EMPIRICAL POLARIZATION DISTRIBUTION MODELS: UPDATE

DANIEL GOLDIN (SSAI/NASA-LARC), **CONSTANTINE LUKASHIN** (NASA-LARC), **WENBO SUN** (SSAI/NASA-LARC)

POLARIZATION: RECAP

- Polarization state fully specified by degree of polarization *P*, angle of polarization χ and total intensity *I* (alternatively, may be specified by Stokes parameters *I, Q, U*)

Polarized radiance

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

Total reflectance *Total radiance*

$$\boxed{\chi = \frac{1}{2}\arctan(U/Q).}$$

where

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

- **(Mean) reflectance needs to be corrected for polarization effects:**

$$\boxed{\rho^{sensor} = \frac{\rho_0}{1+mP},}$$

- **Uncertainty due to polarization contributes to uncertainty in reflectance:** *Imager's sensitivity to polarization*

$$\boxed{\delta_{RI} = \sqrt{\delta^2_{\rho_0} + \left(\frac{mP}{1+mP}\right)^2 (\delta^2_m + \delta^2_P)}}$$

CLARREO's own accuracy *Uncertainties in m and P*

- *m* is a function of χ. Sun and Xiong [2007] have shown *cyclical* dependence for MODIS. The exact dependence would be established by CLARREO instrument. For now, this dependence is folded into δ_m (use mean δ_m)

EMPIRICAL PDMS FROM PARASOL

- PARASOL was the only instrument that provided polarization measurements on orbit
- 3 wavelengths available from PARASOL: 470, 670 and 865 nm
- Goal: construct *P* and χ PDMs for the 3 bands for various scene types (IGBPs, clear-sky, cloudy, aerosols)
- Use interpolation to construct *P* and χ PDMs between the 3 bands

RECENT RESULTS

- Finished 2D fits for the highest polarization scene types
- PDM fits, advantages:
  - As with any fits, PDM fits useful to smooth out statistical fluctuations and fill gaps in data
  - Compact (only 7-8 parameters) and universal (applied to any scene type)
  - Robust, even for low-statistics PDMs
- Use fits (means and fit error) to empirical P and χ PDMs in the final module
- Implemented a working version (C++/C) of the PDM module to retrieve degree of polarization P and angle of polarization χ, with corresponding std. dev., based on PARASOL data
- Working on lower polarization scenes (cloudy scene types)

PDM CLASSIFICATION

- Computed total means and std. devs for P PDMs
- Initially considered highest polarization scenarios:
  - Picked shortest available wavelength (λ = **490 nm**)
  - **SZA = 40** (close to the typical range of Brewster's angles)
- Considered PDMs at least 2 std. dev. away from 0

IGBP	Surface Type	P mean	P std. dev.
1	Evergreen needle-leaf forest	0.19	0.11
2	Evergreen broad-leaf forest	0.26	0.07
3	Deciduous needle-leaf forest	0.14	0.11
4	Deciduous broad-leaf forest	0.20	0.11
5	Mixed forest	0.16	0.12
6	Closed shrubland	0.18	0.12
7	Open shrubland	0.17	0.10
8	Woody savannas	0.17	0.12
9	Savannas	0.23	0.06
10	Grasslands	0.18	0.09
11	Permanent wetlands	0.16	0.13
12	Croplands	0.20	0.08
13	Urban and Built-up	0.24	0.09
14	Cropland Mosaics	0.21	0.09
15	Permanent snow and ice		
16	Bare soil and rocks	0.16	0.06
17	Water Bodies	0.31	0.08
18	Tundra		
19	Fresh Snow		
20	Sea Ice		

P PDM FIT FUNCTION

- Perform a χ^2 fit on *P* PDM:

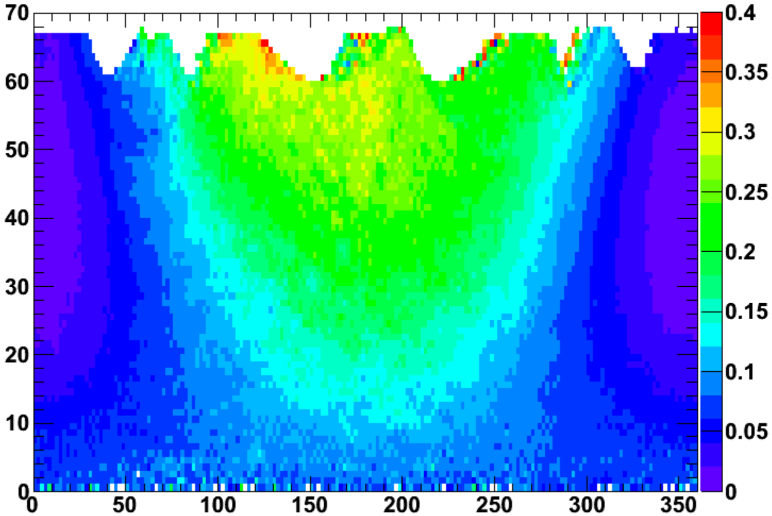
Gaussians describing (mostly) glint region

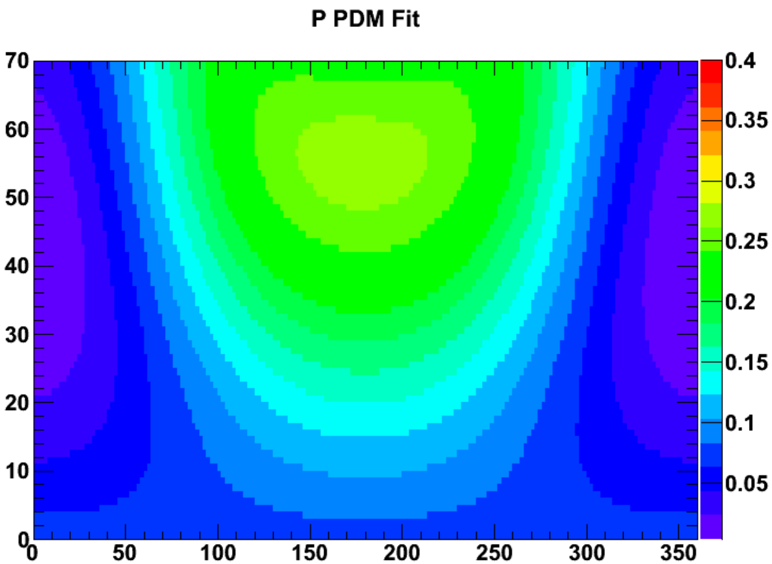
$$f(\phi,\theta) = N \exp\left(-\frac{(\phi-\mu_1)^2}{2\sigma_1^2}\right) \exp\left(-\frac{(\theta-\mu_2)^2}{2\sigma_2^2}\right) + \frac{1-\cos^2\Theta}{1+\cos^2\Theta+\frac{4}{3}AM\left\{\frac{\exp(-M\tau)}{1-\exp(-M\tau)}\right\}}$$

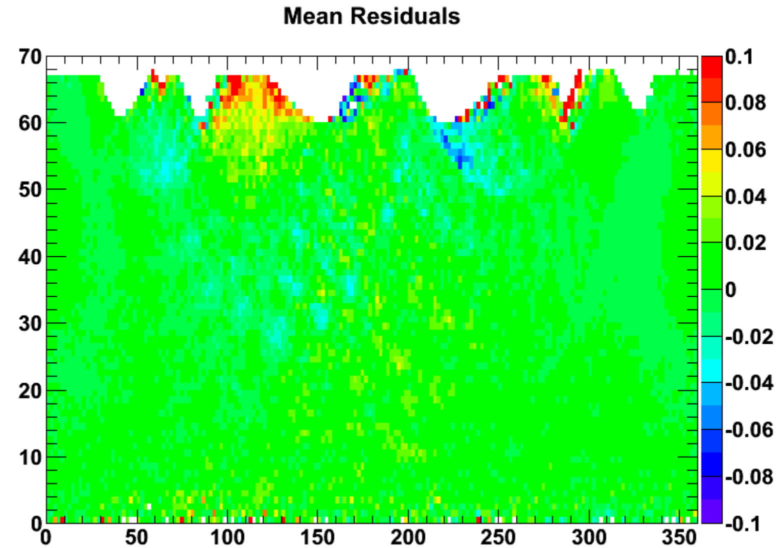
based on 1st order scattering approximation (away from glint)

$\phi = RAZ$, $\theta = VZA$, $\theta_s = SZA$
$\cos\Theta = \cos\theta\cos\theta_s + \sin\theta\sin\theta_s\cos\phi$,
$M = 1/\cos\theta + 1/\cos\theta_s$
and N, μ_1, σ_1, μ_2, σ_2, A, τ are fit parameters.

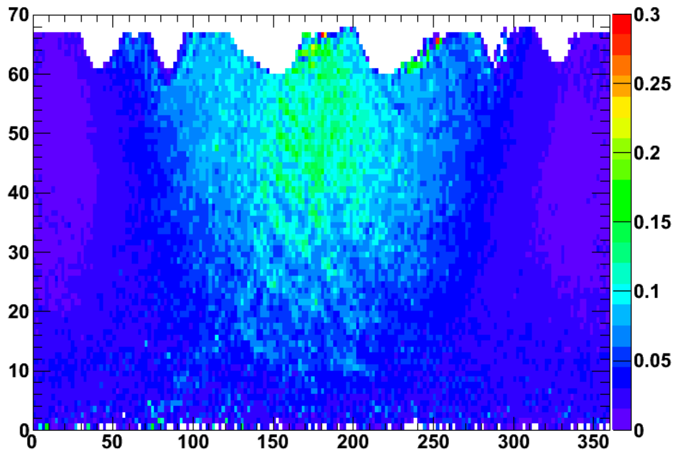
P PDM FIT FOR IGBP = 9 (λ = 670 nm): MEANS

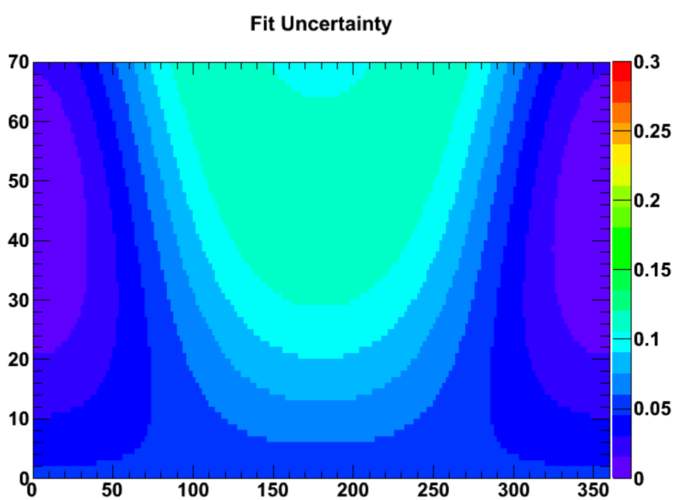


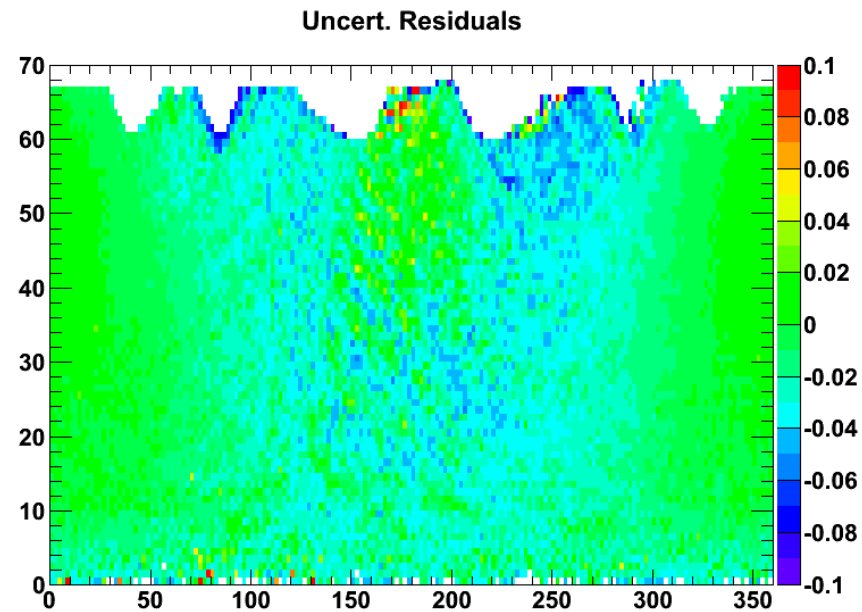




P PDM FIT FOR IGBP = 9 (λ = 670 nm): STD. DEVS

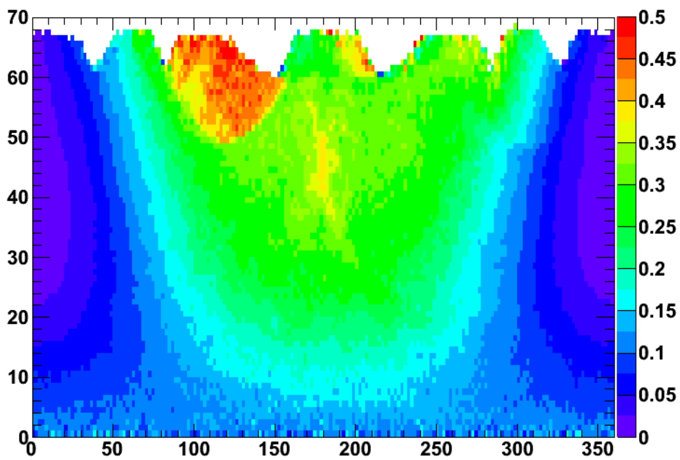


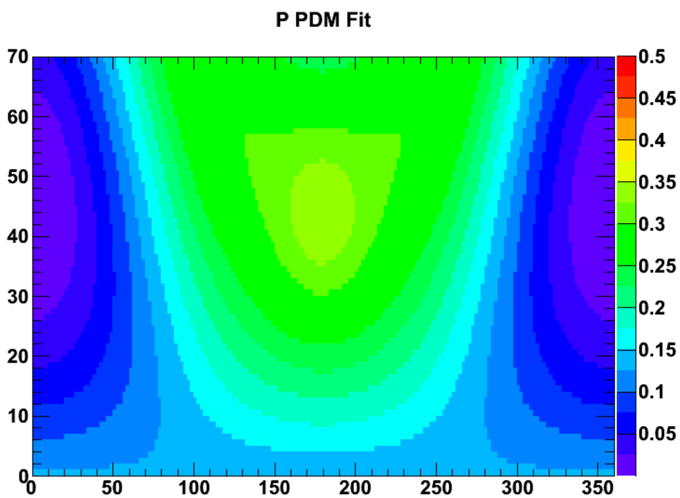


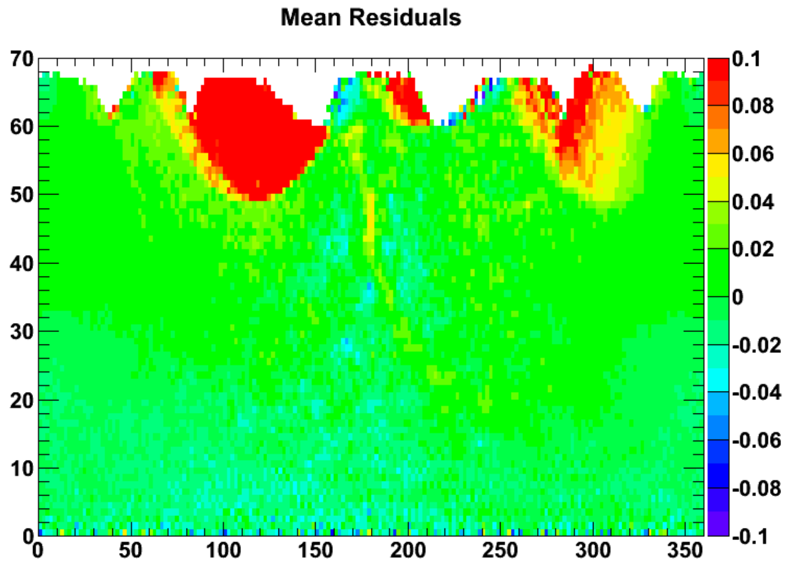


70% C.L. (≈1σ)
uncertainty

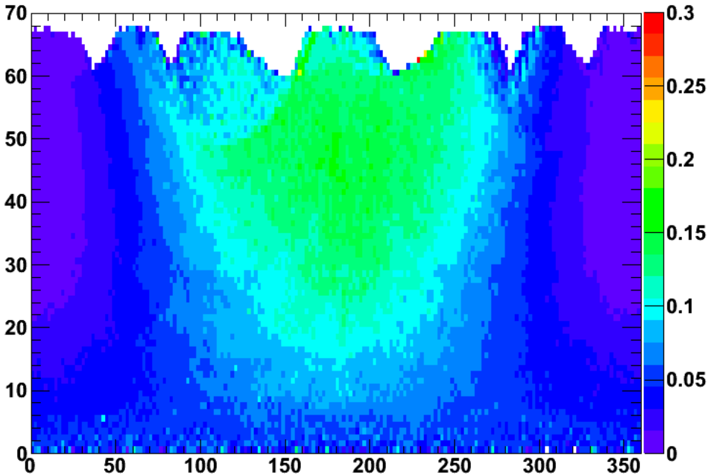
P PDM FIT FOR IGBP = 10 (λ = 490 nm): MEANS

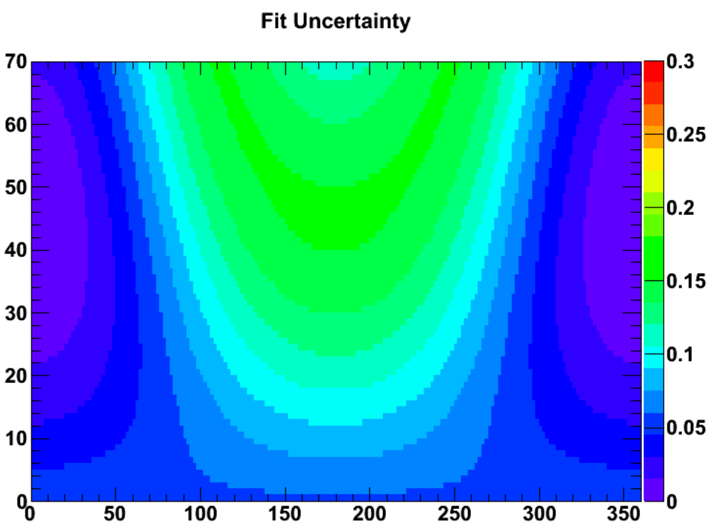


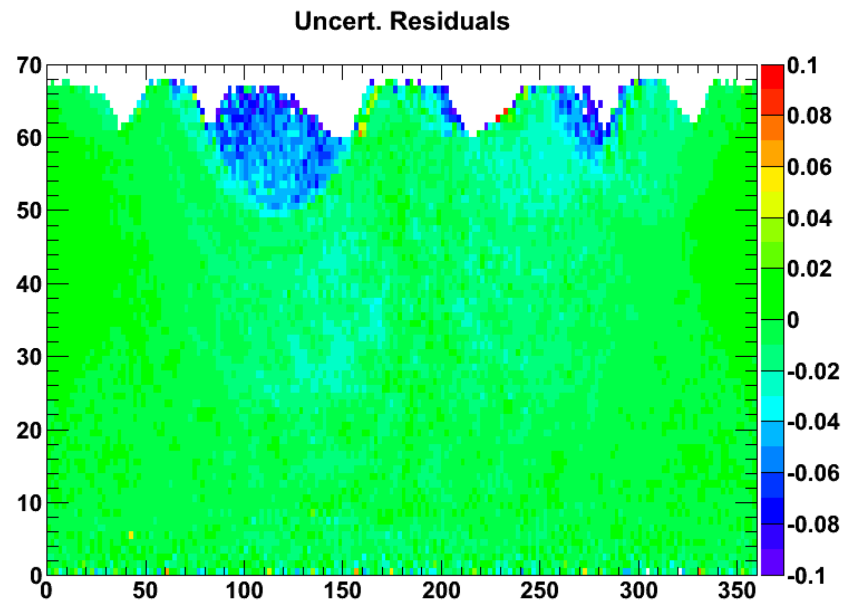




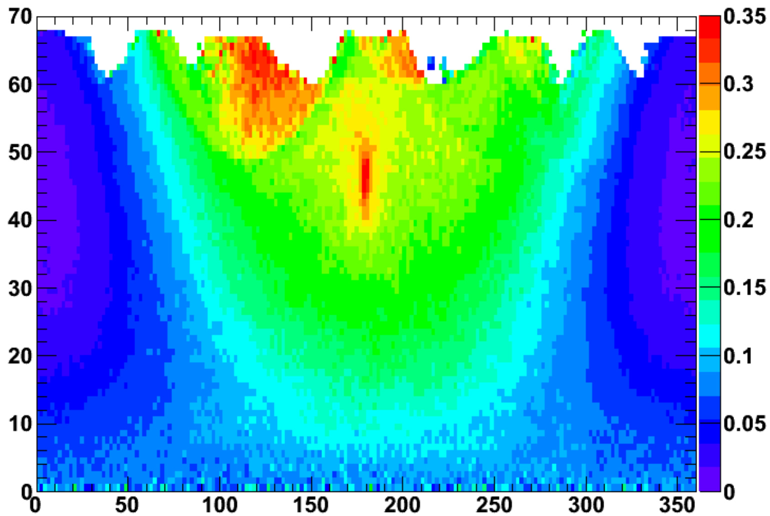
P PDM FIT FOR IGBP = 10 (λ = 490 nm): STD. DEVS



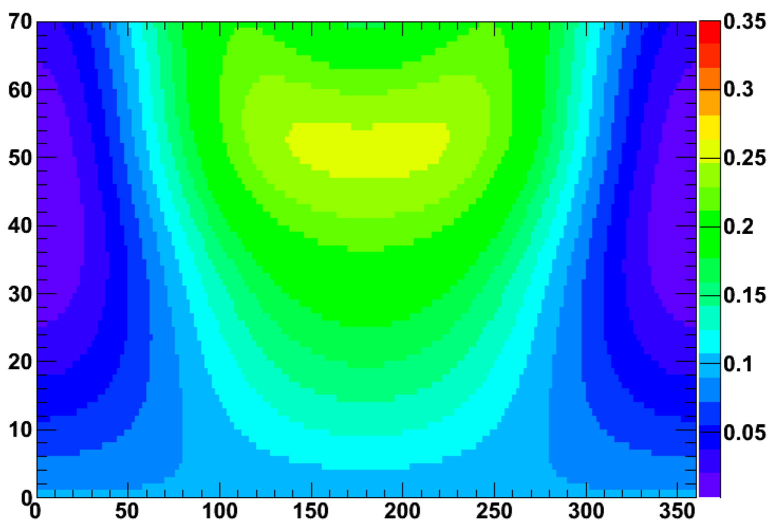




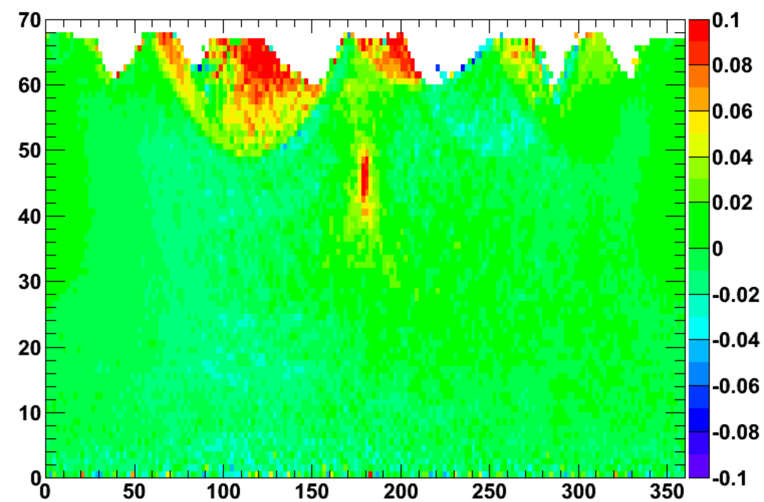
P PDM FIT FOR IGBP = 14 (λ = 490 nm): MEANS



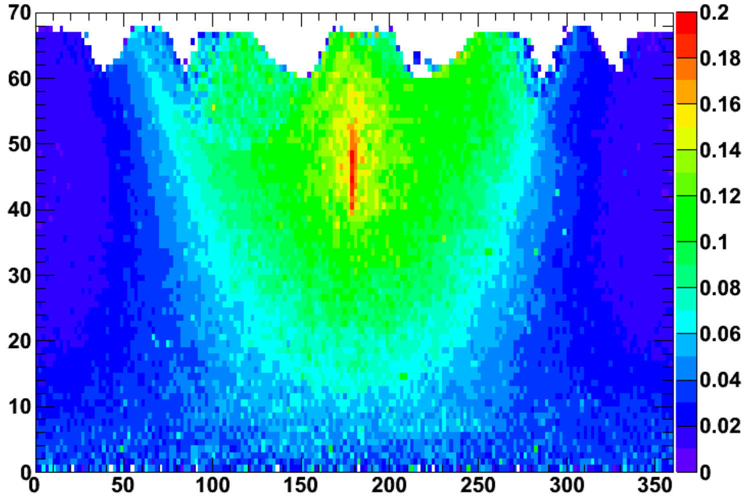
P PDM Fit



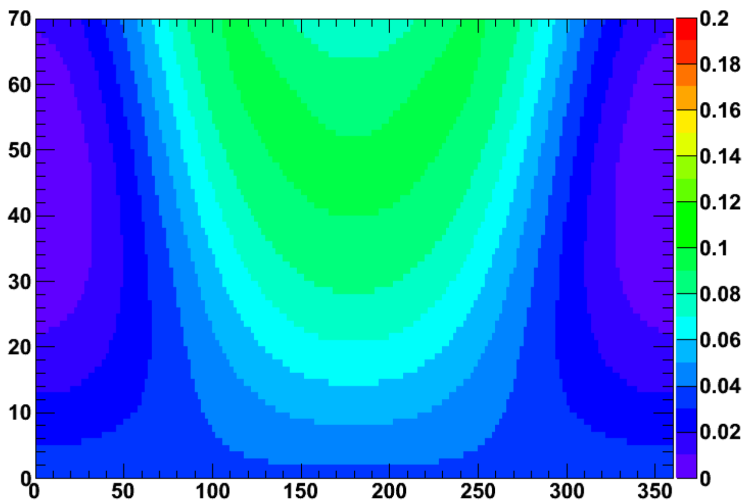
Mean Residuals



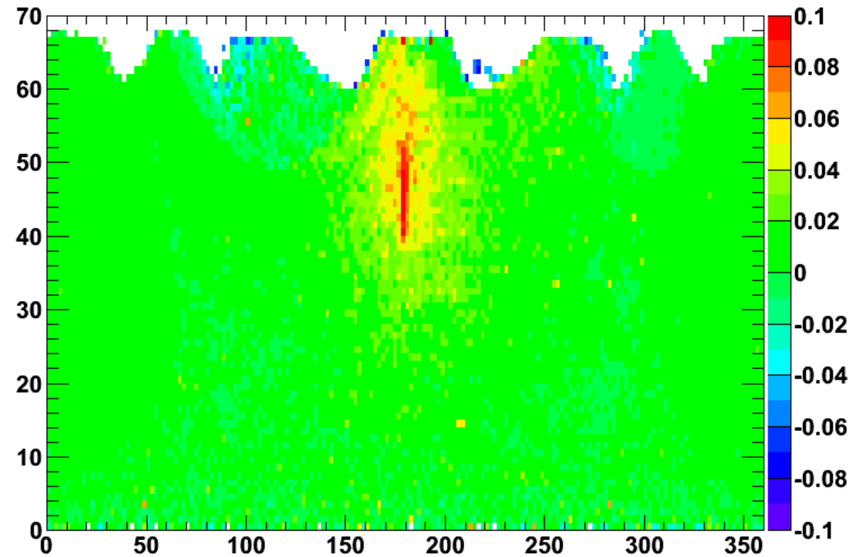
P PDM FIT FOR IGBP = 14 (λ = 490 nm): STD. DEVS



Fit Uncertainty



Uncert. Residuals



P PDMS: SUMMARY

- 2D fits provide good (ΔP ≈ +/-0.1) approximation to P PDMs means and std. devs.
- Final empirical P PDMs recorded (TBD) in the form of the fit coefficients to $f(\phi,\theta)$ or binned values of $f(\phi,\theta)$ and per-bin fit uncertainties

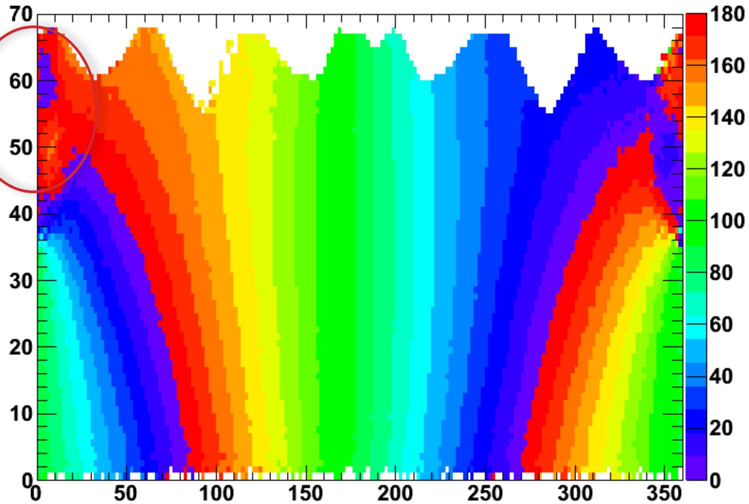
χ: SINGLE SCATTERING APPROXIMATION

- Perform a χ^2 fit on χ PDM:

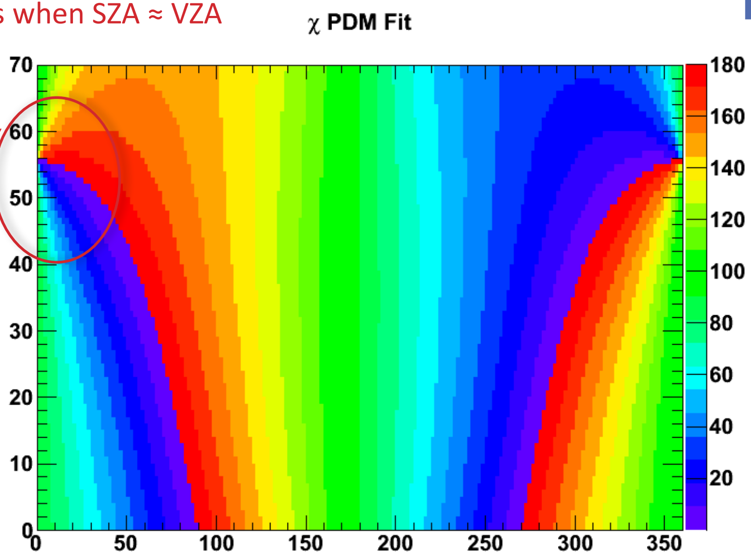
$$\cos \chi_{ss} = \frac{\sin \theta_s \sin \phi}{\sin \Theta},$$

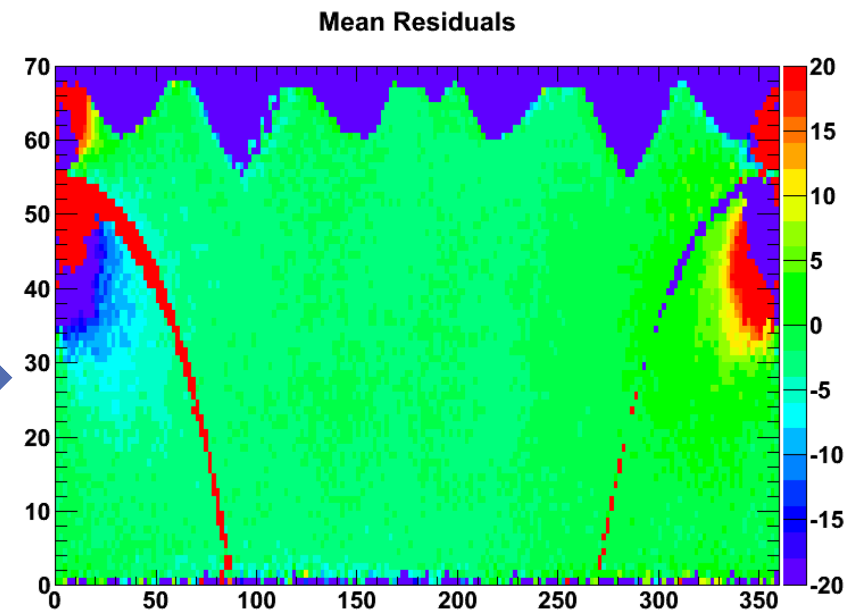
$\phi = RAZ,\ \theta = VZA,\ \theta_s = SZA$
$\cos \Theta = \cos \theta \cos \theta_s + \sin \theta \sin \theta_s \cos \phi,$
and θ_s is the fit parameter.

P PDM FIT FOR IGBP = 14 (λ = 865 nm, 50º < SZA < 60º)



Second/third order scattering
Effects when SZA ≈ VZA





χ PDMS: SUMMARY

- Single scattering is a good approximation to within +/-4^o for empirical χ in the 50^o < RAZ < 310^o region
- In the region RAZ = 0^o/360^o, SZA = VZA:
    - PARASOL has low resolution in χ
    - Single scattering not a good approximation there: higher order scattering model needed
- Single scattering fit yields reasonable mean values but doesn't yield reasonable fit uncertainties, so plan (TBD) to use hybrid approach for final recorded χ values:
    - Use PARASOL for bins with data, χ_{ss} approximation for bins with no data

TO BE DONE

- Work on lower polarizations (clouds) and other IGBPs
- Implement ice & water clouds PDMs

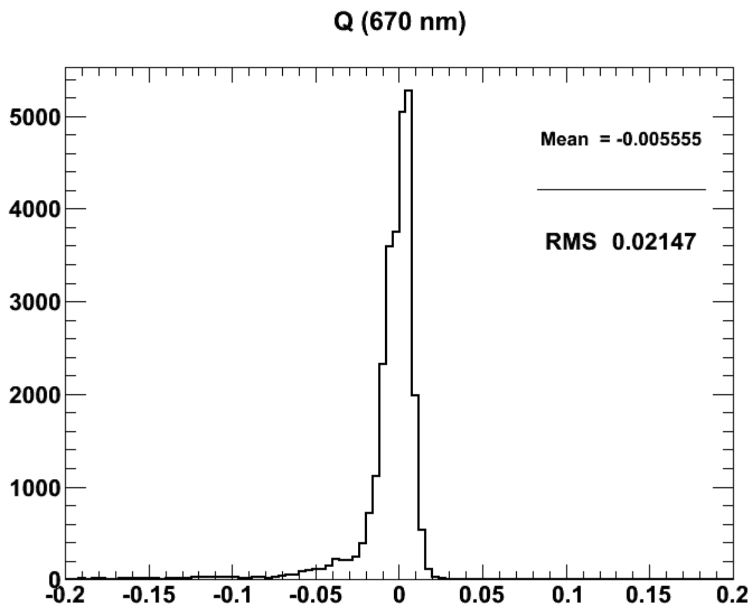
BACKUP

HIGH χ UNCERTAINTY REGIONS

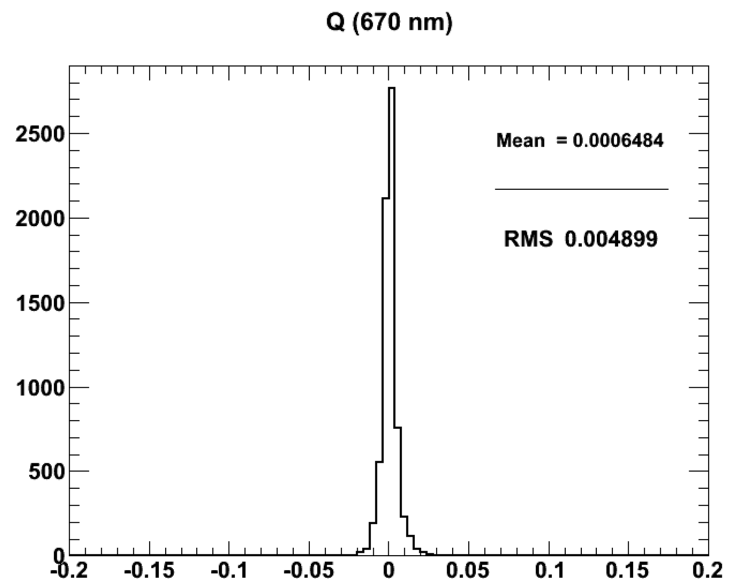
- Regions RAZ = 0°/360°, SZA = VZA have Stokes paramer ≈ 0°, close to PARASOL's resolution
- For single scattering Q = 0 is undefined, need higher order scattering:

$$\chi = \frac{1}{2}\arctan(U/Q).$$

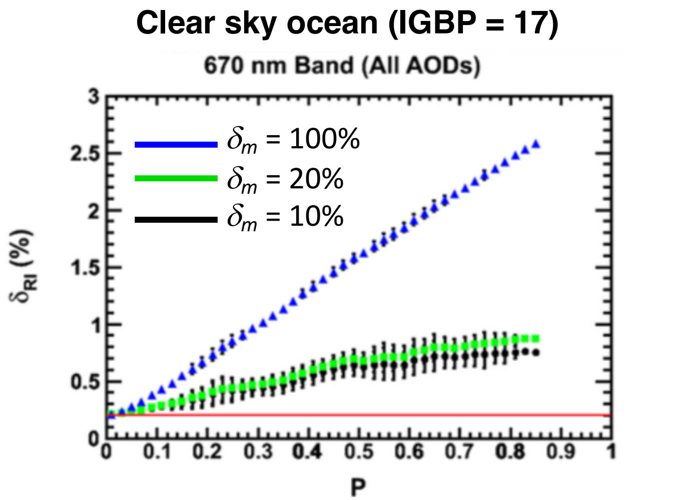
χ PDM central region:
50 < RAZ < 300

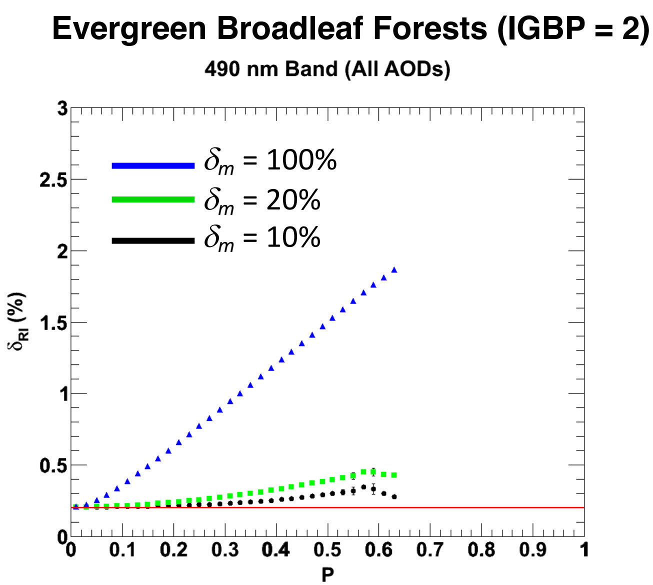


χ PDM high-uncertainty region:
RAZ > 310, VZA > 30



P UNCERTAINTIES





- Plot shows **intercal. uncertainty in reflectance** vs. degree of polarization assuming the intercalibrated imager's sensitivity to polarization *m* = 0.03 and δ_m set to three different values
- Considering CLARREO's own target uncertainty due to polarization $\delta_{\rho 0}$ = 0.15%, one can conclude that:
  - values of *P* < 0.1, may be considered below noise threshold. Thus:
    - due to sharp drop-off in *P* (e.g., next slide), some PDM's for 670 and 865 nm can be neglected
    - snow-covered surfaces can be neglected (IGBP=15, 19 and 20)
  - Low slope indicates intercal. *P* is insensitive to std. devs <≈ 0.1.
    - PDM uncertainties have roughly the necessary precision