Seasonally varying bias in MODIS/Aqua ocean color retrievals and its potential relationship to polarization sensitivity

Amir Ibrahim and Gerhard Meister

NASA

MODIS/VIIRS Science Team Meeting

May 2nd, 2024

Outline

- Background on the seasonal bias
- Investigating bias in SeaWiFS, MODIS Aqua, Terra, and SNPP
- SeaBASS validation at MOBY
- Conclusion

Elements with potential impact on seasonal bias

- Instrument calibration (cross-calibration, polarization correction, RVS, trends, etc.)
- MOBY timeseries data (calibration issues, BRDF correction, vertical depth Lu extrapolation, surface effects).
- Vicarious calibration procedure (i.e., absolute calibration at NIR, data filtering, spatial variability).
- Atmospheric correction (BRDF correction, glint, aerosol type).
- Uncertainties in both in-situ as well as satellite retrievals.

Background

- Much of this work stemmed from a comparative analysis by K. Bisson between the backscattering coefficient derived from MODIS Aqua, CALIOP and Argo floats.
- It was discovered that there is a seasonal and latitudinal discrepancy between MODIS and CALIOP and Argo floats.
- This work summarized in the GRL paper.

Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL090909

Particulate Backscattering in the Global Ocean: A Comparison of Independent Assessments

K. M. Bisson[1], **E. Boss**[2], **P. J. Werdell**[3], **A. Ibrahim**[3,4], and **M. J. Behrenfeld**[1]

[1]Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR, USA, [2]School of Marine Sciences, University of Maine, Orono, ME, USA, [3]NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Greenbelt, Maryland, USA, [4]Science Systems and Applications Inc., Lanham, MD, USA

Key Points:

- Spatiotemporal correlation scales are quantified between global lidar and in situ observations
- Satellite lidar has lower error and bias compared to ocean color observations of particulate backscattering
- Phytoplankton carbon values determined from global lidar and ocean color differ within basins by as much as 50%

Supporting Information:

- Supporting Information S1

Correspondence to:
K. M. Bisson,
bissonk@oregonstate.edu

Citation:
Bisson, K. M., Boss, E., Werdell, P. J., Ibrahim, A., & Behrenfeld, M. J. (2021). Particulate backscattering in the global ocean: A comparison of independent assessments. *Geophysical Research Letters*, *48*, e2020GL090909. https://doi.org/10.1029/2020GL090909

Received 15 OCT 2020
Accepted 8 DEC 2020

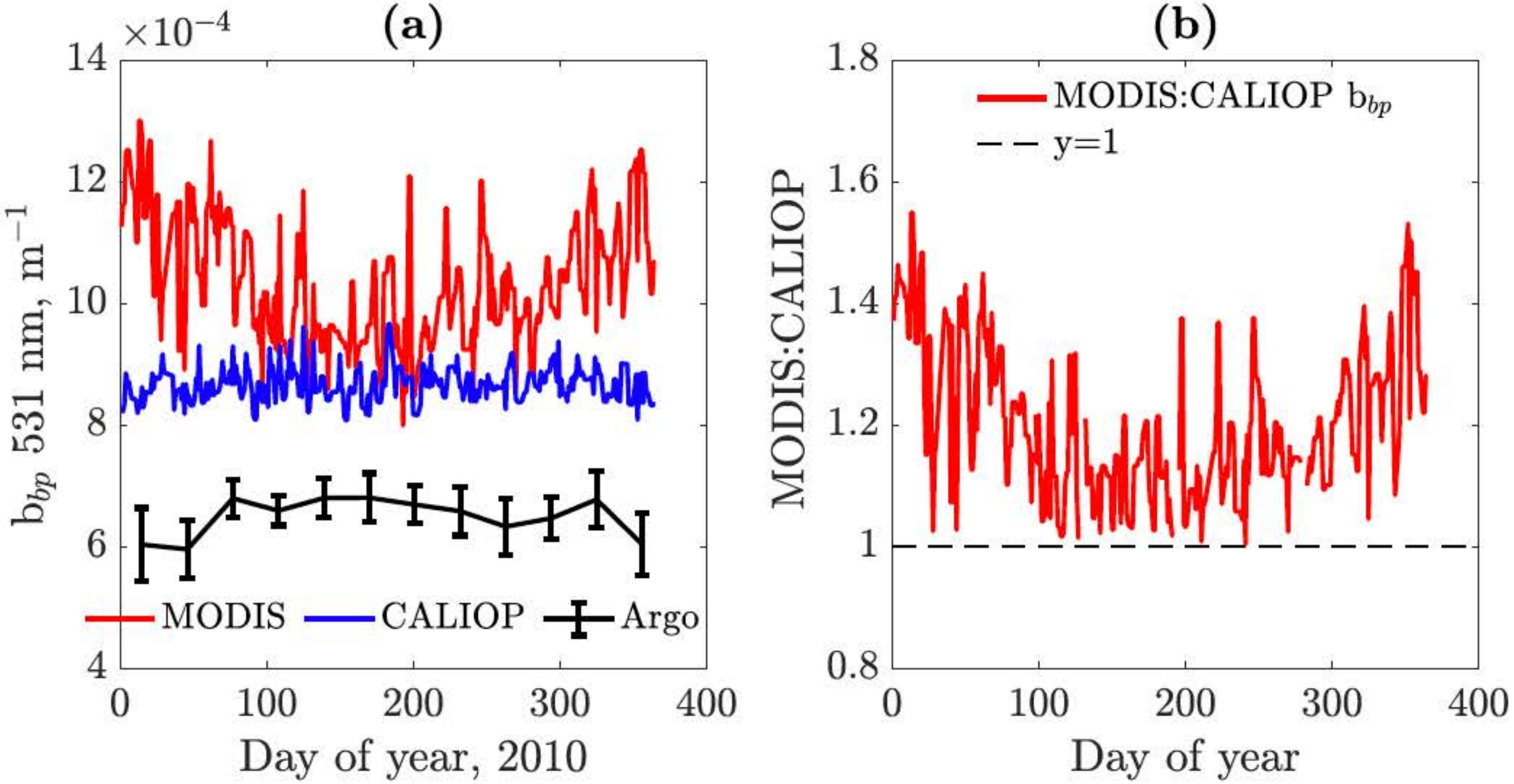
Abstract How well do we know the particulate backscattering coefficient (b_{bp}) in the global ocean? Satellite lidar b_{bp} has never been validated globally and few studies have compared lidar b_{bp} to b_{bp} derived from reflectances (via ocean color) or in situ observations. Here, we validate lidar b_{bp} with autonomous biogeochemical Argo floats using a decorrelation analysis to identify relevant spatiotemporal matchup scales inspired by geographical variability in the Rossby radius of deformation. We compare lidar, float, and ocean color b_{bp} at the same locations and times to assess performance. Lidar b_{bp} outperforms ocean color, with a median percent error of 18% compared to 24% in the best case and a relative bias of −11% compared to −21%, respectively. Phytoplankton carbon calculated from ocean color and lidar exhibits basin-scale differences that can reach ±50%.

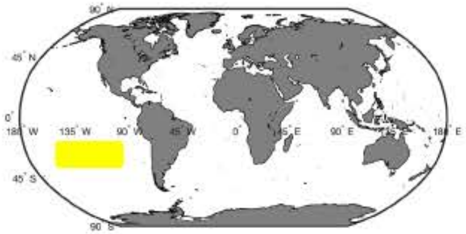
Plain Language Summary Backscattering of light by particles is an important input for many studies concerning ecology and the carbon cycle. There are two main types of satellite sensors that measure backscattering but they have not been validated worldwide. In order to use backscattering for global questions, we need to understand how well both satellite approaches perform. Passive ocean color sensors act like wide-view cameras capturing sunlight scattered by ocean constituents, whereas active sensors use a laser system that illuminates the ocean and measures the return pulses of light within a narrow spatial range. In this study, we compare backscatter data from both satellite sensor types to matchup backscattering data collected in situ by a global network of floats. We find that backscatter data from the active and passive satellite sensors disagree, particularly at low backscattering values. Overall, the active sensor performs best when compared to field data. We applied the lidar data to reassess global phytoplankton carbon and find regional differences from conventional estimates that can reach ±50%.

1. Introduction

The spectral particulate backscattering coefficient (b_{bp}; m^{-1}; with spectral dependence hereafter implied unless noted) is central to applications of ocean optics for marine ecology and biogeochemistry. Satellite-derived b_{bp} has been used to assess particulate organic carbon (Loisel et al., 2001; Stramski et al., 1999), phytoplankton carbon (PhytoC, Behrenfeld et al., 2005; Graff et al., 2015), particle sizes (Brewin et al., 2012;

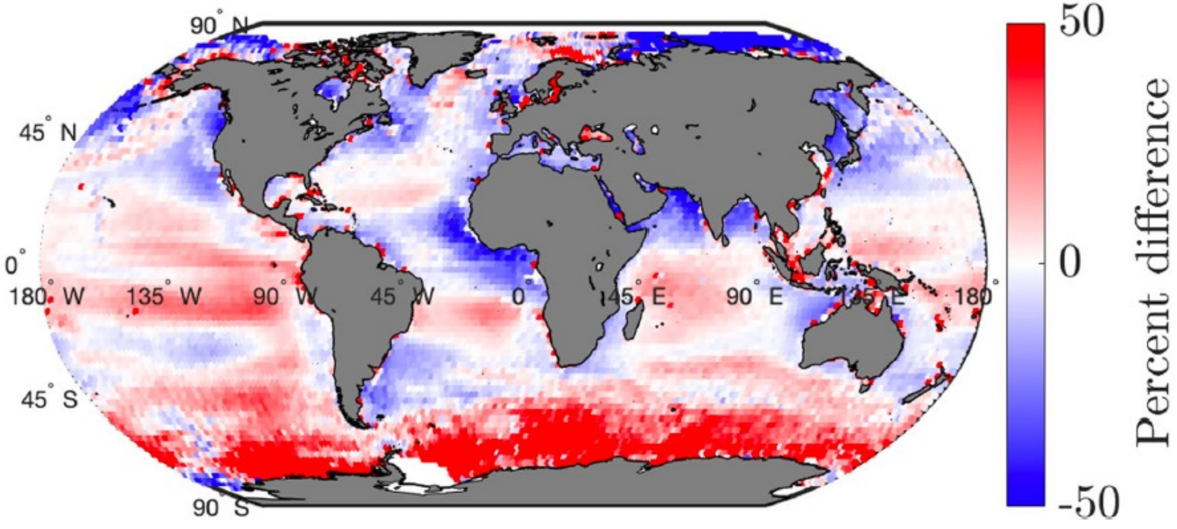
Comparison of MODIS b_{bp} with Argo floats & CALIOP



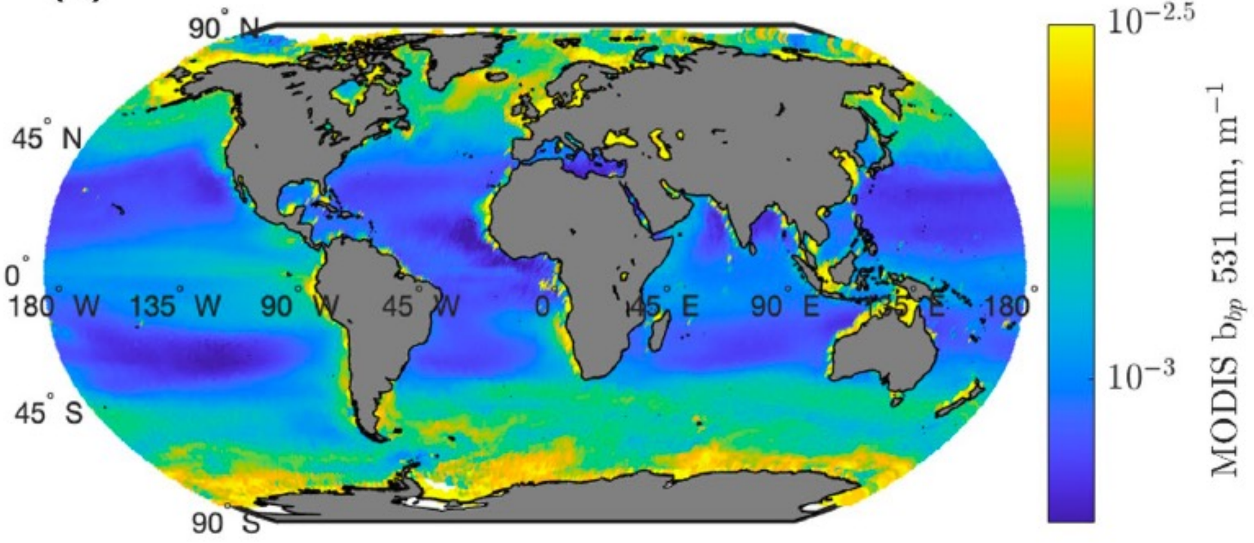


- **MODIS** b_{bp} is parabolic over seasonal cycle
- **CALIOP** and **Argo** show little seasonality

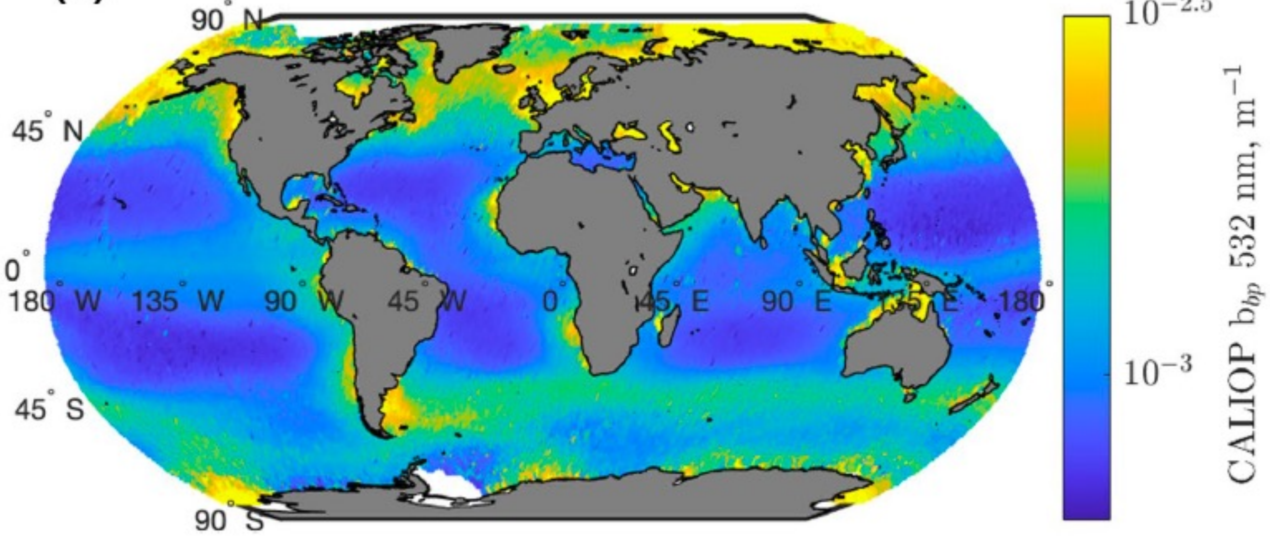
Global comparison



(b)



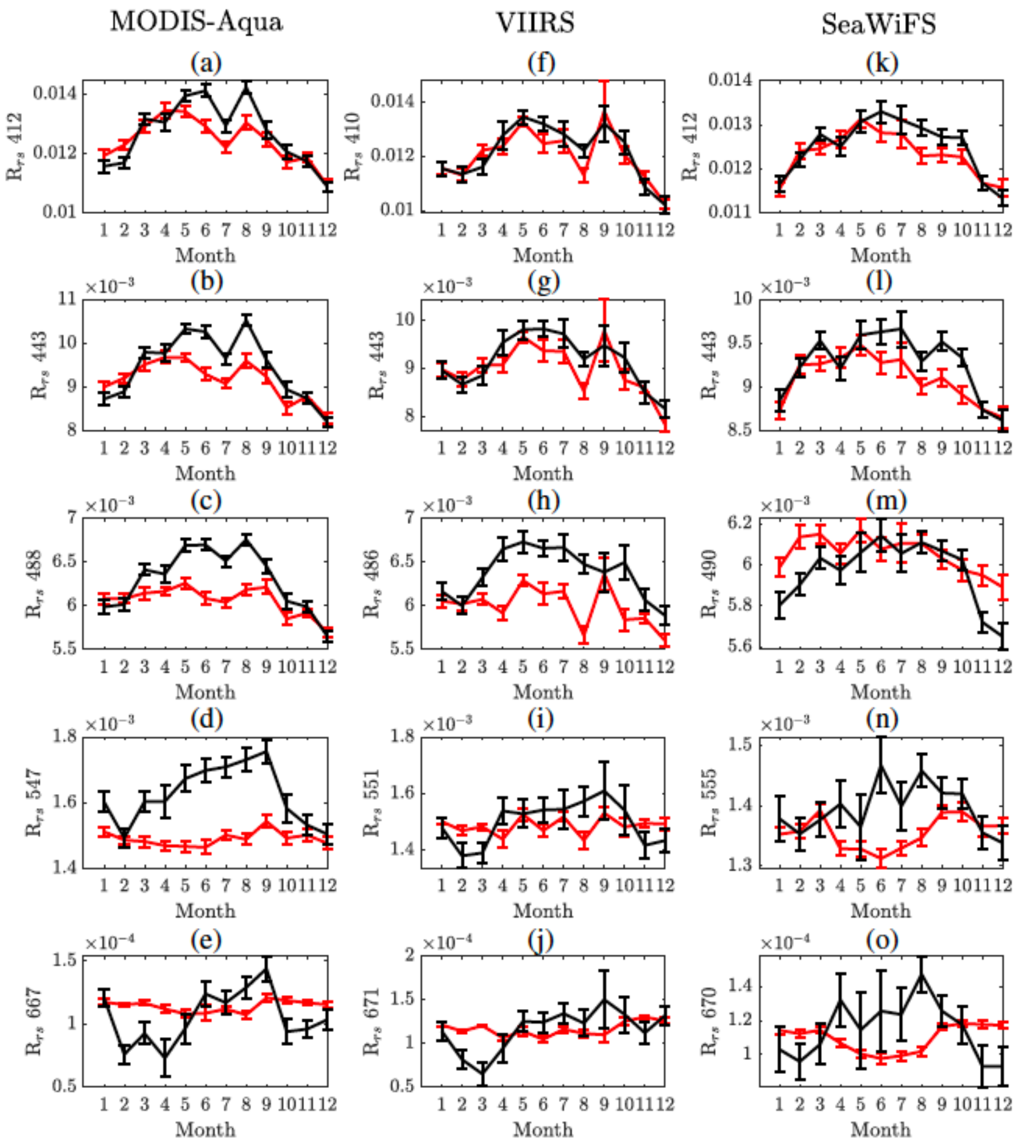
(c)



Bias in the remote sensing reflectance (Rrs)

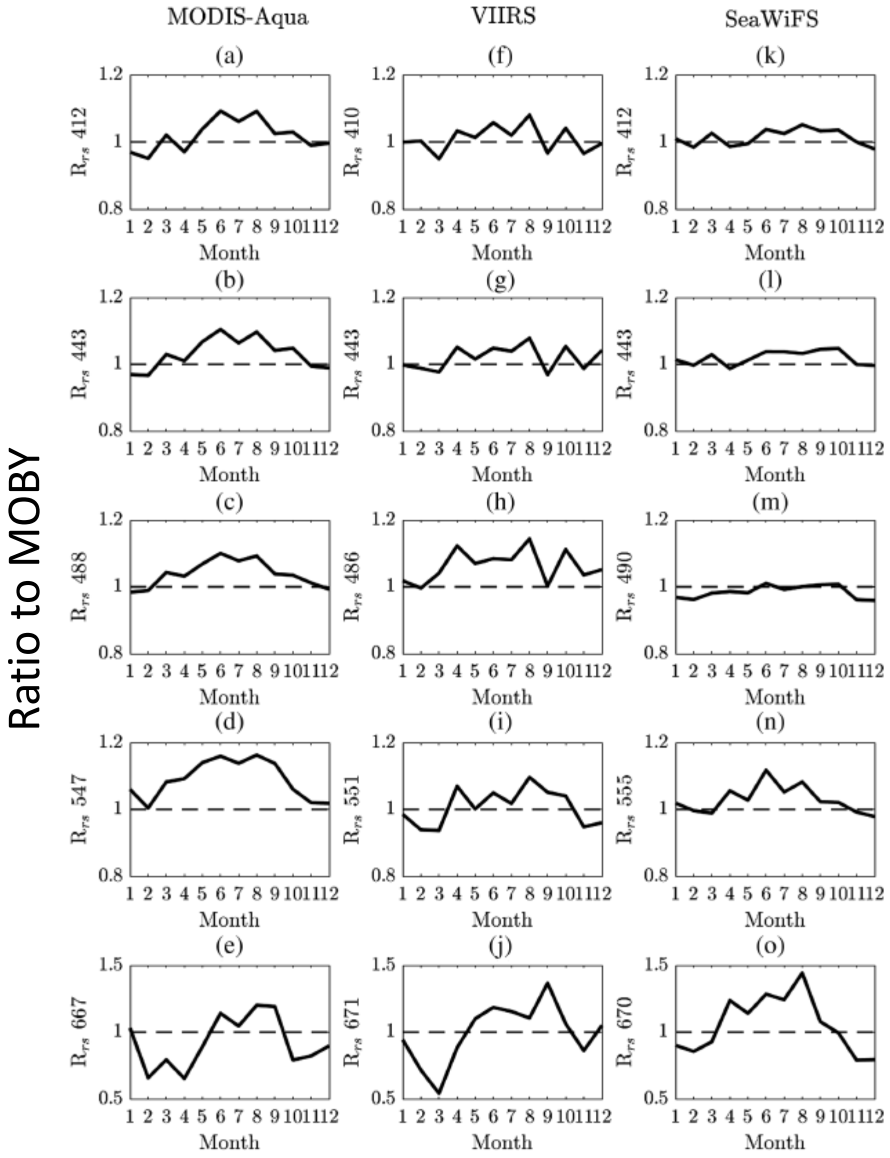
Analysis at MOBY

MOBY
Satellite



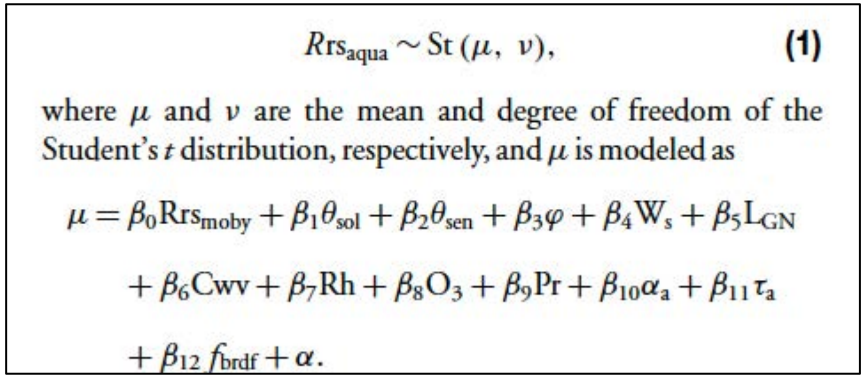
Bias in the remote sensing reflectance (Rrs)

Analysis at MOBY



bias in the summer

Multiple linear regression



$$Rrs_{\mathrm{aqua}} \sim \mathrm{St}\,(\mu,\ \nu), \qquad (1)$$

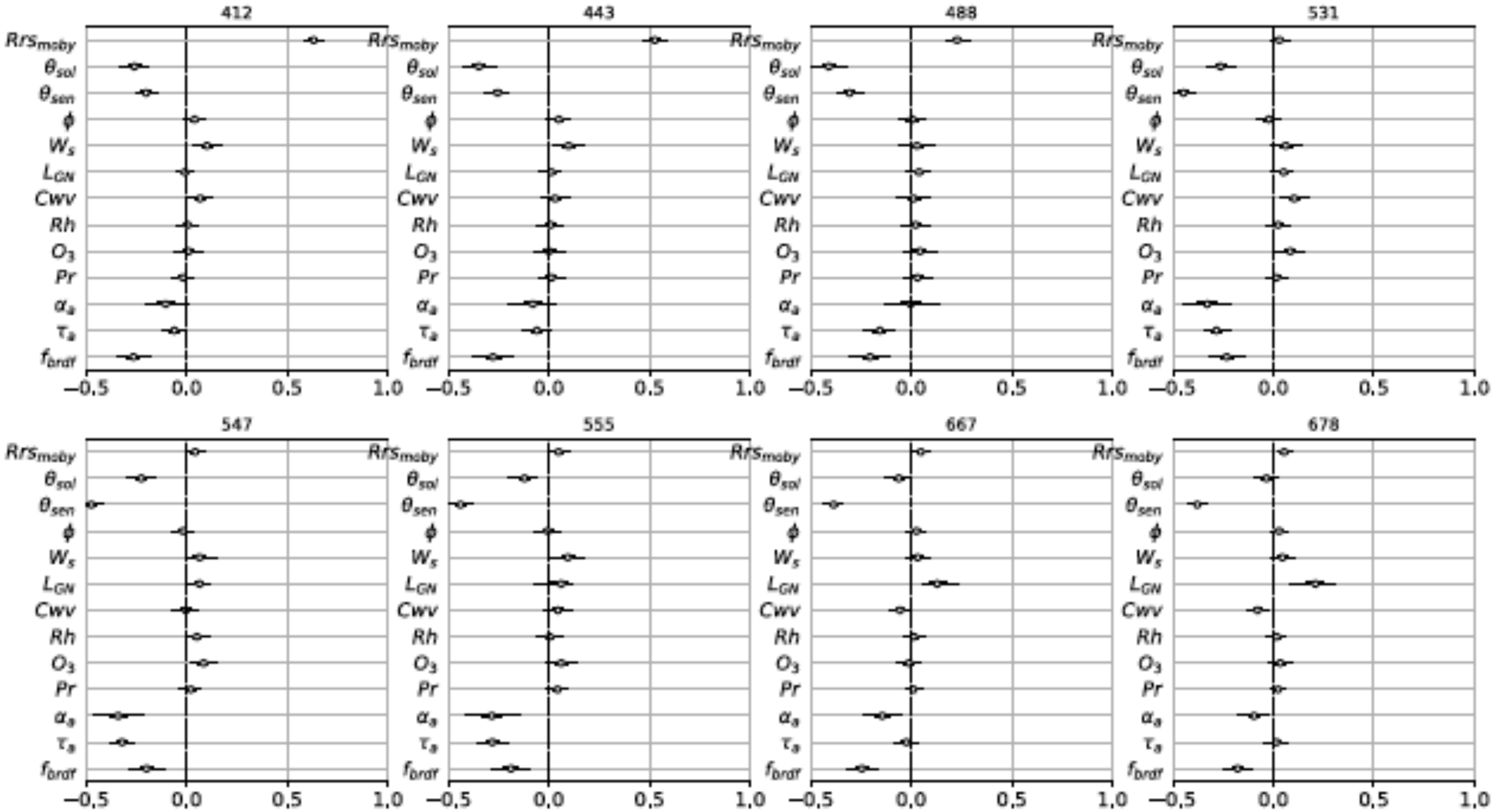
where μ and ν are the mean and degree of freedom of the Student's t distribution, respectively, and μ is modeled as

$$\mu = \beta_0 \mathrm{Rrs}_{\mathrm{moby}} + \beta_1 \theta_{\mathrm{sol}} + \beta_2 \theta_{\mathrm{sen}} + \beta_3 \varphi + \beta_4 \mathrm{W_s} + \beta_5 \mathrm{L_{GN}} + \beta_6 \mathrm{Cwv} + \beta_7 \mathrm{Rh} + \beta_8 \mathrm{O_3} + \beta_9 \mathrm{Pr} + \beta_{10} \alpha_{\mathrm{a}} + \beta_{11} \tau_{\mathrm{a}} + \beta_{12} f_{\mathrm{brdf}} + \alpha.$$

Ideally all independent variables will have a slope of 0 and Rrs_moby of 1

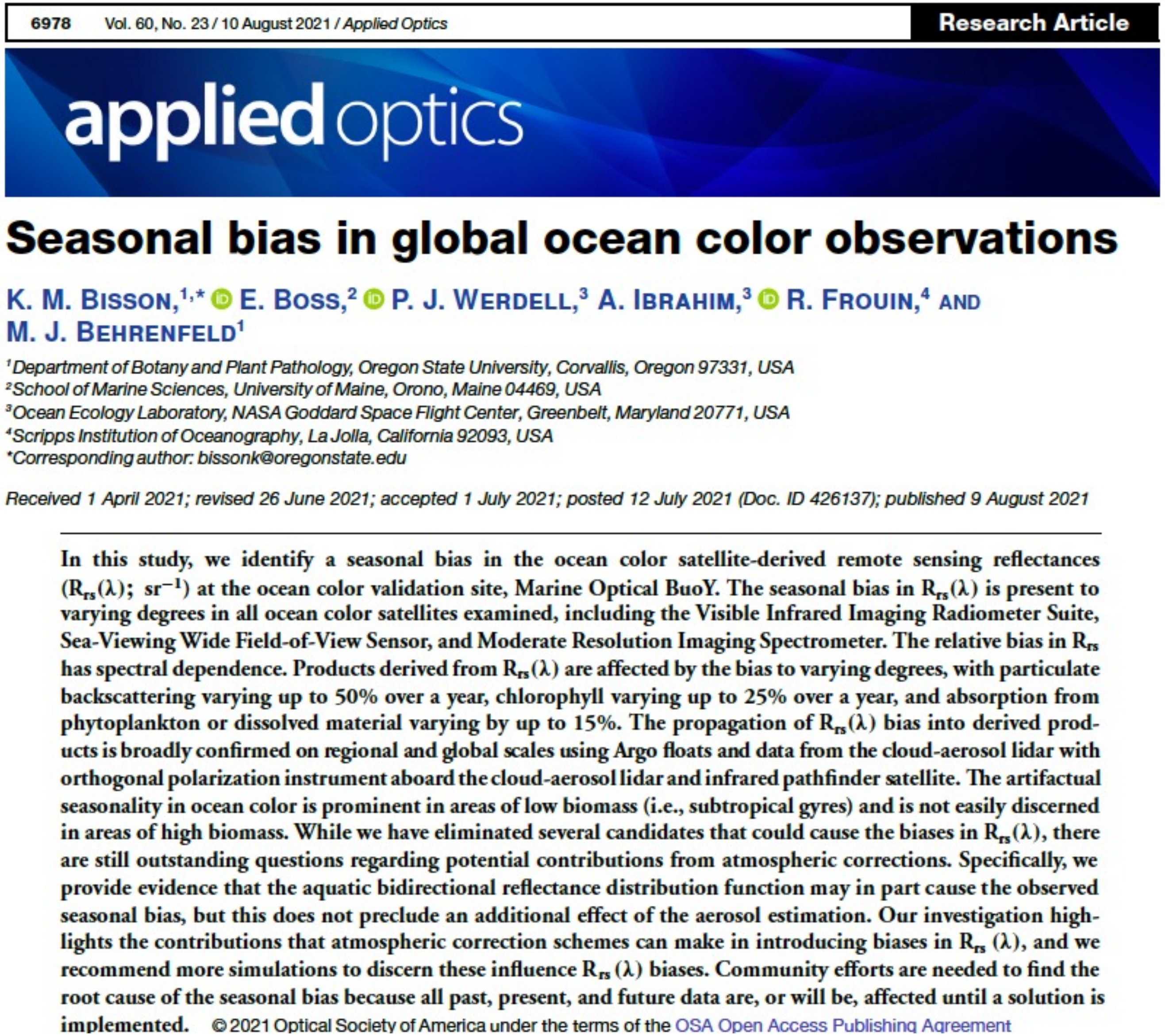
Potential contributors to the bias:

1. BRDF
2. The aerosol type and optical depth



Study summary

- Ocean color data are seasonally biased in low biomass regions.
- In terms of IOPs, bbp is the most affected as it’s directly related to the magnitude of Rrs, while aph and adg are not.
- The bias in Rrs is more pronounced towards longer wavelengths.



6978 Vol. 60, No. 23 / 10 August 2021 / *Applied Optics* **Research Article**

applied optics

Seasonal bias in global ocean color observations

K. M. Bisson,[1,*] E. Boss,[2] P. J. Werdell,[3] A. Ibrahim,[3] R. Frouin,[4] and M. J. Behrenfeld[1]

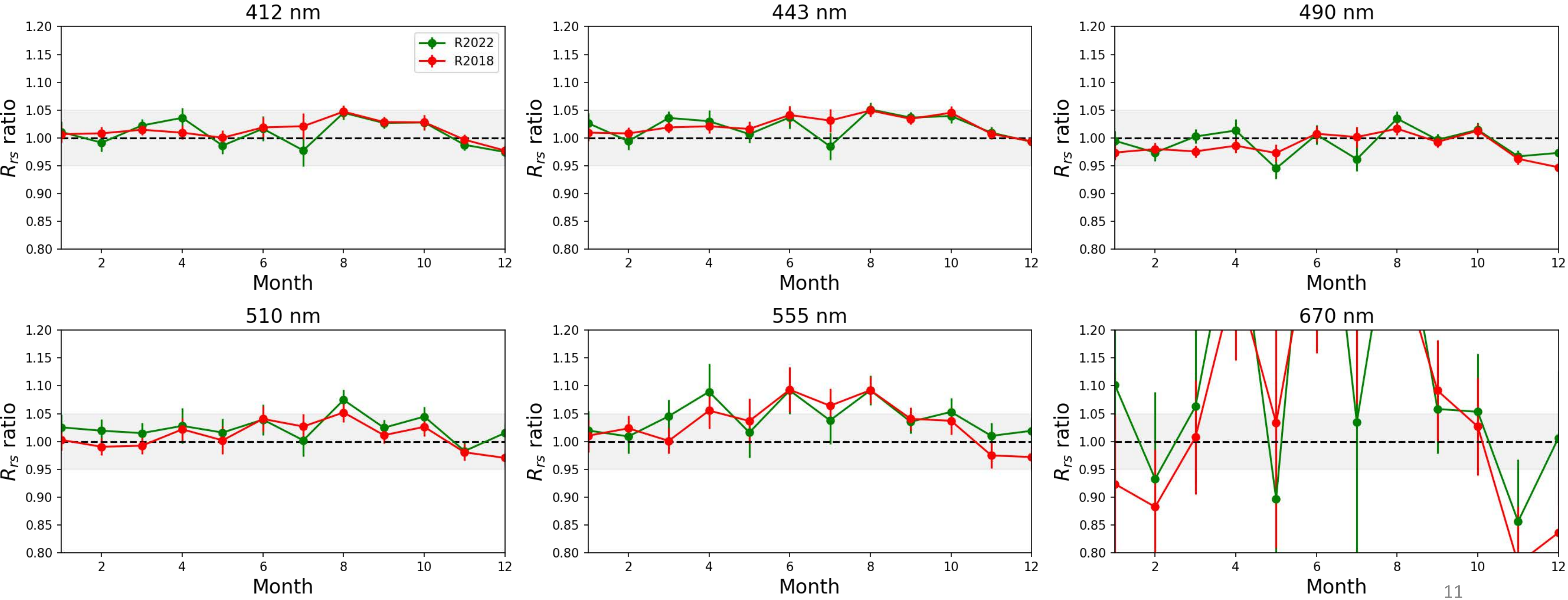
[1]Department of Botany and Plant Pathology, Oregon State University, Corvallis, Oregon 97331, USA
[2]School of Marine Sciences, University of Maine, Orono, Maine 04469, USA
[3]Ocean Ecology Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA
[4]Scripps Institution of Oceanography, La Jolla, California 92093, USA
**Corresponding author: bissonk@oregonstate.edu*

Received 1 April 2021; revised 26 June 2021; accepted 1 July 2021; posted 12 July 2021 (Doc. ID 426137); published 9 August 2021

In this study, we identify a seasonal bias in the ocean color satellite-derived remote sensing reflectances ($R_{rs}(\lambda)$; sr^{-1}) at the ocean color validation site, Marine Optical BuoY. The seasonal bias in $R_{rs}(\lambda)$ is present to varying degrees in all ocean color satellites examined, including the Visible Infrared Imaging Radiometer Suite, Sea-Viewing Wide Field-of-View Sensor, and Moderate Resolution Imaging Spectrometer. The relative bias in R_{rs} has spectral dependence. Products derived from $R_{rs}(\lambda)$ are affected by the bias to varying degrees, with particulate backscattering varying up to 50% over a year, chlorophyll varying up to 25% over a year, and absorption from phytoplankton or dissolved material varying by up to 15%. The propagation of $R_{rs}(\lambda)$ bias into derived products is broadly confirmed on regional and global scales using Argo floats and data from the cloud-aerosol lidar with orthogonal polarization instrument aboard the cloud-aerosol lidar and infrared pathfinder satellite. The artifactual seasonality in ocean color is prominent in areas of low biomass (i.e., subtropical gyres) and is not easily discerned in areas of high biomass. While we have eliminated several candidates that could cause the biases in $R_{rs}(\lambda)$, there are still outstanding questions regarding potential contributions from atmospheric corrections. Specifically, we provide evidence that the aquatic bidirectional reflectance distribution function may in part cause the observed seasonal bias, but this does not preclude an additional effect of the aerosol estimation. Our investigation highlights the contributions that atmospheric correction schemes can make in introducing biases in R_{rs} (λ), and we recommend more simulations to discern these influence R_{rs} (λ) biases. Community efforts are needed to find the root cause of the seasonal bias because all past, present, and future data are, or will be, affected until a solution is implemented.

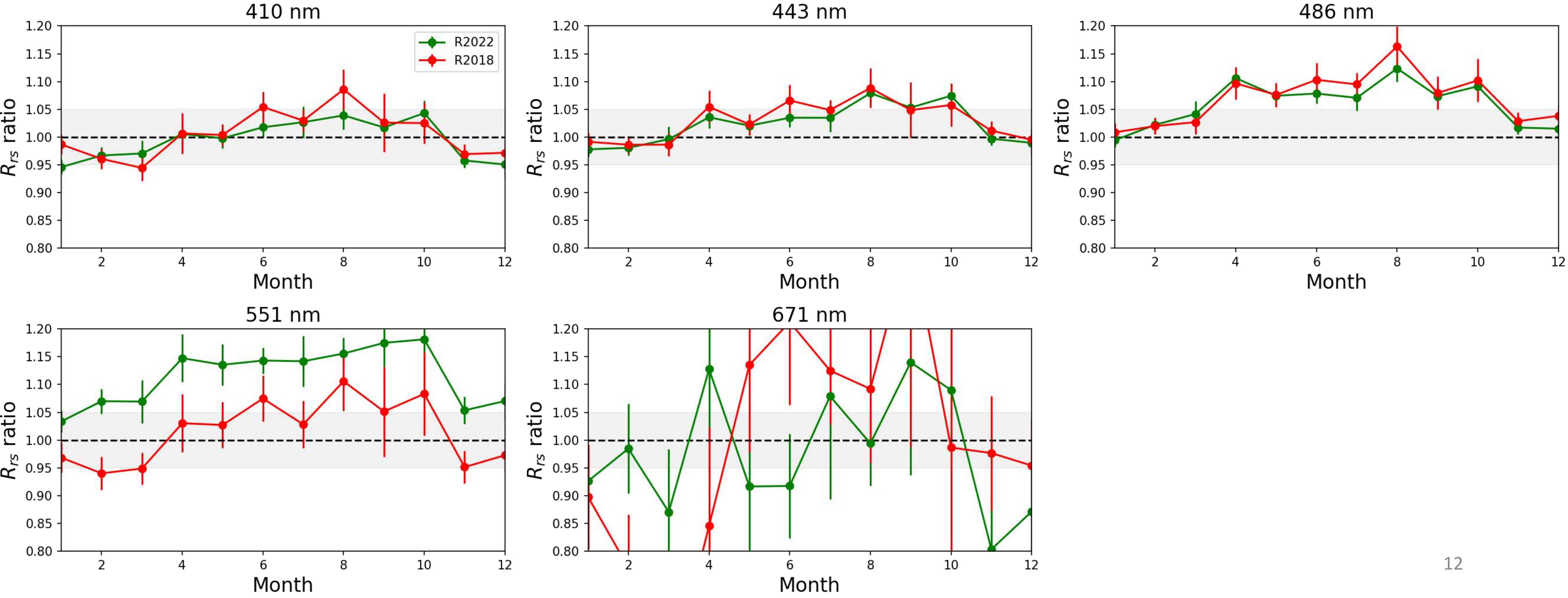
Standard processing: 2018 vs 2022 SeaWiFS

small seasonal bias



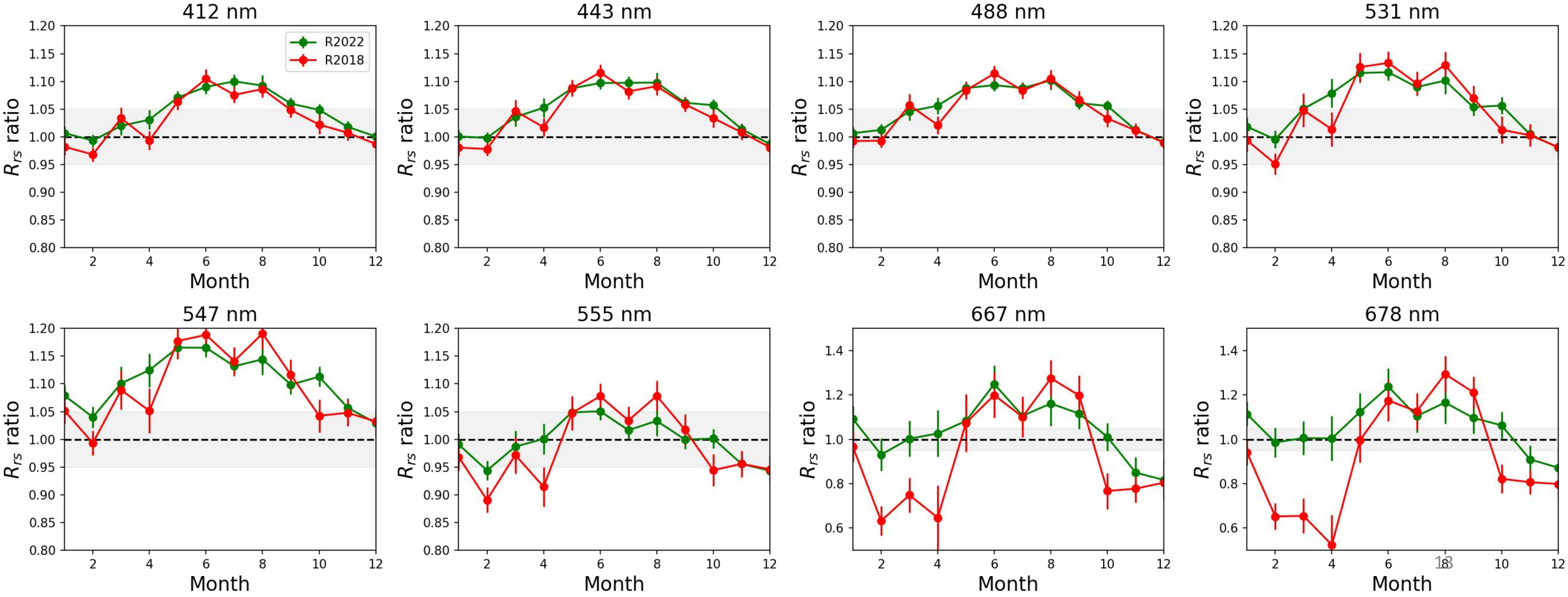
Standard processing: 2018 vs 2022 SNPP

some seasonal bias



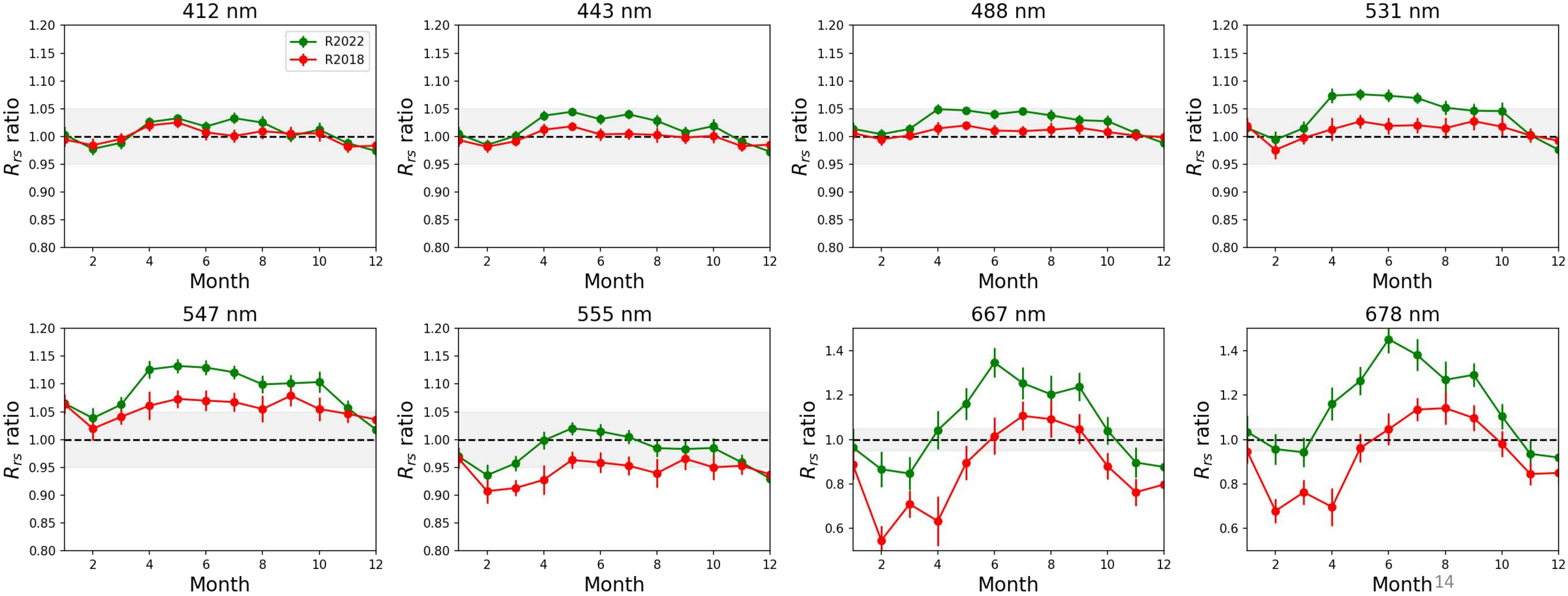
Standard processing: 2018 vs 2022 MODIS Aqua

Strong seasonal bias
Improvement in R2022



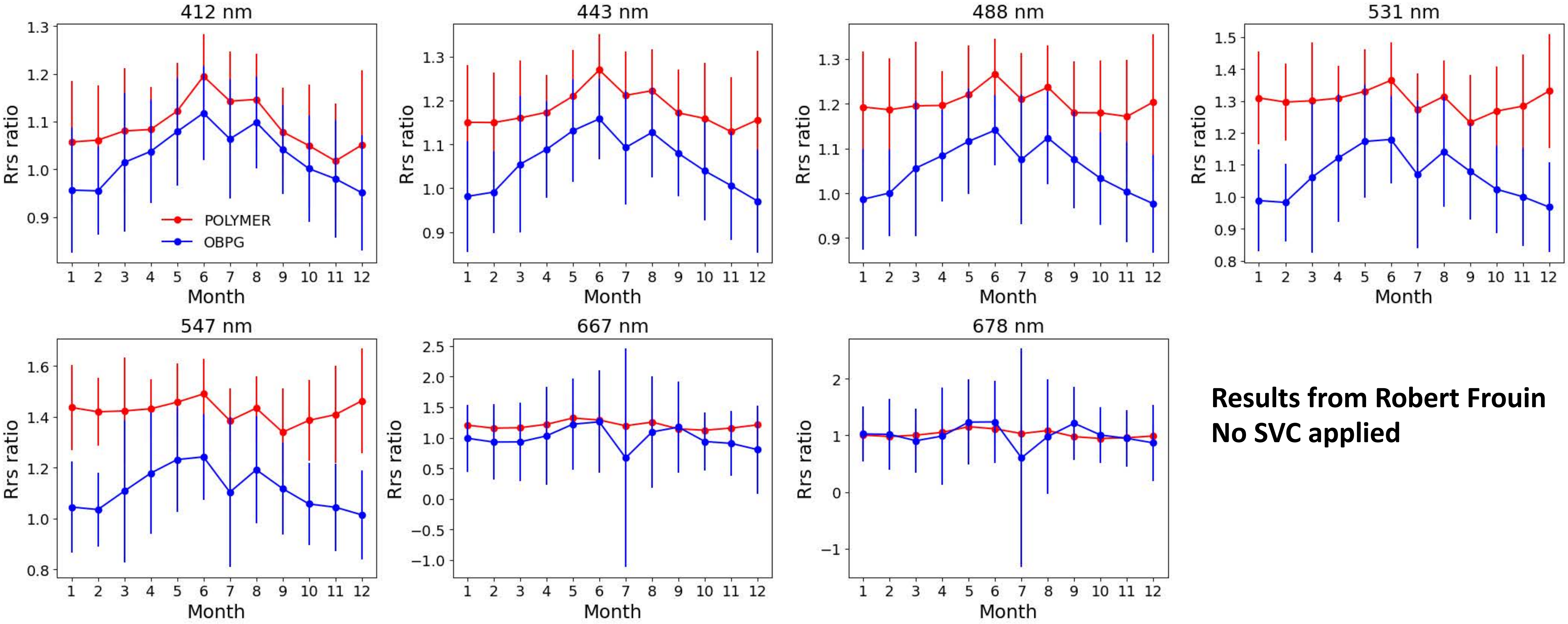
Standard processing: 2018 vs 2022 MODIS Terra

Small seasonal bias



POLYMER algorithm versus OBPG: MODIS Aqua

Strong seasonal bias in the blue



Results from Robert Frouin
No SVC applied

Ratio of Rrs POLYMER or OBPG and Rrs MOBY

A further assessment of calibration

- All sensors use the same algorithms for data processing but exhibit different seasonal biases.
- The primary differences between sensors are related to their cross-calibration and polarization correction.
- Cross-calibration aims to improve the Response versus scan calibration and estimate the polarization sensitivity.
- Cross-calibration is performed differently for each sensor:
  - SeaWiFS - no cross-calibration
  - MODIS Aqua - cross-calibrated to itself
  - MODIS Terra - cross-calibrated to Aqua
  - VIIRS - no cross-calibration
- The polarization correction for Terra is derived from Aqua, but Aqua utilizes pre-launch polarization characterization.
- We are investigating cross-calibration of Aqua to SeaWiFS to derive new polarization elements m12 and m13.

Polarization sensitivity impact on ocean color

- The measured at-sensor radiance I_m is the summation of unpolarized radiance* I_t and the polarized radiance Q_t and U_t modulated by the Mueller elements of the instrument.

$$I_m = I_t + m_{12}Q_t + m_{13}U_t$$

- If the the TOA radiance is unpolarized (i.e., Q_t and U_t are zeros) or if the instrument has no sensitivity to the polarization (i.e., m_{12} and m_{13} are zeros), then $I_m = I_t$.
- TOA radiance is highly polarized and with a polarization sensitive instrument, $I_m \neq I_t$
- The polarization sensitivity is defined as follows:

$$P_s = \sqrt{m_{12}^2 + m_{13}^2}$$

- To perform correction, we need knowledge of: $p_c = I_m/I_t.$
  - The polarized at-sensor radiance Q_t and U_t (if not measured then approximated from Rayleigh scattering)
  - m_{12} and m_{13} (pre-launch characterization of sensorss)

$$\boxed{P_c = \frac{1}{1 - m_{12}\,{}^{Q_t}\!/_{I_m} - m_{13}\,{}^{U_t}\!/_{I_m}}}$$

Polarized radiance unknown

→

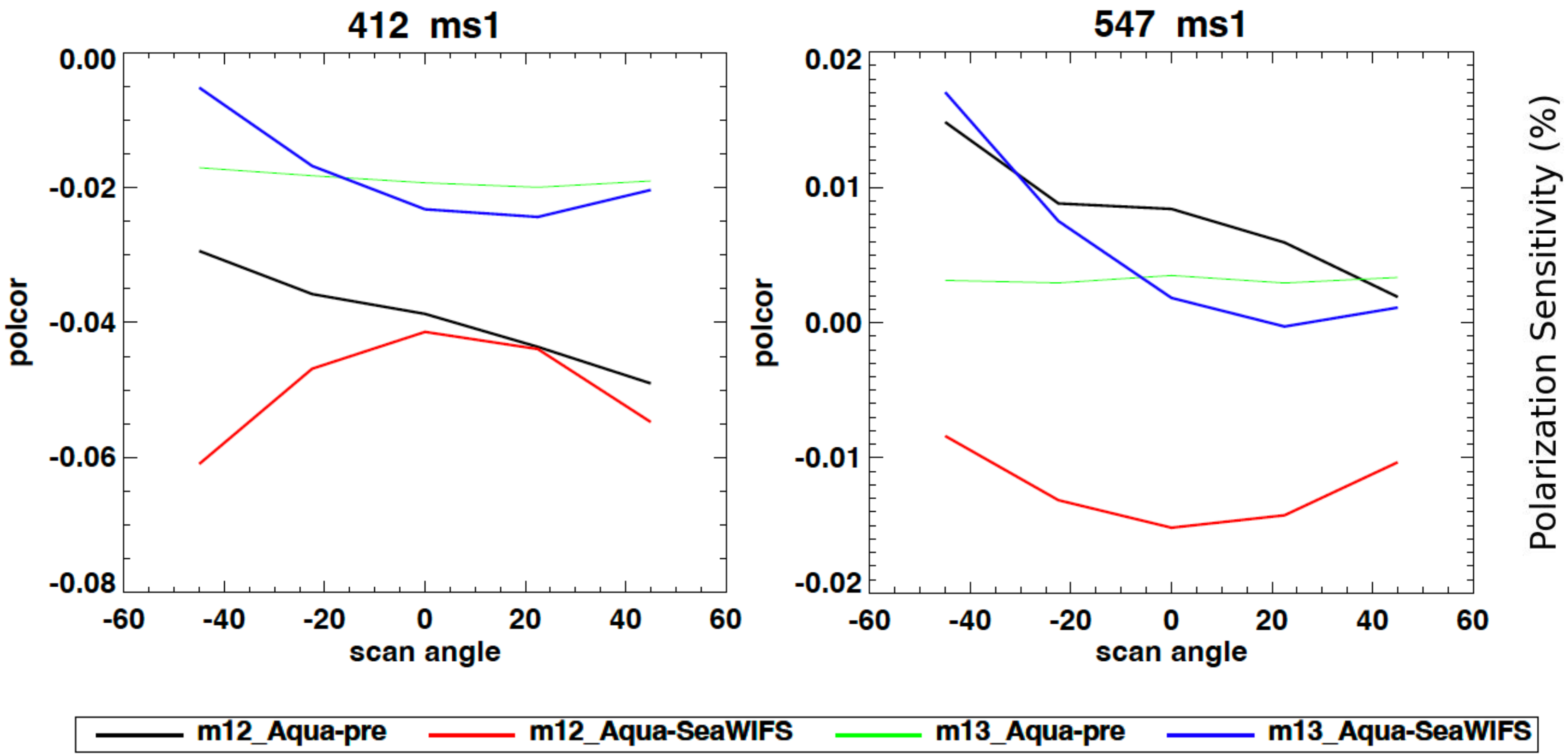
Approximate the polarized radiance from Rayleigh model

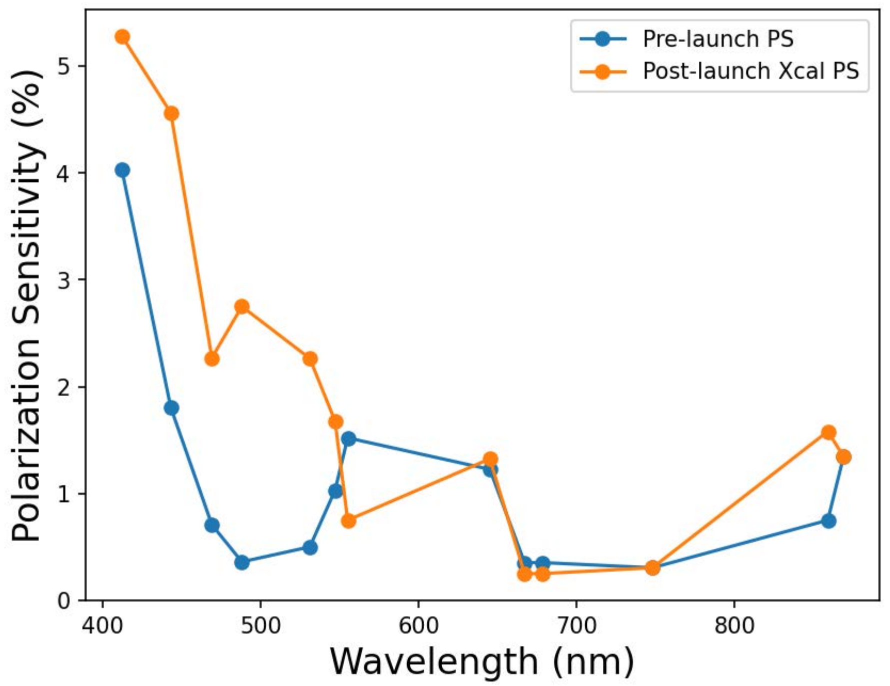
$$\boxed{P_c = \frac{1}{1 - m_{12}\,{}^{Q_R}\!/_{I_m} - m_{13}\,{}^{U_R}\!/_{I_m}}}$$

*I_t is the radiance that would be measured by a sensor with no polarization sensitivity

More details in Meister et al., 2005

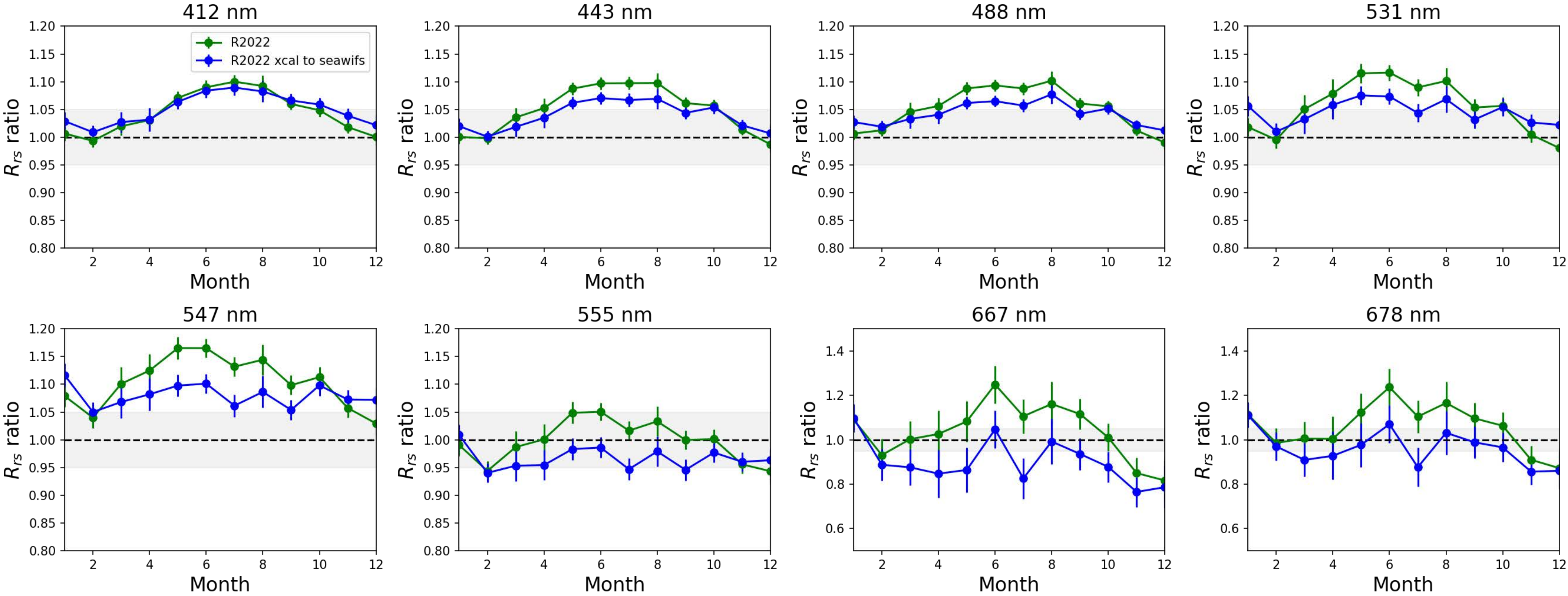
Polarization sensitivity xcal derived vs pre-launch





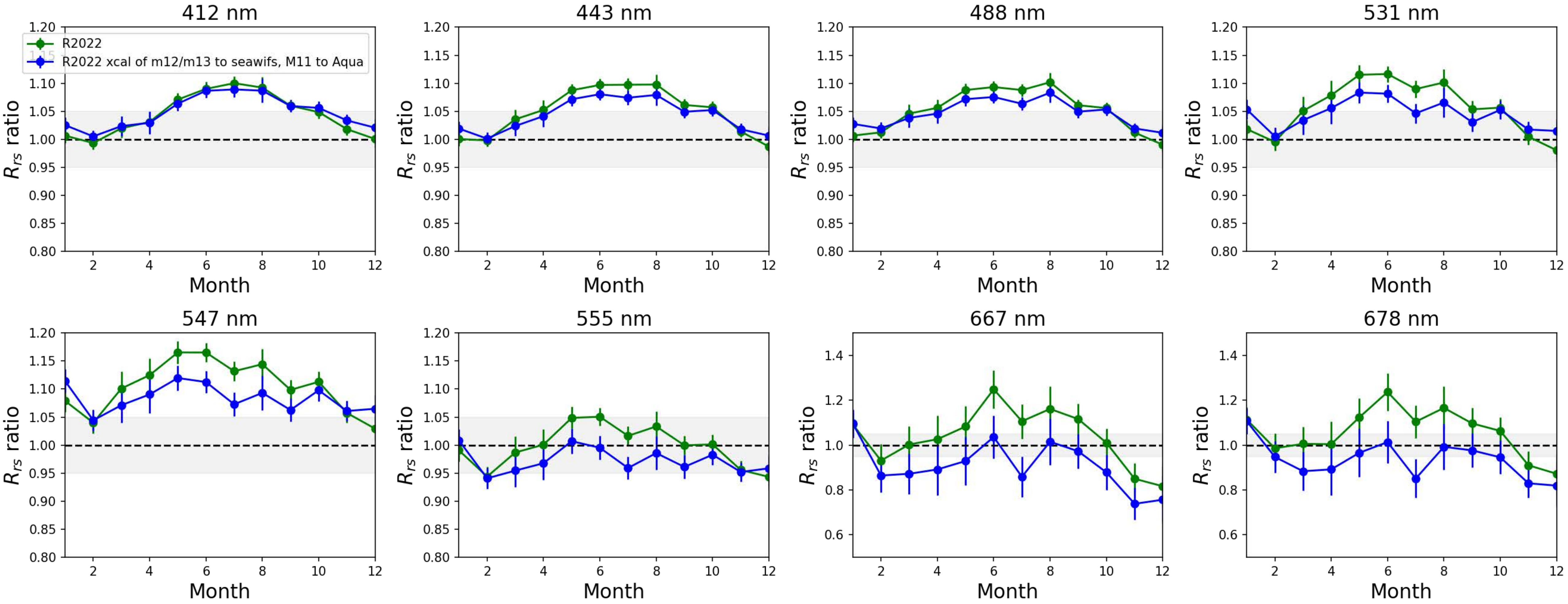
For ms1 and -20 scan angle

Cross-calibration of Aqua to SeaWiFS (M11, m12, and m13)



LUT version axc61e

Cross-calibration of Aqua to SeaWiFS, M11 Aqua xcal to Aqua



LUT version V2.7e

Conclusion

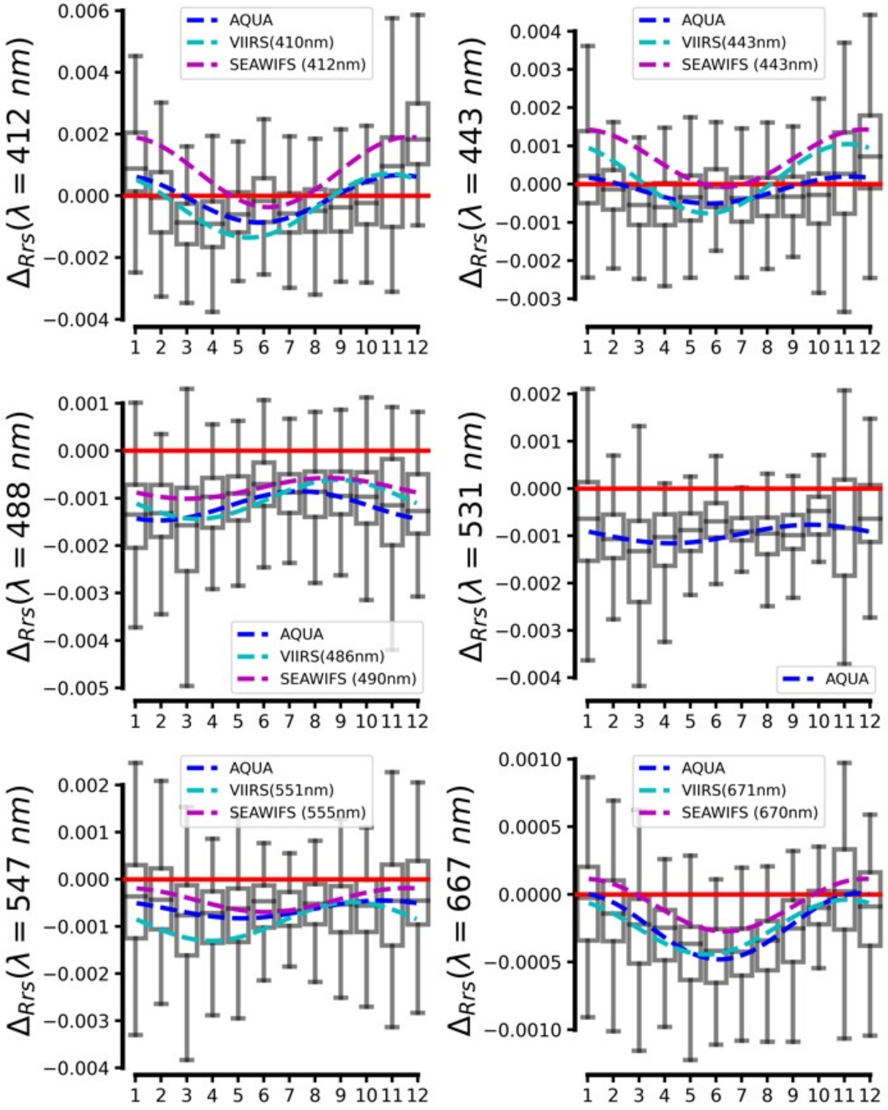
- OBPG is actively working on a resolution, as additional insight is needed.
- The multispectral treatment of MOBY data introduces a constant bias in the validation process compared to SVC, which considers the full RSR of the satellite. Therefore, the validation process is being re-evaluated.
- This constant bias exacerbates the impact of the seasonal bias magnitude.
- Aqua shows significantly larger biases than SeaWiFS, Terra, and SNPP, suggesting an instrument-dependent issue (calibration) with Aqua.
- While there may be residual algorithm biases (AC, BRDF, PS correction, etc.), they are likely not the primary cause of the seasonal bias in Aqua.
- Cross-cal derived polarization sensitivity shows some improvement in reducing the seasonal bias. RVS has a strong impact in the blue and will be further investigated.

Appendix

Seasonal Bias at AERONET-OC sites

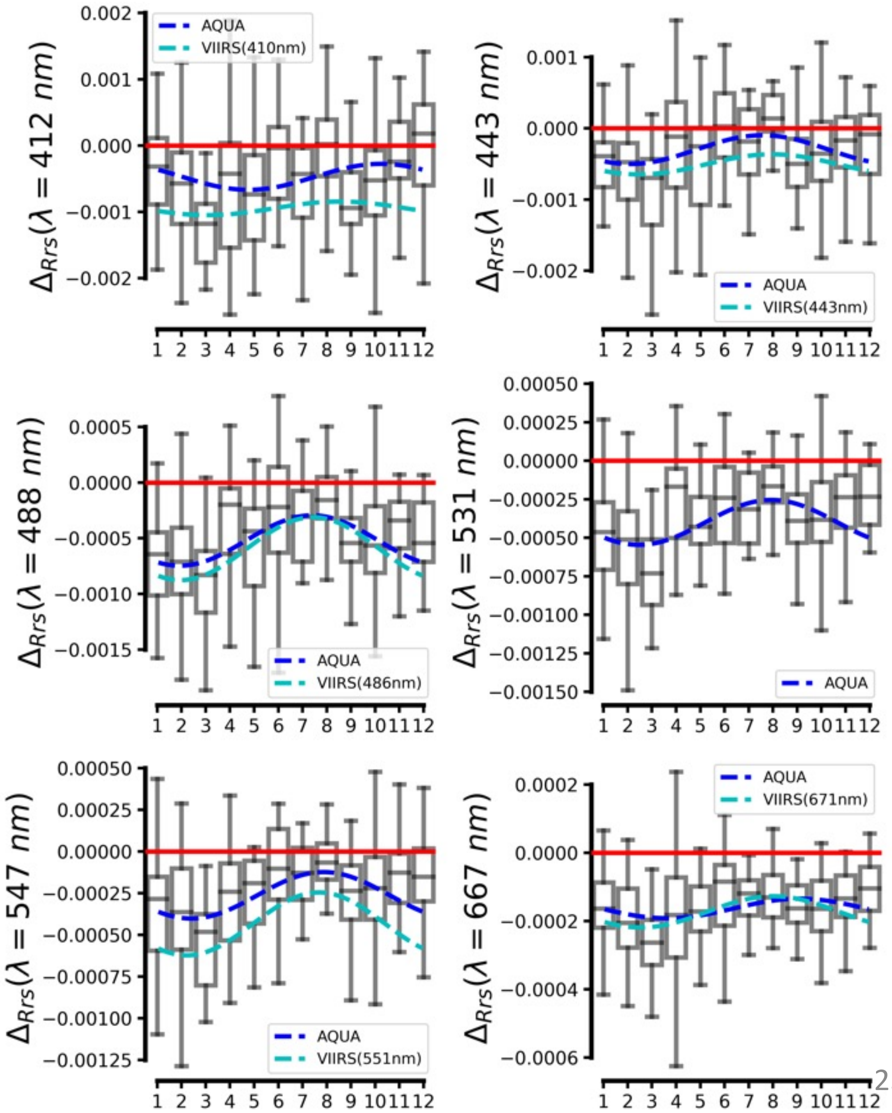
$$\Delta_{Rrs}(\lambda) = (Rrs(\lambda)_{satellite} - Rrs(\lambda)_{in\ situ})$$

Location: AOC VENICE

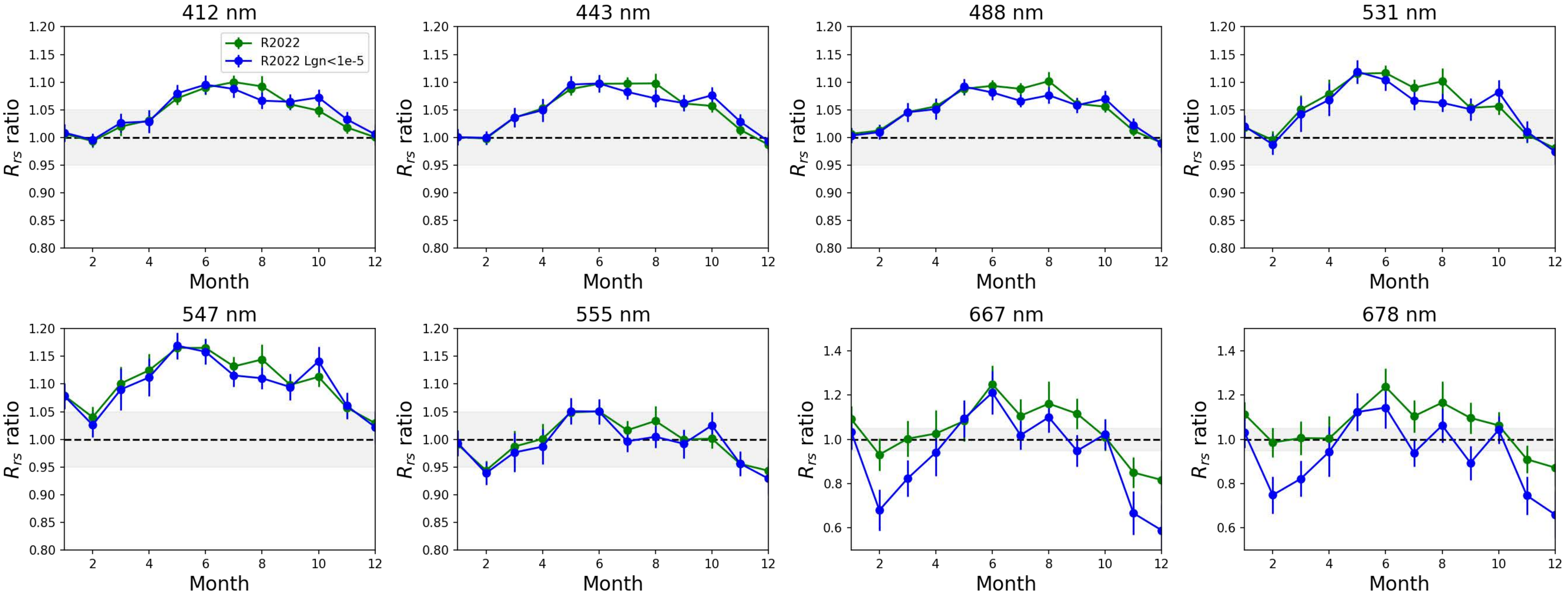


$$\Delta_{Rrs}(\lambda) = (Rrs(\lambda)_{satellite} - Rrs(\lambda)_{in\ situ})$$

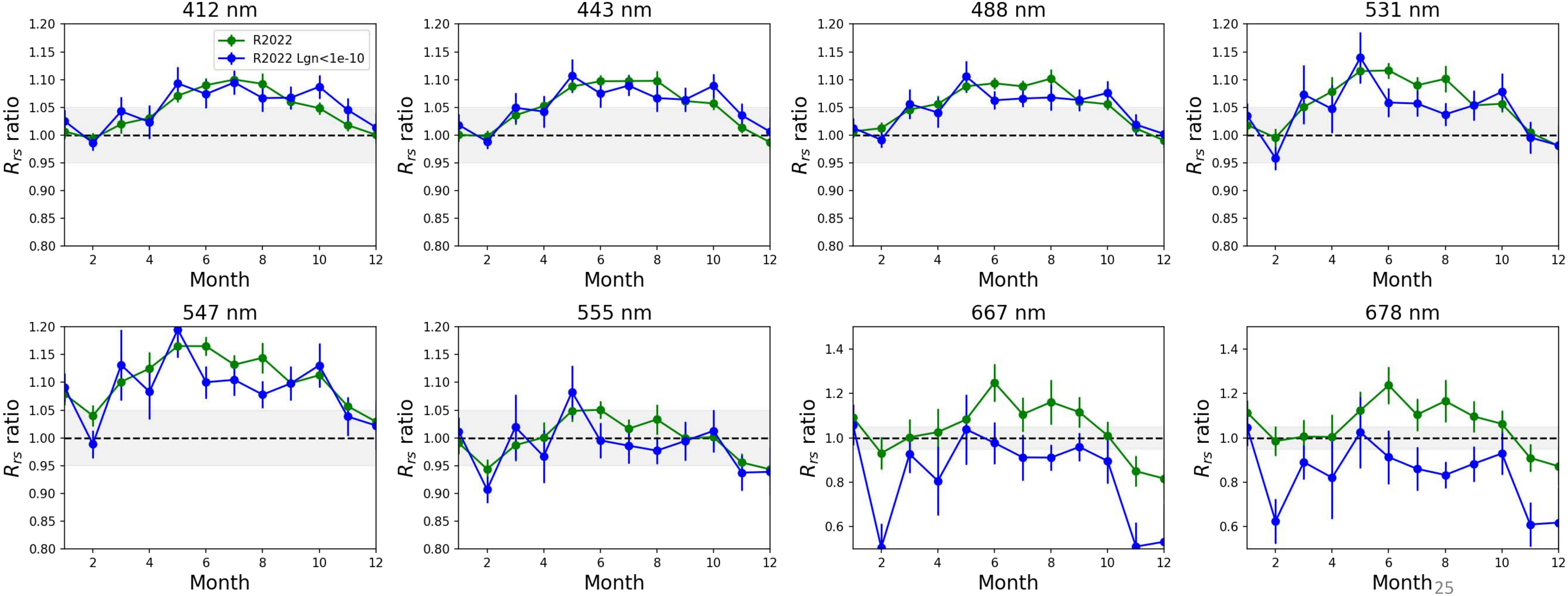
Location: AOC USC



Impact of glint

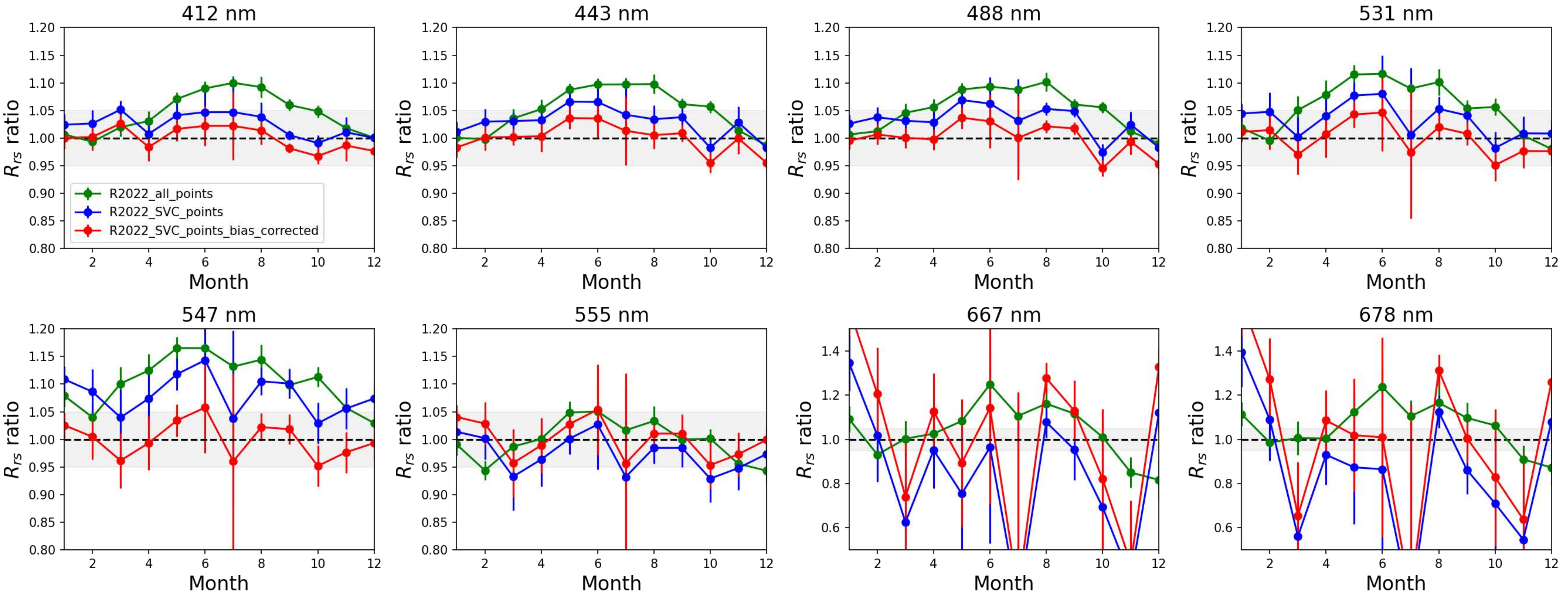


Impact of glint

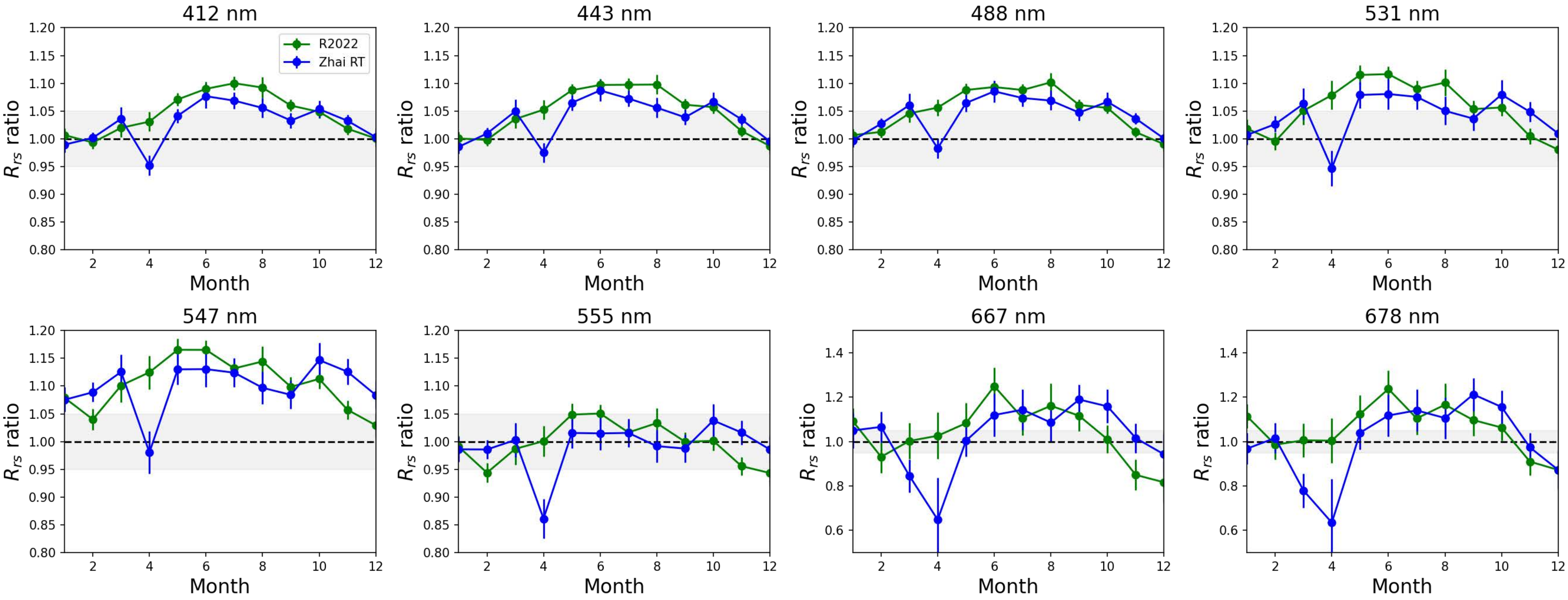


Standard processing: 2018 vs 2022 MODIS Aqua

Seasonal bias exists
Improvement in R2022



Impact of LUTs generated by PW Zhai RT code



Cross-calibration of Aqua to SeaWiFs but with a normalized M11