International Workshop on
"Remote Sensing of Atmospheric Aerosol, Clouds, and Aerosol-Cloud Interactions"
Bremen, Germany, 16-19 December, 2013

Cloud and Aerosol Remote Sensing with AirMSPI

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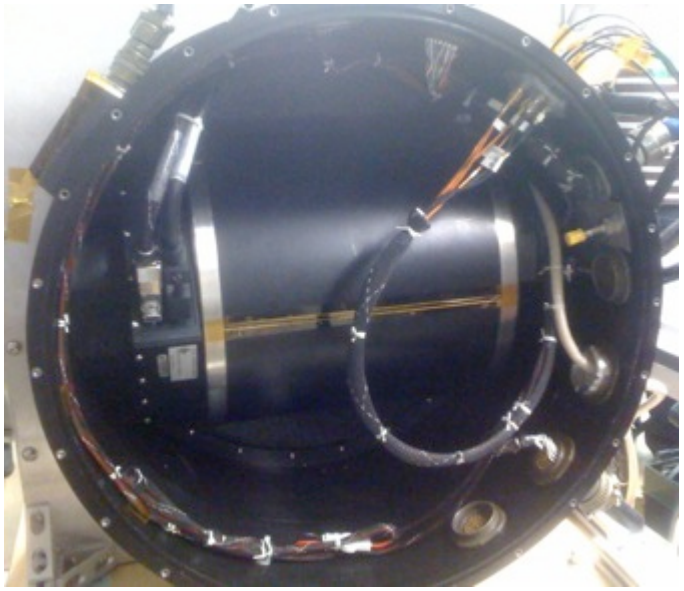
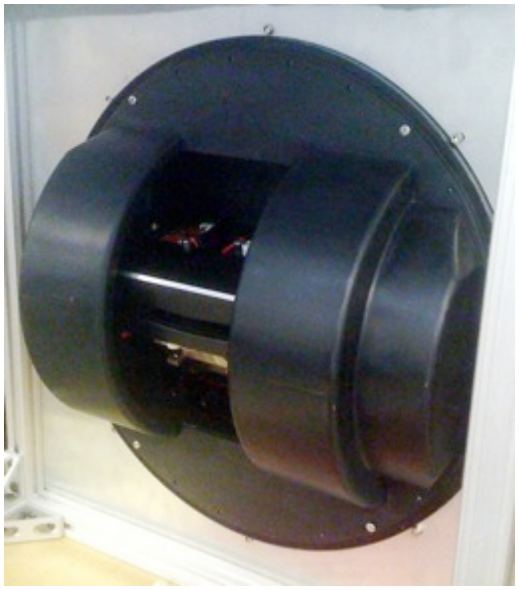
Outline

- Airborne Multi-angle Spectro-Polarimetric Imager (AirMSPI)
- Campaigns
- Aerosols
- Clouds
- Aerosols over clouds
- Discussion …

AirMSPI





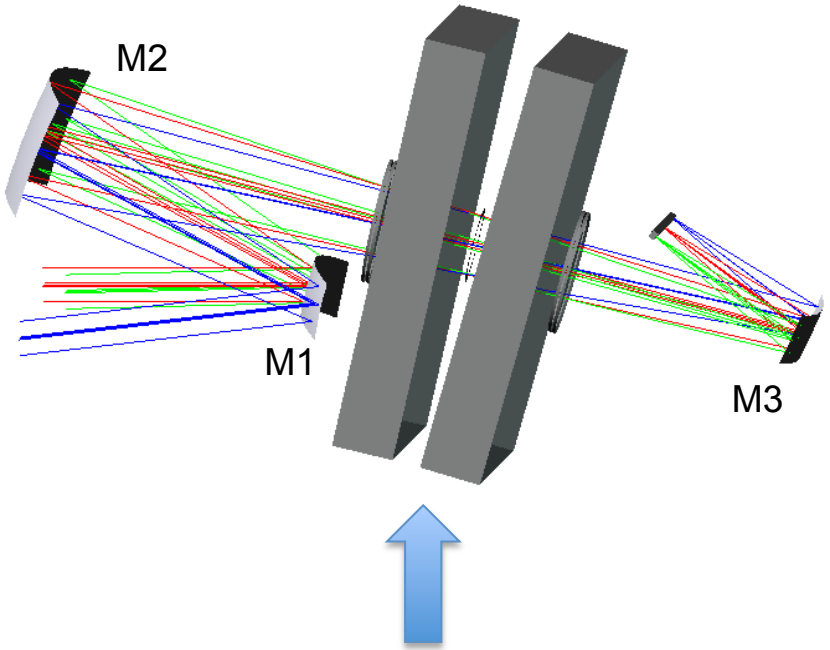
Spectral bands:

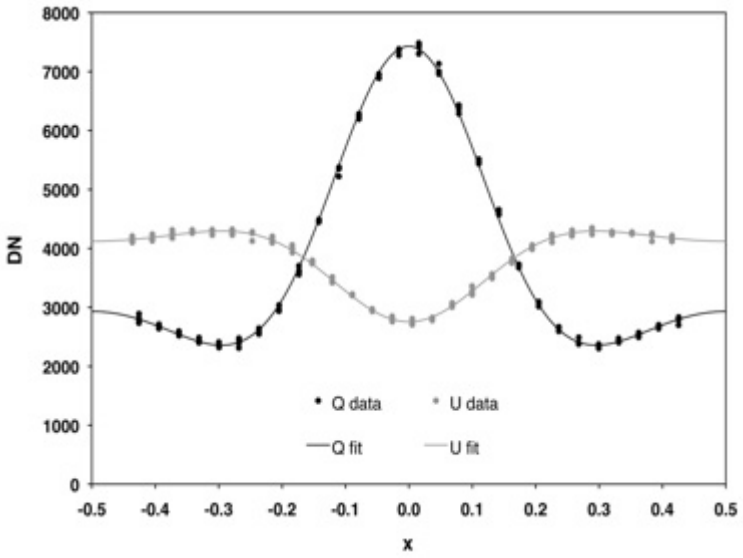
355, 380, 445, 470*,555, 660*, 865*, 935 nm (*polarimetric)

The AirMSPI camera flies in the nose of NASA's ER-2 aircraft (20 km flight altitude)

AirMSPI is mounted in a gimbal for multi-angle viewing between ±67°

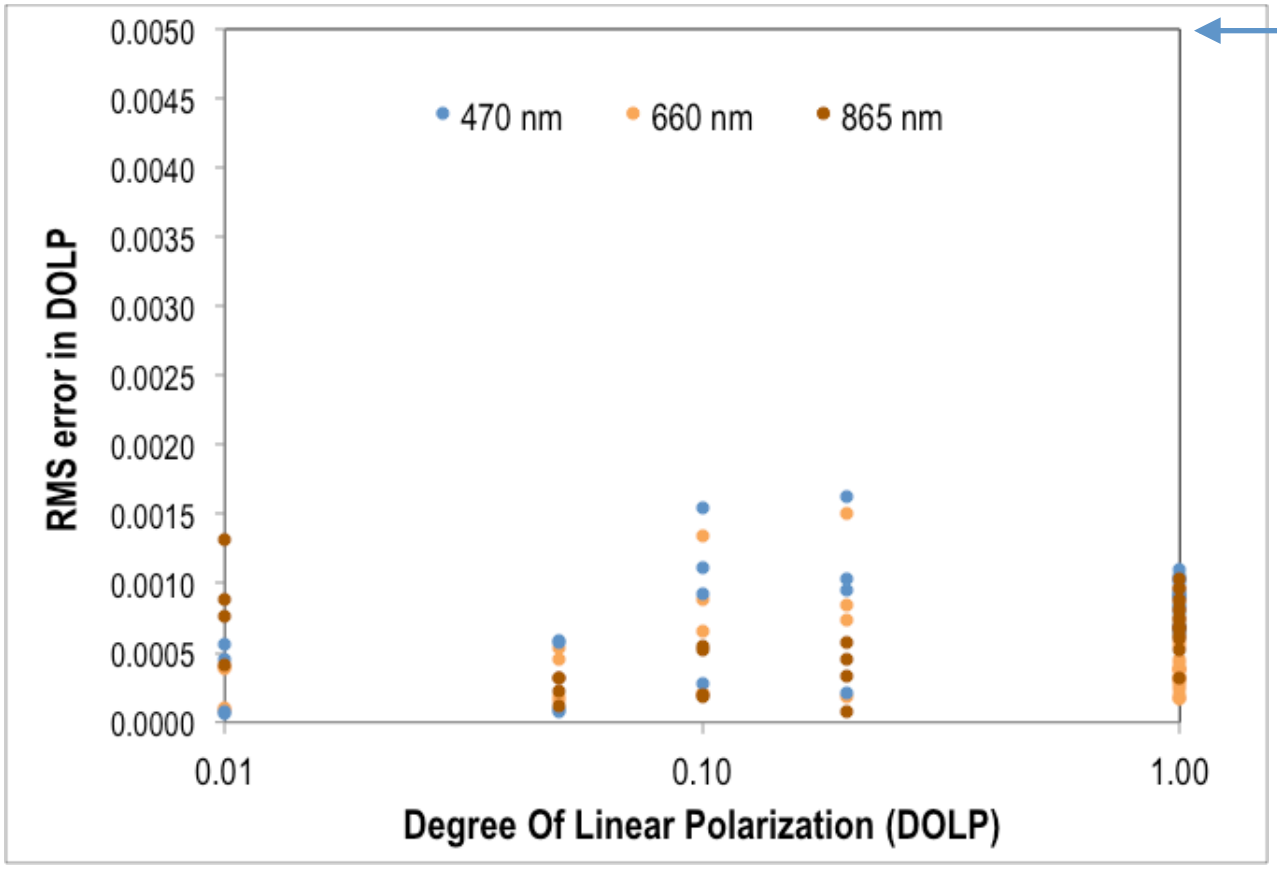
Dual-PEM polarimetric imaging approach





- Photoelastic modulators (PEMs) time-modulate the linear Stokes components *Q* and *U* – leaving intensity *I* unmodulated
  - Enables retrieval of $q = Q/I$ and $u = U/I$ as *relative* measurements
  - Degree of Linear Polarization, DOLP = $(q^2 + u^2)^{1/2}$

Polarimetric uncertainty

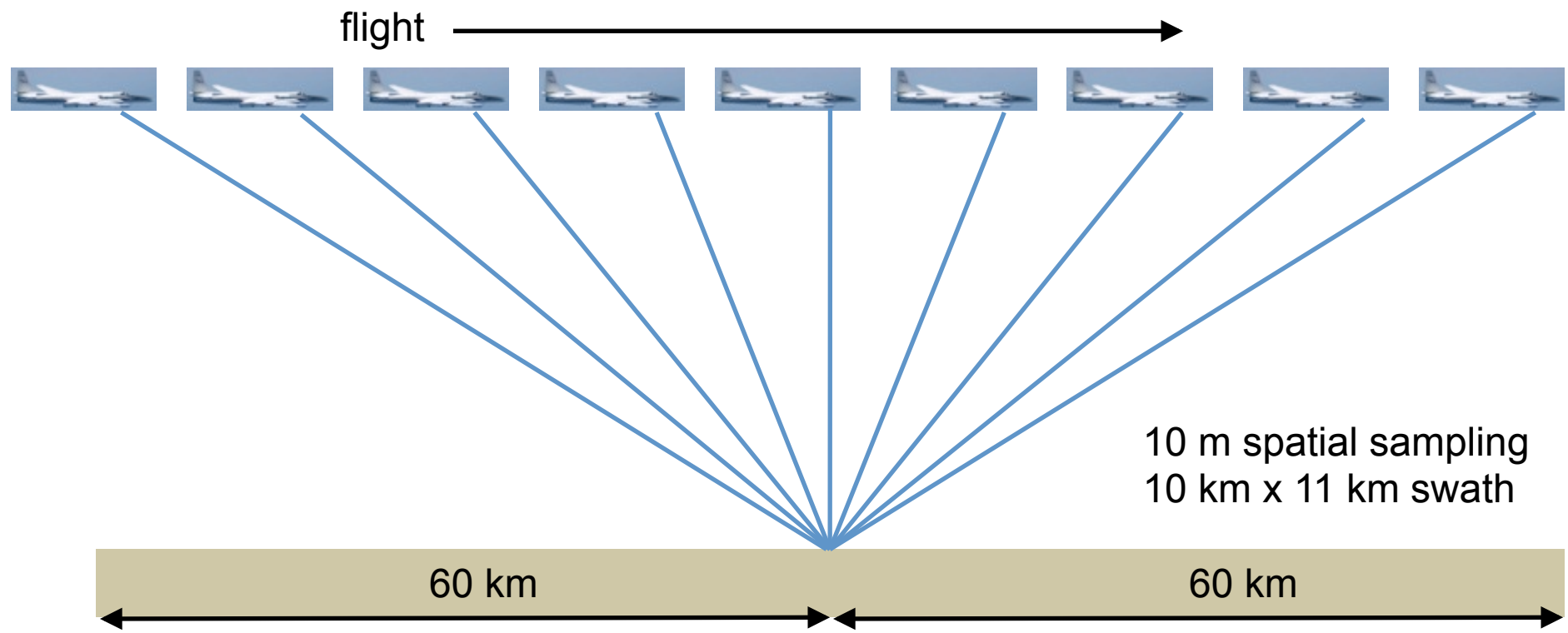


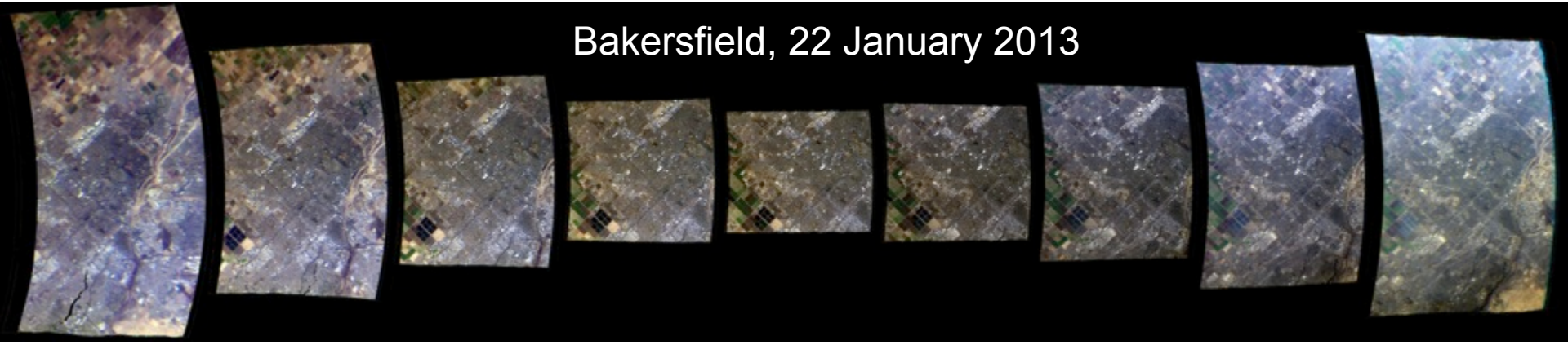
NASA Aerosol-Cloud-Ecosystem (ACE)
DOLP uncertainty requirement:
≤ 0.005

DOLP of 0.01, 0.05, 0.10, and 0.20 measured for polarizer angles 0º, 45º, 90º, 135º

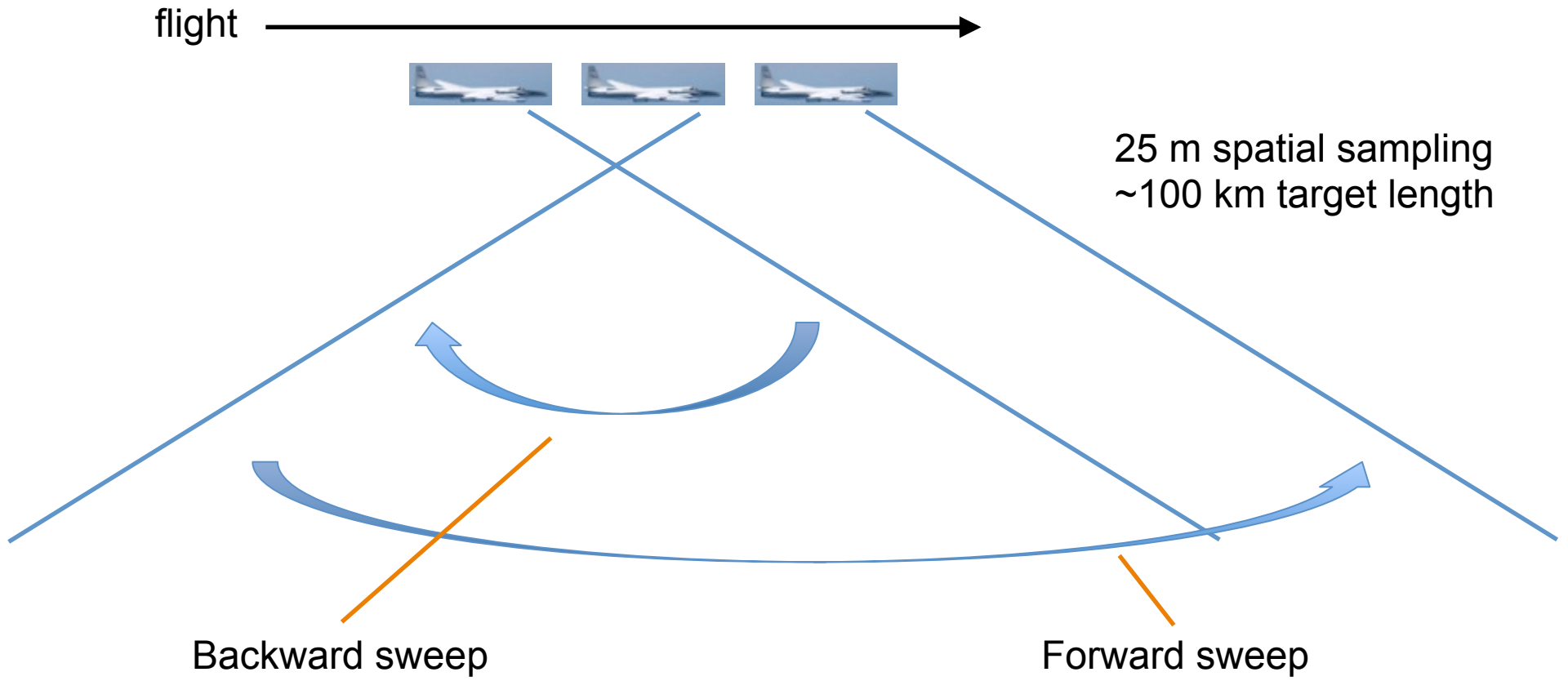
DOLP of 1.0 measured for polarizer angles 0º(10º)170º

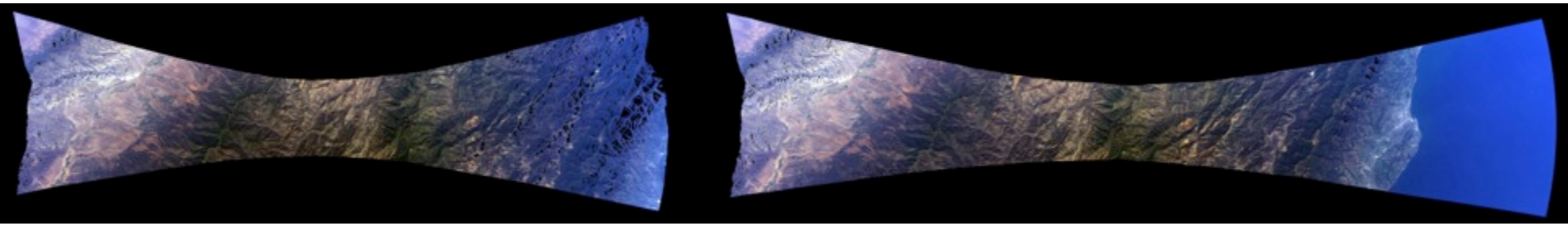
“Step and stare” imaging





“Sweep mode” imaging





Santa Barbara, 1 August 2013

2013 field campaigns

- ACE Polarimeter Definition Experiment (PODEX)
  - Jan 14, 16, 18, 22, 28, 31; Feb 1, 3, 6: California
  - In conjunction with DISCOVER-AQ
- Hyperspectral Infrared Imager (HyspIRI)
  - Apr 19; May 3, 7: California

- Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC^{4}RS)
  - Aug 1, 2, 6, 8, 12, 16, 19, 23, 30; Sep 2, 4, 6, 9, 11, 13, 16, 18, 22, 23:
  - Western US, Central US, Southeast US, Honduras, Canada
- Targets
  - Clear ocean with visible wave structure, sunglint patterns
  - Farmland, foothills, mountains, rivers, lakes, urban areas, snow fields, desert
  - Smoke and pollution aerosols
  - Fog, broken stratus, stratocumulus, scattered cumulus, and cirrus
  - Glories, supernumerary bows, cloudbow
  - Calibration targets: Rosamond Dry Lake, Ivanpah Playa, Railroad Valley

Public release of AirMSPI data

AirMSPI data are made publicly available in HDF5 format at the NASA Langley Atmospheric Science Data Center (ASDC)

Documentation available

https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table

2013 date	Availability (engineering/demo-test flights)
14 Jan	Data publicly available at the LaRC ASDC
16 Jan	More data publicly available at the LaRC ASDC
18 Jan	Yet more data publicly available at the LaRC ASDC
3 Feb	Monterey data publicly available at the LaRC ASDC, remainder currently being delivered

Additional data from the 2013 PODEX, HyspIRI, and SEAC^{4}RS field campaigns to be delivered in Winter and Spring 2014

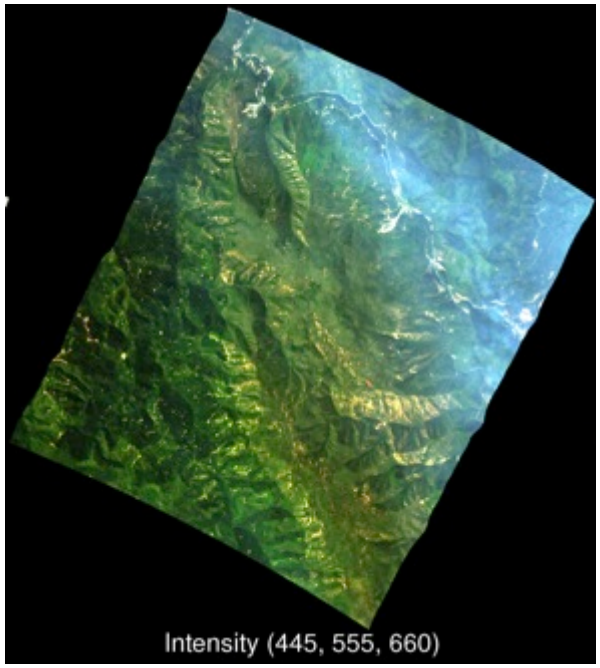
Smoke detection using oblique-angle UV

Oblique viewing angles enhance the presence even very thin smoke

AirMSPI's two UV bands (355nm and 380nm) were used during SEAC^{4}RS to calculate to an absorbing Aerosol Index (AI):

$$AI = -100 \times [\log_{10}(I_{355}/I_{380})_{meas} - \log_{10}(I_{355}/I_{380})_{calc}]$$

(after Herman et al., 1997; Torres et al., 1998)



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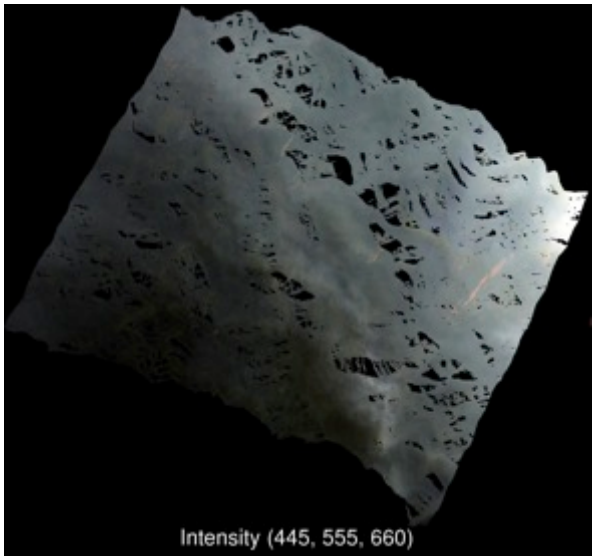
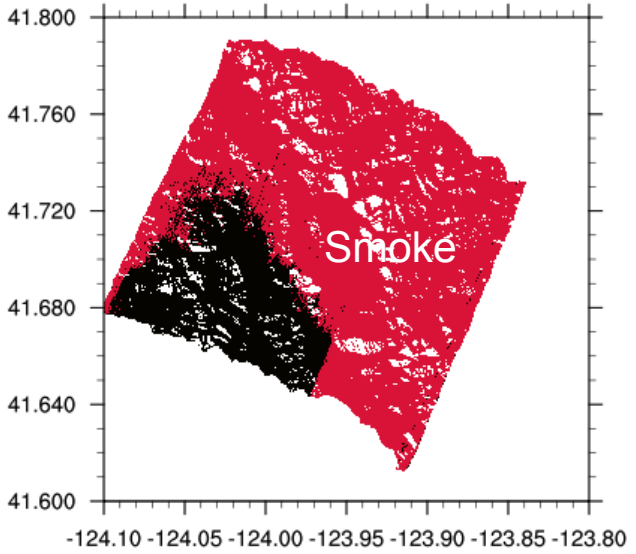
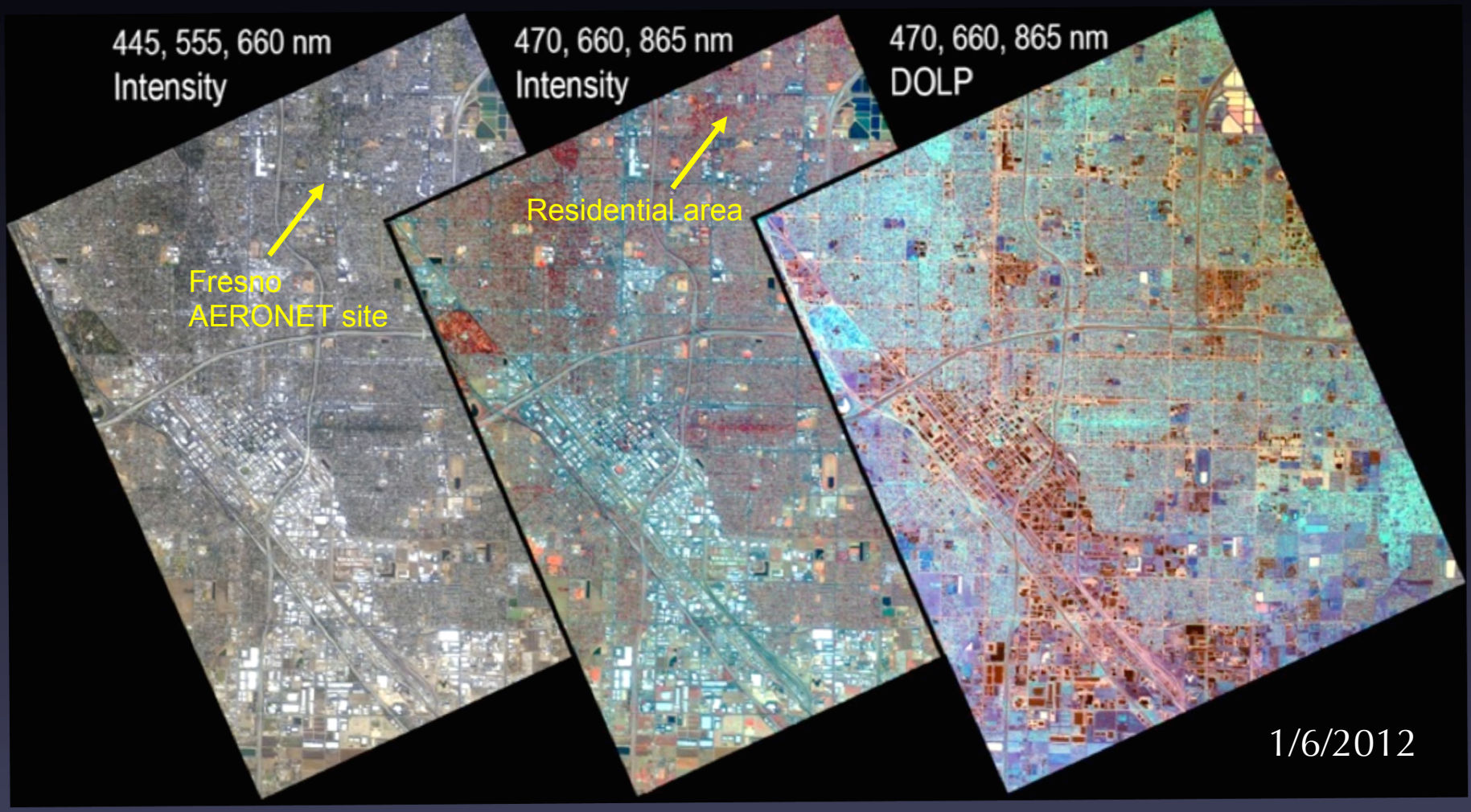


58.9º oblique view



Smoke defined as AI > 0.5 in 58.9º image

AirMSPI observations over Fresno, CA



GRASP approach (see Dubovik et al, 2011)

Simultaneous inversion of a large group of pixels within one or several images

Spatially smooth, spectrally dependent AOD

Size distribution (shape-independent):

- dV/dln$r$ - volume size distribution in total atmospheric column;

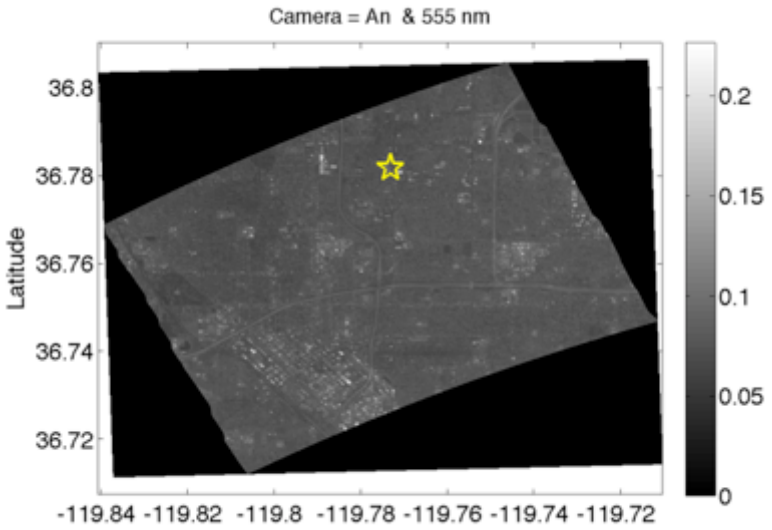
- size distribution is modeled using 22 size bins ($0.05 \le r \le 15$ μm);

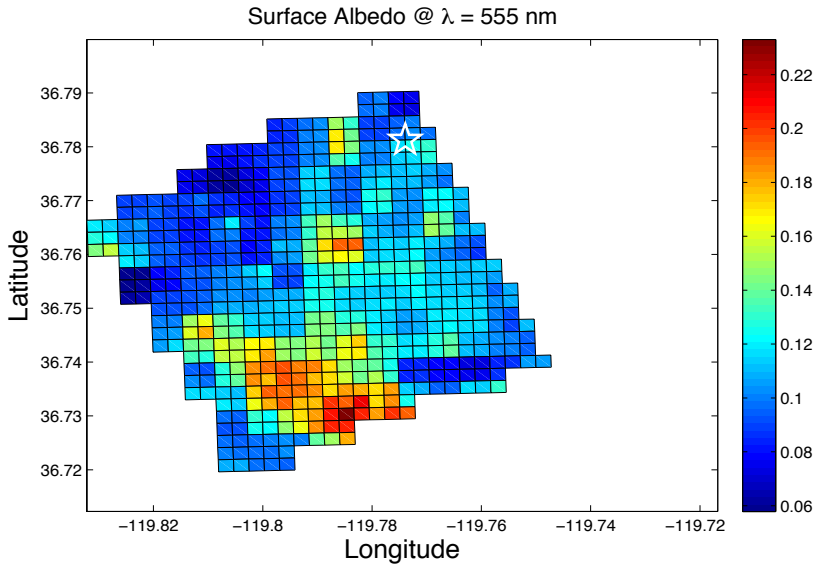
- size distribution is **smooth**

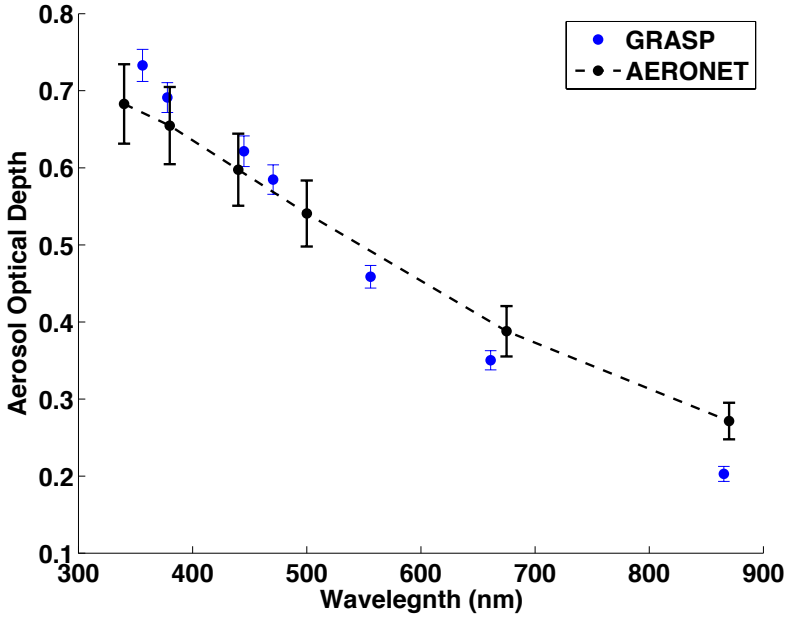
AEROSOL shape and composition (in the total atmospheric column):

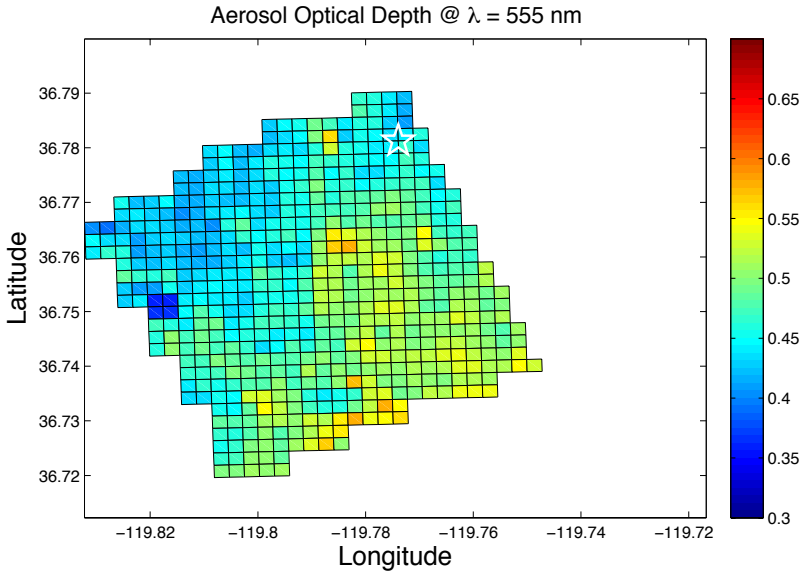
- randomly oriented homogeneous spheroids;
- aspect ratio distribution $N(\varepsilon)$ is fixed to that retrieved by Dubovik et al. 2006
- $1.33 \le n \le 1.6$; $0.0005 \le k \le 0.5$
- n and k **smooth, spectrally dependent**

GRASP retrieval application to AirMSPI data

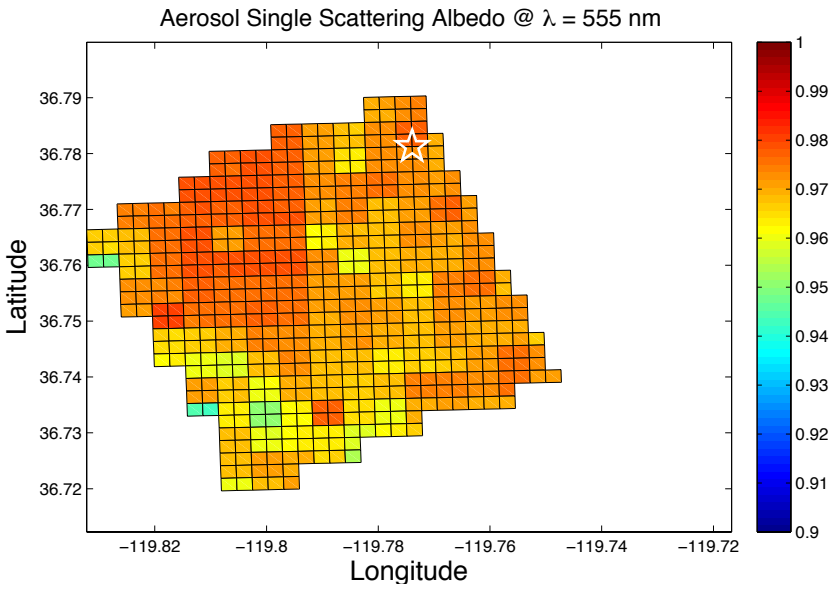


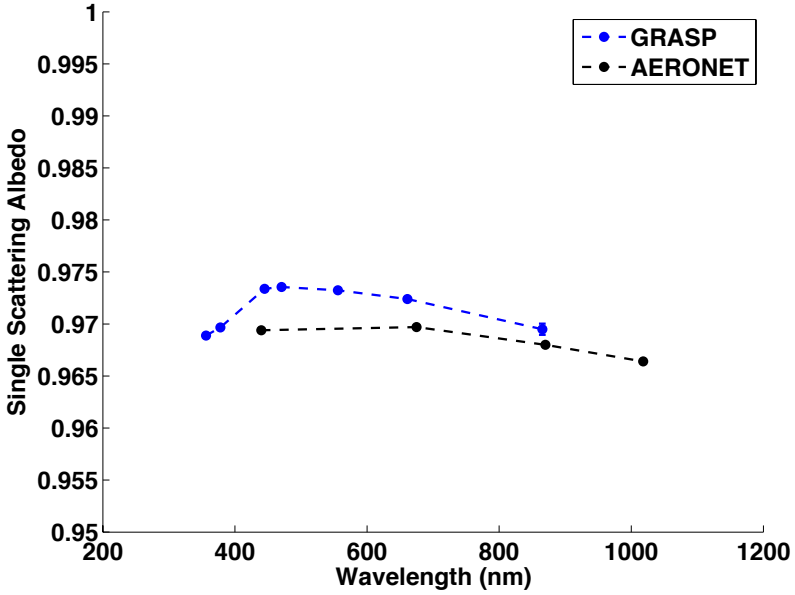


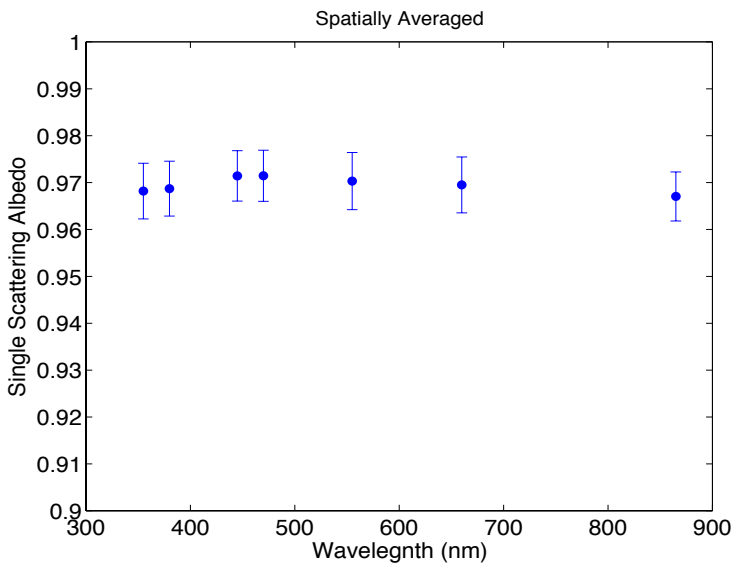


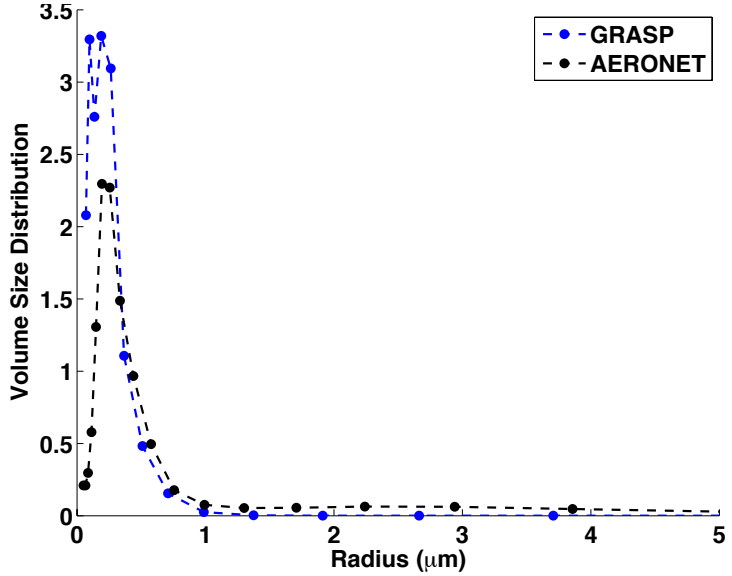


GRASP: aerosol size and composition

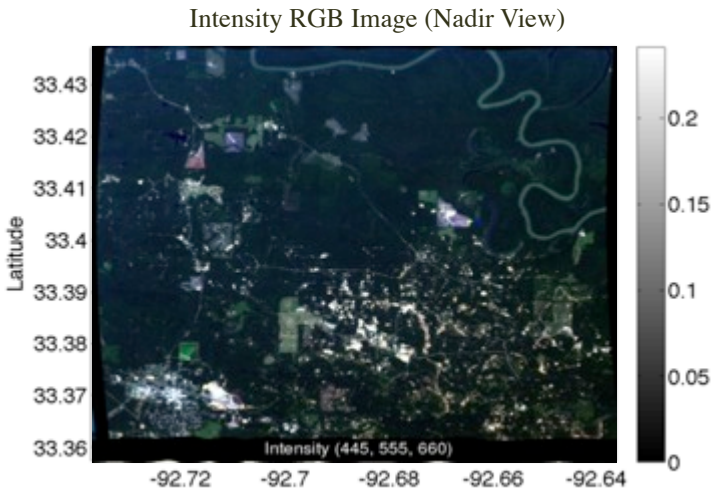




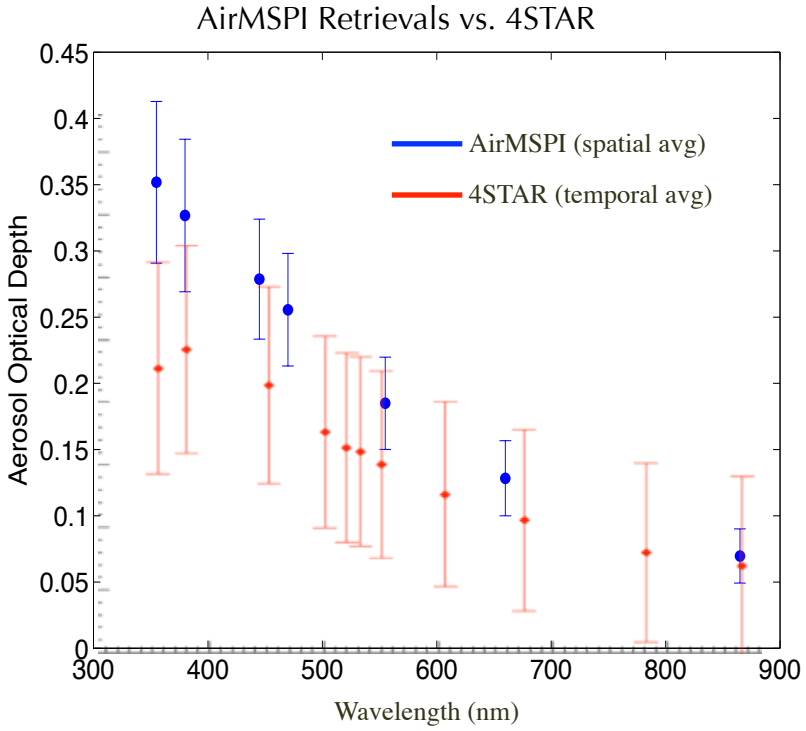


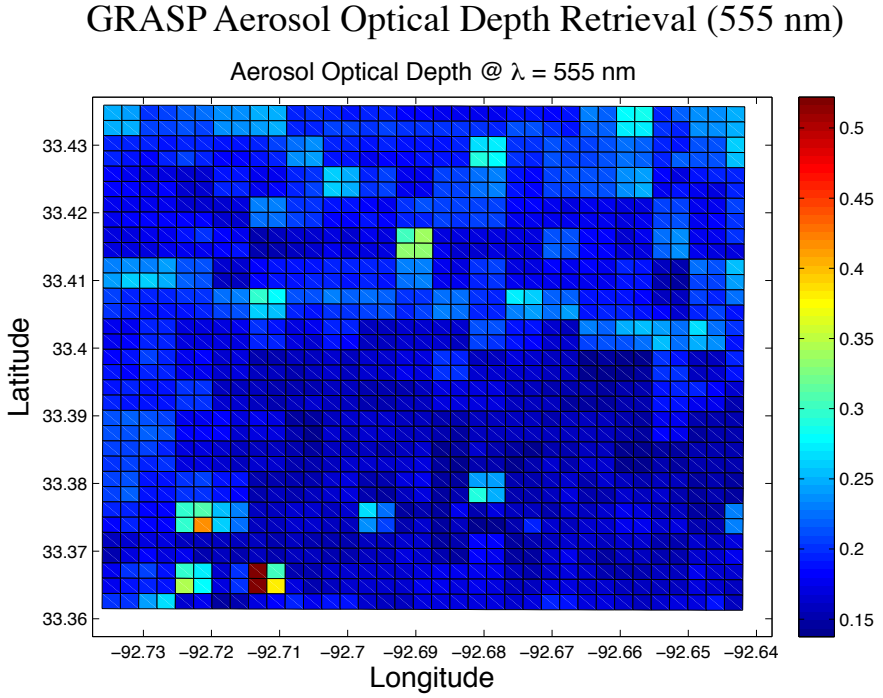


GRASP application to SEAC⁴RS data (preliminary)

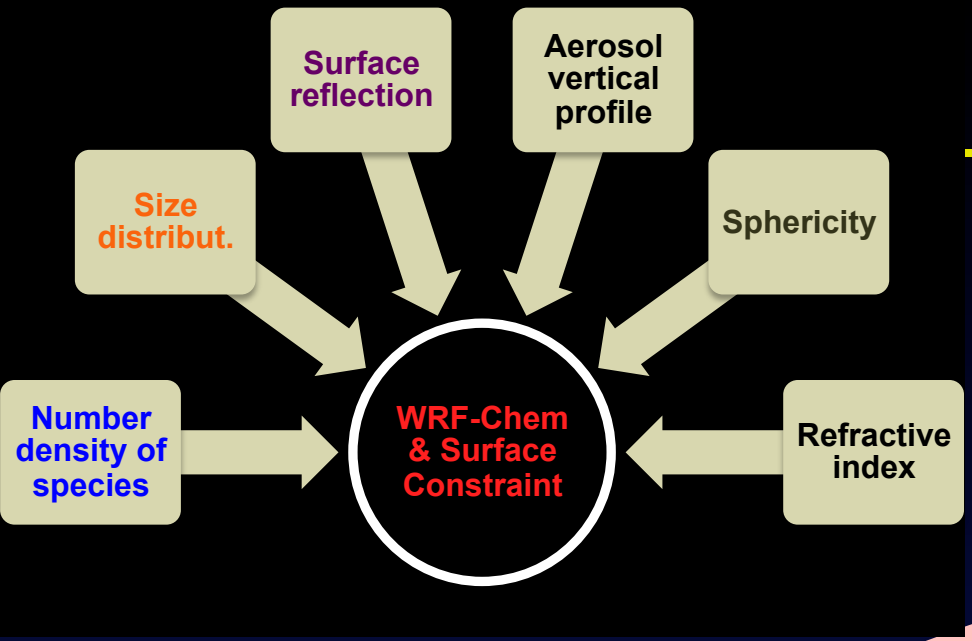


AirMSPI step-and-stare image from 23 August 2013, 16:15 UTC in Arkansas. ER-2 (AirMSPI) and DC8 (4STAR) were collocated.





Retrieval strategy



Air quality and health applications

Minimize error between model and data

More retrieved parameters (fewer constraints)

Relax more WRF-Chem constraints

Relax surface reflection

Relax size distribution

Relax number density of 8 species (or 13 modes)

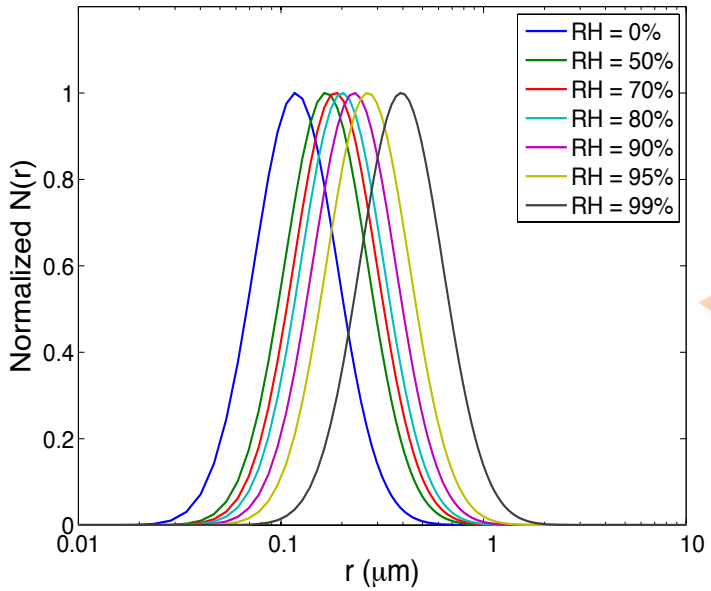
Retrieval over total AOD

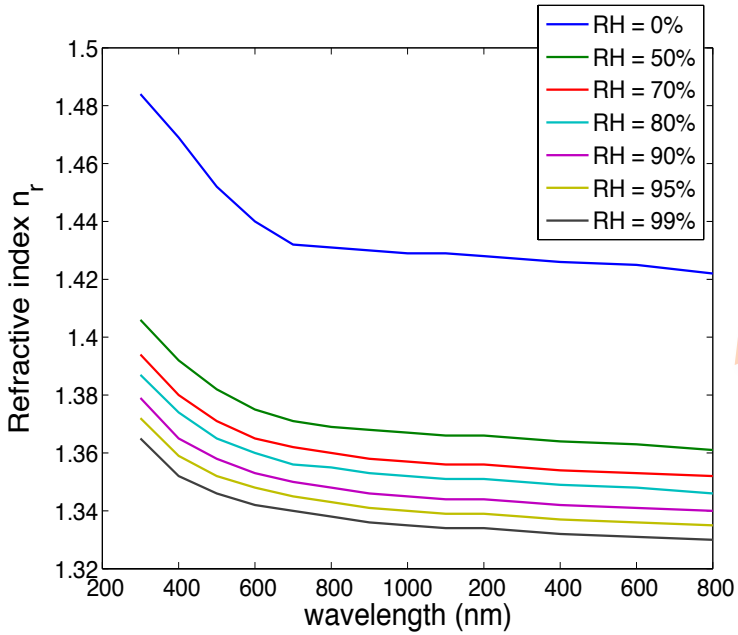
Collaboration with
Jun Wang and Cui Ge
University of Nebraska - Lincoln

Retrieval assumptions

- Band width effect and O_3 absorption ignored
- Surface reflection retrieved assuming AERONET aerosol
- Species limited to (SO_4, NO_3, NH_4), BC and OC
- Species optical properties are defined by WRF-Chem
- Species vertical profile based on WRF-Chem
- Mean radius derived from WRF-Chem

WRF-Chem aerosols – optical characteristics





Aerosol species

Size distribution

Refractive index

Sulfate, Nitrate, Ammonium

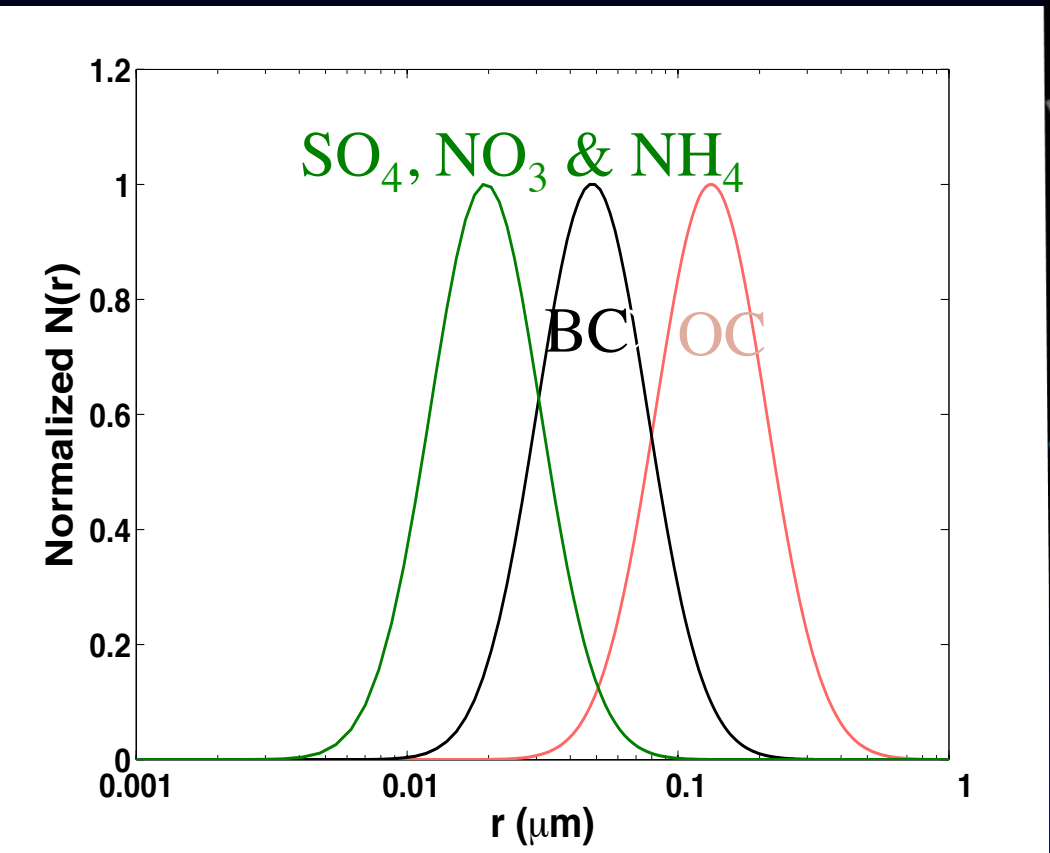
Mixing

Black Carbon

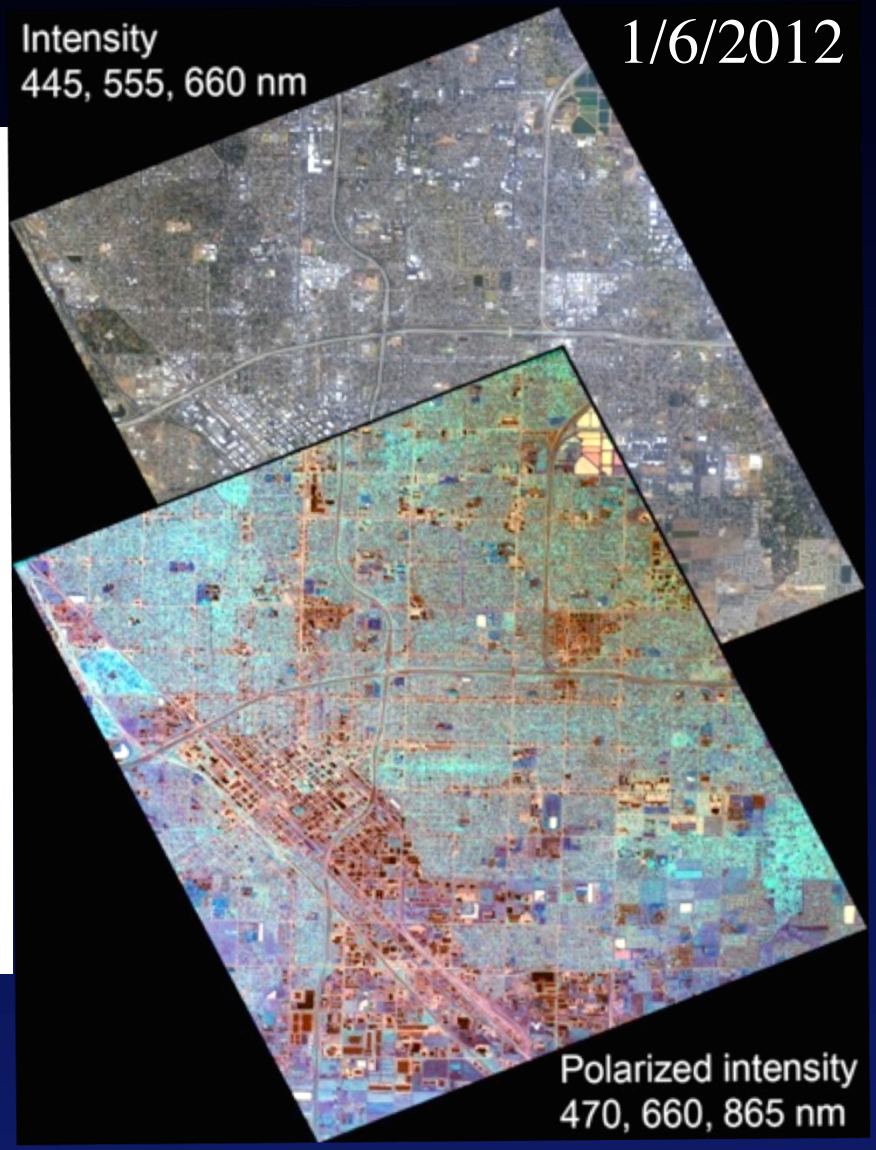
Organic Carbon

WRF-Chem aerosol properties – Fresno

Unimodal distribution of each species



RH = 10%



Step 2: AirMSPI data fit

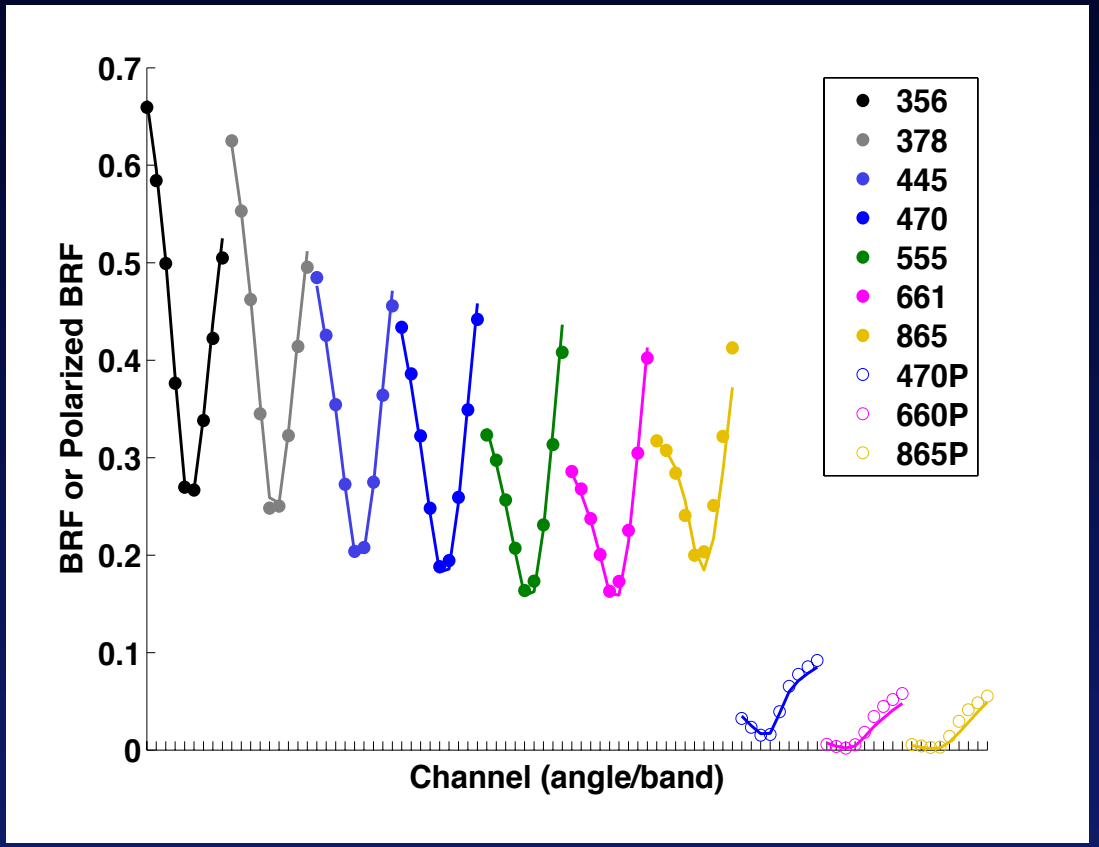
Retrieval over total AOD

Relax fractions of 3 species

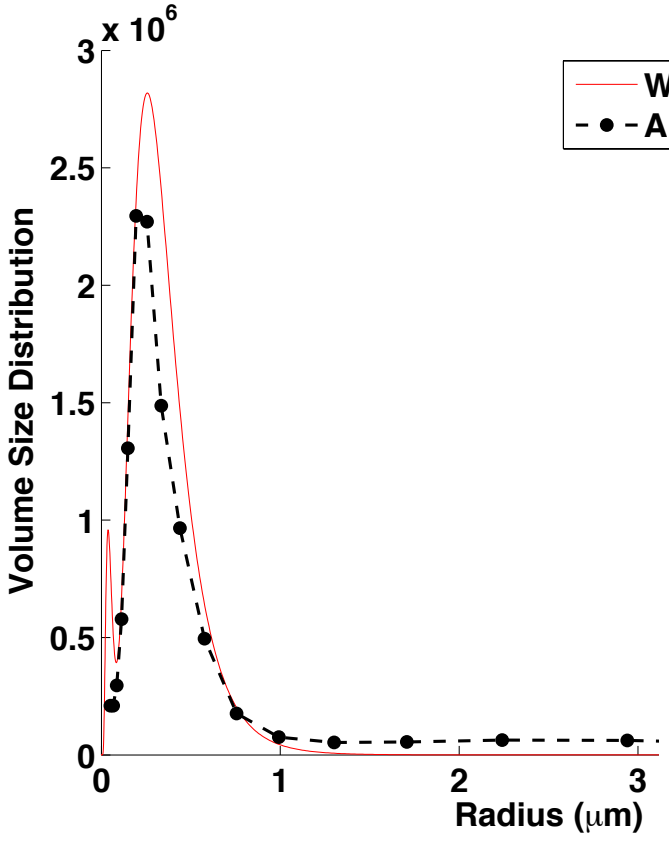
Relax size distribution

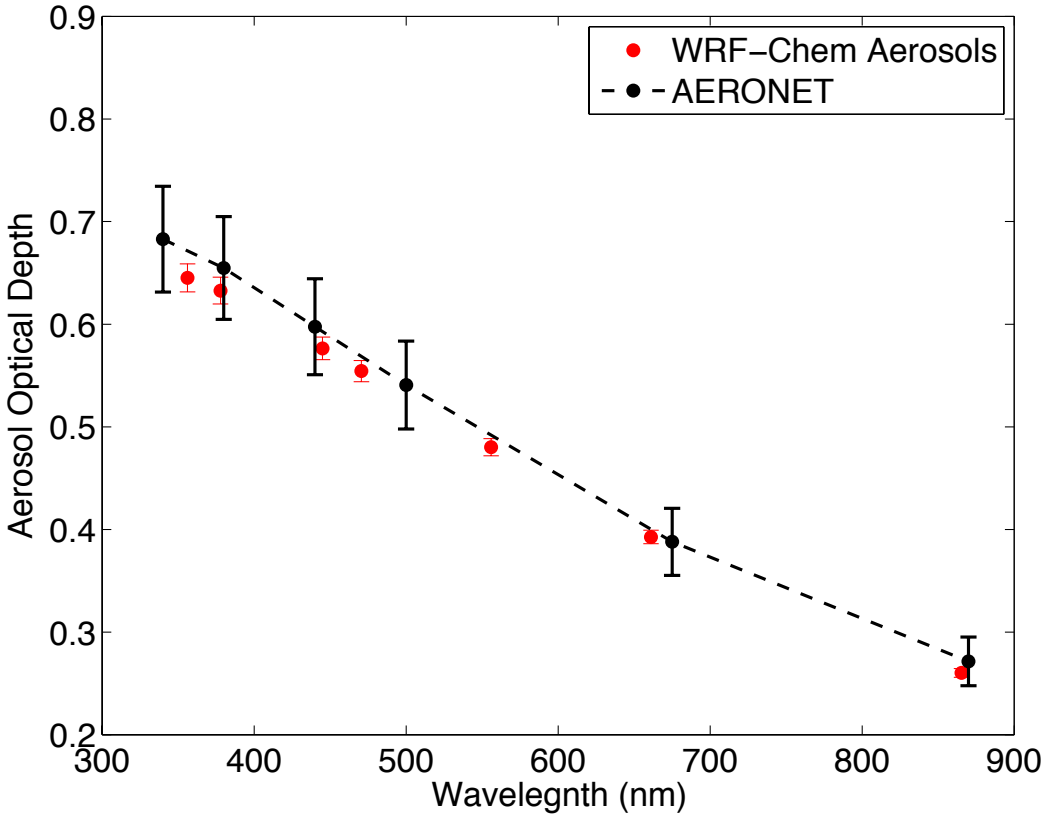
Relax surface reflection

Relax more WRF-Chem constraints

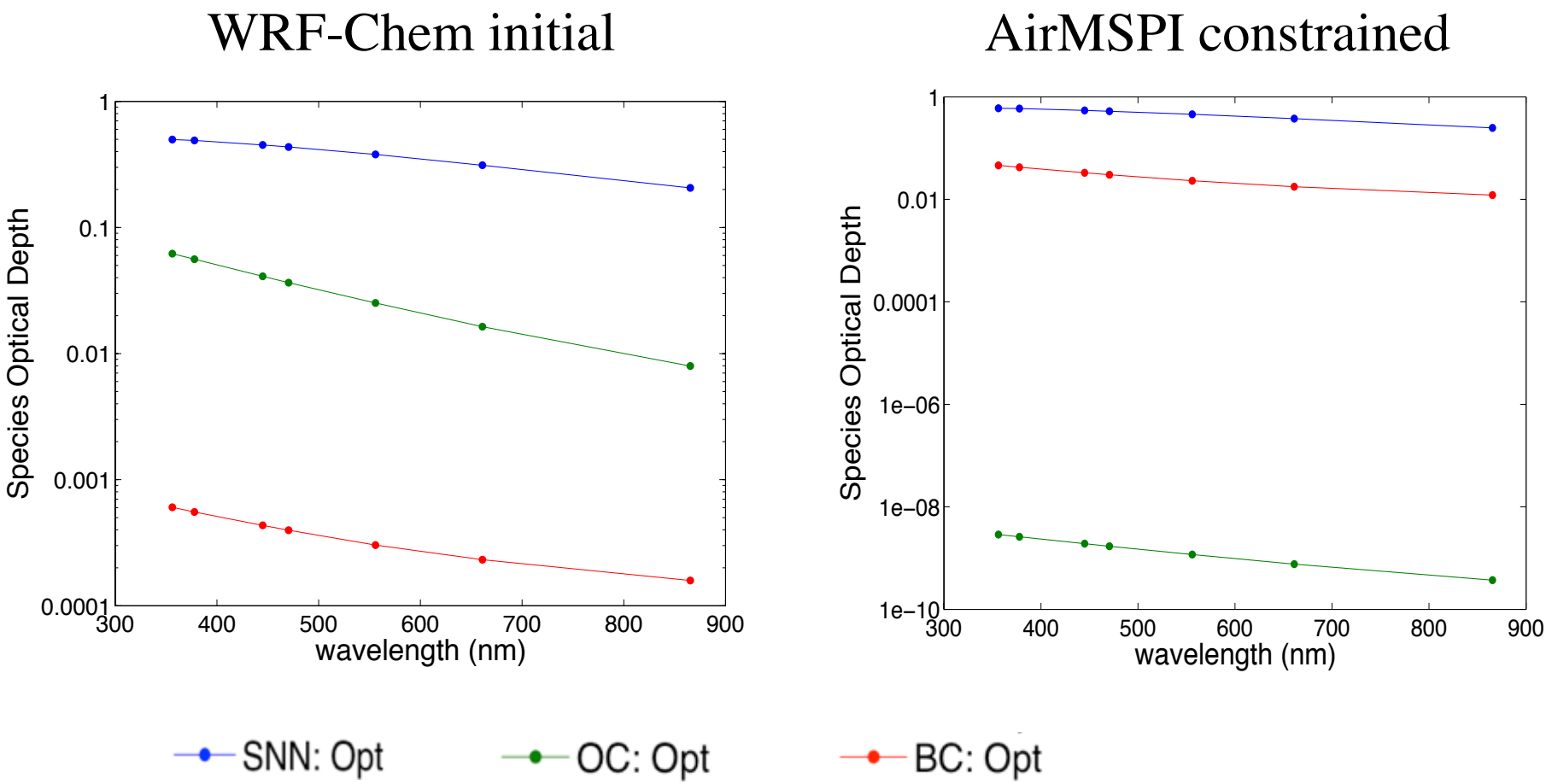


AERONET comparison



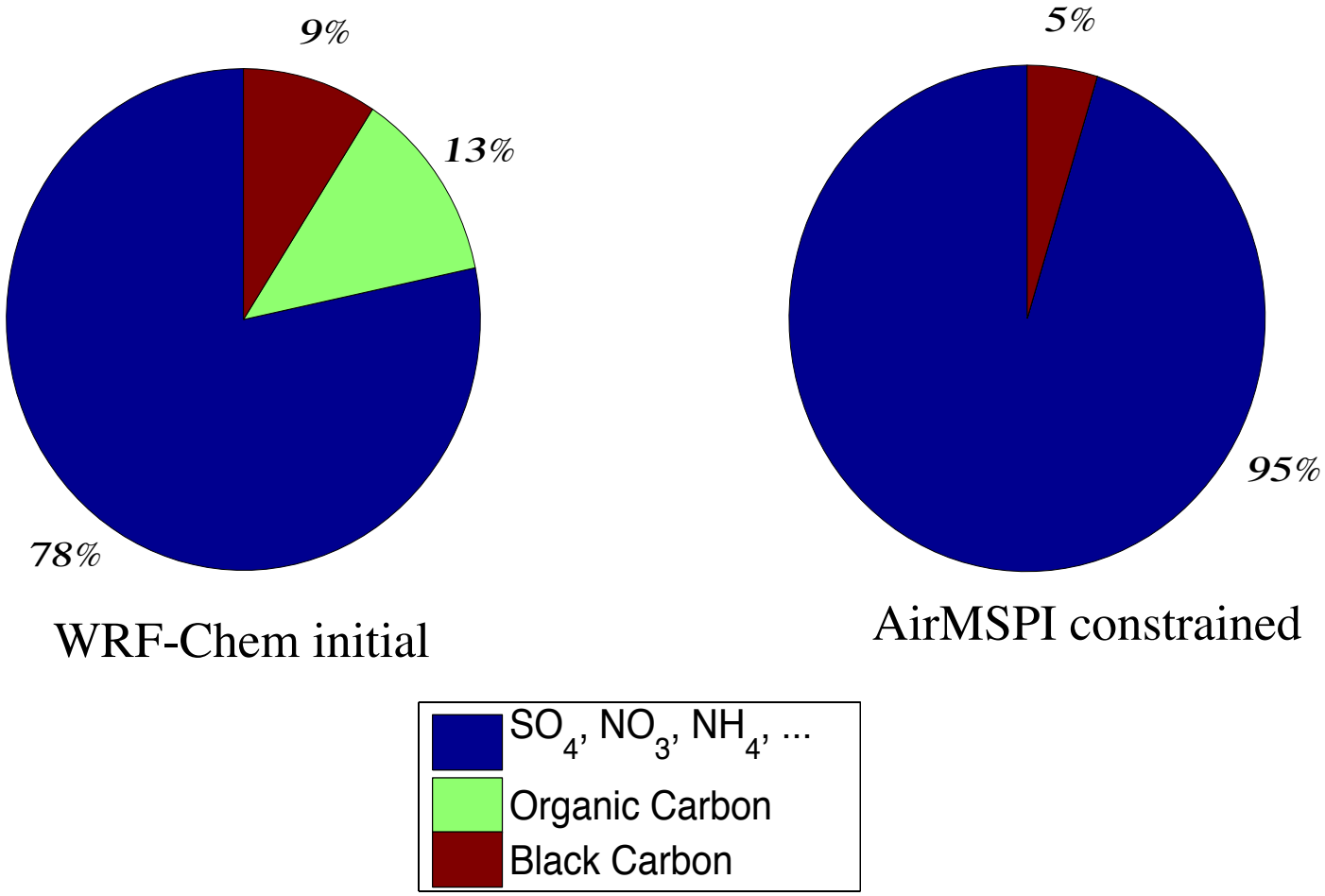


Speciated aerosol optical depth



Species fractions

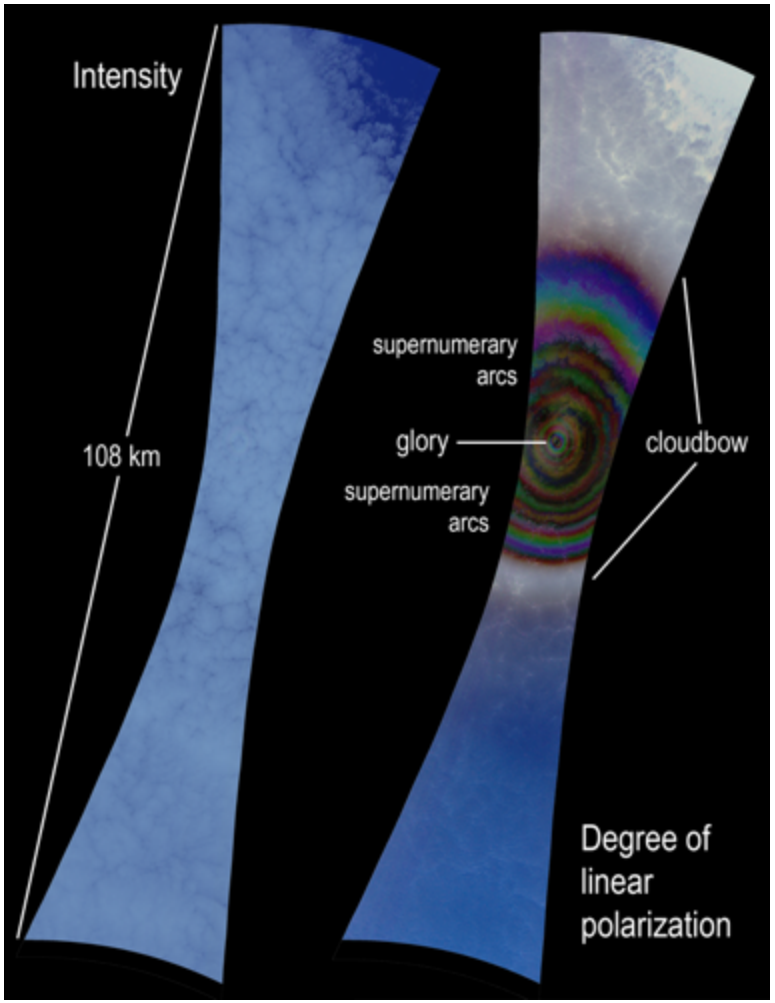
Volume fractions of aerosol species:



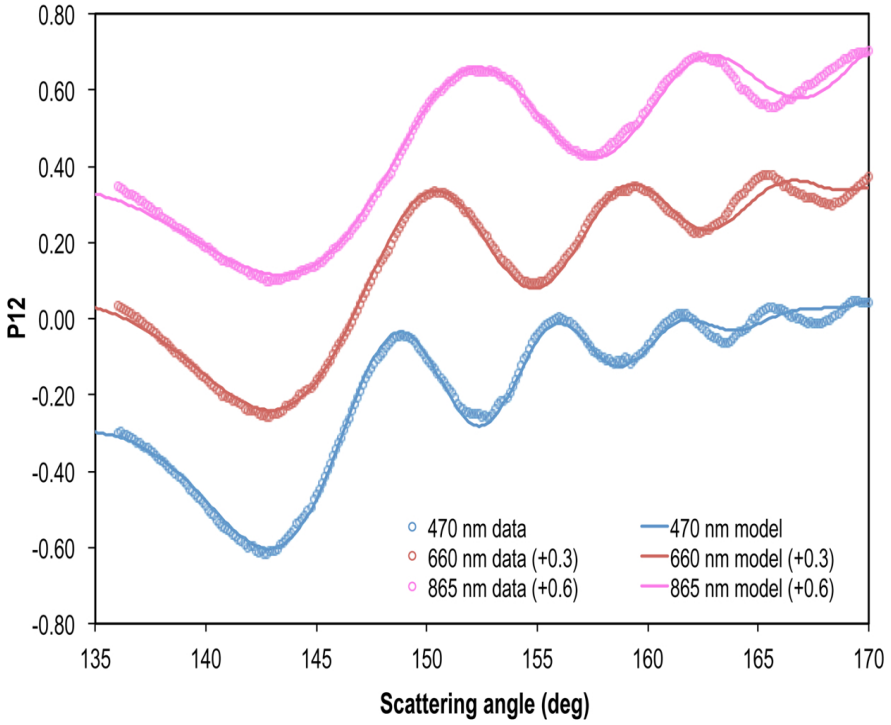
Status (aerosols)

- GRASP retrieval was applied to high-resolution (10m) AirMSPI spectro-polarimetric data for the first time
- This provides high resolution (250 m x 250 m) AOD and aerosol optical property data
- Initial AirMSPI retrieval results obtained with GRASP are consistent with AERONET and 4STAR observations
- We are working on developing a new, integrated WRF-AirMSPI retrieval approach to characterize speciated aerosol properties
- Field campaigns (including PODEX and SEAC^{4}RS) are an excellent opportunity for new polarimetric retrieval validation

AirMSPI cloud observations and modeling



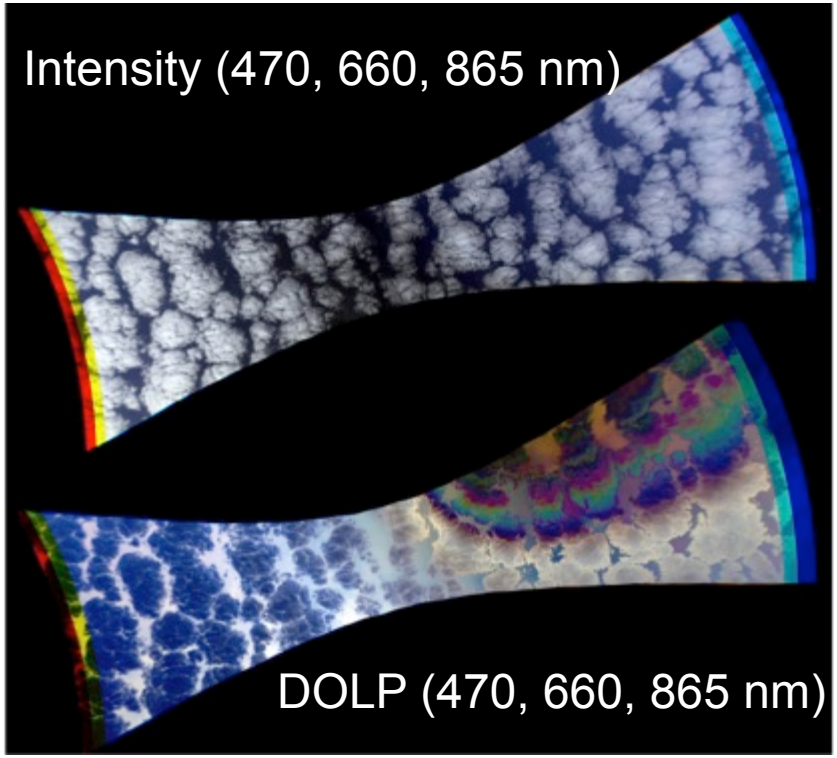
Stratocumulus clouds off the California coast 8/31/2011



Following Bréon and Goloub (1998), the supernumerary bows are modeled with a narrow droplet size distribution with mode radius = 7.5 μm.

The approach of Alexandrov et al. (2012) gives similar results.

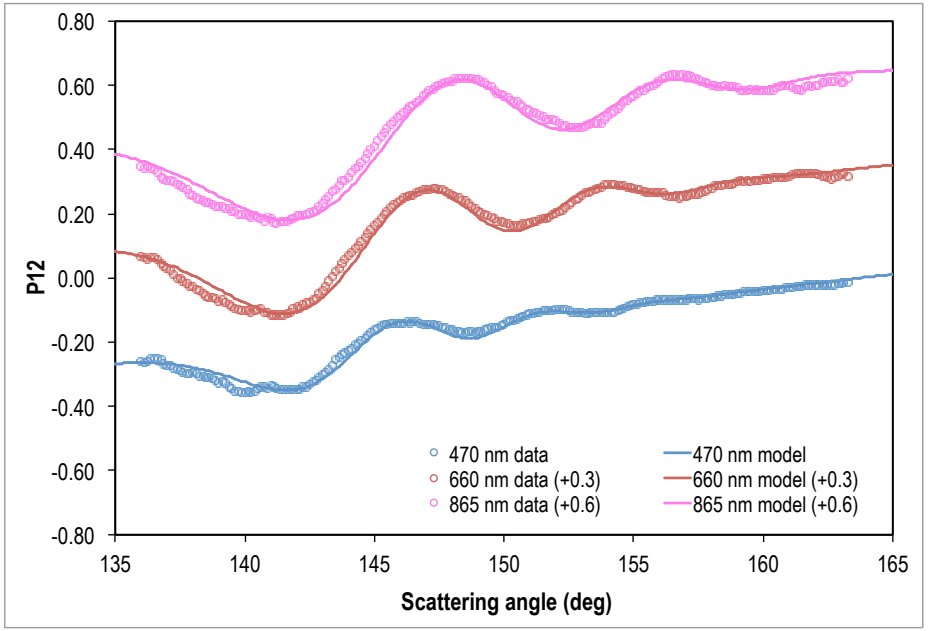
Cloudbow analysis of broken cumulus

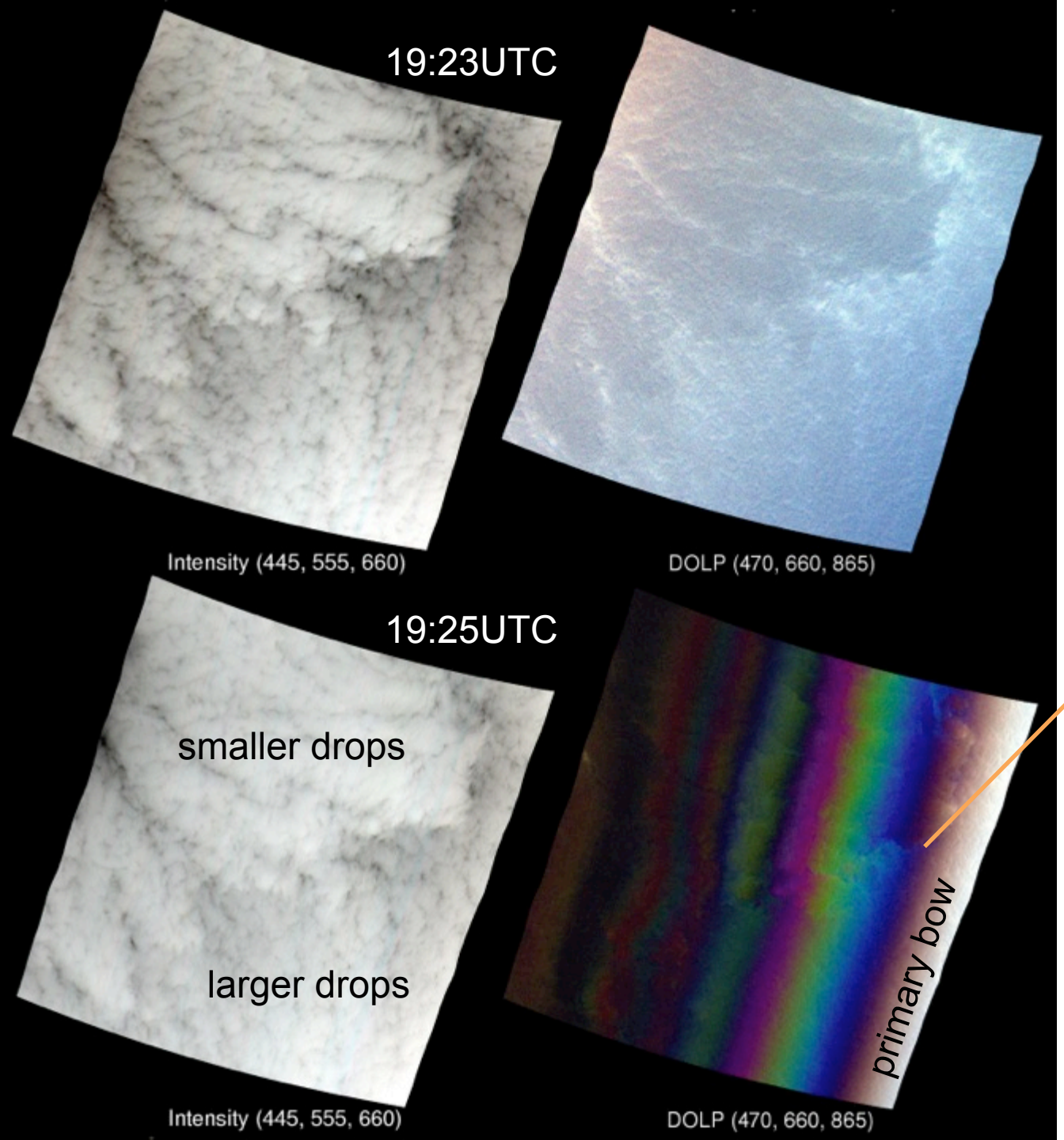


6 February 2013, 22:26 UTC
- Pacific sweep image

The droplet size retrieval also works for broken clouds

A simple intensity threshold was used to separate clouds from ocean. These data are fitted with with a distribution having an effective radius of 12 μm and effective variance of 0.02





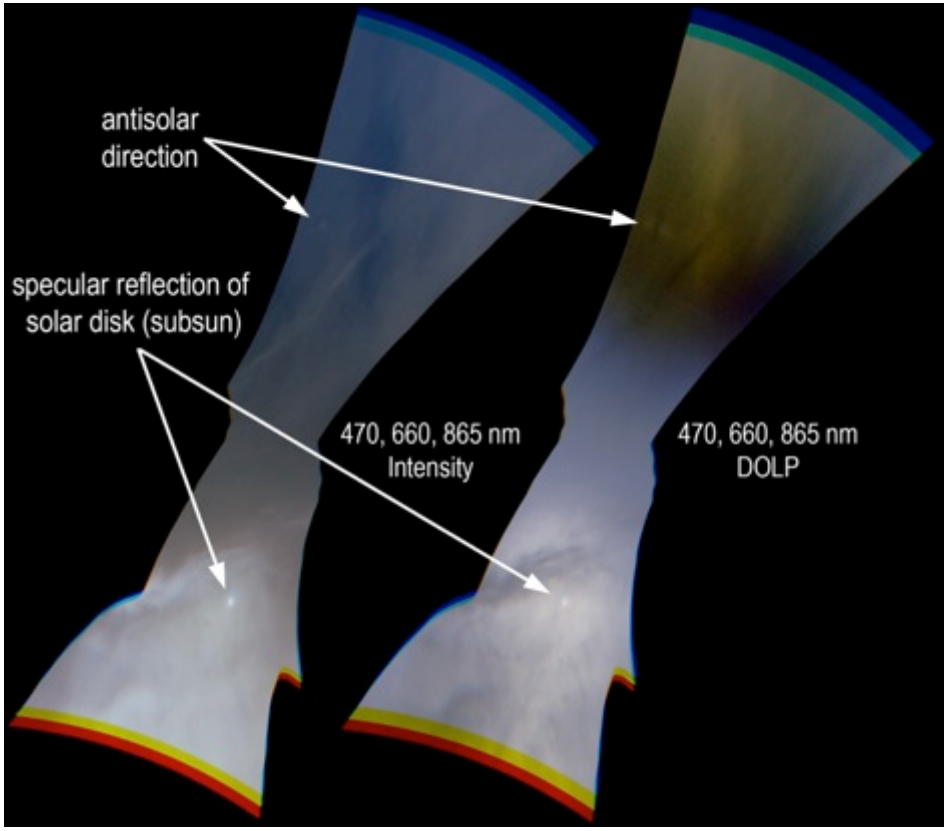
Step and stare views

29º forward view

discontinuity in fringe positions indicates change in droplet size

29º backward view

Identification of cirrus from atmospheric optics

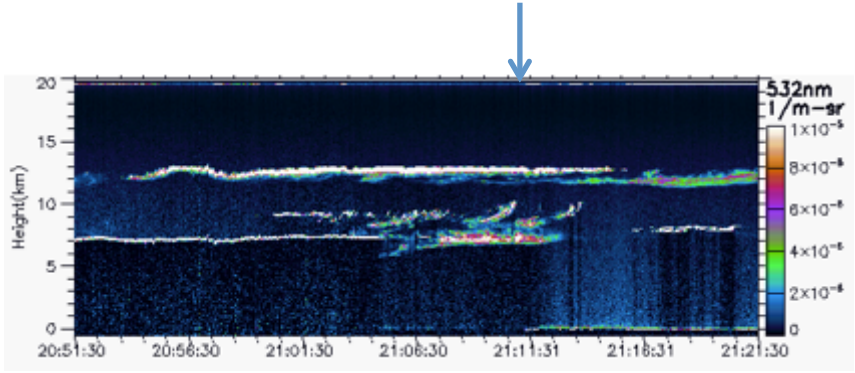


Clouds over ocean – 1 February 2013, 21:11 UTC

The subsun is the reflection of the solar disk from horizontally-oriented ice crystal plates.

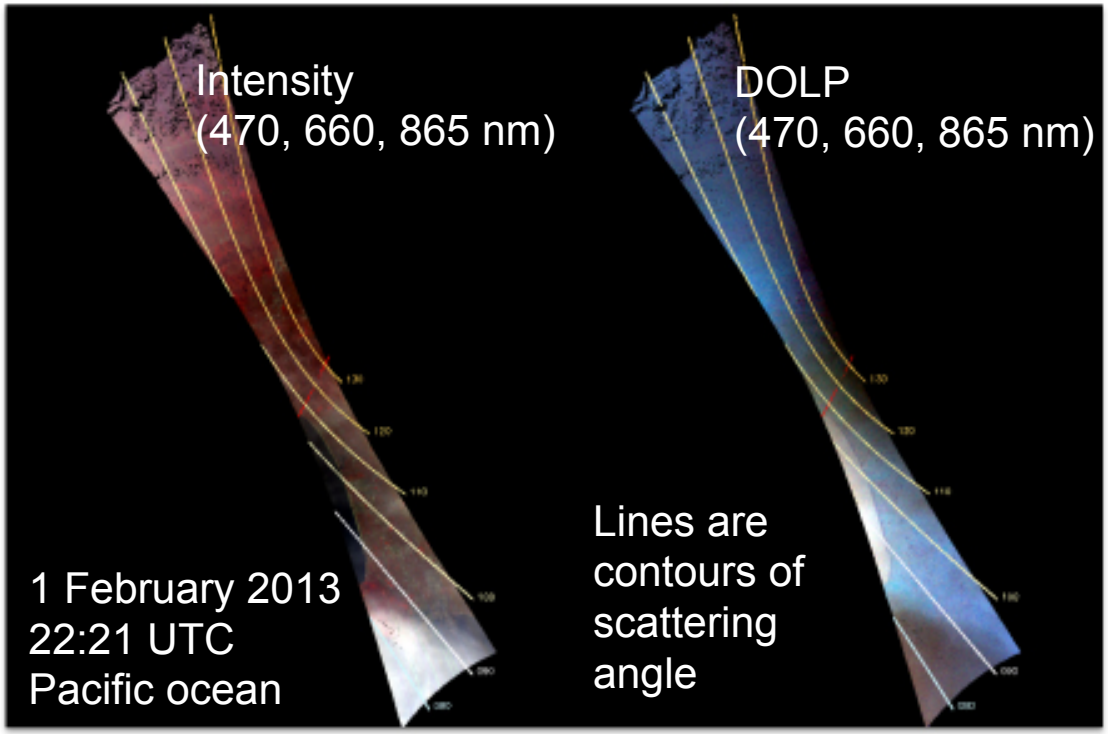
The DOLP of the subsun is 0.65, less than for pure specular reflection, possibly due to:

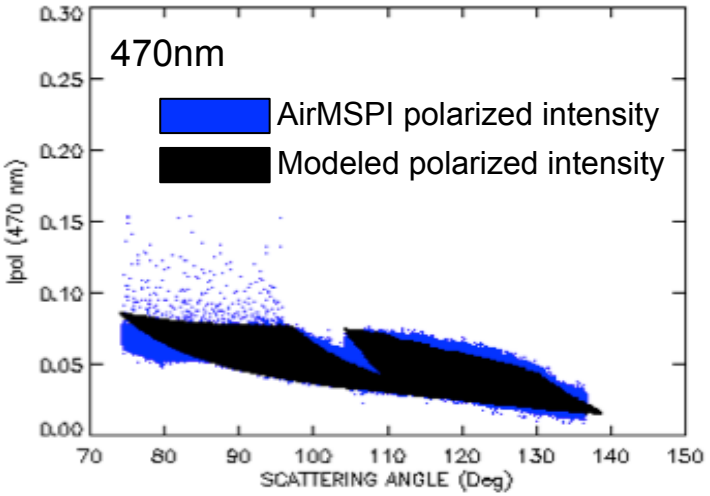
- light from a lower cloud deck
- plates with non-horizontal orientations

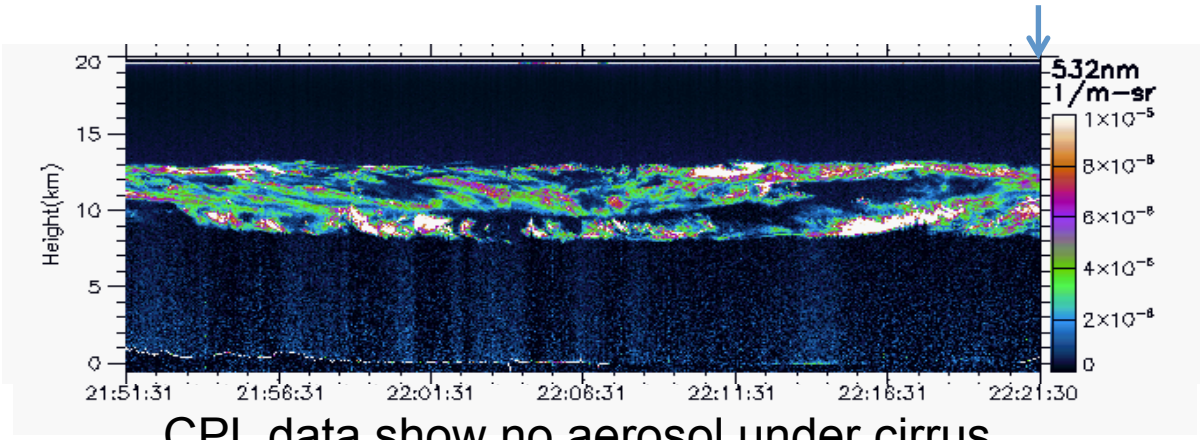


Cloud Physics Lidar (CPL) data show cirrus above lower cloud

Cirrus optical depth estimation



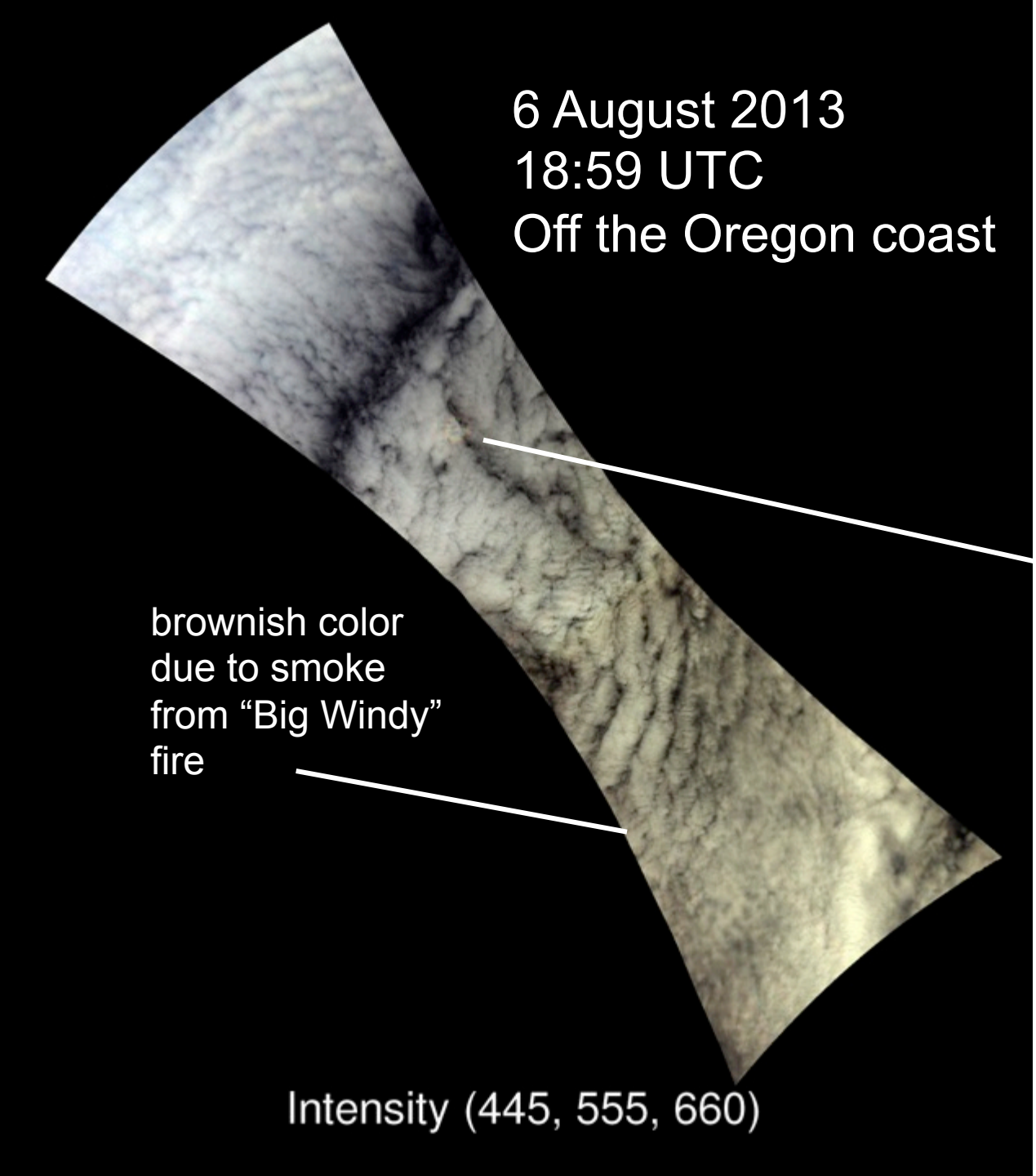


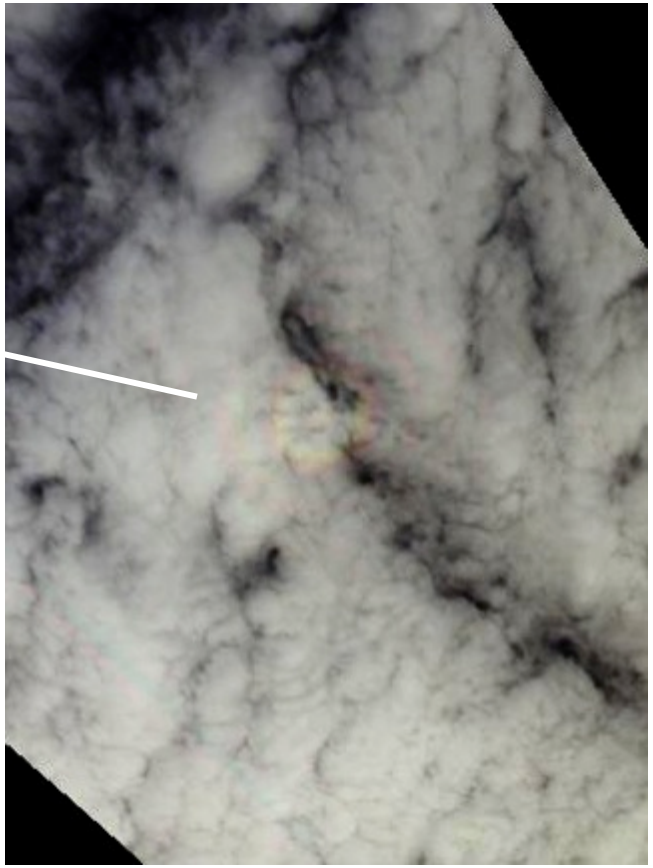


CPL data show no aerosol under cirrus

Following Cole et al. (2013), AirMSPI data were fitted with simulated polarized radiances calculated for a cirrus General Habit Mixture by Bryan Baum. The best fit is obtained with a cirrus optical depth of 0.2.

Smoke over cloud

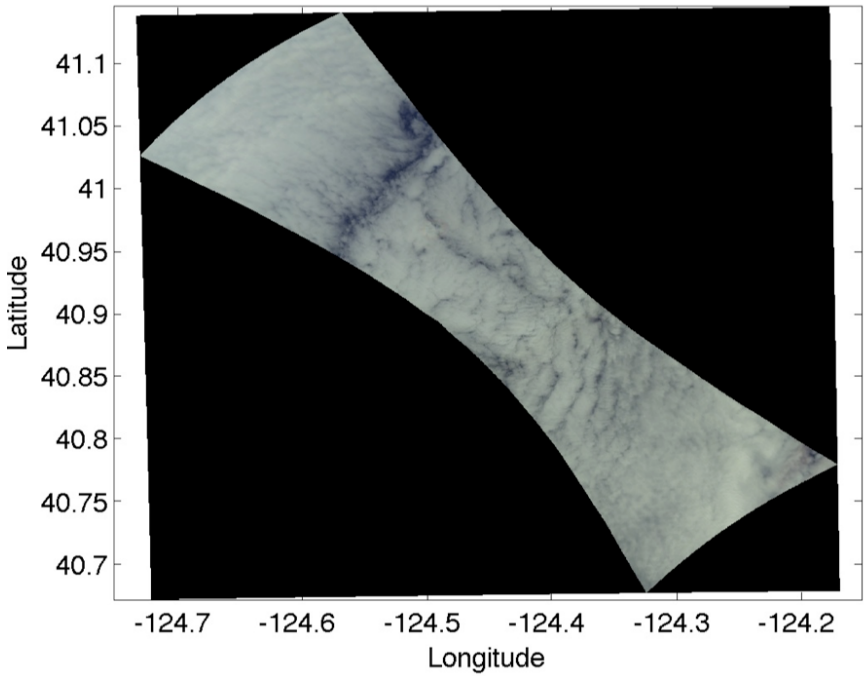


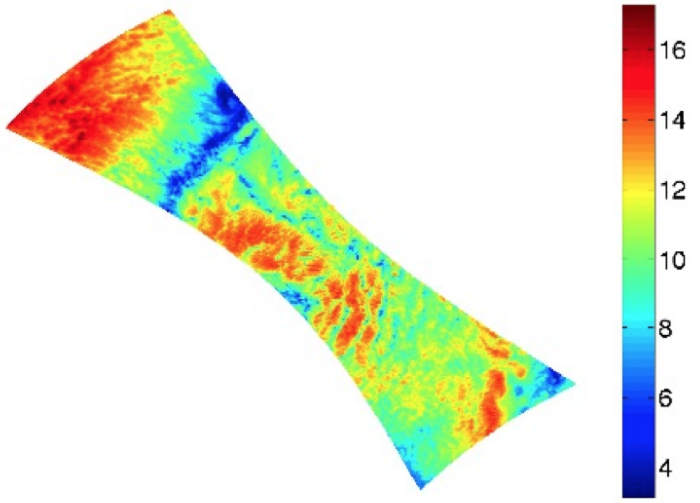


glory at 180º
scattering angle

Exploitation of Intensity Field

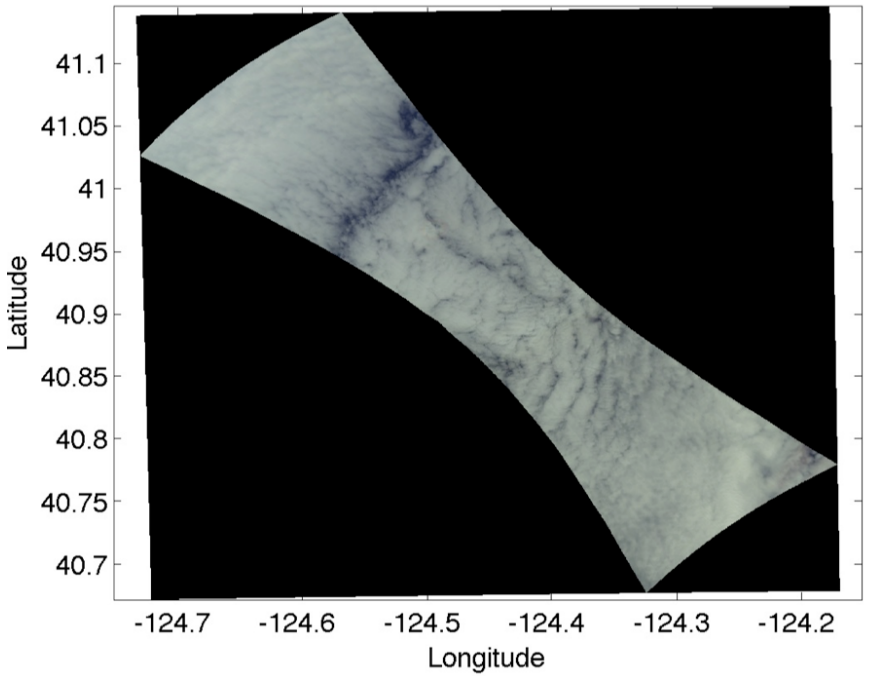
- Reminder: We know droplet size distribution (r_e,v_e) at image/cloud-scale.
- Pixel-scale COD τ is derived from LUT ($\tau,\theta_v,\phi_v,|\,\theta_0,r_e,v_e$), but it is biased by 3D RT (radiative smoothing) effects.

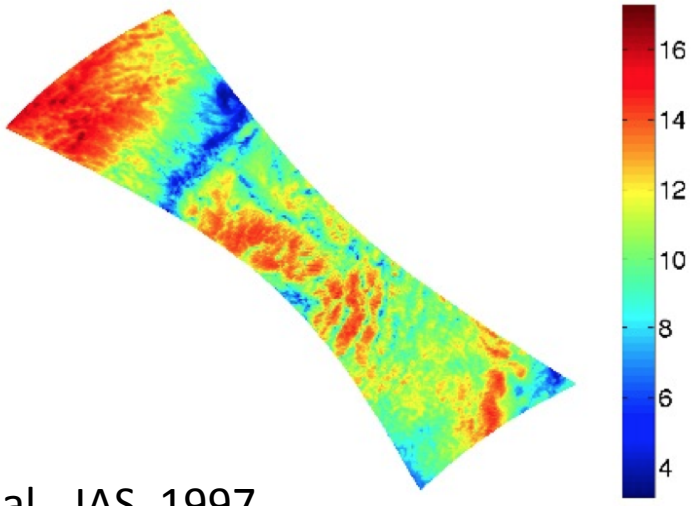




Exploitation of Intensity Field

- To Do:
  - Estimate radiative smoothing scale η from structure function.
  - Derive cloud thickness H from η/H, a weak function of $(1-g)\tau$.
  - Coarsen resolution to ~1 km ≈ 2-3 x η, then derive unbiased τ.
  - Optionally, apply inverse NIPA to restore pixel-scale τ field.

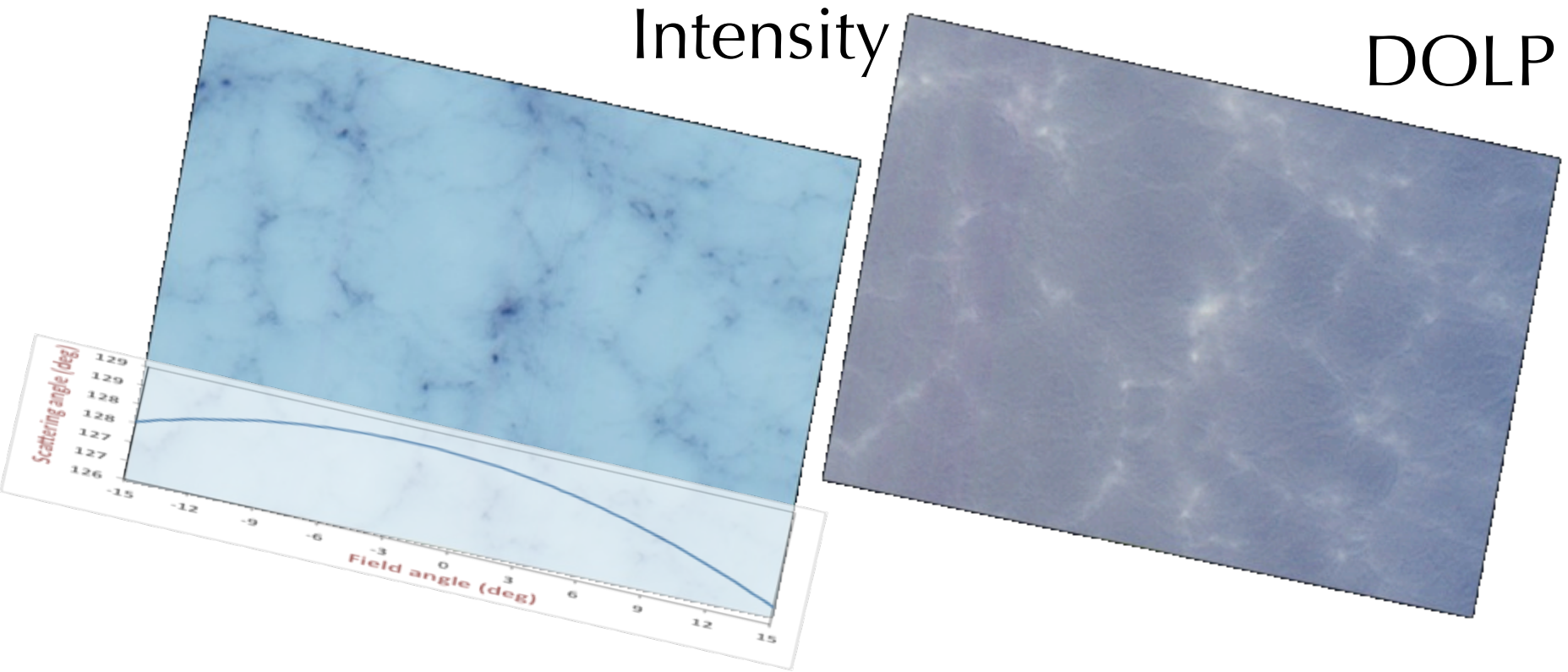




<u>Refs:</u>
Davis et al., JAS, 1997
Marshak et al., IEEE TGRS, 1998.

AirMSPI / marine Sc in ~backscatter views (teaser)

- **Interpretation of intriguing AirMSPI data from marine Sc**
  - **Context**
    - 31 August 2011 – 19:30 UTC, **Step-and-stare mode (10 m resolution) at 26.5º backward**



Color composite: 440 nm (blue), 660 nm (green), and 865 nm (red)

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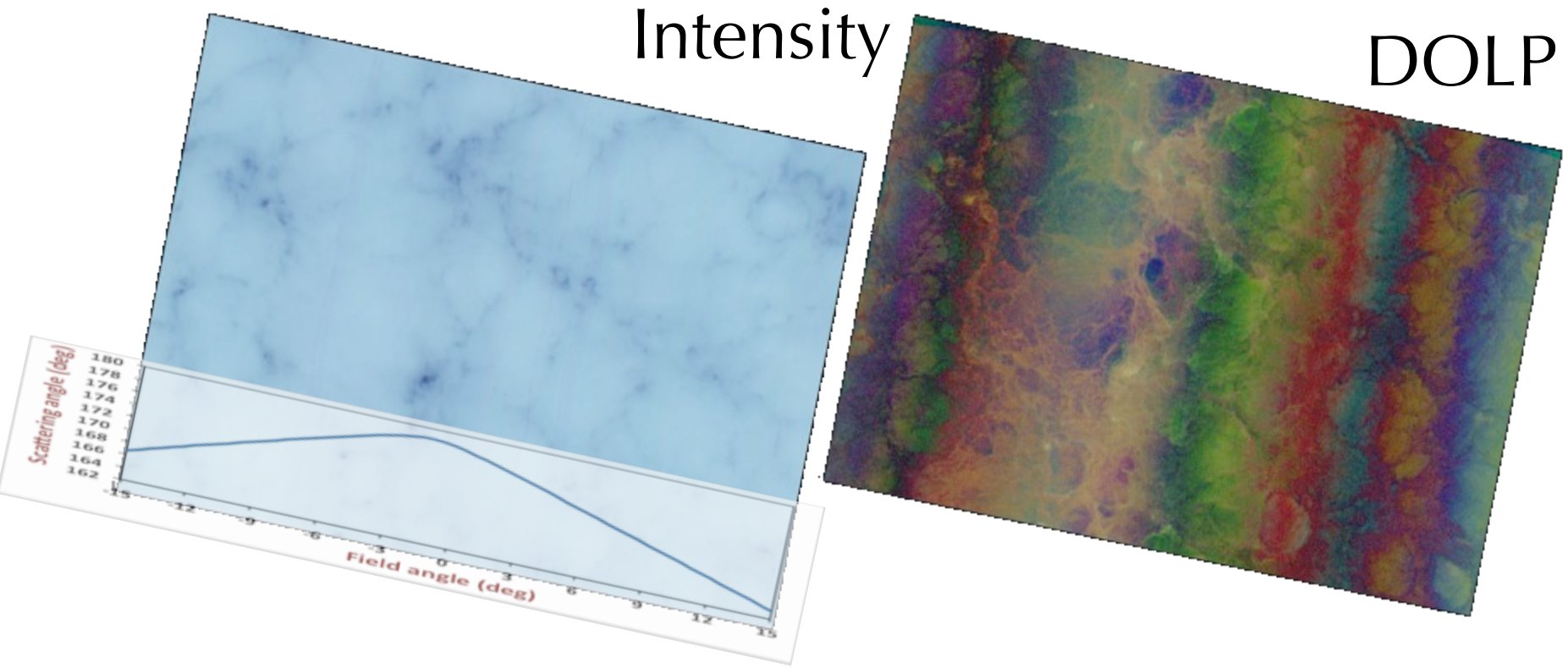
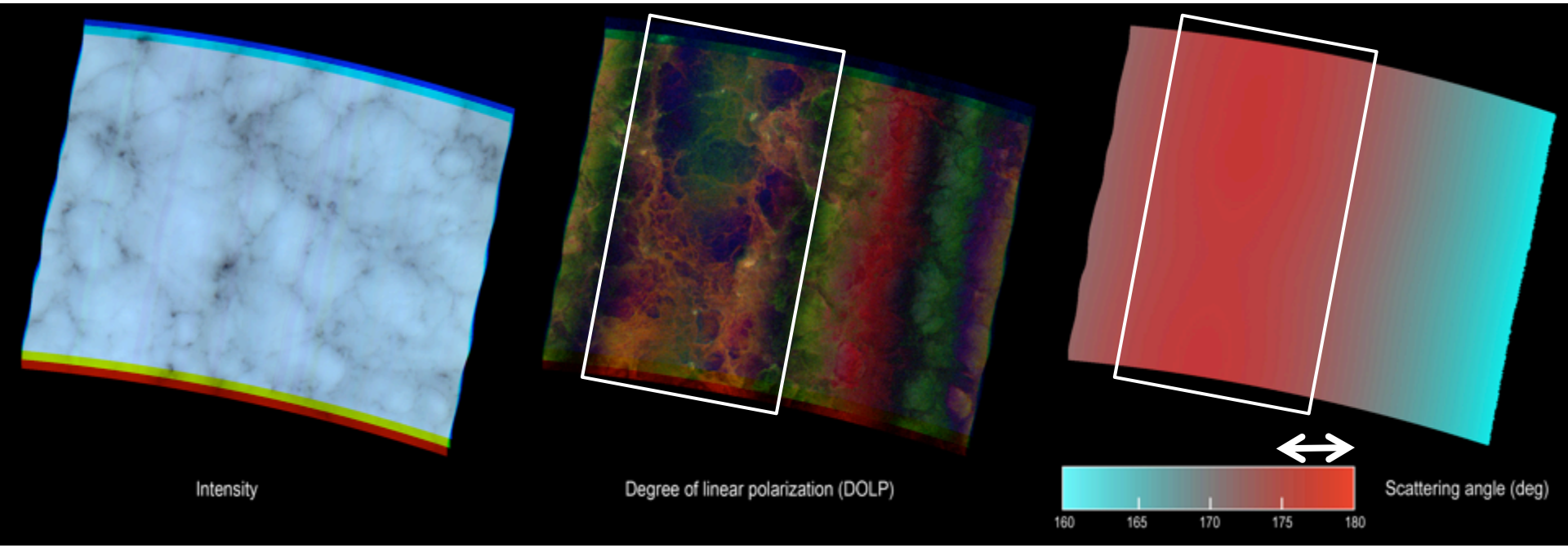


Color composite: 440 nm (blue), 660 nm (green), and 865 nm (red)

AirMSPI / marine Sc in ~backscatter views (teaser)

- **Interpretation of intriguing AirMSPI data from marine Sc**
  - Preliminary diagnostics from AirMSPI's Aug 31st, 2011 flight over marine stratocumulus off the coast near Los Angeles, Ca.
    - **Step & stare mode in near-backscatter geometry**



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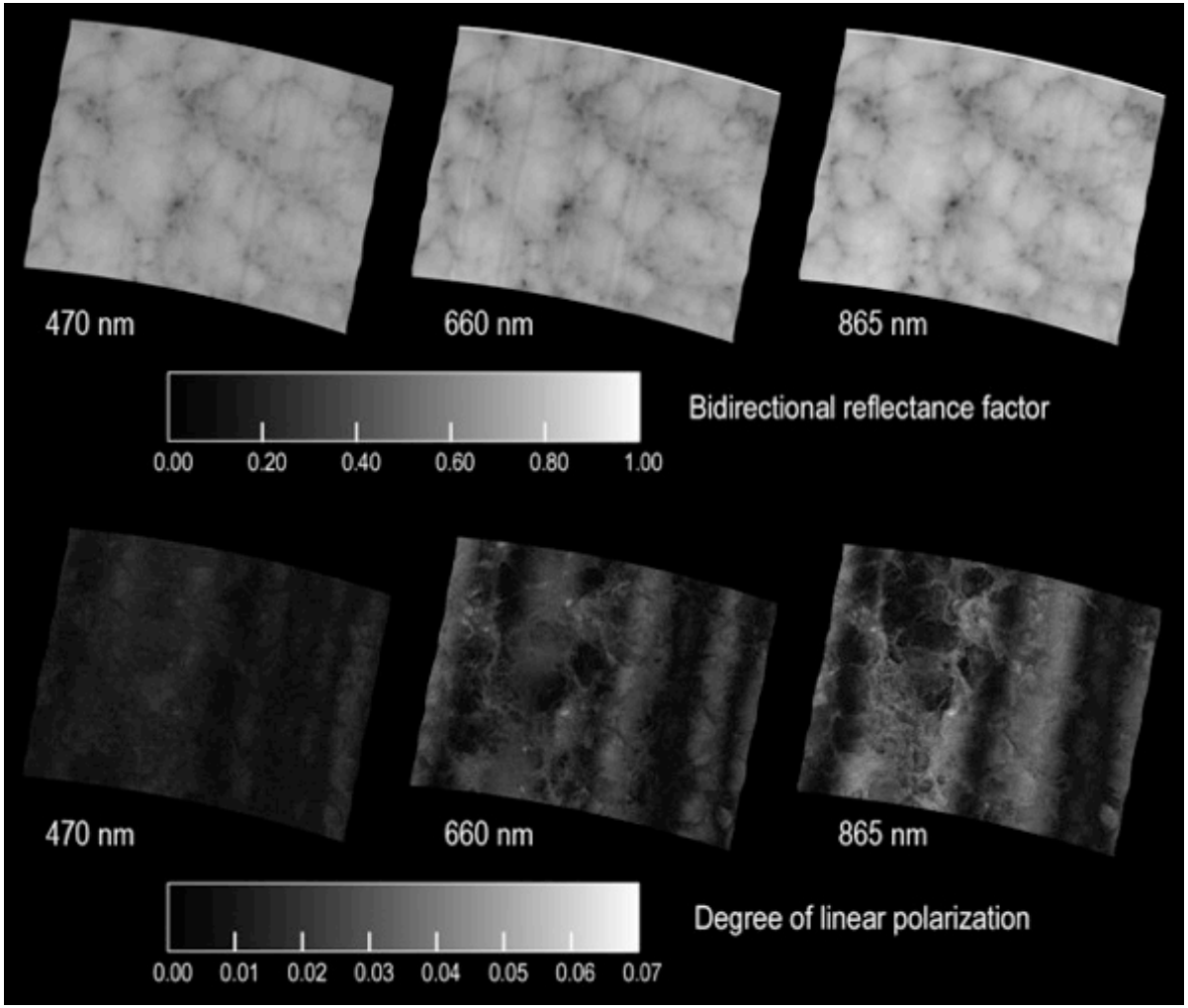
AirMSPI / marine Sc in ~backscatter views (teaser)

- **Interpretation of intriguing AirMSPI data from marine Sc**
  - Preliminary diagnostics from AirMSPI's Aug 31st, 2011 flight over marine stratocumulus off the coast near Los Angeles, Ca.
    - **Step/stare mode in near-backscatter geometry (wavelength decomposed)**



Summary/Discussion/Outlook

- **Airborne Multi-angle Spectro-Polarimetric Imager (AirMSPI)**
- **Campaigns**
- **Aerosols**
- **Clouds**
- **Aerosols over clouds?**

Questions?