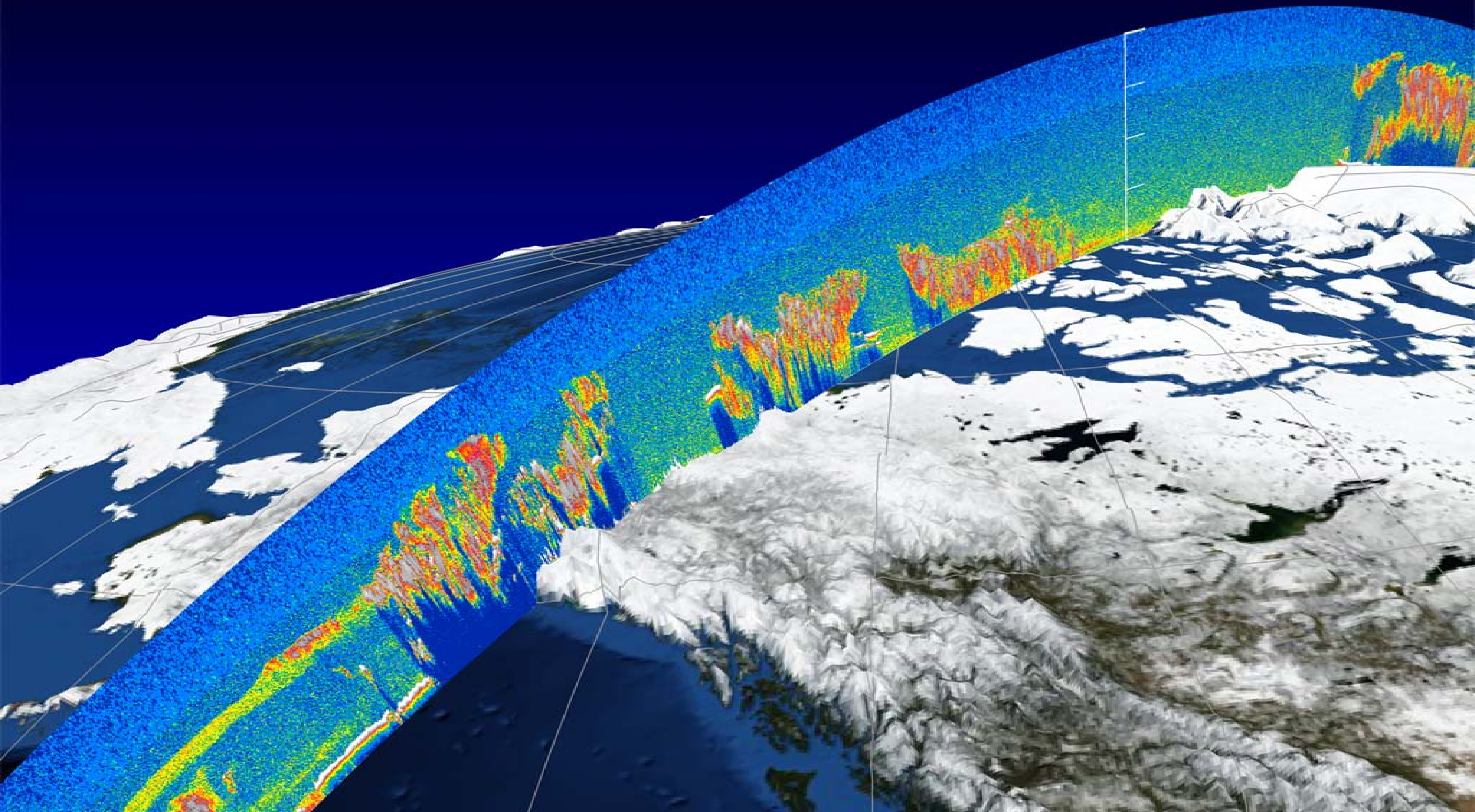
Global observations from CALIPSO

Dave Winker, Chip Trepte, and the CALIPSO team

NRL, Monterey, 27-29 April 2010



Mission Overview

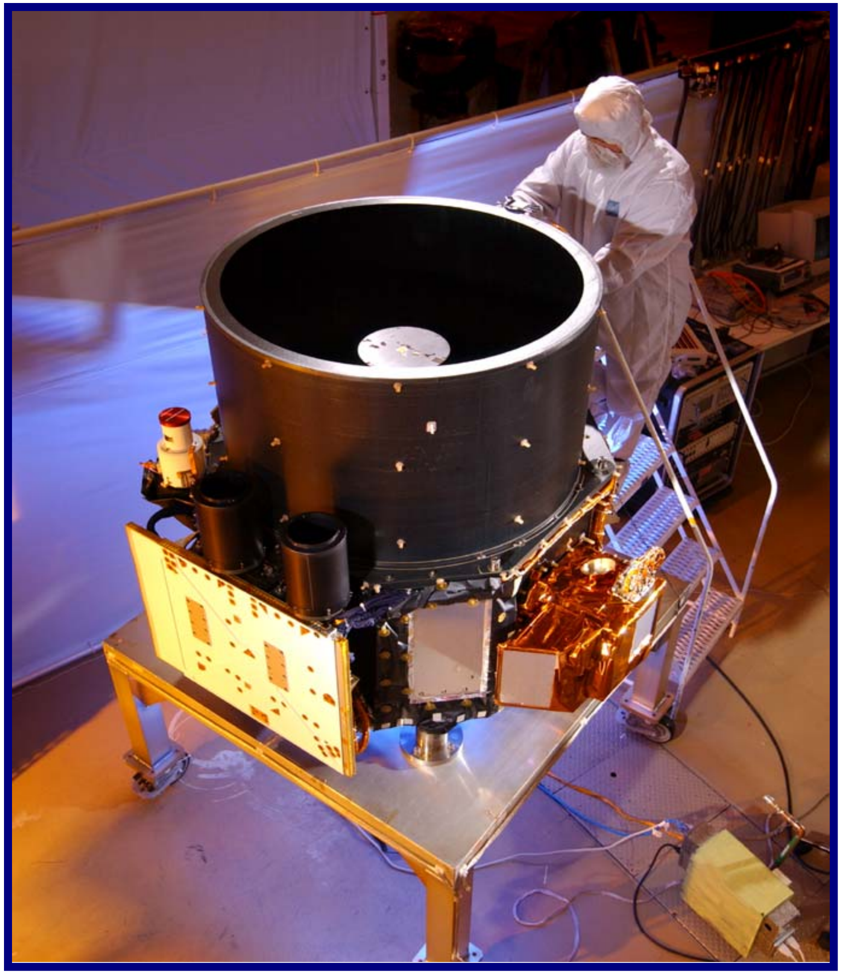
Features:

- ✂Two-wavelength backscatter lidar
- ✂First spaceborne polarization lidar
- ✂Co-aligned IR and VIS imagers
- ✂Launched w/ CloudSat: *28 April 2006*
- ✂Sun-sync (98^{o}) orbit with A-train
- ✂Joint NASA-CNES collaboration

Objectives *(in response to IPCC assessments)*:

- Improved understanding of aerosol & cloud effects on Earth energy budget
- Improved understanding of aerosol sources, transport processes
- Improve predictions of climate, weather, air quality

CALIPSO Payload



CALIOP

Laser	Nd: YAG, 2x110 mJ
Wavelength	532 nm, 1064 nm
Repetition rate	20.25 Hz
Receiver telescope	1.0 m diameter
Polarization	532 || and ⊥
Footprint/FOV	100 m / 130 μrad
Vertical resolution	30 - 60 m
Horizontal resolution	333 m
Lin. dynamic range	22 bits

Wide-Field Camera (WFC)

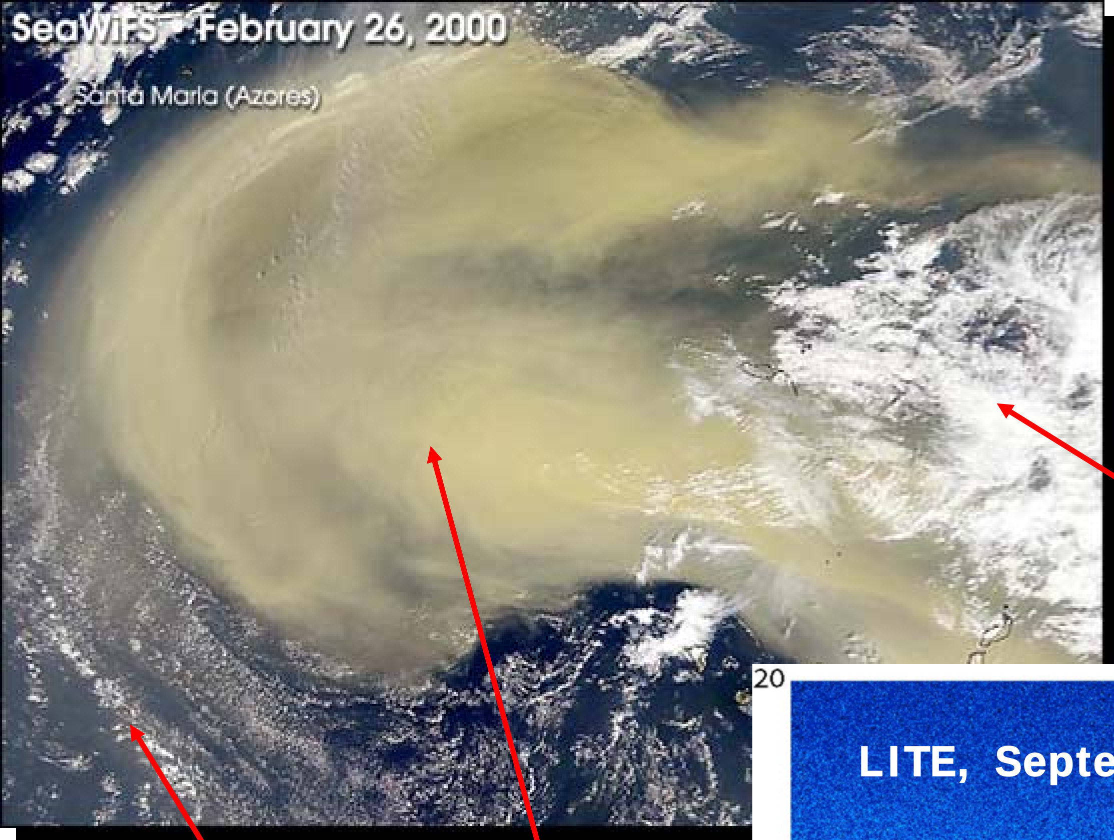
Wavelength	645 nm
Spectral bandwidth	50 nm
IFOV / Swath	125 m / 61 km

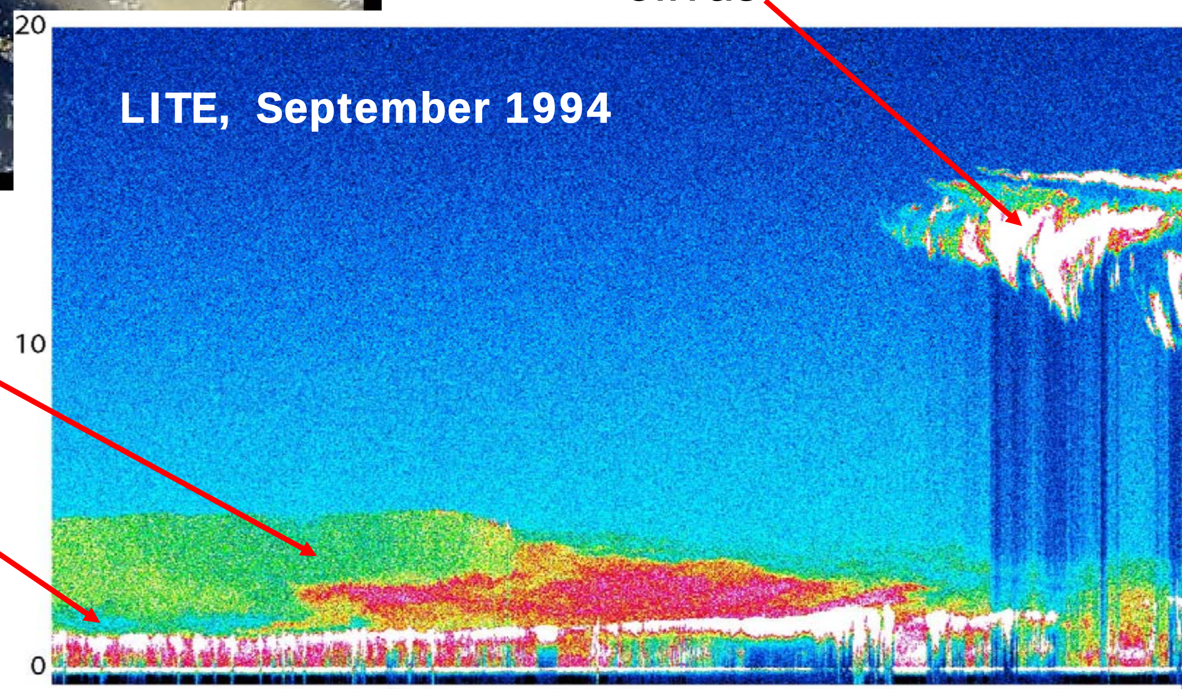
Imaging Infrared Radiometer (IIR)

Wavelength	8.65, 10.6,12.05 μm
Spectral resolution	0.6-1.0 μm
IFOV / Swath	1 km / 64 km
NETD @ 210K	0.3 K
Calibration	±1 K

CALIPSO aerosol products:

- **aerosol layer heights**
- **backscatter and extinction at 532 nm and 1064 nm**
- **depolarization at 532 nm**
- **color ratio (β_{1064}/β_{532})**
- **aerosol "type"**



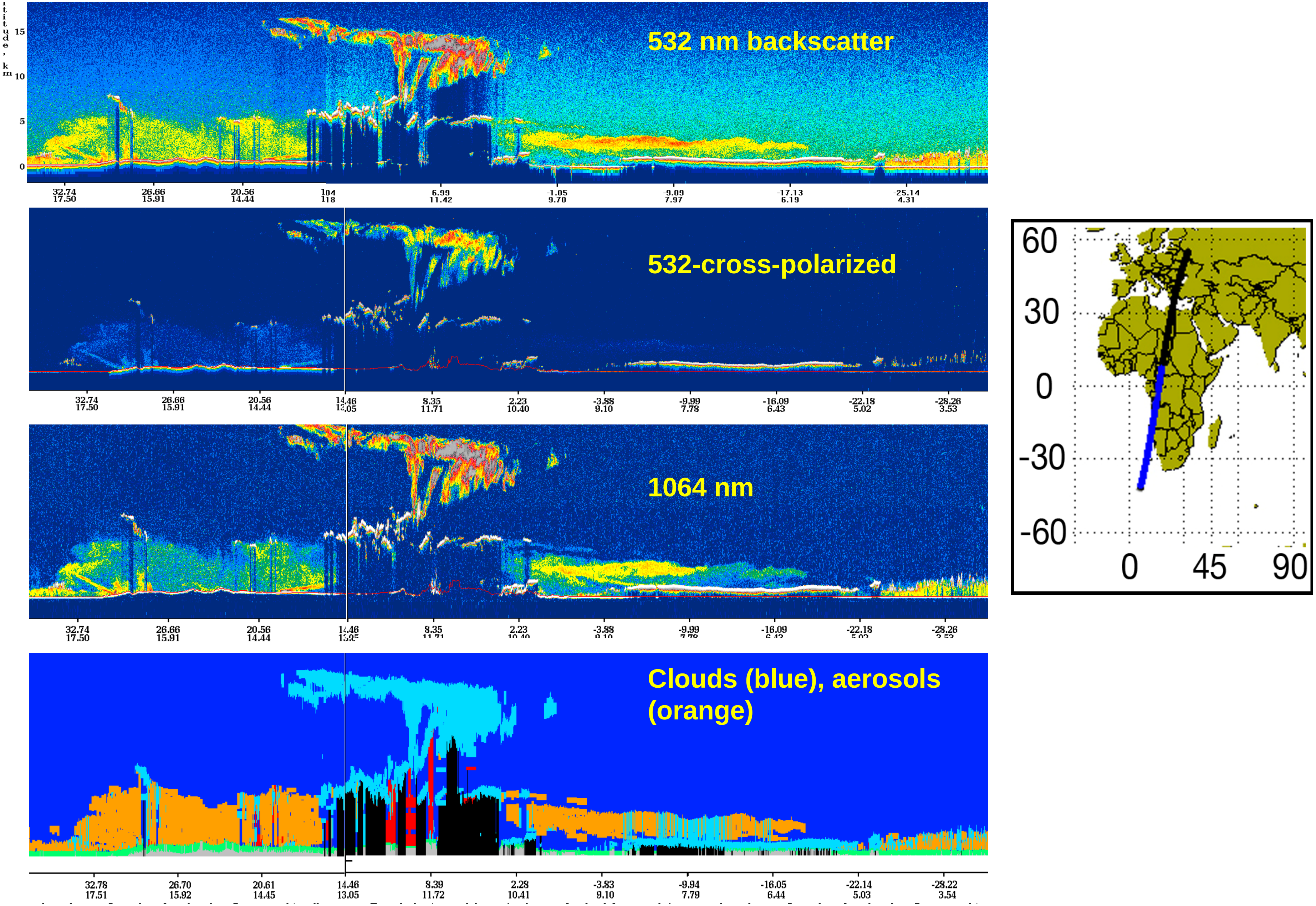


Cirrus

Dust

Low clouds

CALIOP Level 1 profiles + Cloud/Aerosol Mask



Lidar strengths and weaknesses

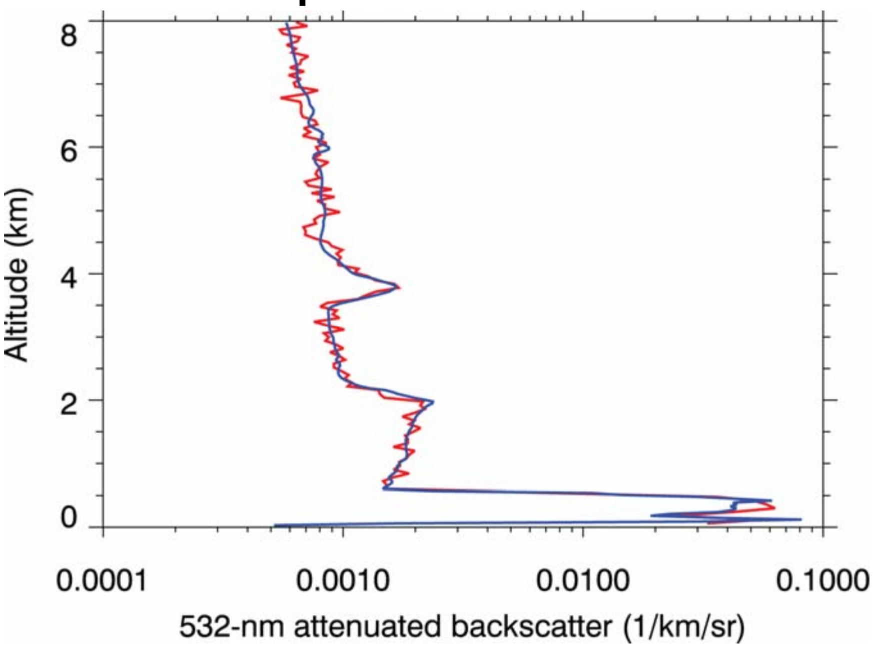
Good

- Vertically resolved (30 m)
- Small footprint (70 m), good cloud clearing
- Not restricted by lighting conditions and surface type
  - aerosol day and night
  - over all surfaces (snow, ...)
- Observes aerosol and cloud in the same column
- Depolarization: great for
  - Identifying dust
  - Separating tenuous ice cloud from non-dust aerosol

Bad

- Nadir only
- Limitations due to SNR
- 180-backscatter has limited information

aerosol profiles over eastern US



CALIOP Data Products

Level 1 (geolocated and calibrated)

- DP 1.1 - profiles of attenuated lidar backscatter (532, $532_{\perp}$, 1064 nm)

Level 2

- DP 2.1A – Cloud/Aerosol layer product
  - layer base and top heights, layer-optical depth, aerosol type, cloud I/W phase
- DP 2.1B – Aerosol profile product
  - Profiles of backscatter, extinction, depolarization,
- DP 2.1C – Cloud profile product
  - Profiles of backscatter, extinction, depolarization, ice/water content
- DP 2.1D – Vertical Feature mask
  - cloud/aerosol locations, aerosol type, cloud phase

Level 3 (in development)

  - Gridded aerosol and cloud statistics

(available at http://eosweb.larc.nasa.gov)

Extinction Uncertainty Estimate

Uncertainty in Particulate Backscatter Coefficients at Altitude *n*

$$\frac{\sigma^2(\beta_{p,n})}{\beta_{p,n}^{\;2}} = A_n^{\;2}\left(\left(\frac{\sigma^2(\mathcal{X}_n)}{\mathcal{X}_n^{\;2}}\right)+\left(\frac{1}{R_n}\right)^2\left(\frac{\sigma^2(\beta_{m,n})}{\beta_{m,n}^{\;2}}\right)+\left(2\eta\tau_{p,n}\right)^2\left(\frac{\sigma^2(S)}{S^2}+\frac{\sigma^2(\eta)}{\eta^2}\right)+\left(\frac{\sigma^2(T^2_{p,n-1})}{\left(T^2_{p,n-1}\right)^2}+B_n^{\;2}\left(\frac{\sigma^2(\beta_{p,n-1})}{\beta_{p,n-1}^{\;2}}\right)\right)\right)$$

Measurement Uncertainty

Molecular Number Density Uncertainty

Lidar Ratio Uncertainty

Multiple Scattering Uncertainty

Accumulated Aerosol Attenuation Uncertainty

Includes errors due to

- ⇨ Calibration
- ⇨ **SNR**
- ⇨ molecular density (again)
- ⇨ offset calculations
- ⇨ polarization gain ratio
- ⇨ polarization cross-talk
- ⇨ ranging

LEGEND

S	= lidar ratio	β = backscatter coefficient
R	= scattering ratio	$\sigma^2(x)$ = variance of x
T	= transmittance	τ = optical depth
m	= molecular	p = particulate (e.g., aerosol)
P	= measured data	C = calibration constant
η	= multiple scattering factor	

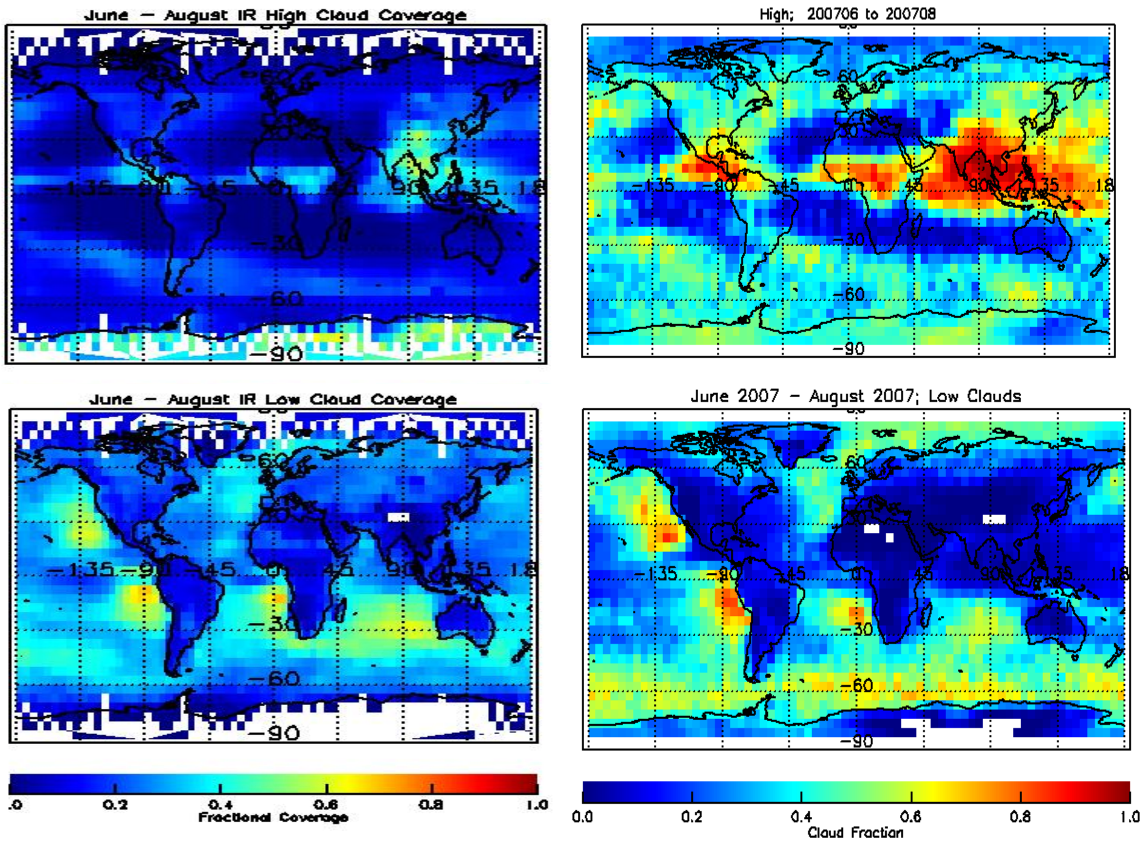
$$\mathcal{X}_n = \mathcal{X}(r_n) = \frac{r_n^{\;2}\cdot P(r_n)}{C\cdot T_m^2(r_n)}$$

$$A_n = \left(\frac{R_n}{R_n - 1}\right)\cdot\left(\frac{1}{1 - R_n\cdot\beta_{m,n}\cdot S\cdot\eta\cdot\Delta r_n}\right)$$

$$B_n = S\cdot\eta\cdot\Delta r_n\cdot\beta_{p,n-1}$$

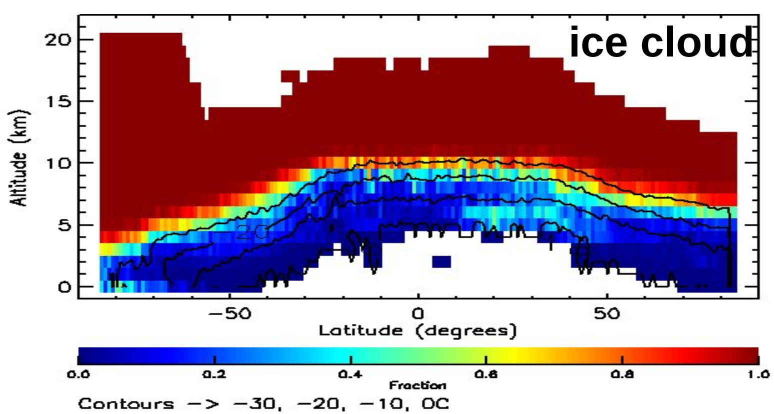
CALIOP measures clouds too!

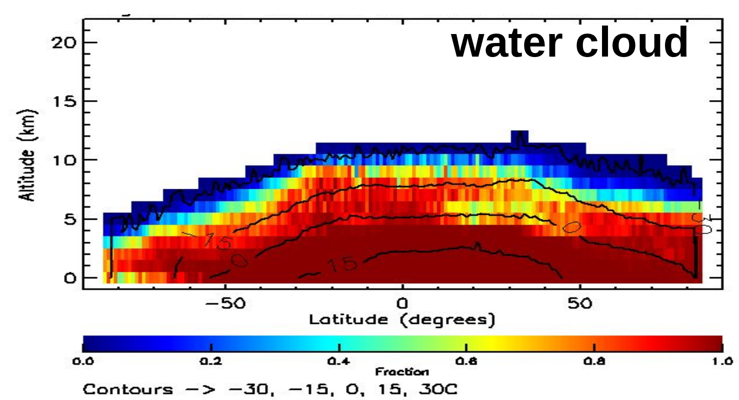
ISCCP-IR **CALIOP**



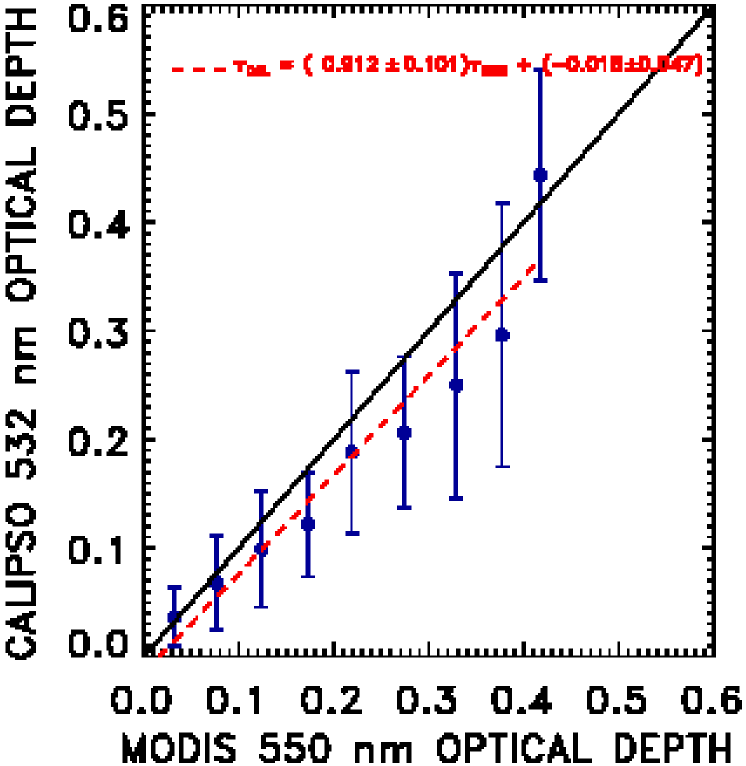
High Cloud (> 440 mb)

Low Cloud (< 680 mb)





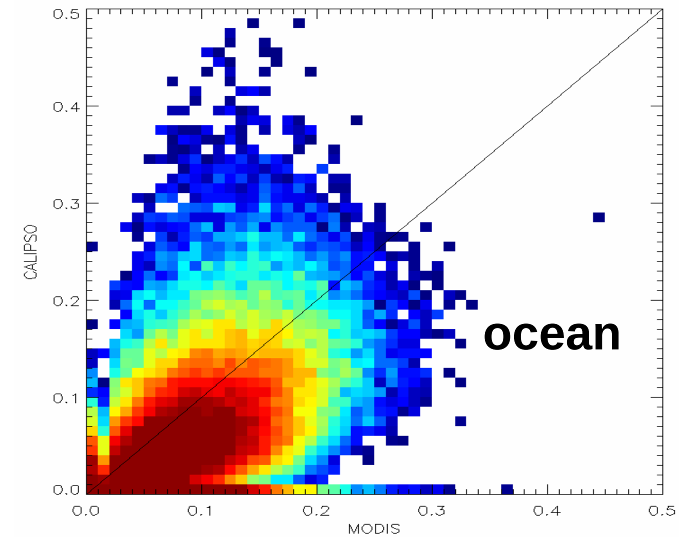
Aerosol Optical Depth: MODIS vs. CALIOP

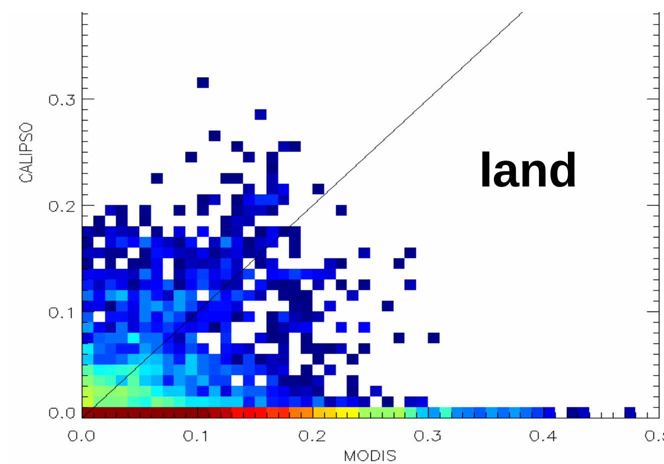


Coakley and Tahnk:

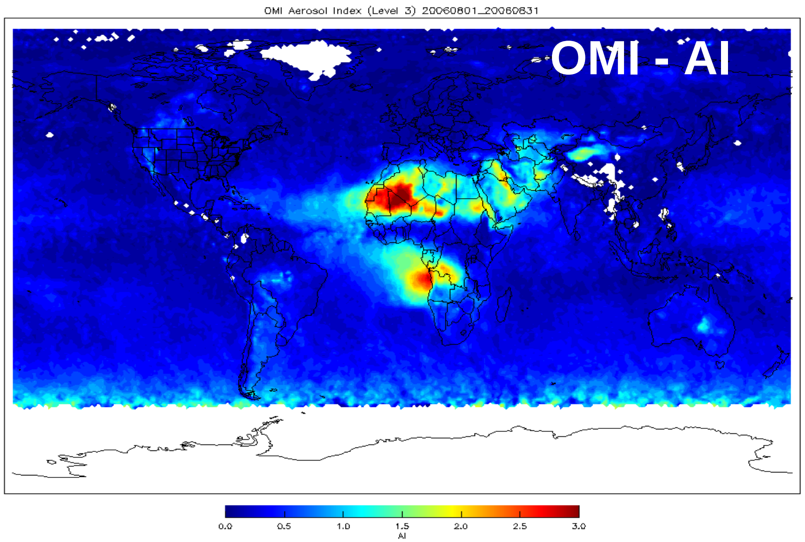
In large, cloud-free ocean regions (to avoid near-cloud effects) find CALIOP 532 nm AOD agrees well with MODIS 550 nm AOD (CALIPSO biased low)

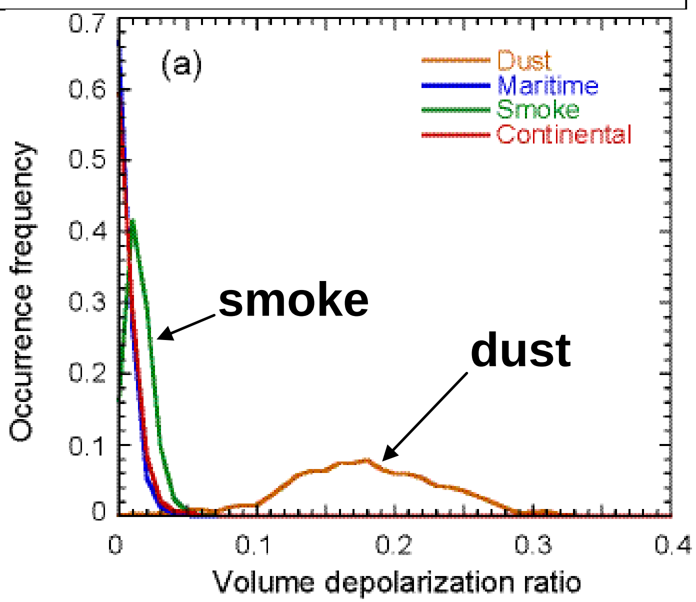
CALIOP AOD vs. MODIS
(matched, instantaneous footprints)





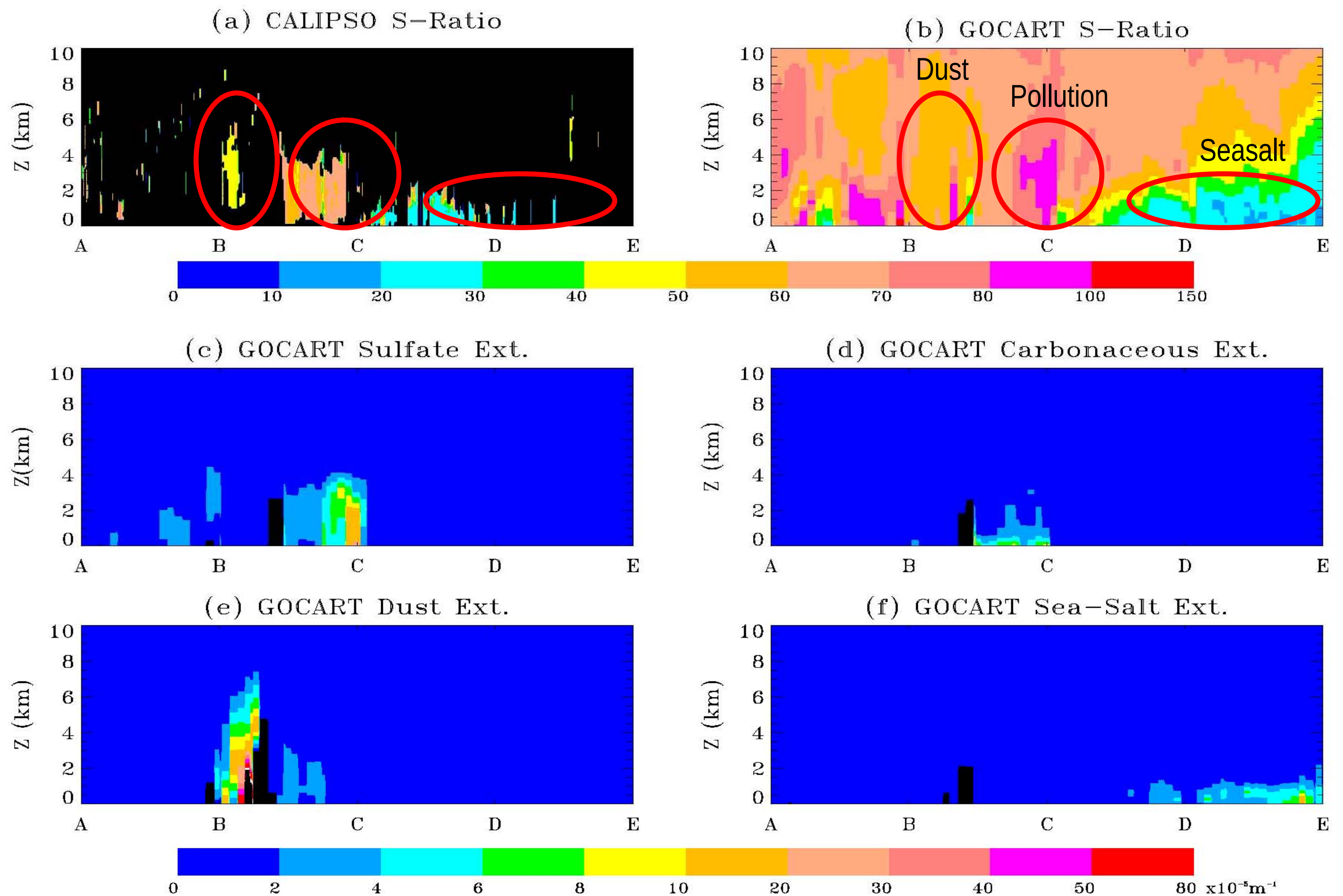
Aerosol type





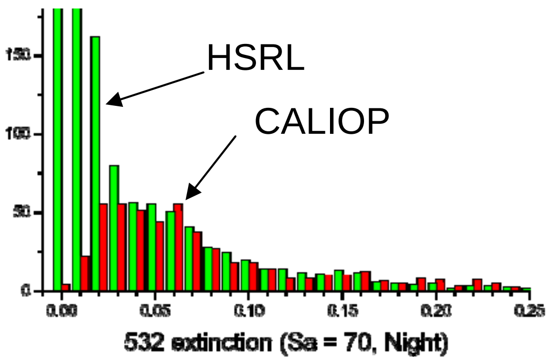
CALIPSO aerosol type vs. GOCART (Mian Chin)

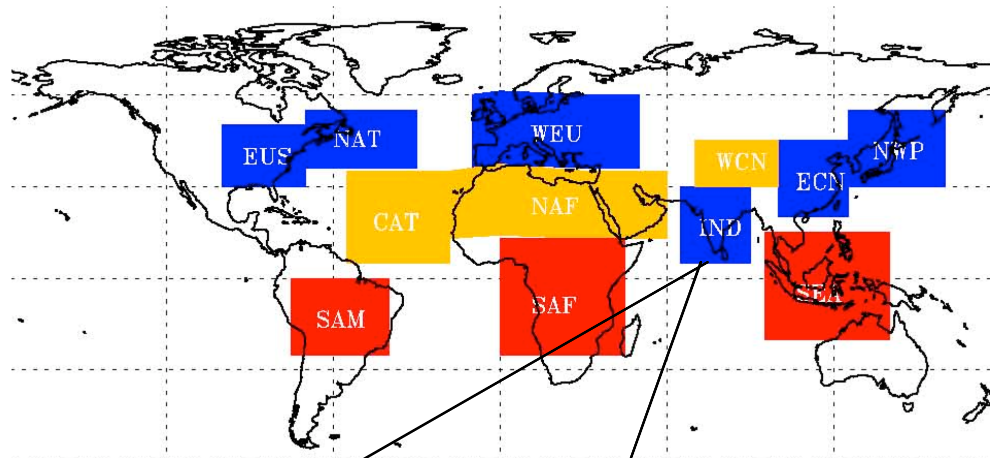
Preliminary comparisons show model and CALIOP agree on aerosol types and vertical distribution most of the time in cases studied



Regional profile comparisons vs GOCART

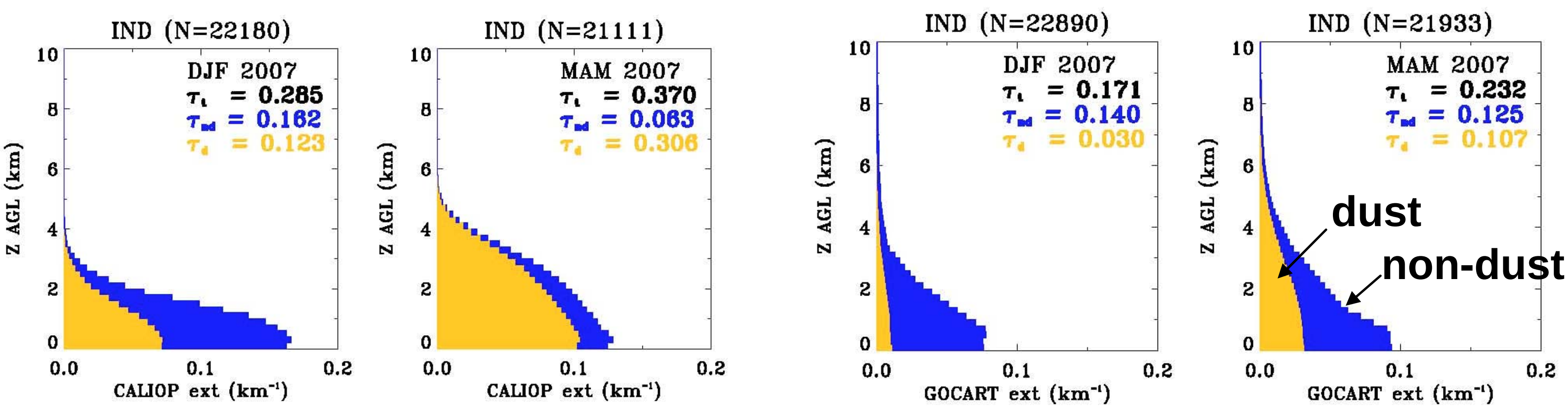
CALIOP instantaneous sensitivity ~ 0.01 /km





Hongbin Yu, et al. (JGR, 2010)

CALIOP extinction **GOCART extinction**



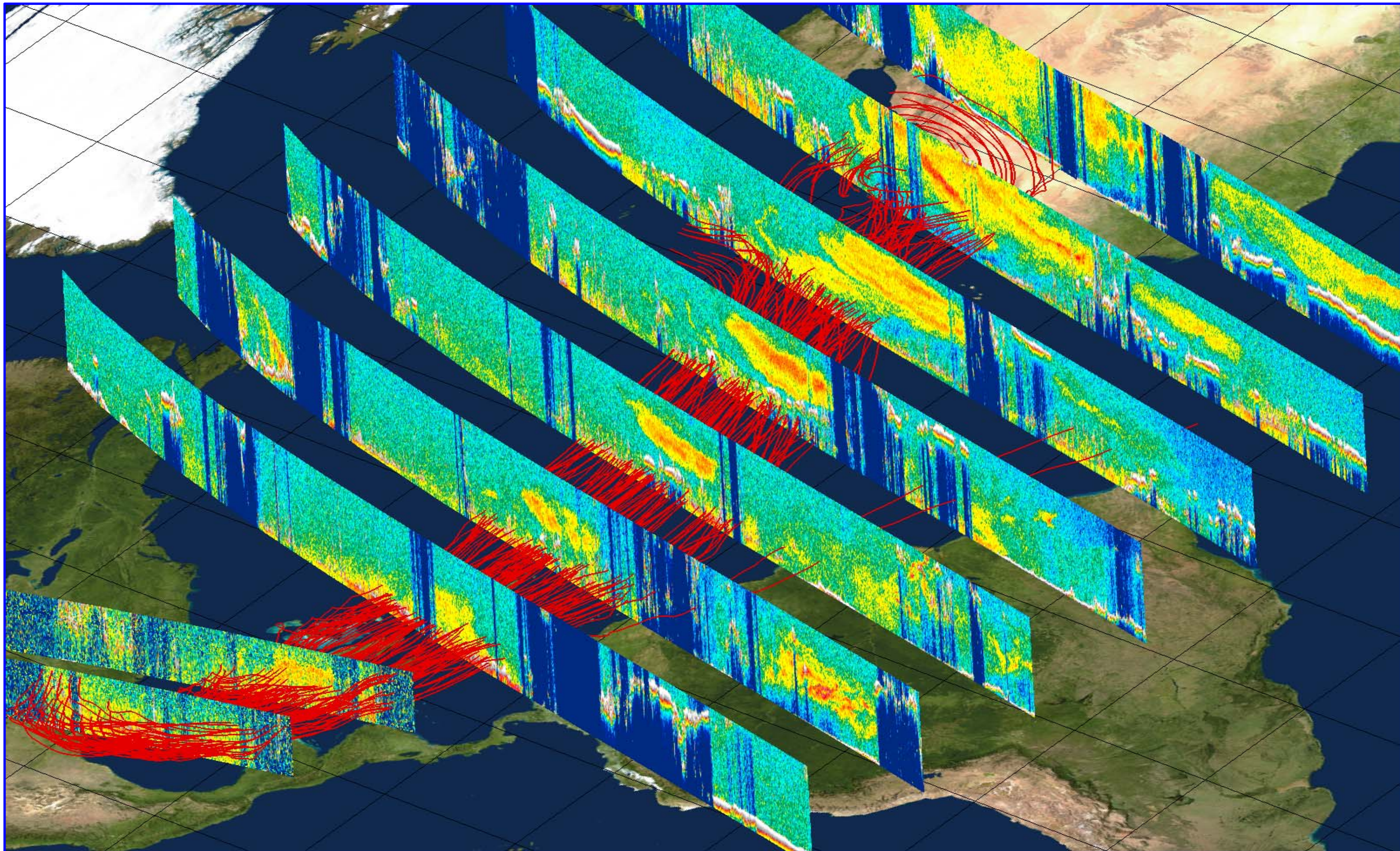
DJF **MAM** **DJF** **MAM**

Aerosol Transport

Studies include

- model verification, skill assessment
- data assimilation and fusion
- forecasts in support of field campaigns

Saharan Dust Outbreak Aug 2006

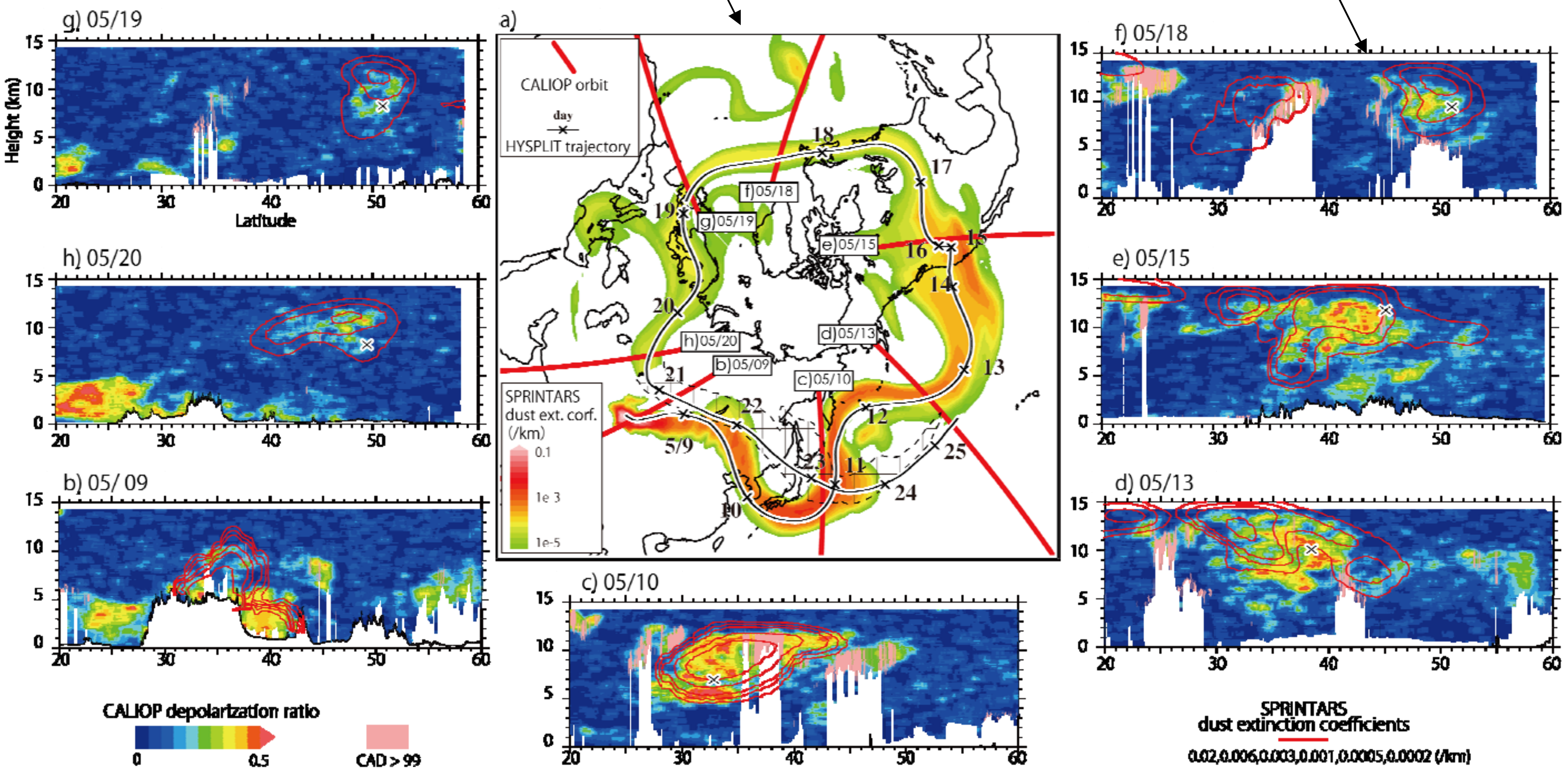


Long Range Transport: Asian dust

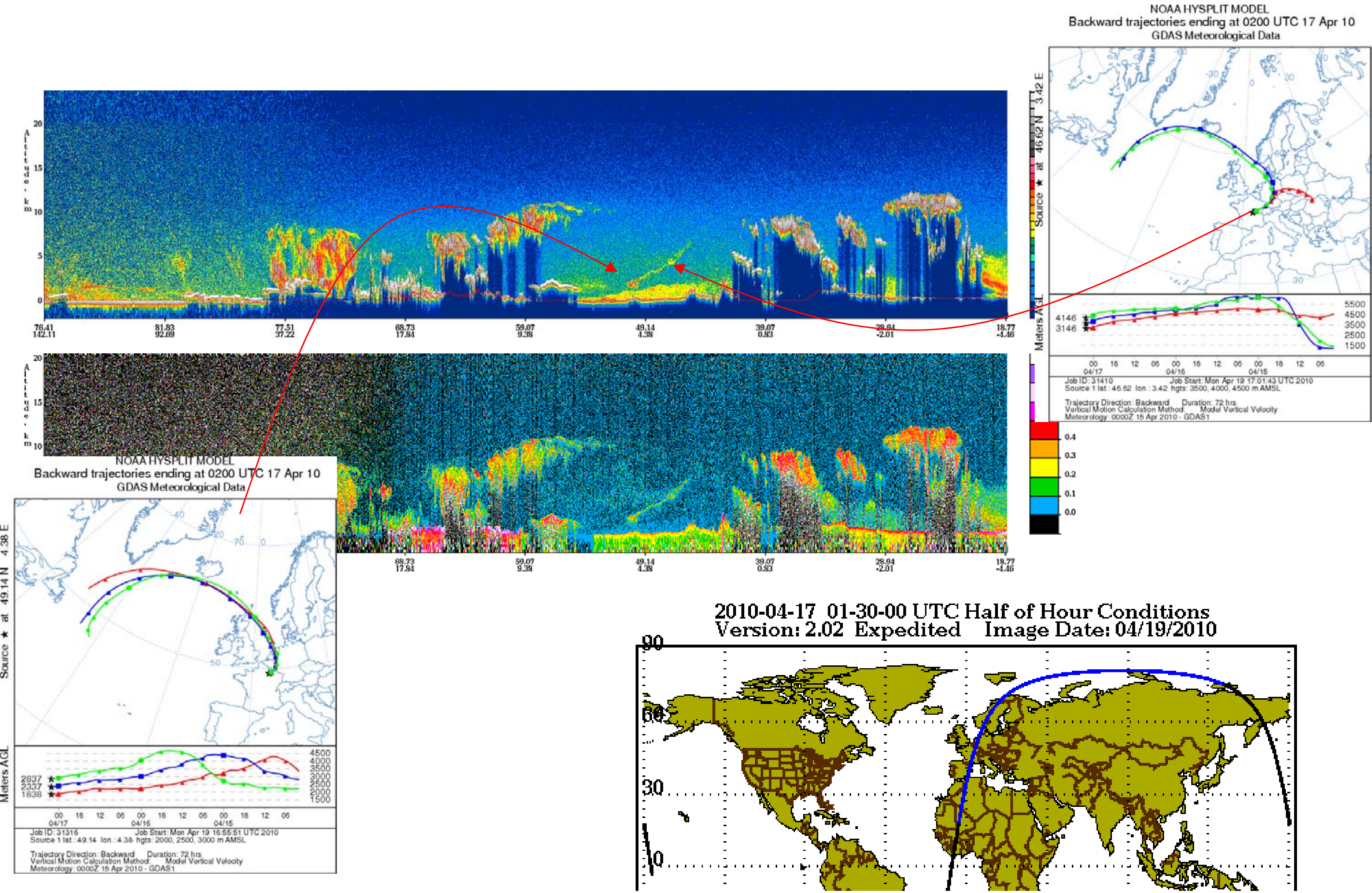
(Uno et al, 2009)

CALIPSO orbit paths (red lines), HYSPLIT dust trajectory (white-black thick line) and SPRINTARS simulated dust extinction (tone) along HYSPLIT trajectory

CALIOP depol + SPRINTARS dust extinction (contours)

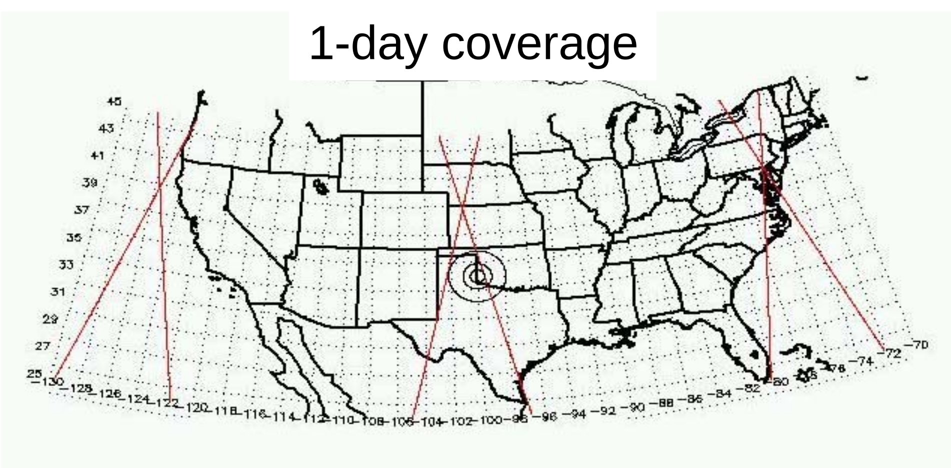


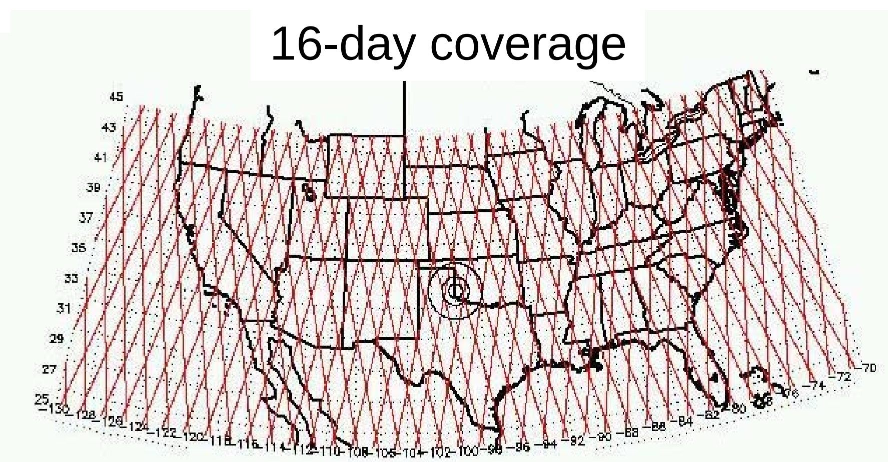
Volcanic plumes: Eyjafjallajökull - 17 April



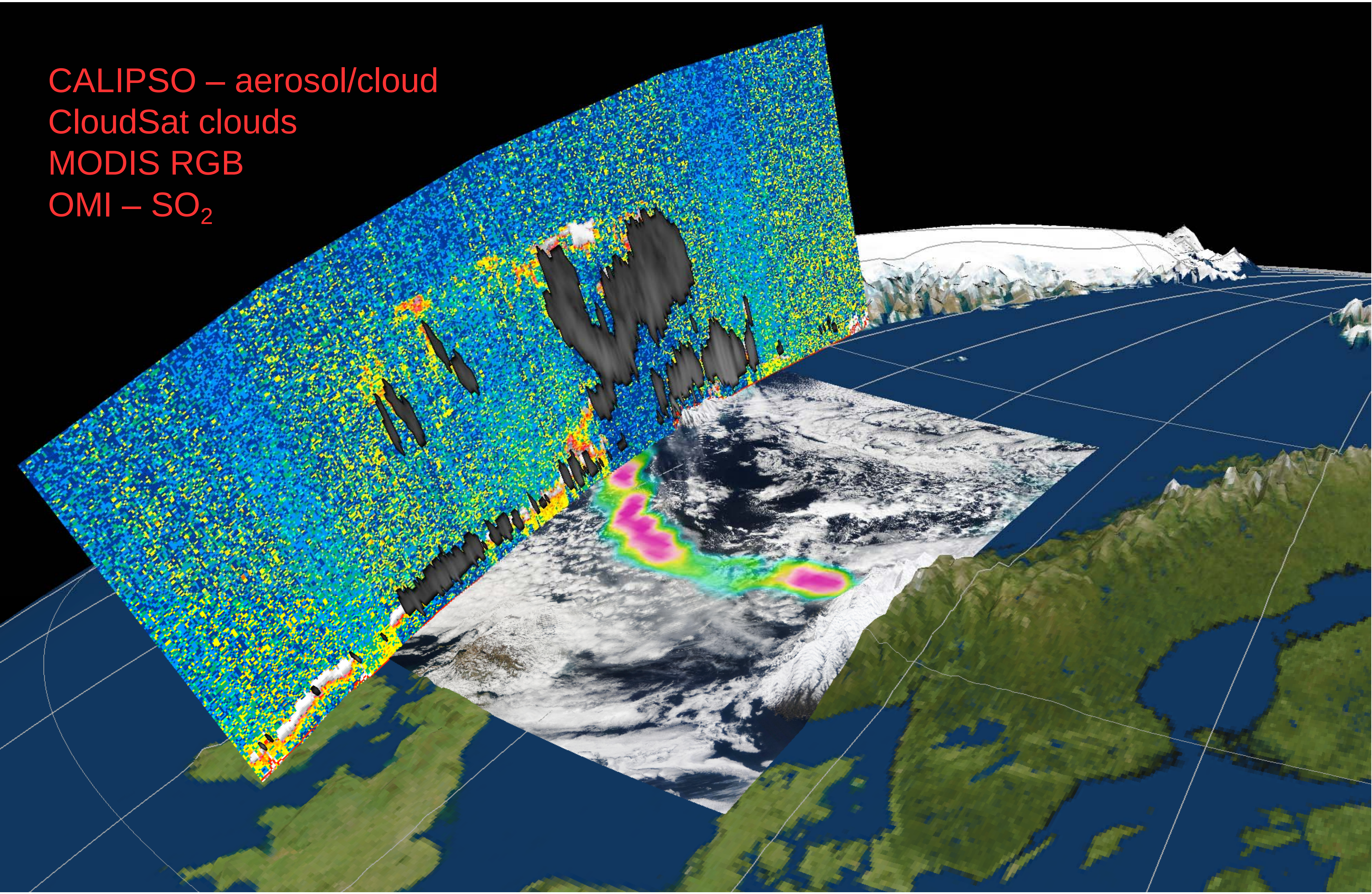
CALIOP and Volcanoes

- Nadir only
  - Sparse coverage, significant features can be missed
- Data latency limitations: driven by payload and ground system
  - Latency of standard products ~3-5 days
  - Expedited product latency ~12 hours from ground reception
- Sensitive to ~ 0.01 /km (roughly 10 $\mu g/m^3$)
  - vs. engine damage threshold ?
- Identification can be ambiguous
  - volcanic sulfate aerosol + ash (possibly mixed with condensed water) vs. normal cloud
  - more difficult to identify plume as it descends lower in the atmosphere





Multi-sensor observations of Eyjafjallajökull plume



Summary

CALIPSO launched on April 28, 2006

Data is used widely, validation is continuing

- >200 Publications published or submitted using CALIPSO data
- New version of data to be released in May 2010

Likely mission life: thru 2014-16

- Spacecraft and payload currently healthy
- Mission currently funded through 2011
- Fuel to remain in A-train till 2016

Continuity of aerosol profiling:

- ADM (ESA) – 2013 (?)
- EarthCare (ESA/JAXA) – 2014
- ACE (NASA) – 2019 (??)