CLARREO/Solar HSI: Requirement on Sensitivity to Polarization

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Presentation Outline

- Definition, CLARREO goal & approach.
- PARASOL polarization data.
- CLARREO sensitivity to polarization.
- Polarization Distribution Models (PDM).
- CLARREO Solar mission requirements.
Sensitivity to Polarization (1)

Definition:
Due to molecular structure of the material and geometry of instrument design fraction of EM energy absorbed in optics can depend on polarization of light: DOP and angle of polarization.

DOP and angle of polarization as functions of Stokes parameters:

\[ I_p^2 = Q^2 + U^2 \ (V^2 \ is \ small) \ ]; \quad DOP = \frac{I_p}{I} \ ; \quad \chi = \arctan\left(\frac{U}{Q}\right) / 2

where \( I_p \) = polarized radiance; \( DOP \) = Degree of Linear Polarization; \( \chi \) = angle of polarization (phase angle)

Sensitivity to polarization of instrument optics translates into dependence of its effective gain on DOP and viewing geometry of instrument (MODIS Characterization, Sun and Xiong, 2007)

CLARREO goal:
To inter-calibrate instrument gain for various polarization states with required accuracy = 0.3\%(2\sigma) on annual time scale.
Sensitivity to Polarization (2)

How to account for sensitivity to polarization?

1) GOME-1, SCIAMACHY, GOME-2 (a few per cent):
   - Ground: Characterization of instrument response function to polarization.
   - In space: Using polarization information from on board polarimeter to derive radiometric corrections.

2) CERES:
   - Ground: Instrument design with no sensitivity to polarization.

CLARREO: Requirement for minimum sensitivity to polarization that meets CLARREO radiometric error budget (approach No. 2).

CLARREO Sensitivity to Polarization Inter-Calibration Approach:

A) Gain correction from comparison of CLARREO high absolute accuracy radiances for samples matched within defined state of polarization and viewing geometry. CLARREO = SI-traceable calibration source in orbit.

B) State of polarization is obtained by applying Polarization Distribution Models (PDM).
PARASOL Data & Scene ID

- PARASOL, A-train, SSP 1:30 pm orbit, 705 km altitude, wide FOV camera.
- Level-1 data product: normalized radiances (9 bands) and Stokes parameters ($Q$ and $U$ in 3 bands). One day per month for year of 2006.
- Pixel size is about 6×6 km at nadir, up to 15 views per pixel.
- Global coverage in about 2 days, 1600 km swath cross-track.
- Absolute accuracy 2 – 3% (Riedi et al., EarthCare Meeting, 2007).
- Scene parameters: corresponding PARASOL Level-2 Clouds data product.

<table>
<thead>
<tr>
<th>Band</th>
<th>Central Wavelength (nm)</th>
<th>Bandwidth FWHM (nm)</th>
<th>Stokes Parameters</th>
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<td>443</td>
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<tr>
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<td>16.5</td>
<td>$I$, $Q$, $U$</td>
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<td>9</td>
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</table>
Distribution of DOP, PARASOL Data, 2006.10.02
Average on 1°×1° grid, fractional units
“cross-track” mode

- $\lambda = 490$ nm
- $\lambda = 670$ nm
- $\lambda = 865$ nm
A. CLARREO Accuracy (1):

CLARREO requirement for sensitivity to polarization

◆ CLARREO sensitivity to polarization requirement is imposed by accuracy goal: $0.3\%(2\sigma)$ (B. Wielicki, P. Pilewskie)

**Requirement:** CLARREO/Solar sensitivity to polarization should be $\leq 50\%$ contribution to the total error budget, $0.15\%(2\sigma)$.

◆ **Study:** simulation of CLARREO annual zonal error due to sensitivity to polarization in visible wavelength range:

- PARASOL data (12 days, 1 per month, 2006) in simulated cross-track data collecting mode (A-train orbit, CERES, MODIS, VIIRS - similar).

- Bands at 490 nm, 670 nm, 865 nm wavelength.

- Zonal width in latitude = 10°.

- Instantaneous uncertainty due to polarization = $S_{\text{CLARREO}} \times \text{DOP} (%)$.

- Uncertainty propagated into zonal means, representative annual sampling for cross-track operating mode.
A. CLARREO Accuracy (2):
Zonal relative errors, CLARREO sensitivity = 0.25% (2σ)

All-Sky Case:
A. CLARREO Accuracy (3):
Zonal relative errors, CLARREO sensitivity = 0.5% (2σ)

All-Sky Case:
A. CLARREO Accuracy (4):
Zonal relative errors, CLARREO sensitivity = 1.0\%(2\sigma)

All-Sky Case:
A. CLARREO Accuracy (5):
Zonal relative errors, CLARREO sensitivity = 0.5%(2σ)

All-Sky Case:

Clear-Sky Case:

**Requirements:**
- CLARREO sensitivity to polarization in VIS \( \leq 0.5\%(2\sigma) \).
- CLARREO sensitivity to polarization in NIR should be verified with RT, possible limit to sensitivity to DOP \( \leq 1.0\%(2\sigma) \).
B. Polarization Distribution Models (1)

- **Empirical Anisotropy Distribution Models (ADM) for ERBE/CERES:**
  - **ADM Purpose:** Inversion of broadband radiance measurements to TOA flux for ERBE and CERES instruments.
  - **ADM Development:** ADMs are empirical functions of physical parameters and geometry of viewed scene. Most recent models are built using 2 years of CERES/MODIS/Terra/Aqua observations.
  - **ADM Uncertainty:** Instantaneous errors in CERES TOA flux due to ADM uncertainty are 10 - 15 Wm\(^{-2}\), 4 - 6% relative to 250 Wm\(^{-2}\) mean (20 km FOV at nadir). Bias of SW TOA flux monthly means < 1%.

- **Empirical Polarization Distribution Models (PDM):**
  - **PDM Purpose:** To provide polarization information as function of physical parameters and geometry of viewed scene for both - CLARREO and inter-calibrated sensor (on NPP, NPOESS).
  - **PDM Development:** PARASOL data, RT calculations and APS data (validation). Amount of data required = at least 1 year.
  - **PDM Uncertainty:** PDM should provide adequate knowledge of polarization state for viewed scene to enable CLARREO to reduce radiometric uncertainty of inter-calibrated sensor to 0.3%(2\(\sigma\)).
B. Polarization Distribution Models (2)

Viewing Geometry Definitions: the same as for CERES ADMs

Note: PARASOL definition for relative solar azimuth is $180^\circ - \phi$
B. Polarization Distribution Models (3)

Example: 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):
B. Polarization Distribution Models (4)
Example: ice clouds over ocean (overcast)

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):
B. Polarization Distribution Models (5)

Example: water clouds over ocean (overcast)

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):
B. Polarization Distribution Models (6)
PDM comparison with RT calculations: clear-sky ocean

Prototype PDM, PARASOL data (12 days of 2006, 1 per month):
Clear-Sky Ocean, WS 5.5 – 7.5 m/s

RT calculation (Zhonghai Jin):
Clear-Sky Ocean, WS = 6 m/s

* Look into disagreement:
More PARASOL data and averaging of RT calculations.
Approach for PDM Development:

- Reduce uncertainty of PDM by increasing statistics, reducing angular bin width and refining scene type definition (using at least 1 year of PARASOL data).

- Use Artificial Neural Network (ANN) algorithms to create PDMs as continuous functions in VZA and RAZ. *(Loukachine and Loeb, 2004)*


- Validate PDM uncertainty using APS data and RT models.

- Develop RT calculation database to retrieve spectral polarization parameters from PDMs at 490, 670, and 865 nm (PARASOL bands). *(Schutgens and Stammes, 2003)*

- Look into PDM development for polarization phase angle $\chi$.

**Note:** PDM availability allows MODIS/VIIRS team to use instrument ground characterization in orbit right away.
Sensitivity to Polarization:
CLARREO/Solar HSI Requirements

1) **Critical:** CLARREO/Solar observation sensitivity to polarization must be $\leq 0.5\%(2\sigma)$ in VIS wavelength range.
   - For discussion: Can it change in orbit? Yes. Validation in orbit with lunar calibration (NIST)? Polarized filters (G. Kopp)?
   - **Study:** Sensitivity to polarization requirement in NIR.

2) **Critical:** CLARREO/Solar pointing ability to provide inter-calibration sampling in angular phase space.

3) **Critical:** Development of empirical PDM as functions of physical properties and geometry of viewed scene. PDMs should be seasonal. Adequate data from polarization measurements, 1 year at least of PARASOL data. Validation with APS data and RT models.

4) **Critical:** A database of RT-based calculations to retrieve spectral dependence of polarization parameters.