CLARREO Reference Intercalibration on Orbit for Reflected Solar Observation

C. Lukashin, C. Roithmayr, P. Speth, B. Wielicki, C. Currey, D. Doelling

NASA LaRC, Hampton, VA

K. Thome, X. Xiong, A. Wu, J. Butler

NASA GSFC, Greenbelt, MD

W. Sun, Z. Jin, D. Goldin

SSAI, Hampton, VA

A. Bartle, T. Thompson

Mechdyne, VA Beach, VA

J. Gallagher

OPeNDAP, Butte, MT

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Presentations:

1) CLARREO Inter-Calibration in Reflected Solar: Status Update and Framework for Sensitivity to Polarization (C. Lukashin)

2) Modeling Polarized Solar Radiation for CLARREO Inter-calibration Applications: Validation with PARASOL Measurements (W. Sun)

3) PARASOL Observations and Empirical Polarization Distribution models (D. Goldin)

4) The Multi-Instrument Inter-Calibration (MIIC) Framework: update (C. Currey)

CLARREO Inter-calibration in Reflected Solar

1) **Objective:** Enabling Climate Benchmark using CLARREO for reference inter-calibration of existing operational sensors.

2) CLARREO Reference Inter-calibration will provide data to determine and correct operational sensors for:
   - Instrument effective offset and gain.
   - Spectral response change on orbit.
   - Sensitivity to Polarization.
   - Non-linearity.

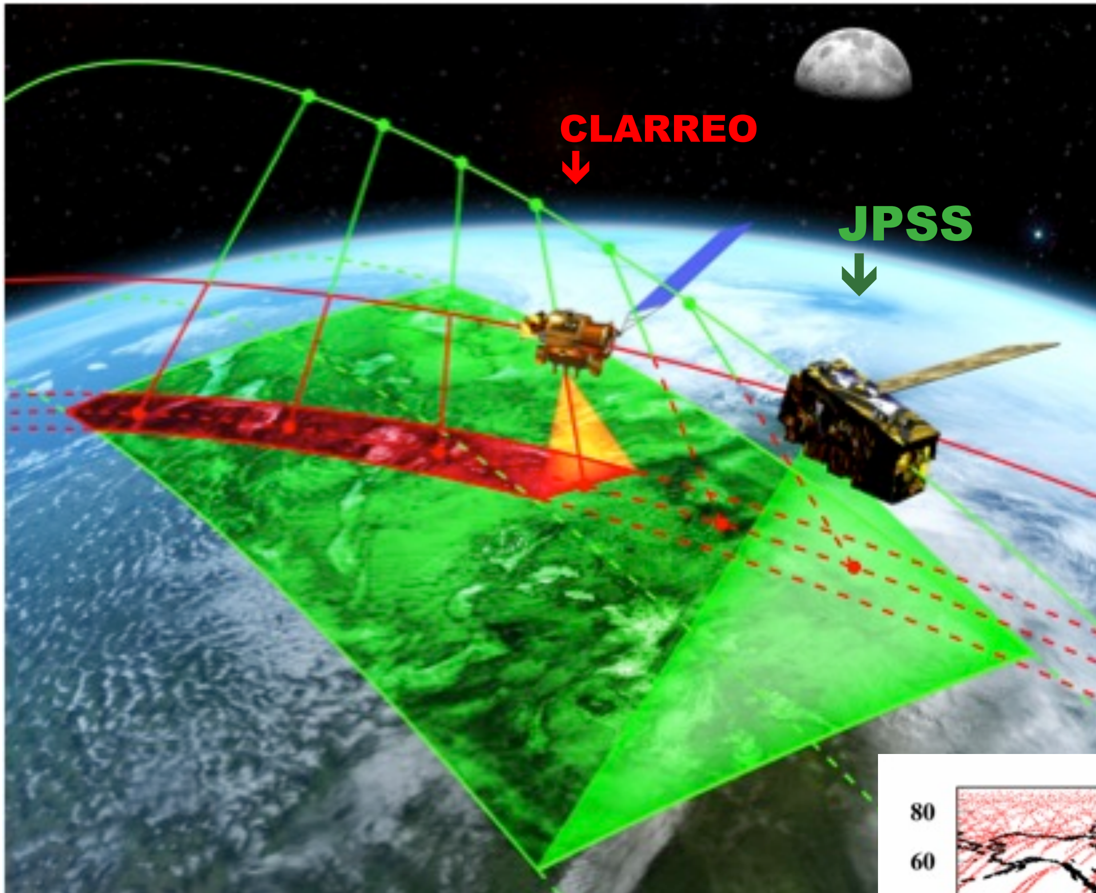
3) CLARREO RSS inter-calibration goal: uncertainty contribution ≤ 0.15% (k=1) over autocorrelation time period ≤ 0.8 year (type-A uncertainty).

   Limit contribution of Type-B uncertainty, e.g. from spectral convolution – (narrowband imagers), and in CERES/RBI broadband.

4) Inter-calibration targets:

   - On-orbit sensors: CERES, RBI & VIIRS/JPSS, AVHRR/Metop, GEO Imagers, Landsats.
   - Surface: Dome C, Desert sites (GSICS list of surface sites).

CLARREO RS Instrument On-Orbit Pointing Operations



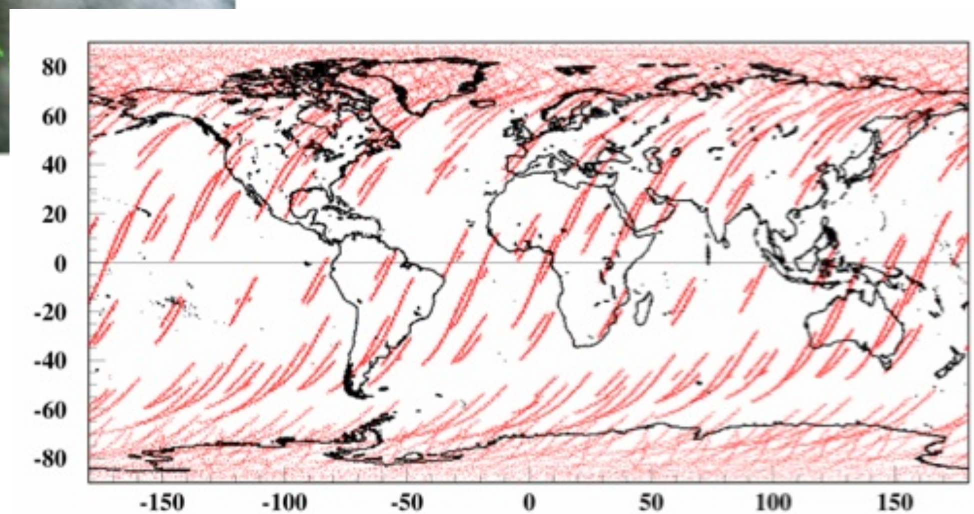
Matching requirements:

- Within +/- 5 min of the JPSS passing;
- VZA match within 1.4°;
- RAZ match within 0.5°;
- SZA < 75°;
- At least 10 km effective width of swath.

Inter-calibration sampling studies:

- CLARREO in polar 90° inclination orbit.
- The ISS orbit.
- Sampling for both, LEO and GEO targets

Figure: CLARREO RSS boresight locations, which matched JPSS cross-track data over one year time period. CLARREO in P90 orbit.



- **2-D pointing on-orbit is required.**
- **Time/space/angle matching to obtain ensemble of samples with data matching noise limited to 1% (k=1)** *(Wielicki et al., IGARS 2008)*

Publications on CLARREO Inter-calibration in the RS:

Wielicki & CLARREO SDT, "Achieving Climate Change Absolute Accuracy in Orbit", BAMS, 2013

C.M. Roithmayr, and P.W. Speth, Chap. 13, "Analysis of Opportunities for Intercalibration between Two Spacecraft", Advances in Engineering Research, Vol. 1, edited by V. M. Petrova, Nova Science Publishers, Hauppauge, NY, 2012, pp. 409 - 436.

C. Lukashin, B.A. Wielicki, D.F. Young, K. Thome, Z. Jin, and W. Sun, "Uncertainty Estimates for Imager Reference Inter-Calibration With CLARREO Reflected Solar Spectrometer", IEEE TGRS, Special Issue on Instrument Inter-calibration, DOI: 10.1109/TGRS.2012.2233480, pp. 1452 – 1436, 2013.

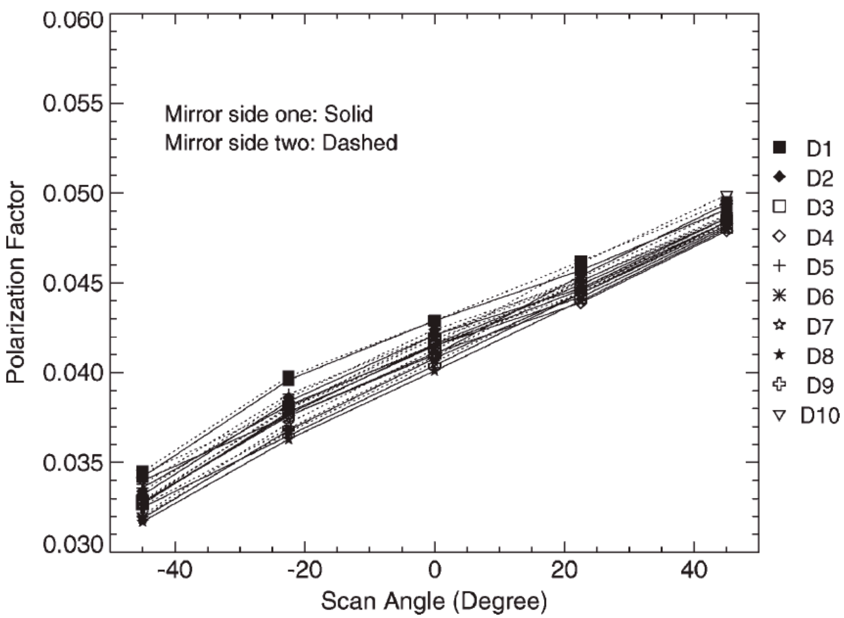
Wenbo Sun and C. Lukashin, "Modeling polarized solar radiation from ocean-atmosphere system for CLARREO inter-calibration applications", Atmos. Chem. Phys., 2013.

C.M. Roithmayr, C. Lukashin, P.W. Speth, K. Thome, B.A. Wielicki, D.F. Young, "CLARREO Approach for On-Orbit Reference Inter-Calibration of Reflected Solar Radiance Sensors", submitted to IEEE Tran. Geo. Rem. Sensing, February, 2013.

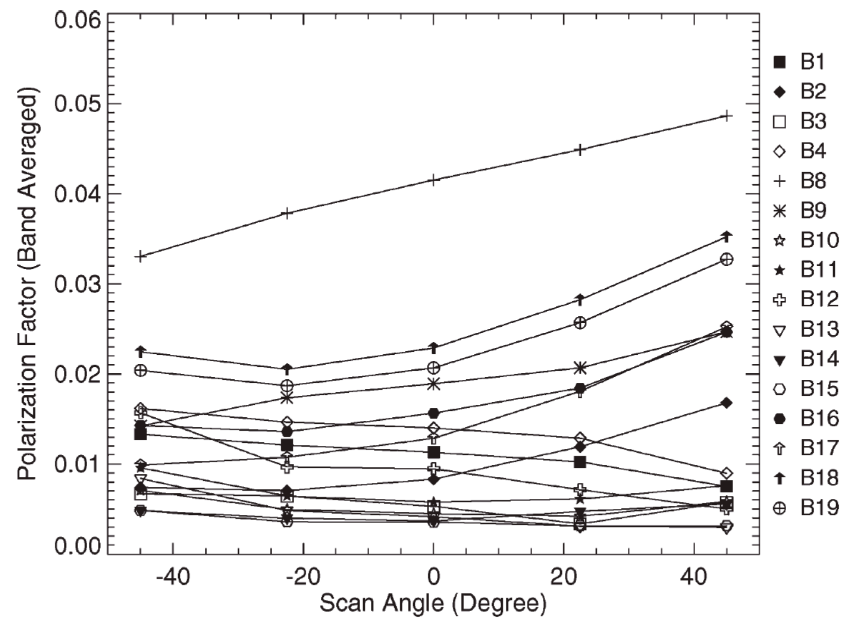
C.M. Roithmayr, C. Lukashin, P.W. Speth, K. Thome, D.F. Young, B.A. Wielicki, "Opportunities to Intercalibrate Radiometric Sensors from International Space Station", submitted to JTECH, July, 2013.

A. Wu, X. Xiong, Z. Jin, C. Lukashin, B. Wenny, J. Butler, "Sensitivity of Intercalibration Uncertainty on the CLARREO Reflected Solar Spectrometer Features", submitted to IEEE , Tran. Geo. Rem. Sensing, January 2014.

CLARREO RSS Approach to Account for Imager Sensitivity to Polarization on Orbit



(a) Polarization factors for Aqua band 8.



(b) Detector-averaged polarization factors for Aqua.

Sun and Xiong: "MODIS Polarization-Sensitivity Analysis", IEEE Trans. on Geo. and Rem. Sensing, v. 45, n. 9, 2007.

Objective: **Take into account MODIS/Terra/Aqua & VIIRS/JPSS sensitivity to polarization in orbit by providing Polarization information on as function of viewing geometry and scene type.**

Impact: **Accuracy of Level-1B data, Ocean Color , Vegetation and Aerosol data products.**

Imager Calibration Model (MODIS as an example)

MODIS calibration model, reflectance factor *(Xiong et al., 2003, 2006)*

$$\rho_{EV} cos\left(\theta_{EV}\right) = m_1 dn_{EV} d_{ES}^2 \left(1 + k_{inst} \Delta T\right) / RVS_{EV}$$

θ_{EV} - **solar zenith angle**
m_1 - **factor from solar calibration (SD and SD Monitor)**
dn_{EV} - **detector response to earth radiance**
d_{ES} - **sun-to-earth distance**
k_{inst} - **temperature correction coefficient**
ΔT - **temperature difference from reference value**
RVS_{EV} - **response versus scan angle**

Simplified RI Imager calibration model with polarization factor in:

$$\rho^{sensor} = \frac{\rho_0}{(1 + mP)}$$

Consistent with Sun and Xiong 2007.

m - **sensitivity to polarization, it is function of** θ **and** χ
$\rho_0 = \rho_{EV}$ **(not-polarized reflectance)**

CLARREO RSS RI: Polarization Parameters

Degree of linear polarization (*P* or DOP):

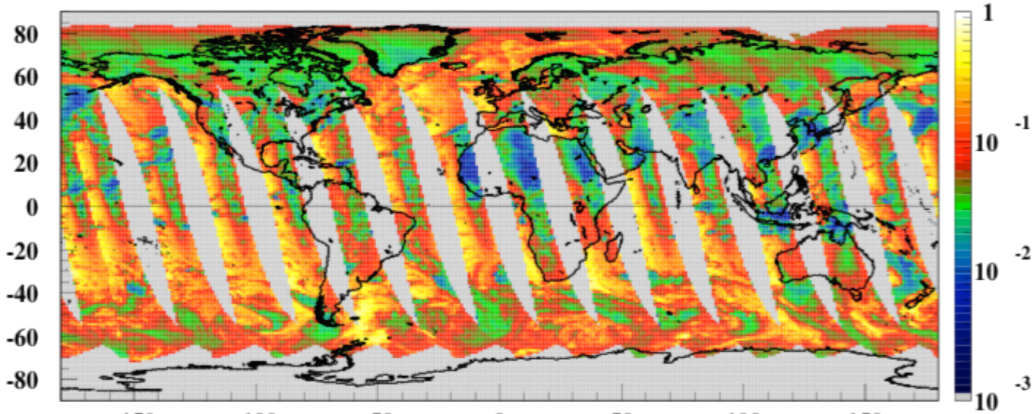
$$P = \frac{L_p}{L} = \frac{\sqrt{Q^2 + U^2}}{L} = \frac{\rho_p}{\rho} \,.$$

Polarization angle, defined relative to viewing plane (PARASOL definition, range from -45° to 135°):

$$\chi = \begin{cases} tan^{-1}\left(U/Q\right)/2 & \\ tan^{-1}\left(U/Q\right)/2 + \pi/2 & \text{if } Q < 0. \end{cases}$$

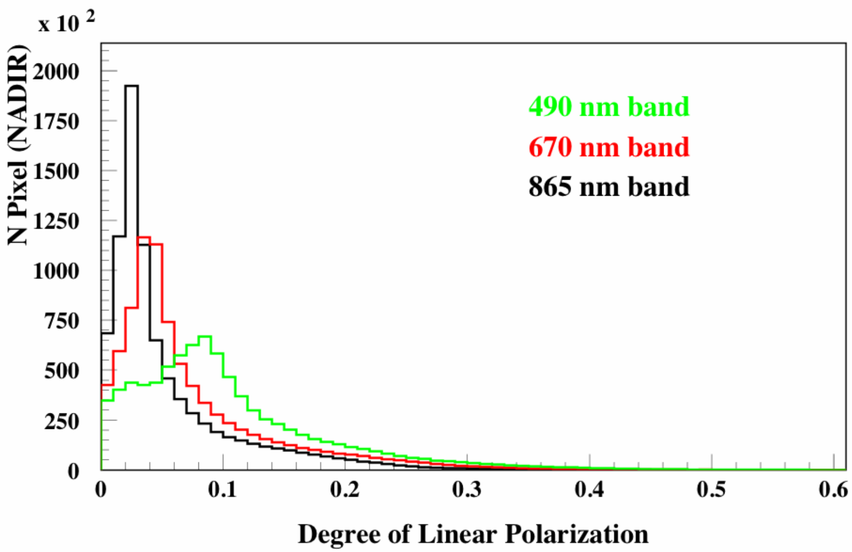
Note: **The χ should be 90° for scattering in principle plane**

Polarization Data from PARASOL (2006.04.01)



a) 2006.04.01: Degree of polarization at λ = 670 nm

a) PARASOL data:
Simulated cross-track sampling,
1° × 1° lon/lat grid,
670 nm wavelength.



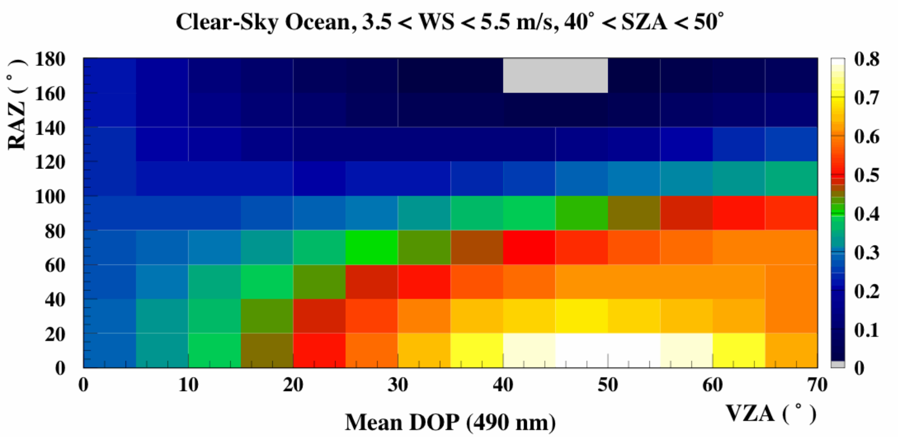
b) PARASOL data:
DOP frequency distribution

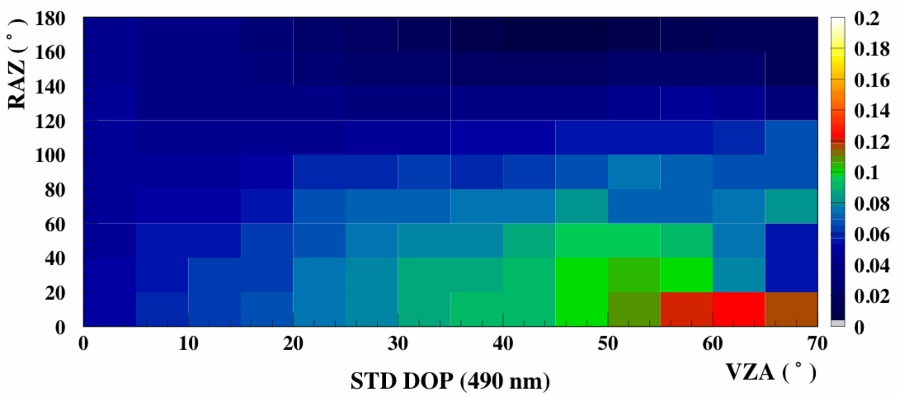
See presentation by Daniel Goldin for more details on the PARASOL data.

Polarization Distribution Models

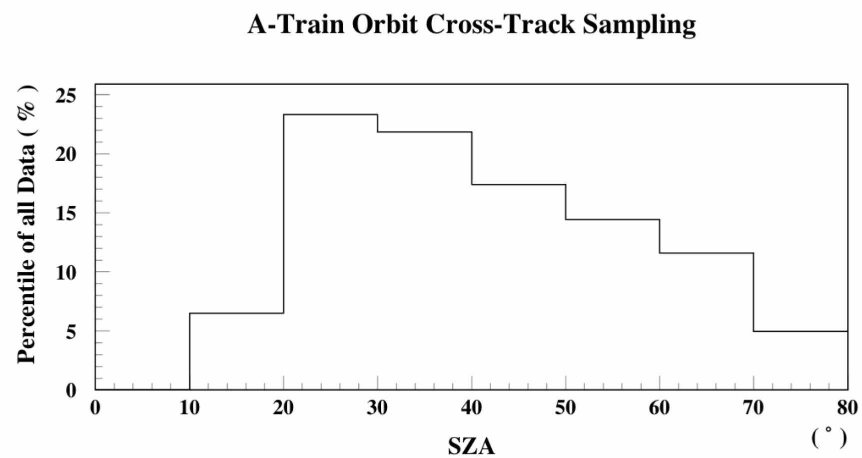
Potentially high DOP: clear-sky ocean

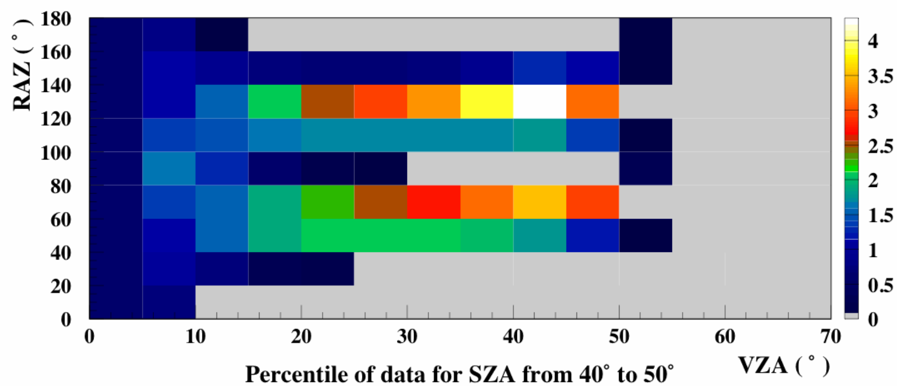
Prototype PDM and its STD, PARASOL Data (12 days of 2006, 1 per month):





A-Train Orbit Cross-Track Sampling (PARASOL 12 days of 2006):

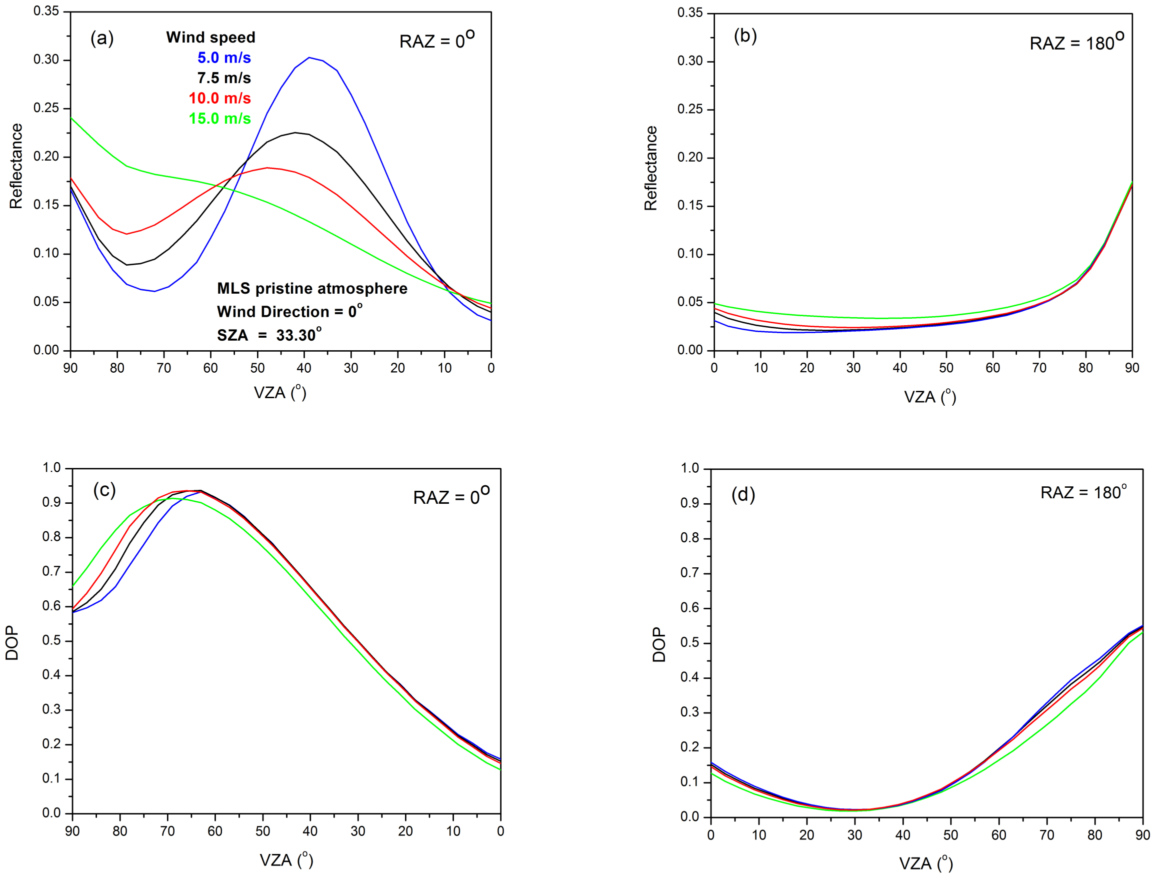




See presentation by Daniel Goldin for more details on the empirical PDMs.

Theoretical PDMs (example of clear-sky ocean)

Calculations by Wenbo Sun



The total reflectance and DOP at the principal plane calculated with the ADRTM at a wavelength of 670 nm. Pristine clear atmosphere with the mid-latitude summer atmospheric profile is assumed. The solar zenith angle is 33.3°. Wind direction is at 0°. Wind speeds are 5.0 m/s, 7.5 m/s, 10.0 m/s, and 15.0 m/s, respectively.

See presentation by Wenbo Sun for details on polarization modeling

CLARREO RSS / Imager Inter-Calibration Formalism

Constraints for CLARREO/Imager RI samples on orbit:

$$\begin{cases} \rho^{clarreo} = \rho_0 & \text{if } P = 0 \\ \rho^{clarreo} = \rho_0/(1+mP) & \text{if } P > 0. \end{cases}$$

CLARREO/Imager reflectance difference (scalar and linear terms):

$$\begin{cases} \rho_0 - \rho^{clarreo} = A_0 + G_0\rho^{clarreo} & \text{if } P = 0. \\ \rho^{sensor} - \rho^{clarreo} = A_p + G_p\rho^{clarreo} & \text{if } P > 0. \end{cases}$$

A_0 and G_0 - for samples with not polarized reflectance
A_p and G_p - for samples with polarized reflectance

Let us call *A's* and *G's* reference inter-calibration offset and gain…

CLARREO RSS Inter-Calibration: Imager Sensitivity to Polarization

$$G_p - G_0 = mP$$

RI gain difference for non-polarized and polarized reflectance is attributed to sensitivity to polarization

$$m = \frac{(G_p - G_0)}{P} = \frac{\Delta G}{P}$$

Imager sensitivity to polarization on orbit

$$\frac{\sigma_m}{m} = \sqrt{\left(\frac{\sigma_{\Delta g}}{\Delta G}\right)^2 + \left(\frac{\sigma_p}{P}\right)^2}$$

Relative uncertainty of sensitivity to polarization on orbit

$$\frac{\sigma_{\Delta g}}{\Delta G} = \frac{\sqrt{\sigma_{g_0}^2 + \sigma_{g_p}^2}}{\Delta G}$$

- **First term is relative uncertainty of RI gain difference (RI sampling).**
- **Second term is relative uncertainty of the PDMs.**

CLARREO/Imager Inter-Calibration: Resulting Radiometric Uncertainty

For fixed θ and χ values, assuming no correlation, reflectance variance:

$$\left(\sigma^{sensor}\right)^2 = \left(1 + mP\right)^2 \sigma_0^2 + \left(m\rho_0\right)^2 \sigma_p^2 + \left(P\rho_0\right)^2 \sigma_m^2$$

Then, relative radiometric uncertainty:

$$\frac{\sigma^{sensor}}{\rho^{sensor}} = \sqrt{\left(\frac{\sigma_0}{\rho_0}\right)^2 + \frac{P^2\sigma_m^2 + m^2\sigma_p^2}{\left(1 + mP\right)^2}}$$

First term is uncertainty for non polarized reflectance. Second term is from polarization effects.

$$\frac{\sigma_0}{\rho_0} = \sqrt{\left(\frac{\sigma^{clarreo}}{\rho_0}\right)^2 + \left(\frac{\sigma_{intercal}}{\rho_0}\right)^2 + \left(\frac{\sigma^{sensor}}{\rho_0}\right)^2}$$

- The first term is combined accuracy of CLARREO, RI random error, and remaining Imager uncertainty (e.g. month-to-month stability).
- Spectral aliasing is not included.

Numerical Estimates of Inter-Calibrated Imager Uncertainty:

Single measurement of *m* on orbit

Inputs for calculation:

m = 3% (k=1)
σ_{pdm} = 5%, 10%, 15% (k=1) ← Uncertainty in Polarization (PDM)
σ_{g0} = 0.10% (k=1)
σ_{gp} = 0.15% (k=1)
$\sigma_{clarreo}$ = 0.15% (k=1)
$\sigma_{residue}$ = 0.10% (k=1)