Cross-calibration of Polar-Orbiting Ocean-Color Sensors Using Geostationary Observations

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IOCS Meeting, 14 – 17 November 2022, St. Petersburg, Florida

Introduction

-Radiometric cross-calibration of optical (e.g., ocean-color) instruments is an important activity to ensure product consistency and generate climate data records.

-It can be easily defined as viewing the same radiance at the same time, but it is much more difficult to achieve during in flight operations of different sensors on different orbits.

-Apart from viewing the Moon, one must rely on measuring the solar radiation reflected by the Earth-atmosphere system at the same time and location because of its time variability.

-The Earth-atmosphere system has generally some bidirectional reflectance function that requires observing under the same solar and viewing geometry (i.e., same line of sight).

-If the spectral bands to be compared do not have the same or close definition, some empirical transformation must be applied to make the cross-calibration.

Methodology

-The methodology examined utilizes a sensor onboard a satellite in geostationary orbit, which acts as an intermediary between the polar-orbiting sensors to calibrate (e.g., MODIS-A and MODIS-T).

-Compared with other cross-calibration techniques (Moon, desert sites), the advantage is that precise coincidences in time and geometry are easier to find.

-Many coincidences occur over oceanic regions, allowing the cross-calibration to be performed at radiance levels typically encountered in ocean-color remote sensing.

-It may not be possible to cross-calibrate the polar-orbiting sensors in all their spectral bands. Only bands closest to those of the GEO sensor, or the combinations of bands that correlate satisfactorily with its spectral bands, are selected.

Methodology (cont.)

-Consider the cross-calibration of two polar-orbiting sensors and assume for simplicity that polar-orbiting and geostationary sensors observe at the same time (t or t'). The cross-calibration coefficients between each polar-orbiting sensor and the geostationary sensor, A_{1i} and A_{2j}, can be written:

$$A_{1i} = \rho_{ref}(t) / f_{1i}[\rho_{1i}(t)]$$

$$A_{2j} = \rho_{ref}(t') / f_{2j}[\rho_{2j}(t')]$$

where f_{1i} and f_{2j} are empirical functions that relate ρ_{1i} and ρ_{2j} to ρ_{ref}. These functions are determined theoretically, from simulations for realistic environment and geometry conditions.

-If the two sensors are perfectly inter-calibrated, A_{1i} is equal to A_{2j}. Differences between A_{1i} and A_{2j}, on the other hand, will indicate that the calibration of the two sensors is not consistent and, therefore, needs to be adjusted accordingly.

Practical Considerations

-The collocated pixels from the pairs of instruments to cross-calibrate, i.e., a low earth orbit (LEO) sensor and the geostationary (GEO) sensor of reference, must be observed under comparable conditions, which means close solar and viewing angles.

-The time difference between the LEO and GEO observations must also be sufficiently small to neglect changes in the reflectance characteristics of the atmosphere and target.

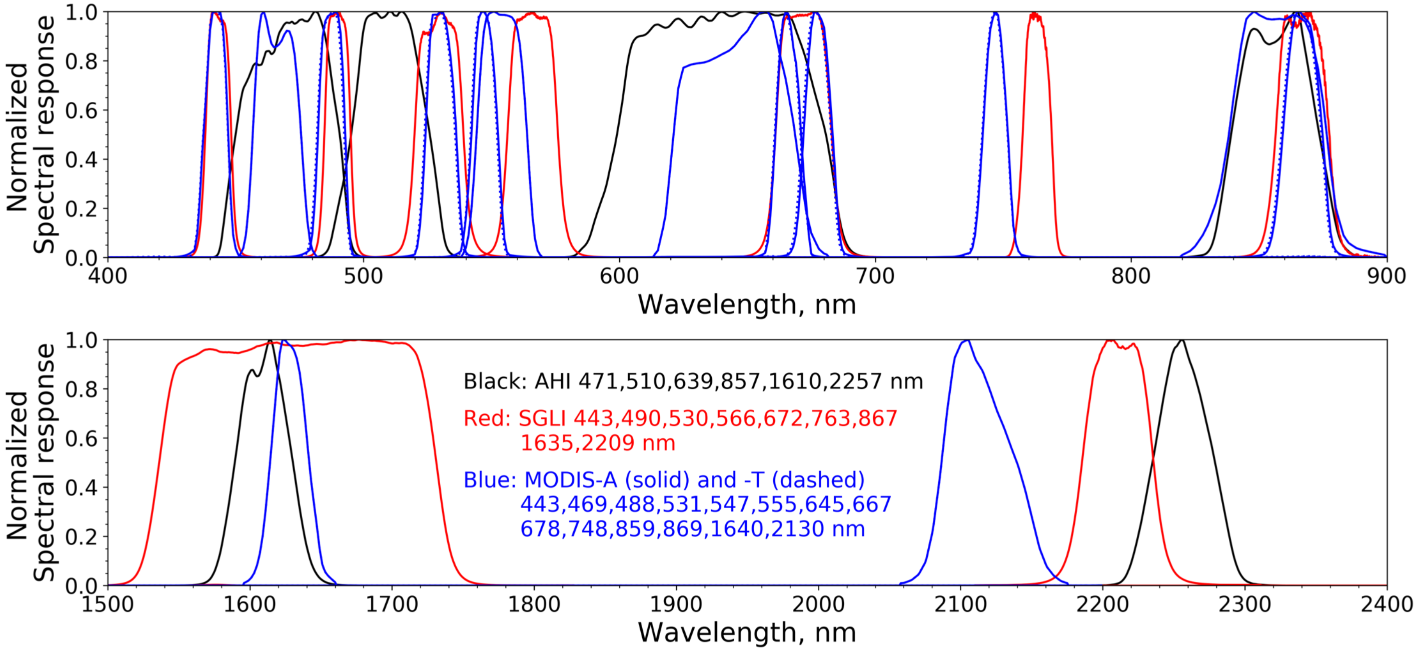
-Criteria to select suitable observations are based on the repeat cycle of the GEO sensor, the type of target, the radiometric noise, the accuracy of the spectral matching, and the impact on the measured reflectance.

-Since the LEO sensor has generally a strongly inclined (i.e., near polar) orbit, observations along the same line of sight by the LEO and GEO sensors are expected to occur near the equator, the only region where the viewing azimuth angles would match.

Application to cross-calibrating SGLI, MODIS-T, and –A (Tan et al., Frontiers, 2023)

-AHI on Hiwamari-8 is the GEO sensor of reference.

-Cross-calibration is performed after system vicarious calibration.



Combinations of SGLI, MODIS-A, and -T bands used for estimating reflectance in AHI bands.

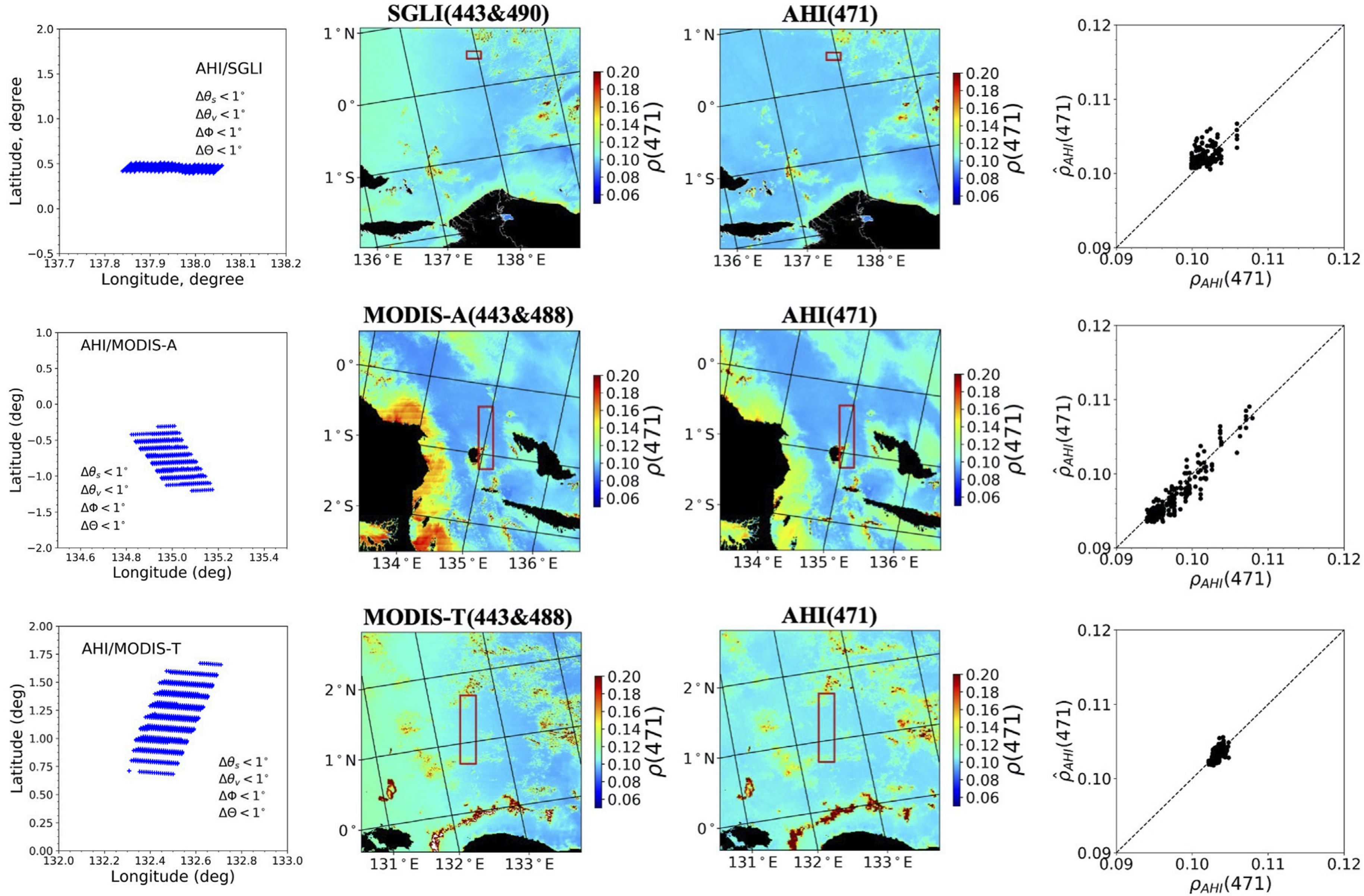
AHI bands (nm)	SGLI bands (nm)	MODIS-A bands (nm)	MODIS-T bands (nm)
471	443&490	443&469, 443&488, 469&488, 469	443&469, 443&488, 469&488, 469
510	490&530	469&531, 469&547, 469&555, 488&531, 488&547, 488&555	469&531, 469&547, 469&555, 488&531, 488&547, 488&555
639	672	645, 667, 678	645, 667, 678
857	867	859, 869	859, 869
1610	1635	1640	1640
2257	2209	2130	2130

-In general, the RMSD of spectral band matching are quite small, i.e., less than 0.7%.

-Only AHI 471, 510, and 639 nm are used. Longer wavelengths are not of interest due to relatively large AHI image noise and that the SVC makes assumptions about radiometric calibration in the near infrared.

Geometry coincidence

-Criteria: Δt < 10 min; $\Delta\theta_s, \Delta\theta_v, \Delta\emptyset, \Delta\Theta$ < 1°; Adjacency, Sun glint effects minimized

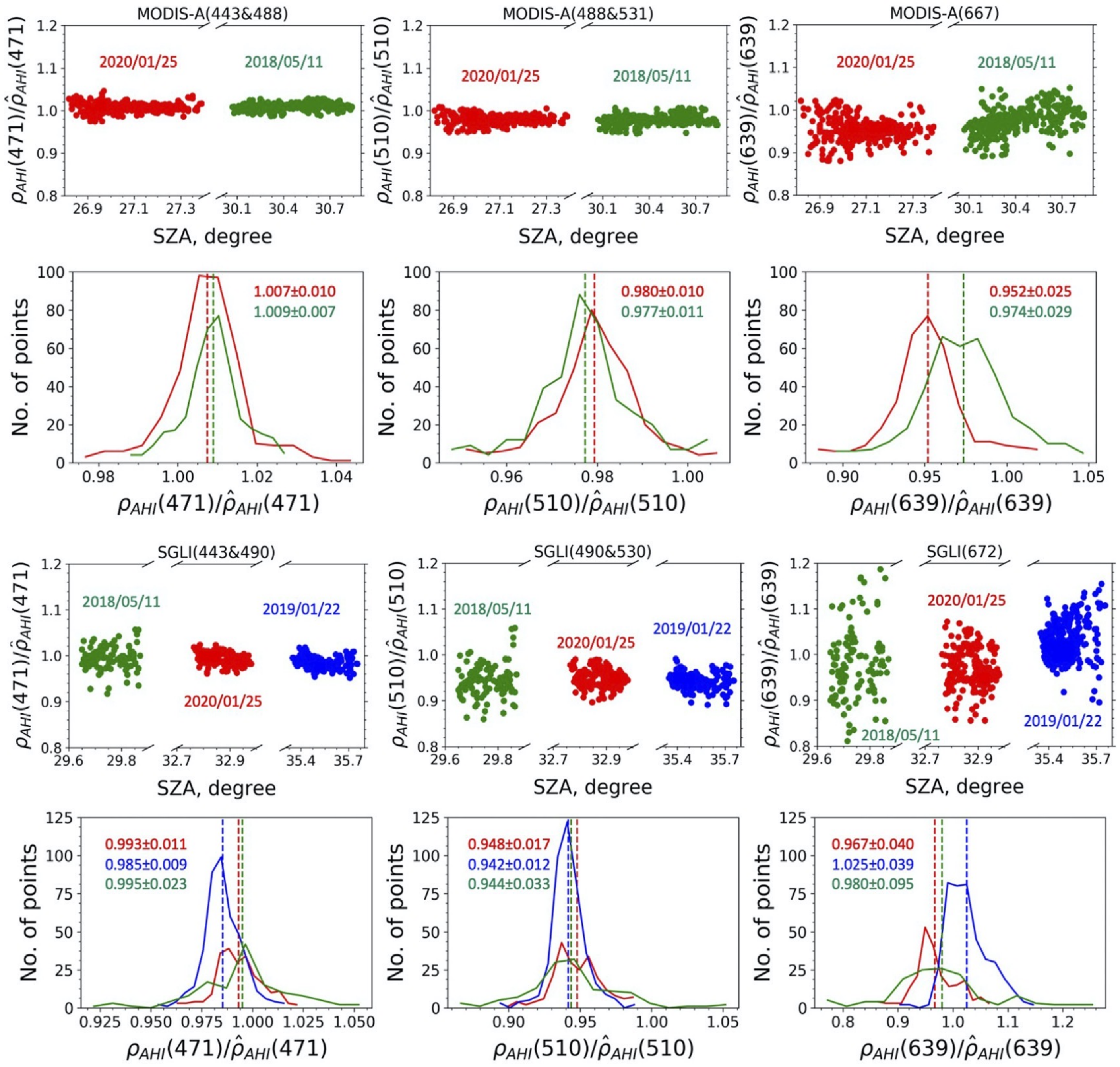


Cross-calibration Coefficients

-The mean of the reflectance ratios (with respect to AHI) is considered as the best estimate, and the associated uncertainty is calculated as $\sqrt{e_1^2 + e_2^2}$, e_1=SD/$\sqrt{N}$, e_2 is the spectral matching RMSD.

-If we know *A*/*B* and *A*/*C* (*A* is for geostationary sensor, *B* and *C* are for polar orbiting sensors), we know the cross-calibration coefficient *C*/*B*, and the associated errors can be propagated.

-Underlying assumption is that cross-calibration coefficients are identical if obtained within the same day but may be different for different days, especially if those days are far apart, due to uncertainties in their determination (e.g., time drift imperfectly corrected).



Results

Band combinations	Cross-calibration coefficients A		
	SGLI/MODIS-A	SGLI/MODIS-T	MODIS-A/MODIS-T
A(471) 469			(0.991, 0.984) 0.988±0.010
A(471) 443&488/443&490	(1.014, 1.014) 1.014±0.010	(1.018, 1.018, 1.008) 1.015±0.008	(1.004, 0.994) 0.999±0.006
A(471) 443&469			(0.993, 0.988) 0.991±0.007
A(471) 469&488			0.997, 0.991 0.994±0.009
A(510) 488&531/490&530	(1.035, 1.033) 1.034±0.010	(1.043, 1.051, 1.041) 1.046±0.008	(1.008, 1.008) 1.008±0.006
A(510) 488&547			(1.004, 1.009) 1.007±0.006
A(510) 488&555			(1.005, 1.010) 1.008±0.006
A(510) 469&531			(1.007, 1.005) 1.006±0.006
A(510) 469&547			(0.999, 1.002) 1.000±0.006
A(510) 469&555			(0.999, 1.005) 1.002±0.006
A(639) 645			(1.002, 0.989) 0.995±0.007
A(639) 667/672	(0.994, 0.984) 0.989±0.023	(0.999, 0.977, 0.980) 0.985±0.019	(1.005, 0.996) 1.001±0.007
A(639) 678			(1.006, 1.001) 1.004±0.007

-Three days considered: 5/11/2018, 1/22/2019, and 1/25/2020.

-MODIS-A and MODIS-T after SVC are well cross-calibrated in the bands of reference, with differences of about 1% from unity, generally within the uncertainties, for all band combinations.

-SGLI shows larger cross-calibration differences, i.e., 1.4%, 3.4%, and 1.1% with MODIS-A and 1.5%, 4.6%, and 1.5% with MODIS-T, respectively.

-Such differences may introduce significant discrepancies between ocean-color products generated from SGLI and MODIS data, but some compensation may occur because different AC schemes are used to process SGLI and MODIS imagery, and SVC is based on the selected scheme.

Results (cont.)

-Analysis of additional cross-calibration days from 2016 to 2022 strongly suggest that TOA radiance measured in MODIS-A and MODIS-T spectral bands 443 to 678 nm is consistent between the two sensors during that period.

Band combinations	MODIS-A/MODIS-T cross calibration coefficients
469	(0.991, 0.984, 0.999, 0.994, 1.005, 0.989, 0.998) 0.995±0.006
443&488	(1.003, 0.994, 1.004, 0.996, 1.007, 0.992, 1.005) 1.000±0.003
443&469	(0.993, 0.988, 1.008, 1.002, 1.006, 0.989, 0.997) 0.998±0.004
469&488	(0.997, 0.991, 1.007, 1.001, 1.006, 0.989, 1.000) 0.999±0.005
488&531	(1.008, 1.008, 1.010, 1.002, 1.010, 0.999, 1.005) 1.006±0.003
488&547	(1.004, 1.009, 1.007, 0.995, 1.006, 0.996, 1.000) 1.002±0.003
488&555	(1.005, 1.010, 1.006, 0.992, 1.005, 0.996, 0.999) 1.002±0.003
469&531	(1.007, 1.005, 1.011, 1.005, 1.014, 1.001, 1.009) 1.007±0.003
469&547	(0.999, 1.002, 1.003, 0.994, 1.007, 0.995, 0.999) 1.000±0.003
469&555	(0.999, 1.005, 1.001, 0.990, 1.006, 0.994, 0.998) 0.999±0.003
645	(1.002, 0.989, 0.986, 0.994, 0.995, 0.996, 0.998) 0.994±0.004
667	(1.005, 0.996, 1.002, 0.994, 0.997, 0.997, 0.991) 0.997±0.004
678	(1.006, 1.001, 1.007, 0.993, 0.995, 0.996, 0.989) 0.998±0.004

Conclusions

-Using an intermediary sensor in GEO orbit allows one to find numerous coincident measurements in space, time, and geometry over oceanic regions (signal level for ocean-color applications), an advantage over other cross-calibration techniques.

-MODIS-A and MODIS-T after SVC are well cross-calibrated in the bands of reference, with differences of 1% from unity, generally within the uncertainties, for all band combinations.

-Using diverse band combinations further suggested that the MODIS-A and MODIS-T individual bands at 443, 469, 488, 531, 547, and 555 nm are also well cross-calibrated.

-In comparison, larger differences, i.e., 1.9%, 3.6%, and 3.3%, between SGLI and MODIS-A, were found for the equivalent AHI bands at 471, 510, and 639 nm. Similar results were obtained between SGLI and MODIS-T, with the differences of 1.7%, 4.5%, and 3.0%, respectively.

-These cross-calibration differences are above the estimated uncertainties except for SGLI/MODIS-T coefficients at 639 nm, affirming that significant differences exist between SGLI and MODIS-A and -T TOA signals, especially in the blue-green spectral range.

-This does not necessarily mean than water reflectance retrievals are less accurate with SGLI, because SVC was performed differently.

Conclusions (cont.)

-One expects that the population variance will be closer to the actual one with an increased number of days, and the uncertainty reduced with an increased number of coincidences.

-Methodology is generic and generally applicable to optical sensors in polar orbit.

-Methodology has great potential in view of new GEO sensors, particularly GLIMR, which has improved performance and hyper-spectral ocean-color bands, allowing a more accurate and complete cross-calibration of ocean-color sensors in polar orbit (e.g., PACE OCI and VIIRS series).