Field Experiments I Have Known and Loved

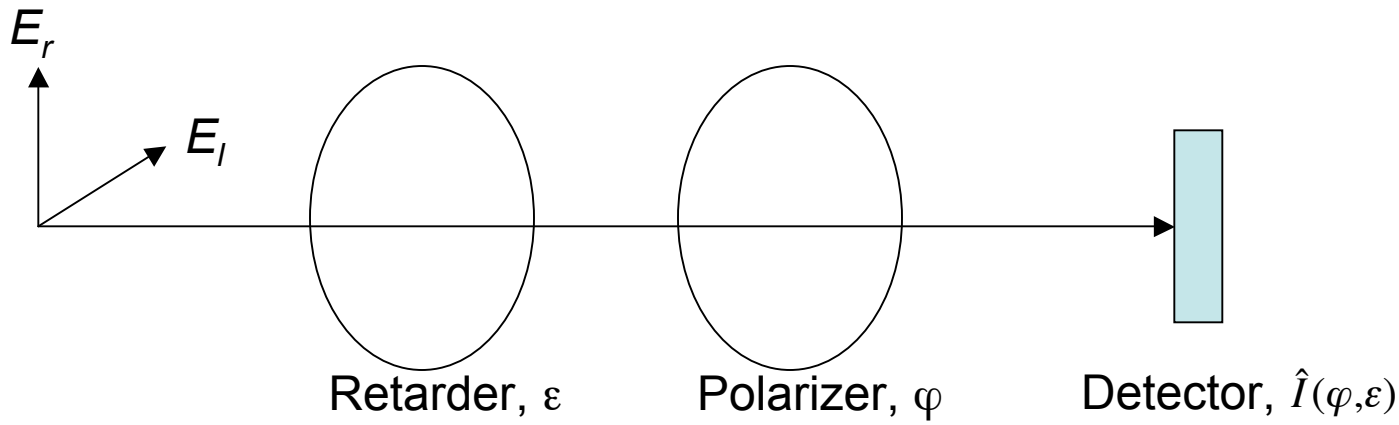
or

Using aircraft measurements from the Research Scanning Polarimeter (RSP) to develop techniques for spaceborne remote sensing of aerosols and clouds for the NASA Glory mission)

Brian Cairns

Introduction

– Definitions



Stokes Vector

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} \langle E_l E_l^* + E_r E_r^* \rangle \\ \langle E_l E_l^* - E_r E_r^* \rangle \\ \langle E_l E_r^* + E_r E_l^* \rangle \\ -i\langle E_l E_r^* - E_r E_l^* \rangle \end{bmatrix} = \begin{bmatrix} \hat{I}(0°,0) + \hat{I}(90°,0) \\ \hat{I}(0°,0) - \hat{I}(90°,0) \\ \hat{I}(45°,0) - \hat{I}(135°,0) \\ \hat{I}(45°,\pi/2) - \hat{I}(135°,\pi/2) \end{bmatrix}$$

Degree of Linear Polarization, Angle of Polarization

$$\mathrm{DoLP} = \frac{\sqrt{Q^2 + U^2}}{I} \quad , \quad \mathrm{AoP} = \tan(2\chi) = U/Q$$

Introduction

– Definitions

- Remote measurements of the polarized radiance (Stokes vector) of scattered sunlight can be expressed as:

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \frac{\mu_0}{\pi r^2} \begin{bmatrix} R_{11} & R_{21} & R_{31} & R_{41} \\ R_{12} & R_{22} & R_{32} & R_{42} \\ R_{13} & R_{23} & R_{33} & R_{43} \\ R_{14} & R_{24} & R_{34} & R_{44} \end{bmatrix} \times \begin{bmatrix} F_0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

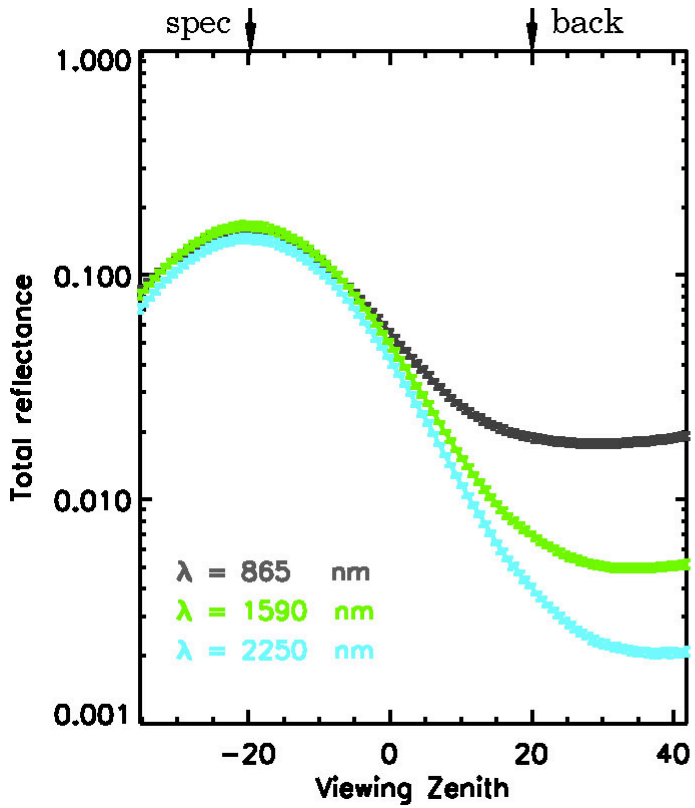
where F_0 is the solar flux, r is the sun-earth distance in AU, $\mu_0=\cos(\theta_0)$ and θ_0 is the solar zenith angle. The reflectance usually considered in remote sensing is R_{11}

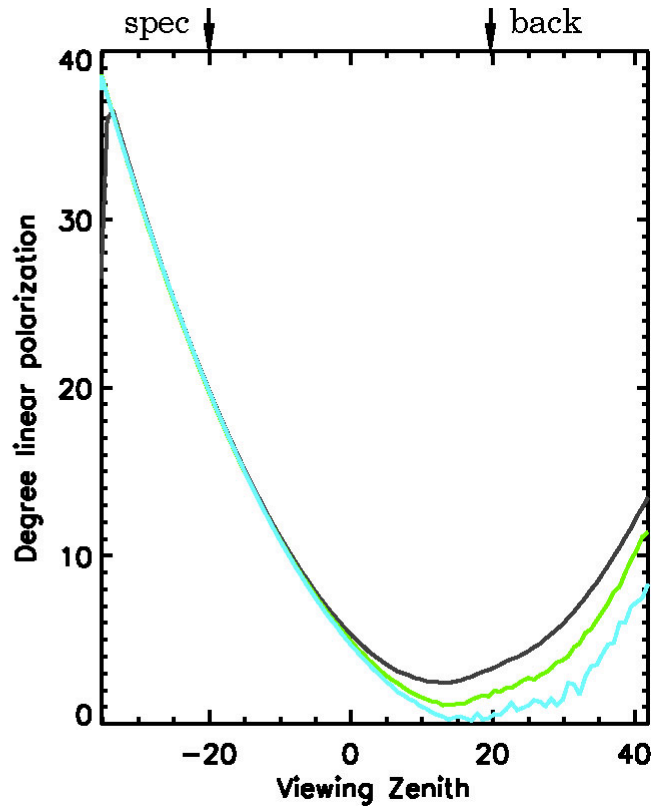
- Since circular polarization of sunlight scattered by all natural targets is negligible we define the polarized reflectance (R_P) to be:

$$R_P = \sqrt{R_{12}^2 + R_{13}^2}$$

Introduction

– What can you use polarization for?
  - Sunglasses

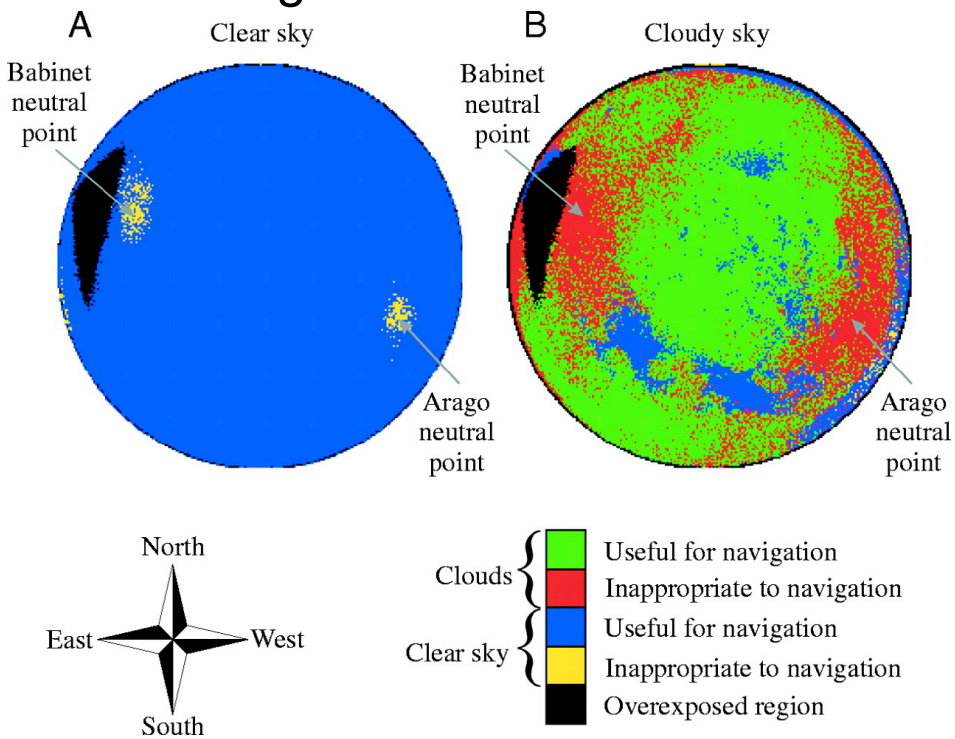


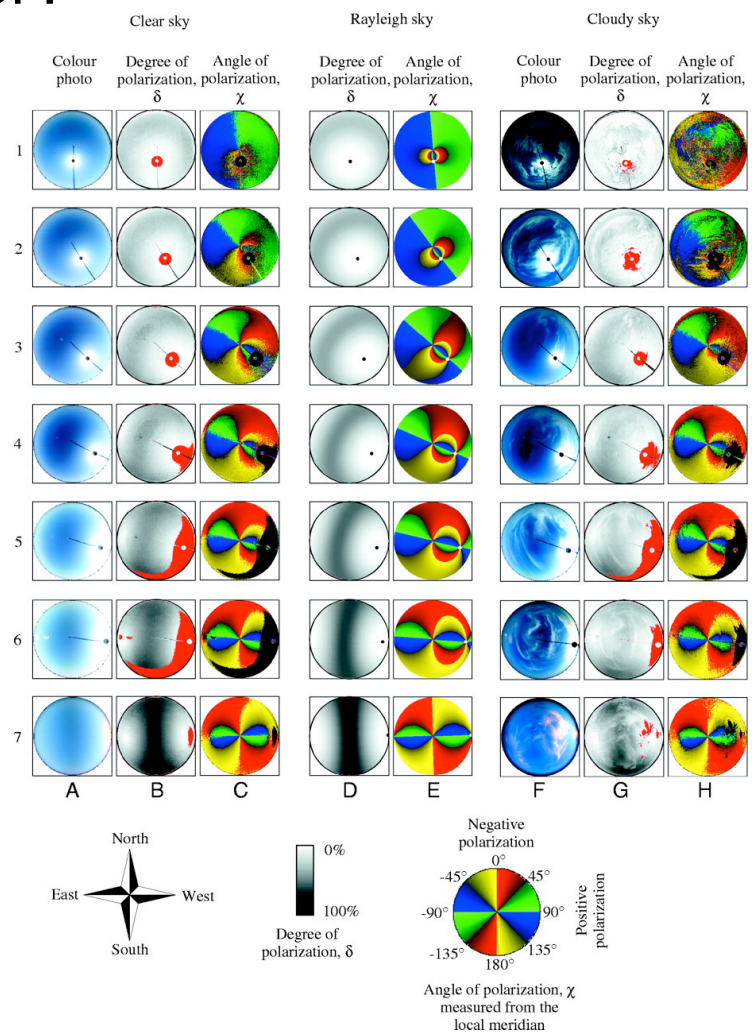


Introduction

– What can you use polarization for?

- Navigation

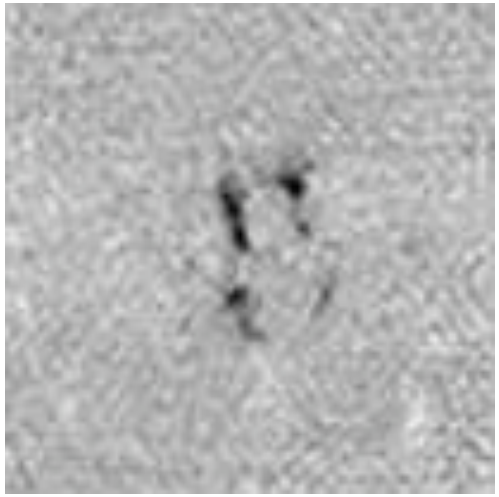




Desert ants and honey bees use ultraviolet receptors in a specialized dorsal rim area of the eye as polarization analyzers that provide a polarization "compass" even under cloudy skies.

Introduction

– What can you use polarization for?
  - Remote Sensing
    – of stars



12.5 arcsecs

First direct measurement of the magnetic field strength in solar intra-network fields (Keller et al. 1994).

Introduction

- What can you use polarization for?
  - Remote Sensing
    - of other planets

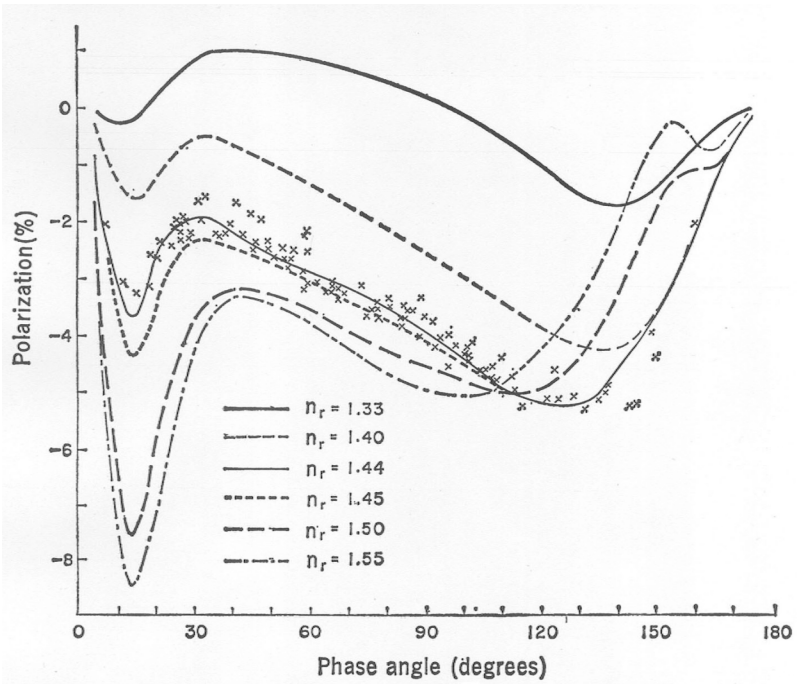


Fig. 2. The crosses show the observations of Coffeen and Gehrels of the polarization of Venus at a wavelength of 0.99 μ (*2*). For each refractive index n_r the theoretical calculations are for the particle size giving best agreement with the observations: $\bar{r}$ = 0.6, 0.8, 1.1, 1.1, 1.2, and 1.2 μ, respectively, beginning with $n_r = 1.33$. The curves for $n_r = 1.44$ and 1.45 are indistinguishable for phase angles greater than 110°. The albedo of Venus is assumed to be ~ 90 percent at $\lambda = 0.99\ \mu$.

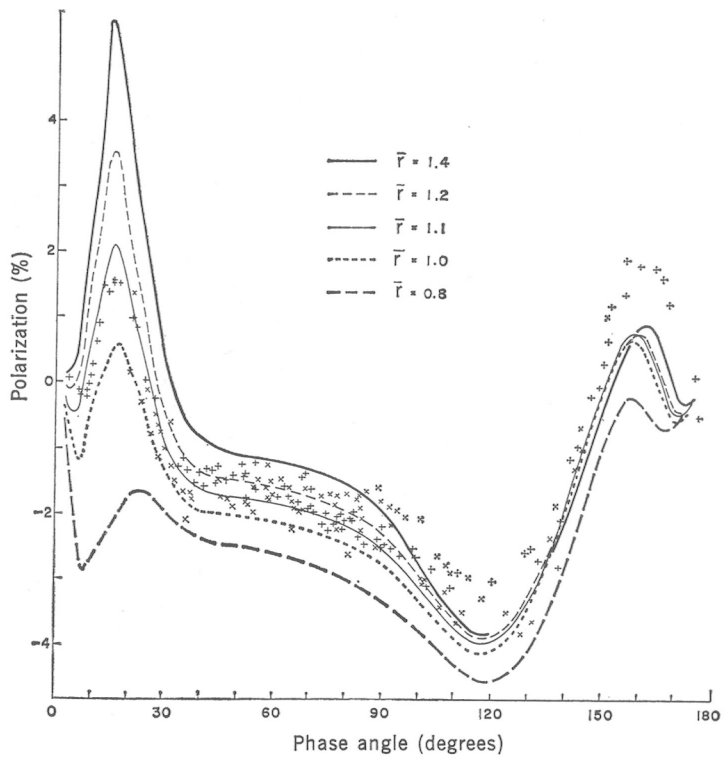
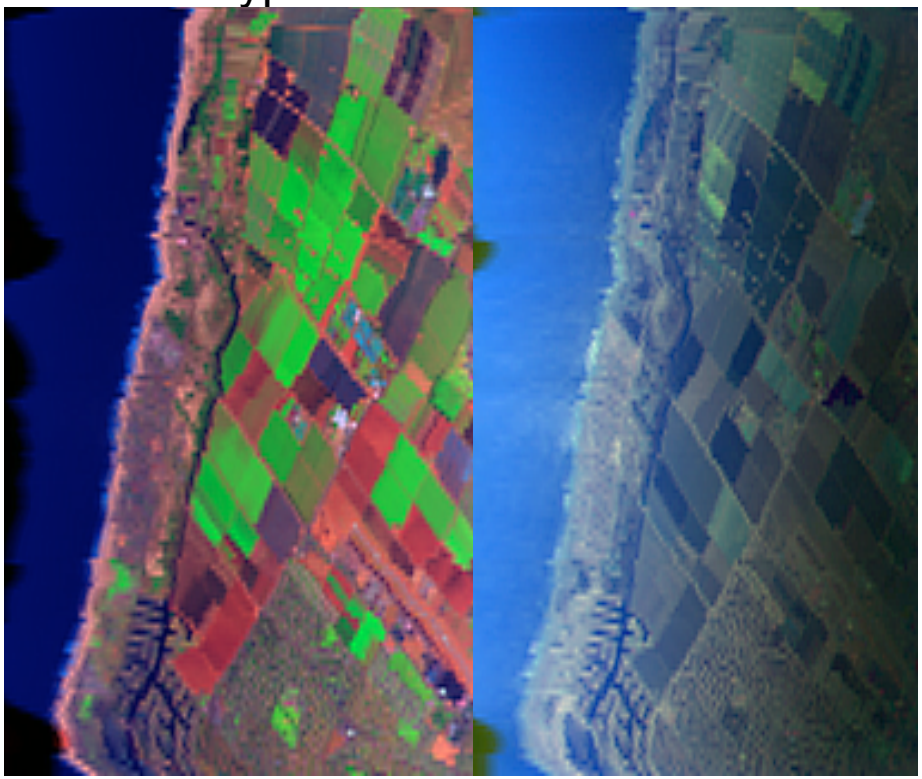


Fig. 4. The pluses represent the visual observations of Lyot (*1*), and the crosses are the intermediate-bandwidth observations of Coffeen and Gehrels at $\lambda = 0.55\ \mu$ (*2*). The theoretical curves are for $n_r = 1.45$ with several values for the mean radius $\bar{r}$. The albedo of Venus is assumed to be ~ 87 percent, and the Rayleigh scattering determined in the ultraviolet region ($f_R = 0.045$) is included after reduction by a λ^{-4} law.

Introduction

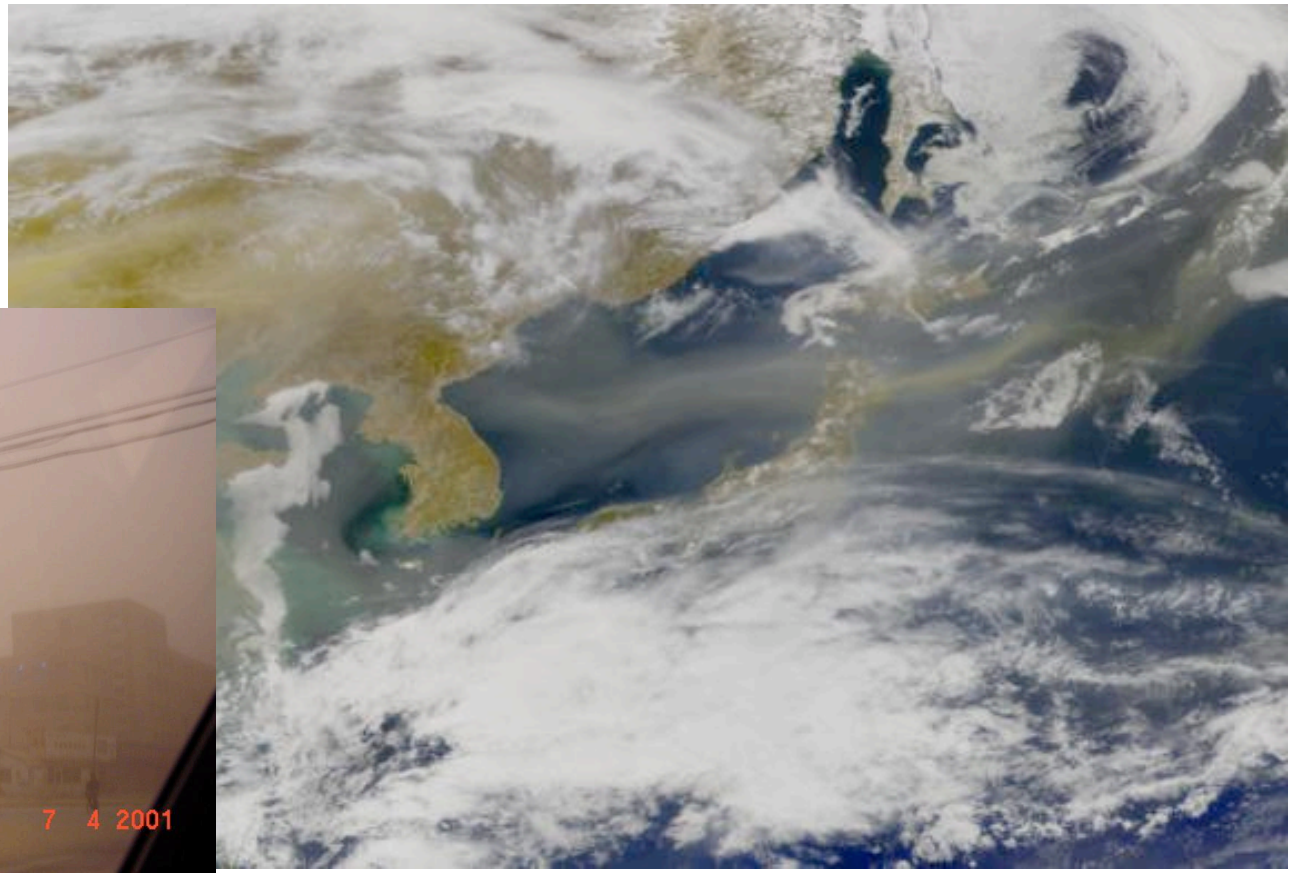
- What can you use polarization for?
  - Remote Sensing
    - of the earth in order to get the global distribution of terrestrial aerosol amounts and types



One of the first suggestions of the use of polarization for atmospheric correction was by Raman (Nature, 1921).

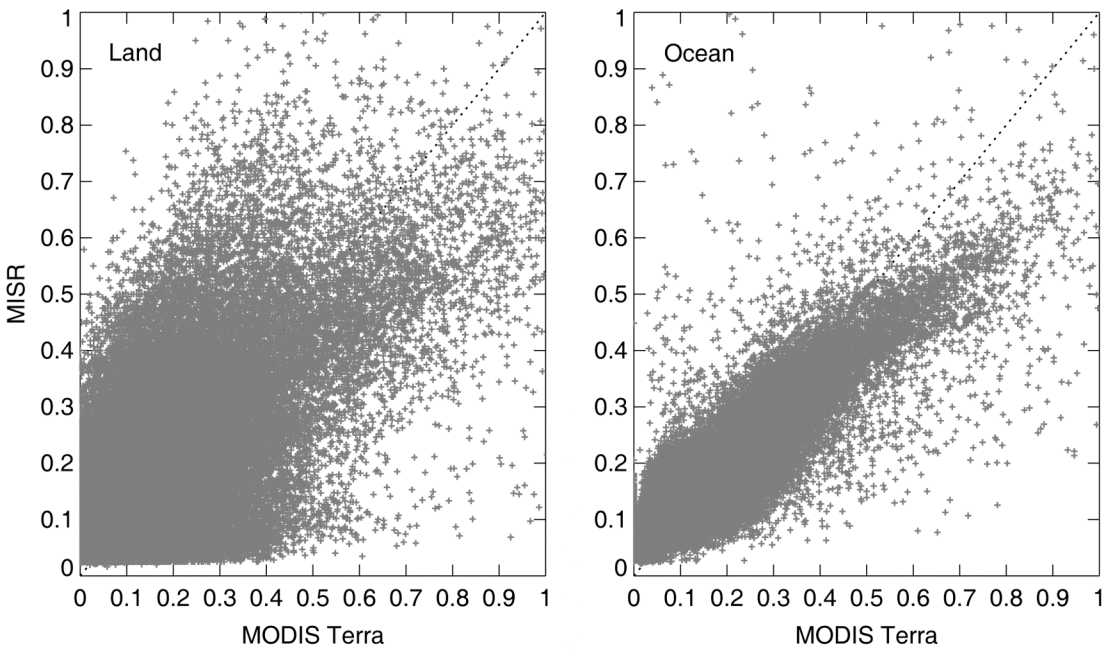
Introduction

- Current satellite imagers
  - If a picture is worth a thousand words why do they take up so much space….



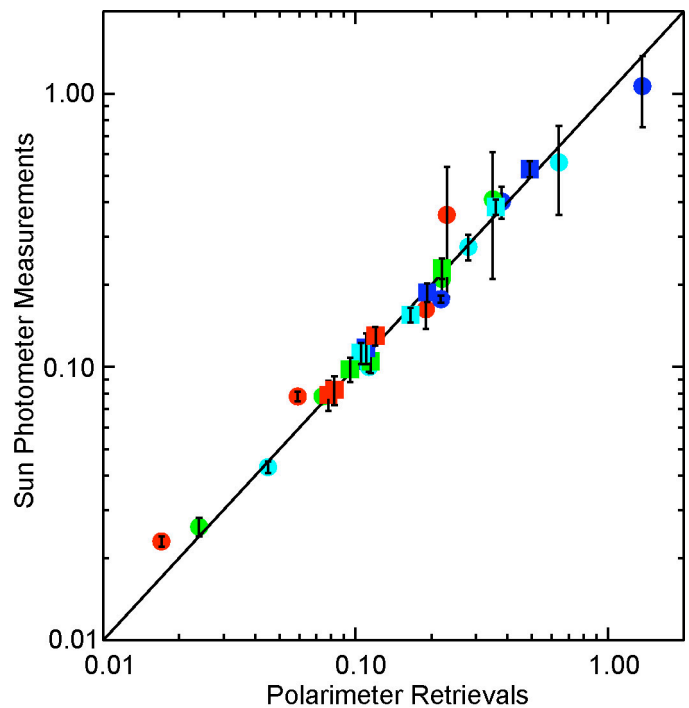
Introduction

– Current satellite imagers
  - and provide so little information



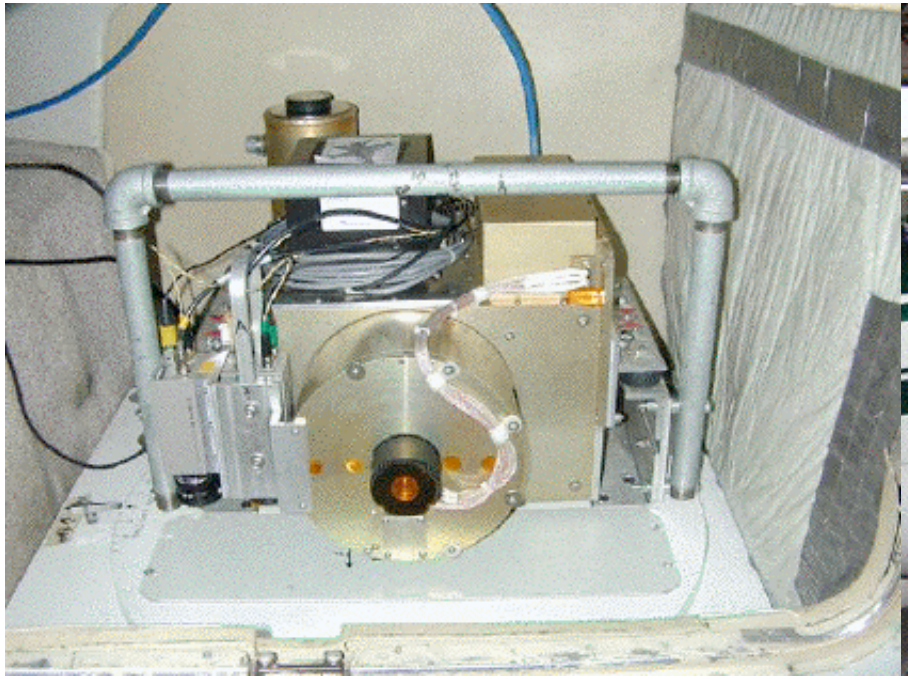
Introduction

- The solution
  - If you don't like the way things are, fix them.
    - In conjunction with Ed Russell, Dick Chandos and SpecTIR Corp. we developed an instrument called the Research Scanning Polarimeter which is by far the best polarimetric remote sensing instrument in the world.



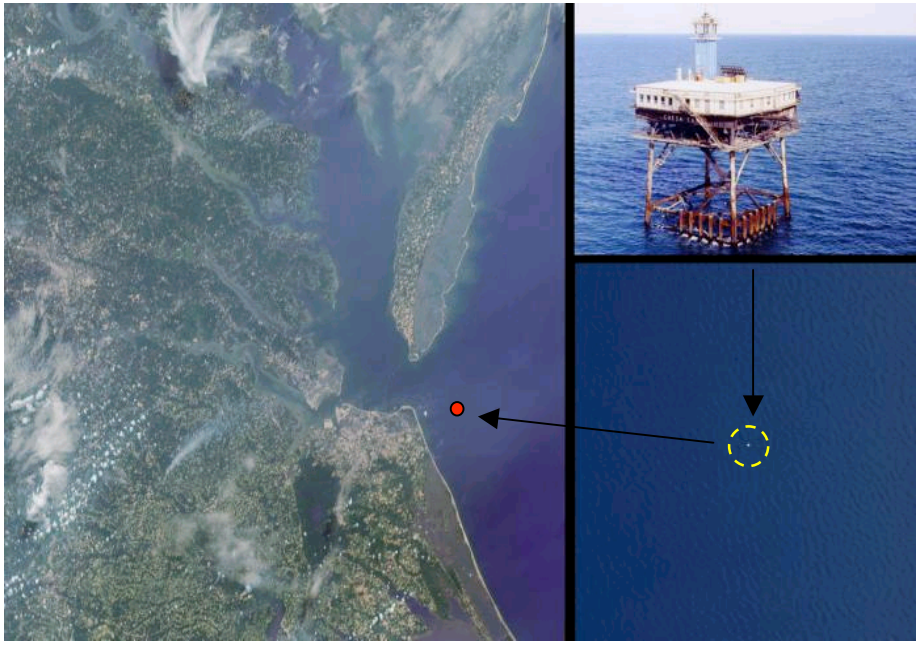
Introduction

- The solution
  - If you don’t like the way things are, fix them.
    - Once you have an instrument you just need to put it on a plane and find a good pilot.
    - And funding!



Field Experiments

– Data available at GISS for the general public:
  - CLAMS - measurements in the vicinity of the Chesapeake Bay Lighthouse and over the Dismal Swamp during July 2001. Reasonable aerosol in situ validation from one of the last campaigns on which the UW CV580 was used. Measurements were also taken over the site used by ONR LEOP-17 during a period when they were doing ocean color validation/ evaluations on 17th July



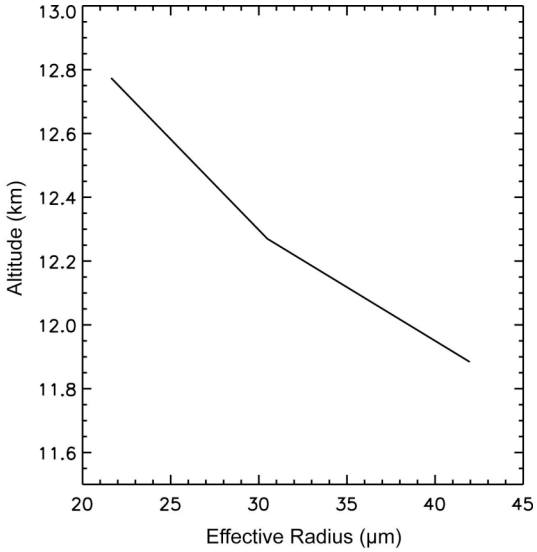
Field Experiments

– Data available at GISS for the general public:
  - IHOP - high altitude measurements based in Ponca City, OK that allowed the RSP to view cirrus clouds in April and May 2002. Limited *in situ* validation opportunities.

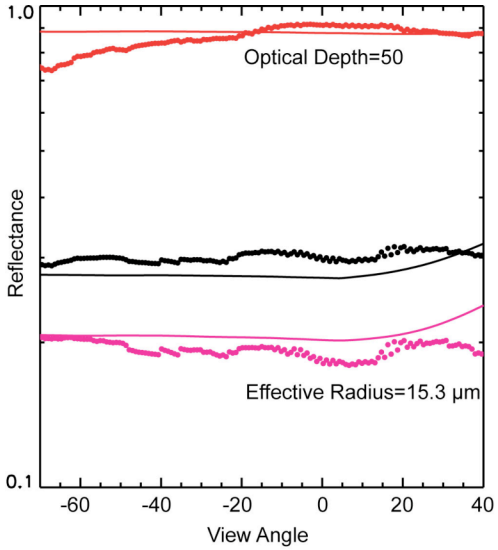
Field Experiments

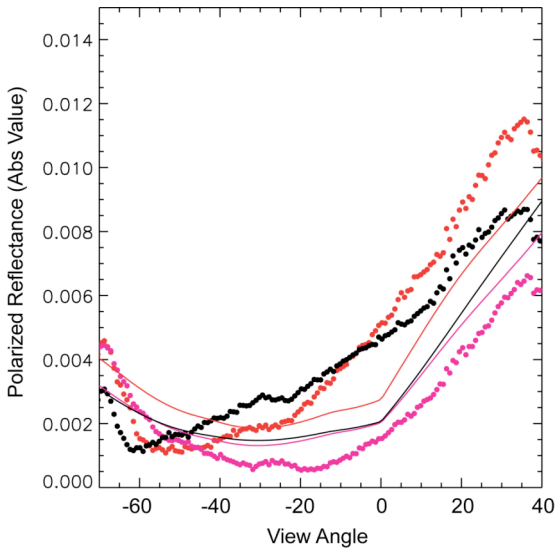
- Data available at GISS for the general public:
  - CRYSTAL-FACE - high altitude measurements with lots of cirrus based in Key West in July 2002 with excellent *in situ* validation from UND Cessna and NASA WB57.

Field Experiments



- Reflectance fit is much better than the polarized reflectance fit. Still working on a more diverse set of particle shapes that would provide greater diversity in asymmetry parameter, possibly allowing both reflectance and polarized reflectance to be fitted better. Whether this would allow for better size estimates is open to question given the vertical structure.

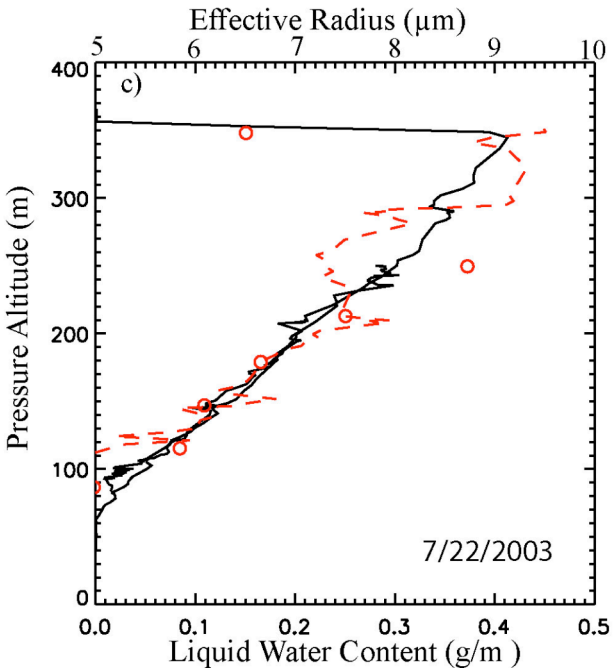


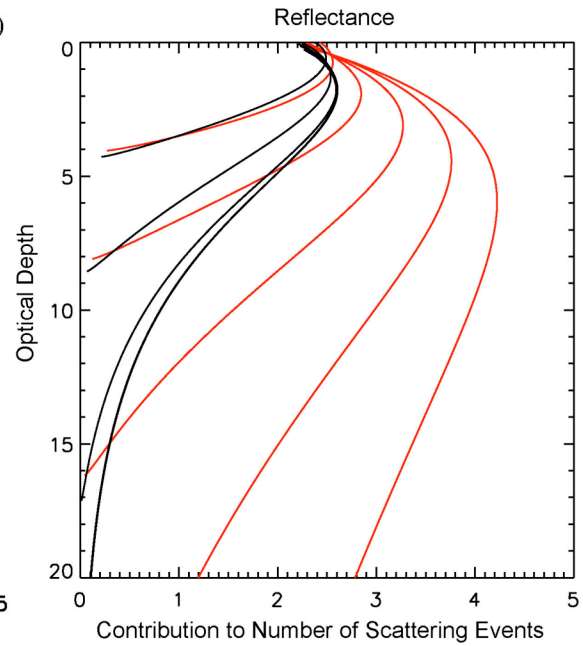


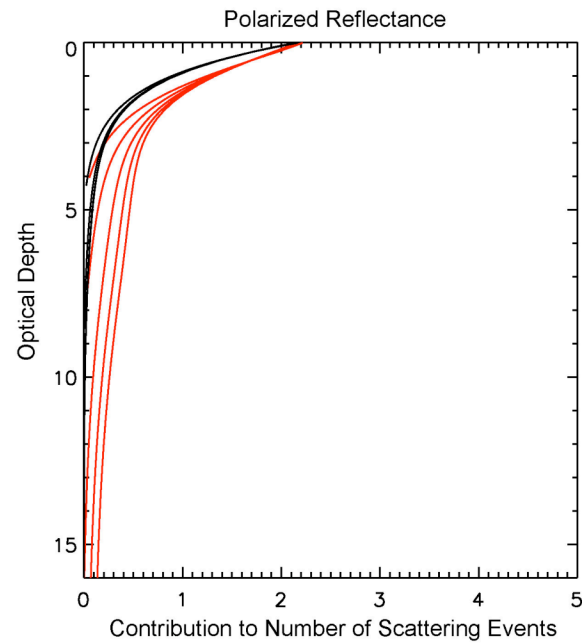
Field Experiments

– Data available at GISS for the general public:
  - CSTRIPE - measurements at 3-4 km (and at cloud top) over coastal stratocumulus near Monterey and over a superfund site near Fresno in July 2003. Extensive cloud and aerosol in situ measurements were made by the CIRPAS Twin Otter.

Field Experiments







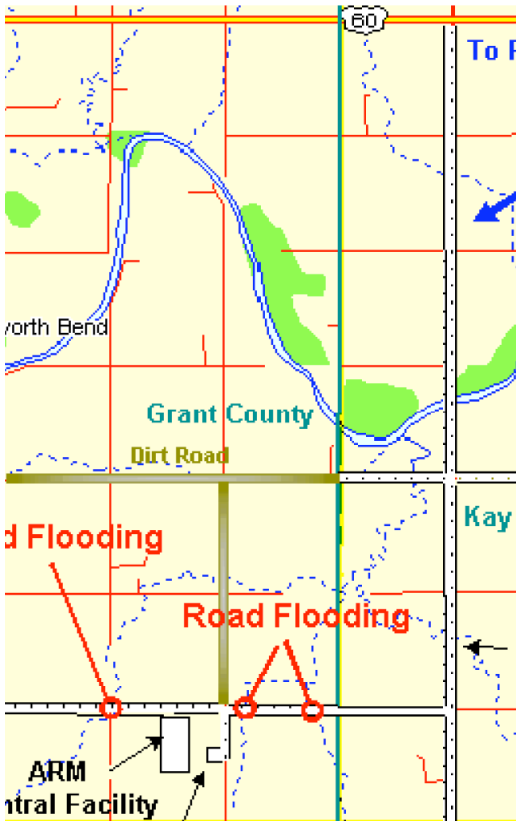
	Effective Radius (μm)		Effective Variance	
	7/22/2003	7/25/2003	7/22/2003	7/25/2003
Retrieval	9.228	7.938	0.152	0.039
In Situ	9.365	8.726	0.176	0.067

Field Experiments

- Data available at GISS for the general public:
  - ALIVE - measurements from the surface to 5 km over the Department of Energy's Atmospheric Radiation Measurement Program sites in the southern great plains near Ponca City, OK.
  - Miss Ponca City is Lana Elaine Brewer, daughter of Doyle and Nancy Brewer who is a freshman student at Oklahoma State University.

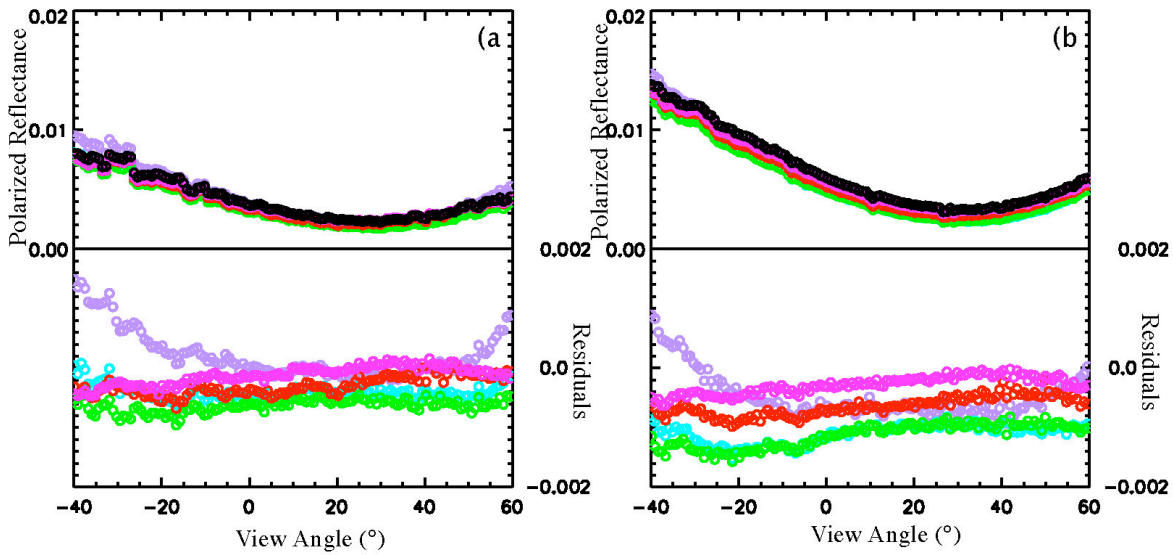
Field Experiments

– Data available at GISS for the general public:
  - ALIVE
    – Primarily agricultural land with winter wheat in early stages of growth and mature soy bean.



Field Experiments

- Data available at GISS for the general public:
  - ALIVE
    - Having a sunphotometer on top of the plane and one on the ground provides the best possible information to do atmospheric correction.



Field Experiments

- Data available at GISS for the general public:
  - ALIVE
    - The fact that the surface is grey allows for really good aerosol retrievals even under “severe clear” conditions. Only problem with such conditions is that they do not provide much dynamic range to test algorithms.

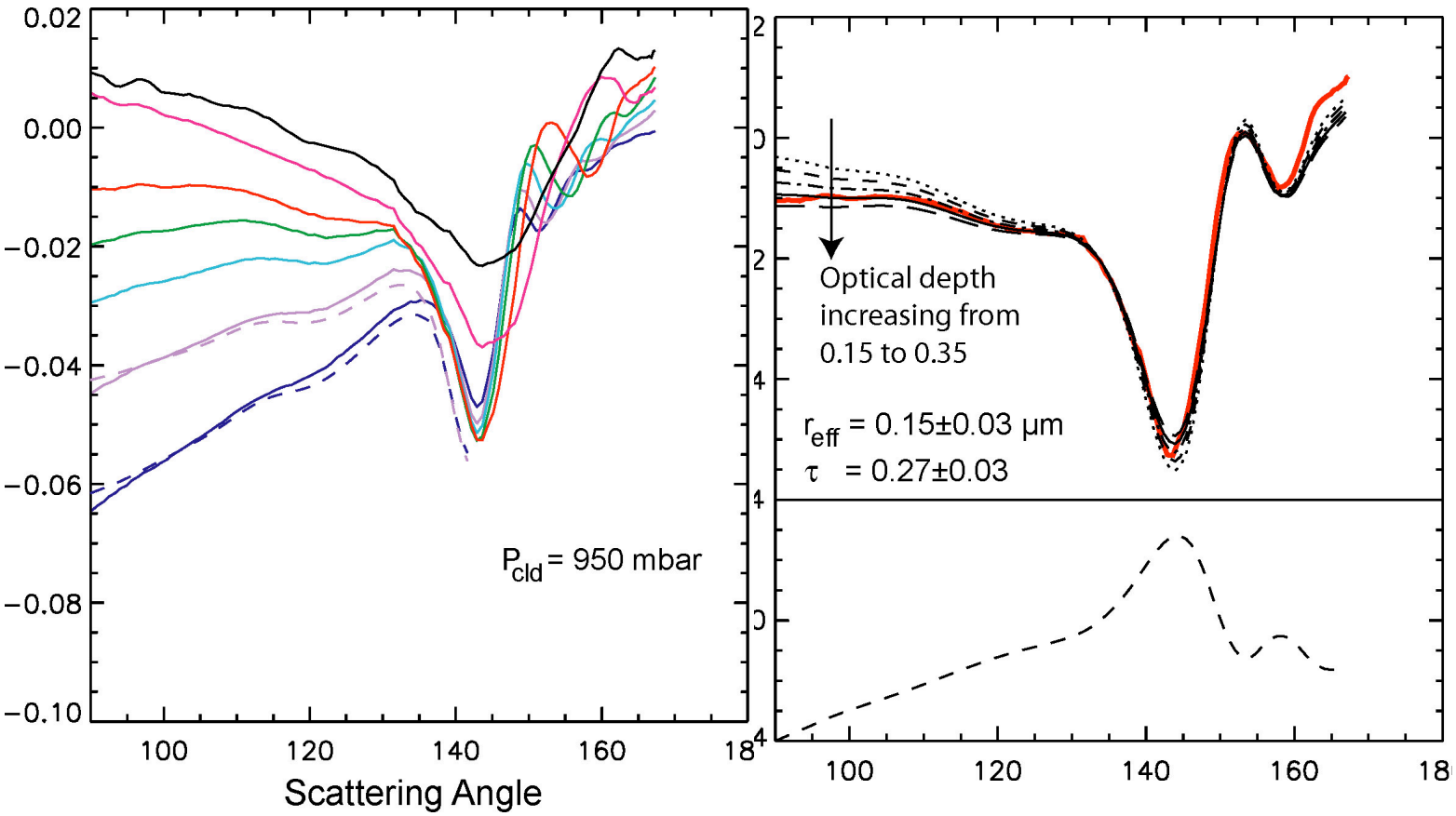
AOT_ret	AOT_cim
0.045	0.03
0.04	
0.085 (0.005)	0.08
0.09 (0.01)	
0.07 (0.005)	
0.095 (0.005)	0.075

Field Experiments

- Data available at GISS for the general public:
  - MILAGRO/INTEX-B - measurement from the surface to 5 km over urban pollution, biomass burning, anthropogenic dust, coastal stratocumulus and of the same aerosols transported over the ocean.

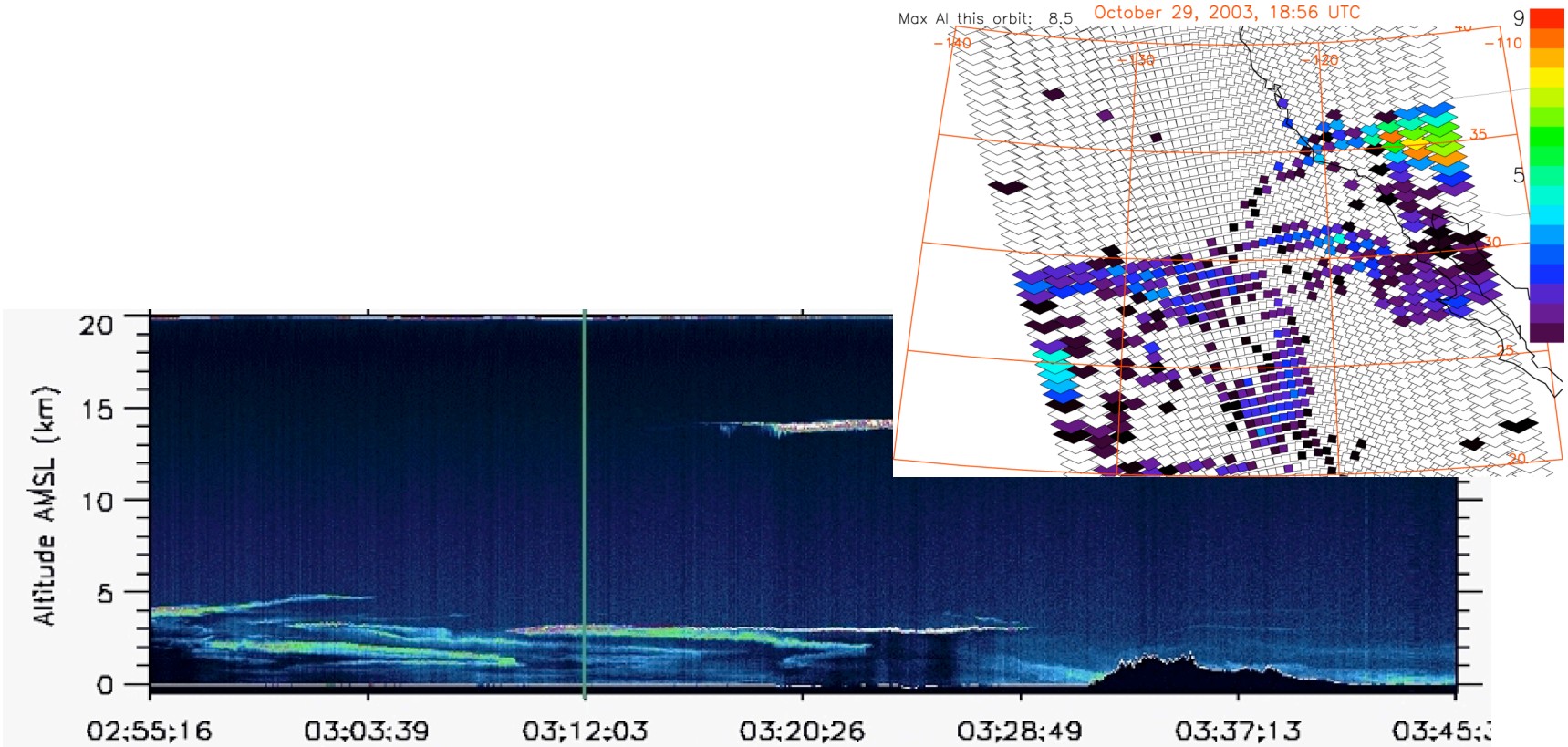
Field Experiments

– Unique capabilities of polarization
  - Clouds are white and bright, or **NOT**, as the case may be.



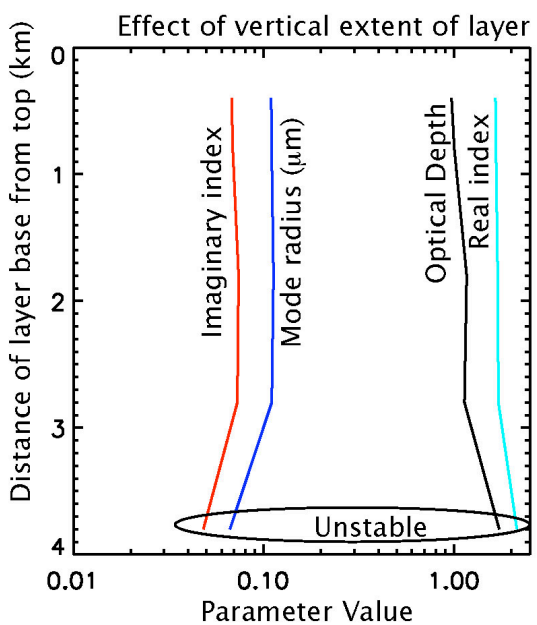
Field Experiments

- Data available at GISS for the general public:
  - SoCal Smoke.
    - An impromptu set of measurements that we took when there were large wildfires in southern California in October 2003.



Field Experiments

– Unique capabilities of polarization
  - Polarization is not only sensitive to aerosol absorption in the blue/UV (like TOMS, OMI etc) but also allows you to get an aerosol transport model independent estimate of absorption.
  - The uncertainties would however be substantially reduced if the layer base height were known, as would be the case with a coincident lidar.



Physical Thickness (km)	SSA	AOT	Mi	Ptop
1.2	0.85	0.56 (0.01)	0.032 (0.0015)	560 (10)
2.4	0.83	0.59	0.035	559 (10)

- A practical approach to dealing with layer depth is to assume that it has zero pressure thickness. This will provide a result that is biased towards higher ssa and lower optical depth, but that can be readily corrected post-facto if layer thickness information is available.

Field Experiments

- Next Up
  - ARCTAS, summer deployment to measure smoke plumes with in situ measurements so we can evaluate how good/bad the remote sensing estimates of ssa are.