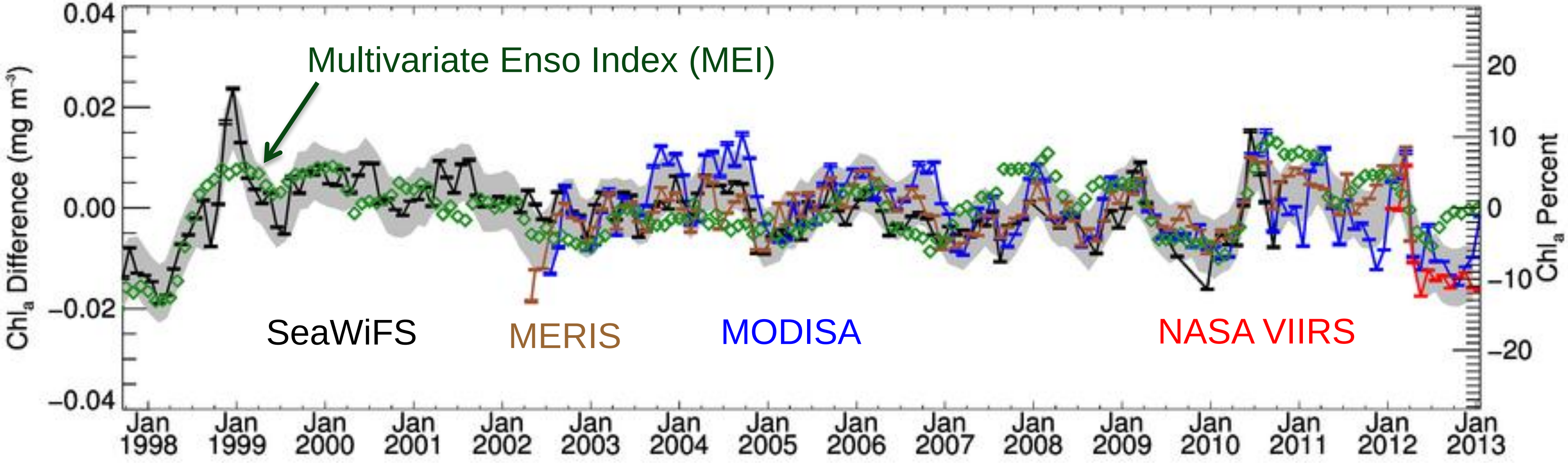
November 2013

we want to produce high quality data records of sufficient length, **consistency**, and continuity to support climate and ecosystem research

Following
Berenfeld et al. 2006
Mean SST > 15C



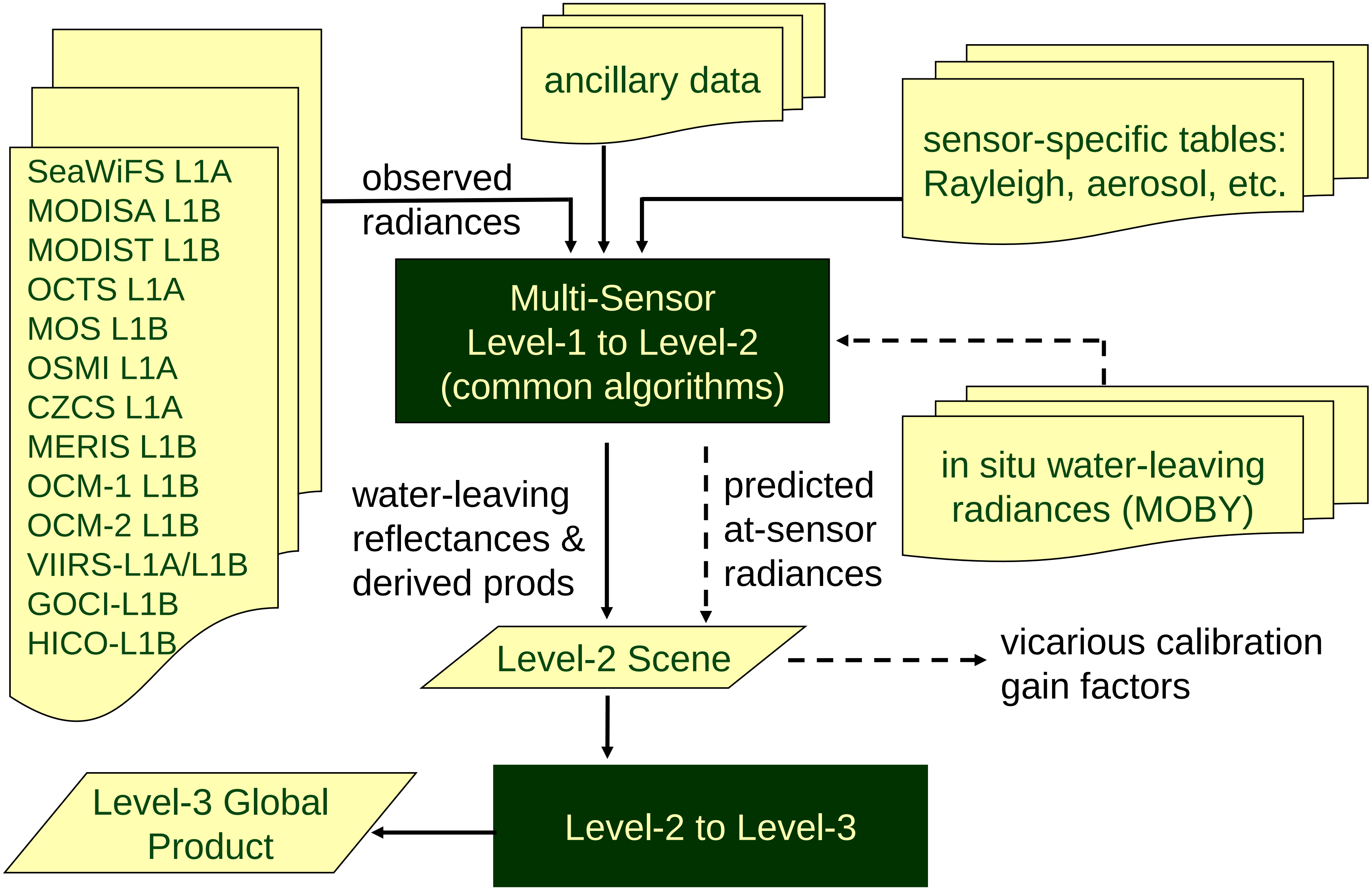
PSO Anomaly



How do we achieve consistency?

- Focus on instrument calibration
  - establishing temporal and spatial stability within each mission
- Apply common algorithms
  - ensuring consistency of processing across missions
- Apply common vicarious calibration approach
  - ensuring spectral and absolute consistency of water-leaving radiance retrievals under idealized conditions
- Perform detailed trend analyses (hypothesis testing)
  - assessing temporal stability & and mission-to-mission consistency
- Reprocess multi-mission timeseries
  - incorporating new instrument knowledge and algorithm advancements

Common Processing Approach



SeaWiFS L1A
MODISA L1B
MODIST L1B
OCTS L1A
MOS L1B
OSMI L1A
CZCS L1A
MERIS L1B
OCM-1 L1B
OCM-2 L1B
VIIRS-L1A/L1B
GOCI-L1B
HICO-L1B

observed radiances

ancillary data

sensor-specific tables: Rayleigh, aerosol, etc.

Multi-Sensor
Level-1 to Level-2
(common algorithms)

in situ water-leaving radiances (MOBY)

water-leaving reflectances & derived prods

predicted at-sensor radiances

Level-2 Scene

vicarious calibration gain factors

Level-2 to Level-3

Level-3 Global Product

NASA/OBPG Vicarious Calibration

band-specific “adjustment” factors that minimize mean bias between in situ calibration source and satellite $R_{rs}(\lambda)$ retrievals.

system calibration

- compensates for error in both instrument calibration and retrieval algorithm

two step process

- calibrate NIR bands to improve aerosol type retrieval
- calibrate visible using calibrated aerosol retrieval and in situ radiometry

derived at top of atmosphere, fixed in space and time

- ratio of predicted TOA radiance to observed TOA radiance
- averaged over all match-ups

$$g_i(\lambda) = \frac{L_t^{predicted}}{L_t^{observed}} \qquad g(\lambda) = \frac{1}{n}\sum_{i=1}^{n} g_i(\lambda)$$

Vicarious Calibration of NIR

$$L_t(\mathrm{NIR}) = \underset{\text{calculated}}{L_{other}(\mathrm{NIR})} + L_a(\mathrm{NIR}) + \underset{\text{known}}{L_w(\mathrm{NIR})}$$

requires two assumptions:

- L_w in two NIR bands negligible (or known)
- calibration of one NIR band is perfect (e.g., g(865) = 1 for SeaWiFS)

calibration of remaining NIR band (e.g., 765 for SeaWiFS):

- using an assumed aerosol type, the associated model can be used in combination with $L_a(865)$ to predict $L_a(765)$
- operationally executed using a 15x15 pixel target in the South Pacific Gyre (aerosol model r70f10v01; $\alpha = 0.685$; based on Tahiti AERONET site)
- remains spatially/temporally independent of visible band calibration

Construction of predicted TOA radiance in visible

vicarious TOA radiance

predicted air aerosol whitecap glint water gas pol

$$L_t(\lambda) = [\, L_r(\lambda) + \mathbf{L_a(\lambda)} + tL_f(\lambda) + TL_g(\lambda) + t_d(\lambda)\mathbf{L_w(\lambda)} \,] \cdot t_g(\lambda)\, f_p(\lambda)$$

from satellite NIR bands

conversion for time and view

$$(\theta_{0,},\theta=0,\Delta\phi=0) \rightarrow (\theta_0,\theta,\Delta\phi)$$

in situ $L_w(\lambda)$

$$g_i(/) = \frac{L_t^{predicted}}{L_t^{observed}}$$

in practice, 5x5 pixel average

Conversion of in situ L_w to satellite L_w

given in situ L_w at satellite bandpass λ with radiant path geometry ($\theta_0, \theta=0, \Delta\varphi=0$), convert to satellite L_w and path geometry ($\theta_0,\theta,\Delta\varphi$).

iteration

brdf

Sun

$$R_{rs}(\lambda) = L_w(\lambda)\, \overset{\text{brdf}}{f_b(\lambda,\theta_0,0,0,C_a)} / t_0(\lambda,\theta_0) \cos(\theta_0)\, \overset{\text{Sun}}{F_0(\lambda)}$$

$t_0(\lambda,\theta_0) = \exp[-\tau_{eff}/\cos(\theta_0)]$ where $\tau_{eff} = -\ln[t_0(\lambda,\theta_0)\cos(\theta_0)]$

$$f_b(\lambda,\theta_0,0,0,C_a) = \overset{\theta_0=0,\ \theta=0,\Delta\varphi=0}{(R_0\, f_0/Q_0)} / \overset{\theta_0,\ \theta=0,\Delta\varphi=0}{(R\, f/Q)}$$

Morel at al. 2002

$C_a = f(R_{rs}(\lambda))$

satellite standard algorithm (OCx)

in situ Lw for satellite viewing geometry

$$\boxed{L_w(\lambda) = R_{rs}(\lambda)\, t_0(\lambda,\theta_0) \cos(\theta_0)\, F_0(\lambda) / f_b(\lambda,\theta_0,\theta,\Delta\varphi,C_a)}$$

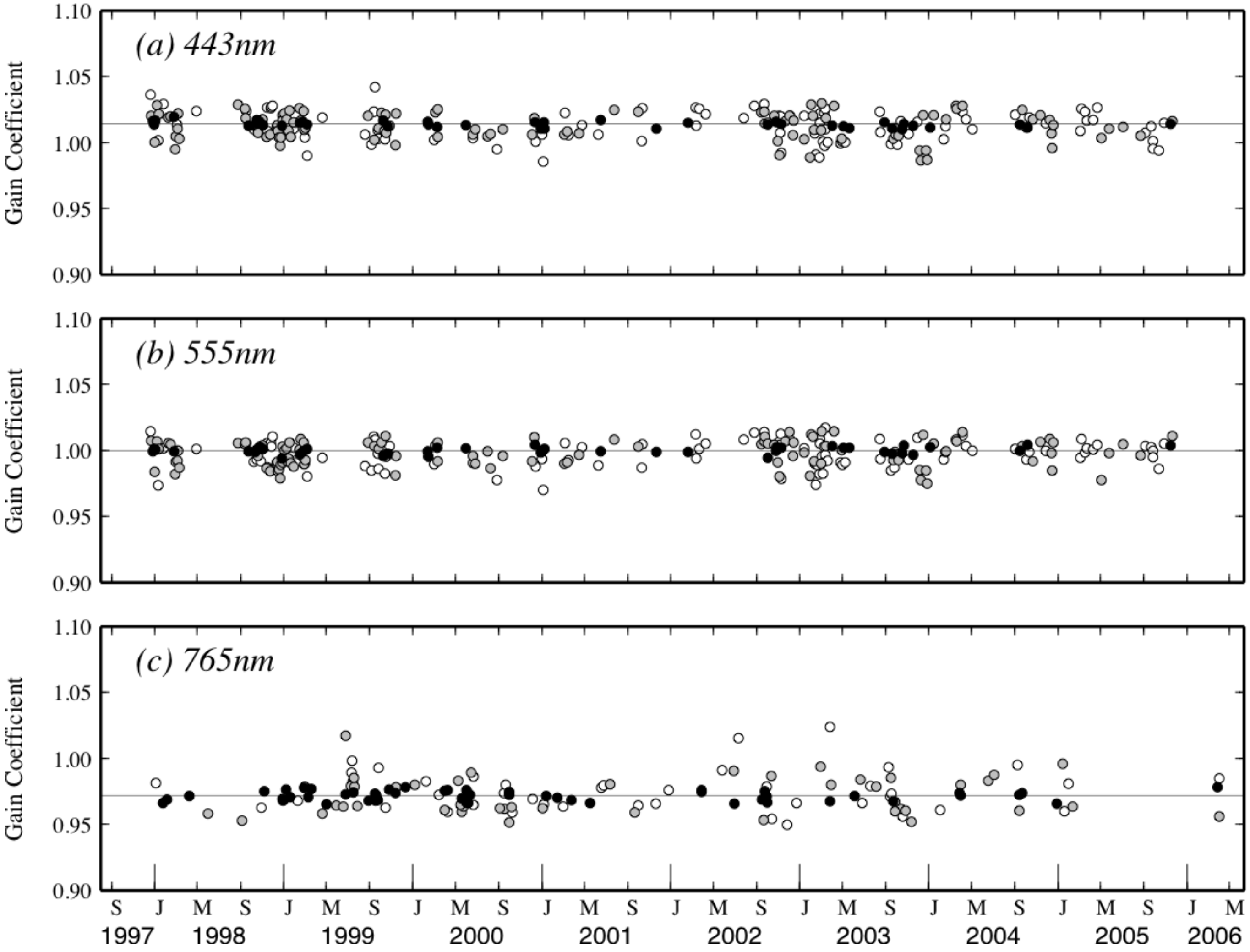
MOBY Exclusion Criteria

Lw rms <= 5 %
Es rms <= 10 %
Es stability <= 10 %
Es diff <= 15 %
tilt and roll <= 5 degrees

where:

- Lw rms: The RMS of the percent error between Lw computed from the top 2 arms and Lw computed from all 3
- Es rms: The RMS of the percent error between Es and Ed(0+) (i.e. Es sensor compared to Es extrapolated from Ed)
- Es stability: The percent error between the min and max measured Es (i.e. we assess how much Es varies throughout the multiple Es measurements that are interspersed between the lengthy Lu and Ed sampling cycle)
- TheoryEs diff: The RMS of the percent error between a modeled clear sky Es and the measured Es (i.e. Es closest in time to the averaged Lu measurement time)
- Wavelengths between 425 & 575 nm are used to evaluate these criteria.

Example: SeaWiFS Vicarious Gains over Time using MOBY and SPG

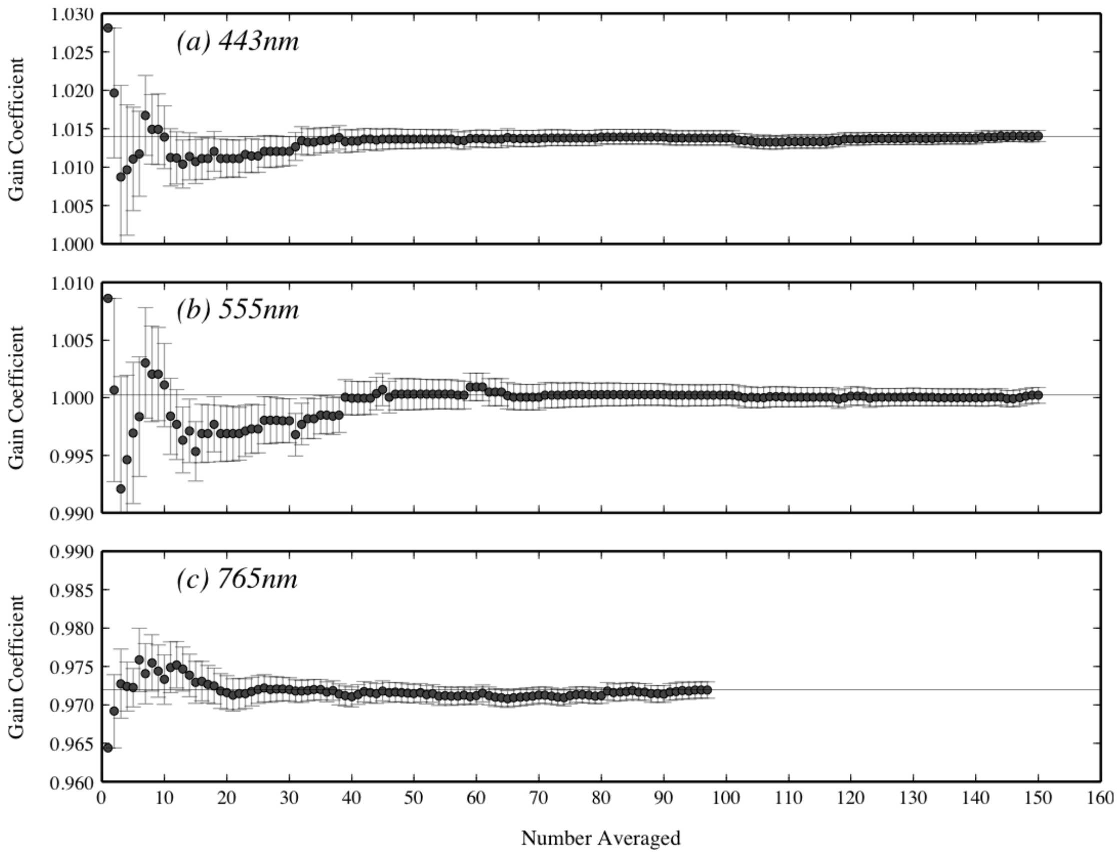


Franz, B.A., S.W. Bailey, P.J. Werdell, and C.R. McClain, F.S. (2007). Sensor-Independent Approach to Vicarious Calibration of Satellite Ocean Color Radiometry, Appl. Opt., 46 (22).

Cumulative mean vicarious gain

It requires many samples to reach a stable vicarious calibration, even in clear (homogeneous) water with a well maintained instrument (MOBY)

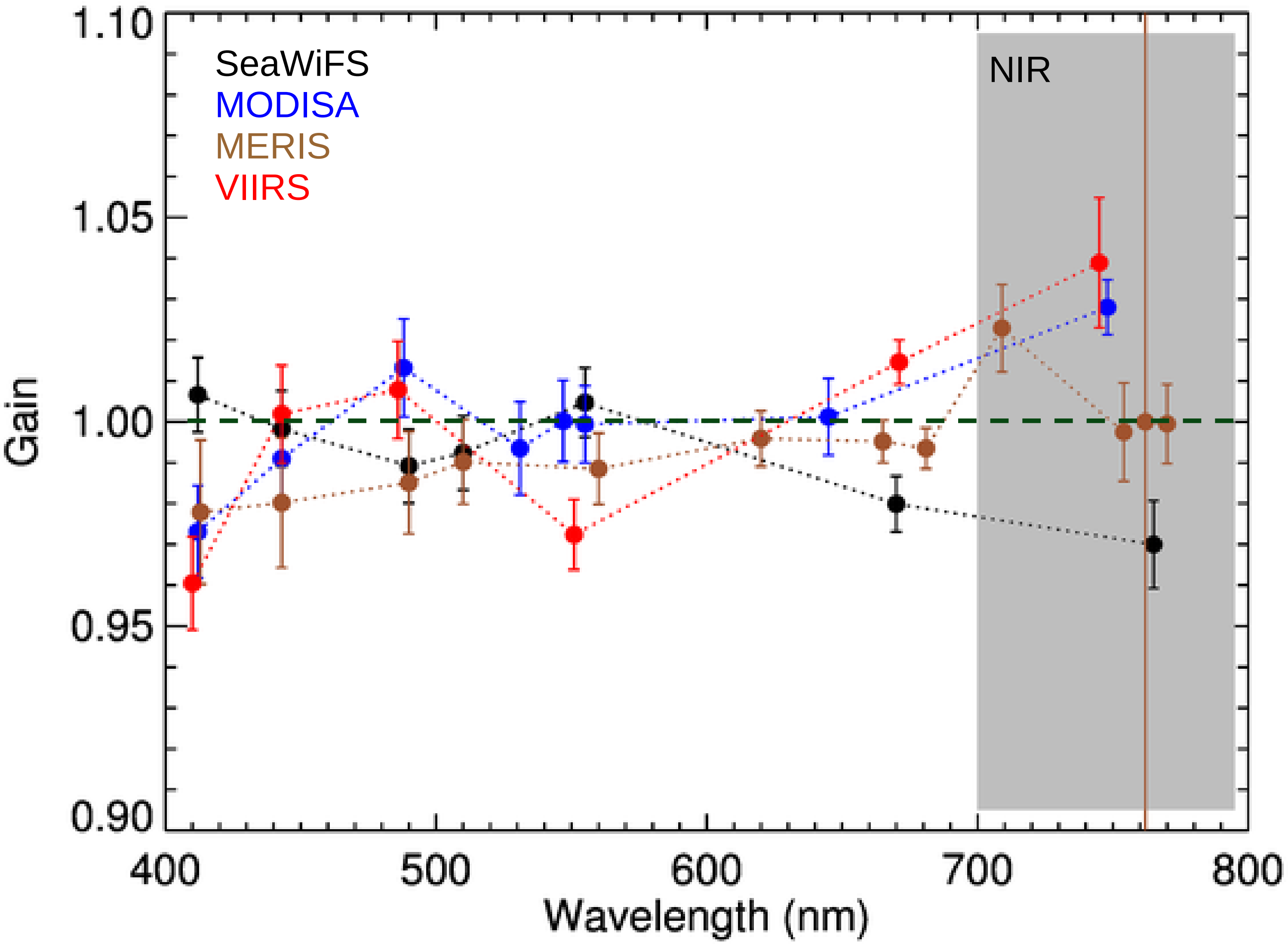
SeaWiFS to MOBY



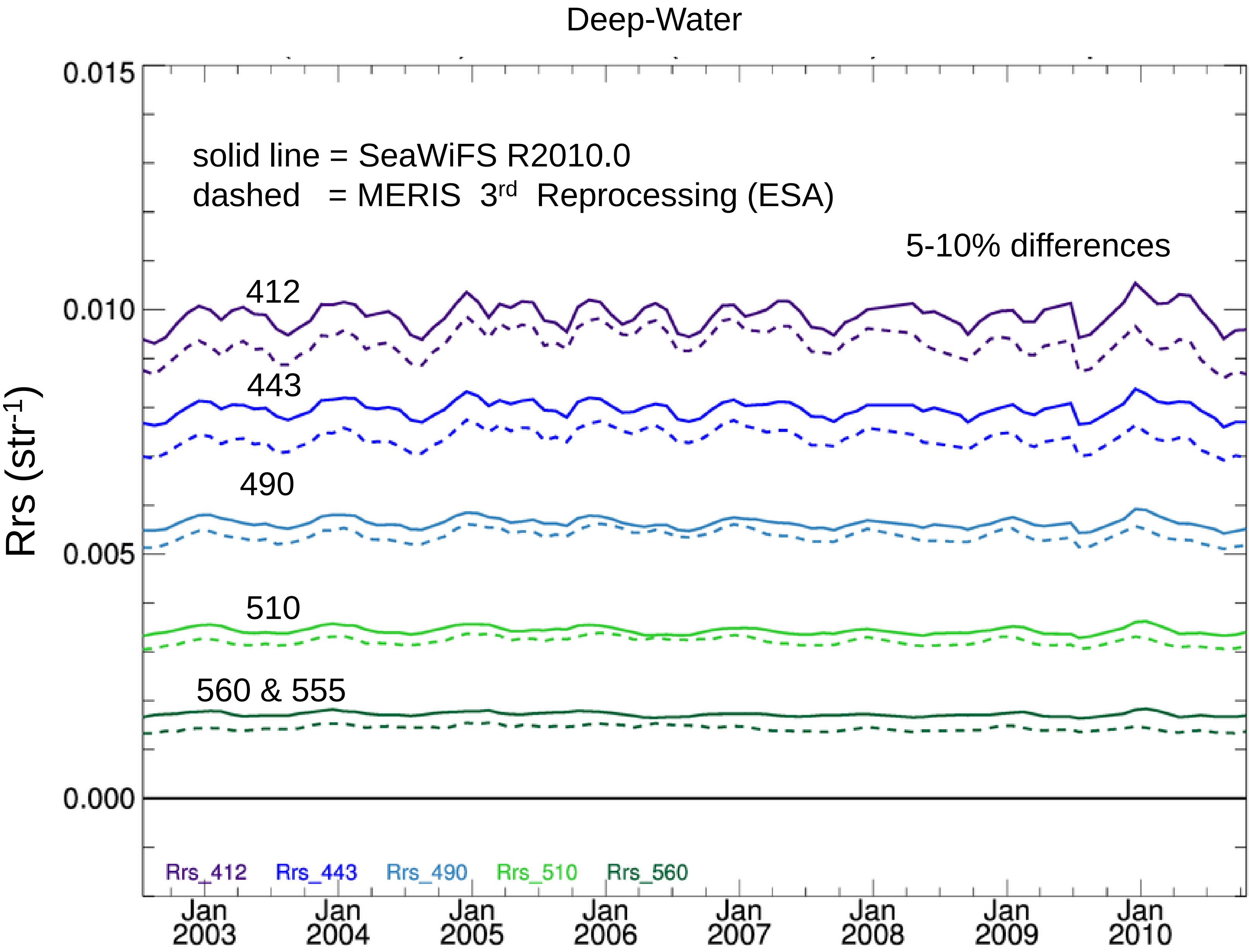
Franz, B.A., S.W. Bailey, P.J. Werdell, and C.R. McClain, F.S. (2007). Sensor-Independent Approach to Vicarious Calibration of Satellite Ocean Color Radiometry, Appl. Opt., 46 (22).

NASA-derived Vicarious Gains

consistent processing algorithms and vicarious calibration methods and sources



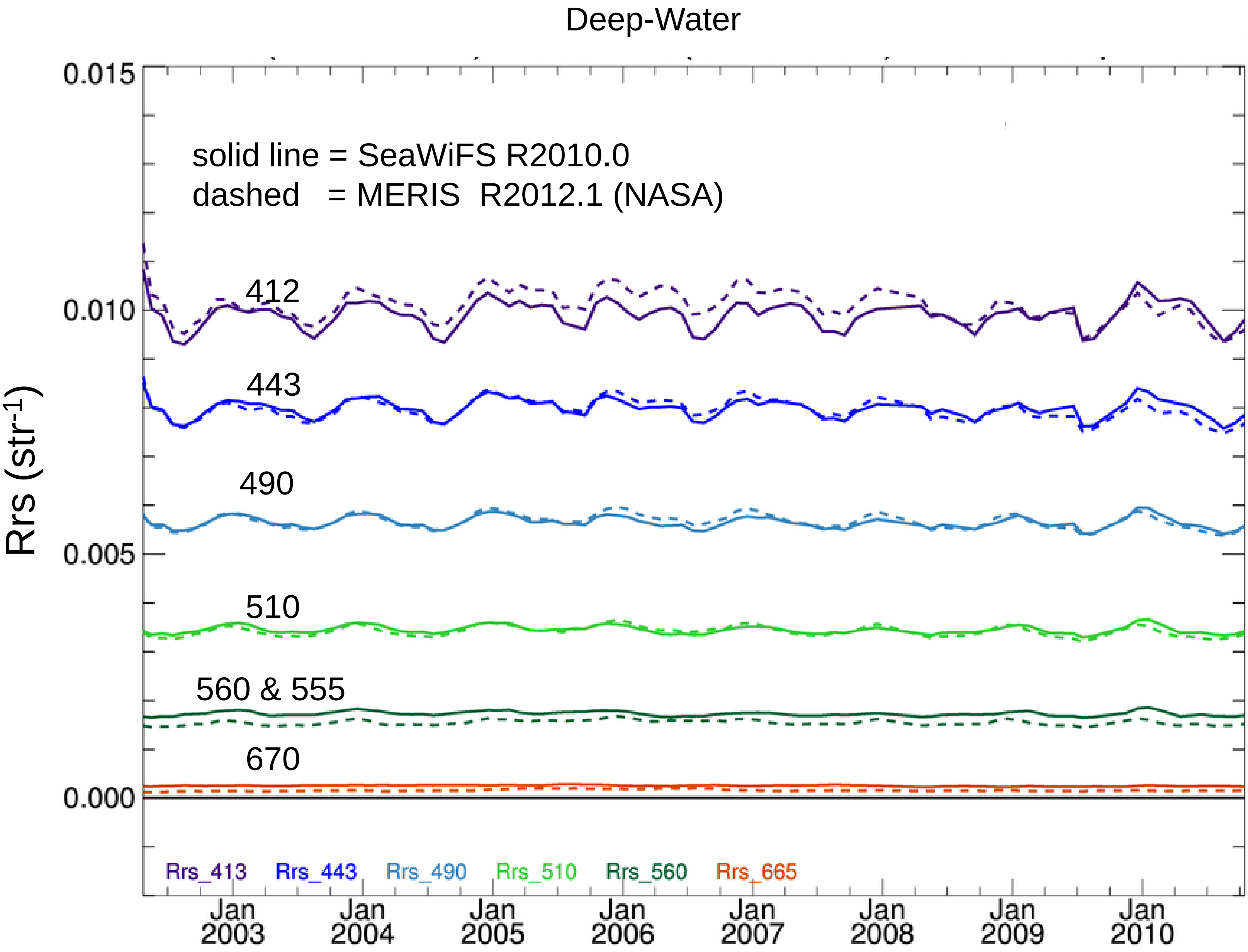
Radiometric (in)Consistency of MERIS & SeaWiFS


Deep-Water

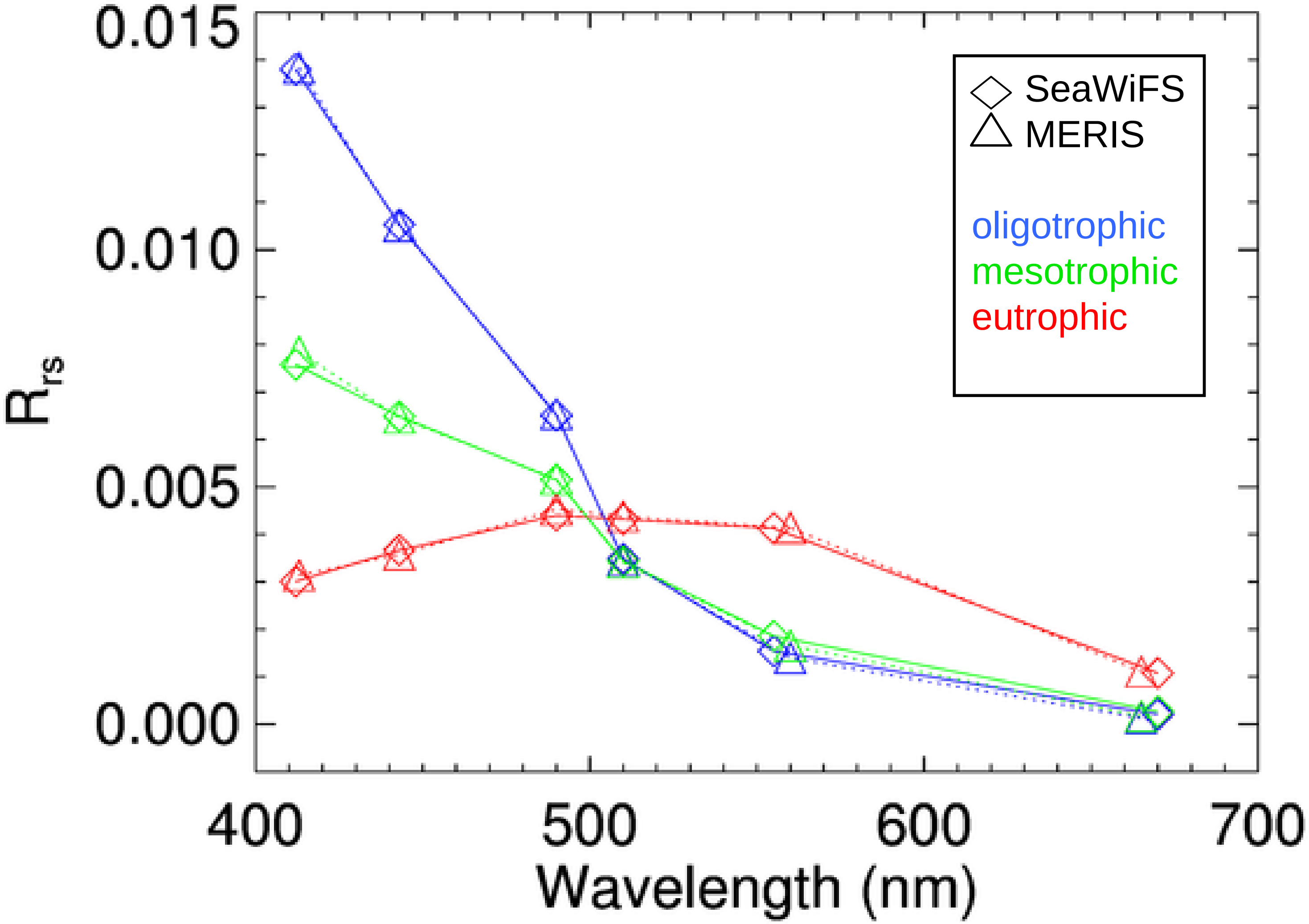
solid line = SeaWiFS R2010.0
dashed = MERIS 3rd Reprocessing (ESA)

5-10% differences

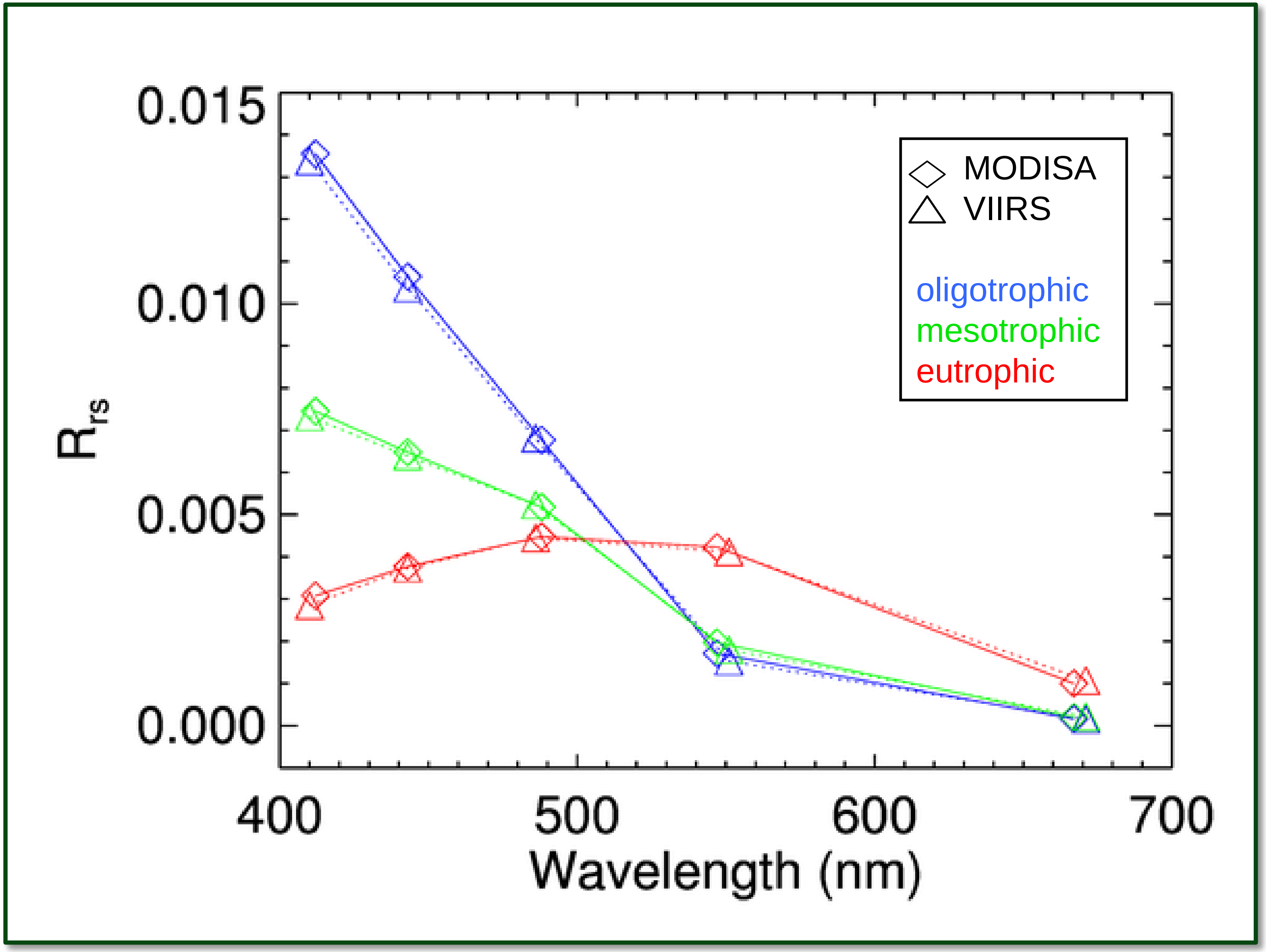
Radiometric Consistency of MERIS & SeaWiFS



Common Mission Mean Spectral Agreement

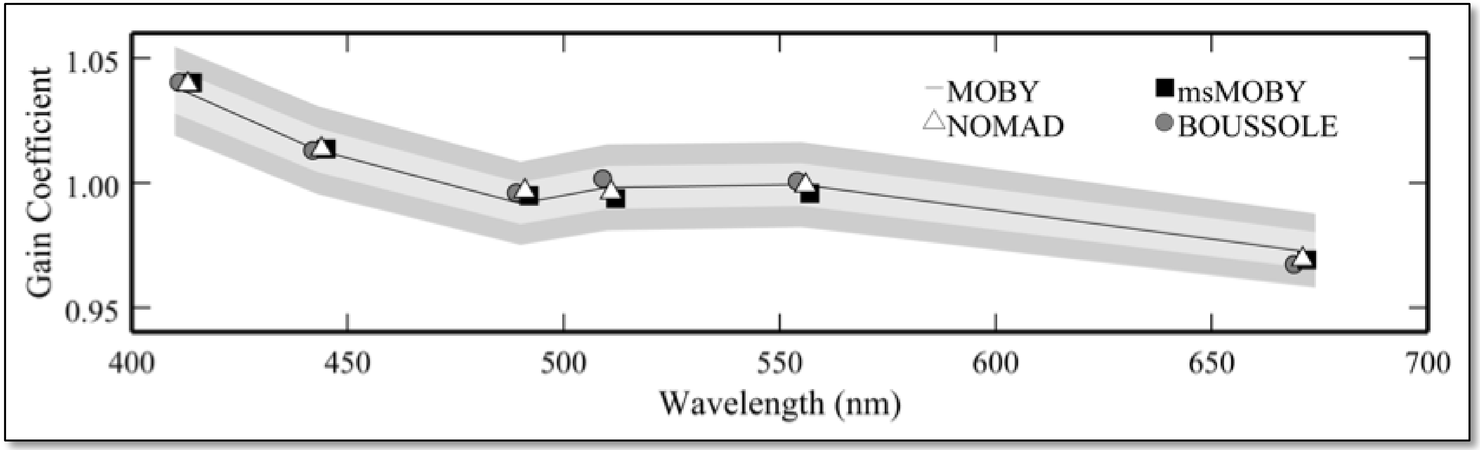


Common Mission Mean Spectral Agreement

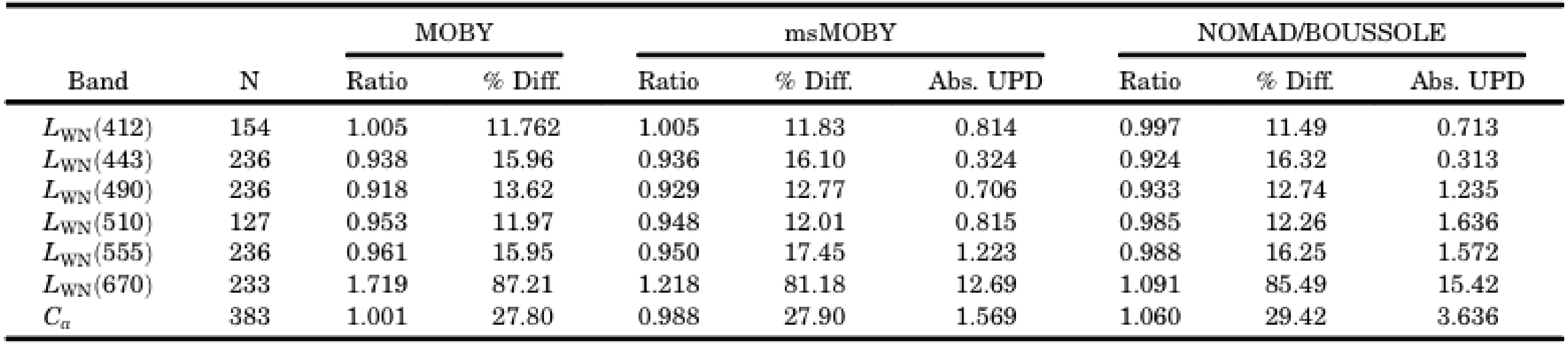


Alternative calibration sources, similar results

SeaWiFS Gains



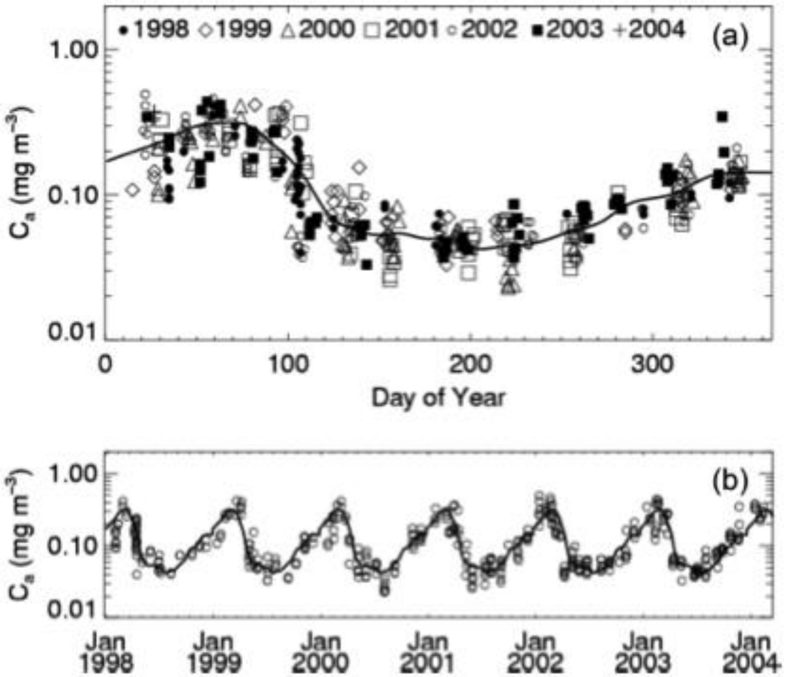
Validation of Satellite Retrievals



Band	N	MOBY		msMOBY			NOMAD/BOUSSOLE		
		Ratio	% Diff.	Ratio	% Diff.	Abs. UPD	Ratio	% Diff.	Abs. UPD
$L_{\mathrm{WN}}(412)$	154	1.005	11.762	1.005	11.83	0.814	0.997	11.49	0.713
$L_{\mathrm{WN}}(443)$	236	0.938	15.96	0.936	16.10	0.324	0.924	16.32	0.313
$L_{\mathrm{WN}}(490)$	236	0.918	13.62	0.929	12.77	0.706	0.933	12.74	1.235
$L_{\mathrm{WN}}(510)$	127	0.953	11.97	0.948	12.01	0.815	0.985	12.26	1.636
$L_{\mathrm{WN}}(555)$	236	0.961	15.95	0.950	17.45	1.223	0.988	16.25	1.572
$L_{\mathrm{WN}}(670)$	233	1.719	87.21	1.218	81.18	12.69	1.091	85.49	15.42
C_a	383	1.001	27.80	0.988	27.90	1.569	1.060	29.42	3.636

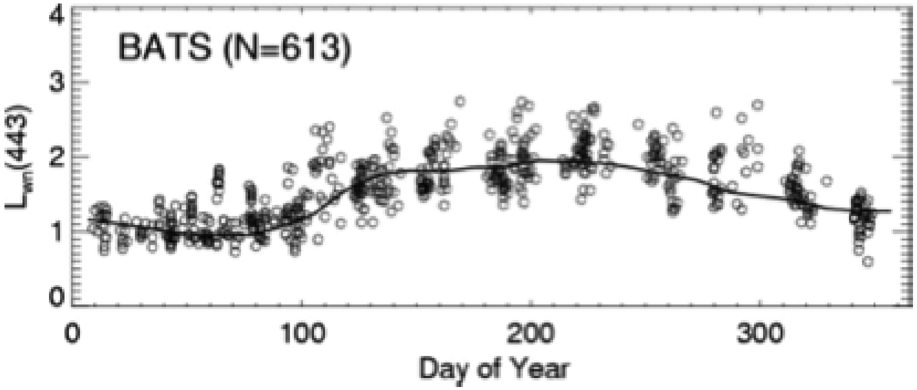
Bailey, S.W., Hooker, S.B., Antoine, A., Franz, B.A., and Werdell, P.J. (2008). Sources and assumptions for the vicarious calibration of ocean color satellite observations, Appl. Opt., 47 (12).

Model-based Vicarious Calibration



Bio-optical Model

Morel and Maritorena, 2001.



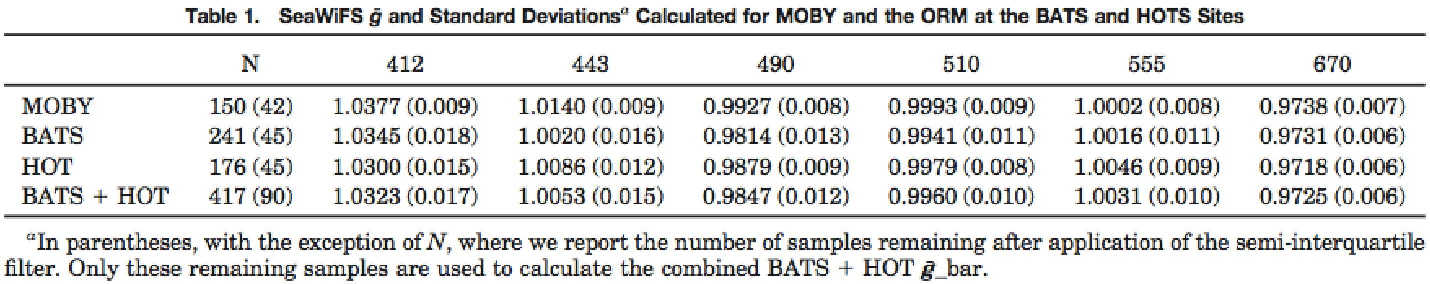


Table 1. SeaWiFS $\bar{g}$ and Standard Deviations[a] Calculated for MOBY and the ORM at the BATS and HOTS Sites

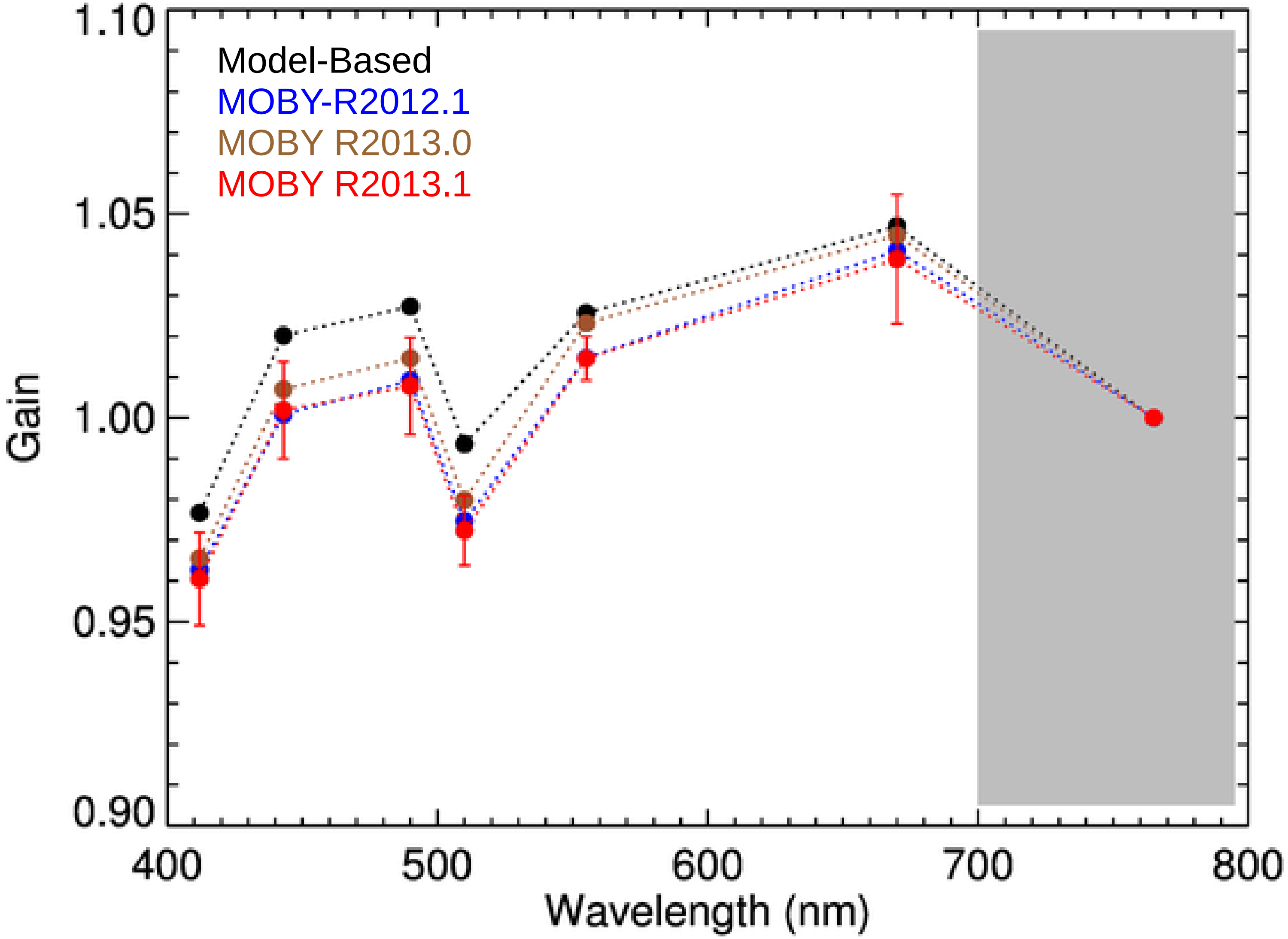
	N	412	443	490	510	555	670
MOBY	150 (42)	1.0377 (0.009)	1.0140 (0.009)	0.9927 (0.008)	0.9993 (0.009)	1.0002 (0.008)	0.9738 (0.007)
BATS	241 (45)	1.0345 (0.018)	1.0020 (0.016)	0.9814 (0.013)	0.9941 (0.011)	1.0016 (0.011)	0.9731 (0.006)
HOT	176 (45)	1.0300 (0.015)	1.0086 (0.012)	0.9879 (0.009)	0.9979 (0.008)	1.0046 (0.009)	0.9718 (0.006)
BATS + HOT	417 (90)	1.0323 (0.017)	1.0053 (0.015)	0.9847 (0.012)	0.9960 (0.010)	1.0031 (0.010)	0.9725 (0.006)

[a] In parentheses, with the exception of *N*, where we report the number of samples remaining after application of the semi-interquartile filter. Only these remaining samples are used to calculate the combined BATS + HOT $\bar{g}$_bar.

Werdell, P.J., S.W. Bailey, B.A. Franz, A. Morel, and C.R. McClain (2007). On-orbit vicarious calibration of ocean color sensors using an ocean surface reflectance model, Appl. Opt., 46 (23).

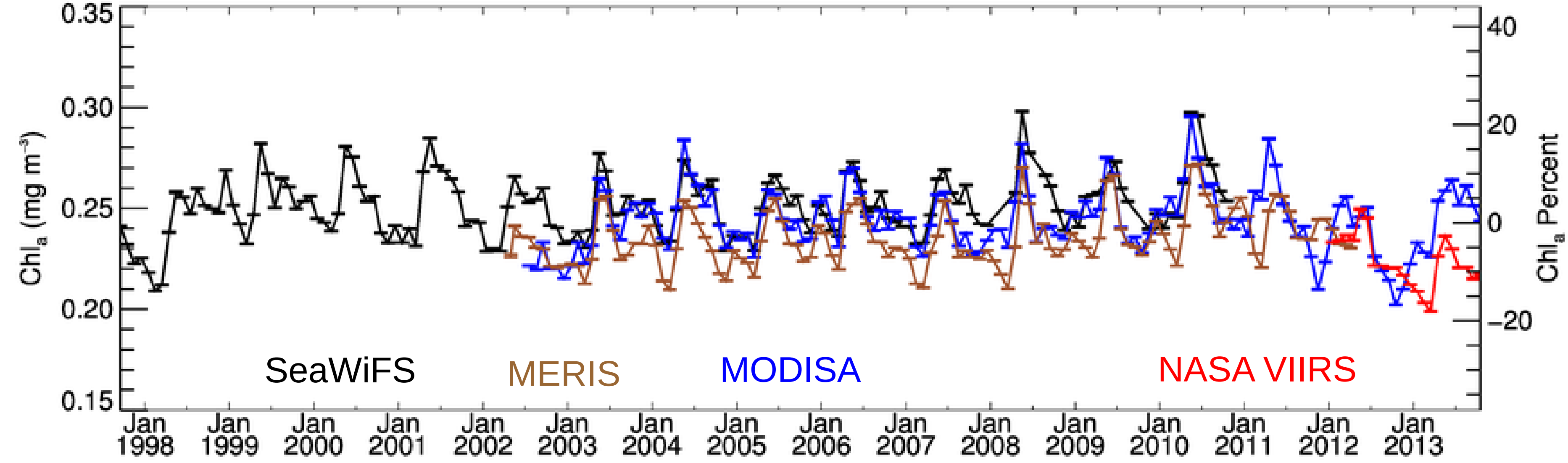
NASA-derived VIIRS Vicarious Gains

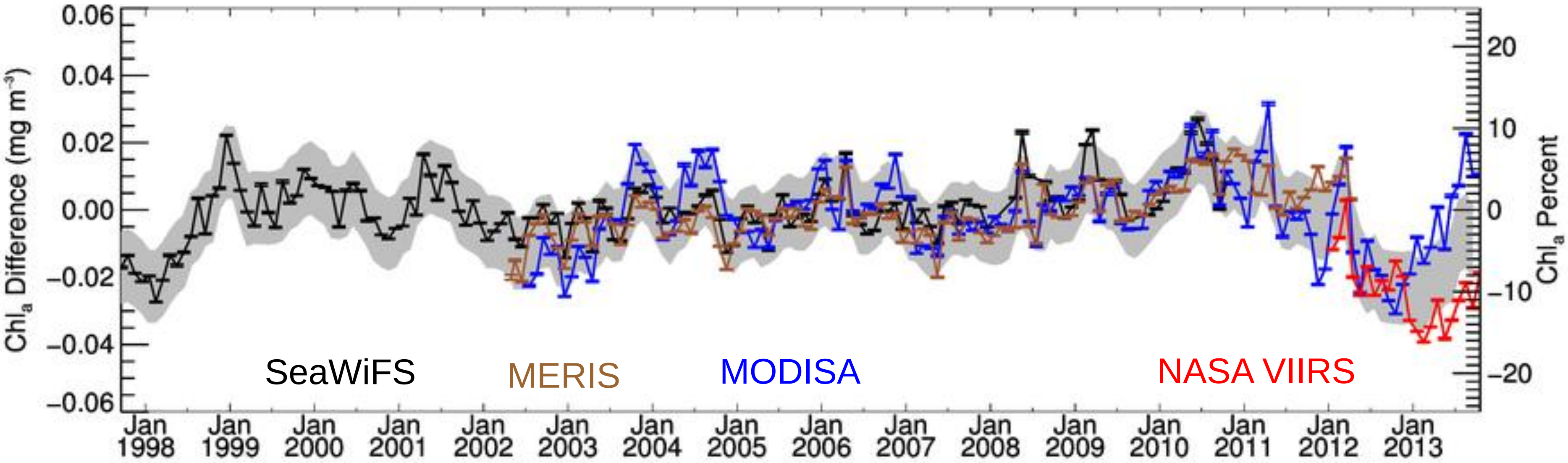
changes as mission progresses



consistency of multi-mission time-series

global mean mesotrophic waters





Final Thoughts

- consistency in algorithms, calibration methods, and sources is required to achieve consistency in the multi-mission data record

- we expect vicarious adjustment factors within a few %, otherwise we’re doing something wrong in instrument calibration or algorithms

- typically, the standard deviation about the mean vicarious gain is ~1% in all bands; uncertainty on the mean is assumed to decrease with samples size

- the most critical impact of vicarious calibration is to refine the spectral dependence of the system, which drives most derived product algorithms

- the spectral dependence can be significantly refined in early mission operations using alternative “truth” sources to get “in the ballpark”

- from the perspective of global change research, we just need one high quality source with sufficient match-ups over the mission lifespan to achieve a stable and accurate vicarious calibration (there is no rush)

Thank You