Along Track Polarization Measurements

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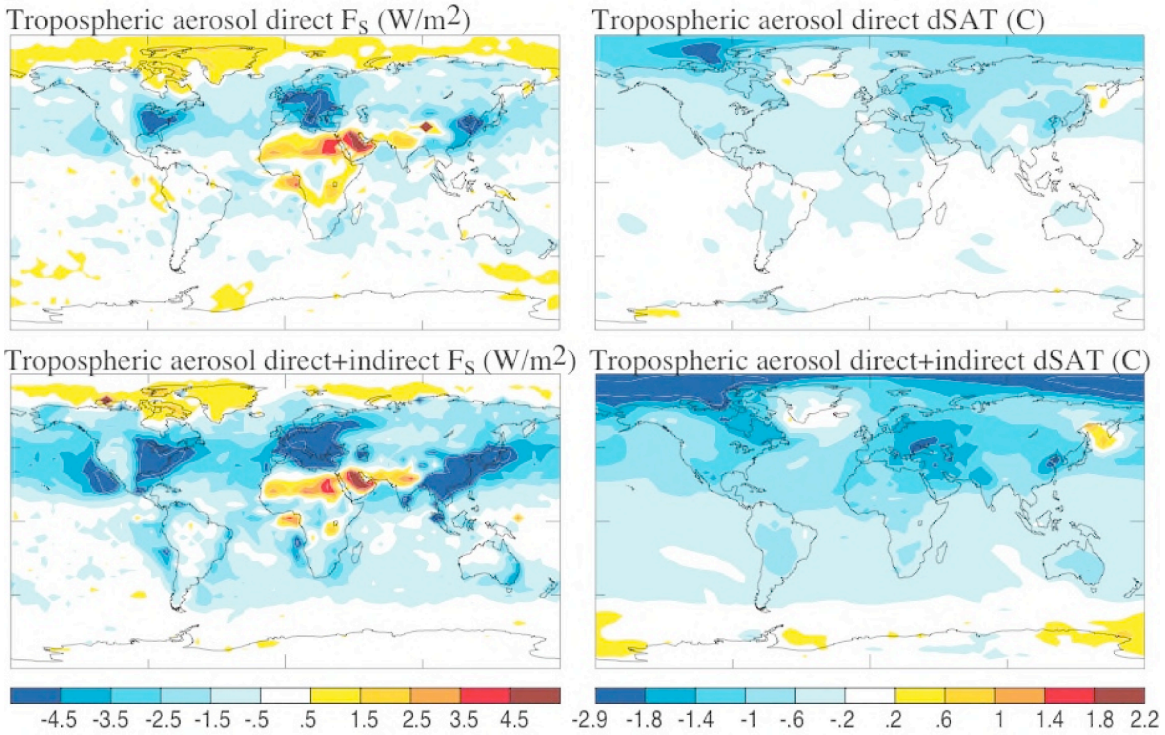
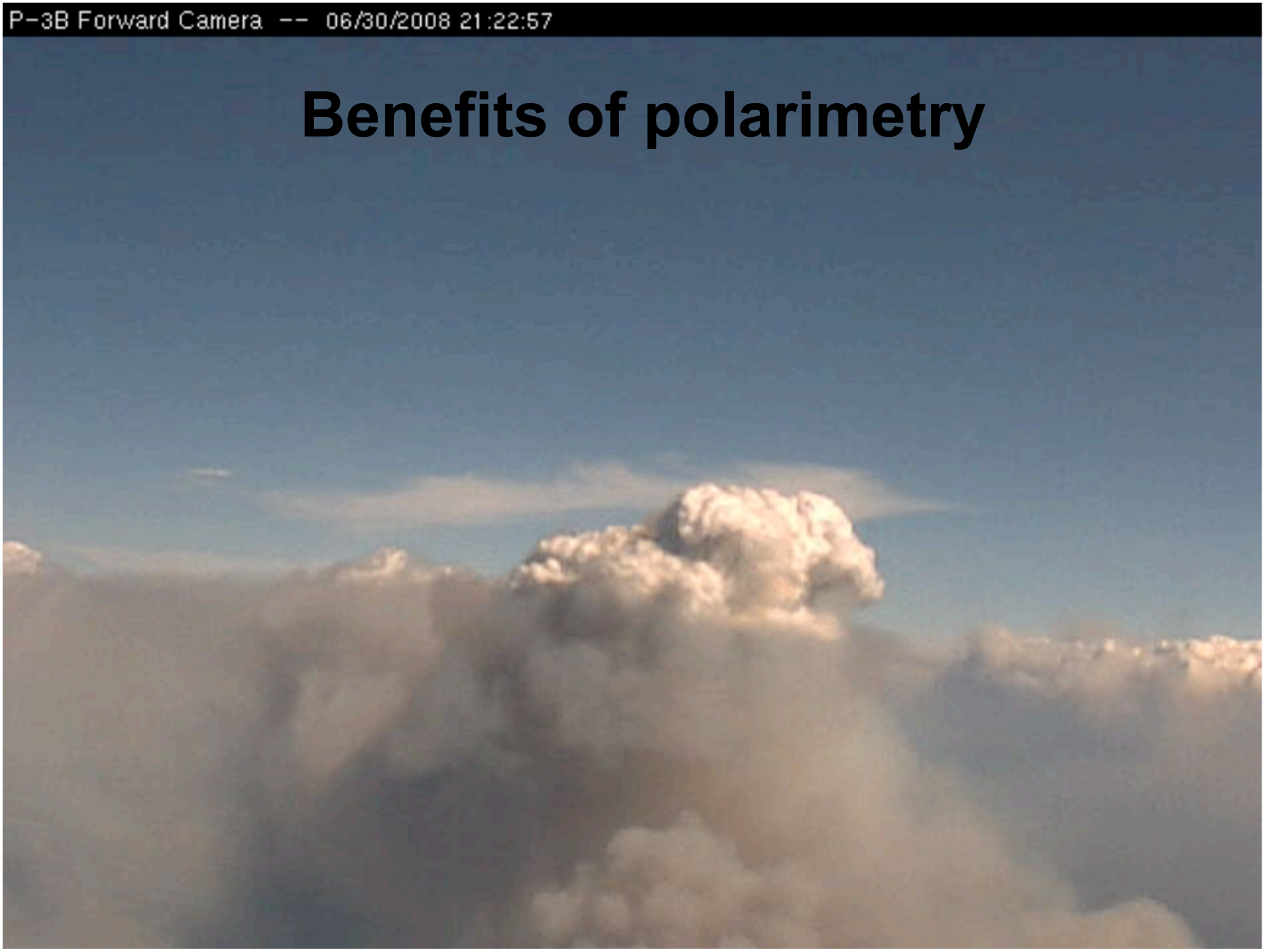
Climate Benchmarks

- Global mean preindustrial to present-day aerosol forcing from Shindell and Faluvegi (Nature Geoscience, 2009) is -1.31 ± 0.52 W/m^2.



Climate Benchmarks

- Regional Forcings:
  - When a forcing is spatially concentrated, the regional climate response does *not* closely follow the spatial pattern of the forcing.
  - Black carbon contributed 0.9 ± 0.5°C to 1890-2007 Arctic warming (which has been 1.9°C total), making BC potentially a very large fraction of the overall warming there.
  - Aerosols in total contributed 1.1 ± 0.8°C to the 1976-2007 Arctic warming.
    - This latter aerosol contribution to Arctic warming results from both increasing BC and decreasing sulfate.
    - Total observed Arctic warming during 1976-2007 was 1.5 ± 0.3°C. One way to think of this is that there is a 50% chance that aerosols contributed about 70% of the observed warming.
  - Since reducing black carbon emissions can have significant human health impacts it is the only policy change that is likely to be implemented in the near term.
  - If CLARREO cannot monitor the changing aerosol forcing this would represent a significant deficiency in its capability to provide a climate benchmark.

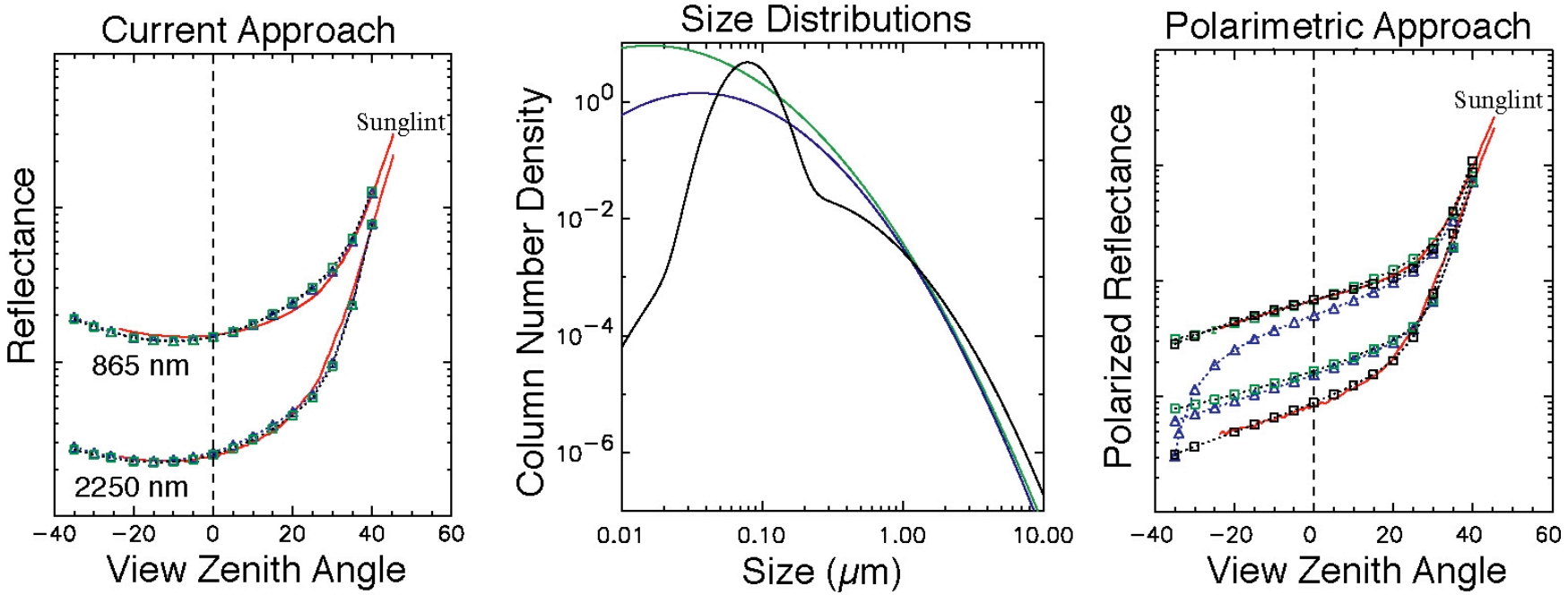


Benefits of polarimetry

Benefits of polarimetry

Why use polarimetry:

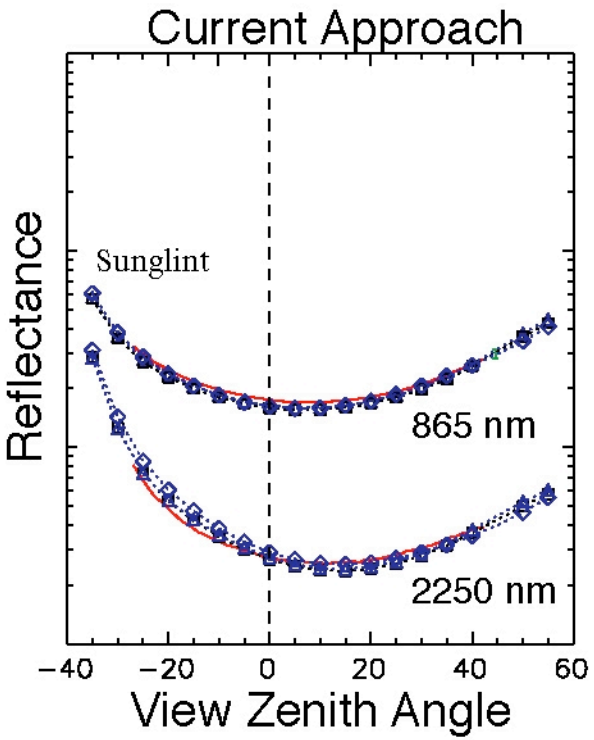
- Measure something that is sensitive to the aerosol composition.
- Multi-angle polarization measurements provide better constraints on aerosol size and composition

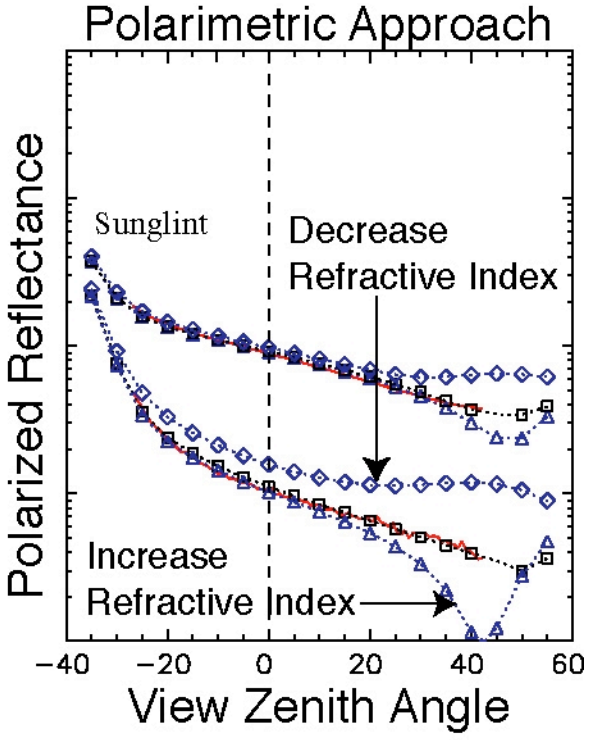


Benefits of polarimetry

Why use polarimetry:

- Variations in refractive index of ±0.05 are indistinguishable from variations in size and optical depth if only radiance measurements are available.

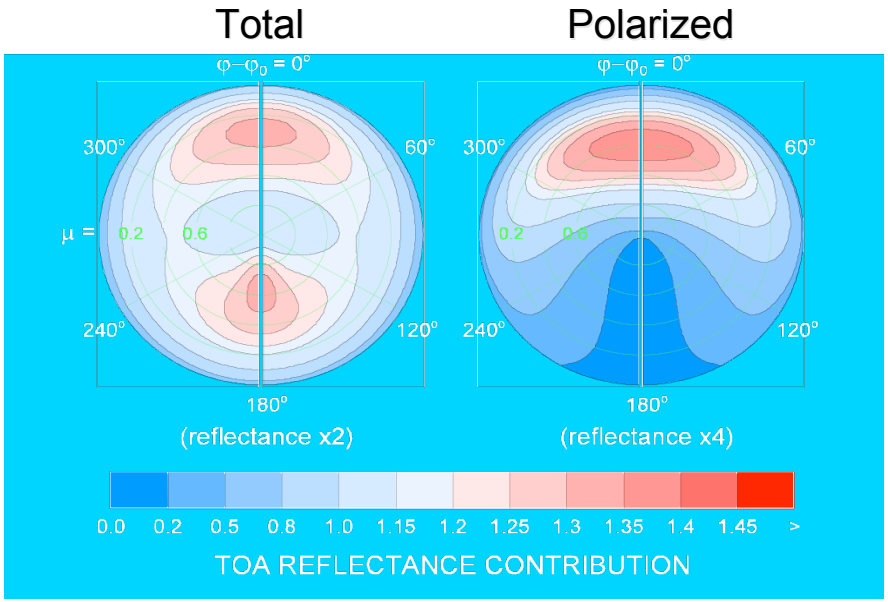




Benefits of polarimetry

Why use polarimetry:

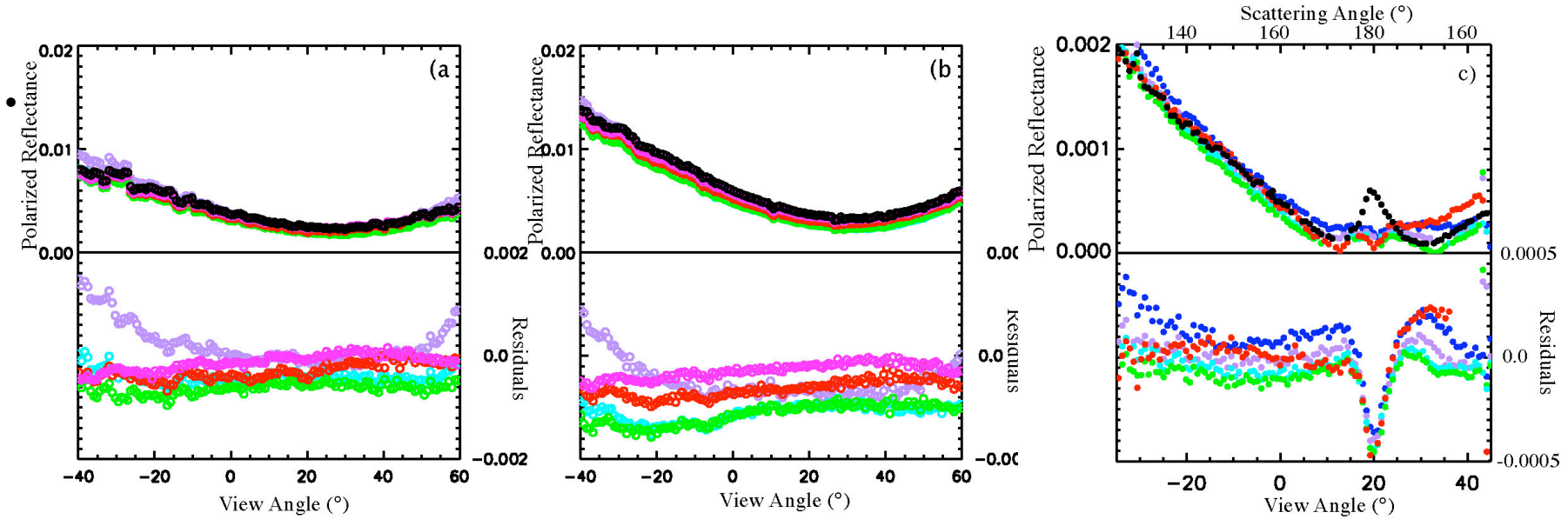
- Polarized reflectance of the ocean body has a weaker and very different dependence on Chlorophyll concentration to that of the reflectance.
- BRDF shape of polarized ocean body reflectance is spectrally invariant,



Benefits of polarimetry

Why use polarimetry:

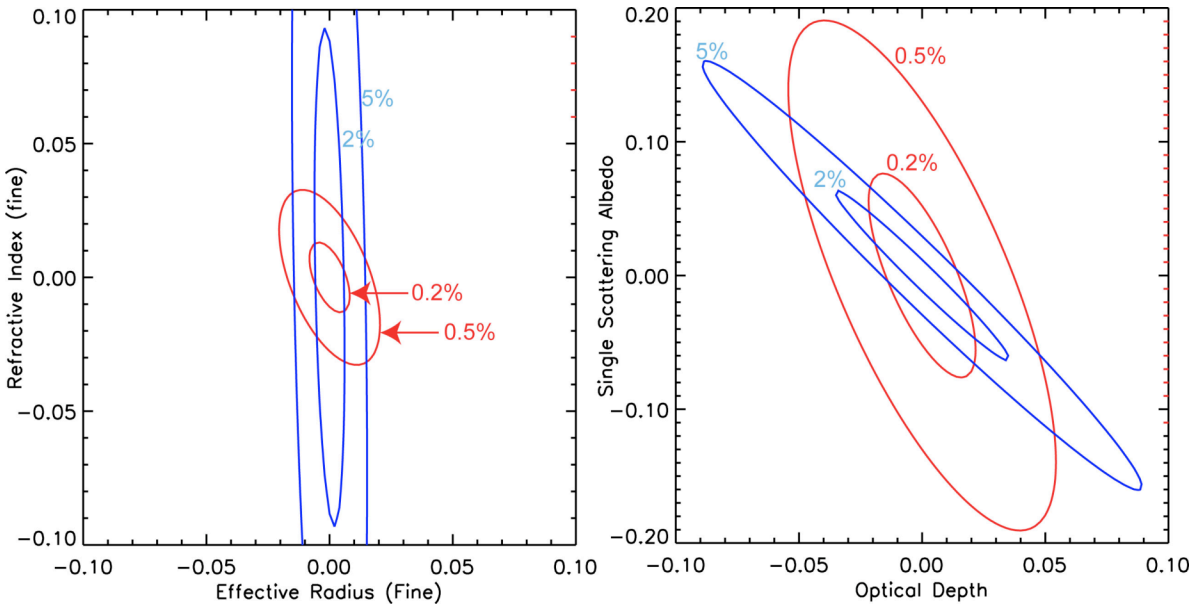
- Not only is BRDF shape constant for polarized reflectance of land surfaces, but the surface polarized reflectance is also grey.
- This does not mean that there is no contrast between different surface types.
  - This means that polarization measurements should have good suppression of false polarization in order to be effective. (APS < 0.3% for 100% sub-pixel contrast.)



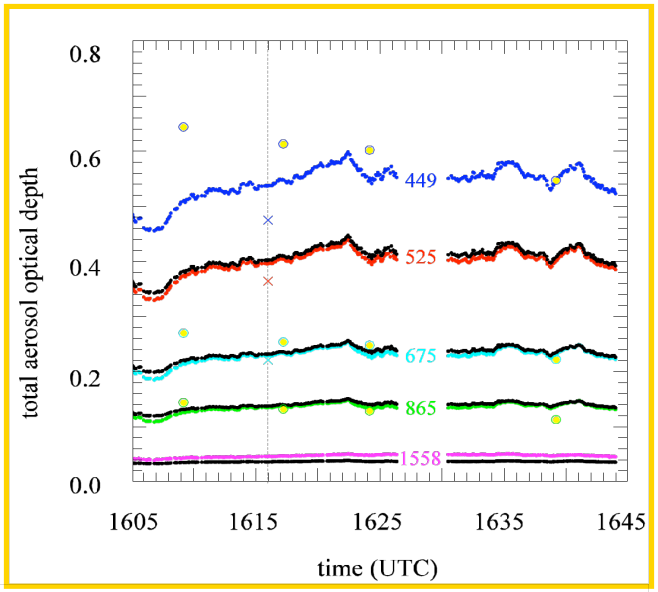
Benefits of polarimetry

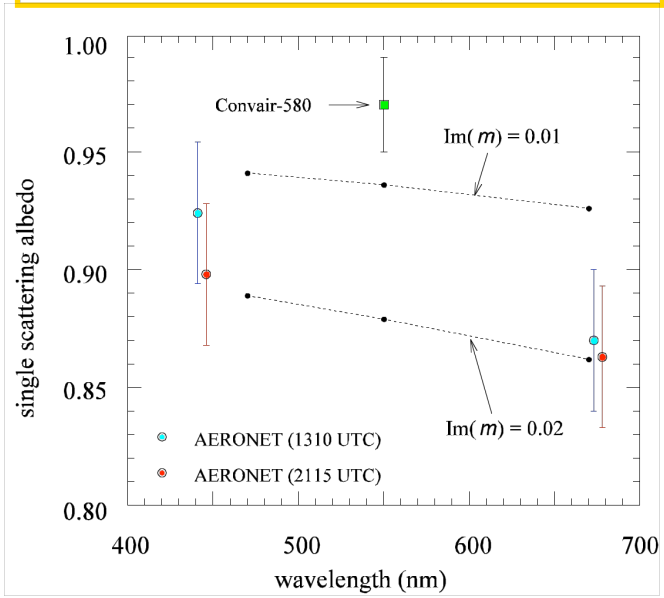
Why use polarimetry:

- Combining accurate polarimetric and radiometric measurements over a wide-view angle range allows the maximum amount of information (decrease in volume of the retrieval space compared with prior) to be retrieved about the aerosol composition, size and burden.
- Since the aerosol spectral properties are smooth this information is not present in the spectrum.



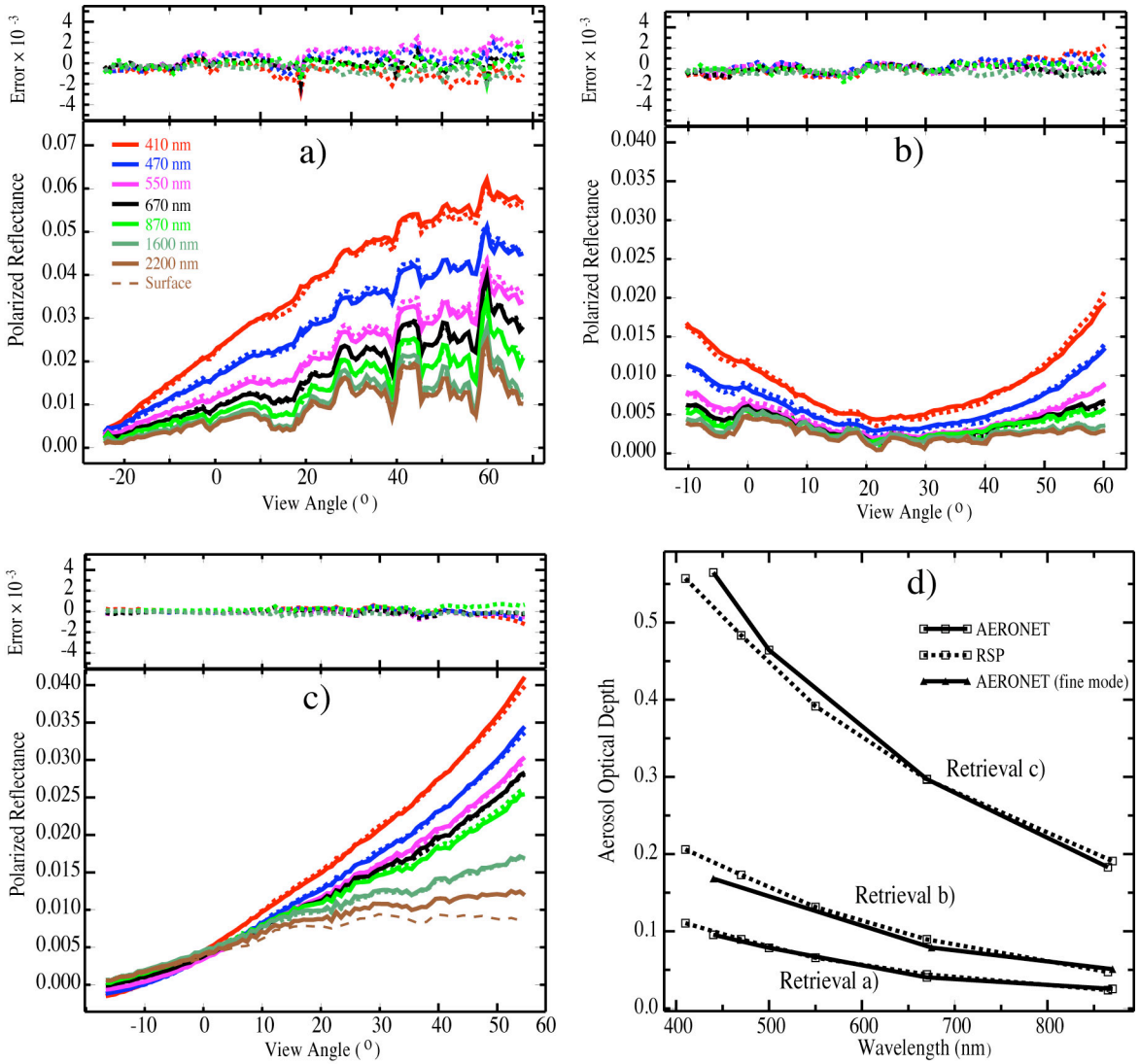
Benefits of polarimetry





- Aerosol retrievals over the ocean are more accurate than over land because the lower boundary condition is better constrained. Example here is from CLAMS.
- d_g retrieved is 0.23 μm while in situ (dry) value is 0.19±0.02 μm
- Ocean color model that also predicts polarization has been validated during CLAMS and MILAGRO.
- Absorption/ssa estimates require simultaneous estimate of aerosol mixed layer depth.

Benefits of polarimetry



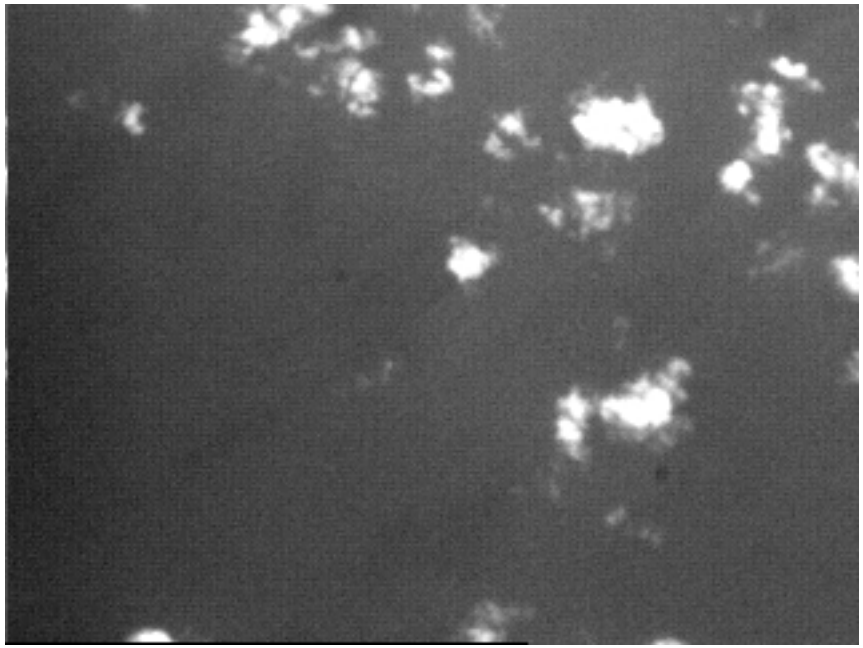
- Polarization is sensitive to the aerosol load over land, even over urban areas (c, Mexico City).
- Not only can the aerosol burden be identified, but the spectral and angular signature in the polarized reflectance is sensitive to the complex refractive index (1.54 + *i* 0.027) and the single scattering albedo (0.865).
- These retrieval examples are over an effective “pixel” size of 10 km since the multiple views are instantaneous and are NOT aggregated to the same point at the surface.

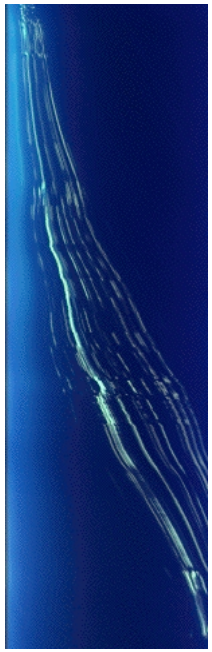
Benefits of polarimetry

Benefits of polarimetry

Why use polarimetry:

- Sub-pixel clouds and cloud contamination are suppressed in polarized reflectance.
  - Left panel shows image from camera, right image shows RSP scans concatenated as an image as if it were a push broom imager.
  - Because of cloud/aircraft motion a small cloud may not be seen from all directions. The clouds here are around 100 m in size.

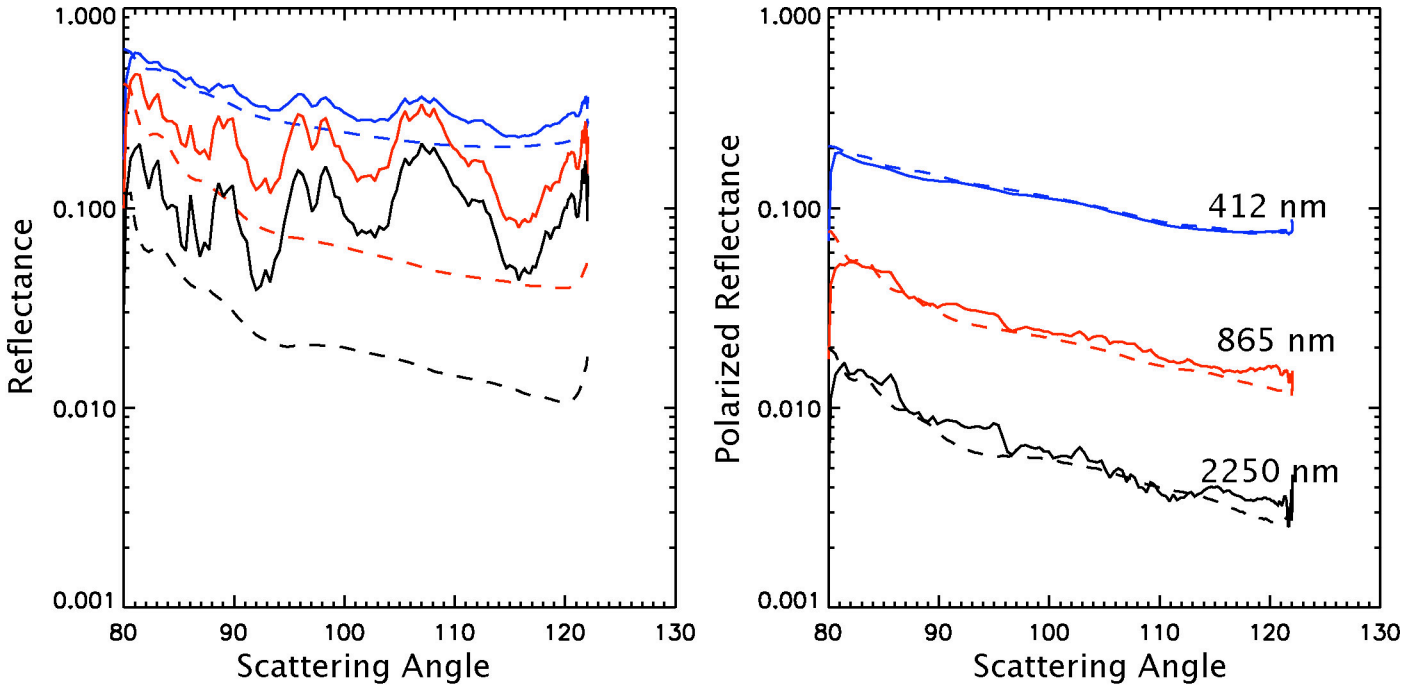




Benefits of polarimetry

Why use polarimetry:

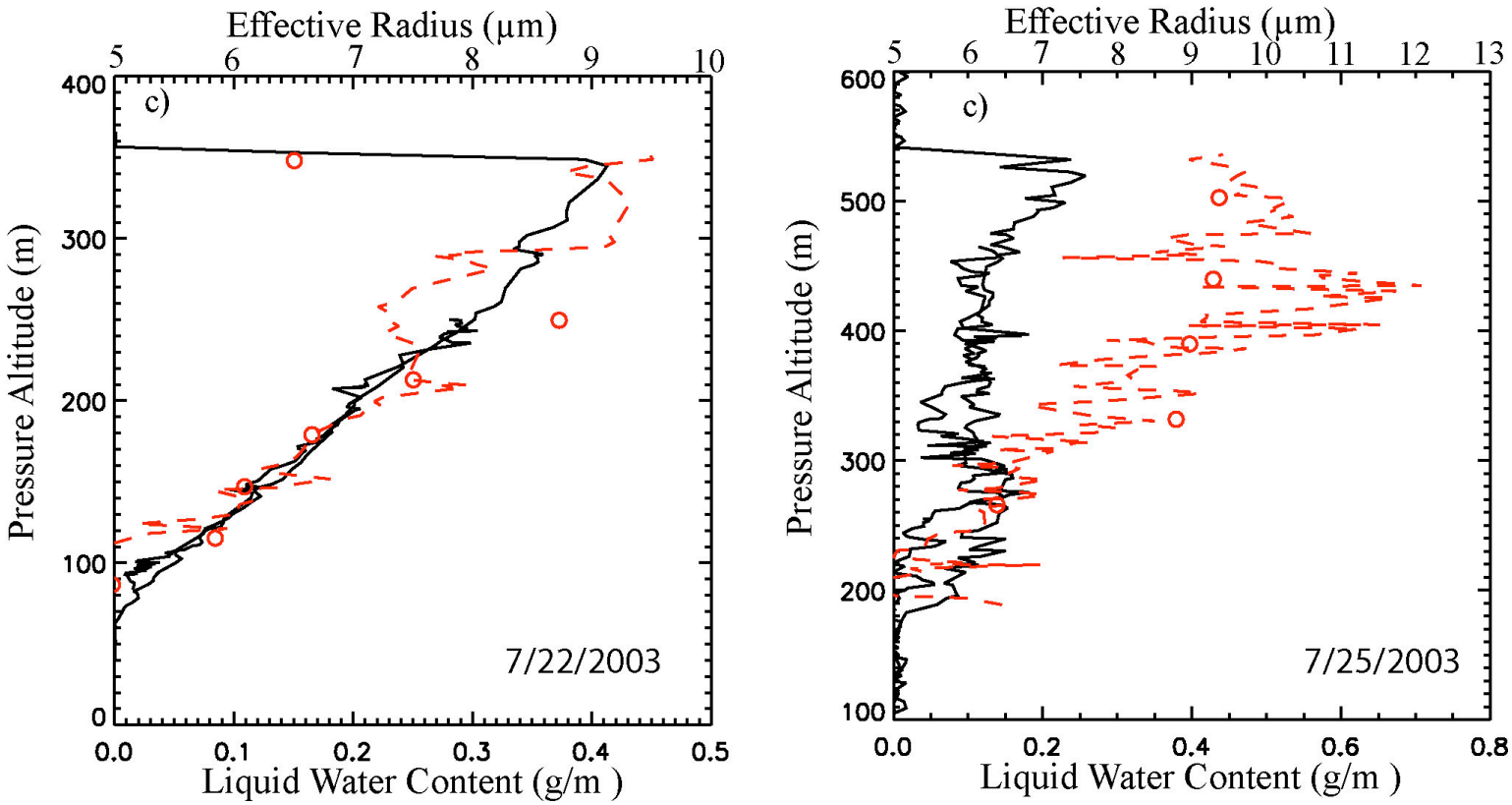
- Clouds are black!
  - Solid lines are for a partially cloudy pixel (sometimes see the cloud sometimes not). Dashed lines are for a nearby (2 km) clear pixel. Reflectance changes by order of magnitude at 2250 nm while effect on polarized reflectance is small.



Benefits of polarimetry

Why use polarimetry:

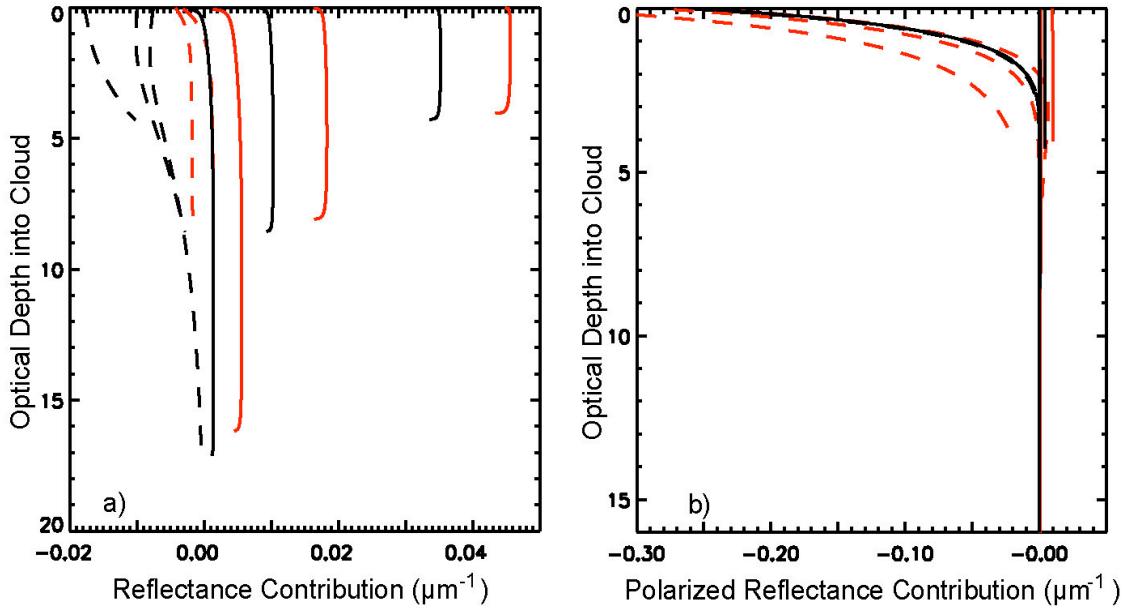
- To assess the impact of aerosol on cloud albedo and cloud life cycle, unambiguous & quantitative retrieval schemes of both LWP and N_{act} are necessary, Brenguier 2006.



Benefits of polarimetry

Why use polarimetry:

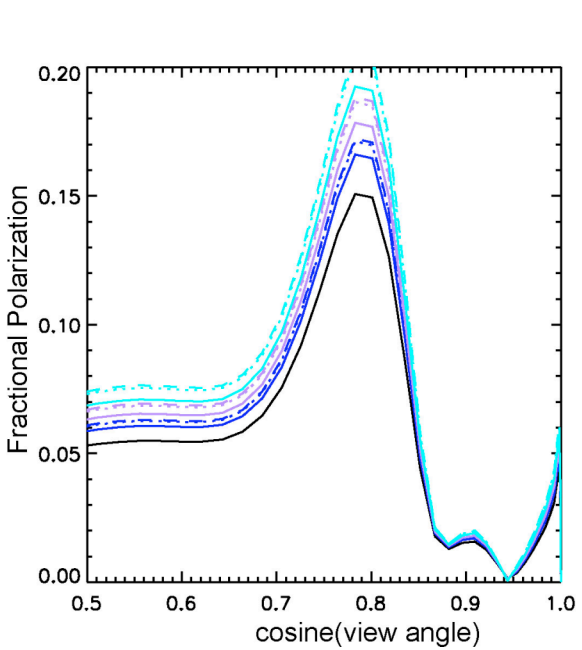
- Polarized reflectance and reflectance measurements have differential sensitivity to vertical variations in particle size.
- A parametric estimate of vertical profile is possible without assuming an adiabatic profile (cf Brenguier, Schüller and co-workers)

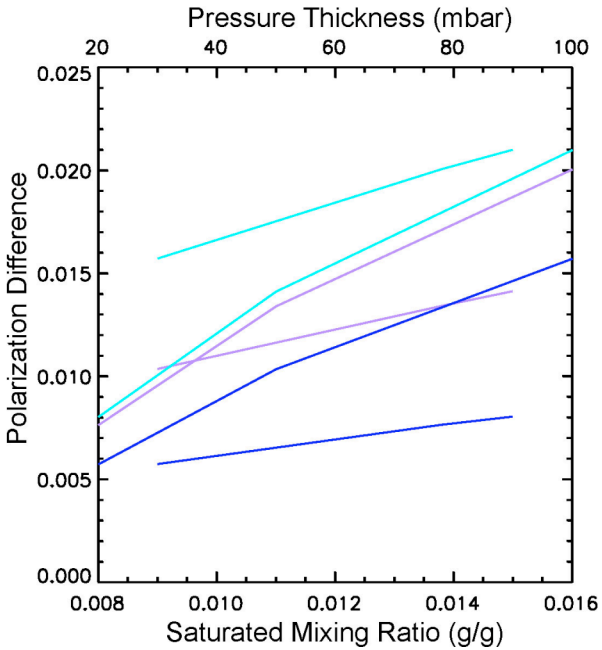


Benefits of polarimetry

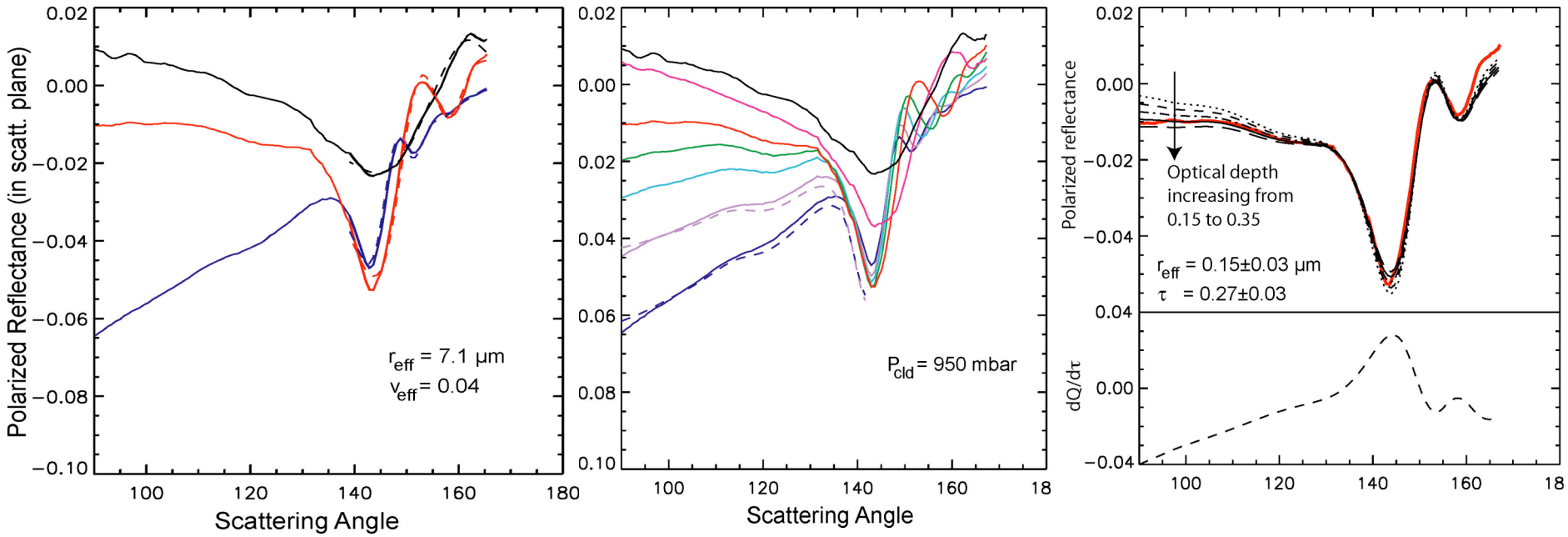
Why use polarimetry:

- Increase in polarization caused by in-cloud absorption when looking at difference between 865 and 910 nm measurements provides estimate of cloud physical thickness.
- Errors in estimated cloud height (temperature) will affect the estimated saturated mixing ratio and therefore the pressure thickness. Few cases tested are ±20 mbar.



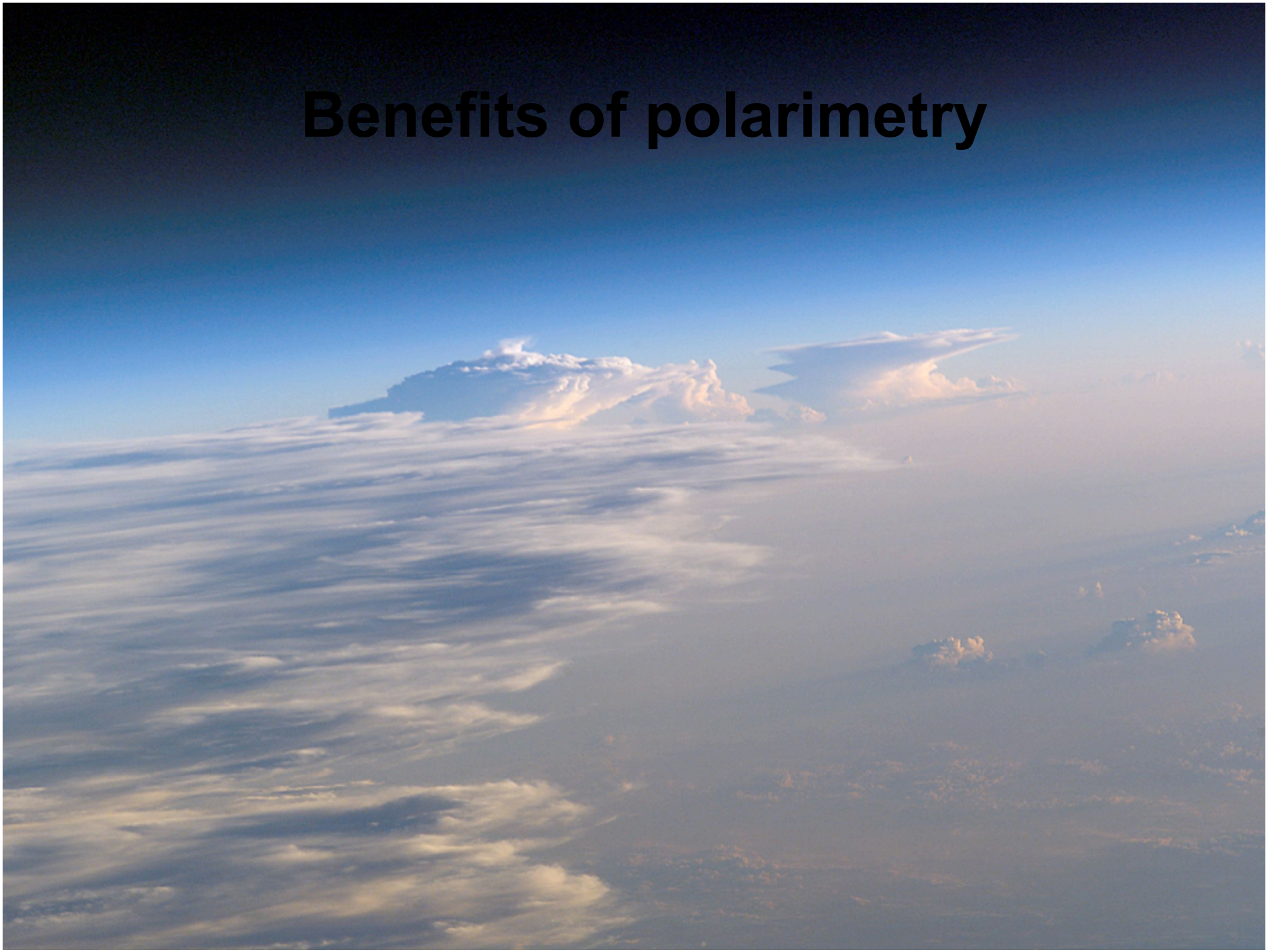


Benefits of polarimetry



Polarized observations of clouds are sensitive to the cloud droplet size distribution (rainbow), the cloud top pressure (side scattering in the blue UV) and aerosols above the cloud (side scattering in the red/NIR/SWIR).

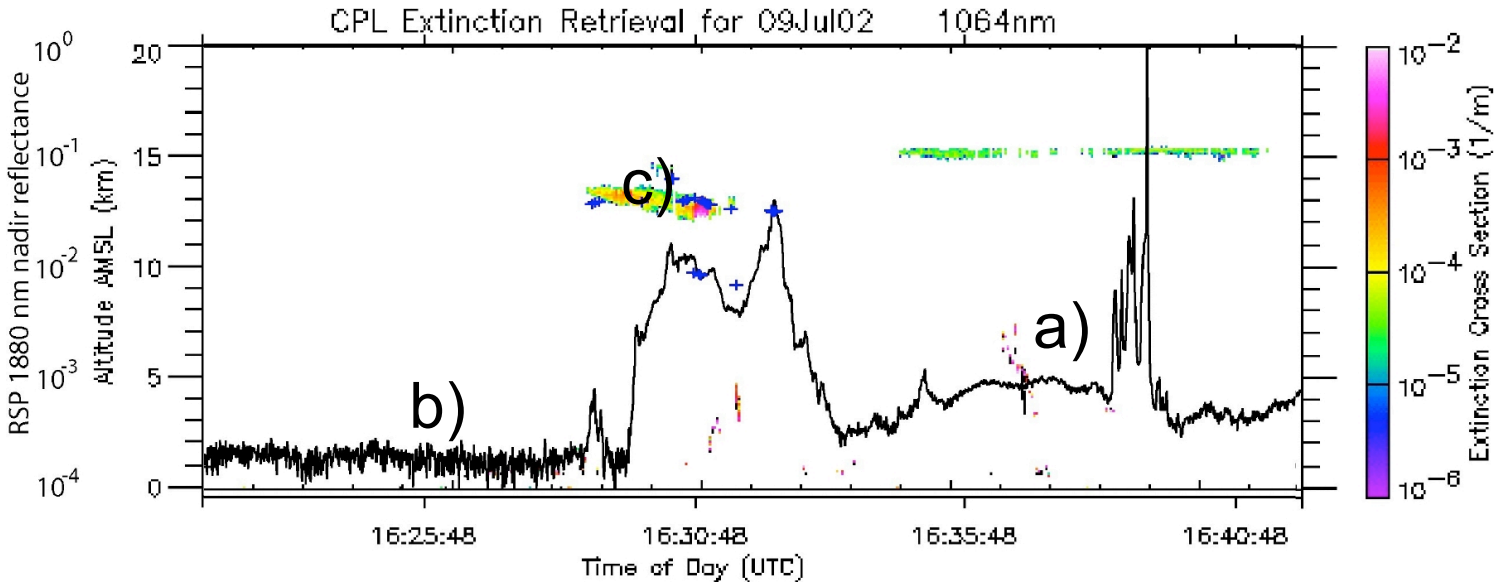
Benefits of polarimetry



Benefits of polarimetry

Why use polarimetry:

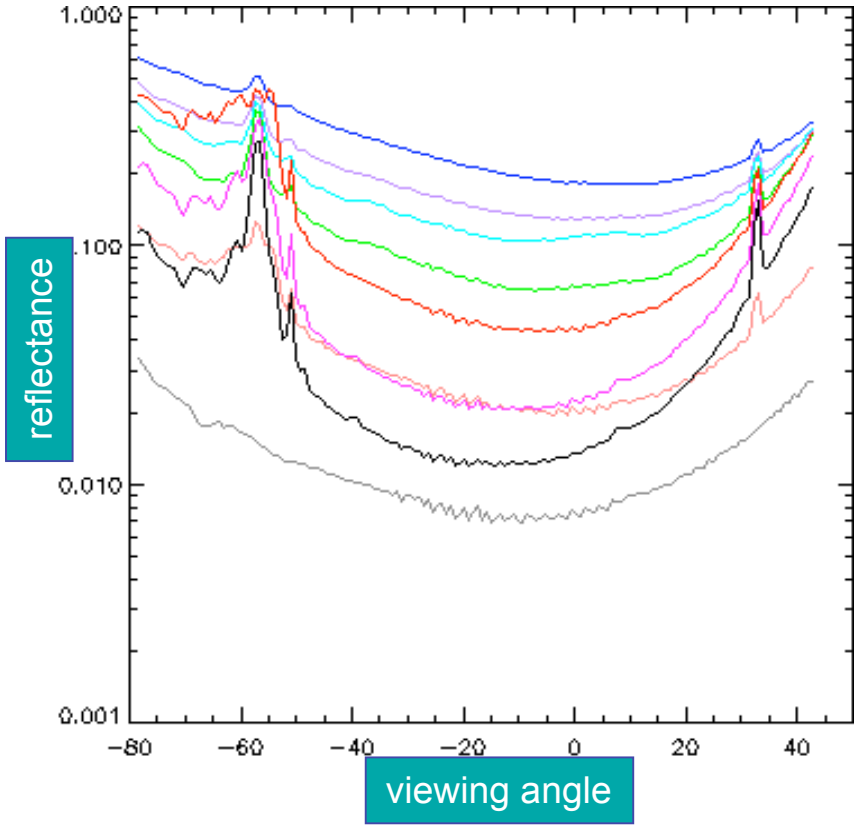
- Detection and remote sensing of ice clouds is important to ensure that aerosol retrievals are not being contaminated by thin cirrus clouds and to determine the radiative effects of these very cold clouds.
  - a) COD=0.007 and r_{eff}=20 μm size assuming a fractal shape.
  - b) Clear skies with a Rayleigh optical depth of 0.00025.
  - c) Pressure height estimate for cloud top is accurate to ±2km for COD of 0.1

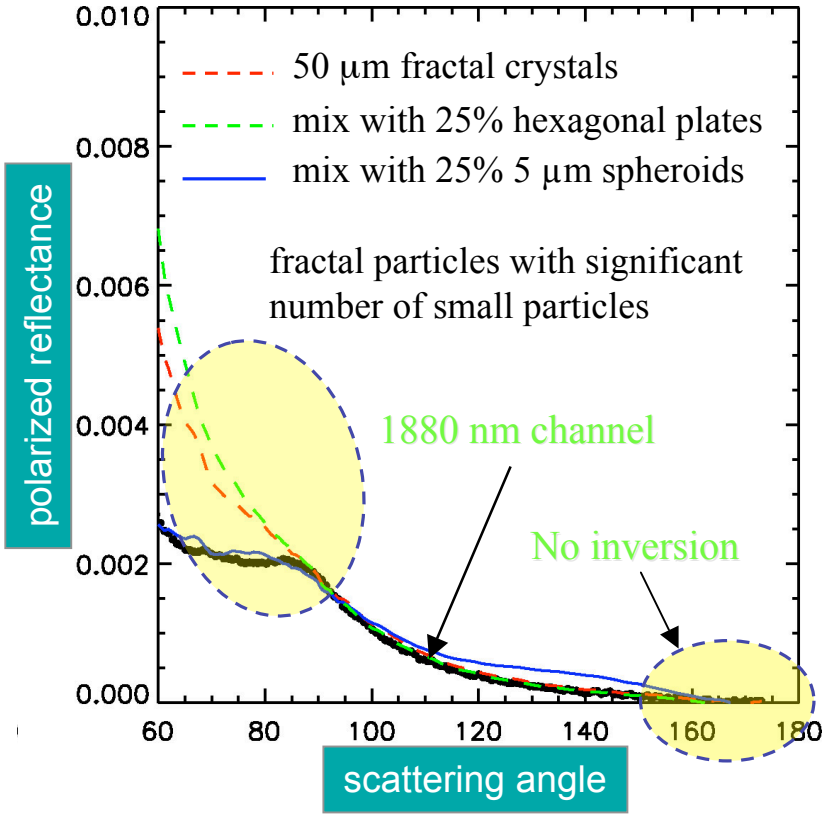


Benefits of polarimetry

Why use polarimetry:

- Use 1.88/1.37 µm data to mask lower (< 3 km) cloud layers & surface
- Optical depth (0.1) & size distribution in agreement with lidar & in situ data
- Polarized reflectance constrains shape with consequent benefits for particle size estimates





Benefits of polarimetry

All polarimeters are not created equal:

- Need to suppress false polarization for effective use over land.

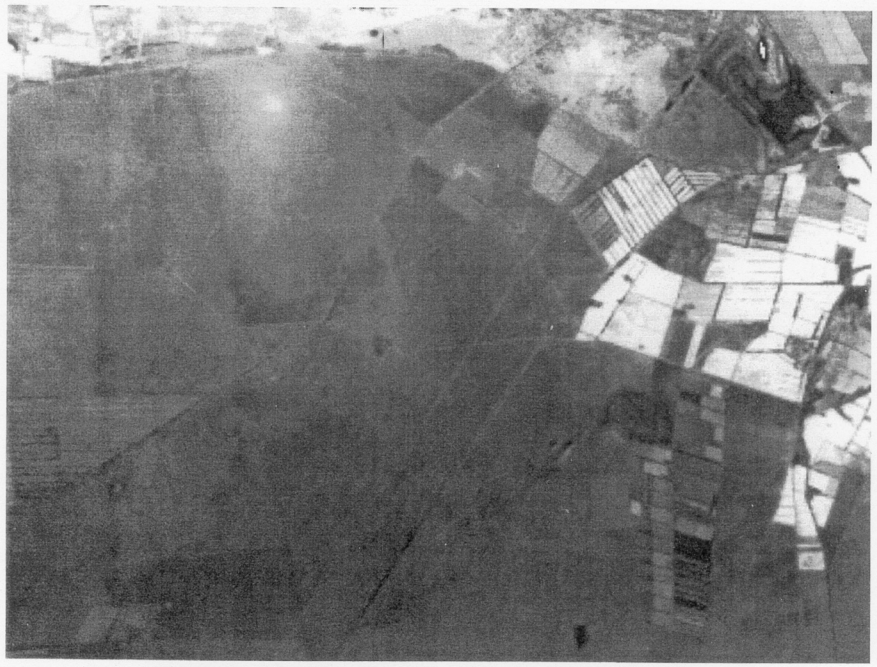


Figure 4. Example of Polarization and Directionality of the Earth Reflectances (POLDER) image data for radiance measurements at $\lambda = 865$ nm. Measurements acquired on June 23, 1991, over the area of La Crau. The middle part of the picture is the Centre National d'Etudes Spatiales calibration site consisting in bare soils (pebbles, sparse vegetation). The normalized radiances range from 0 to 0.40.

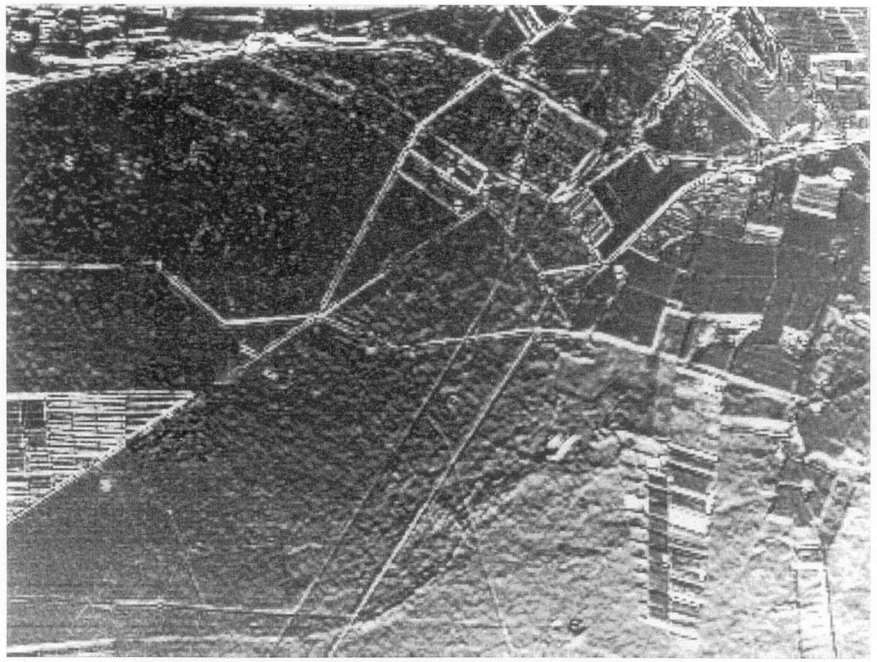
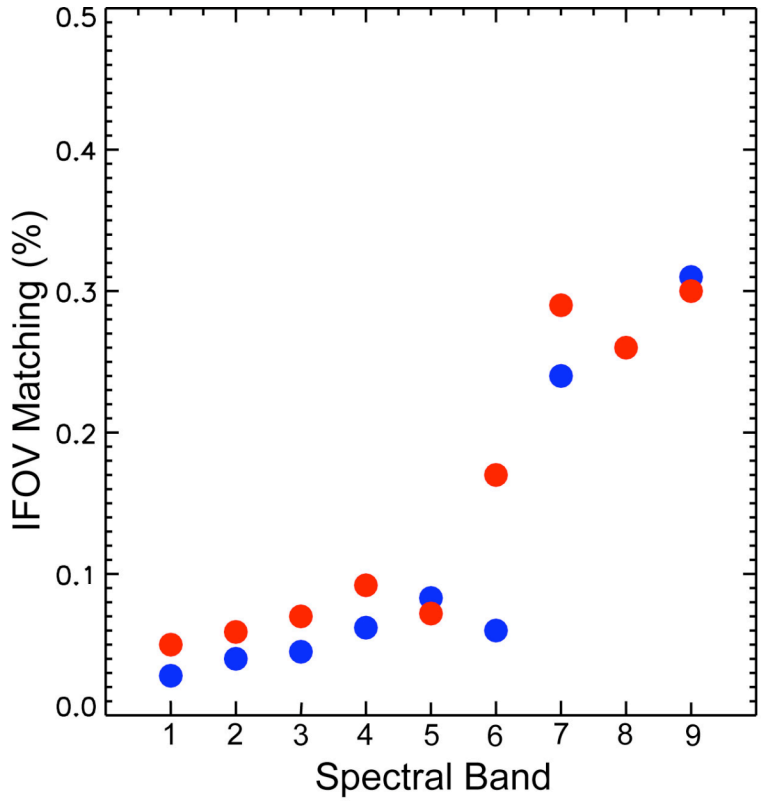


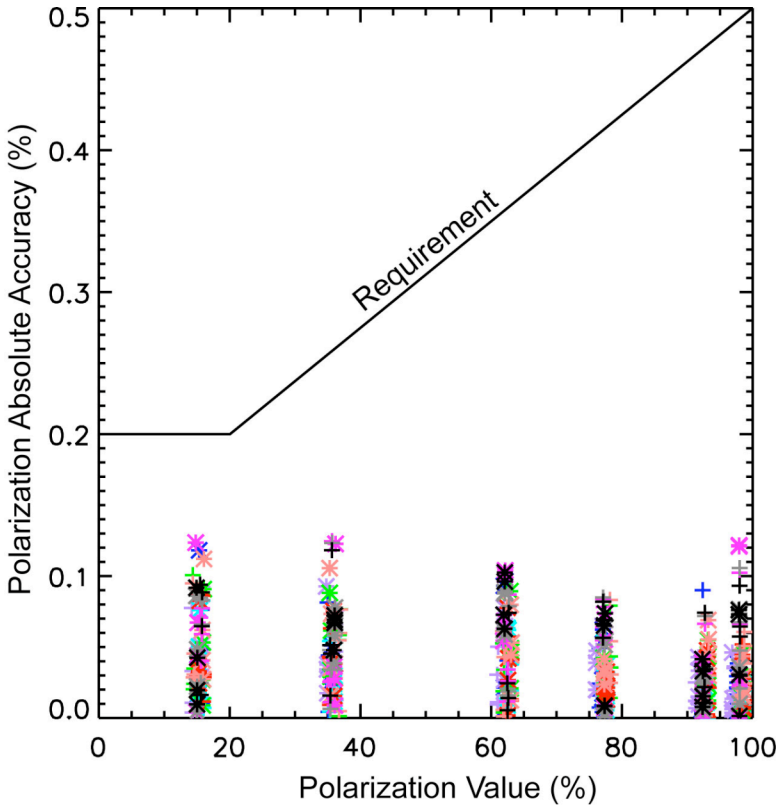
Figure 5. Same as in Figure 4 but for polarized radiance measurements. The normalized polarized radiances range from 0 to 0.015. The picture is a composite of three pictures acquired with different polarizers, which explains polarization artifacts due to misregistrations between adjacent areas with contrasted reflectances.

Benefits of polarimetry

All polarimeters are not created equal:

- IFOV matching of 0.3% or better for APS means that even when a broken cloud field over ocean is being observed the measurements will be accurate to better than 0.15% (CS inequality).

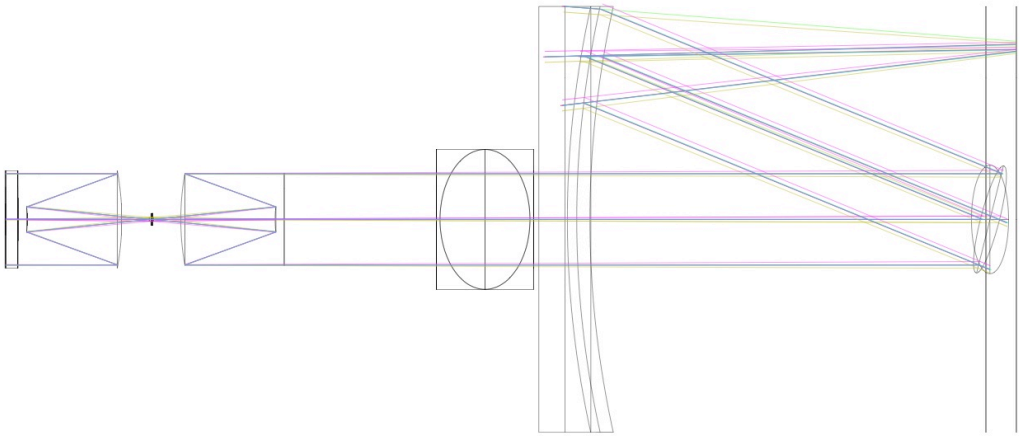




Benefits of polarimetry

All polarimeters are not created equal:

- Using a spectrometer for spectral analysis is relatively straightforward for an APS-like instrument.
- Adding cross-track coverage is possible but there are always penalties in terms of complexity, cost, accuracy, SNR etc.
- If you know what you want you can make the best trade between these various parameters.



Summary

Why use polarimetry:

- Measure something that is sensitive to the state of the climate.
- Measurements can be made with sufficient accuracy that the sensitivity can be used.
- Minimize impacts of surface on observations of atmosphere and allow for its effects to be characterized.

Making polarization measurements:

- False polarization is unacceptable.
- Good SNR is necessary otherwise accuracy of measurements cannot be effectively used.
- Broad spectral and angular range is necessary for aerosol radiative forcing applications.