NASA Multi-Mission Ocean Color Reprocessing 2018.0

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INTRODUCTION

The NASA Ocean Biology Processing Group (OBPG) recently reprocessed the multi-mission ocean color time-series from SeaWiFS, MODIS-Aqua (MODISA), and VIIRS on SNPP. Changes for this R2018.0 reprocessing were limited to instrument calibration updates and vicarious calibration updates, with the latter utilizing the recently improved straylight characterization of the Marine Optical Buoy (MOBY, Clark et al. 1997) and associated reprocessing of the MOBY time-series. Here we present the impact of R2018.0 reprocessing changes relative to the previous R2014.0 reprocessing, and assess quality of the resulting satellite ocean color retrievals of spectral water-leaving reflectance (Rrs) and chlorophyll *a* concentration. Results show that the satellite sensor ocean color data records are generally consistent over the common mission lifespans, and in good agreement with in situ measurements, with a notable reduction in satellite to in situ bias errors due to the vicarious calibration update, and improved temporal stability in the MODISA time-series after 2012.

REVISED MOBY TIMESERIES

NASA ocean color processing employs a vicarious calibration (Franz et al. 2007) for all satellite sensors, utilizing in situ radiometery from MOBY. Several updates to MOBY characterization and post processing by the MOBY Operations Team (MOT) have occurred in recent years. These include:

1. Implementation of new Straylight Correction (SLC), November 2011
   - applied only to MOBY data after 2011 (VIIRS-SNPP era)

2. MOBY Reprocessing, October 2016 (Revised March 2017)
   - arm depth revised (+.234m)

3. MOBY Reprocessing, November 2017 (Revised December 2017)
   - applied new SLC to retrospective MOBY time-series 1996-2011

More details on the MOBY reprocessing events are available from NOAA/NESDIS,

https://www.star.nesdis.noaa.gov/sod/moby/oct_2016_reprocessing.html
https://www.star.nesdis.noaa.gov/sod/moby/nov_2017_reprocessing.html

and a detailed discussion of SLC development and impact to the MOBY time-series is available here:

https://www.star.nesdis.noaa.gov/sod/moby/Nov%202017%20ReprocessingV8.pdf

It is important to note that the impact of the SLC, as shown in the above document, varies spectrally and temporally. The largest impact is to the bluest wavelengths and for the most recently acquired MOBY water-leaving radiance (Lw) measurements. For example, at 416nm the SLC increases the MOBY Lw by nearly 6% in 2010, but less than 2% in 2000. In addition, the timing and application of the SLC updates relative to the timing of NASA reprocessing R2014.0 resulted in an inconsistent MOBY time-series being applied across SeaWiFS, MODISA, and VIIRS missions. Specifically, in R2014.0, the SeaWiFS and MODISA missions did not benefit from the new SLC, but VIIRS did. The resolution of this inconsistency was one of the primary motivations for reprocessing R2018.0. In addition, the R2018.0 reprocessing incorporates the October 2016 MOBY reprocessing, which resolved an error in the assumed depth of the MOBY arms and associated upwelling radiance (Lu) sensors, and thus the propagation of MOBY measurements to surface Lw. This arm-depth change has the largest relative impact on MOBY Lw measurements in the red spectral range.

REVISED INSTRUMENT CALIBRATIONS

MODISA and VIIRS instrument calibrations were also revised for R2018.0, based on re-analysis of on-board (solar, lunar) calibration measurements (Eplee et al. 2013) and supplemented with vicarious characterization methods (Mesiter et al. 2009, Meister & Franz 2014). No changes were made to the SeaWiFS instrument calibration relative to R2014.0. The major changes for each instrument are listed below.

VIIRS Instrument Calibration

- temporal calibration updated to incorporate additional solar and lunar calibration measurements since the R2014.0 reprocessing
- lunar measurements corrected for detector gain variability as derived from solar diffuser measurements
- absolute calibration of all spectral bands revised based on observations of the sun through the solar diffuser, replacing prelaunch absolute calibration
- for further details see: https://oceancolor.gsfc.nasa.gov/reprocessing/r2018/viirs-snpp/

MODISA Instrument Calibration

- smoothing rather than fitting to derive instrument temporal calibration trend from the solar calibration measurements (i.e., no assumption on functional form)
- solar diffuser (SD) Bidirectional Reflectance Function (BRF) and SD / solar diffuser stability monitor (SDSM) screen transmission computed from yaw maneuver data using linear fits rather than geometric modeling
- SD degradations in red/NIR determined by wavelength modeling
- simple atmospheric correction performed in computing desert trends for response versus scan angle (RVS)
- modulated RSR impact on ocean data estimated and used to adjust 412nm band temporal gains (Lee et. al. 2017).
- lunar, solar, desert trends used to compute RVS for 412nm and 443nm bands using a 2nd order polynomial as a function of scan angle.
- for further details see: https://oceancolor.gsfc.nasa.gov/reprocessing/r2018/aqua/

RESULTS AND DISCUSSION

Our analyses indicate that the revised MOBY record and associated update to the vicarious calibrations for R2018.0 had a substantial impact, and resulted in improved quality of the satellite retrievals, as detailed below.

- The MOBY revision resulted in a significant bias shift in the Rrs retrievals (+2-10%) and derived Chlorophyll (-8%) (Figure 1).
- The impact of the MOBY revision varies by mission (Figures 2-4) due to the timing of the R2014.0 satellite data reprocessing relative to the timing of the MOBY reprocessing(s), and also because the MOBY straylight correction itself varies with time, with the impact to the SeaWIFS mission being minimal (Figure 4).
- Relative to in situ measurements, the bias changes resulted in a significant improvement in MODISA and VIIRS satellite Rrs and Chlorophyll retrievals (Figures 5-6 and Table 1).
- The largest impact was to increase the Rrs in the blue wavelengths, which also reduces the frequency of negative Rrs retrievals (Table 1).
- For MODISA, the mean bias in Chlorophyll relative to in situ measurements was reduced from 32% to 18% for R2018.0.
- For VIIRS, the mean bias in satellite Chlorophyll relative to in situ for R2018.0 is only 5%, but the number of available match-ups is limited and is dominated by higher-chlorophyll waters (>2 mg/m^3).

For MODISA, the revised instrument calibration has resolved the non-physical late-mission degradation previously observed in the blue channels of the R2014.0 Rrs (Figure 2). For VIIRS, the revised instrument calibration resulted in a large increase to the Rrs trends at 412 and especially 443nm over the last 3 years of the mission (Figure 3). This brought the trends in these blue channels into better consistency with the 490nm trends, and increased the downward trend in derived Chlorophyll by 5% over the 2015-2016 period (Figure 3).

Figure 7 shows the 21-year monthly mean time-series of R2018.0 Chlorophyll retrievals from SeaWIFS, MODISA, and VIIRS, for the global deep-water region spanning +/- 40-deg latitude. A time-series of anomalies relative to the 2003-2011 mean seasonal cycle is also shown. The Multvariate ENSO Index (MEI) is overplotted on the anomaly time-series to demonstrate that the multi-mission data record is generally able to track the oceans biological response to major climatic events.
For R2018.0, good consistency in the long-term trends and interannual variability between the missions over their common lifespans is demonstrated (Figure 7), but with a notable discrepancy in the trends from MODISA and VIIRS after 2015, suggesting that further work on the instrument temporal calibrations is needed. Note that MODISA late-mission trends are more consistent with expectations based on MEI.

REFERENCES

Clark, D. K., H. R. Gordon, K. J. Voss, Y. Ge, W. W. Broenkow, and C. Trees (1997). Validation of atmospheric correction over the oceans, J. Geo. Res. 102, 17209– 17217.

Eplee, R., K. R. Turpie, G. Meister, F. S. Patt, G.F. Fireman, B. A. Franz, and C. R. McClain (2013). A synthesis of VIIRS solar and lunar calibrations, Proc. SPIE 8866, Earth Observing Systems XVIII, 88661L (October 15, 2013); doi:10.1117/12.2024069.

Franz, B. A., S. W. Bailey, P. J. Werdell and C. R. McClain (2007). Sensor-independent Approach to the Vicarious Calibration of Satellite Ocean Color Radiometry. Applied Optics, 46: (22) 5068-5082.

Lee, S. and G. Meister (2017). MODIS Aqua Optical Throughput Degradation Impact on Relative Spectral Response and Calibration of Ocean Color Products, IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 9, pp. 5214-5219. doi: 10.1109/TGRS.2017.2703672.

Meister, G., Franz, B. A., Kwiatkowska, E. J., Eplee, R. E., McClain, C. R. 2009. Detector dependency of MODIS polarization sensitivity derived from on-orbit characterization. In SPIE Optical Engineering+ Applications (pp. 74520N-74520N). International Society for Optics and Photonics. http://dx.doi.org/10.1117/12.825385

Meister, G., & Franz, B. A. (2014). Corrections to the MODIS Aqua Calibration Derived From MODIS Aqua Ocean Color Products. IEEE Transactions on Geoscience and Remote Sensing, 52(10), 6534-6541. http://dx.doi.org/10.1109/tgrs.2013.2297233

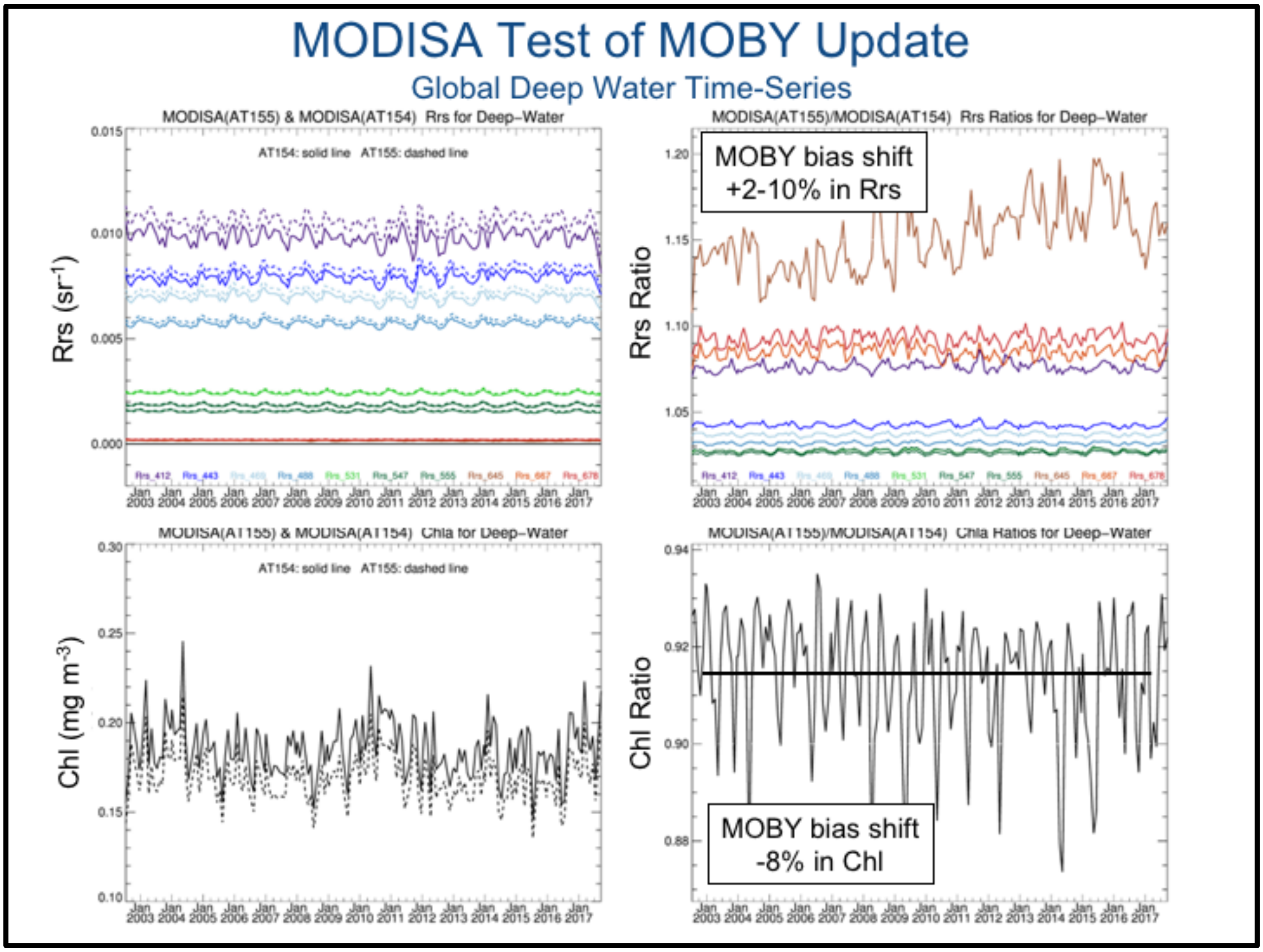

Figure 1: *Comparison of global mean deep-water Rrs and Chlorophyll time-series for MODIS-Aqua, before and after updating vicarious calibration to incorporate revised MOBY record. Solid line is before, dashed is after update. Effect of MOBY change is +2-10% increase in mean Rrs (highest in red and blue wavelengths) with resulting 8% reduction in derived Chlorophyll.*

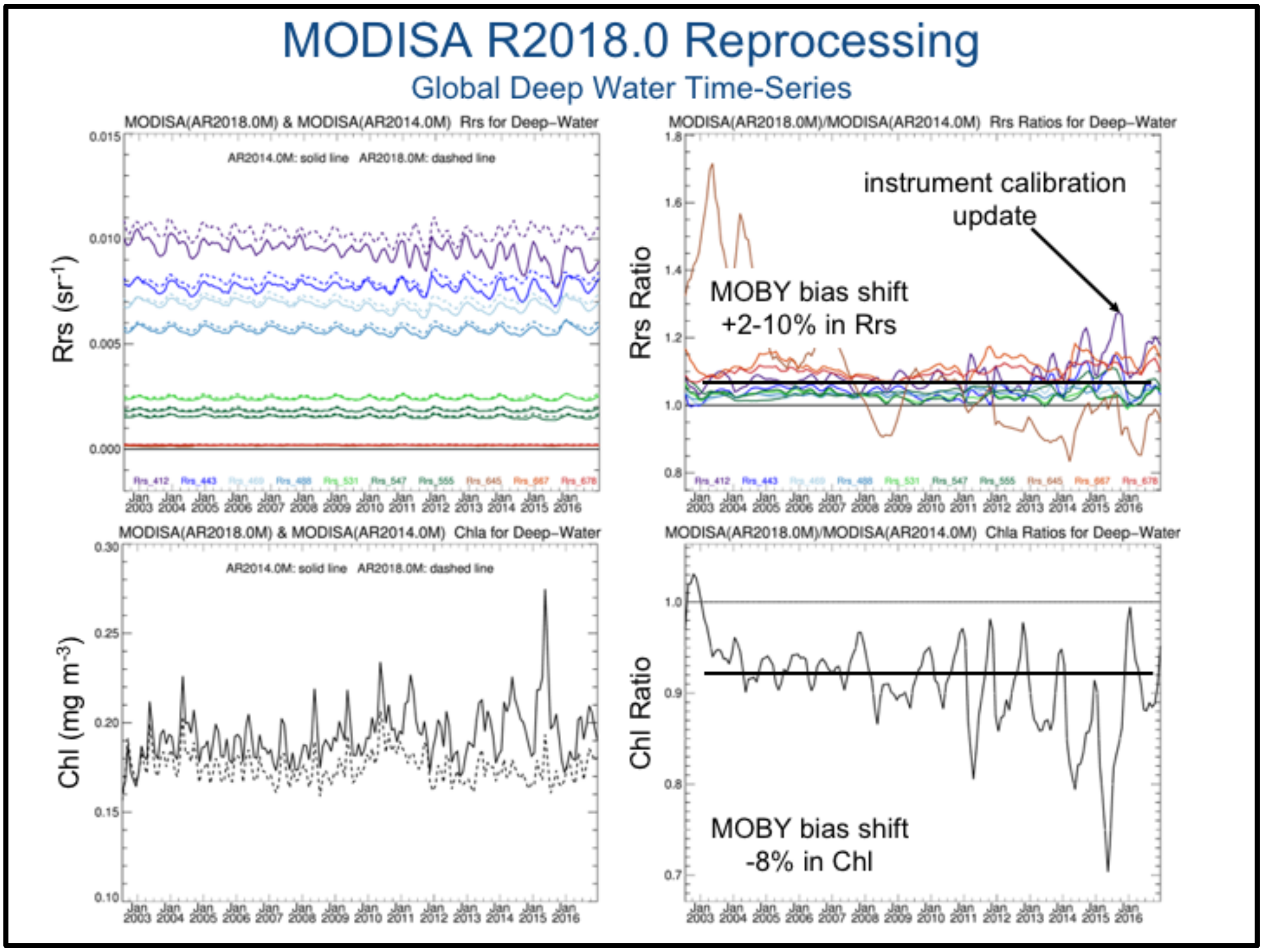

Figure 2: *Comparison of global mean deep-water Rrs and Chlorophyll time-series for MODIS-Aqua. Solid line is R2014.0, dashed is R2018.0. Shows impact of MOBY changes as in Fig. 1, plus improved instrument calibration that resolves non-physical degradation of the Rrs time-series in the blue wavelengths.*

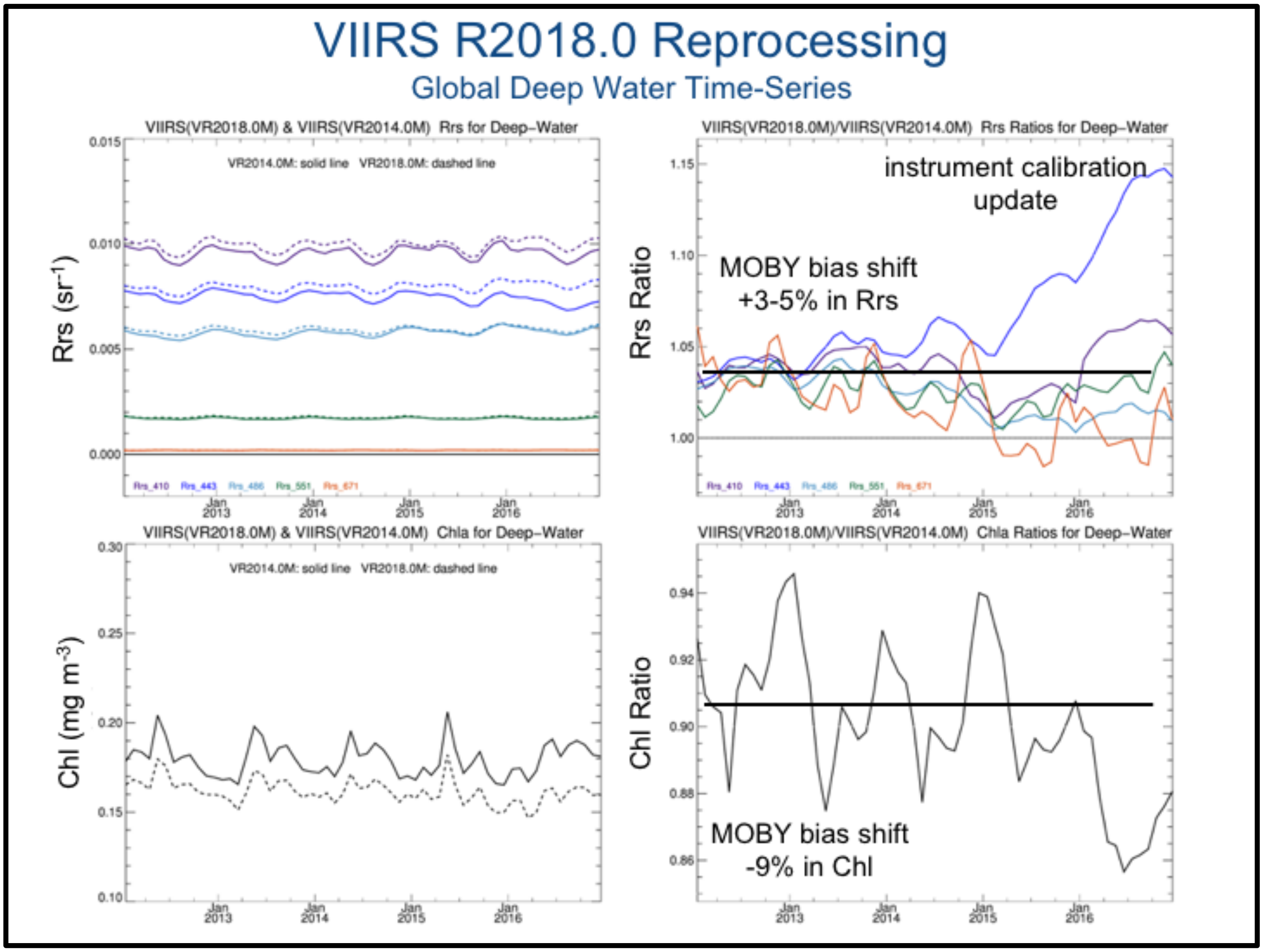

Figure 3: *Same as Figure 2, but for VIIRS. Similar shift in Chlorophyll bias as for MODISA. Rrs bias changes are smaller, as R2014.0 included SLC.*

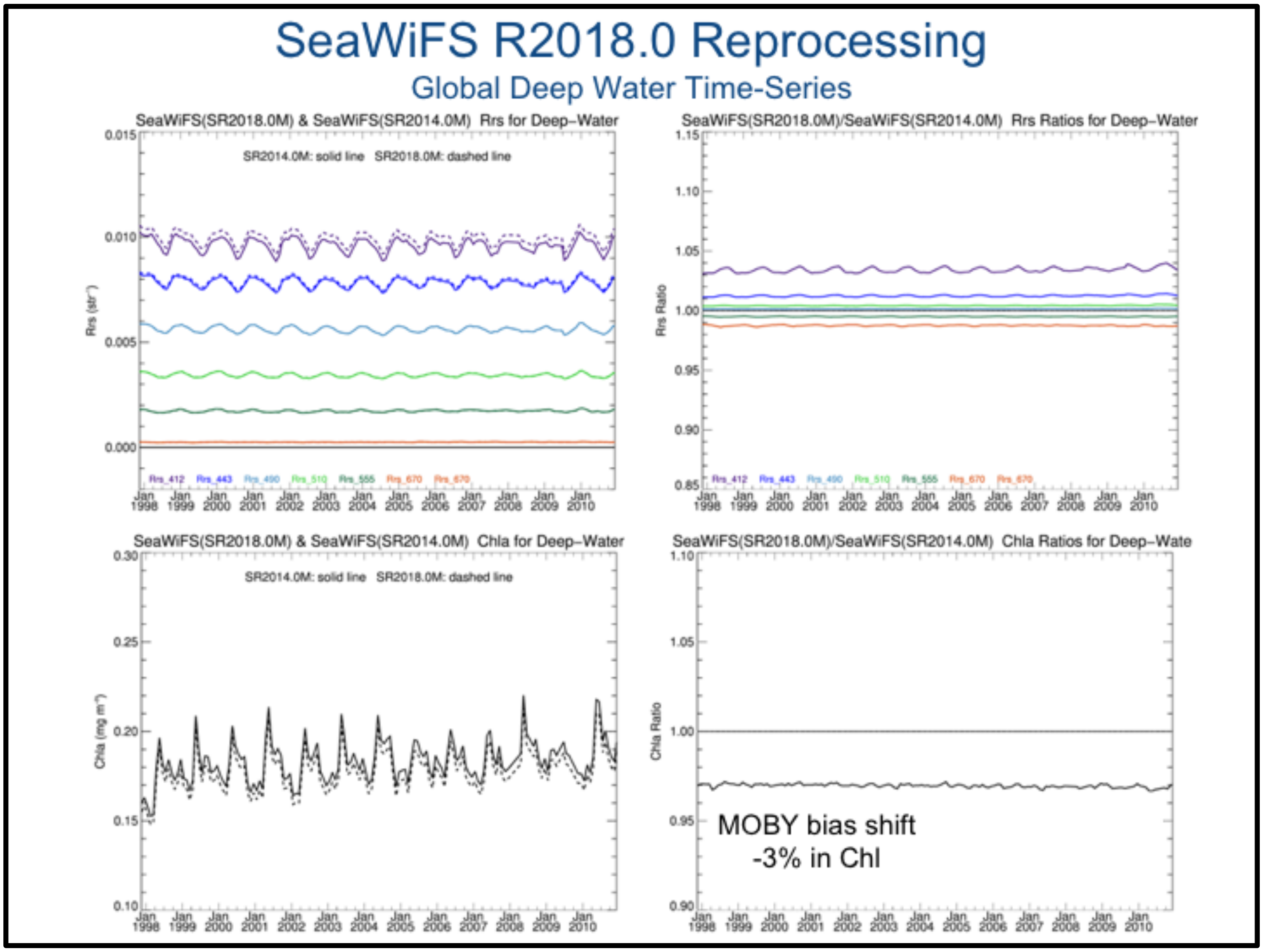

Figure 4: *Same as Figure 2, but for SeaWiFS. Only change was MOBY update. Magnitude of MOBY SLC varies with time, smallest in the SeaWIFS era.*

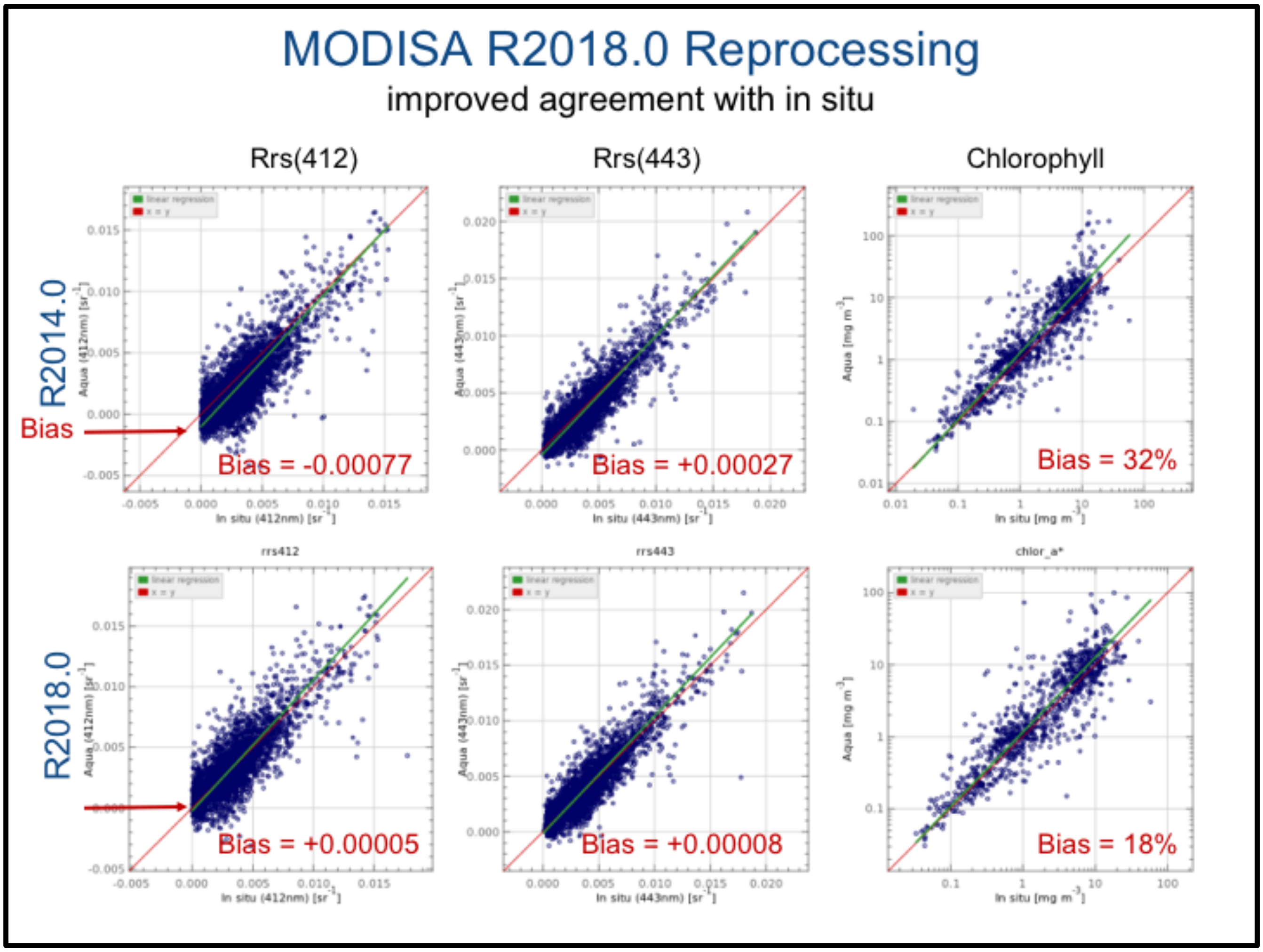

Figure 5: *Comparison of R2014.0 and R2018.0 in situ match-up analyses for MODISA, for Rrs in blue wavelengths and Chlorophyll, using all available data from AERONET-OC and SeaBASS databases.*

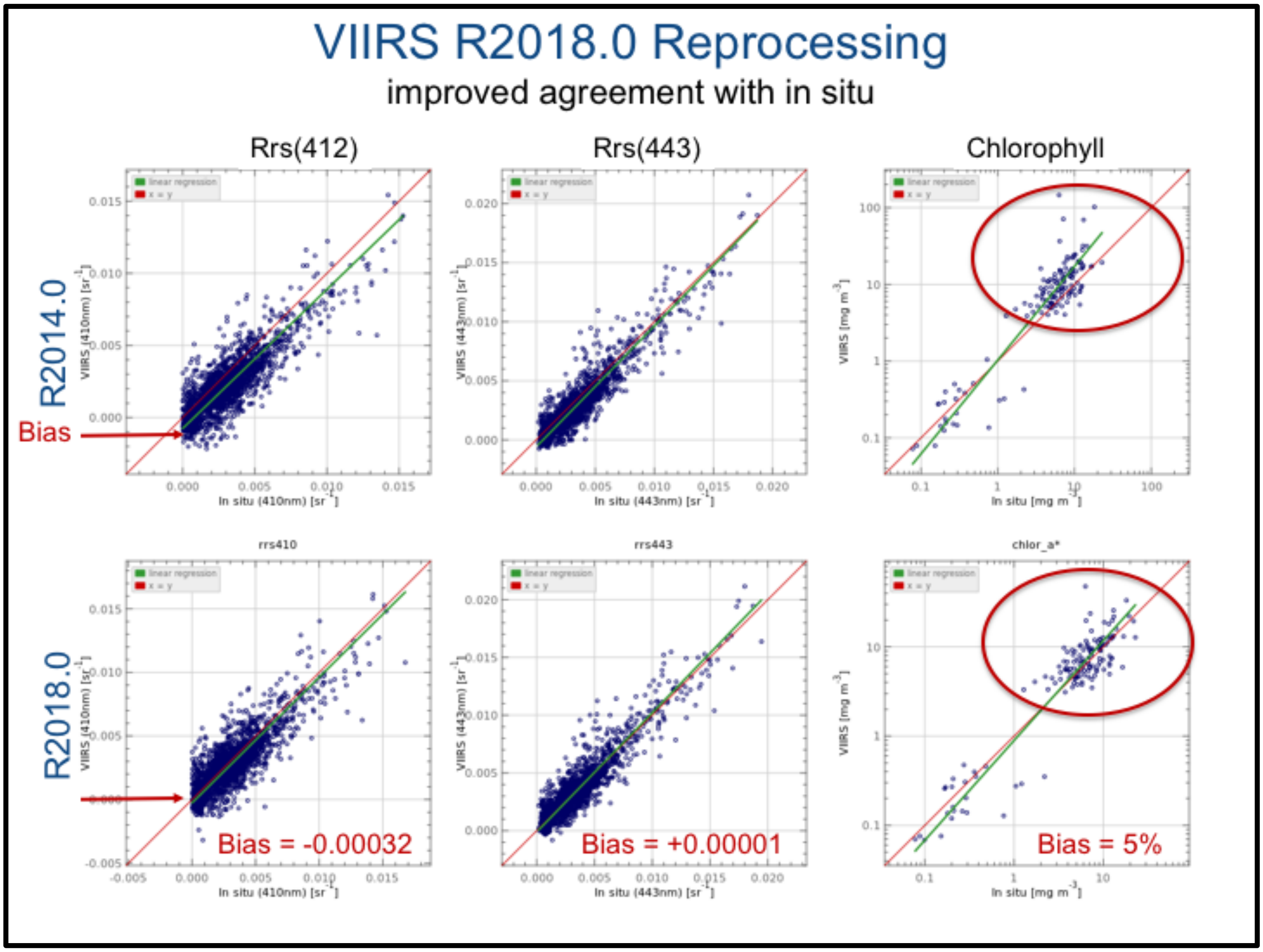

Figure 6: *Comparison of R2014.0 and R2018.0 in situ match-up analyses for VIIRS, for Rrs in blue wavelengths and Chlorophyll, using all available data from AERONET-OC and SeaBASS databases.*

Product	Number Matchups	Mean Bias (sr^{-1})		Mean Absolute Error (sr^{-1})	
		R2014.0	R2018.0	R2014.0	R2018.0
Rrs(412)	3934	-0.00077	0.00005	0.00125	0.00099
Rrs(443)	4134	-0.00027	0.00008	0.00082	0.00075
Rrs(488)	3772	-0.00067	-0.00050	0.00088	0.00077
Rrs(531)	2076	-0.00063	-0.00057	0.00083	0.00079
Rrs(547)	3619	-0.00052	-0.00048	0.00078	0.00076
Rrs(555)	3534	-0.00081	-0.00075	0.00096	0.00090
Rrs(667)	3573	-0.00017	-0.00016	0.00030	0.00029
Rrs(678)	472	-0.00016	-0.00014	0.00034	0.00033

Table 1: *MODISA R2014.0 and R2018.0 in situ match-up statistics for Rrs, using all available data from AERONET-OC and SeaBASS databases, and restricting to common match-up points.*

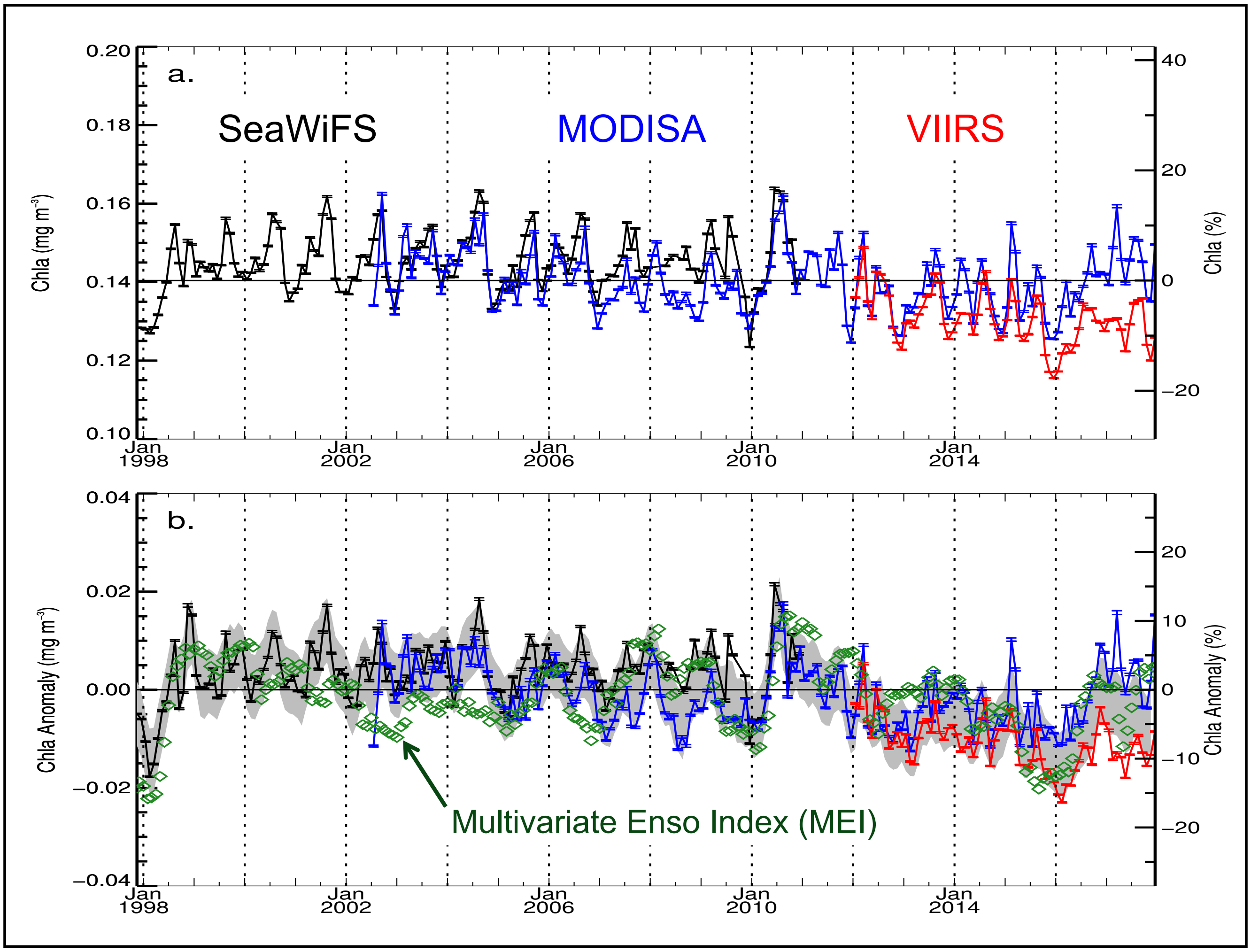

Figure 7: NASA ocean color reprocessing *2018.0, 21-year monthly mean Chlorophyll-a time-series (a), and associated anomaly relative to the mean seasonal cycle (b), computed over all deep water (>1000m) within +- 40-deg latitude, for independent SeaWIFS, MODISA, and VIIRS record.*