# Global Aerosol Observations from CALIPSO

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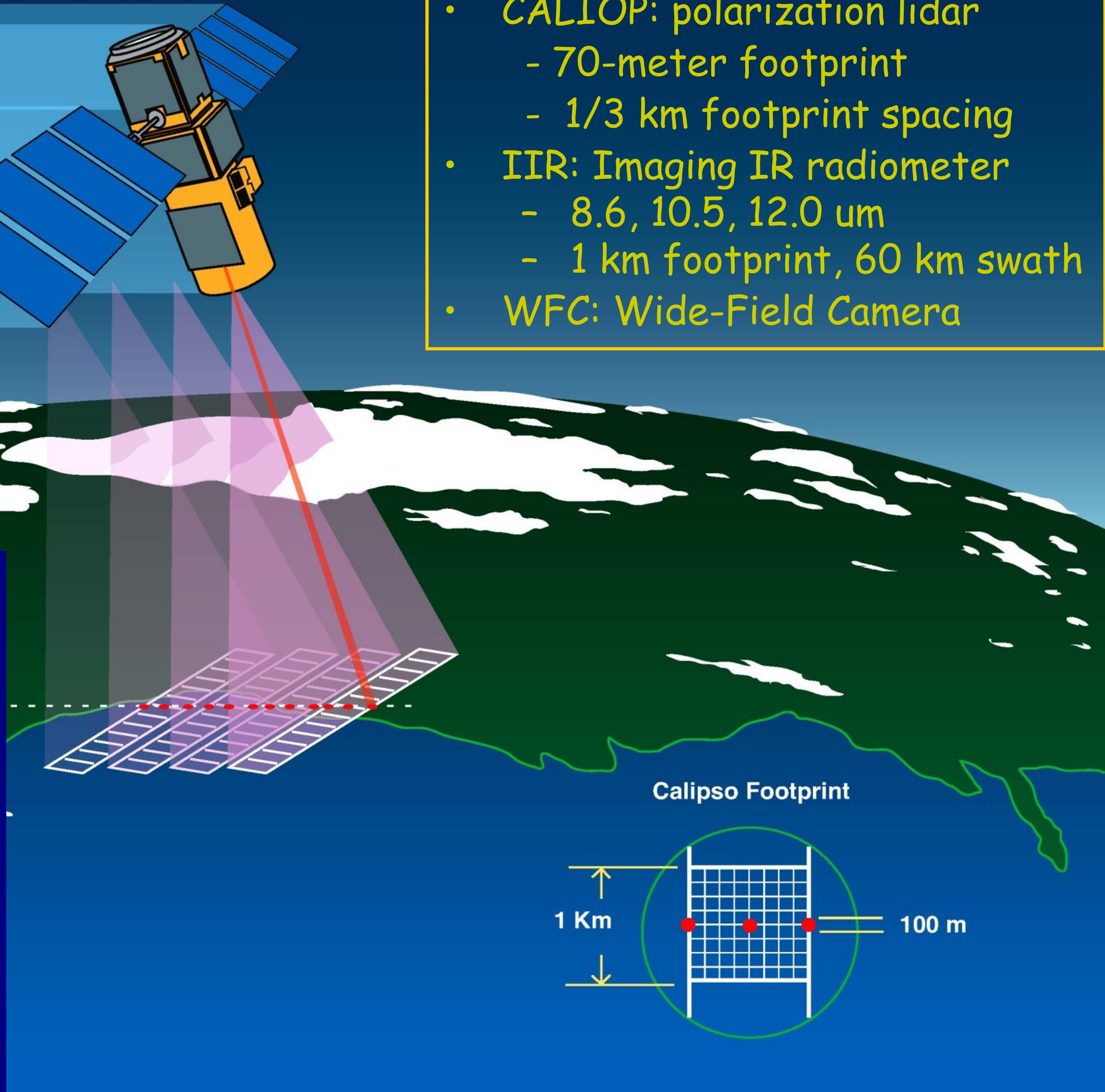
# Outline

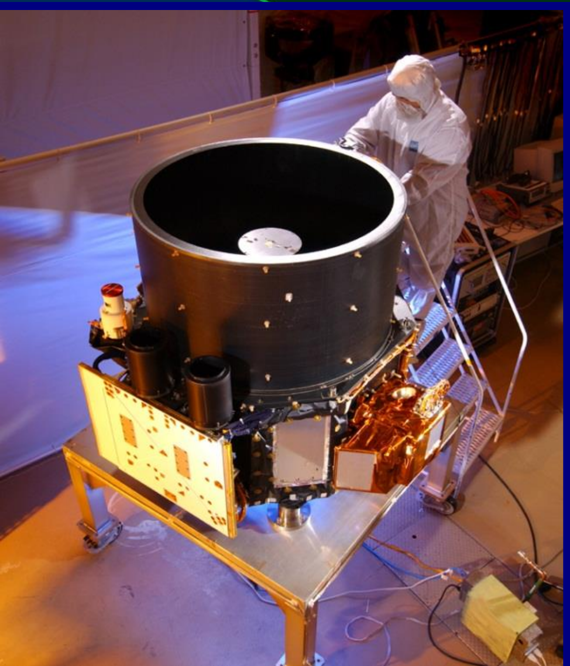
- Introduction to CALIPSO
- Global aerosol distribution
- Global radiative effects

**First light: 7 June 2006**

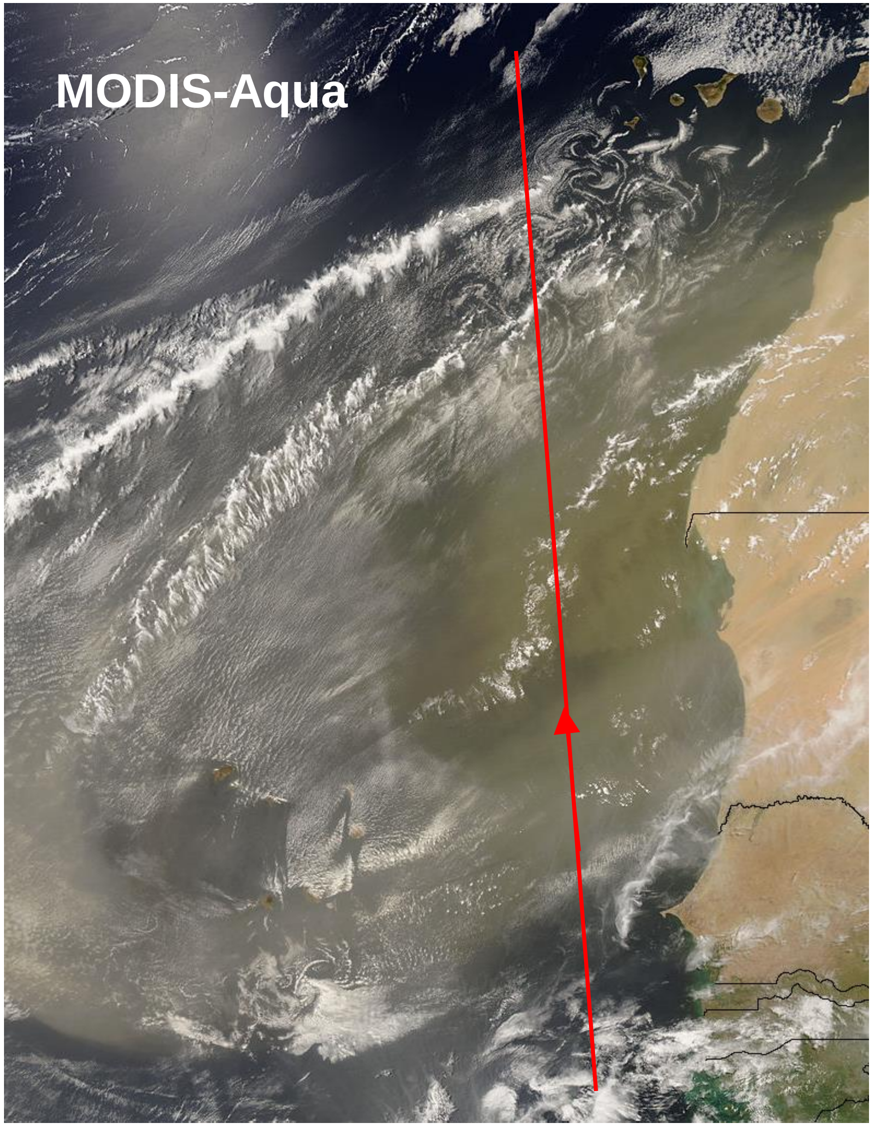
Three co-aligned instruments:

- CALIOP: polarization lidar
  - 70-meter footprint
  - 1/3 km footprint spacing
- IIR: Imaging IR radiometer
  - 8.6, 10.5, 12.0 um
  - 1 km footprint, 60 km swath
- WFC: Wide-Field Camera

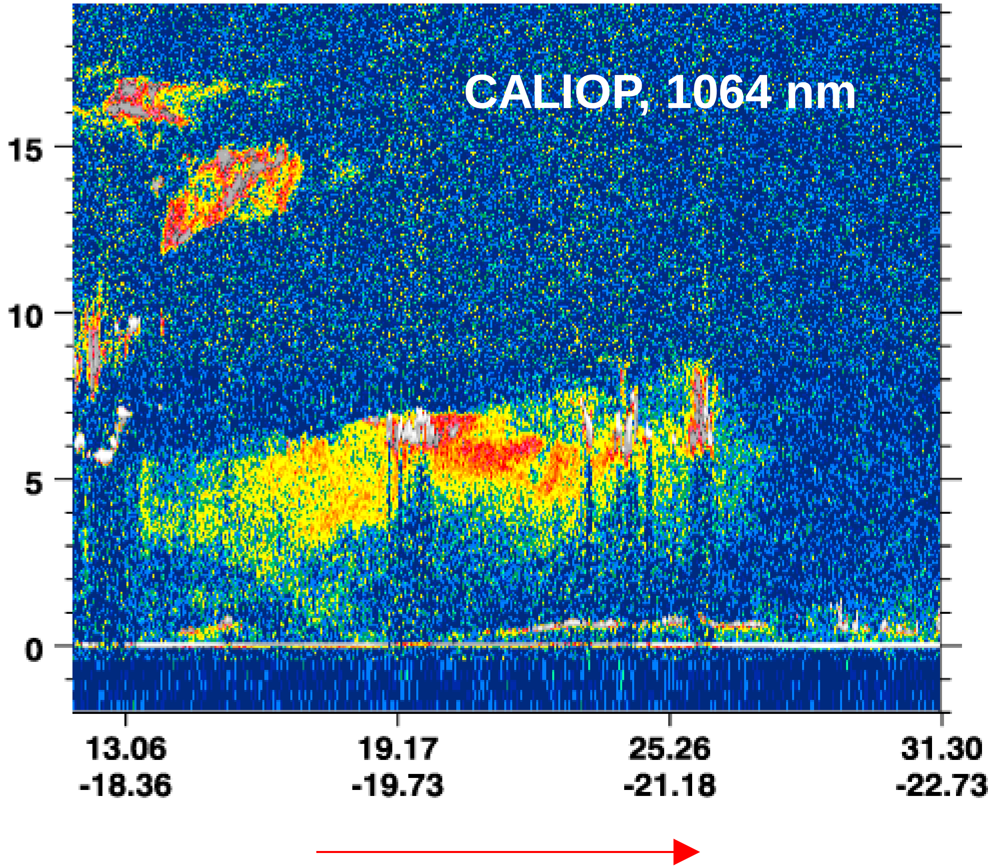


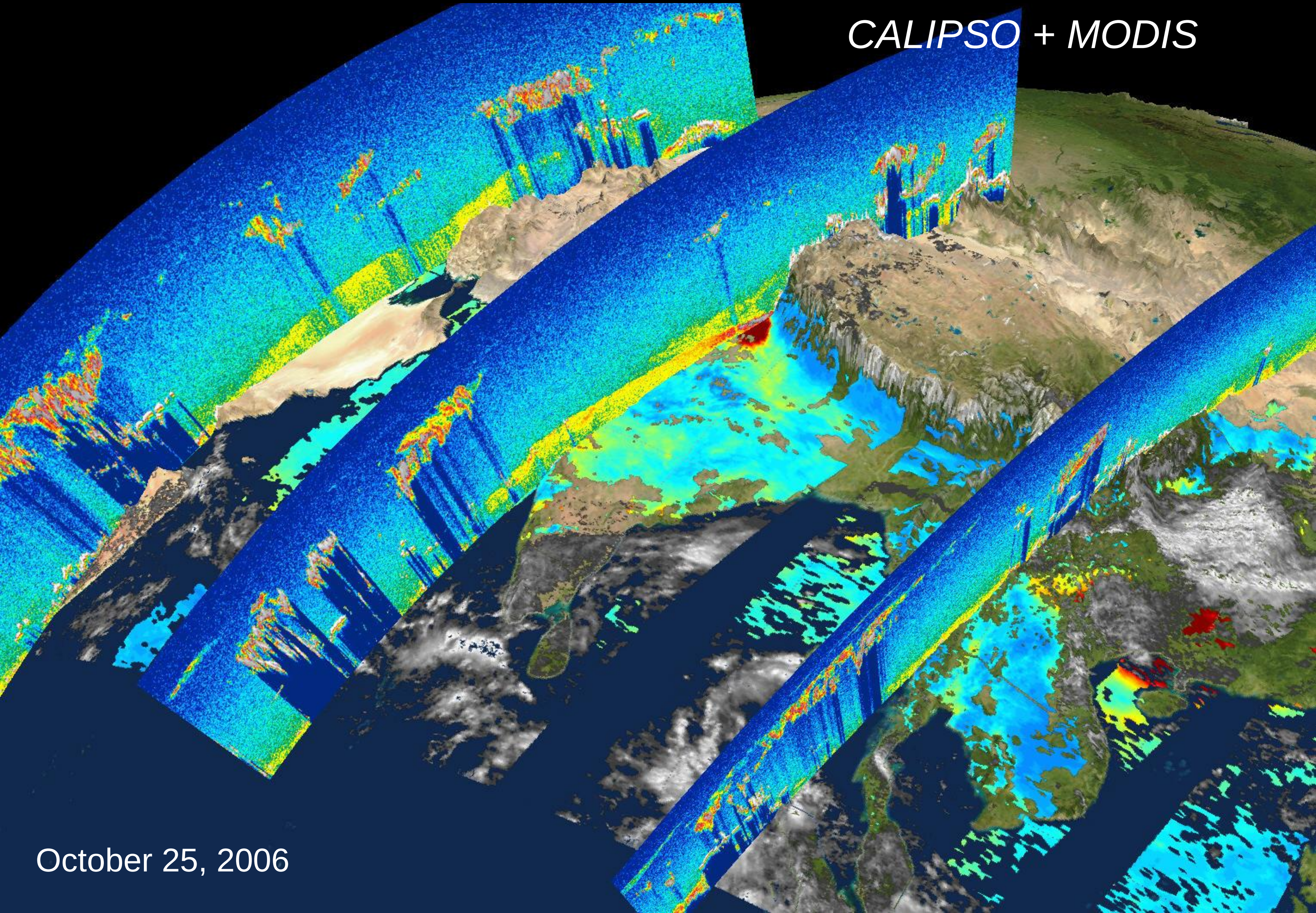
# Passive and active retrievals: fundamentally different, but complementary



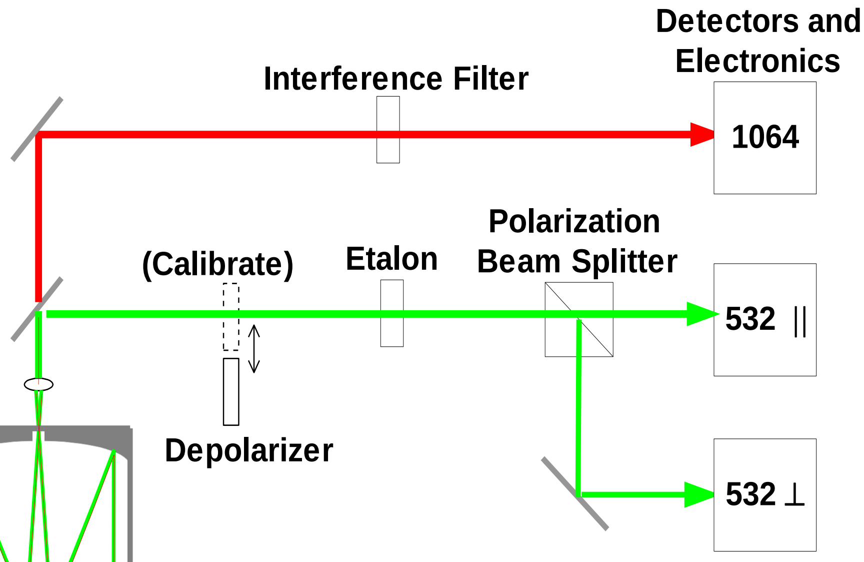

21 June 2008

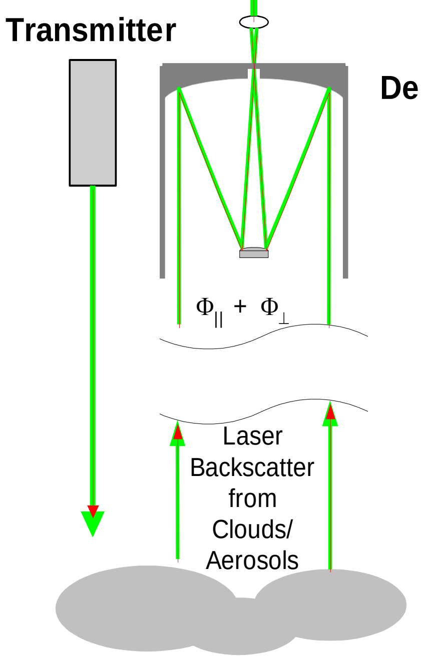


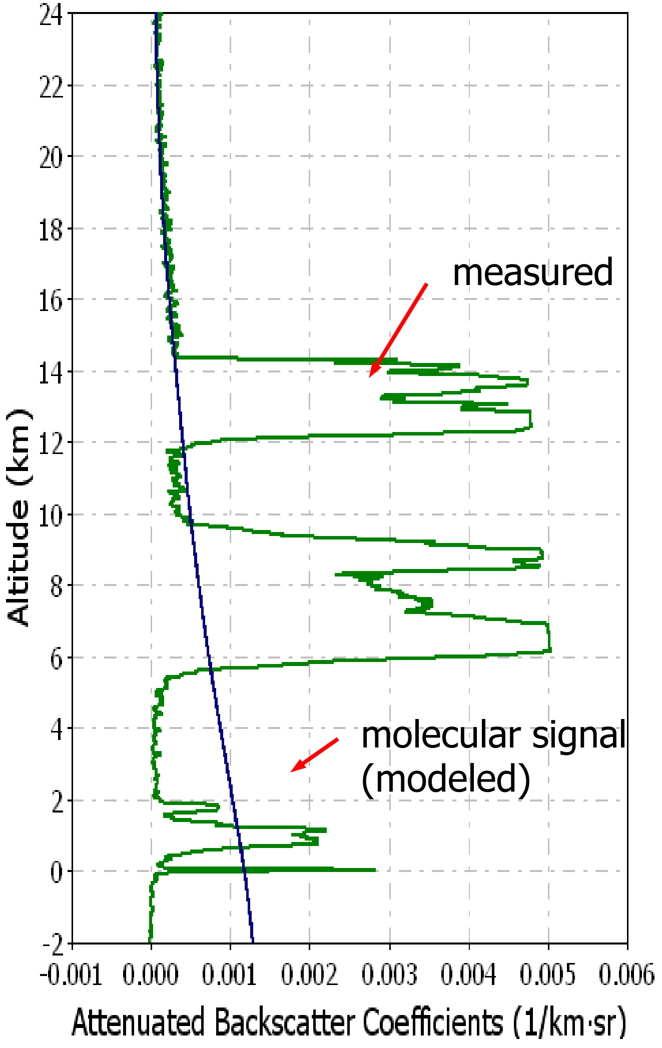
# Aerosol and Cloud Observations over South Asia



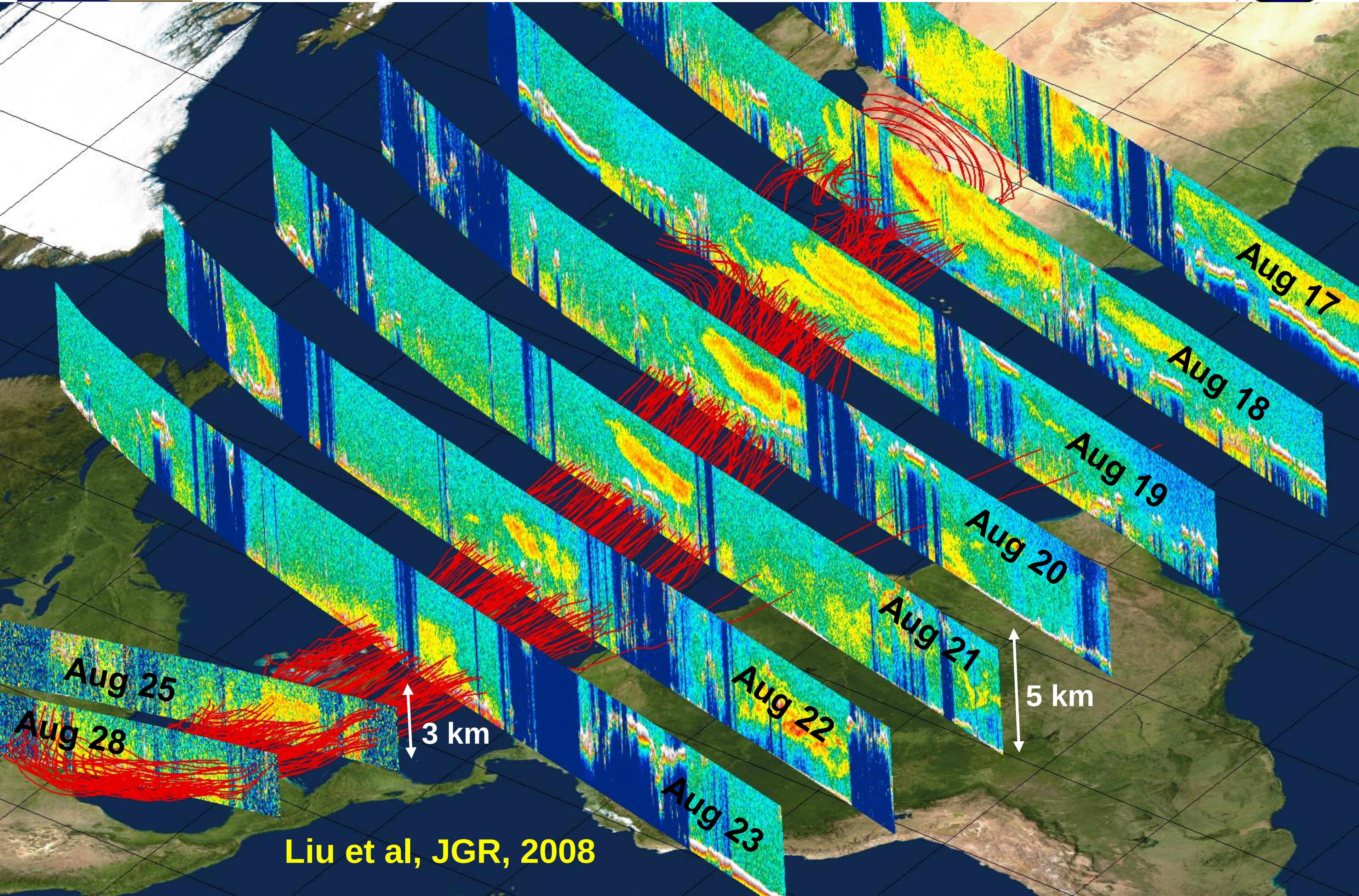
# Time-of-flight laser backscatter measurement



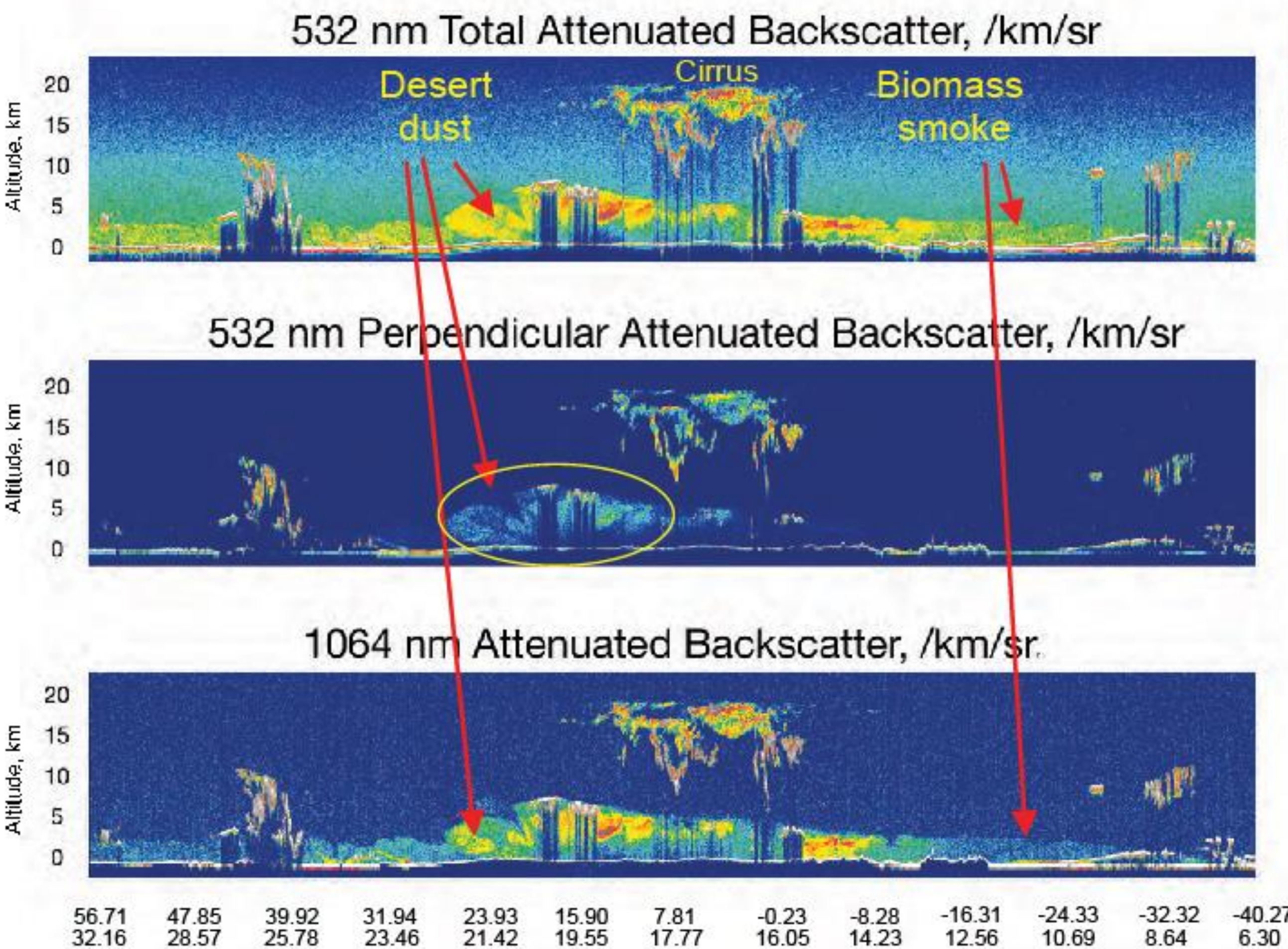



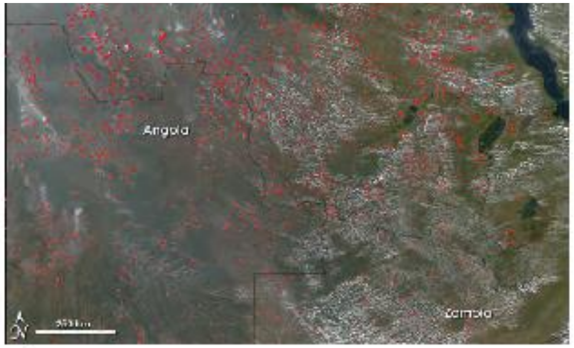
# Case study of Sahara dust outbreak



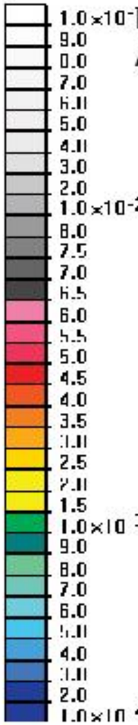
# CALIOP First Light Observations

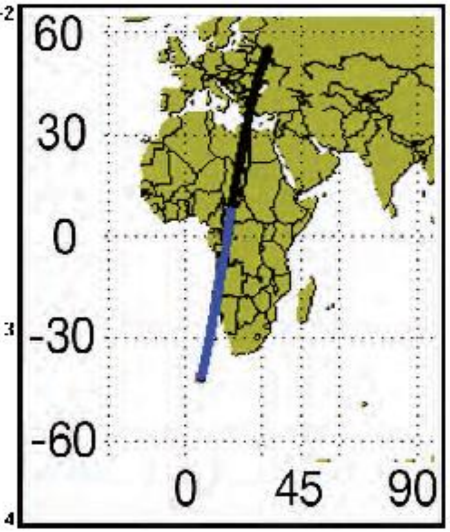
*June 9, 2006*



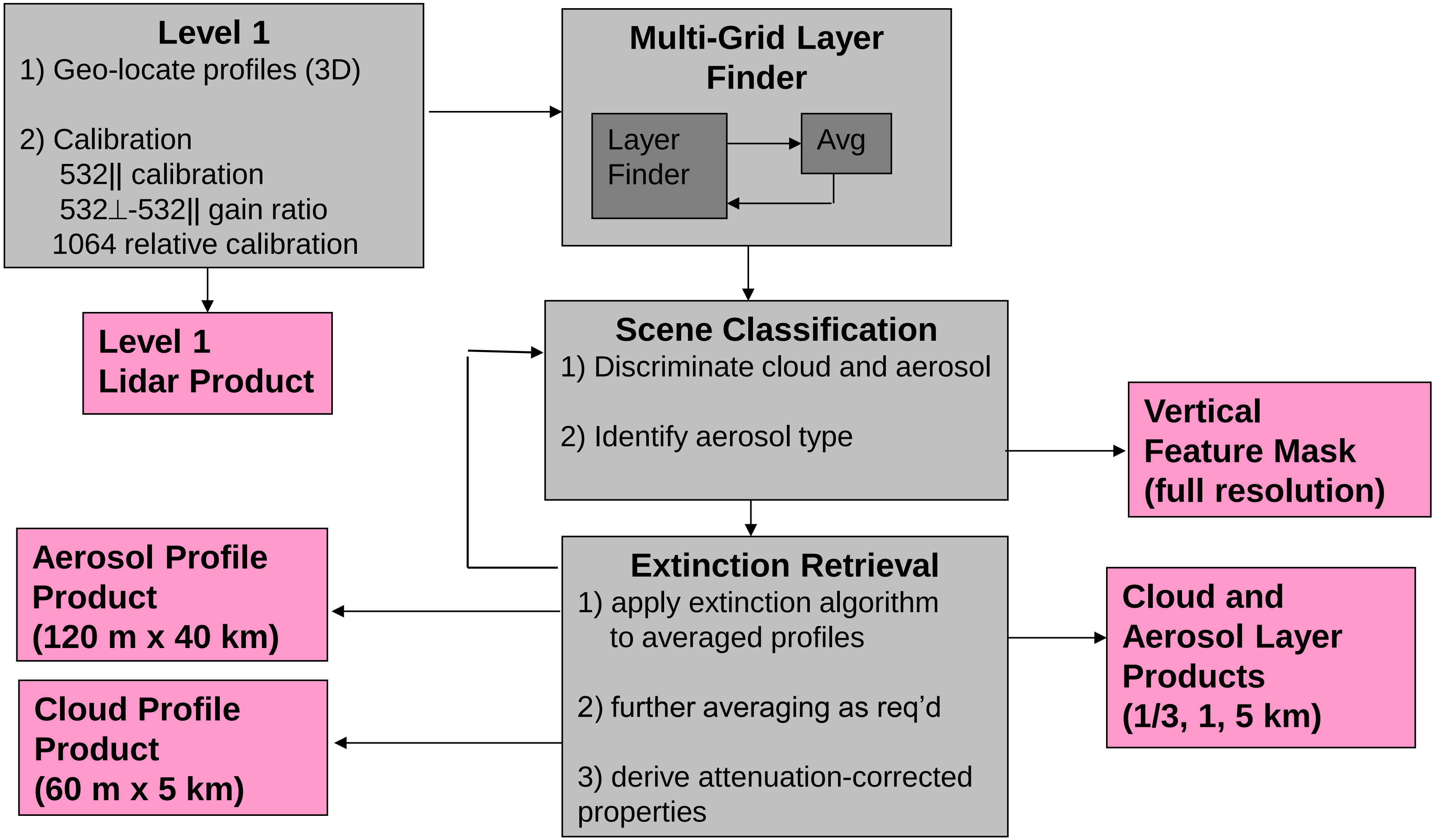




Fire locations in southern Africa from MODIS, 6/10/06



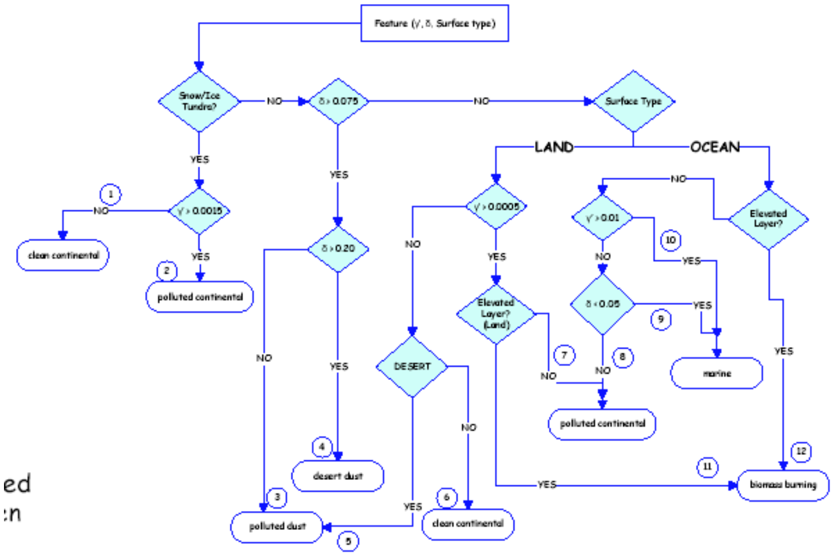


# CALIOP Retrieval Algorithms and Products



# Aerosol type algorithm

- An algorithm identifies aerosol type based on observed backscatter and depolarization profiles
- Used to select lidar ratio from a lookup table, but also provides useful clues to aerosol source and composition

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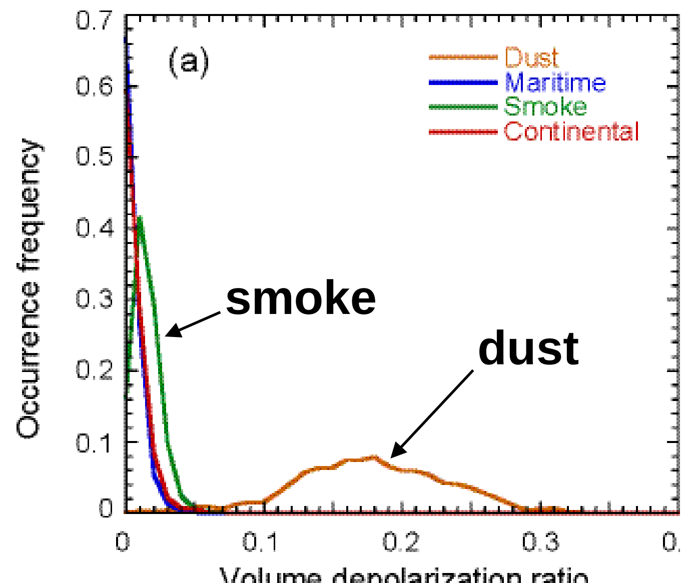
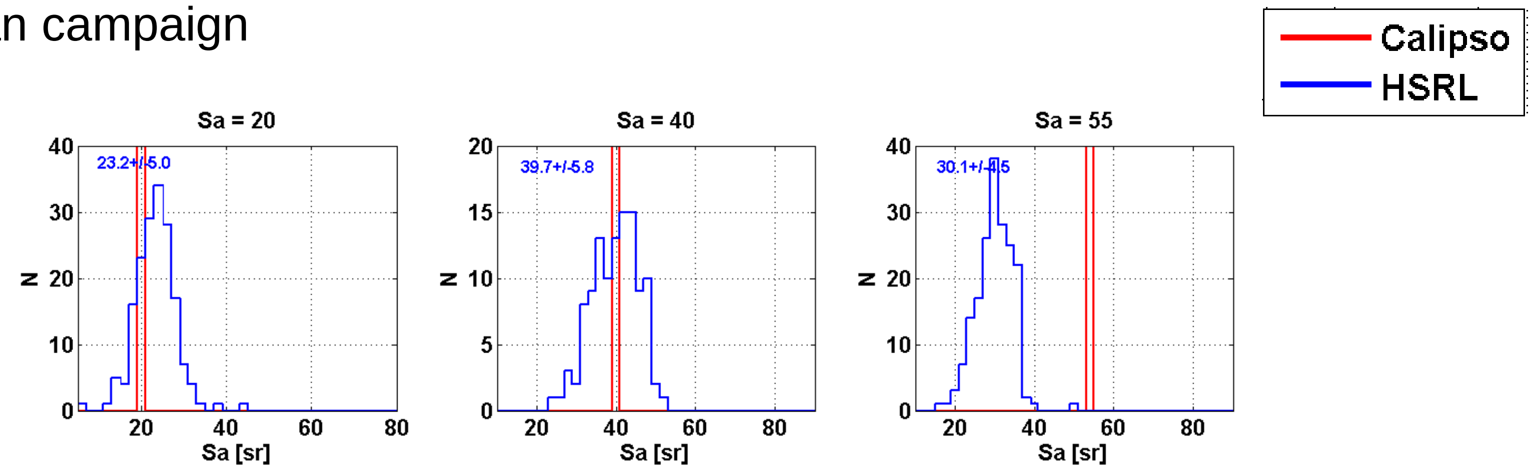
- Currently, 6 aerosol types:
- Pollution 70 sr
- Smoke 70 sr
- Dust 40 sr
- Polluted dust 55 sr
- Clean marine 20 sr
- Clean continental 35 sr



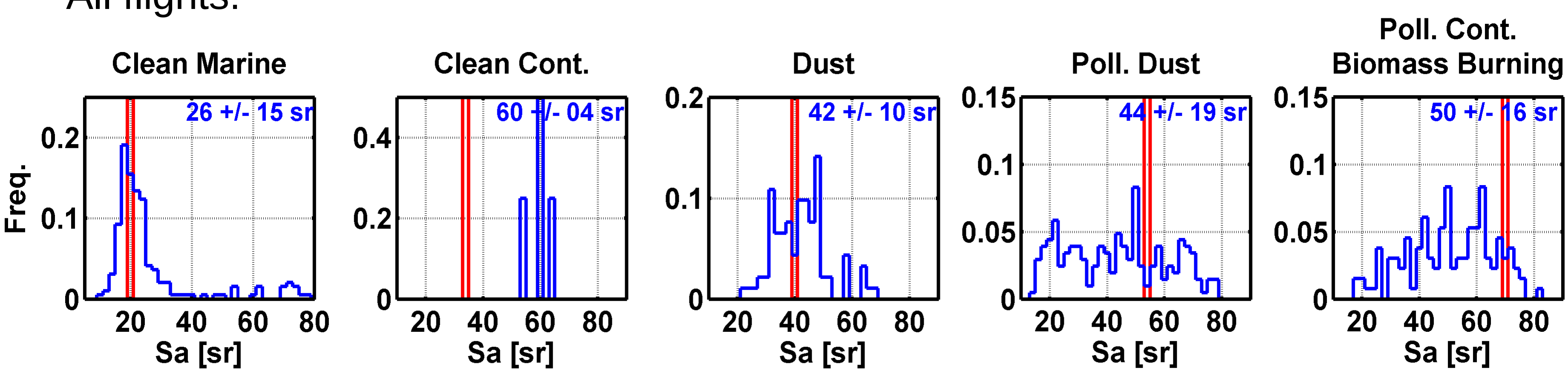
# Validation of Lidar Ratio Selections

HSRL measured lidar ratio vs. CALIOP aerosol type

Caribbean campaign

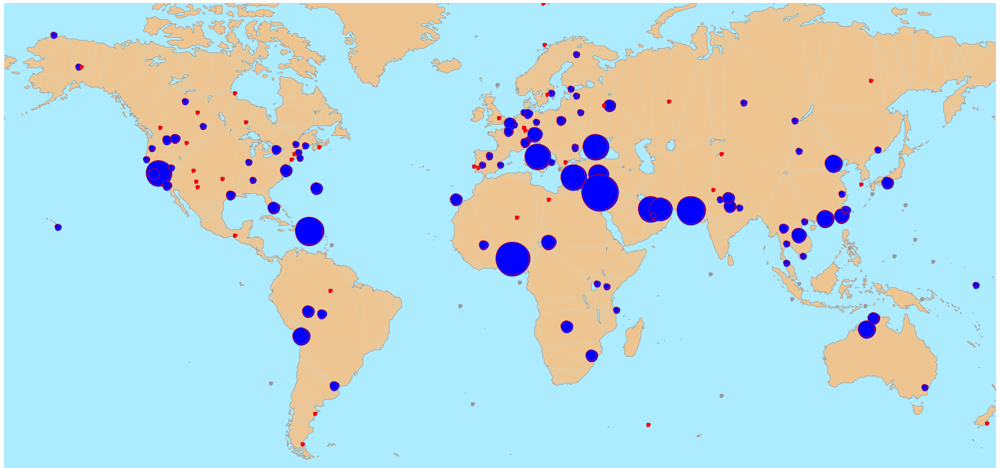



All flights:

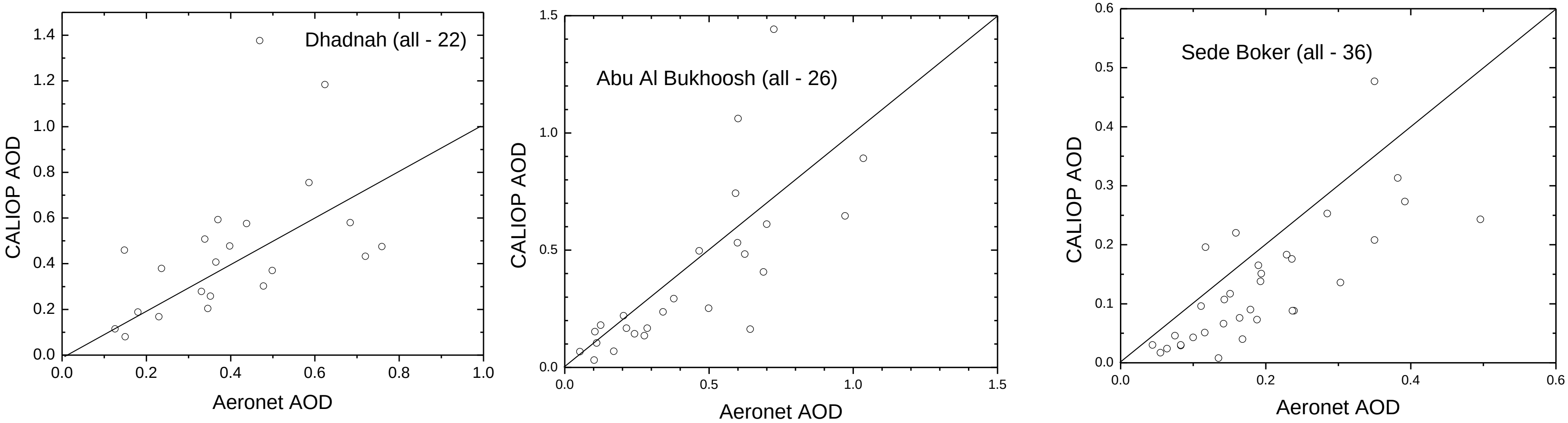


# Validation: AOD vs. Aeronet

- Aeronet: a global network of > 200+ sunphotometers
- Detailed point-point AOD comparison (Omar et al., JGR, 2013)
- Restricted to overpasses with 40 km of Aeronet sites
- Spatial variability of AOD can be an issue
- Aeronet screened for cloud contamination



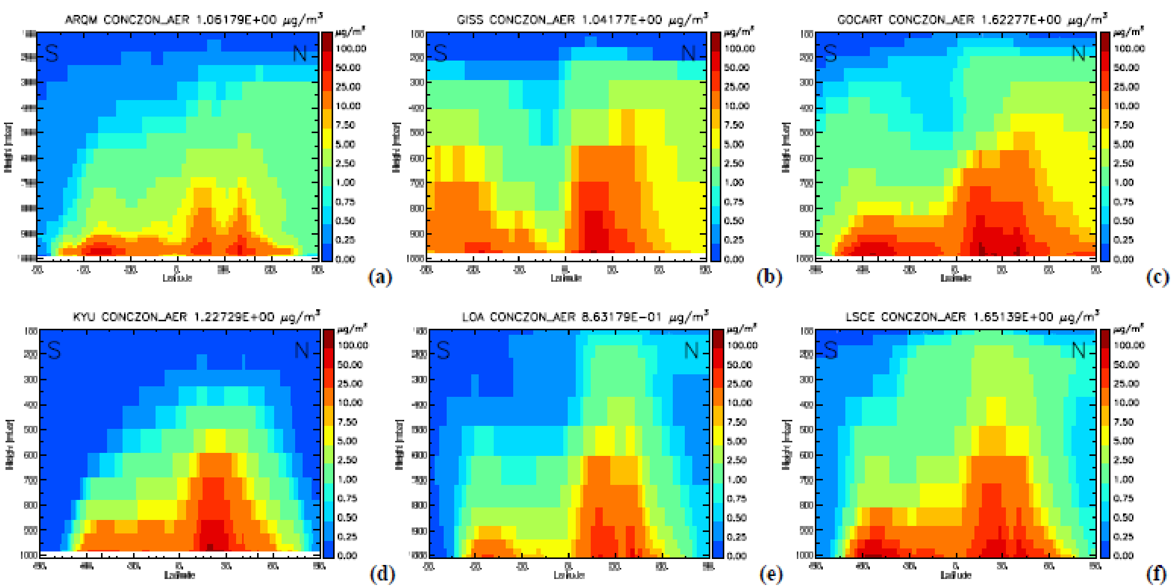
**Example: three desert sites**



# Global Aerosol Models

**The vertical distribution of aerosol impacts:**

- **atmospheric lifetime and global transport**
- **aerosol radiative effects**
- **aerosol effects on cloud and precipitation**

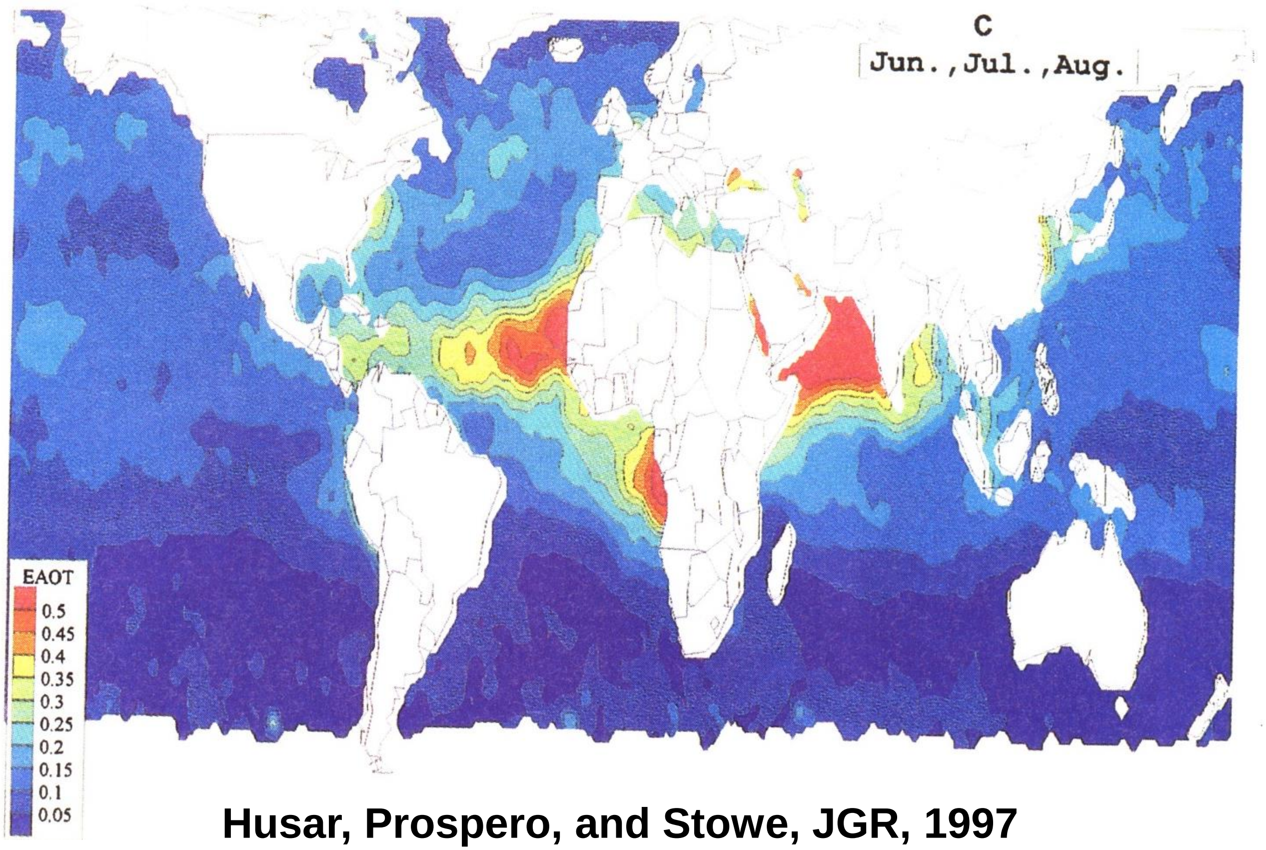



**Zonal mean mass concentration 6 global aerosol models (Textor et al., 2006)**

**The vertical distribution of aerosol varies widely between models. Before CALIPSO there were no global observations to evaluate model performance.**

# 1997: First global aerosol observations

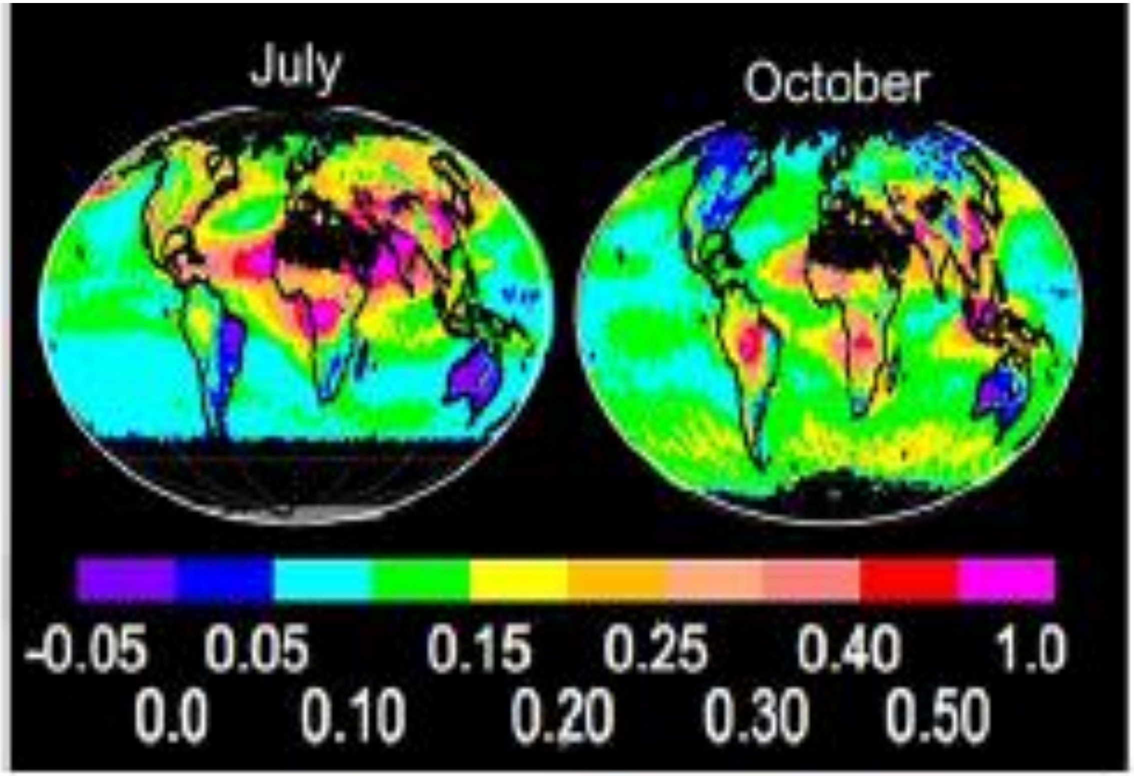
16,892 HUSAR ET AL: AEROSOLS OVER OCEANS WITH AVHRR




**Husar, Prospero, and Stowe, JGR, 1997**

# Circa 2000: AOD over land

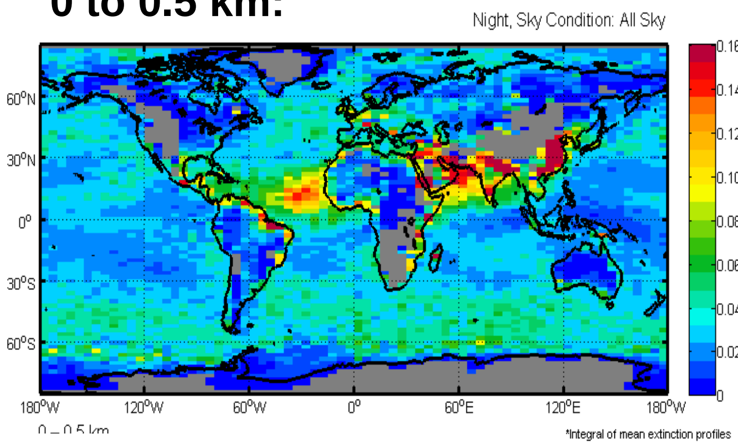
## MODIS



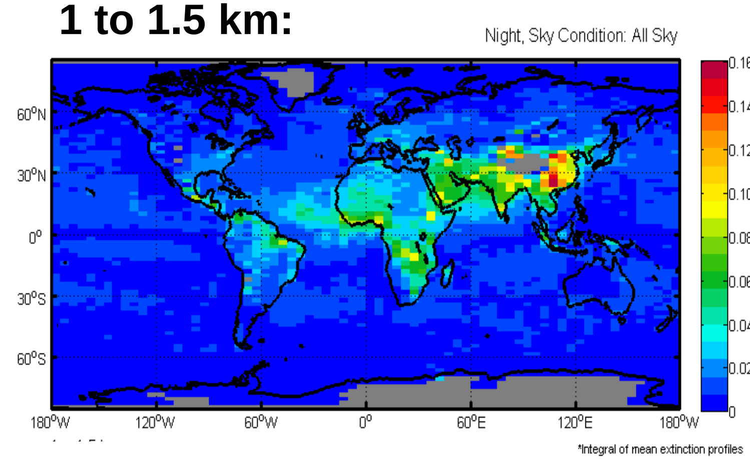

(Remer et al. 2005: 'Dark Target' only)

# Now: A 3D global aerosol climatology

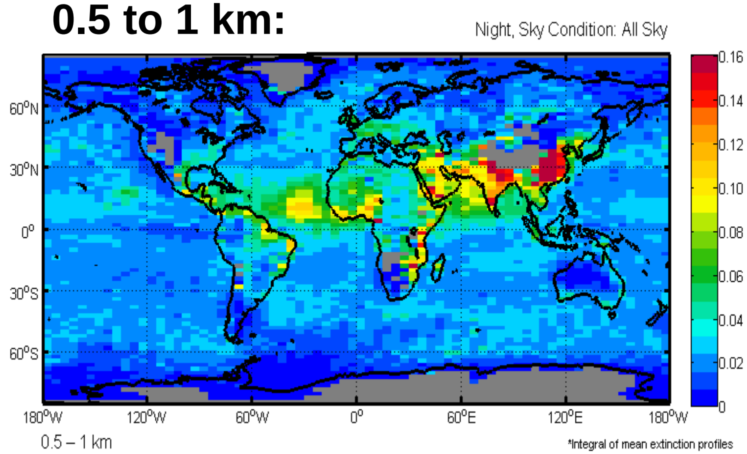
**0 to 0.5 km:**



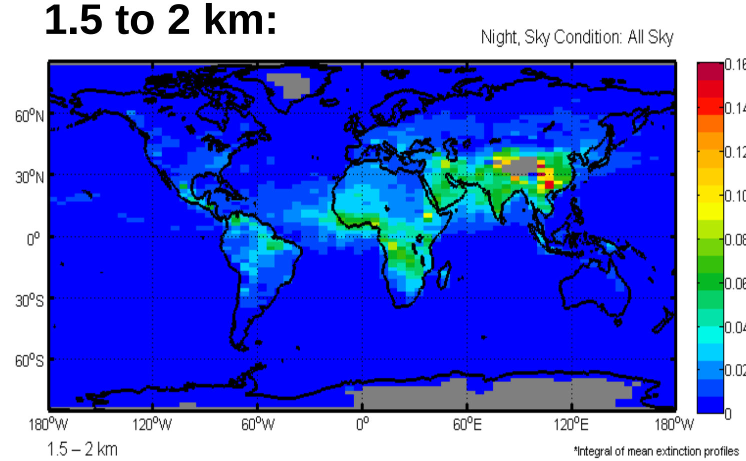

**1 to 1.5 km:**




**0.5 to 1 km:**




**1.5 to 2 km:**




**→Basis of major global aerosol model intercomparison (Aerocom, 2012)**

**→ Highlighted in IPCC AR5 (2013)**

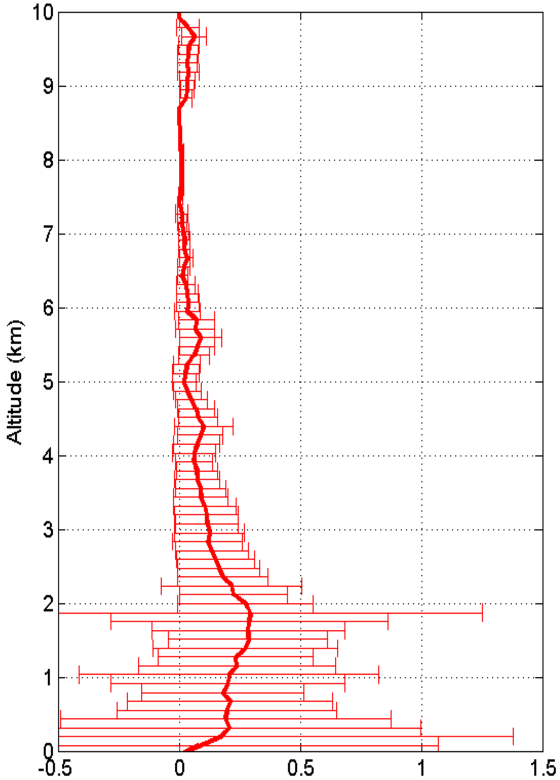
# Level 3 Product

Monthly-average profiles on a global grid:

- Extinction in ‘clear-air’ set to 0.0 $km^{-1}$
- ‘Clear-air’ samples near surface ignored
  - Assume that aerosol layer base incorrectly identified
- Screen out low confidence aerosol layers
  - CAD flag
- Screen out low confidence retrievals
  - Extinction_QC flag
- Require extinction uncertainty < 99
  - Indicates a failed retrieval
  - Remove profile below any sample with unc = 99
- Remove thin-cloud edge artifacts
- Several types of near-surface artifacts are removed

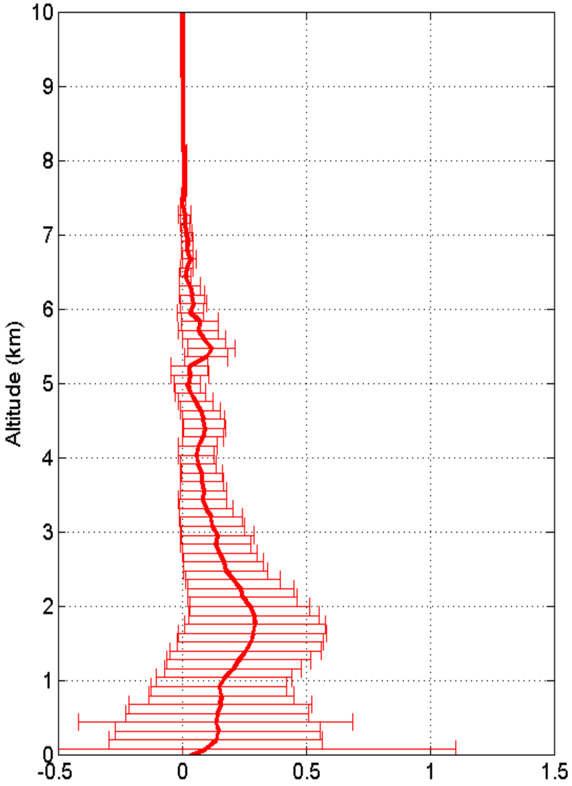
# Impact of quality screening

**August 2007**
**35-50N**
**75-80W**




**aerosol extinction, km$^{-1}$**

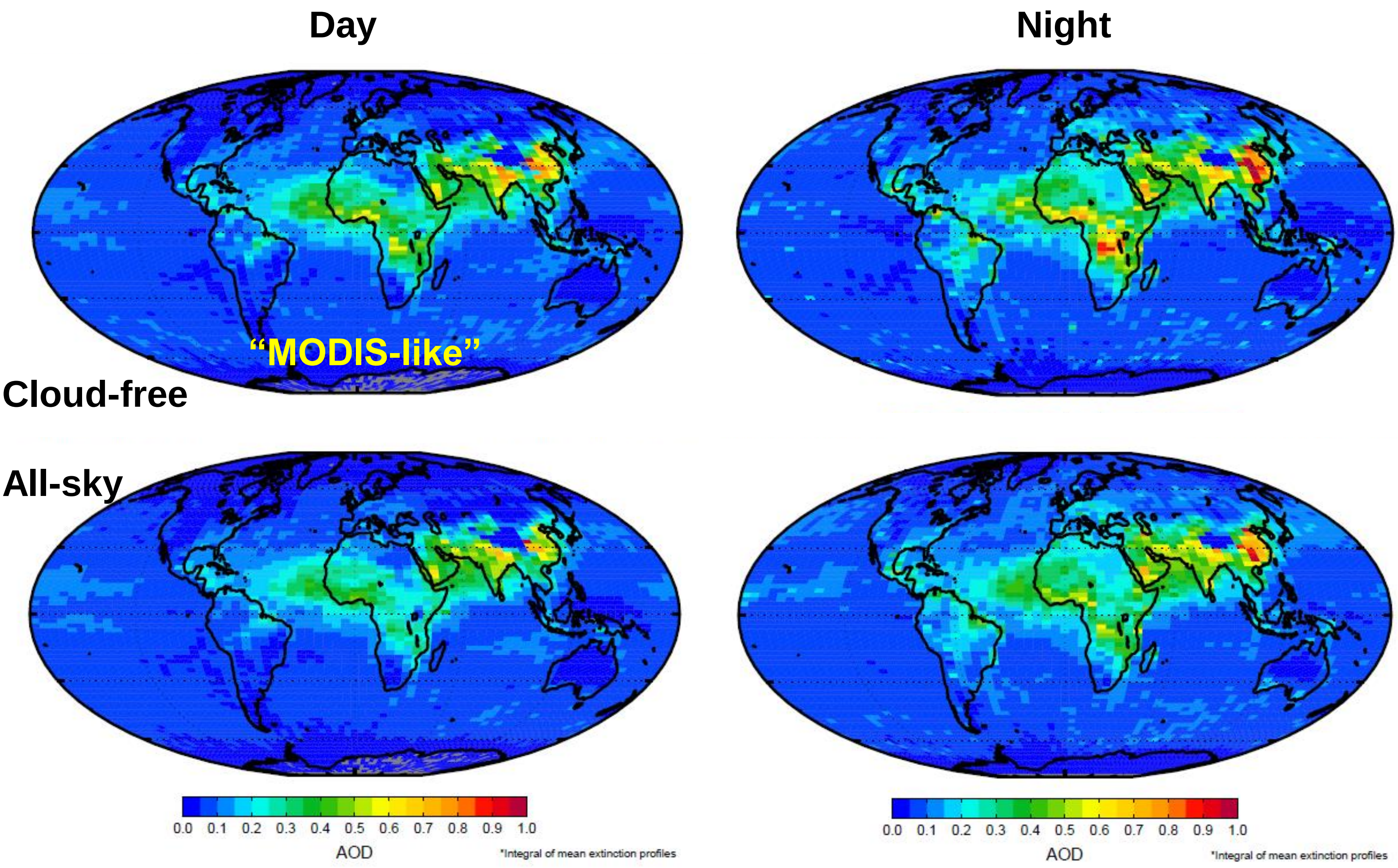
**clear-sky**
**before screening**




**aerosol extinction, km$^{-1}$**

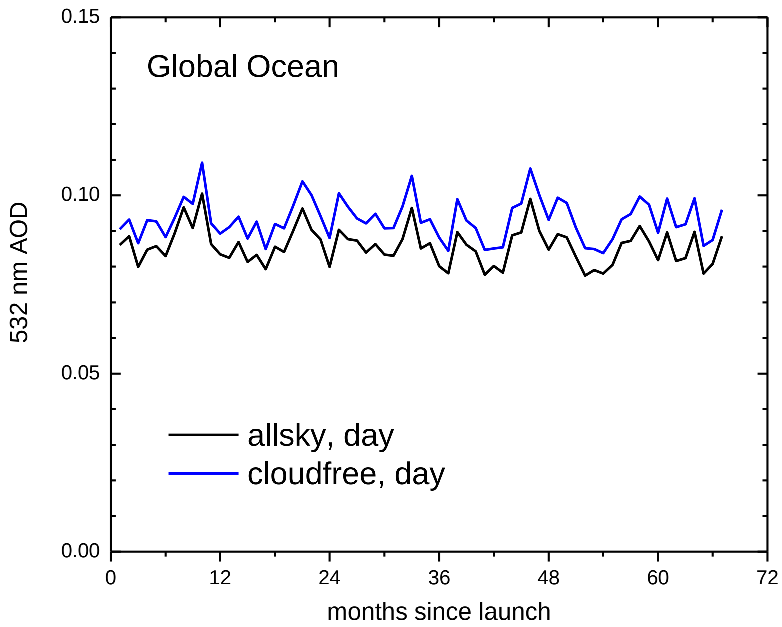
**clear-sky**
**after screening**

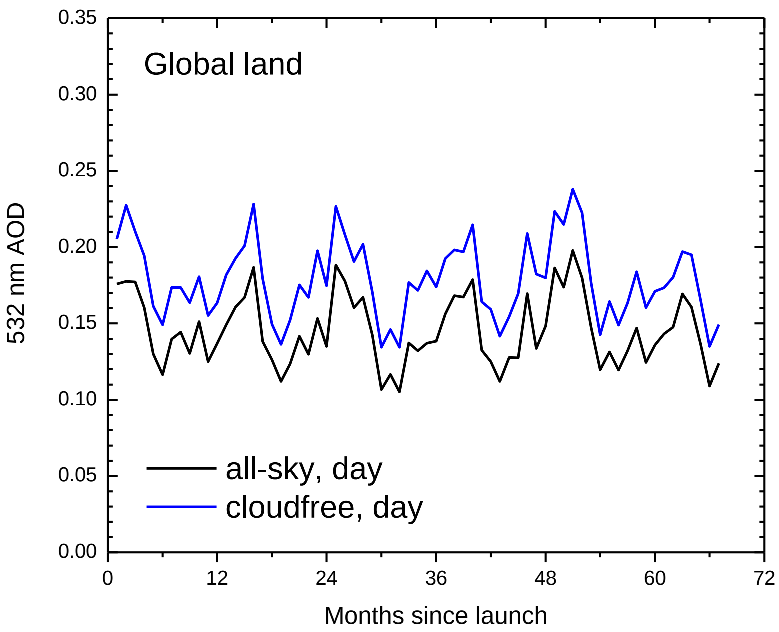
# 2008 Annual Mean AOD



# Daytime AOD

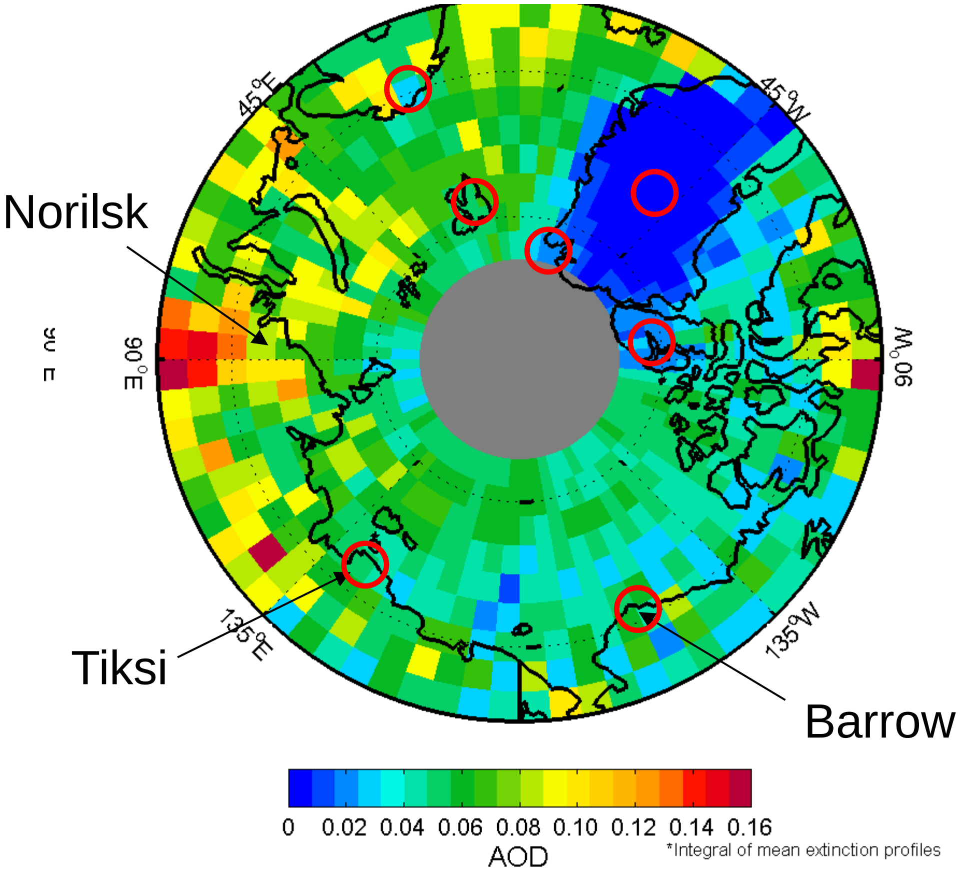
| | global ocean | | global land | |
|---|---|---|---|---|
| | CALIOP | MODIS | CALIOP | MODIS |
| cloud-free | 0.093 | 0.13 | 0.18 | 0.19 |
| all-sky | 0.086 | --- | 0.15 | --- |

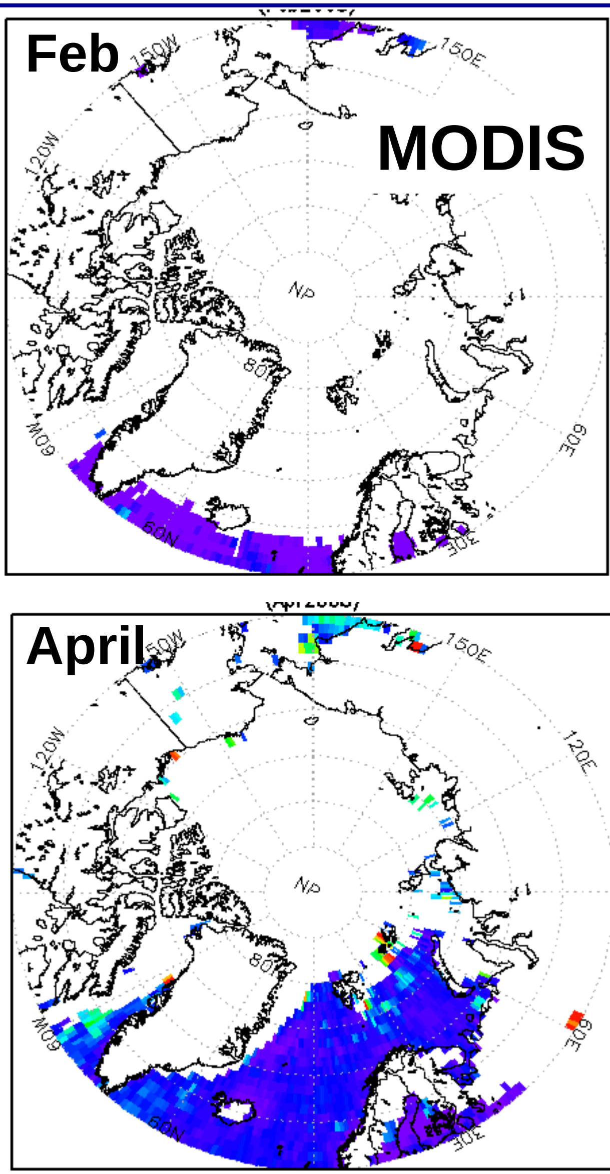


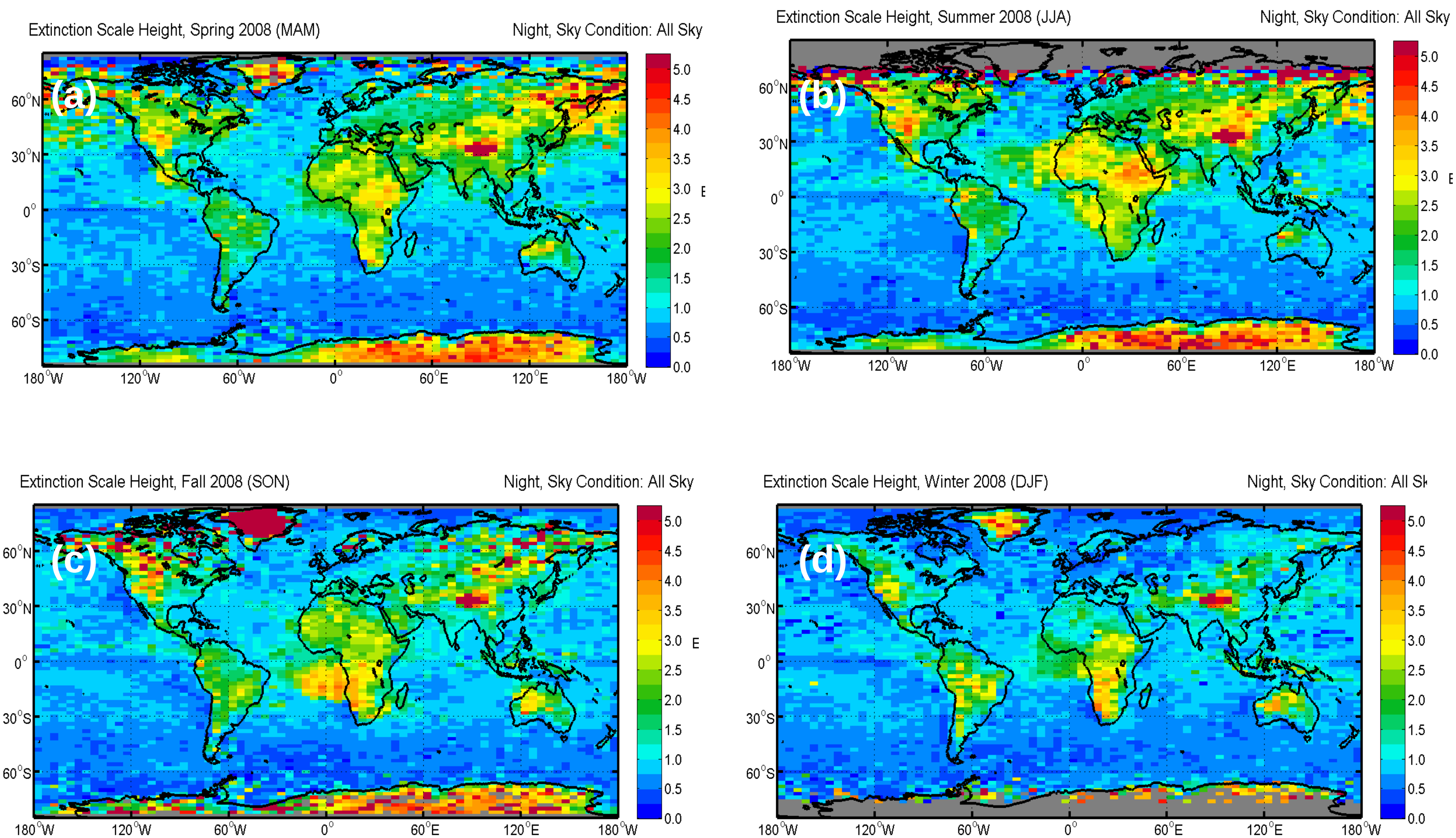
# First Arctic AOD

## CALIOP AOD, DJF 2007-2011

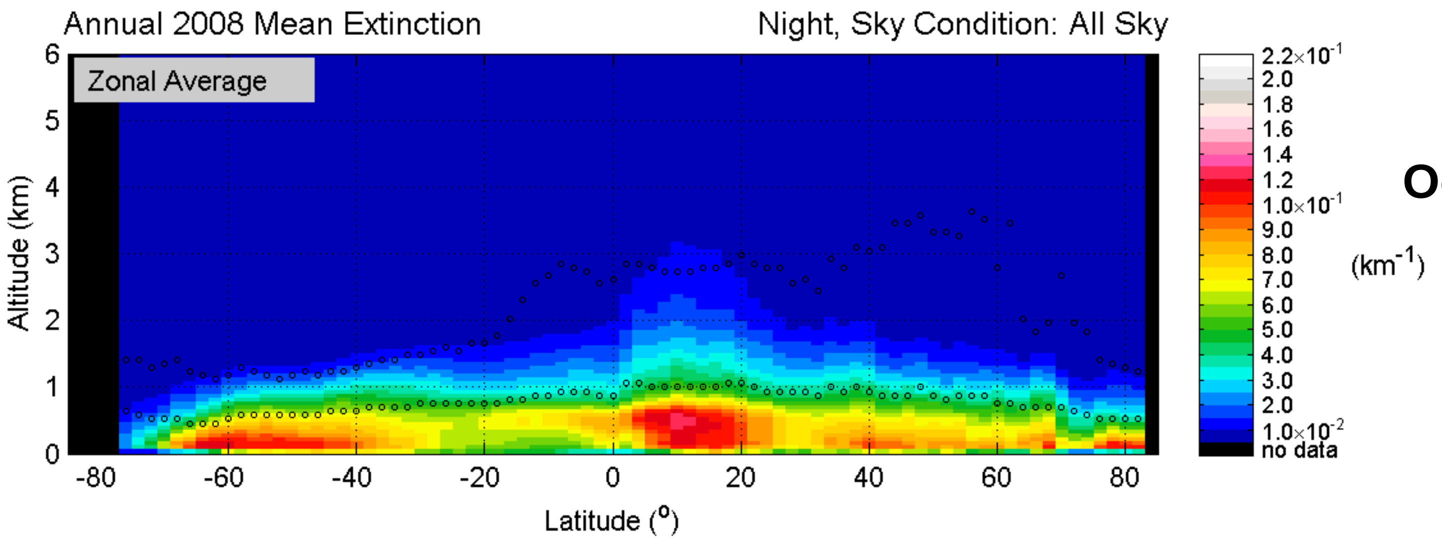


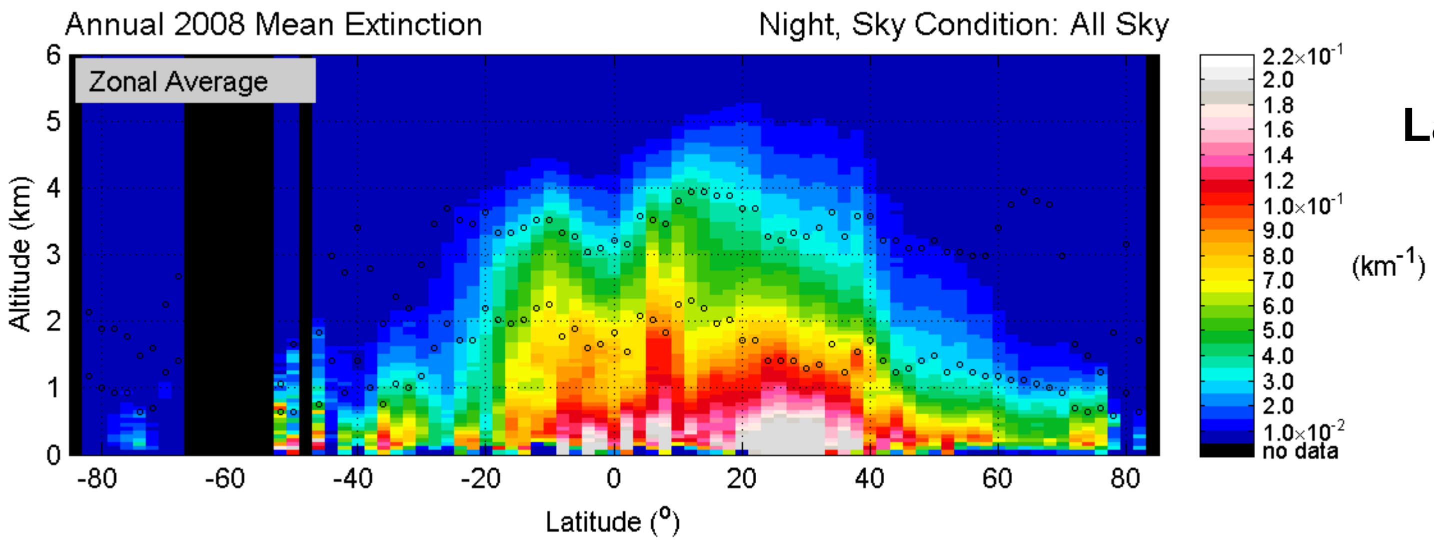
# Aerosol extinction scale height (km)
## (x% of AOD below h)



# 2008 annual zonal means: Land vs. Ocean



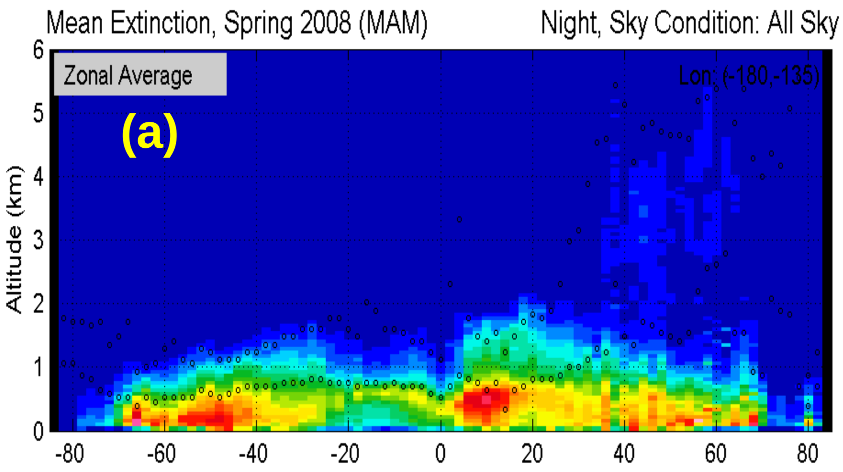

**Ocean-only**



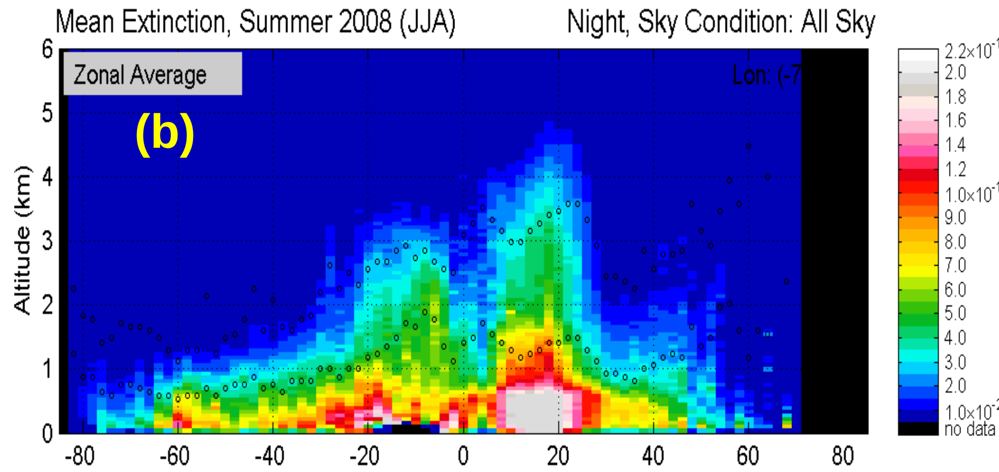

**Land-only**

# Regional zonal aerosol extinction, 2008: a) 180W – 135W, MAM; b) 75W – 40W, JJA; c) 15W – 30E, JJA; d) 70E – 90E, JJA.

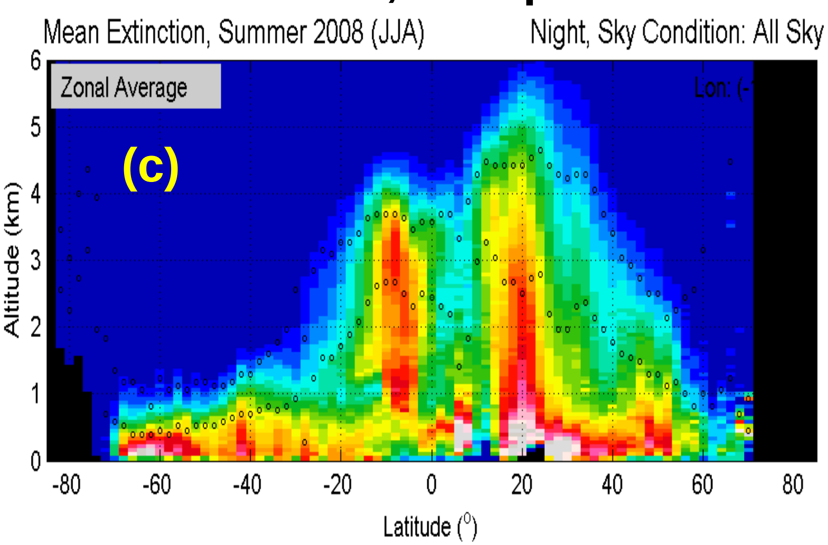
## Eastern Pacific



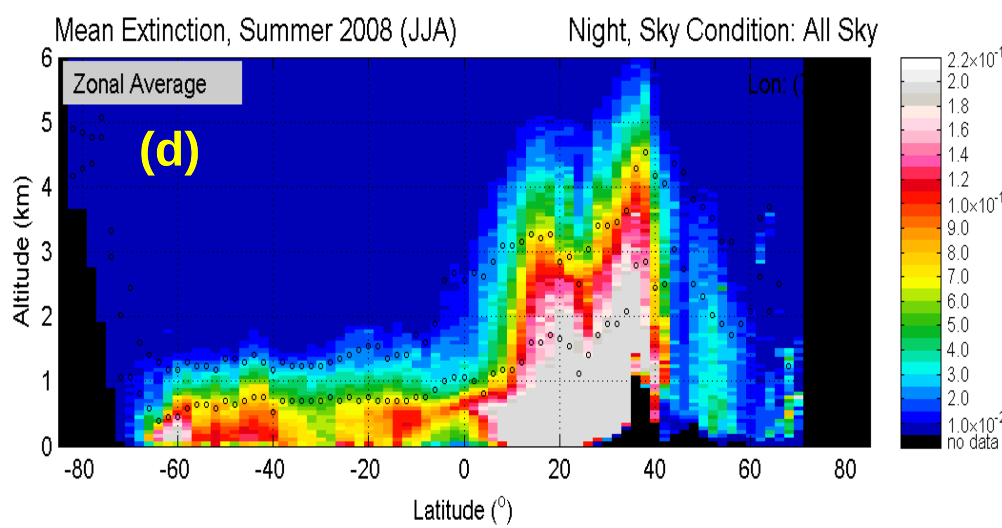

## South America, North Atlantic



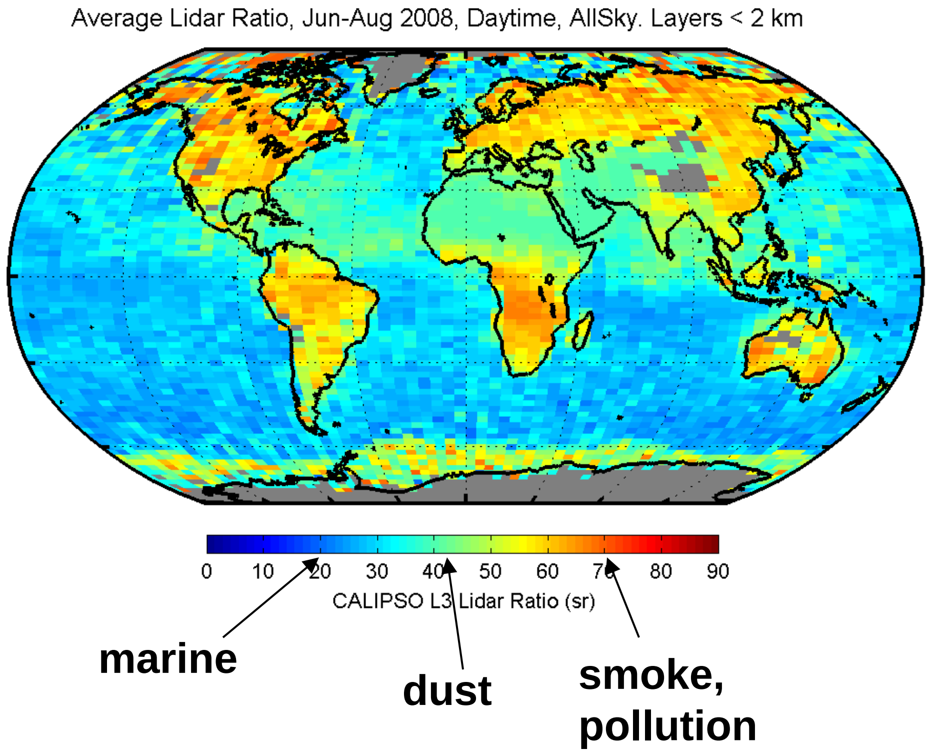

## Africa, Europe

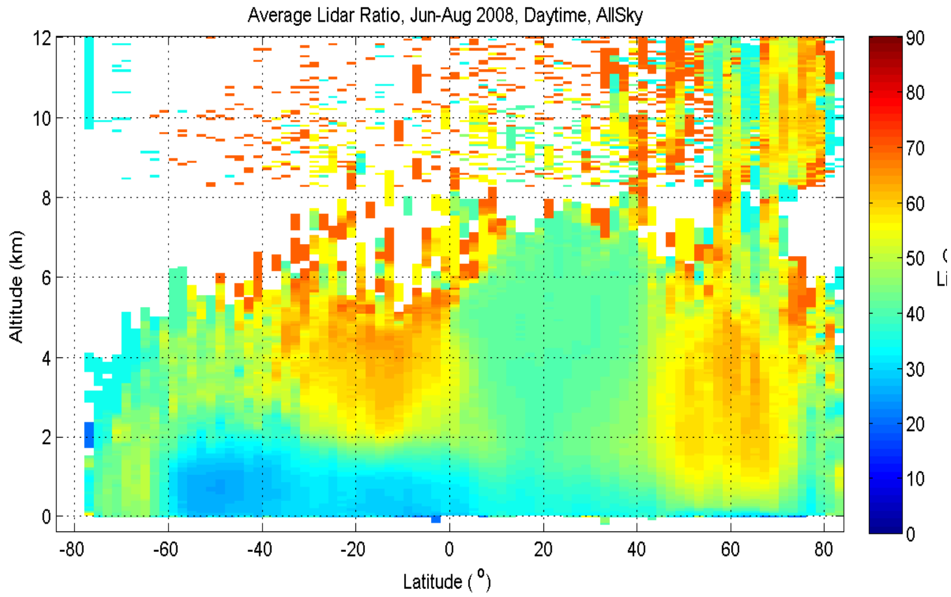



## India, Central Asia

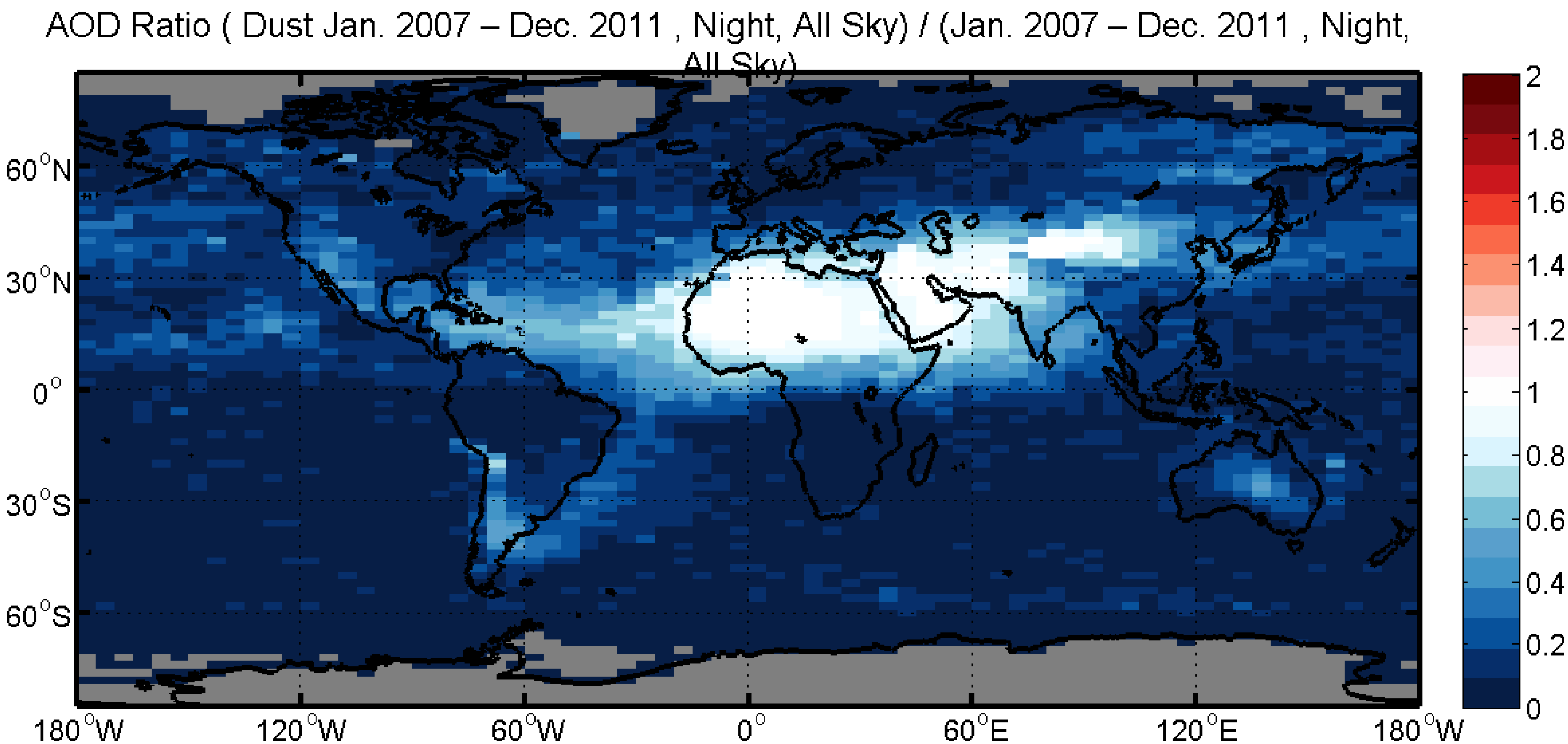


# Average Aerosol Type, JJA 2008



# Depolarization allows robust identification of dust

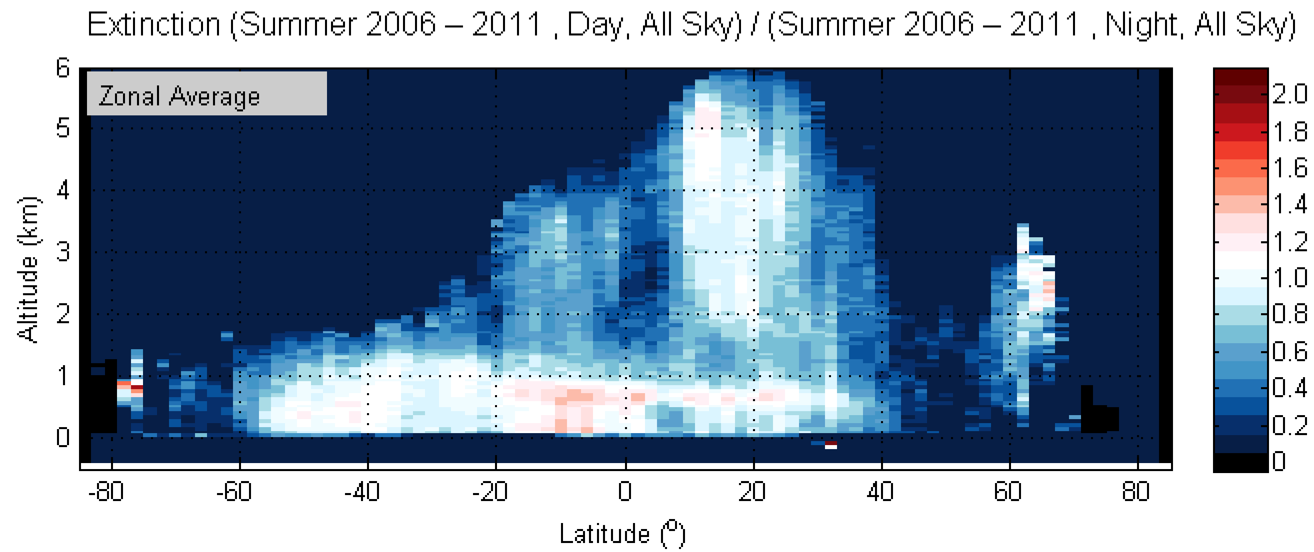


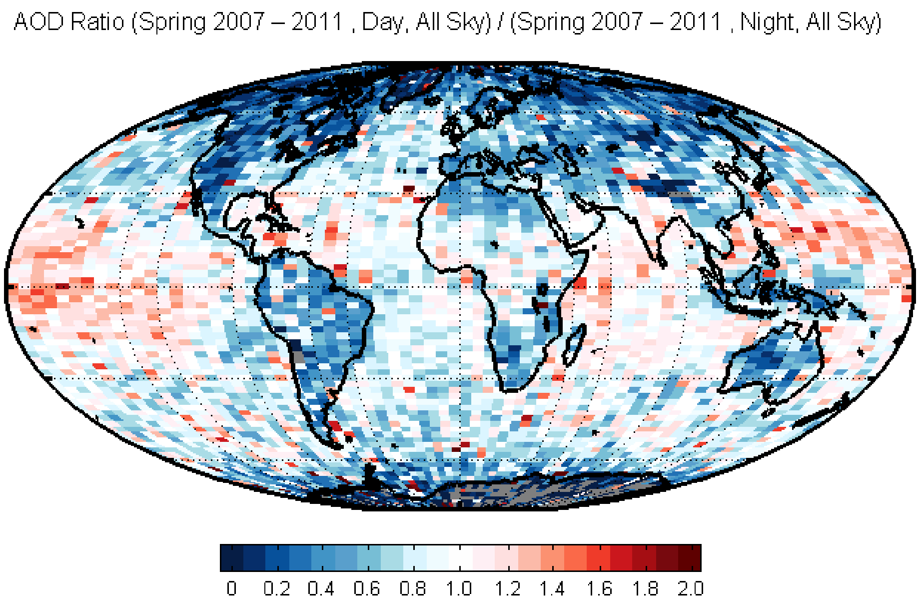

**Fraction of AOD due to Dust**

*Integral of mean extinction profiles

# Diurnal Variability

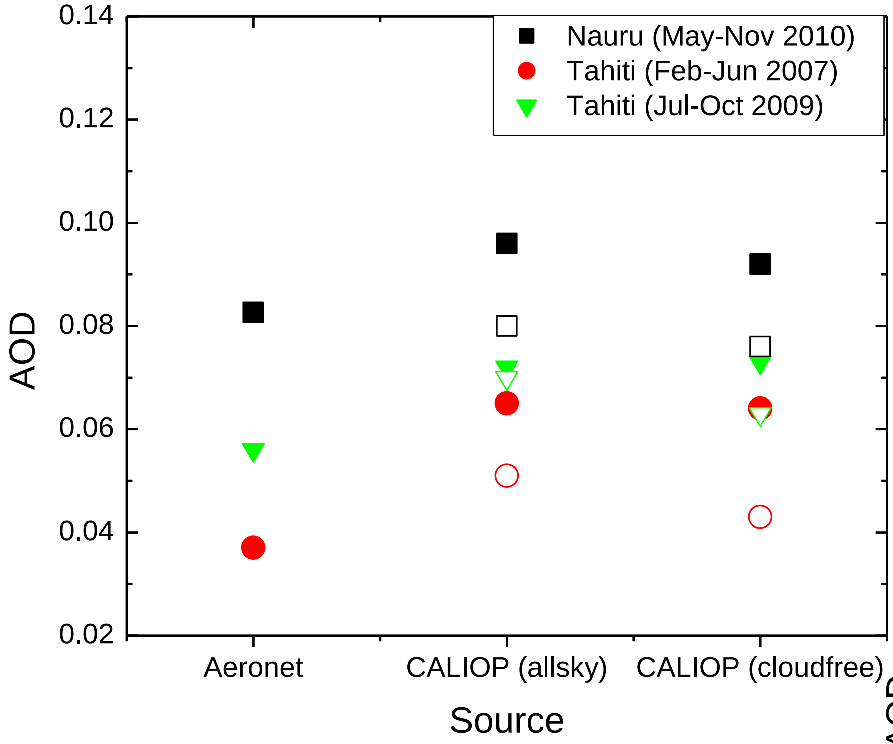
**Day**
**Night**



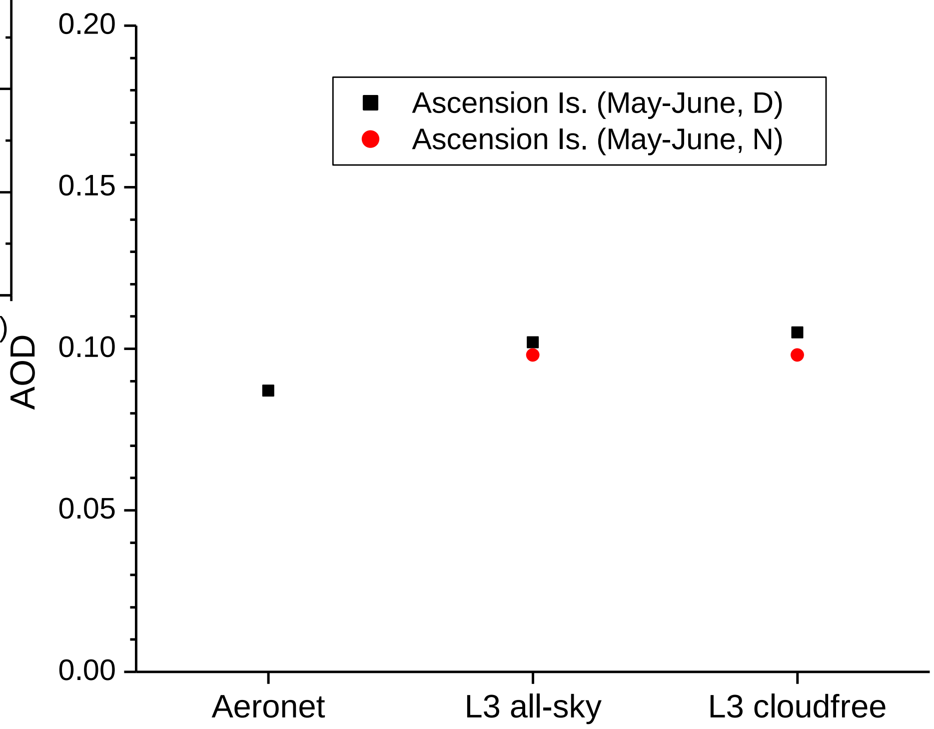




**Diurnal differences primarily due to detection sensitivity? Diurnal differences can also be due to geographical sampling and possible real variations.**

# Level 3 Validation: vs. Aeronet AOD

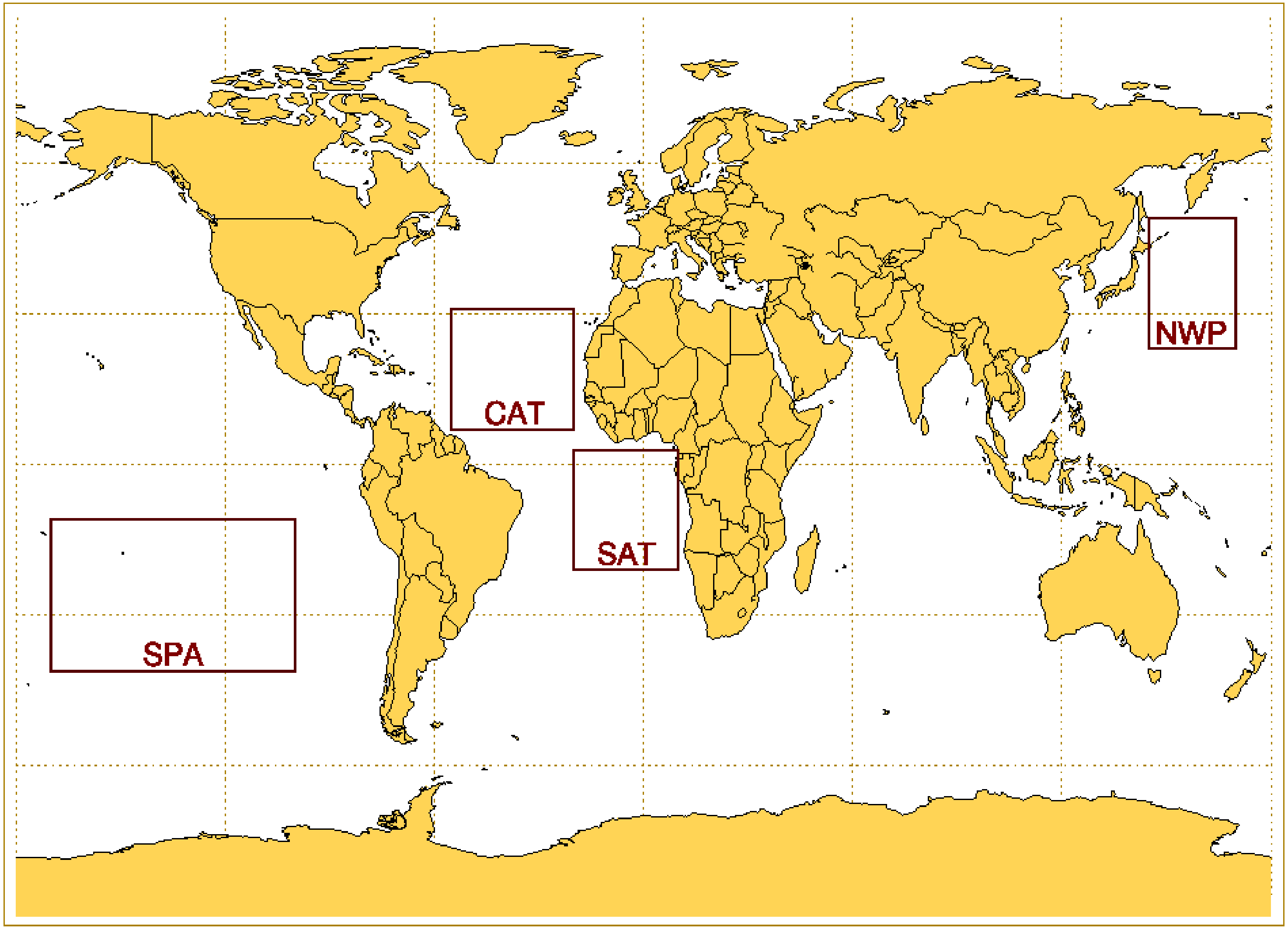



## Based on regional-seasonal averages




| | CALIOP box | |
|---|---|---|
| Nauru | 4S-4N | 160E-170E |
| Tahiti | 16S-20S | 160W-140W |

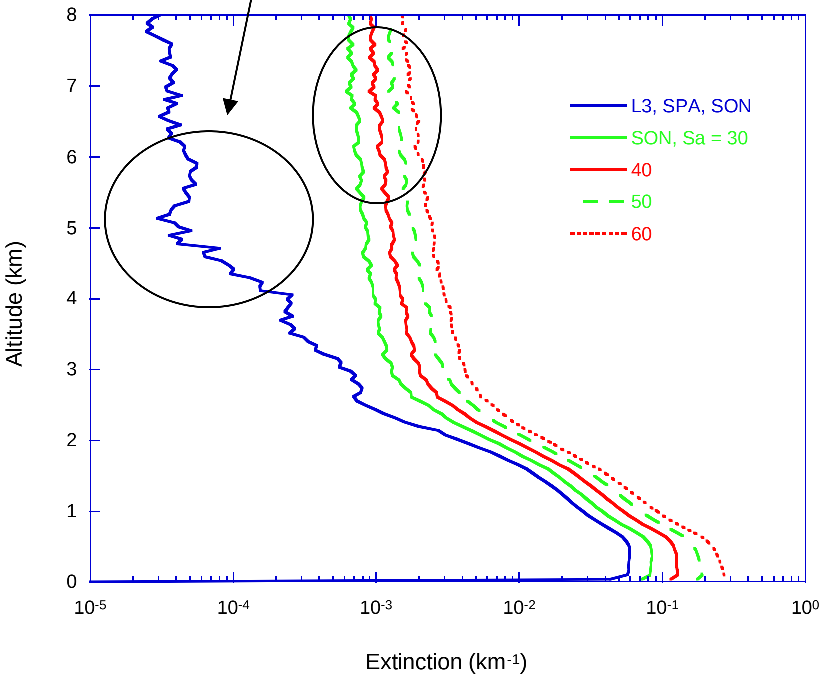
# Profile Validation



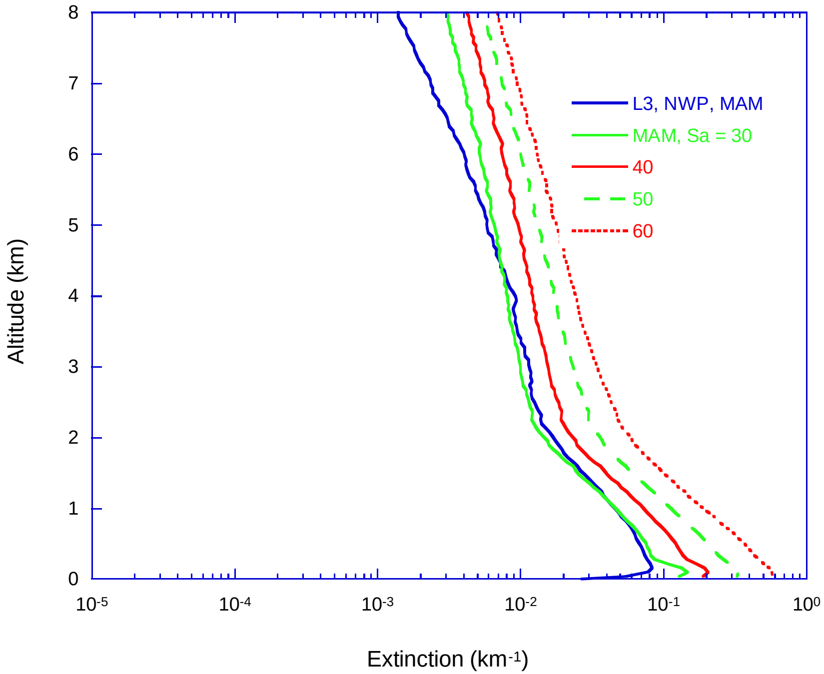
# Standard Retrieval vs. Full-Column Retrieval

underestimated

likely overestimated




**South Pacific (SON)**

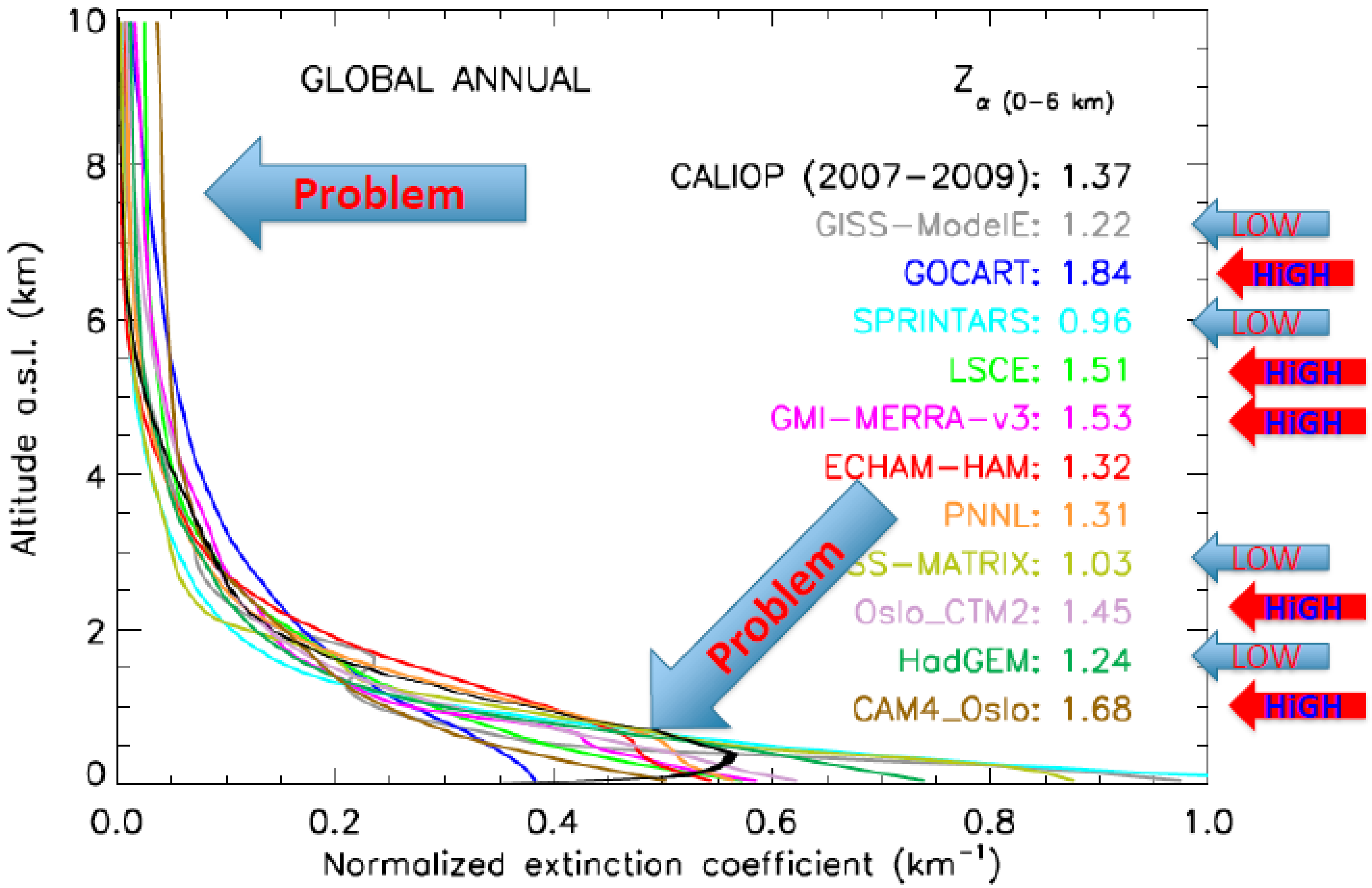



**Northwest Pacific (MAM)**

**(Winker et al., ACP, 2013)**

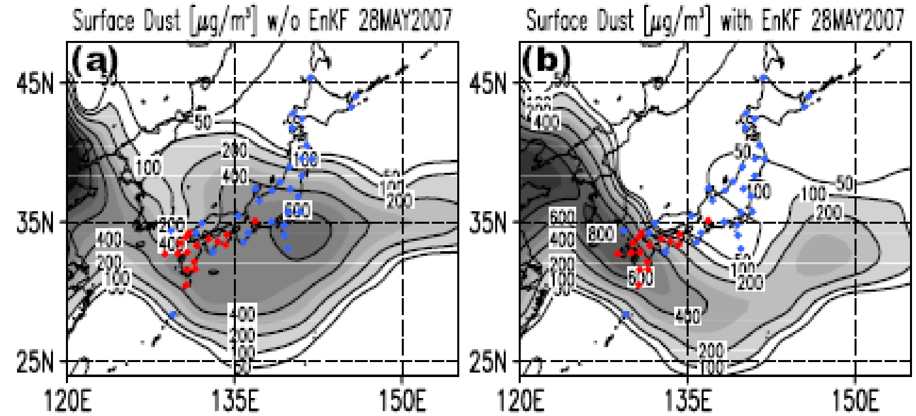
# Aerocom Phase-II Comparison

**CALIOP profiles used to evaluate aerosol vertical distributions predicted by 11 global aerosol models (Koffi et al., JGR, 2012)**



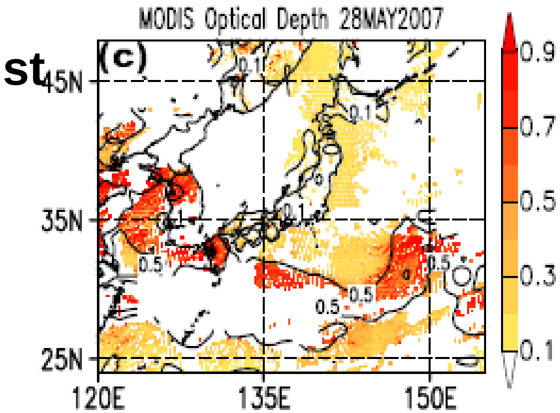
# Assimilation of Dust Profiles

**Global aerosol chemical transport model MASINGAR**
**CALIOP profiles assimilated using ensemble Kalman filter scheme**




**Modeled surface dust concentrations**
**Left: without assimilation**
**Right: assimilating CALIOP profiles**
**blue circles: ground stations observing no dust**

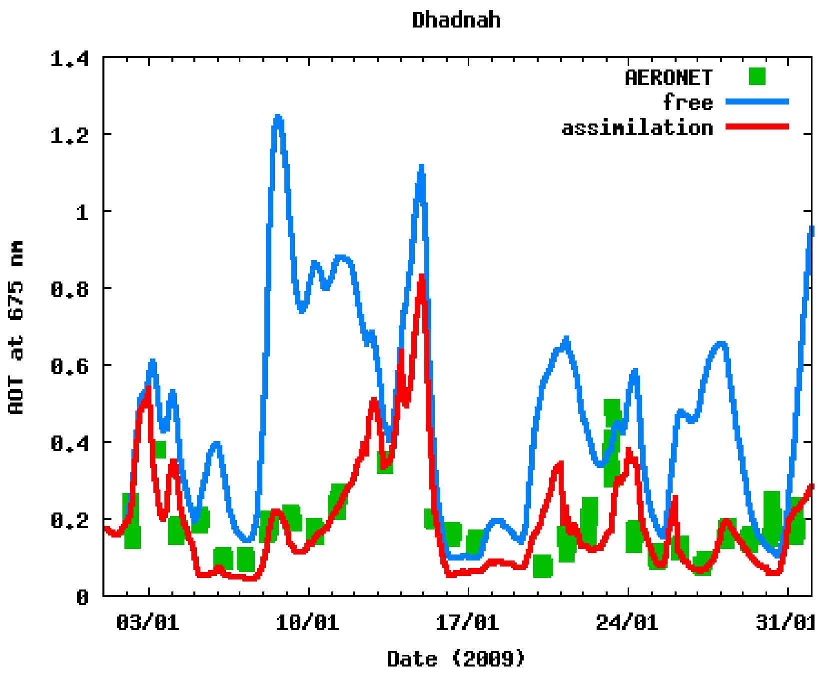
**MODIS AOD observations:**




**Sekiyama, et al., 2010**

# Assimilation of CALIOP Aerosol Profiles

- CALIOP nighttime Level 1 profiles assimilated into SPRINTARS global aerosol transport model
  - SPRINTARS driven by MIROC global model
  - Local Ensemble Transform Kalman filter assimilation scheme
  - Assimilation observation operator assumes single scattering, treats dust as spheroids
- Improves agreement with AERONET *AOD* at Dhadnah
  - Assimilation removes dust storms in free troposphere
  - Aerosol loading of boundary layer increases



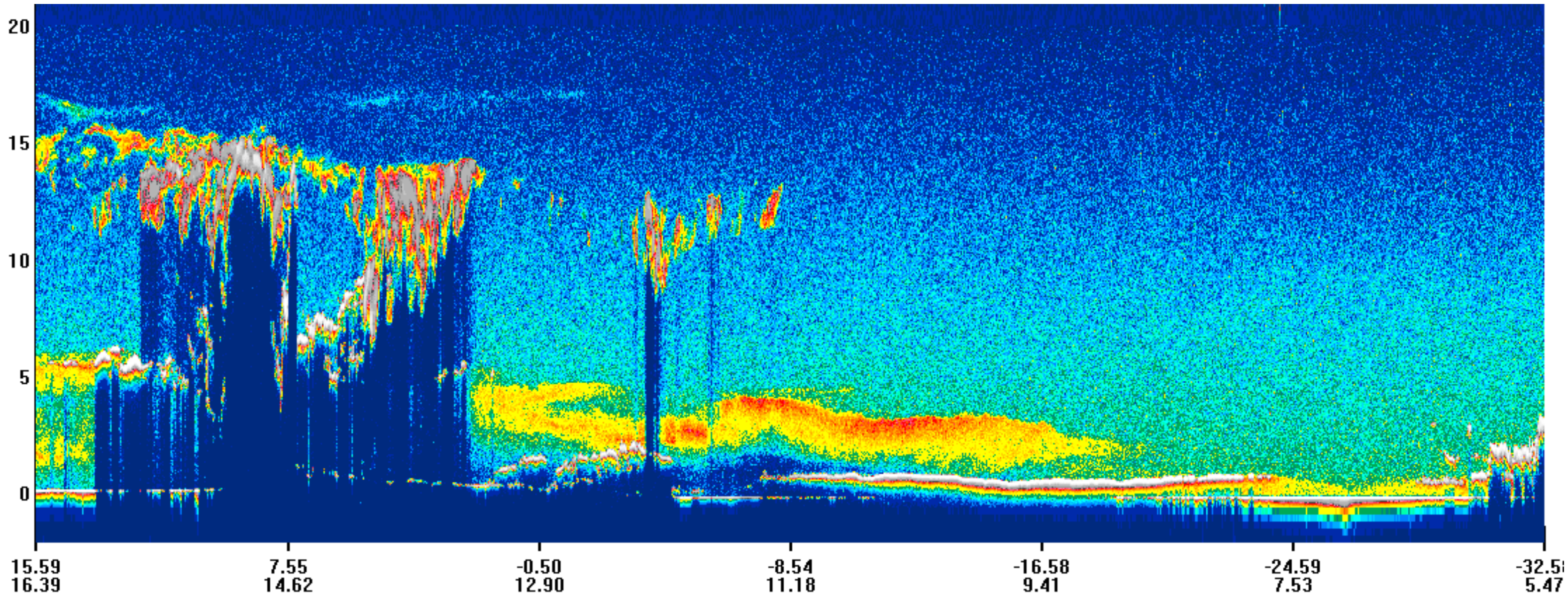

Nick Schutgens & Eiji Oikawa, Tokyo U.

# Aerosol Direct Radiative Effects

Cloudy-sky aerosol DRE and DARF have been estimated in various ways, often using models or simple assumptions

Aerosol profile data from CALIPSO/CALIOP is a new resource for estimating global aerosol effects:

- Aerosol retrievals in cloudy skies
  - Above clouds
  - Beneath thin clouds
- Aerosol retrievals over bright surfaces (deserts)



# C3M (CCCM) product (Kato et al. 2010)

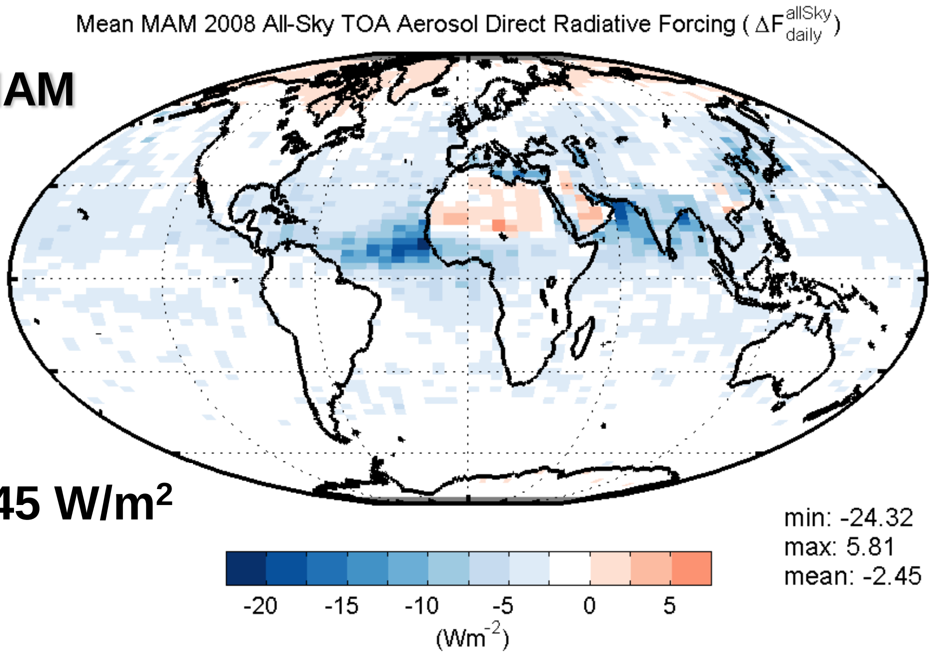
C3M is a Level 2 product, along the CALIPSO-CloudSat groundtrack

Co-located, merged CALIPSO, CloudSat, CERES, and MODIS data

- Aerosol extinction profiles from:
  - CALIOP
  - MATCH (assimilates MODIS AOD)
    - MATCH used in columns where there is no CALIOP aerosol
- Cloud profiles and properties from:
  - CALIOP/CloudSat
  - MODIS
    - over the co-located CERES footprint
- Broadband RT calculations simulate up & down LW and SW fluxes using CALIPSO/CloudSat vertical structure above CERES footprints
- Co-located CERES TOA radiative fluxes (SW, LW, and WN)

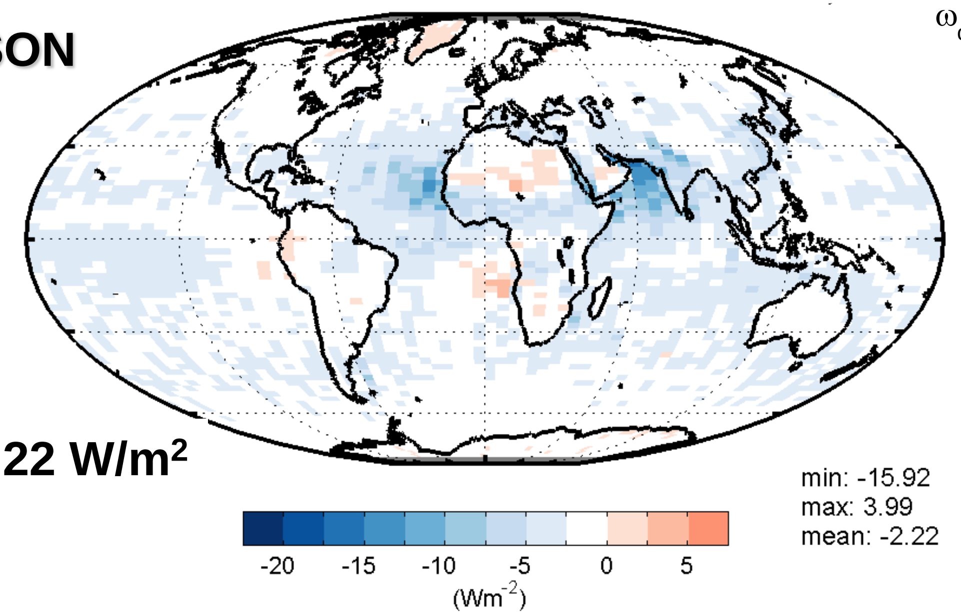
# Seasonal All-sky SW DRE

MAM

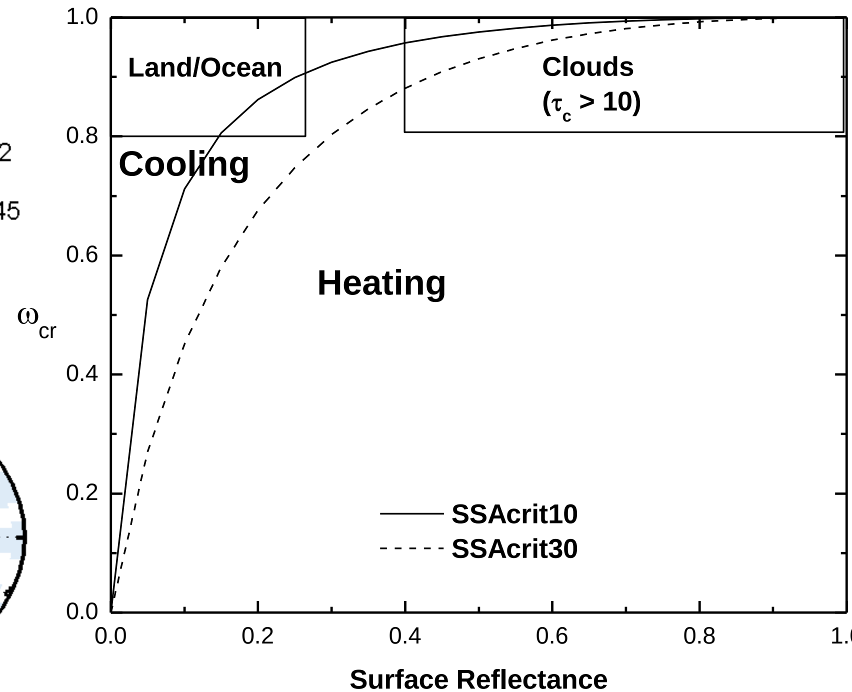



-2.45 W/m²

SON



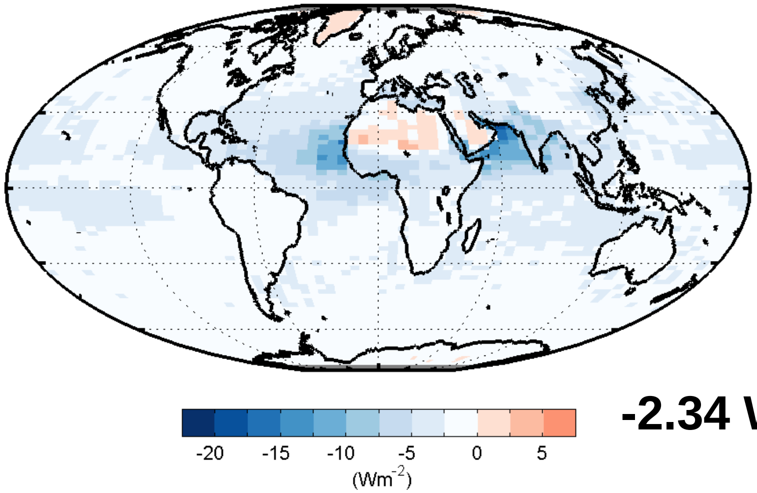

-2.22 W/m²




(Haywood and Shine, 1995)

# All-sky vs. Clear-sky

## All-Sky Aerosol SW DRE




-2.34 W/m²

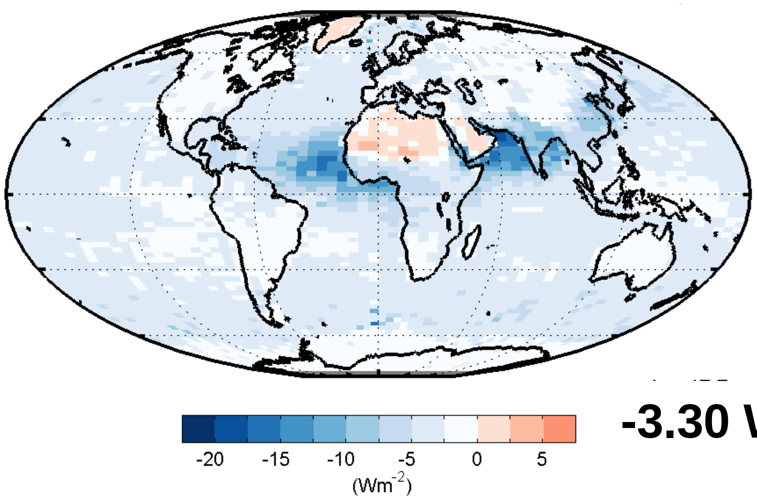
**2008 global annual mean**

all-sky - 2.34 W/m²

clear-sky - 3.30 W/m²

cloudy-sky -1.93 W/m²

## Clear-Sky Aerosol SW DRE




-3.30 W/m²

$$DRE_{total} = (1 - A_c)\, DRE_{clr} + A_c\, DRE_{cldy}$$

$$A_c \sim 0.7$$

# Uncertainties

- Clear-sky ocean DRE within ballpark of previous estimates
- Largest uncertainties probably related to:
  - – Magnitude of AOD
    - CALIOP/C3M AOD somewhat less than MODIS Coll. 5
  - – Aerosol absorption
    - C3M tends to have too little aerosol absorption

**Initial sensitivity study:**
**SSA of smoke reduced by ~ 0.03**

| | All-sky TOA DRE ($W/m^2$) control | reduced $\omega_o$ |
|---|---|---|
| global | -2.34 | -2.06 |
| ocean | -2.78 | -2.57 |

**DRE difference, Aug 2008**
**($\omega_o$ reduced − control)**