ESTIMATING INTERCALIBRATION UNCERTAINTIES DUE TO POLARIZATION

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OVERVIEW

- Motivation:
  - reflectance measurements need to be corrected for polarization effects
  - uncertainty due to polarization contributes to overall intercalibration uncertainty
- Extending the work done by C. Lukashin et al. [IEEE Trans. Geosci. Remote Sens. V. 51, No.3, 2013]
  - 12 days of PARASOL data for clear and cloudy scenes over water bodies
  - Constructed Polarization Distribution Models (**PDMs**) and estimated uncertainties due to polarization effects. Uncertainties need to be limited to 0.3% over climate autocorrelation time period (0.8 years)
- Current work: Processed entire volume of 2006 PARASOL data
  - Wrote readers (C++) to process Level-1 and Level-2 PARASOL data
  - Created a subset of data (ROOT ntuples) filled only with variables of interest (SZA, VZA, tau, etc.). Now able to process the entire 2006 dataset in ~ 10-30 min on SunGrid
  - Constructed PDMs for clear sky ocean scenes
  - Used PDMs to look at resulting intercalibration accuracy

DEGREE OF POLARIZATION P

_P_ as measured by POLDER/PARASOL

Polarized reflectance — *Polarized radiance*

$$P = \frac{\rho_p}{\rho} = \frac{I_p}{I} = \frac{\sqrt{Q^2 + U^2}}{I}$$

Total reflectance — *Total radiance*

where

Stokes parameters (i.t.o. intensities)

$$I = I_{0^\circ} + I_{90^\circ} \;,$$
$$Q = I_{0^\circ} - I_{90^\circ} \;,$$
$$U = I_{45^\circ} - I_{135^\circ} \;,$$

Calculated _P_ (single scattering approximation)

Single Rayleigh scattering

$$P_{\mathrm{sr}}(M,\Theta) = \frac{1-\cos^2\Theta}{1+\Delta+\cos^2\Theta + \frac{4}{3}\frac{AM}{\Delta'}\left\{\frac{\exp(-M\tau_{\mathrm{s}})}{1-\exp(-M\tau_{\mathrm{s}})}\right\}}.$$

[Tilstra, Schutgens, Stammes 2003]

Lambertian surface component (depolarizing component)

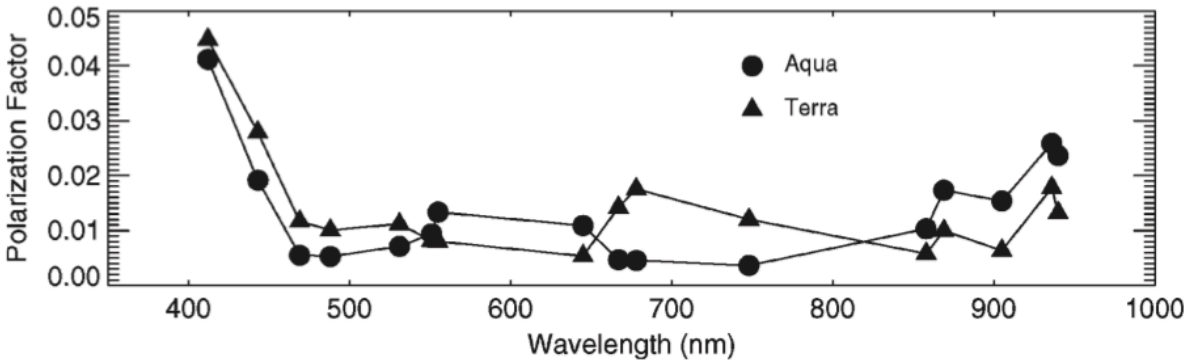
where

Θ = scattering angle: $f(\theta, \phi, \theta_0)$
Δ and Δ'= anisotropy correction factors
A = surface albedo
M = 1/cosθ + 1/cosθ_0 factor related to airmass traversed by photons
τ_s = atmosphere optical depth: $f(\lambda)$

POLARIZATION EXAMPLE: MODIS

Degree of polarization for 15 Terra and Aqua MODIS bands:

[J-Q Sun, X. Xiong, 2007]



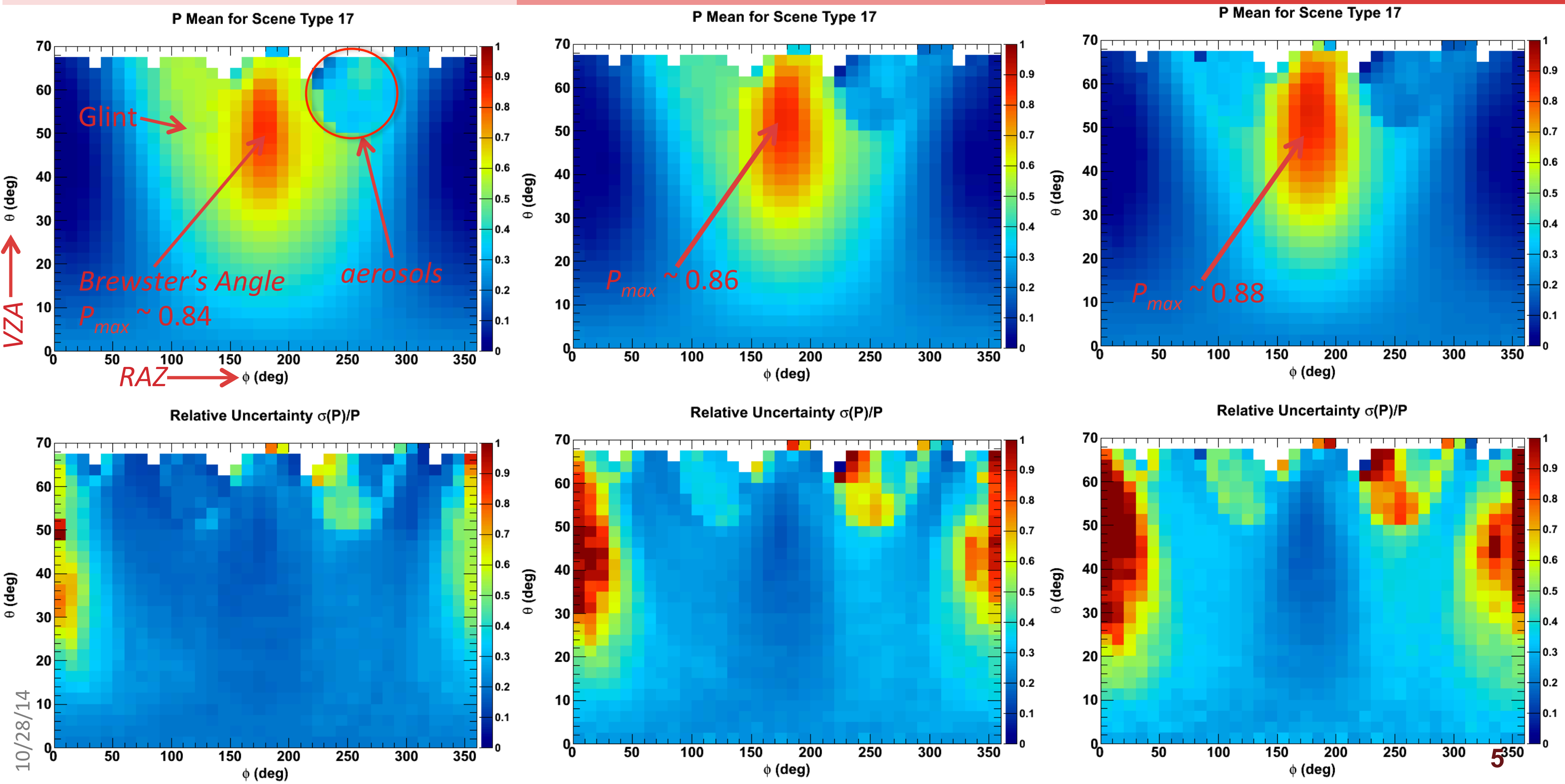
Typical *P* ~ 0.01-0.02. As high at ~0.04 for some bands.

Daniel Goldin

P PDM'S FOR CLEAR SKY OVER OCEAN (IGBP = 17)

Cut	Value
IGBP index	17
θ_s	$40^o < \theta_s < 50^o$
Cloud fraction	< 0.01
Cloud phase	240
Wind speed	< 2.5 m/s

λ = 490 nm	λ = 670 nm	λ = 865 nm



REFLECTANCE AND ITS UNCERTANTY DUE TO STATISTICAL ERROR IN POLARIZATION

target imager calibrated reflectance

target imager uncalibrated reflectance

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

target imager sensitivity to polarization

degree of polarization

[C. Lukashin et al., 2013]
[J.-Q. Sun and X. Xiong, 2007]

Reference intercalibration (RI) relative uncertainty (σ_ρ/ρ_{RI}):

Relative uncertainties:
$\sigma(\rho_0)/\rho_0$, $\sigma(m)/m$, $\sigma(P)/P$

$$\delta_{RI} = \sqrt{\delta_0^2 + \left(\frac{mP}{1 + mP}\right)^2 (\delta_m^2 + \delta_P^2)}$$

(CLARREO accuracy)^2
+ (autocorrelation uncert.)^2
+(target sensor stability uncert.)^2

Fix some variables at reasonable values [C. Lukashin et al, 2013]:

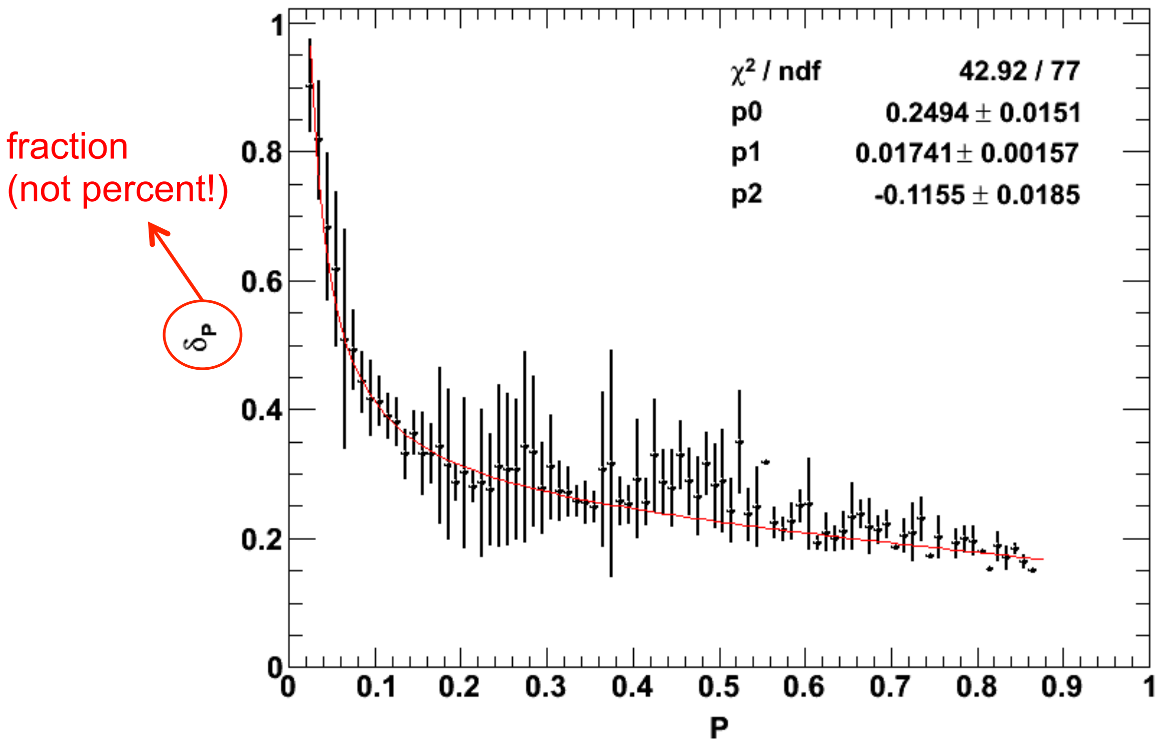
- δ_0 = 0.2%
- 3 values for *m* and δ_m for comparison

Step 1: **Use PDM (previous slide)** to plot δ_P vs *P*. Make a fit to it

Step 2: Use δ_P vs *P* relationship/fit to plot δ_{RI} *vs P*

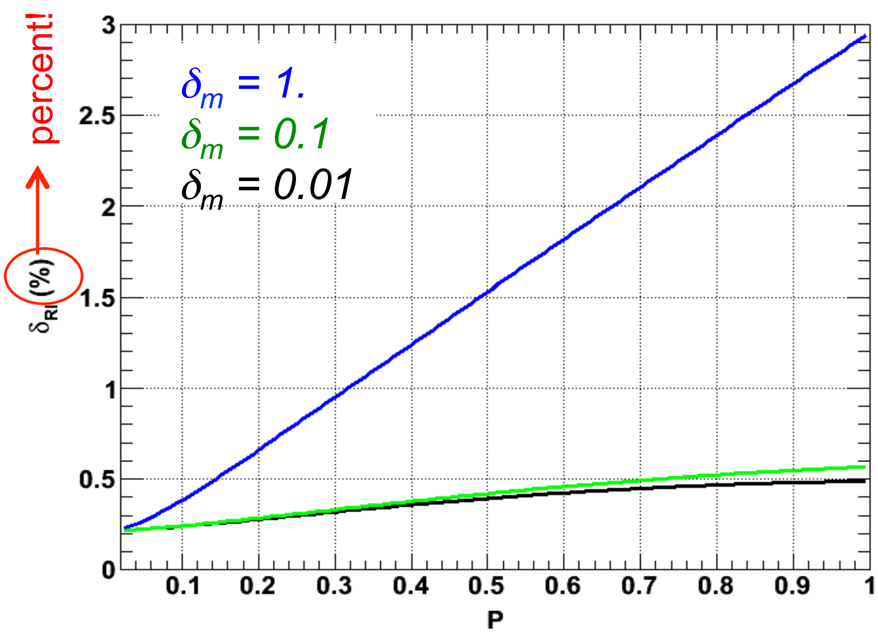
STEP 1: RELATIVE UNCERTAINTY ON POLARIZATION VS P FOR CLEAR-SKY OCEAN

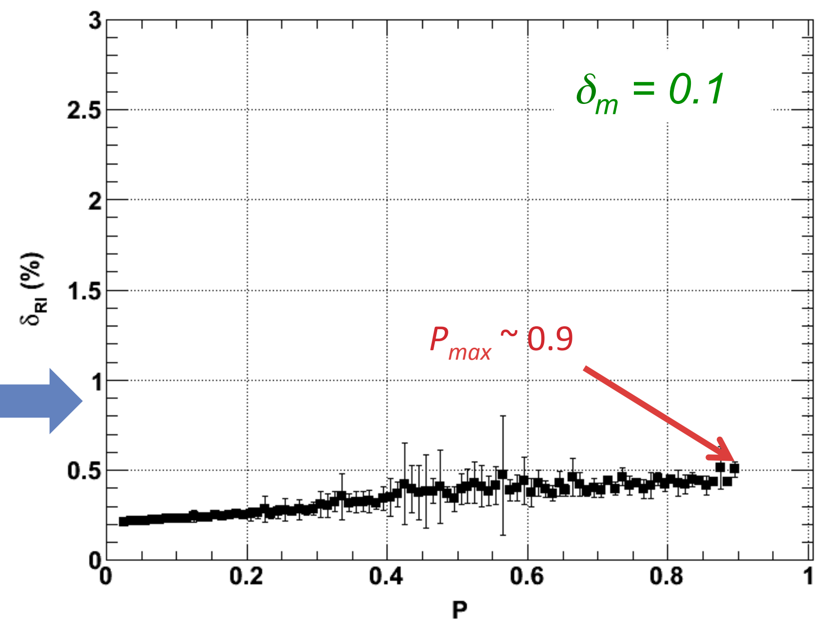
- Pick clear-sky ocean: highest polarization. Use **λ = 490 nm**
- Fit $p_0 + p_1/x + p_2x$ to δ_P *vs P* profile histogram



STEP 2: INTERCALIBRATION UNCERTAINTY VS P FOR CLEAR-SKY OCEAN

- Set imager sensitivity to polarization (*m*) to 0.03 (roughly, MODIS & VIIRS' sensitivity)
- Three different δ_m's = {0.01, 0.1, 1}. Uncertainty of 1. corresponds to the completely undetermined sensitivity to polarization





- *m* = 0.01 and *m* = 0.1 uncertainties virtually indistinguishable
- Error bars show statistical errors on intercal uncertainty

SYSTEMATIC UNCERTAINTY ON THE DEGREE OF POLARIZATION

- Use RAZ reciprocity to estimate the uncertainty on *P*
- Basically RAZ reciprocity means that scattering matrix is invariant under reflections around principal plane (RAZ = 180^o). [Hovenier (1969)]
- For the ideal case, for a fixed VZA and SZA two RAZ bins symmetric around principal plane (**reciprocal bins**) should have the same *P*
- The differences in *P* for reciprocal RAZ bins can be counted as systematic uncertainty of the PDMs
- Nadal and Bréon (1999) have looked at reciprocity to validate the PARASOL reflectance but didn't consider it as a source of systematic error

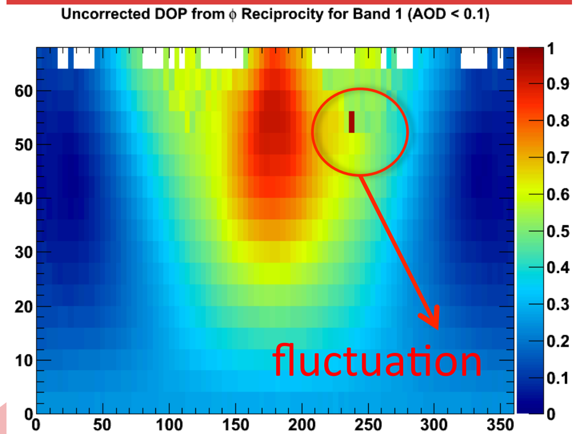
CALCULATING RAZ RECIPROCITY UNCERTAINTY

- Use clear-sky ocean scene with λ = 670 nm
- **PDMs with AOD < 0.1 will be used** to estimate systematic error. Setting the limit higher would admit more aerosols, setting it lower affects the statistics
- Use bins symmetric in RAZ relative to the principal scattering plane. At a given VZA bin, at a RAZ bin number *i* (RAZ_i) and the maximum number of RAZ bins *NBIN* (360^o in our case):
  - corrected DOP mean: $\mathbf{P_{RAZ} = (P(RAZ_{NBIN+1-i}) + P(RAZ_i))/2}$
  - systematic uncertainty: $\mathbf{\sigma_{RAZ} = |P(RAZ_{NBIN+1-i}) - P(RAZ_i)|/2}$

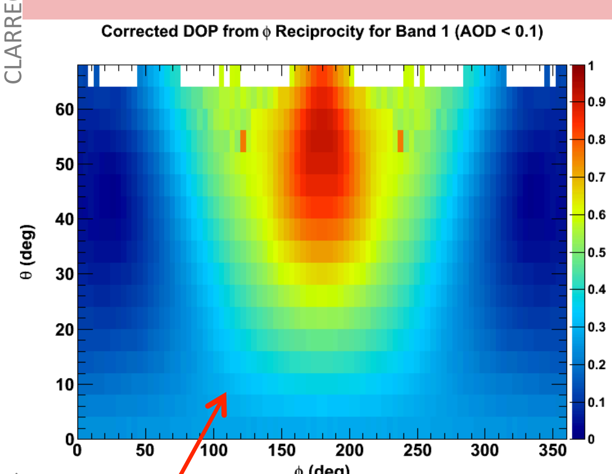
RAZ RECIPROCITY SYSTEMATIC UNCERTAINTY (AOD < 0.1)

Cut	Value
IGBP index	17
θ_s	$40^o < \theta_s < 50^o$
Cloud fraction	< 0.01
Cloud phase	240
Wind speed	< 2.5 m/s
λ	670 nm
AOD	< 0.1

Uncorrected *P*

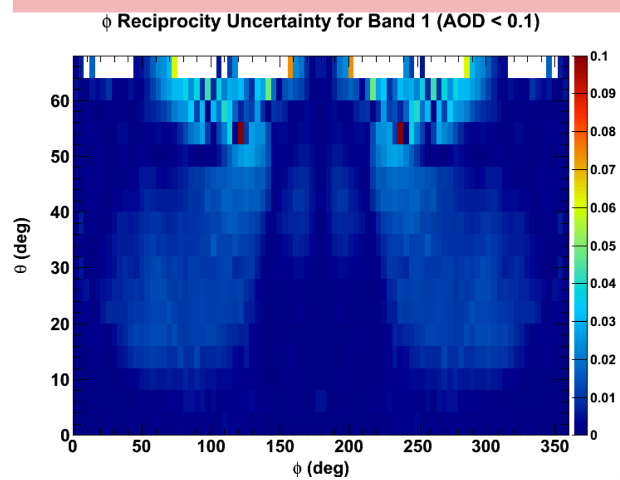


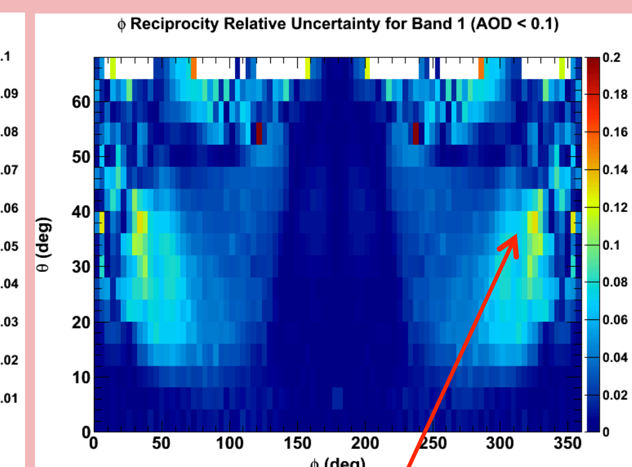
Corrected *P*



symmetric around RAZ = 180°

Systematic Uncertainties: Absolute (Left) and Relative (Right)

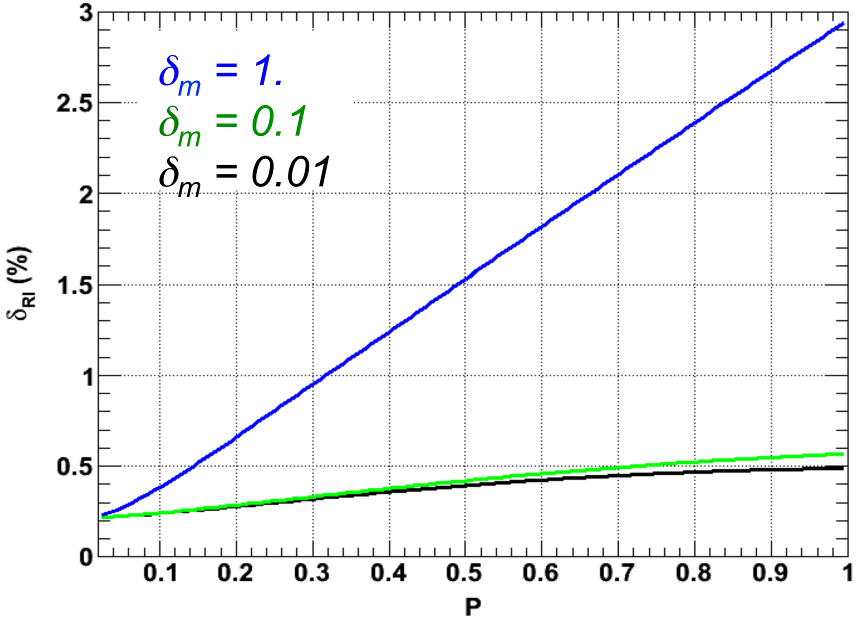




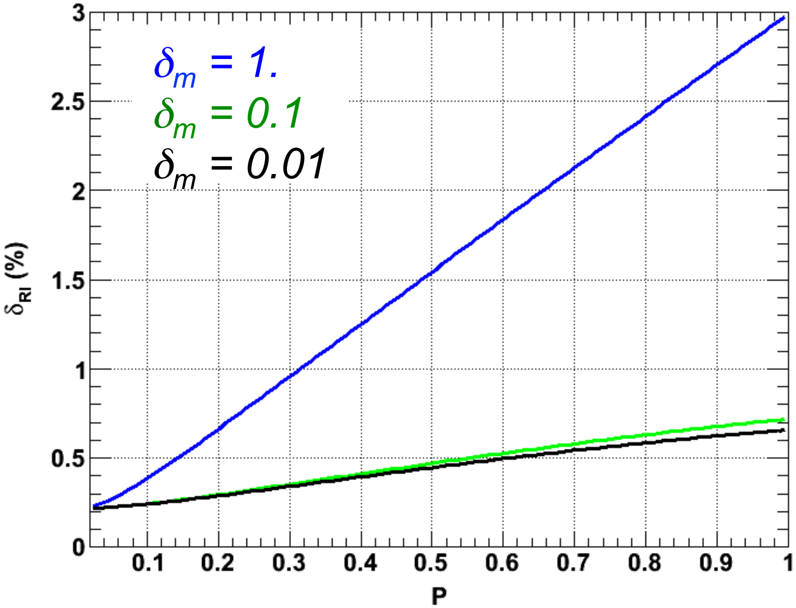
relative error as high as 0.12

COMBING SYSTEMATIC AND STATISTICAL ERROR: RESULTS

Statistical Error only



Combined (stat.+syst.) Error



- Very little difference due to large statistical fluctuations
- Some possible (?) difference at higher P

COMBING SYSTEMATIC AND STATISTICAL ERROR: POSSIBLE APPROACH

- Used clear-sky ocean scene with λ = 670 nm and AOD < 0.1 to estimate RAZ reciprocity systematics
- For AOD < 0.1 and AOD > 0.1 apply systematic correction only for VZA < 50^o (not enough stats for the VZA > 50^o region). Leave the VZA > 50^o region uncorrected
- For AOD < 0.1:
  - use corrected means
  - use combined error: $\sigma_{tot} = \sqrt{\sigma_{syst}^2 + \sigma_{stat}^2}$
- For AOD > 0.1:
  - correct the means using the residuals from the previous slide (AOD < 0.1)
  - use systematic error for AOD < 0.1 and combine with statistical error: $\sigma_{tot} = \sqrt{\sigma_{syst}^2 + \sigma_{stat}^2}$

CONCLUSIONS AND PLANS

- Constructed PDMs for different scene types and quantified statistical and systematic errors due to polarization using PARASOL data
  - Due to low statistics influence of the systematics not very significant, but we'll include in the final product nevertheless
- Where available, the two types of errors will be combined to produce the overall intercalibrated imager reflectance uncertainty due to polarization
- The final PDM product will include:
  - **corrected means and combined uncertainties (stat. + syst.)** for clear-sky ocean for λ **= 670** and **865** nm
  - **uncorrected mean and statistical uncertainty** for clear-sky ocean for λ **= 480** nm
- Plans:
  - Publish clear-sky ocean PDMs and intercalibration studies
  - Develop clear-sky land PDMs

ASSESSING AMAZON CLOUD SUITABILITY FOR CLARREO'S COMPUTATIONAL NEEDS

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MOTIVATION AND CONCERNS

- Cloud suitability study prompted by the expiring (2016) maintenance contract on the LaRC **clarreo** cluster
- Amazon Web Services (AWS), a.k.a. Amazon cloud, pros:
  - Reduced IT and maintenance costs
  - On-demand allocation of computing resources (CPUs, memory, storage)
  - Accessibility for collaborative processing of data
- AWS concerns:
  - Hard-to-predict expenses. AWS costs based on resource utilization and data transfer
  - Latency (slow to open remote GUI-based applications)
  - Need to transfer data into/out of the cloud
  - Need to modify existing code to manage data transfer

PROGRESS

- Used open-source toolkit from MIT called StarCluster (http://web.mit.edu/starcluster) to provision, start and stop nodes on Amazon's Elastic Compute Cloud (EC2)
- Cloud configured with the same number of cores and memory as **clarreo** cluster
- gcc compiler, Sun Grid Engine, ROOT were installed on the cloud cluster
- Processed 1 month (250 GB) and 1 year (3 TB) of 2006 PARASOL data (~90% read/write). Output: ROOT ntuples produced with C++ code
- Evaluated performance of **NFS** shared filesystem and **S3** storage.
- On **clarreo** cluster use **GPFS** filesystems to read/write data

RESULTS AND PLANS

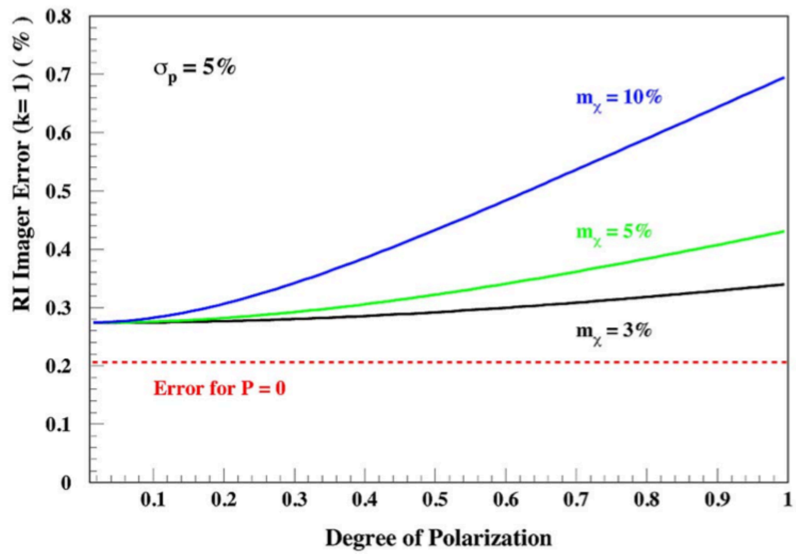
- Results:
  - 1 month and 1 year processing using S3 yields **comparable** performance to that on clarreo. Cloud's NFS performance found to be **inferior** to clarreo GPFS
- Plans:
  - More testing using SCIAMACHY data, PCRTM
  - Publish the results
  - Choices: buying another cluster, cloud only or hybrid?

BACKUP

PREVIOUS INTERCAL UNCERTAINTY ESTIMATES

- σ_P assumed constant

[C. Lukashin et al., 2013]



- Yields conservative estimate (cf. Slide 8)