OUTLINE

• Motivation: Why use PARASOL data for CLARREO
• Previous results
• Overview of PARASOL/POLDER-3 instrument
• Overview of Level-1 and Level-2 Products
• Software tools used

Results
• Data description and global cuts
• Cloud Fraction vs Degree of Polarization (DOP) parametrization
• Preliminary PDM distributions
• DOP vs optical depth

Plans
MOTIVATION AND GOALS

**Motivation:**
- Knowledge of polarization necessary for intercalibration between CLARREO and narrowband imagers
  - 0.3% (k=2) contribution from intercalibration uncertainty
- Radiometric measurements need to be corrected for polarization effects to achieve climate accuracy

**Goals:**
- Construct **Polarization Distribution Model (PDM)** as a function of physical parameters and viewed scene type (e.g. surface, clouds)
- Extend the 12-day dataset (next slide) to cover the entire 2006 to improve statistics and PDM uncertainty
- Provide empirical PDMs for Wenbo Sun to compare with **Radiation Transfer Models (RTMs)**
- Merge PARASOL and MODIS Level-2 data

- Used 12 days of 2006 PARASOL data (1 day/month)
- Derived a prototype global set of empirical PDM’s as a function of scene type and viewing geometry using PARASOL data.
- Framework for estimating uncertainty of CLARREO RS intercalibrating imager’s sensitivity to polarization.
PARASOL: OVERVIEW

- Part of A-Train, 705 km altitude
- 274×242 pixel CCD detector array, wide view optics
- 9 spectral channels from blue (443 nm) to infrared (1020 nm)
  - 3 polarization bands: 490 nm, 670 nm, 865 nm
- Pixel resolution for Level-1B data: 5.3×6.2 km (at nadir)
- Absolute accuracy: 2-3% [Riédi et al., EarthCare Mtg, 2007]
- Up to 14 views per pixel (collected off-line): multi-angular sampling improves PDMs’ precision
- Current status: after ~9 years in orbit PARASOL was shut off on Dec. 18, 2013
PARASOL: LEVEL-1

- Date and time of the first and last image acquisition
- Geolocation data
- Data quality flags
- Solar zenith angle (SZA)
- Viewing zenith angle (VZA)
- Relative azimuth (RAZ)
- Normalized radiances (I) (all bands)
- Stokes vector components (Q,U) for polarized channels (490, 670 and 865 nm)

Loop over views (max=14)
### PARASOL: LEVEL 2

#### RADIATION BUDGET (RB)
- Surface type indicator
- Cloud fraction
- Cloud pressure
- Cloud optical depth
- Cloud spherical albedo
- Cloud phase
- Water vapor column

#### OCEAN (OC)
- Solar geometry (SZA, RAZ)
- Aerosol Angstrom coefficient (model)
- Pixel confidence data
- Aerosol optical depth (670, 865 nm)
- Optical thickness for different aerosol types (fine/coarse, spherical/non-spherical)
- Refractive index for fine/coarse aerosols
- Backscattering coefficient

#### LAND SURFACE (LS)
- Solar geometry (SZA, RAZ)
- Aerosol optical depth (865 nm)
- Real part of index of refraction (model)
- Angstrom coefficient (model)
- Aerosol index
OWN CODE STRUCTURE

- Code in C++
- We have implemented PARASOL binary file readers for Level-1 and Level-2 data (Level-1: Kam-Pui Lee)
- Ability to read several processing lines at once
- Input: PARASOL binary Level-1 and Level-2 data and IGBP map
- Output: ASCII (for now) table to compare PDMs with Wenbo Sun’s RTM, and/or ROOT histogram files and/or ntuples
  - In the future plan to move to another PDM, possibly NetCDF
SELECTION CUTS FOR PRELIMINARY PDM’S

- Cloud Fraction (CF)
  - Clear sky: CF < 1%
- Cloud phase (CPh) (PARASOL’s definition):
  - Clear sky: CPh = 240
- Wind speed < 2.5 m/s
- $40^\circ < \text{SZA} < 50^\circ$
- Binning in VZA: $2.5^\circ$, binning in RAZ: $10^\circ$
- Focus on Degree of Polarization:

$$DOP = \frac{\rho_p}{\rho}$$

Polarized radiance
Total reflectance
DEGREE OF POLARIZATION (DOP)

Preliminary Results

DOP Distributions for 3 Ocean Scenes

Differences need to be understood
CLOUD FRACTION VS DOP

• Can parametrize cloud fraction vs DOP. This allows one to find cloud fraction for arbitrary DOP

• Polynomial parametrization yields good fit: $p_0x + p_1 + p_2x + p_3x^2 + p_4x^4$

• Fits were done without regard to cloud type. In the future, cloud types (ice, water) will be incorporated into PDM parametrizations
CLOUD FRACTION VS DOP

**Evergreen Needleleaf Forest (01/2006)**

- IGBP = 1
- \( p_0 = 0.2017 \)
- \( p_1 = 0.0003076 \)
- \( p_2 = -0.1498 \)
- \( p_3 = 0.1696 \)
- \( p_4 = -0.09797 \)

**Grasslands (01/2006)**

- IGBP = 10
- \( p_0 = 0.1551 \)
- \( p_1 = 0.0001374 \)
- \( p_2 = -0.1316 \)
- \( p_3 = 0.1613 \)
- \( p_4 = -0.1051 \)

**Clear Ocean (01/2006)**

- IGBP = 17
- \( p_0 = 0.2441 \)
- \( p_1 = 0.0003784 \)
- \( p_2 = -0.04015 \)
- \( p_3 = -0.09264 \)
- \( p_4 = 0.03287 \)

**Preliminary Results**

- **Cloud Fraction vs DOP Parametrization**
• Looked at all available scene types for 01/2006. DOP biggest for Clear Ocean (DOP up to 1)
• DOP smaller for other common scene types but still needs to be accounted for
• $\tau$ inversely proportional to wavelength. Few differences visible, especially at higher optical depths.
Aerosols clearly affect polarization. Final PDM’s will account for this dependency.
PLANS

• Generate PDMs using entire 2006 data and compare with RTM
  • Final PDMs will include DOP and polarization angle for different scene types
  • PARASOL has only 3 bands (490, 670 and 865 nm). Wenbo will extend PDMs over entire spectrum

• Validate PARASOL retrievals (AERONET and ARM data)

• Publish a paper on the PARASOL-only PDMs + RTM (Edition-1, FY14)

• Merge PARASOL (18x18 km² superpixel) data with MODIS Level-2 Clouds

• Validate PARASOL results against MODIS retrievals

• PDM parameterization using Artificial Neural Network algorithms

• Publish a paper on the PARASOL/MODIS PDMs + RTM (Edition-2, FY15)

• Long-term: Incorporate polarization correction algorithms & PDMs into MIIC framework (C. Currey, next presentation)
DEFINITIONS

\[ \chi = \begin{cases} \frac{1}{2} \arctan \left( \frac{U}{Q} \right) & \text{if } Q > 0 \\ \frac{1}{2} \arctan \left( \frac{U}{Q} \right) + \pi / 2 & \text{if } Q < 0 \end{cases} \]

\[ I_p^2 = Q^2 + U^2 \quad (V^2 \text{ negligible}) \]

\[ DOP = I_p / I = \frac{\rho_p}{\rho} \]

INTERCALIBRATION (EXPRESSED I.T.O. REFLECTANCES)

\[ \begin{aligned} \rho_{0}^{\text{sensor}} - \rho_{0}^{\text{CLARREO}} &= A_0 + G_0 \rho_0^{\text{CLARREO}} \\ \rho_{p}^{\text{sensor}} - \rho_{p}^{\text{CLARREO}} &= A_p + G_p \rho_p^{\text{CLARREO}} \end{aligned} \]

\[ \rho_p^{\text{sensor}} = \frac{\rho_0^{\text{sensor}}}{1 + mP} \]

CLARREO’s benchmark reflectance

January 8, 2014
PROCESSING STEPS AND EXECUTION TIMES

- ROOT output done in several steps for faster processing:
  1. Generate histogram files (1 histo file ↔ 1 day of the month) [“C++-like” ROOT macro]
  2. Merge histogram files into one (1 histo file ↔ 1 month) [short shell script calling ROOT executable]

- Execution times for 1 month of 2006 data on CLARREO SGE cluster at LaRC:
  - Step 1: ~ 30 min
  - Step 3: < 15 sec
COMPUTING GLOBAL FRACTION OF AEROSOLS

- Global Fraction of Aerosols = (# of sampling points with $\tau >$ threshold) / (# of sampling points)

<table>
<thead>
<tr>
<th>$\tau$ thresholds</th>
<th>Aerosol fraction (670 nm)</th>
<th>Aerosol fraction (865 nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.00</td>
<td>1.</td>
<td>1.</td>
</tr>
<tr>
<td>&gt; 0.25</td>
<td>0.0357</td>
<td>0.0276</td>
</tr>
<tr>
<td>&gt; 0.50</td>
<td>0.0043</td>
<td>0.0029</td>
</tr>
<tr>
<td>&gt; 0.75</td>
<td>0.0010</td>
<td>0.0007</td>
</tr>
<tr>
<td>&gt; 1.00</td>
<td>0.0005</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

- Global (sampled) mean $\tau$ for 01/2006:
  - 670 nm: $\tau = 0.083$
  - 865 nm: $\tau = 0.077$

- Global aerosol coverage is only a few %, but needs to be accounted in building PDMs (see Slide 14)