Remote Sensing & Understanding of Cloud and Aerosol Parameters and Their Interactions

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Outline

- Retrieval of Cloud Cover and Cloud Height
  - Conventional approach
  - Our approach
  - Comparisons of cloud products (MODIS, MODIS-CL, ISCCP, CloudSat/Calipso)
  - Validation of NOAA models against satellite
- Differentiating aerosol's real effect and artifacts on clouds
  - Conventional approach
  - Global perspective
  - Real and artifacts
- Ground-based Remote Sensing in China
  - EAST-AIRE and AMF deployment

Key Questions

- What is the global cloud 3-dimensional structure?
- How do cirrus and low-level water clouds overlap on global scale and what are their seasonal variations?
- Do the existing satellite-based cloud products, like the MODIS and ISCCP, provide sound global climatology of cloud vertical structure and optical properties?
- How well are passive sensor based cloud products compared with active sensor based cloud products?
- How well do current weather and climate models treat clouds ?

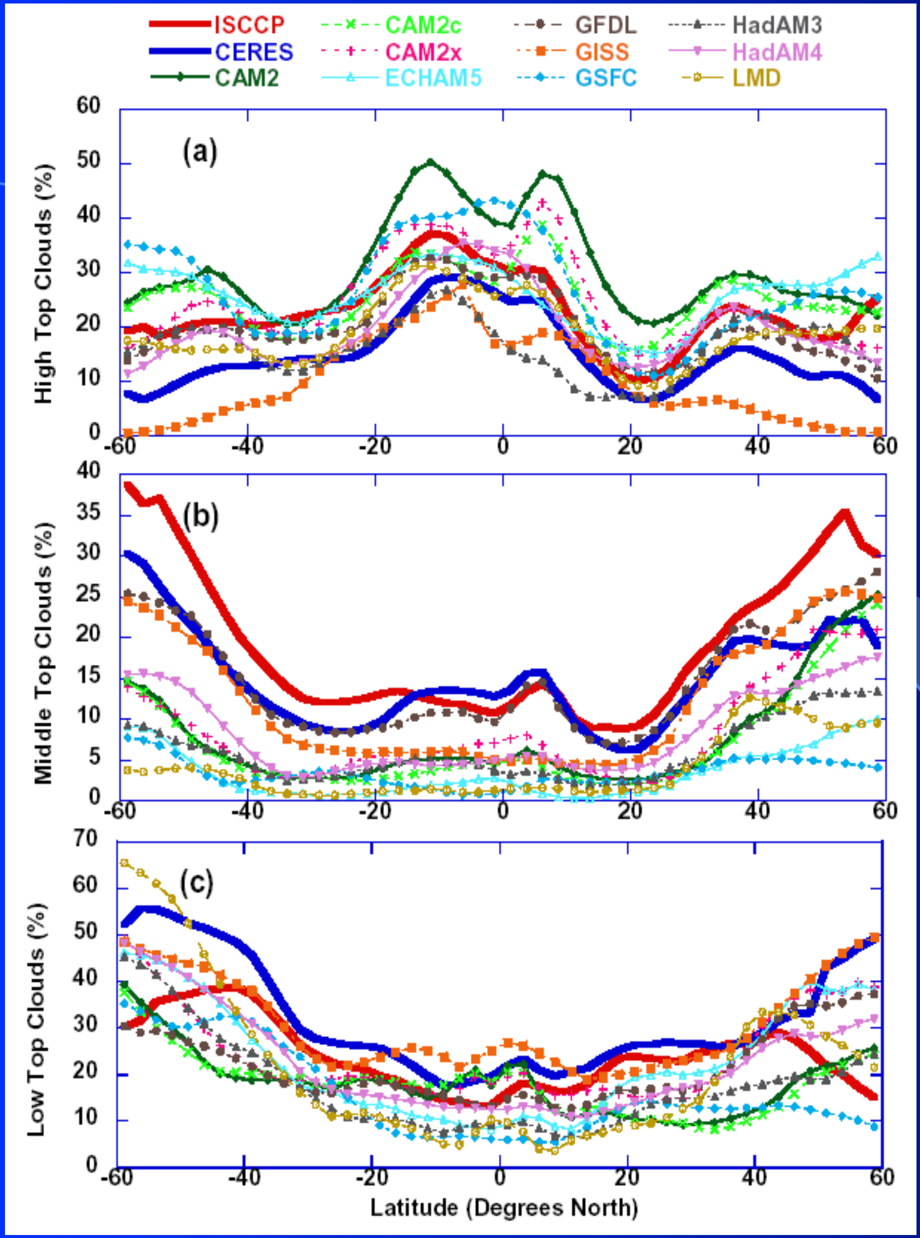
Data Sources

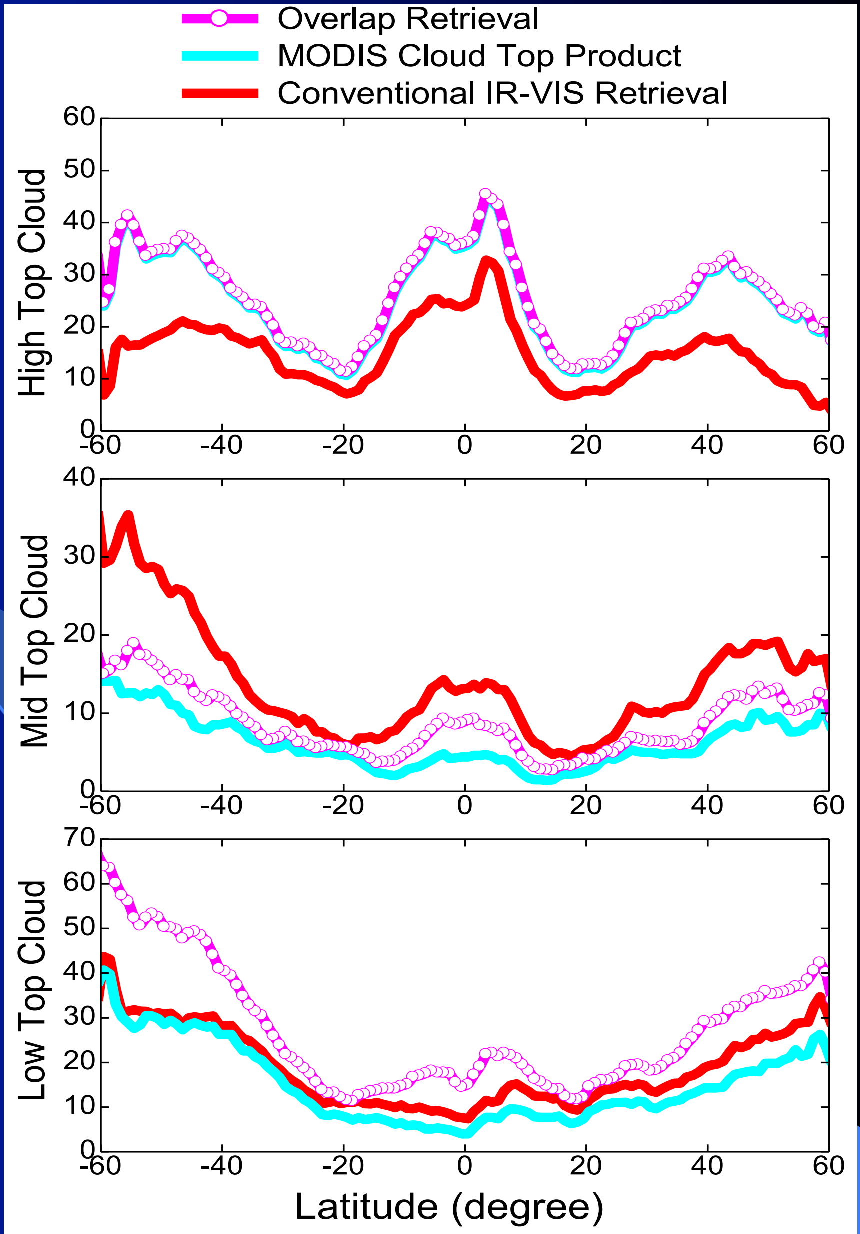
Three sources of cloud information used in this study:

- MODIS-NASA product
- MODIS-CL Product (Chang and Li 2005a,b)
- Simulated ISCCP product (ISCCP-Like)
- CloudSat/CALIPSO cloud products
- NOAA Global Forecast System model output

Years/Dates chosen for study: January, April, July, October 2001, 2006 and 2007

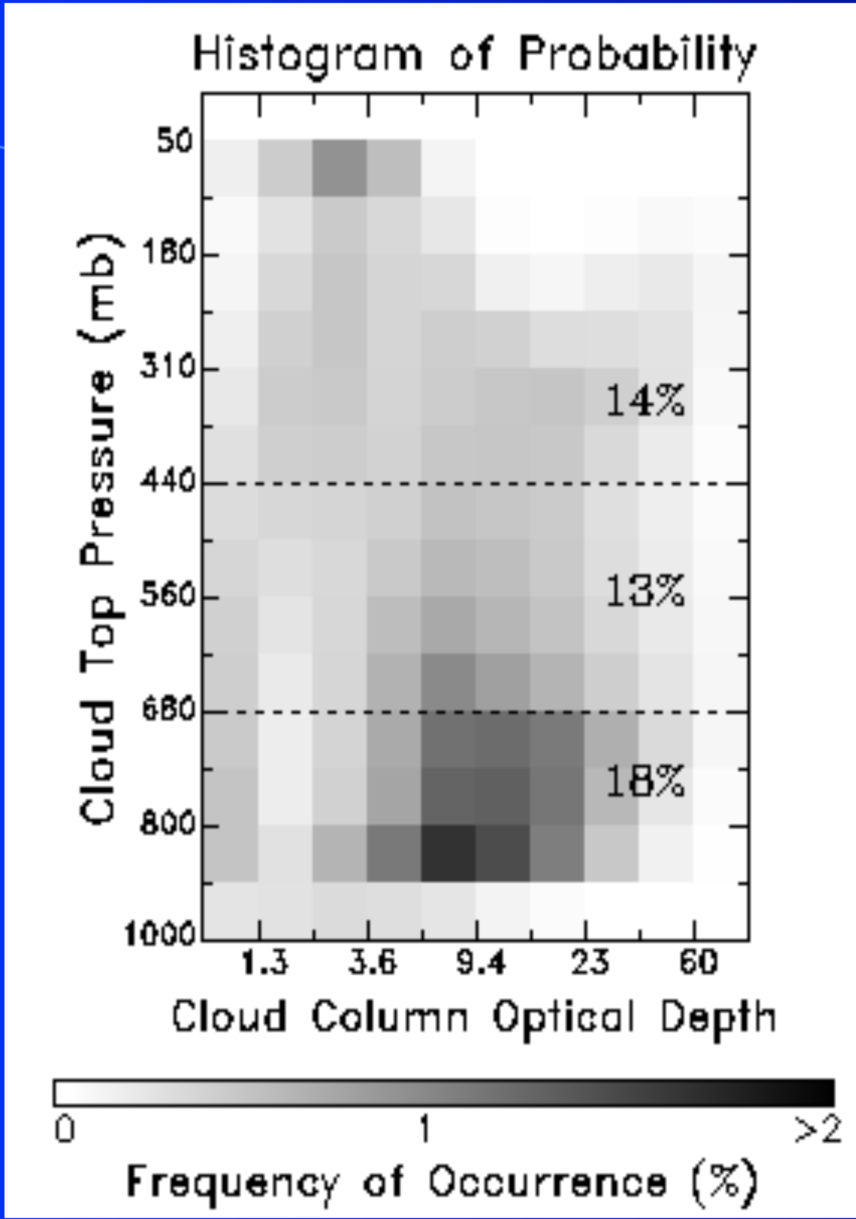
Comparisons of High, Mid, Low Cloud Amounts





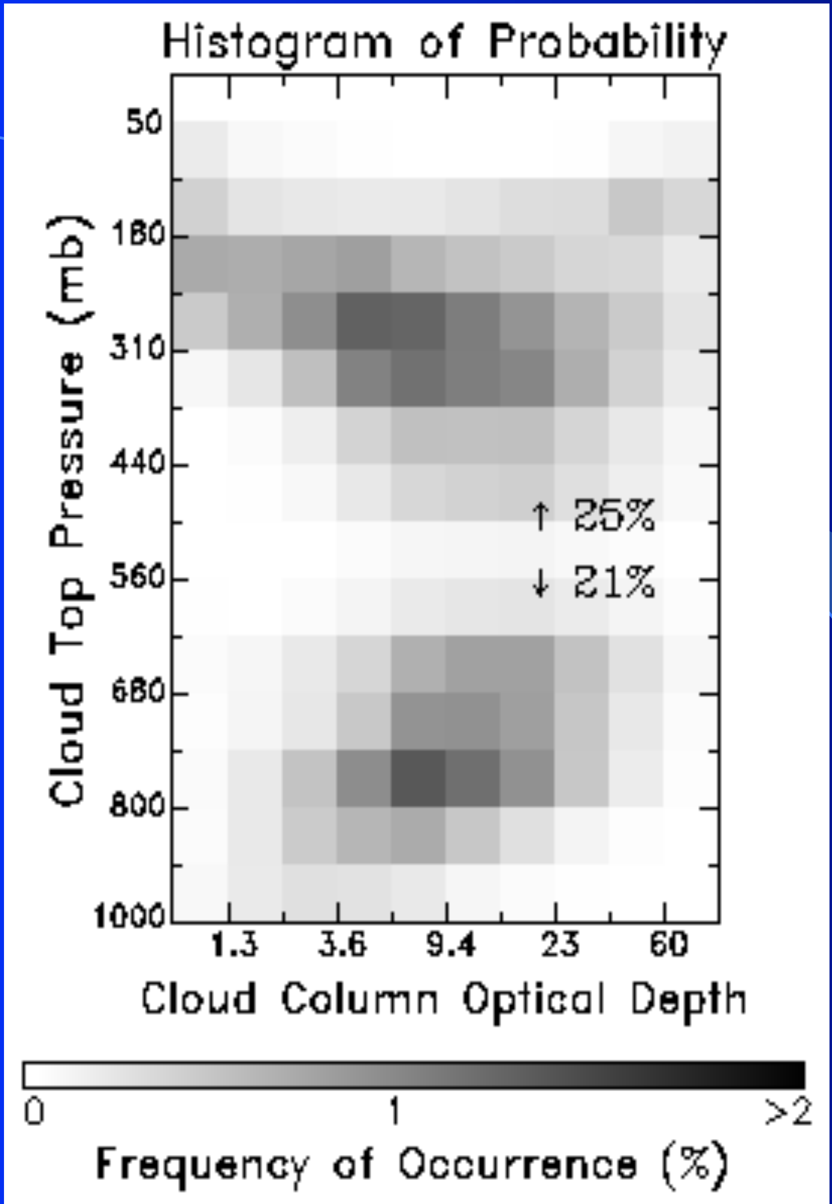
Zhang et al. 2006

The ISCCP-like Bispectral Visible/Infrared Method



- ✓ Cloud top pressure is retrieved from the infrared (~11 μm) channel and
- ✓ Cloud column optical depth is retrieved from the visible (~0.6 μm) channel (ISCCP, Rossow and Schiffer 1999)
- ➢ Single layer cloud is assumed in retrievals.

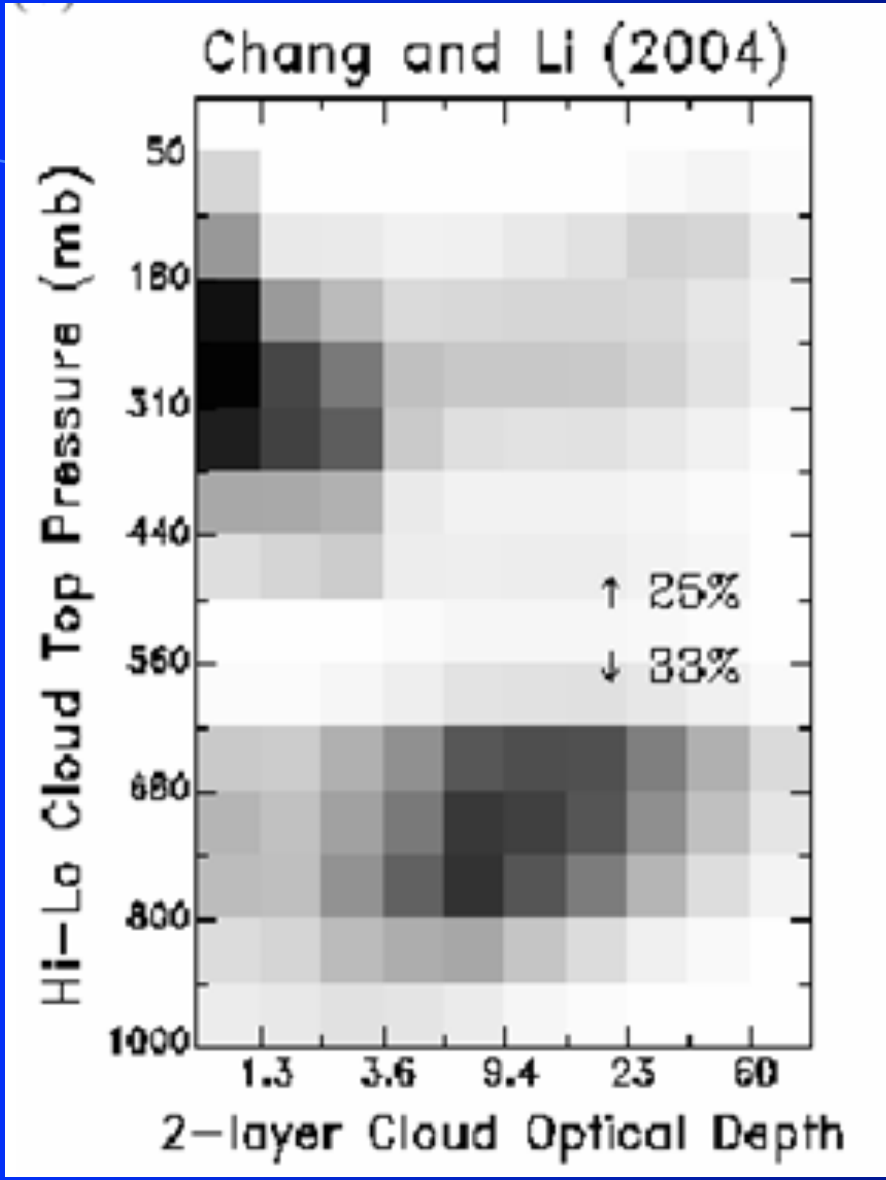
MODIS Cloud Top Pressure and Optical Depth Products



- ✓ Cloud top pressure: < 700 mb is retrieved from the CO_2-slicing channels (Menzel et al. 2002) and

  > 700 mb is from the 11-μm channel (Platnick et al. 2003).
- ✓ Cloud column optical depth is from the visible channel.
- ➢ Single layer cloud is assumed in retrievals.

The Overlapped Retrieval Scheme (Chang and Li, 2005a)



- Two or multi-layer clouds can be detected by using CO2 slicing channel and IR channels.
- Retrieve high-cloud optical depth from infrared radiative transfer model
- Retrieve low-cloud optical depth from visible radiative transfer model
- Iterate between steps 1 and 2 to fit best high and low cloud optical depths to the observed radiances at both visible and infrared channels.

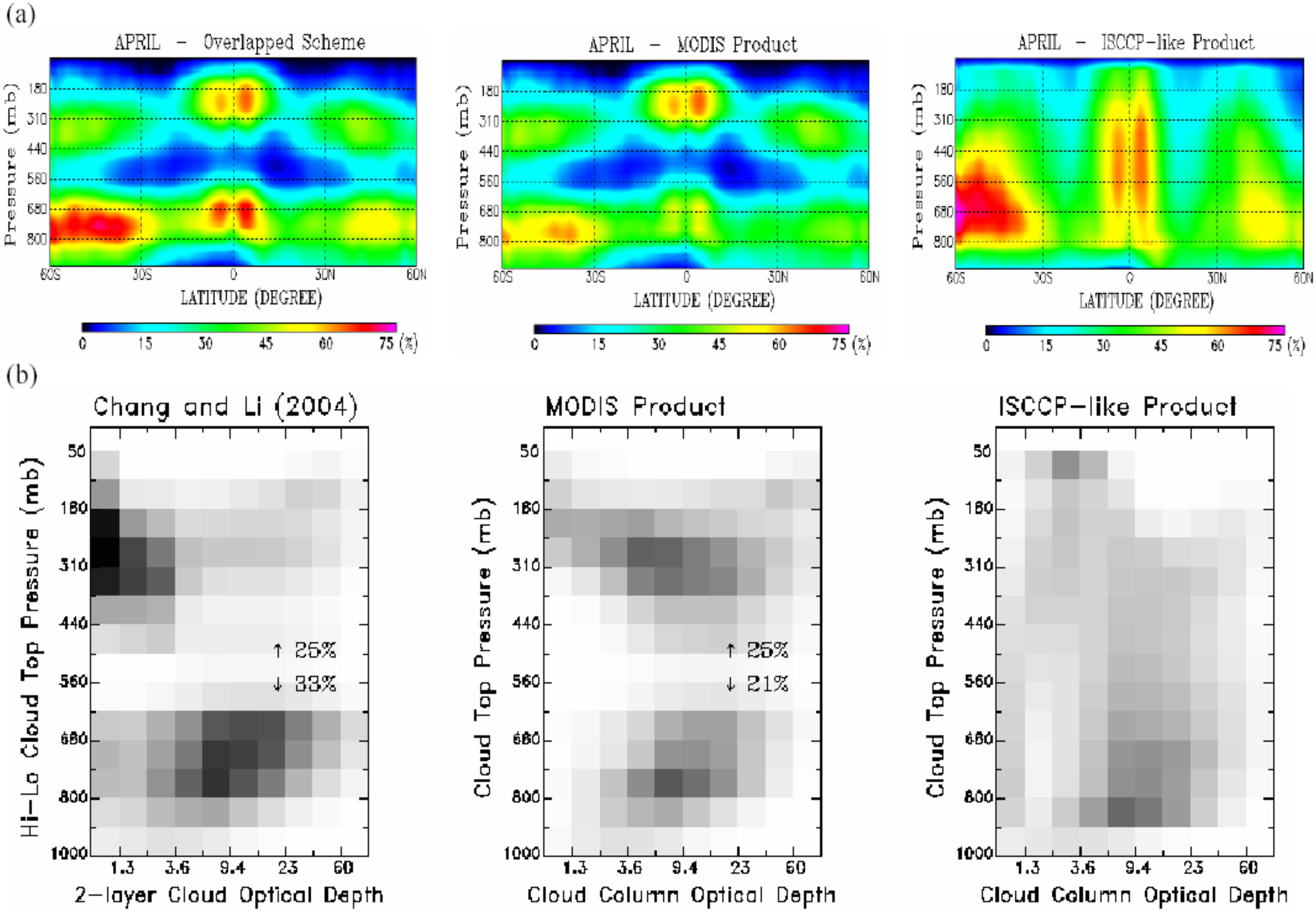
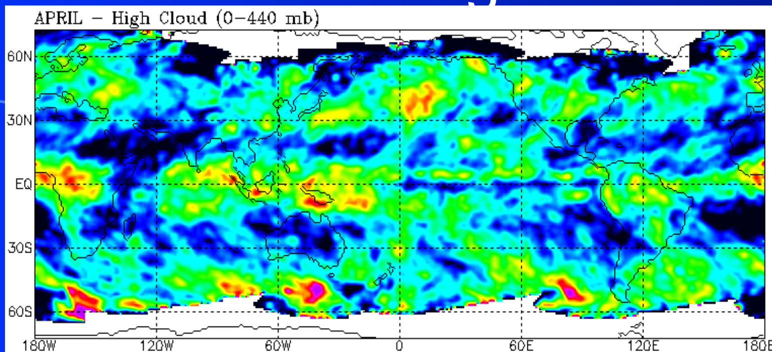


Fig. 6 a) Probabilities of cloud occurrence and b) joined-probabilities of Pc and τ_{VIS} derived from three different satellite inversion algorithms applied to the MODIS pixel data.

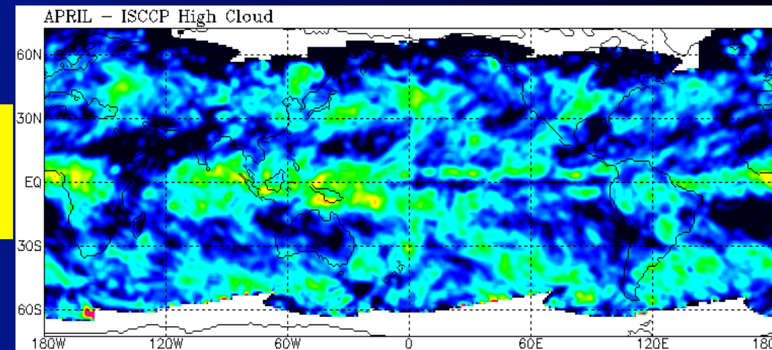
High (< 440mb), Mid (440-680mb), Low (> 680mb) Cloud Amounts

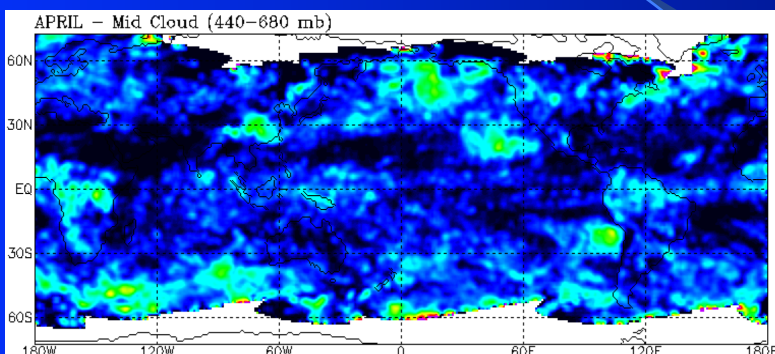
Chang and Li

ISCCP-like

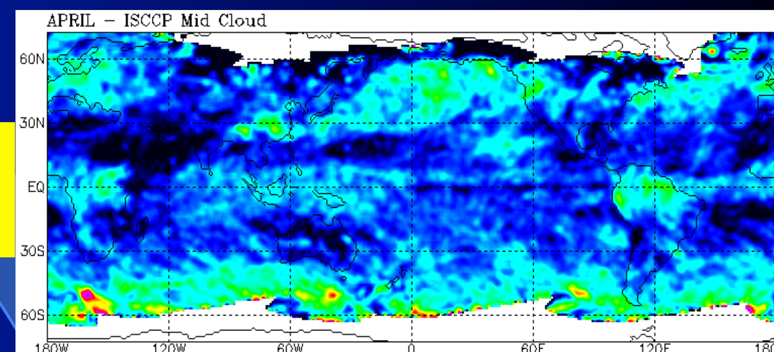


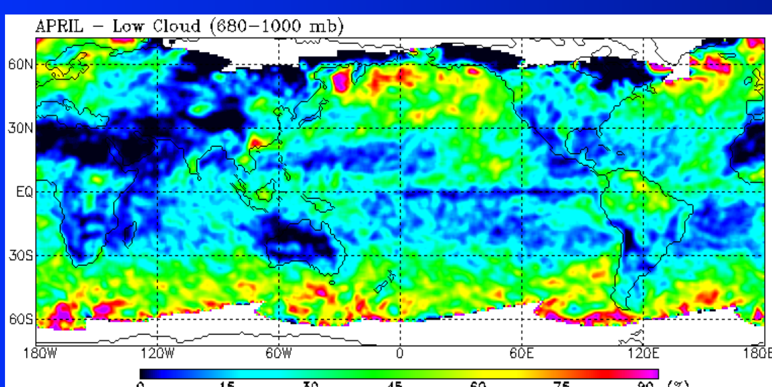
High cloud



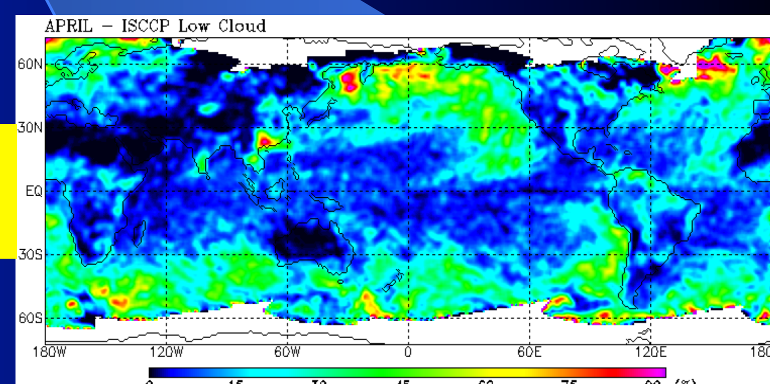


Mid cloud

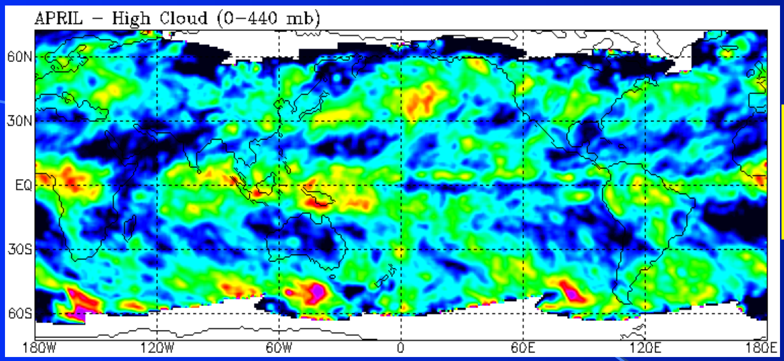


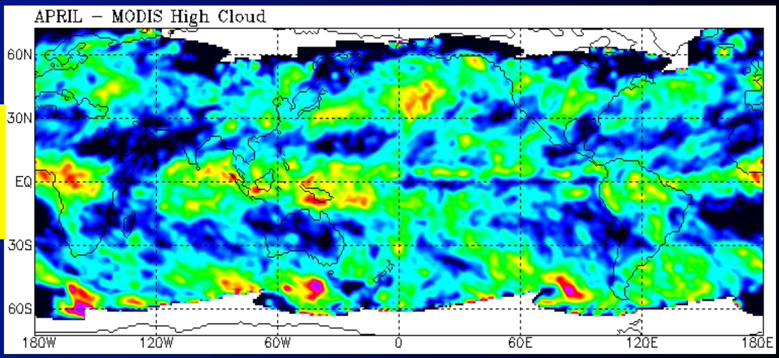


Low cloud

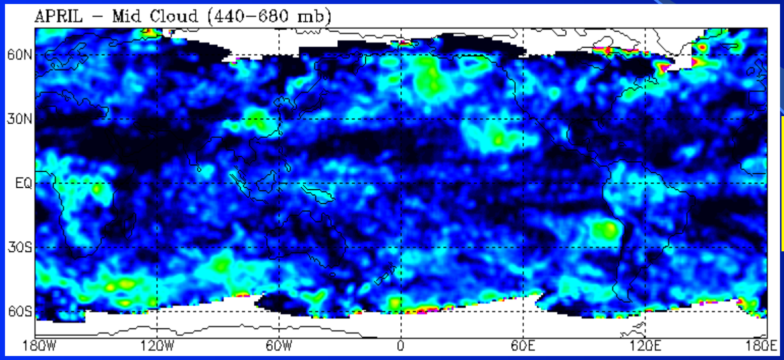


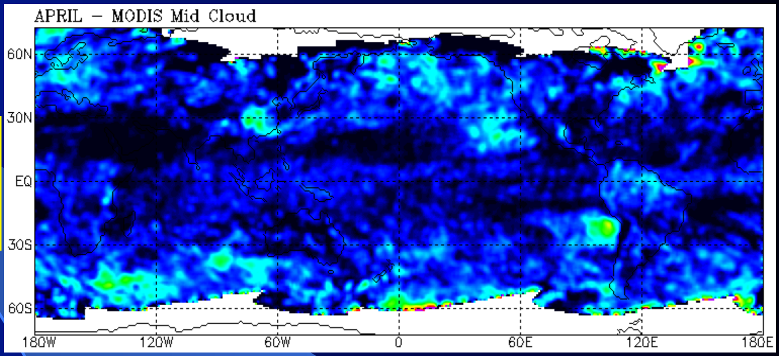
High (< 440mb), Mid (440-680 mb), Low (> 680mb) Cloud Amounts from the Chang and Li (left) and the MODIS Product (right)



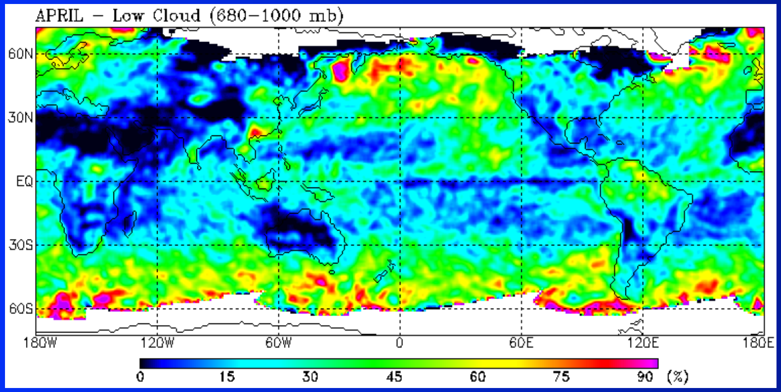


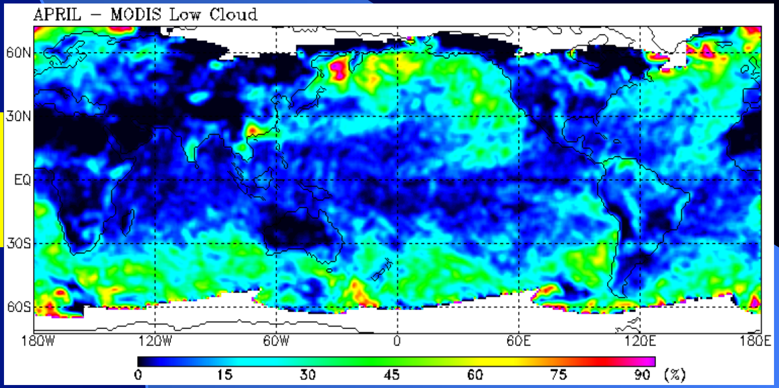
High cloud





Mid cloud

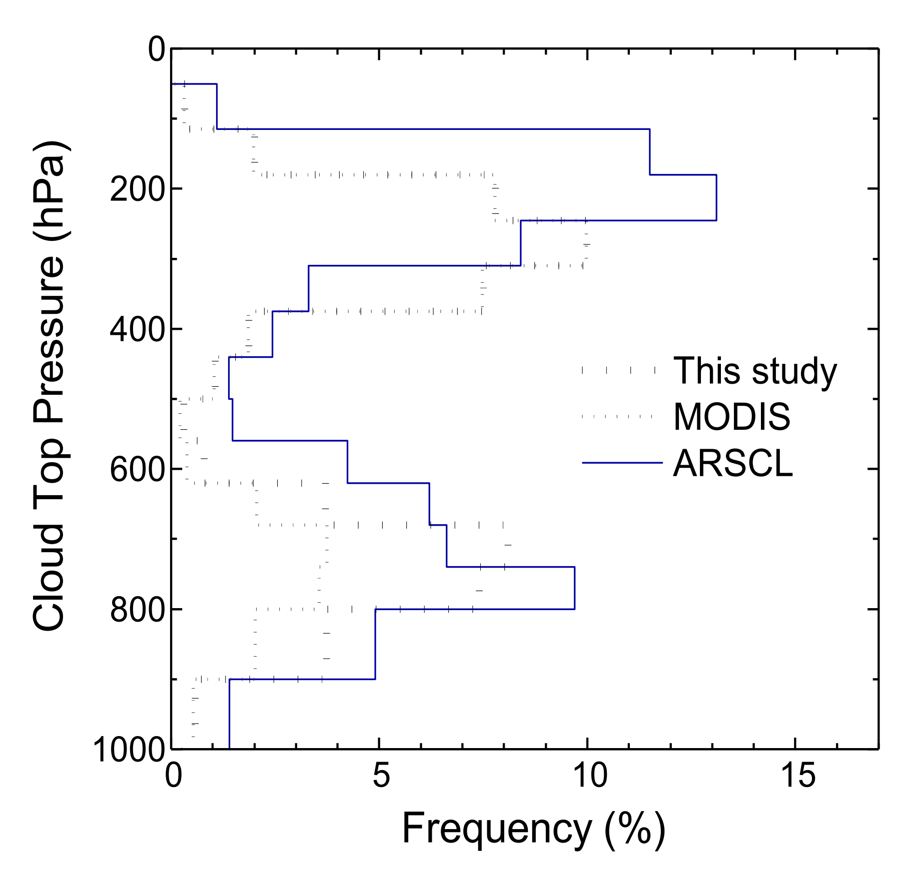




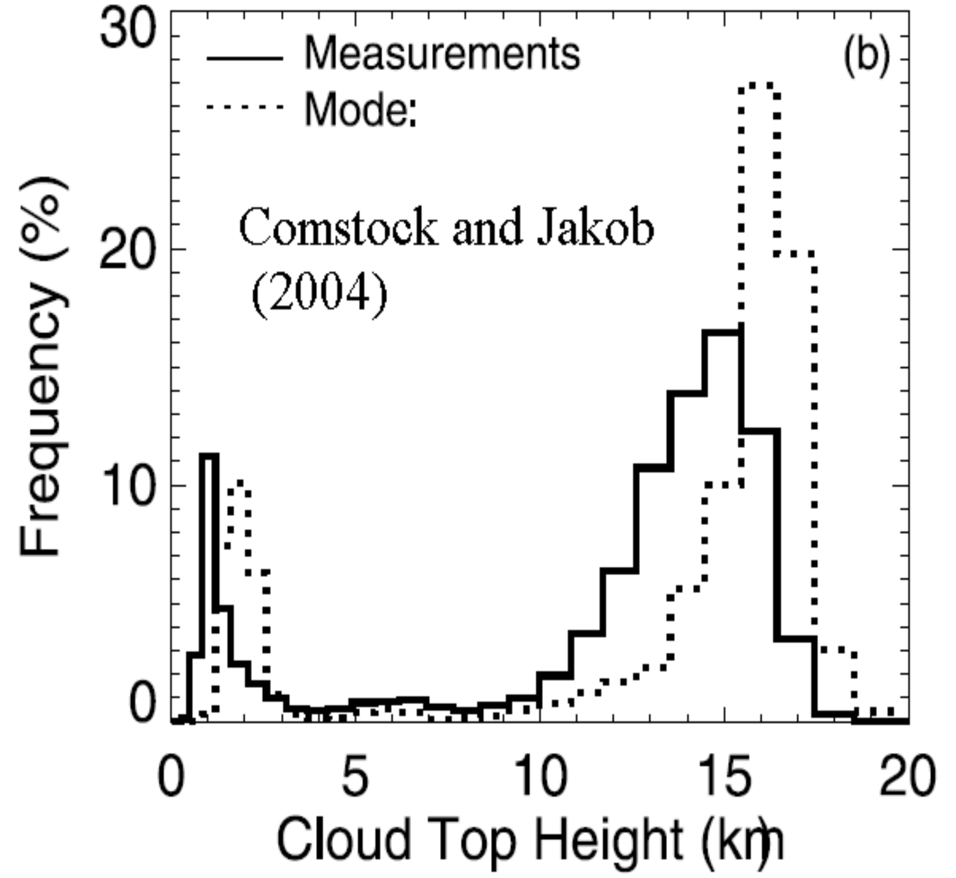
Low cloud

A Bimodal Frequency Distribution of Cloud Top Height

Apr.-Nov. 2001 at SGP



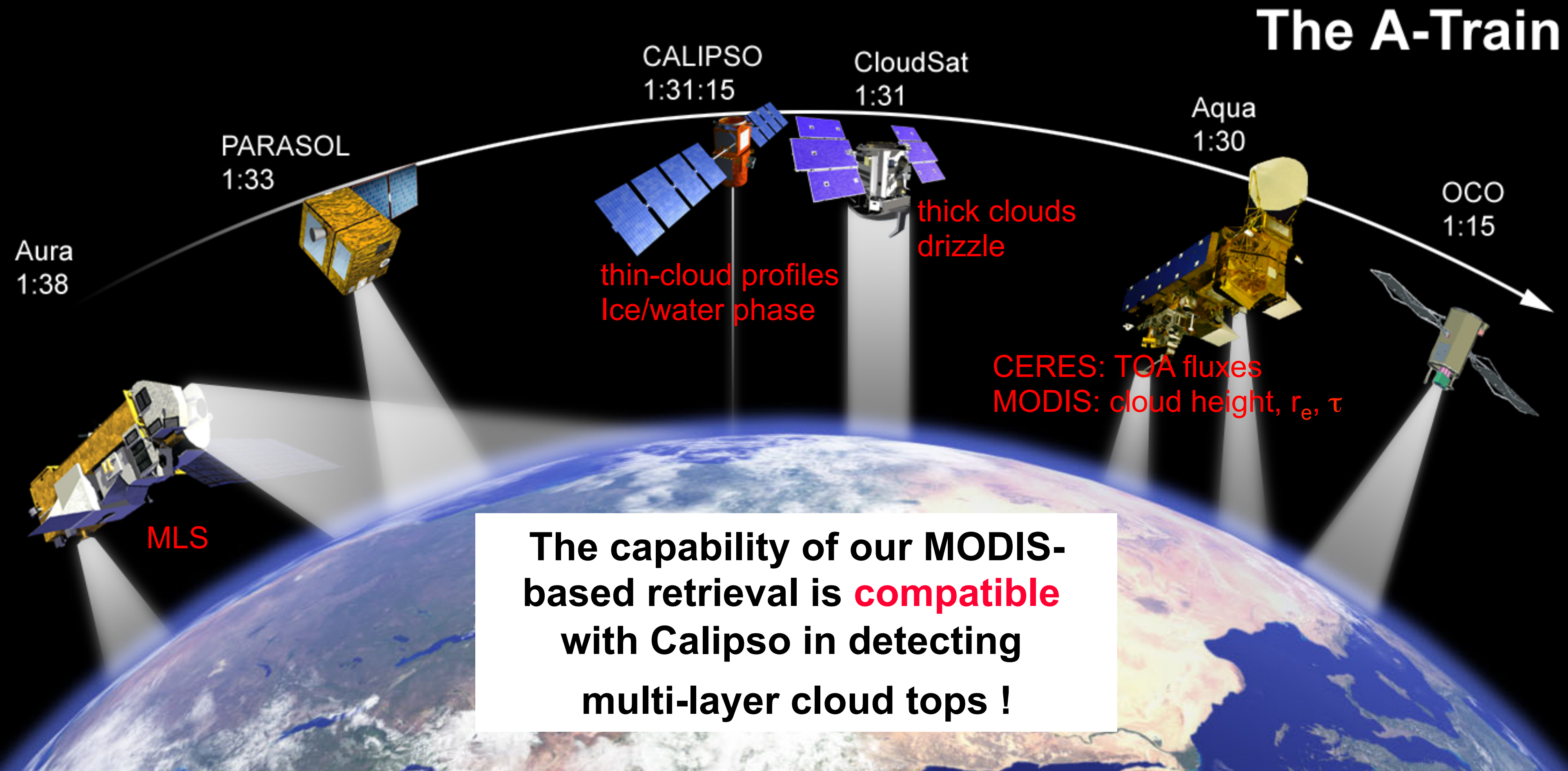
Apr.-Nov. 1999 at NAU



GLOBAL CLOUD COVER

Global Frequency of Cloud Layering from GLAS

From GLAS :	From MODIS
70 % Global Cloud Cover	71 % Global Cloud Cover
45 % Single Layer Cloud	44 % Single Layer Cloud
25 % Multiple Layer Cloud	27 % Multiple Layer



The capability of our MODIS-based retrieval is compatible with Calipso in detecting multi-layer cloud tops !

Cloud ice/water mass	CloudSat MLS AMSR
Cloud microphysics	MODIS CloudSat PARASOL
Precipitation	CloudSat

Aerosol optics	CALIPSO MODIS PARASOL OMI
Cloud optics	CALIPSO, MODIS, and PARASOL

NCEP Global Forecast System (grid 003)

- Global Latitude/Longitude 1 deg Resolution

- Control time chosen: 00Z
  Forecast times chosen: 03, 06, 09, 12, 15, 18, 21, 24Z

- Variables extracted:
  - high, middle, and low cloud cover
  - cloud-top and cloud-base pressures
    - converted to km using relation:

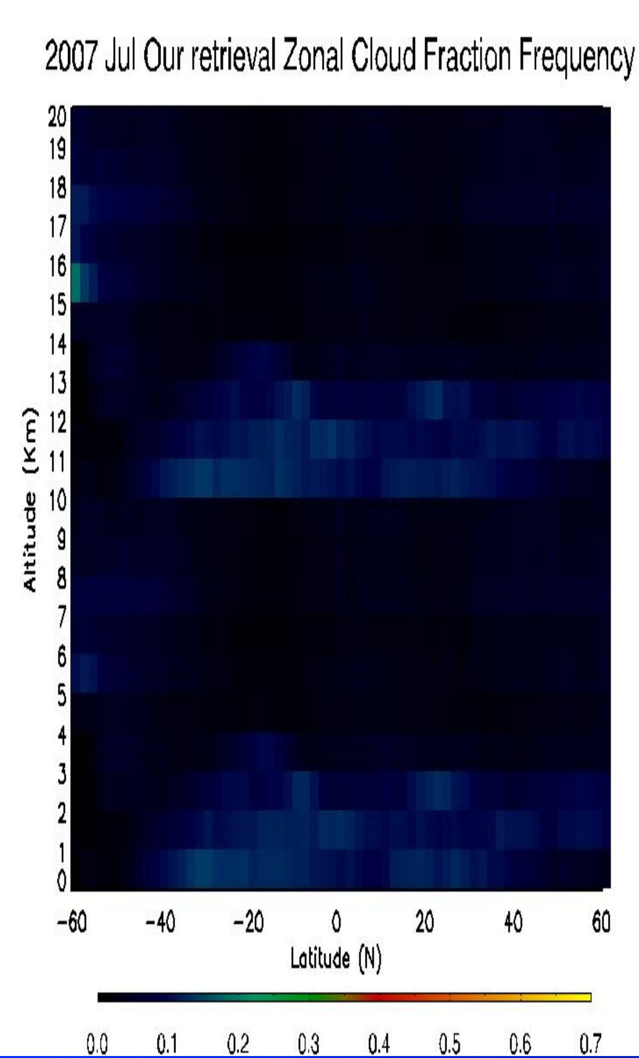
      $44307.693\,[1-(\text{pressure}/1013.25)^{0.190284}]/1000$

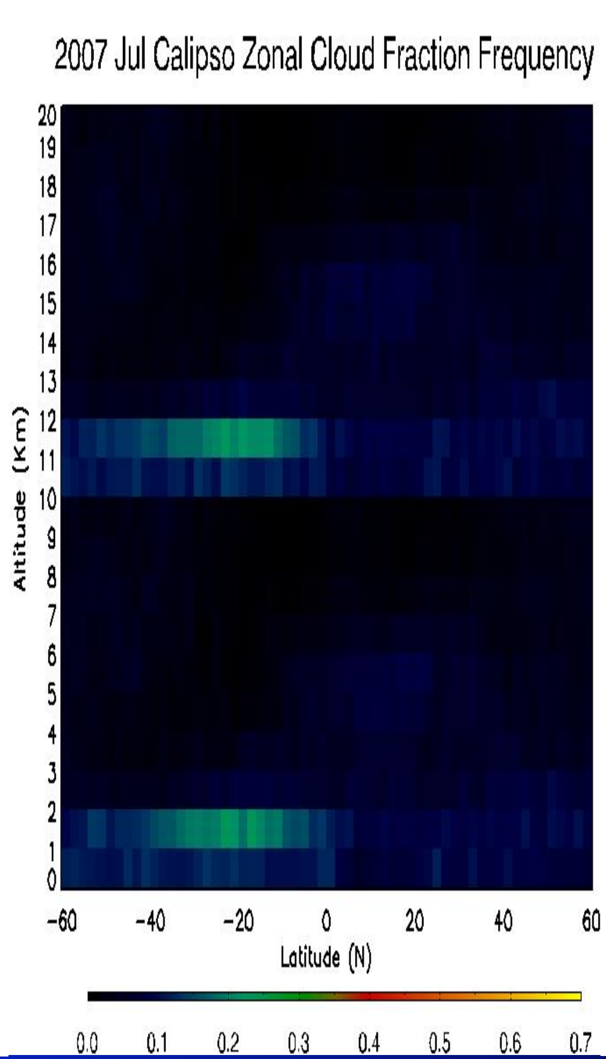
- Data availability (daily) : off-line Feb. 15, 2005 to May 31, 2007
  on-line June 1, 2007 to current date

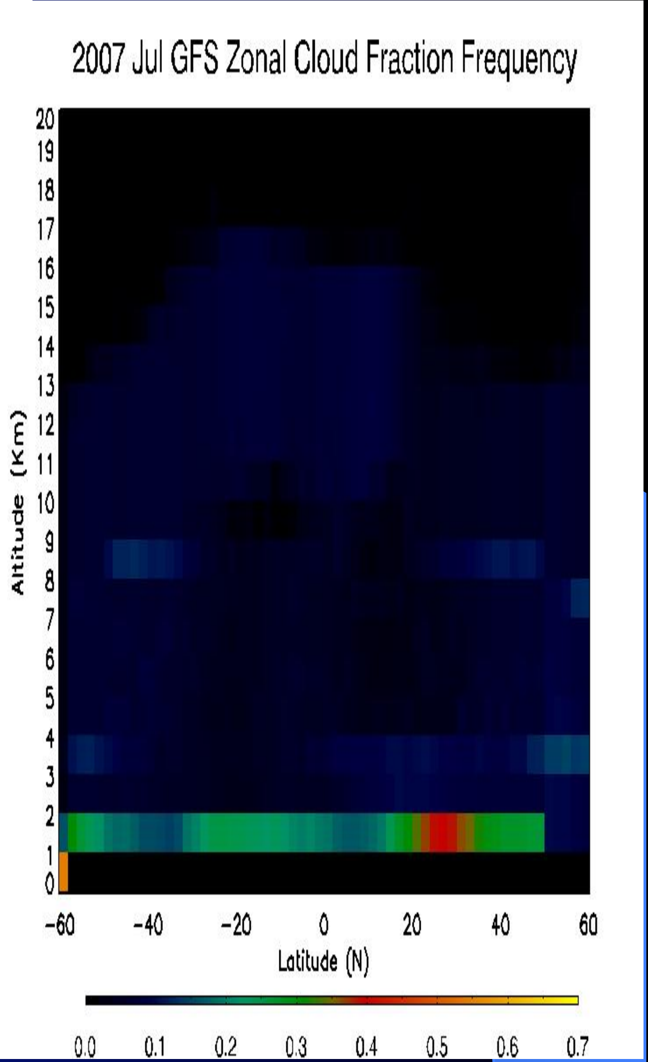
http://nomads.ncdc.noaa.gov/cgi-bin/ncdc-ui/define-collection.pl?model_sys=gfs-hi&model_name=gfs&grid_name=3

Avg Box : 2.0 degrees Latitude, 2007 July

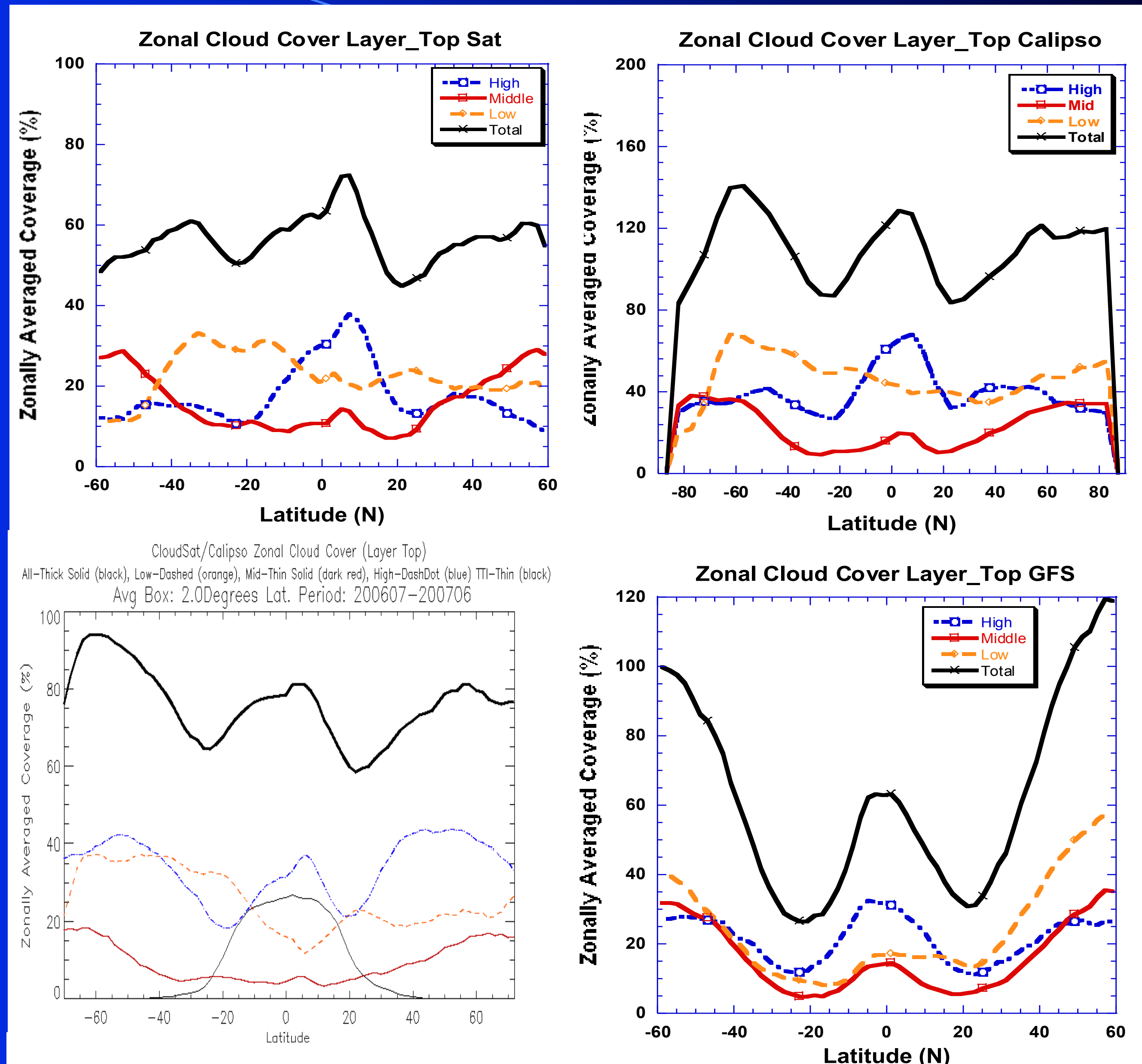
Our_retrieval | **Calipso** | **GFS_Model**





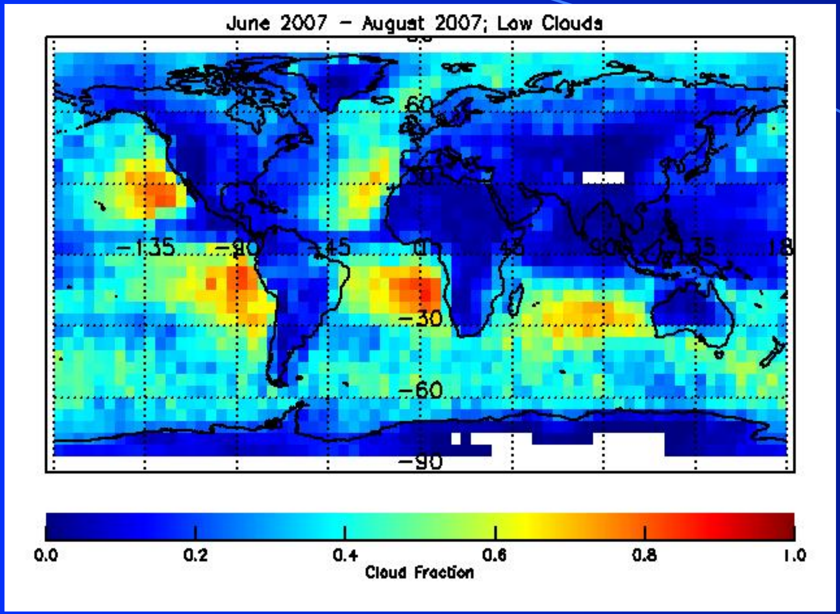


Calipso Our_retrieval

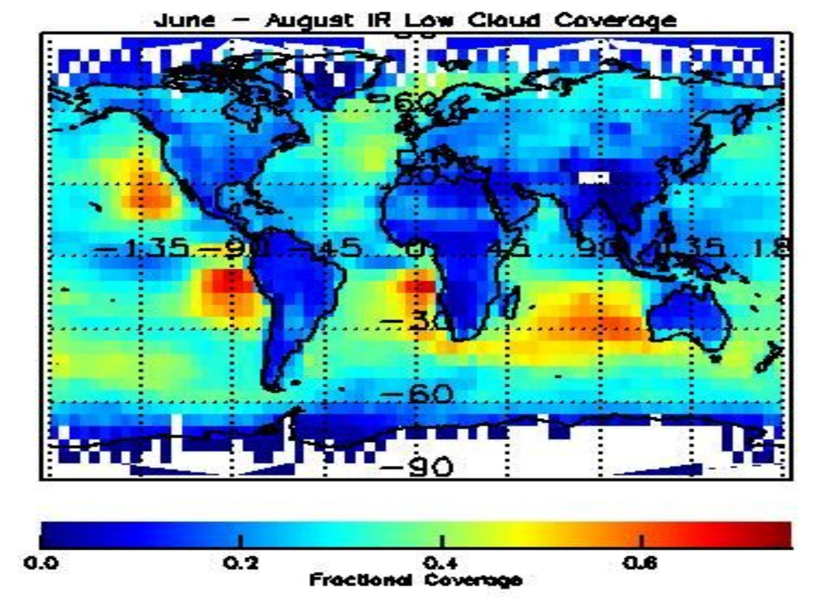


CloudSat GFS_Model

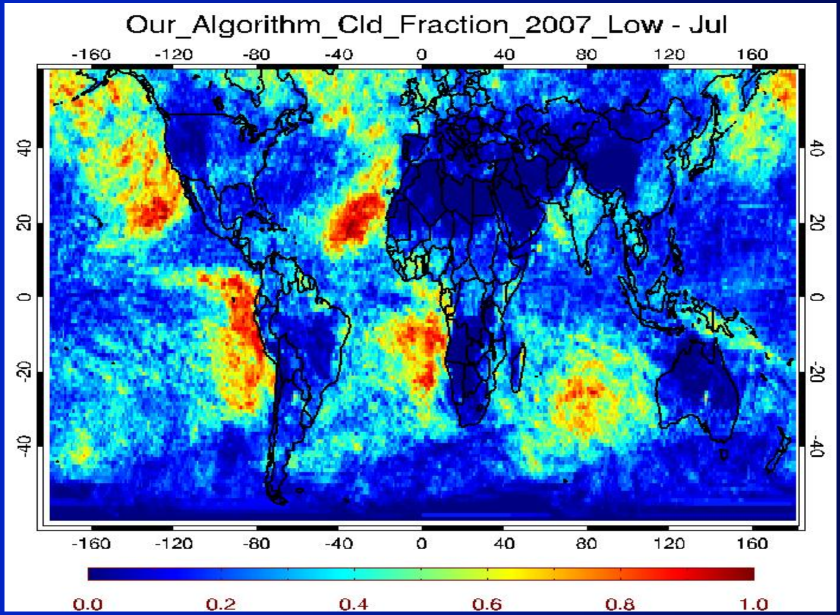
CALIPSO, single-layer low cloud: 27.5%



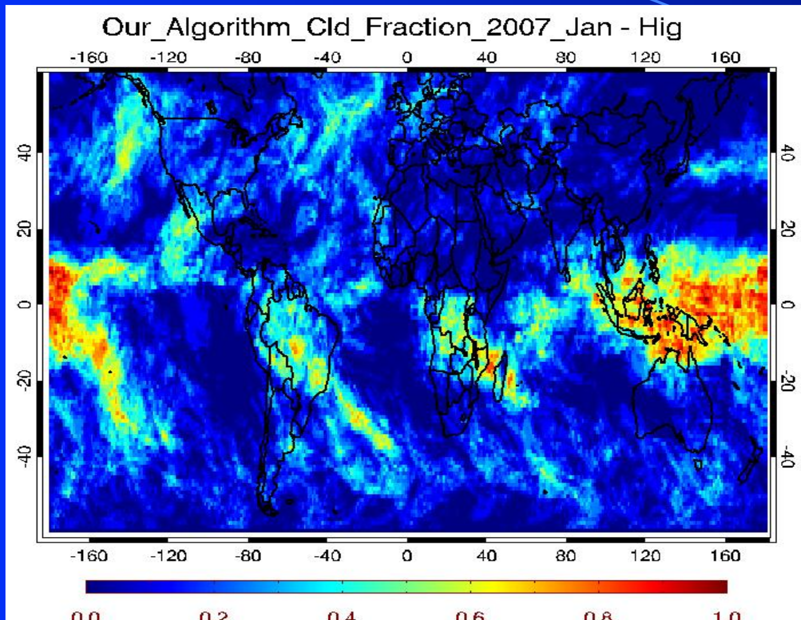
ISCCP: 25.2%

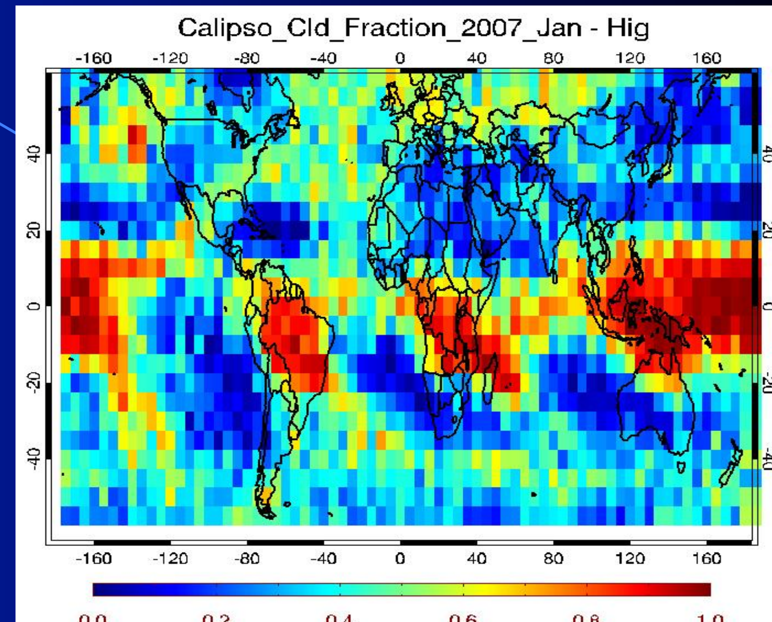


Our retrieval, single-layer low cloud: 27.13%

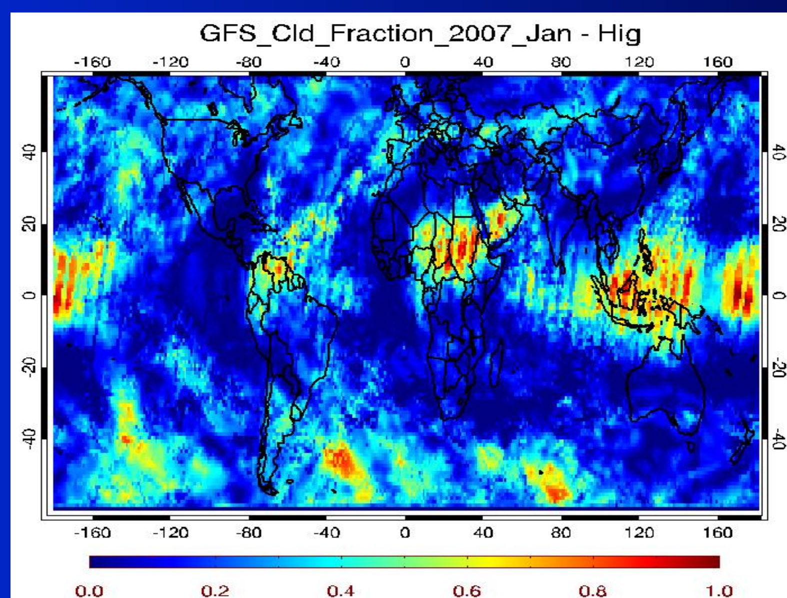


Comparison of high cloud fraction in Jan 2007

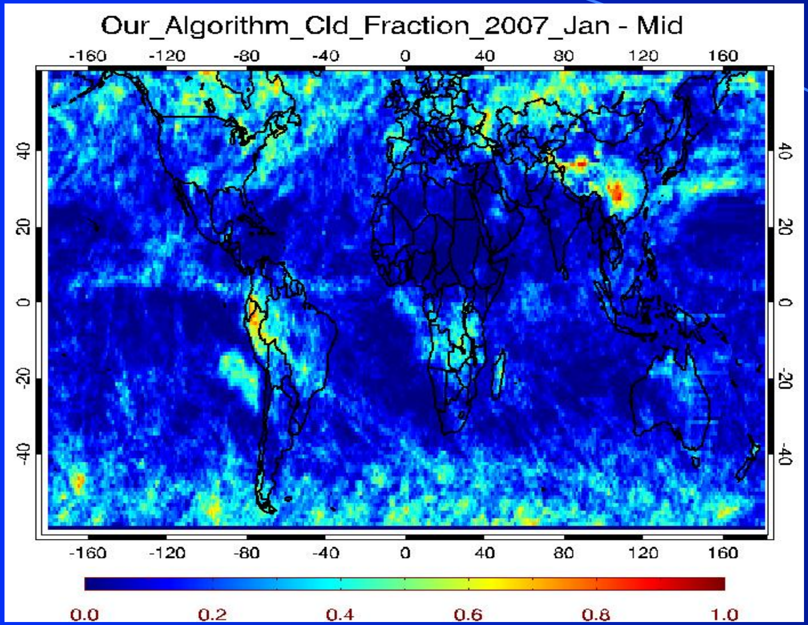


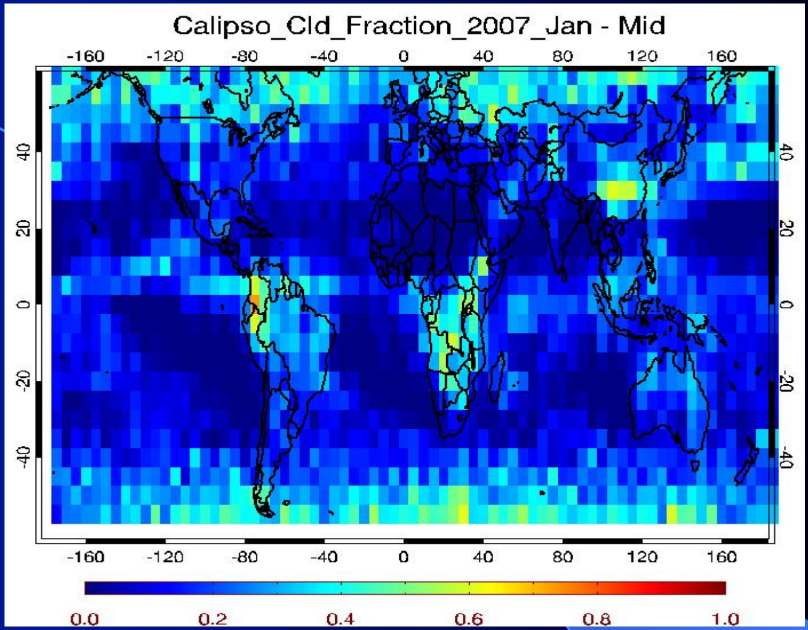


Ours **GFS** **CALIPSO**



Comparison of mid cloud fraction in Jan 2007

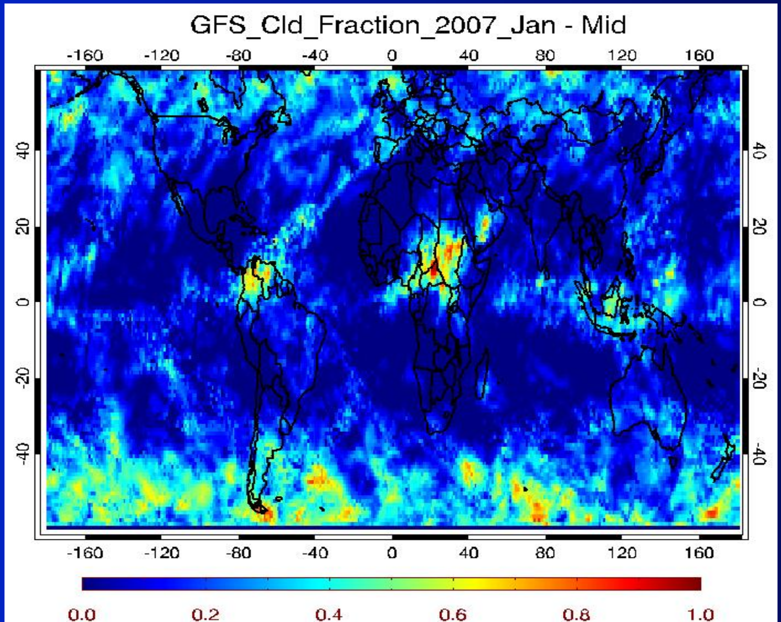




Ours

GFS

CALIPSO



Major findings

- Cloud products from three satellites sensors (MODIS-CL, CALIPSO and CLOUDSAT) bear great resemblance
- MODIS-CL is most compatible with CALIPSO
- In general, the GFS produce sound total cloud patterns on the global scale.
- The GFS model tends to generate less high clouds, more middle clouds and less low clouds than C-C clouds
- The GFS produces far less cirrus cloud in the tropics
- The GFS clouds are generally too thin by about 50%
- Many regional features are yet to be explored,e.g. too much clouds over deserts, too little over cold oceans, …

Separating Aerosol Effects from Artifacts Using Space-borne, Air-borne and Ground Measurements

Conventional Approach for Studying Aerosol Indirect Effects

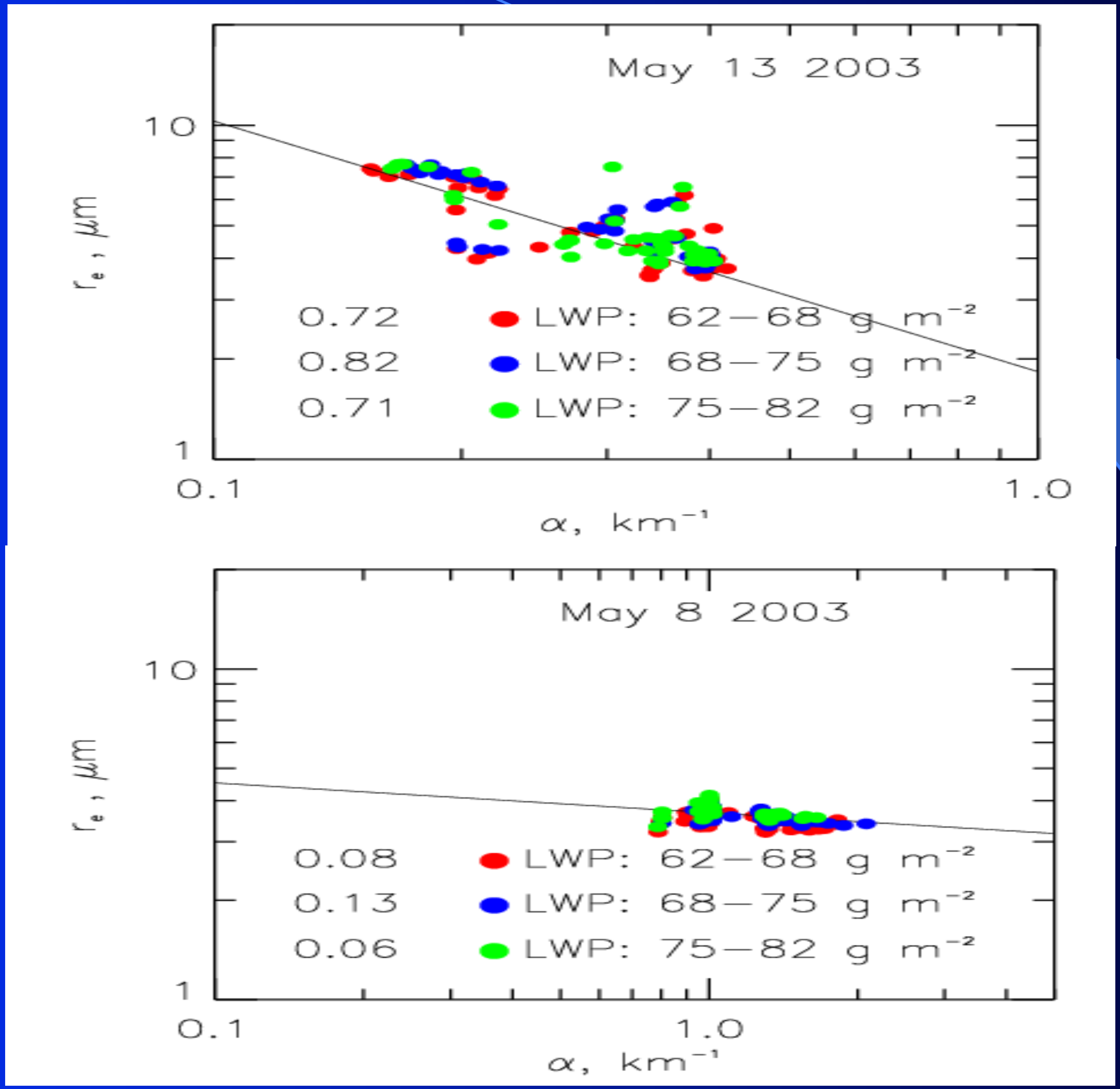
$IE = -\Delta \ln r_e / \Delta \ln \tau_a$ (1)

$IE = -\Delta \ln r_e / \Delta \ln N_a$ (2)

Values of IE reported in the past:

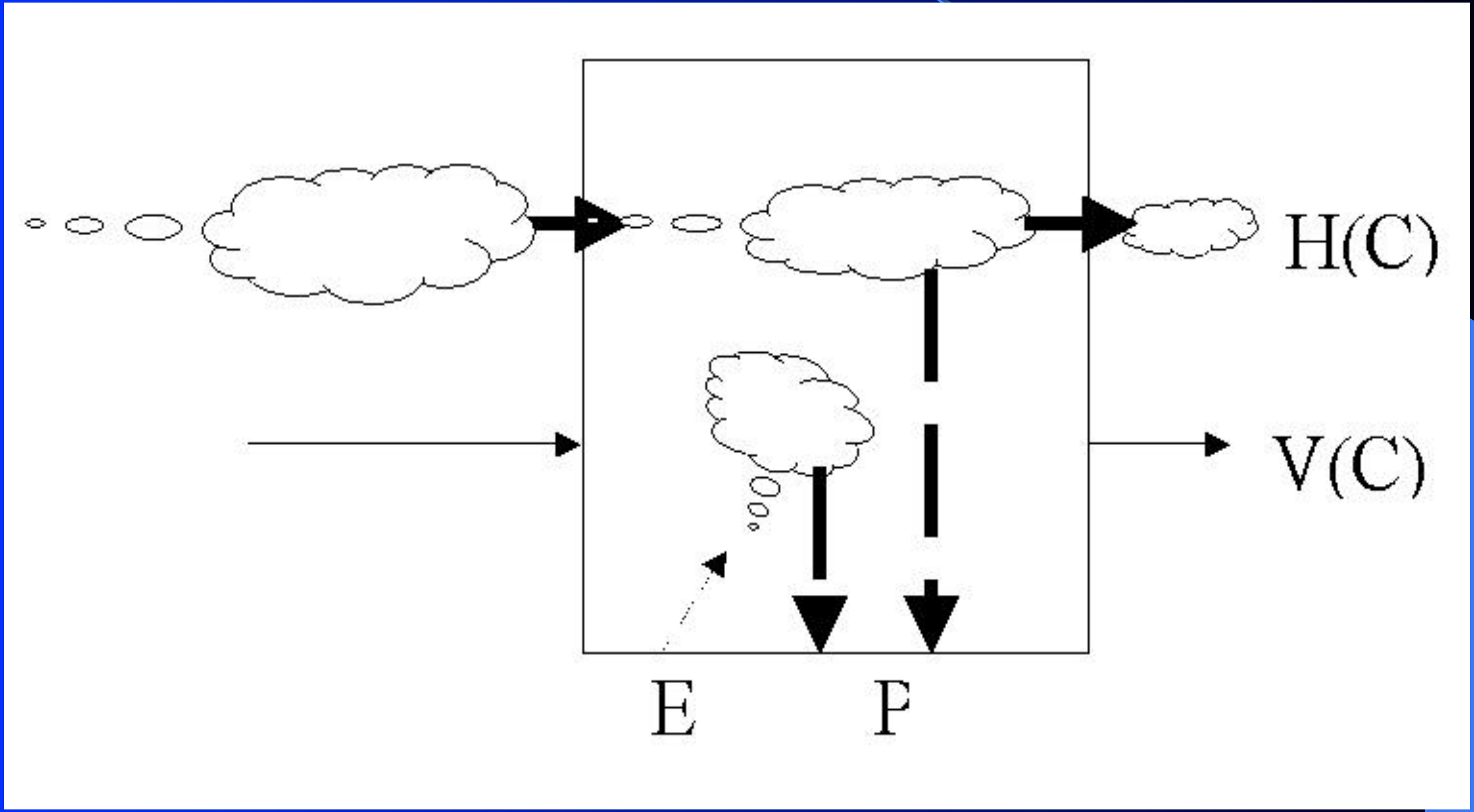
- AVHRR (Nakajima et al. 2001)
  IE = 0.17 (Oceans)
- POLDER (Breon et al. 2002)
  IE=0.085 (oceans) 0.04 (land)
- Surface Observation (Feingold et al. 2003)
  IE=0.02~0.82

Relationship between cloud droplet size and aerosol extinct



Feingold et al. (2004)

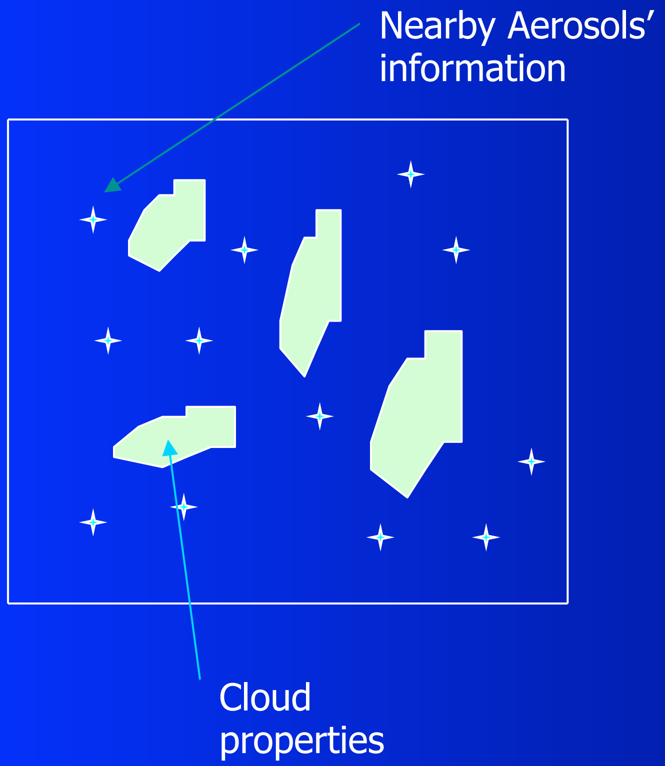
A framework for studying aerosol-cloud interaction

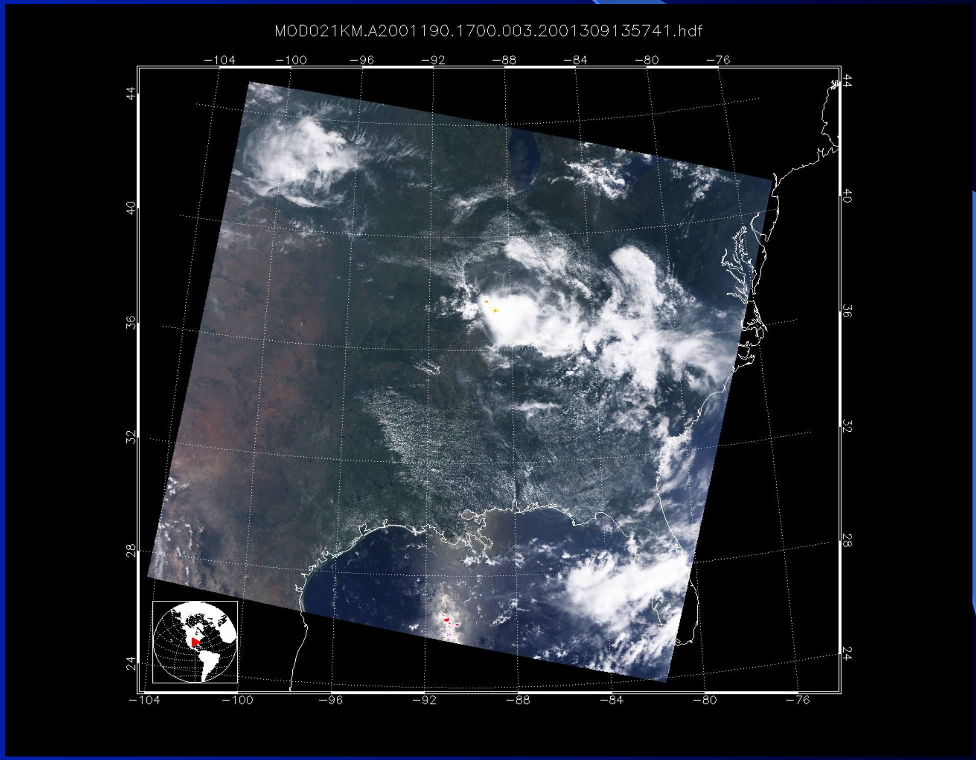


Methods

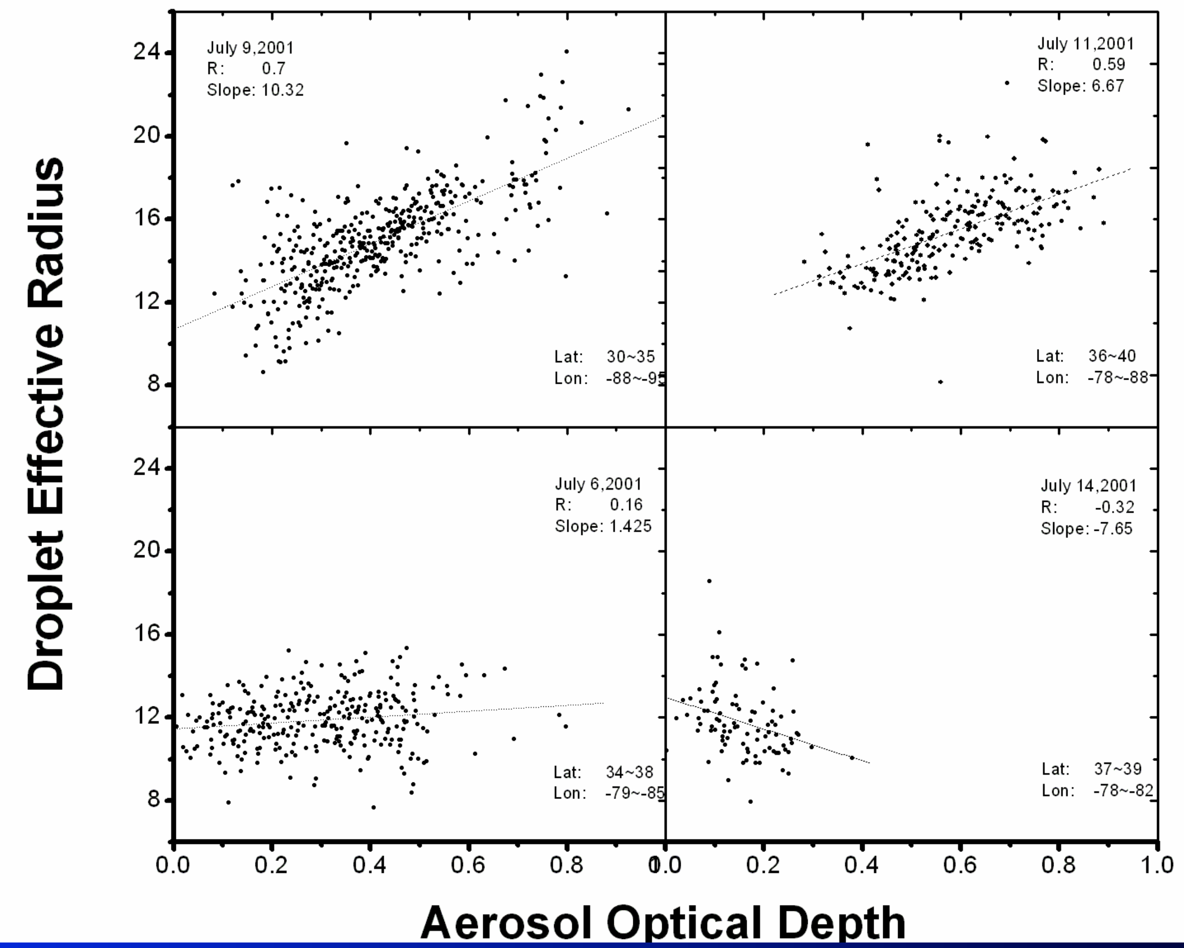
- Analyses of satellite data to examine the issues in perspective: scene-by-scene selection, automated ensemble analysis
- Analysis of in-situ/ground data to evaluate various effects
- Use of cloud resolving model to understand the physical processes

Cumulus clouds and aerosols: the most challenging problem, but essential for AIE studies



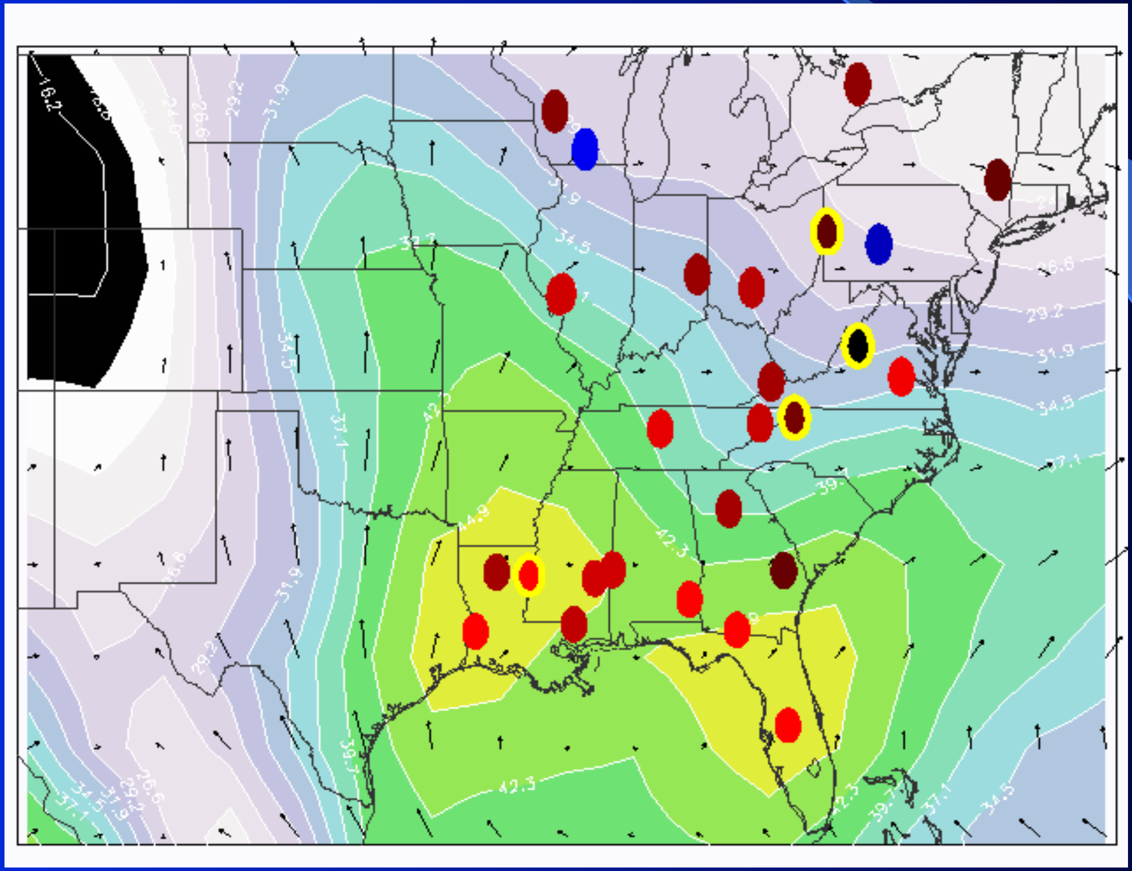


DER-AOD relationship

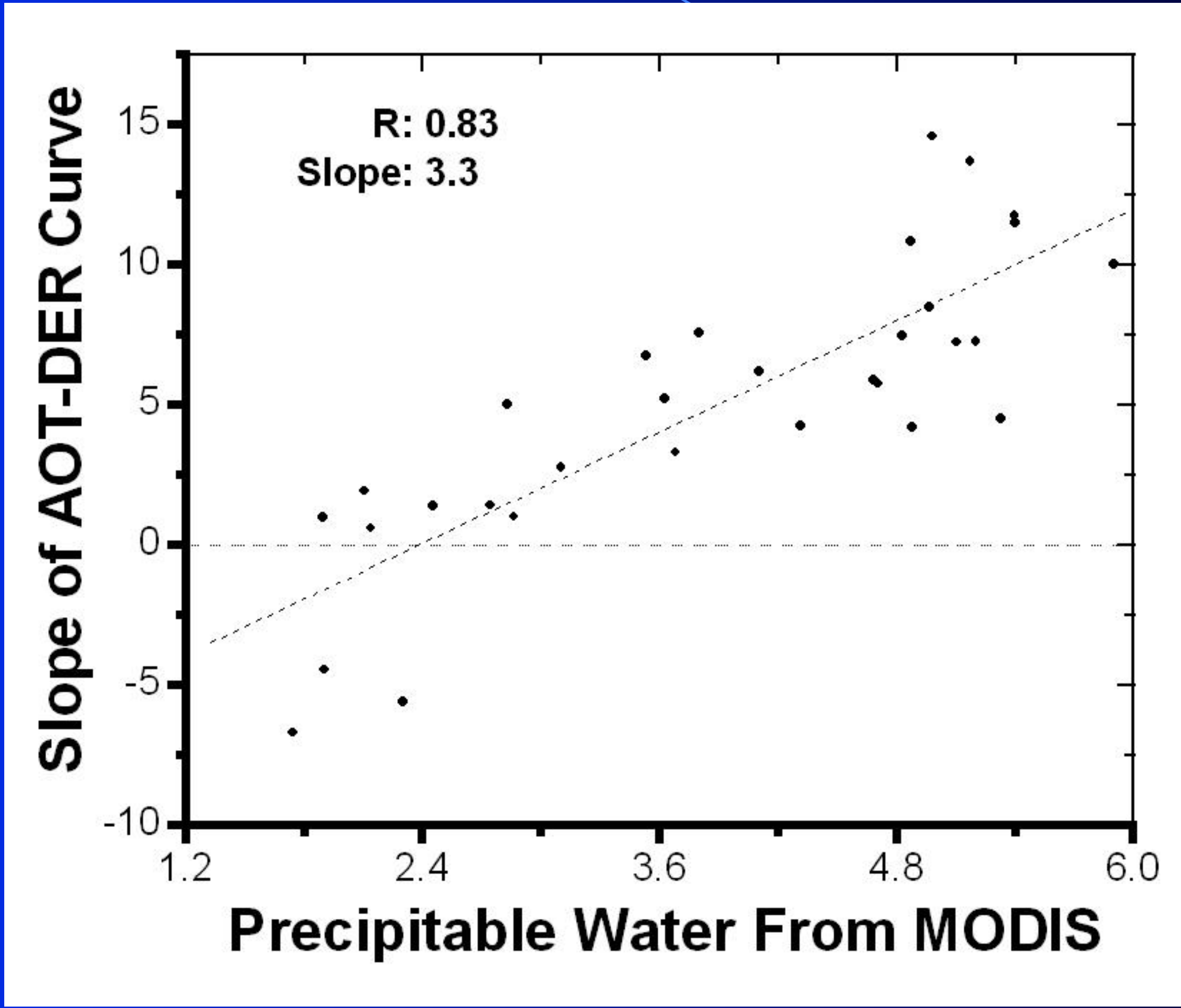


Yuan et al. 2008

AIE efficiency distribution



AIE efficiency determining factor



Global analysis

Region	Latitude range	Longitude range	Dominant Aerosol/Cloud Types	Period	AIE efficiency	Sample size
North Atlantic	10-20N	20-40 W	Dust, Stratocumulus	June-August, 2002	Negative	99,978
South Atlantic	5-20S	5E-20W	Smoke, Stratocumulus	June-August,2002	Negative	100,377
Southern Pacific	5-25S	75-105W	Sea salt, sulfate and pollution, Stratocumulus	August-October, 2002	Negative	74,216
Indian Ocean	12-20N	60-70E	Dust with pollution, Trade cumulus	June-August, 2002	Negative	94,023
India	13-24N	70-85E	Mixture of sulfate, dust, sea salt and smoke, cumulus	June-August,2002	Neutral	53,888
Amazonia	8S-12N	44-76W	Mainly smoke	August-October, 2002	Negative	672,421
Southeastern China	23-43N	100-120E	Mixture, cumulus	June-August,2002	Positive	179,533

Student-t test indicates except India the difference among different loading of aerosols are statistically significant at least at the 95% level

Yuan et al. 2008

Factors Causing the Correlation between the AOT and Cloud Parameters

Physical Effects

- Aerosol humidification effect
- Convergence of aerosols
- Aerosol production (Cloud-processed particles/New particle genesis) associated with cloud

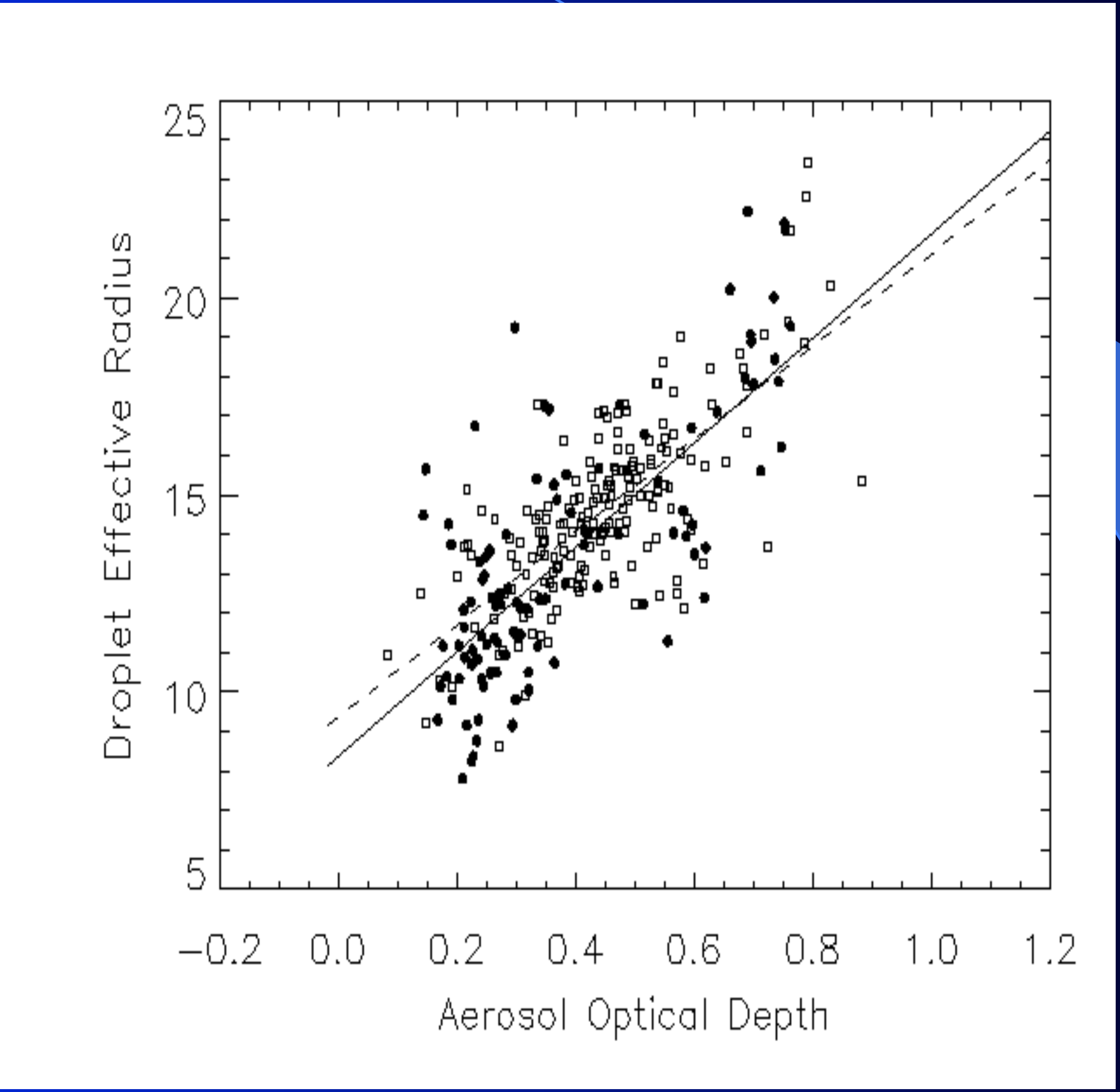
Artifacts

- Cloud contamination
- Erroneous cloud cover estimation associated with aerosol
- Enhanced diffuse radiation due to clouds (twilight)

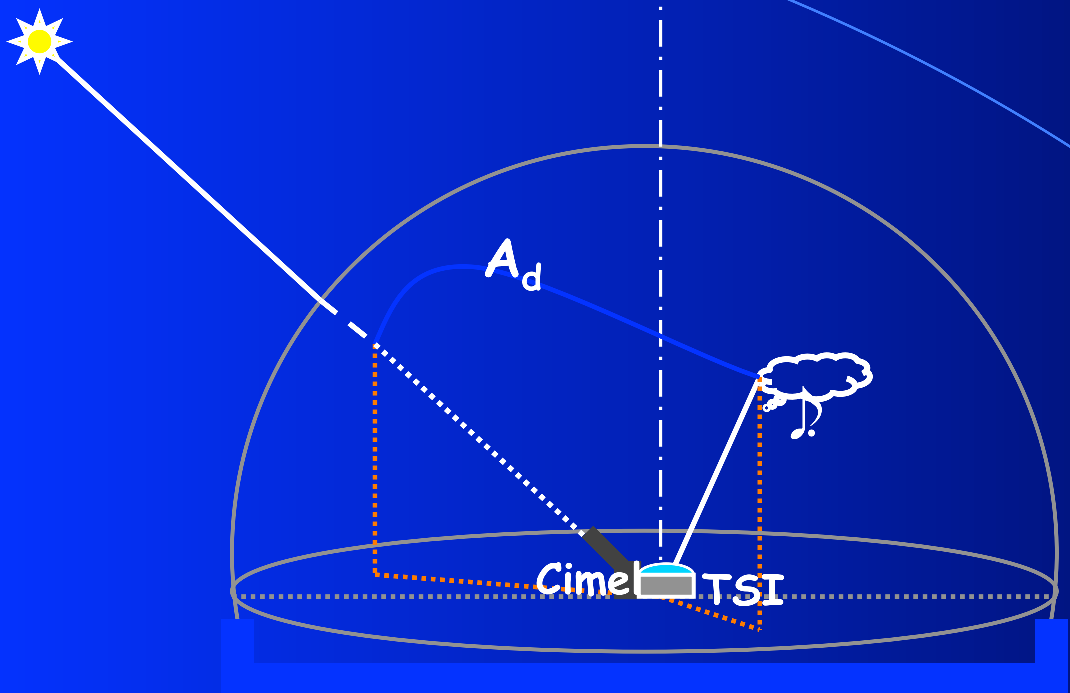
Analysis of four factors

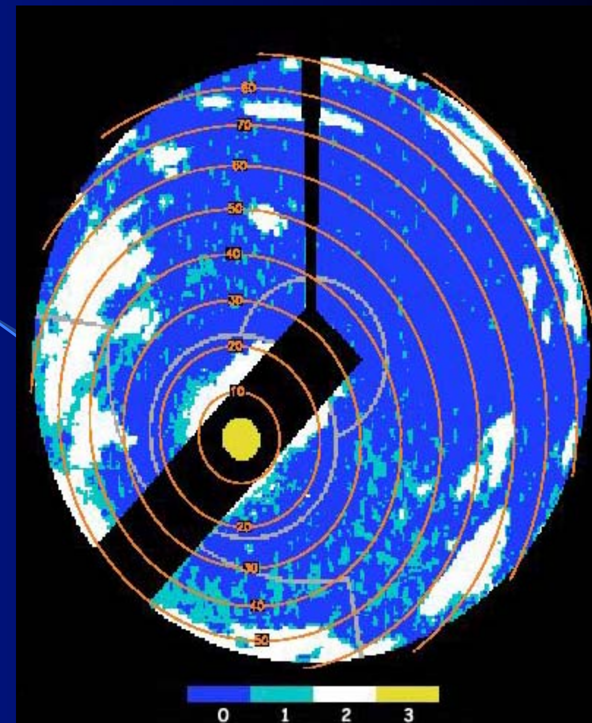
- Partially cloudy pixels
- Aerosol hygroscopic growth
- Cloud 3-D effect
- Cloud dynamics effect (vertical profile)

The Effect of Cloud Fraction



Cloud Contamination?
Erroneous Cloud Cover Estimation?



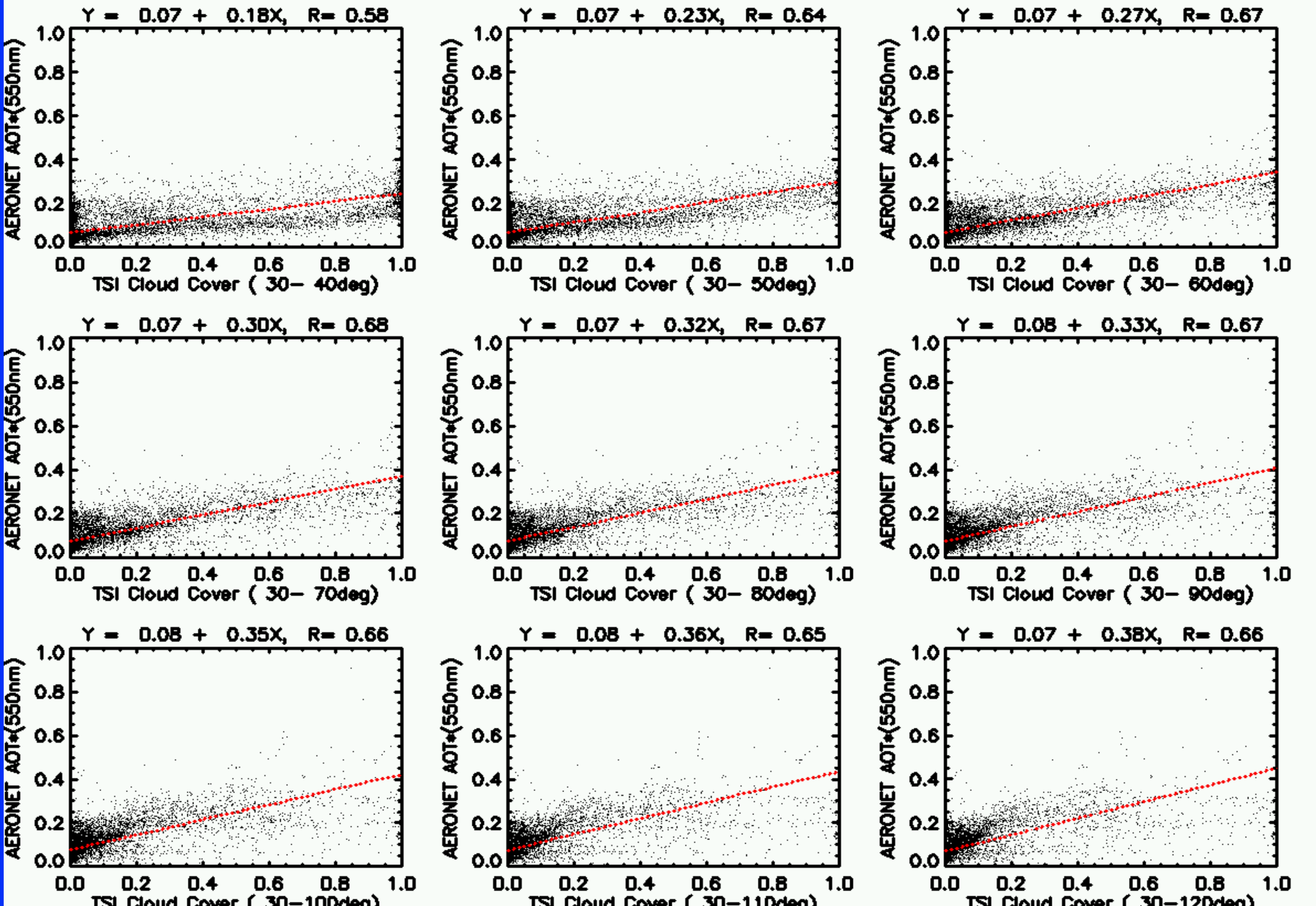


TSI cloud mask (19:42Z, May 4, 2003)

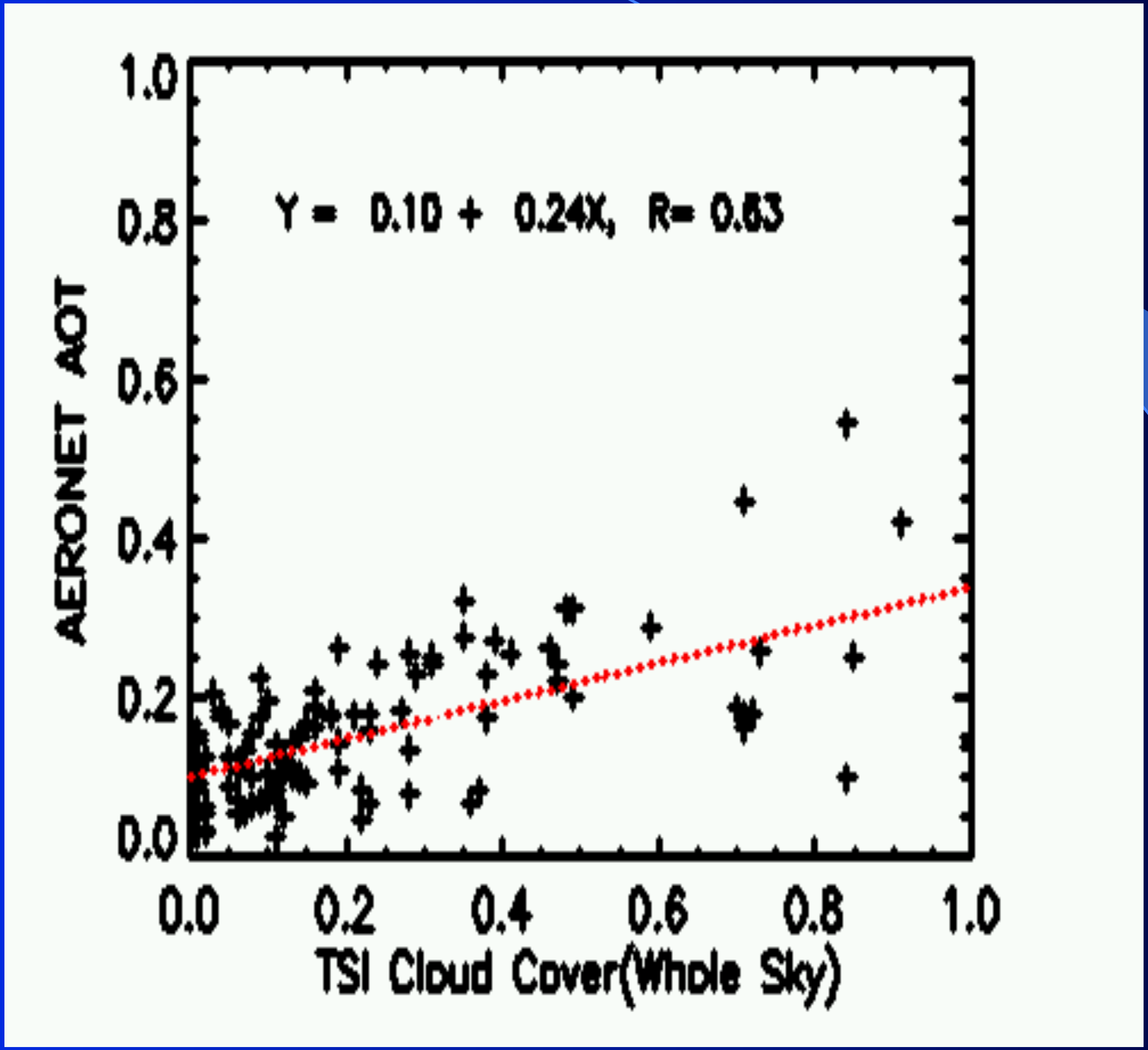
TSI Cloud cover was acquired for circumsolar areas with increasin g angular distance from the sun (w/ 10-deg. increment). Then, it wa s examined if there is any correlation between the AOT and cloud cover.

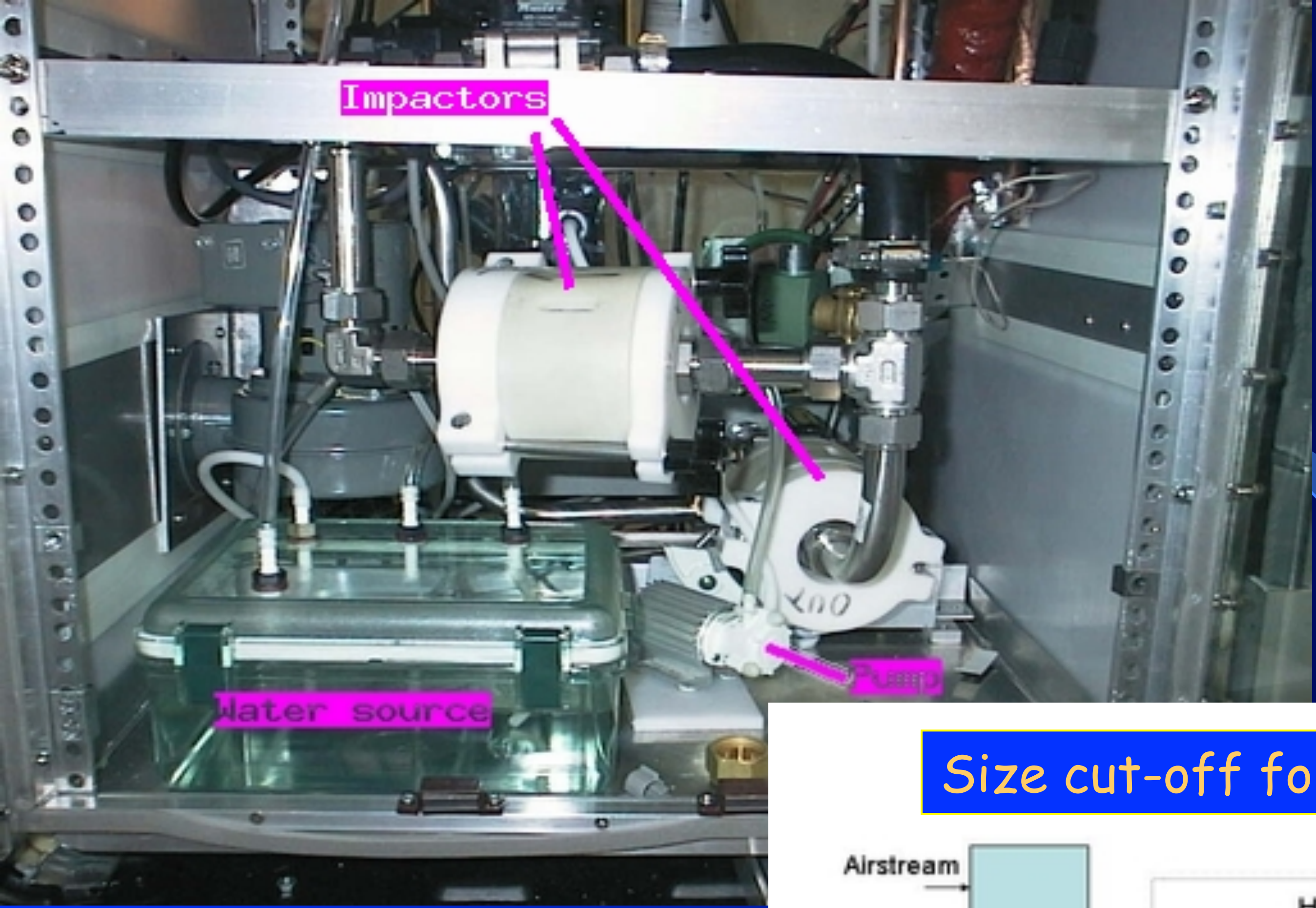
0: clear sky; 1: thin cloud;
2: opaque cloud; 3: location of the sun

AERONET AOT v.s. Cloud Cover for Various Circum-Solar Areas



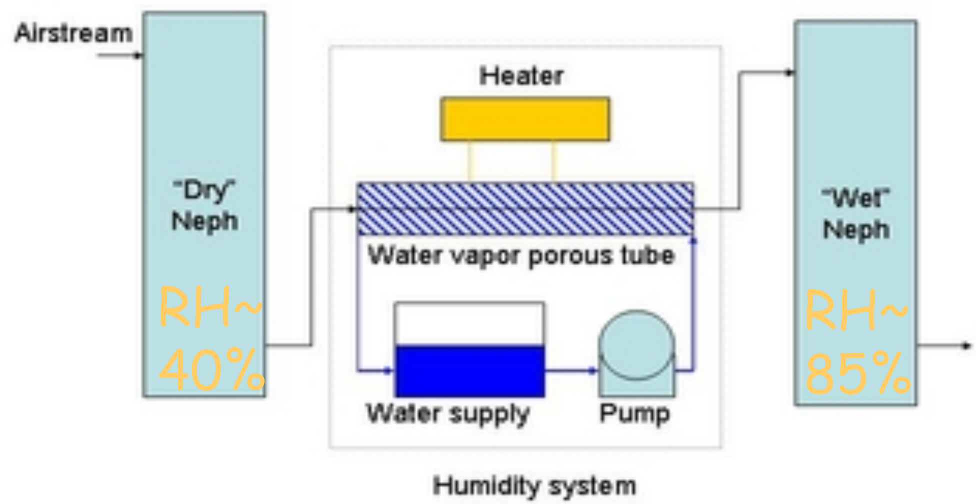
AOT v.s. TSI Cloud Cover





←♪
Nephelometer for the In-Situ Aerosol Profiling (IAP) flights

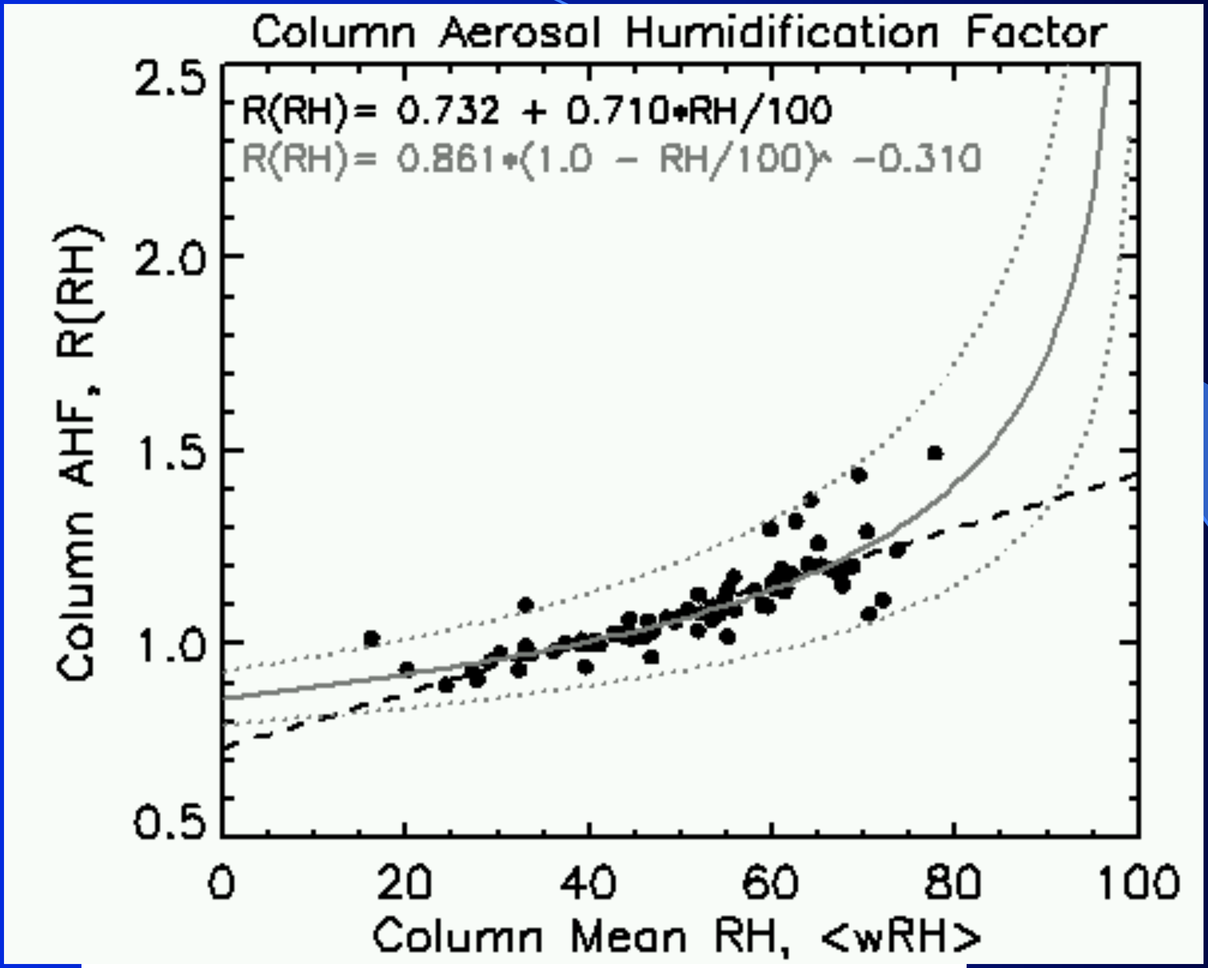
Size cut-off for IAP/Neph → 1um



→
A flow schematic for the IAP

Ex

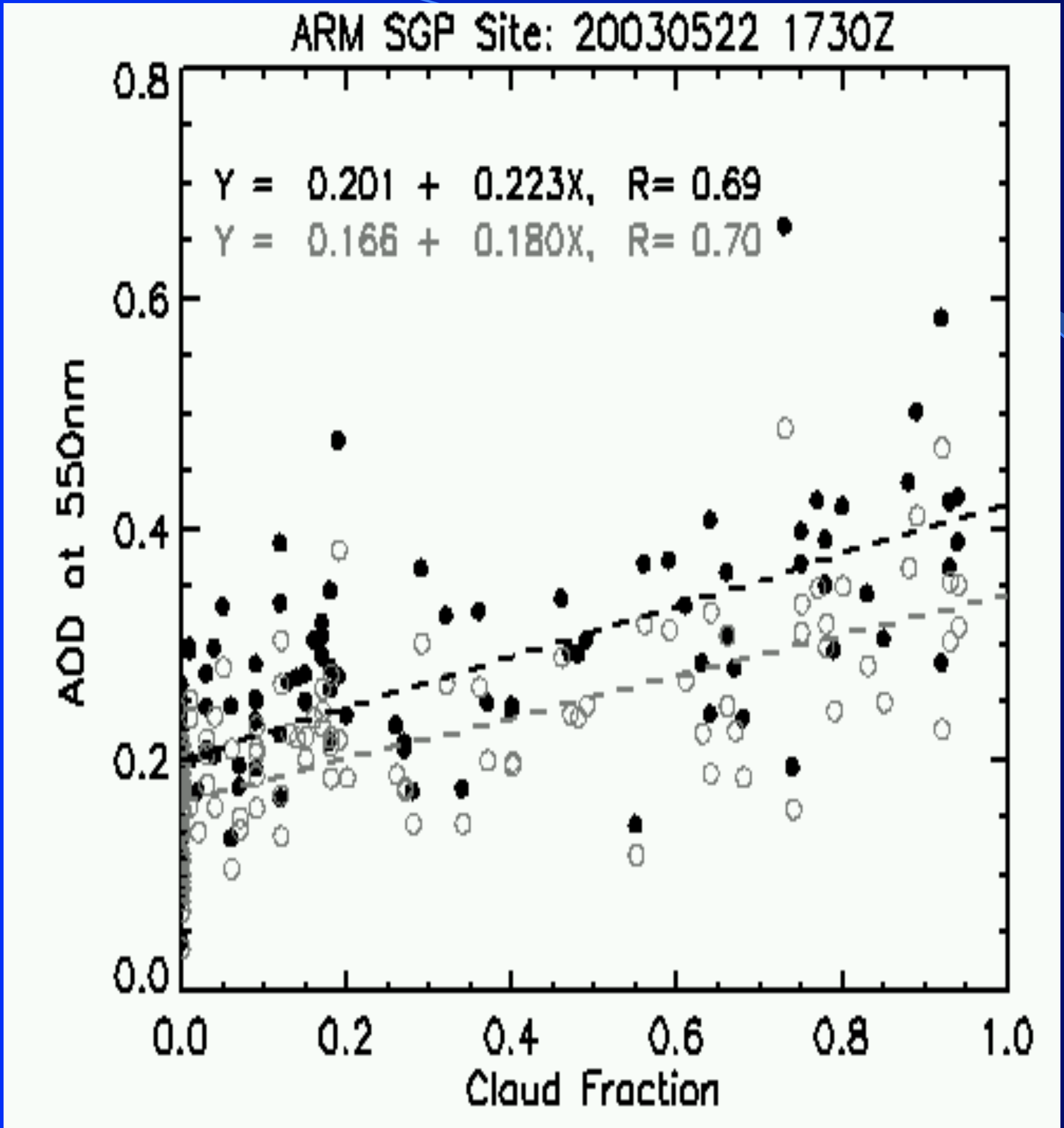
Column Aerosol Humidification Factor at the SGP Site
(Apr. 2003-Jun. 2004)



Column AHF

$$R(RH) = a \cdot \left(1 - \frac{<wRH>}{100}\right)^{-b}$$

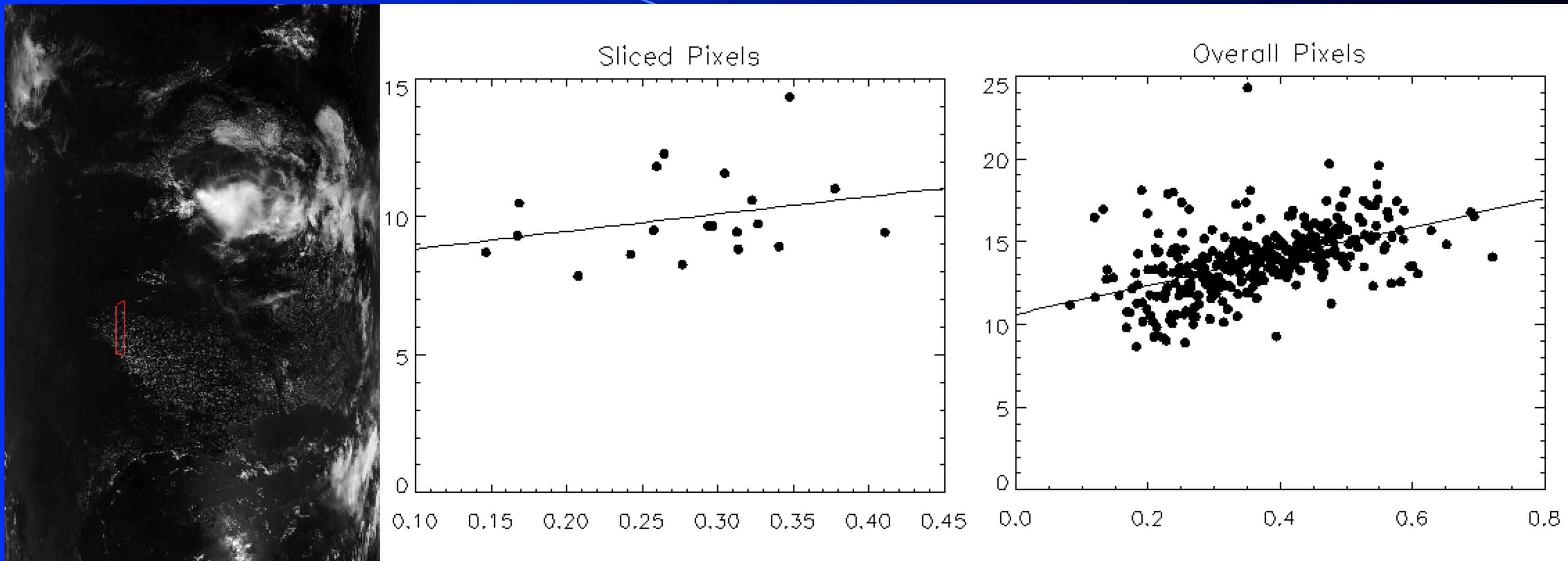
→ Compute the AHE

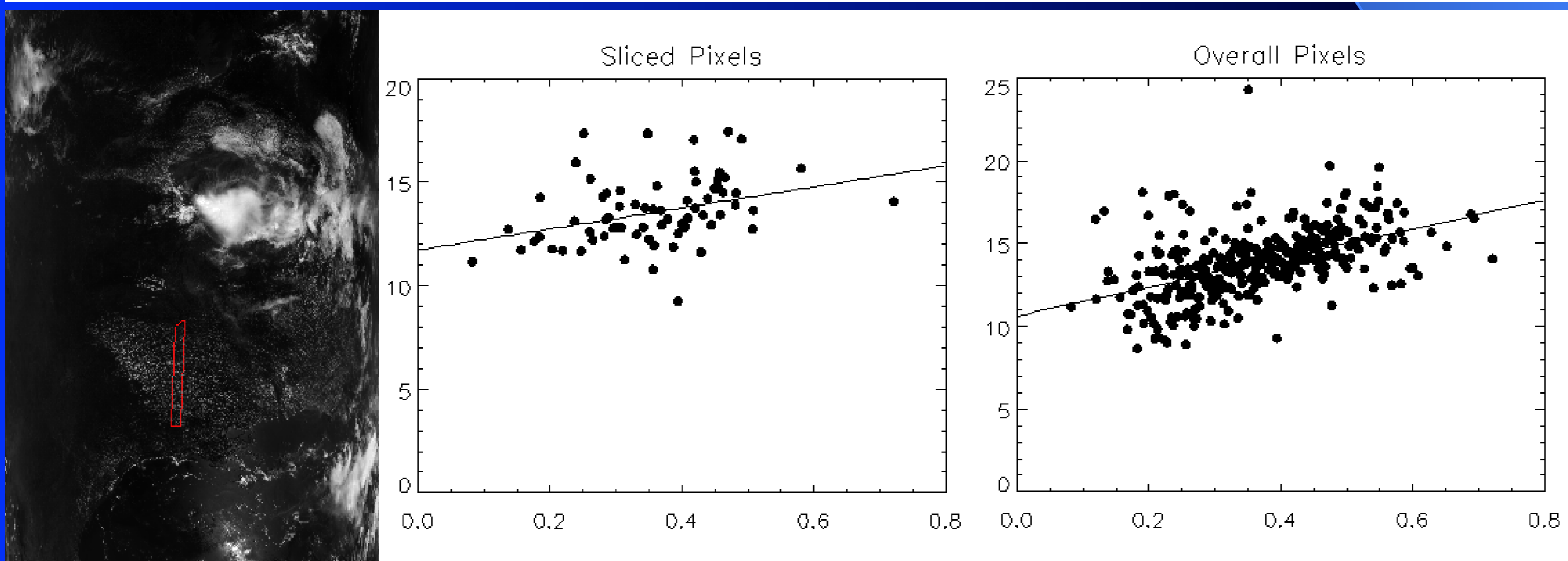


After the AHE is taken out, there remain a correlation.

SZA~20°
VZA~13°
Θ_{sca}~150°

3-D Effects ?


Sliced Pixels
15
10
5
0
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
Overall Pixels
25
20
15
10
5
0
0.0
0.2
0.4
0.6
0.8


Sliced Pixels
20
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0.2
0.4
0.6
0.8
Overall Pixels
25
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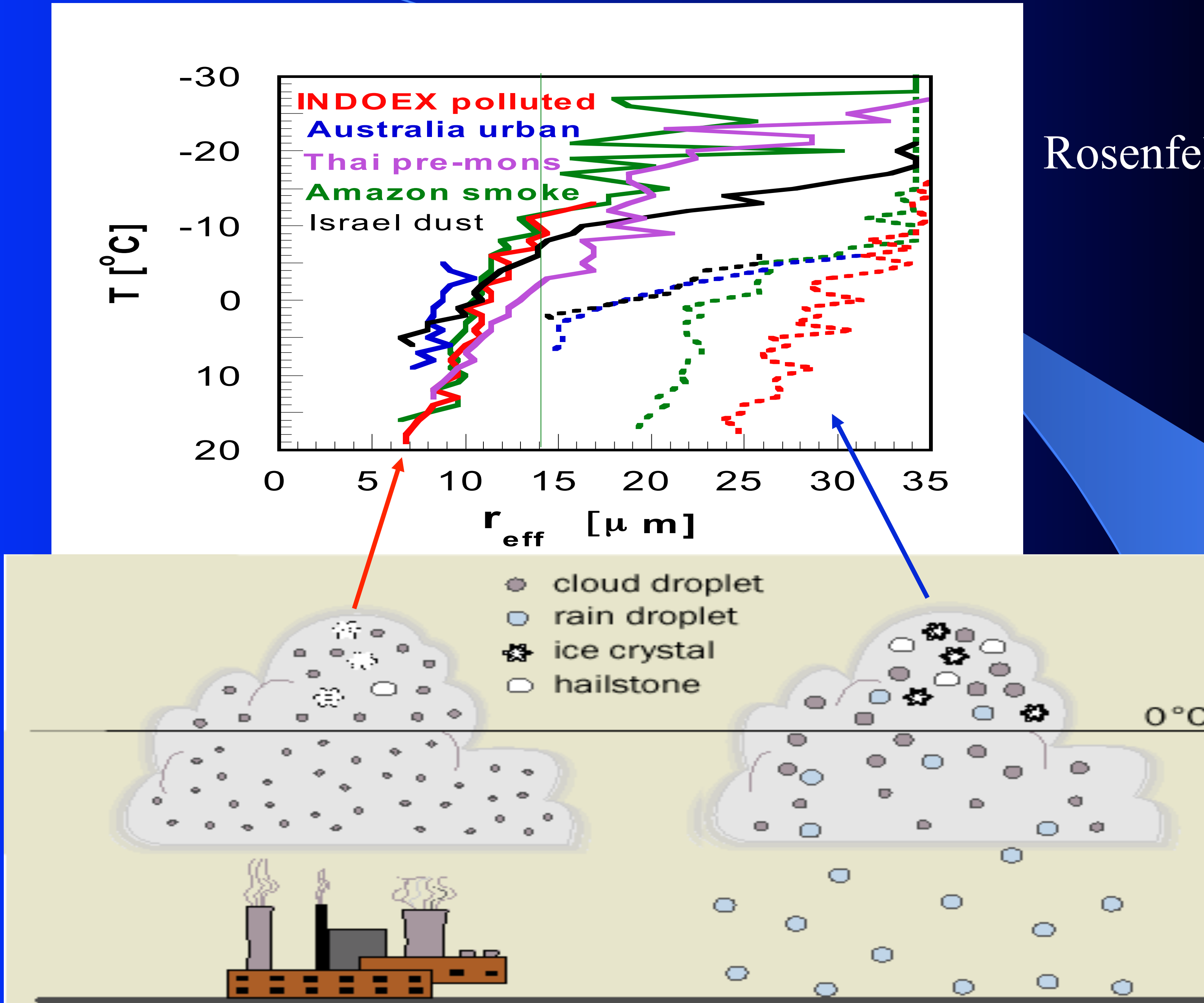
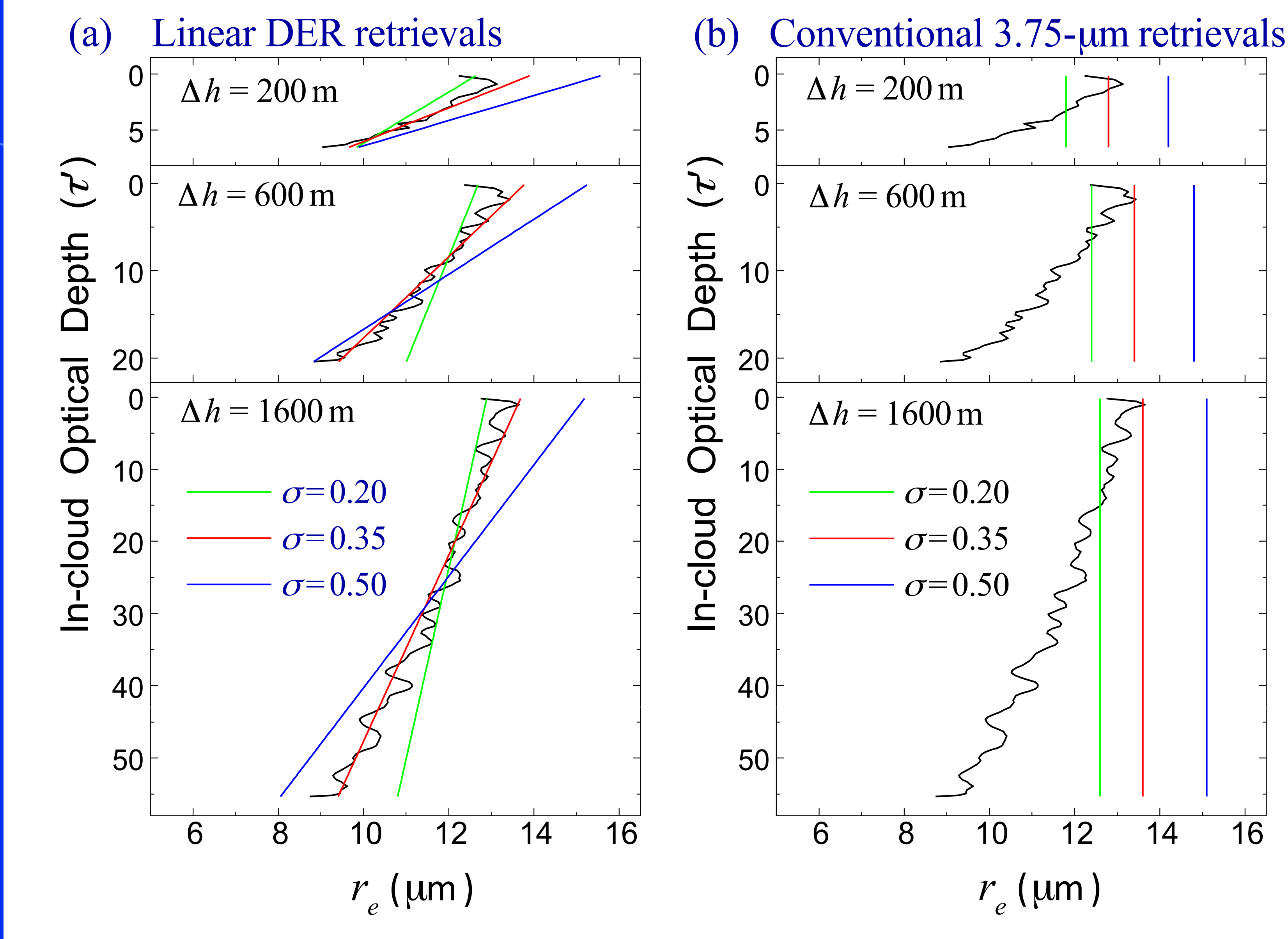
5
0
0.0
0.2
0.4
0.6
0.8

Observational sorting of aerosol indirect effect



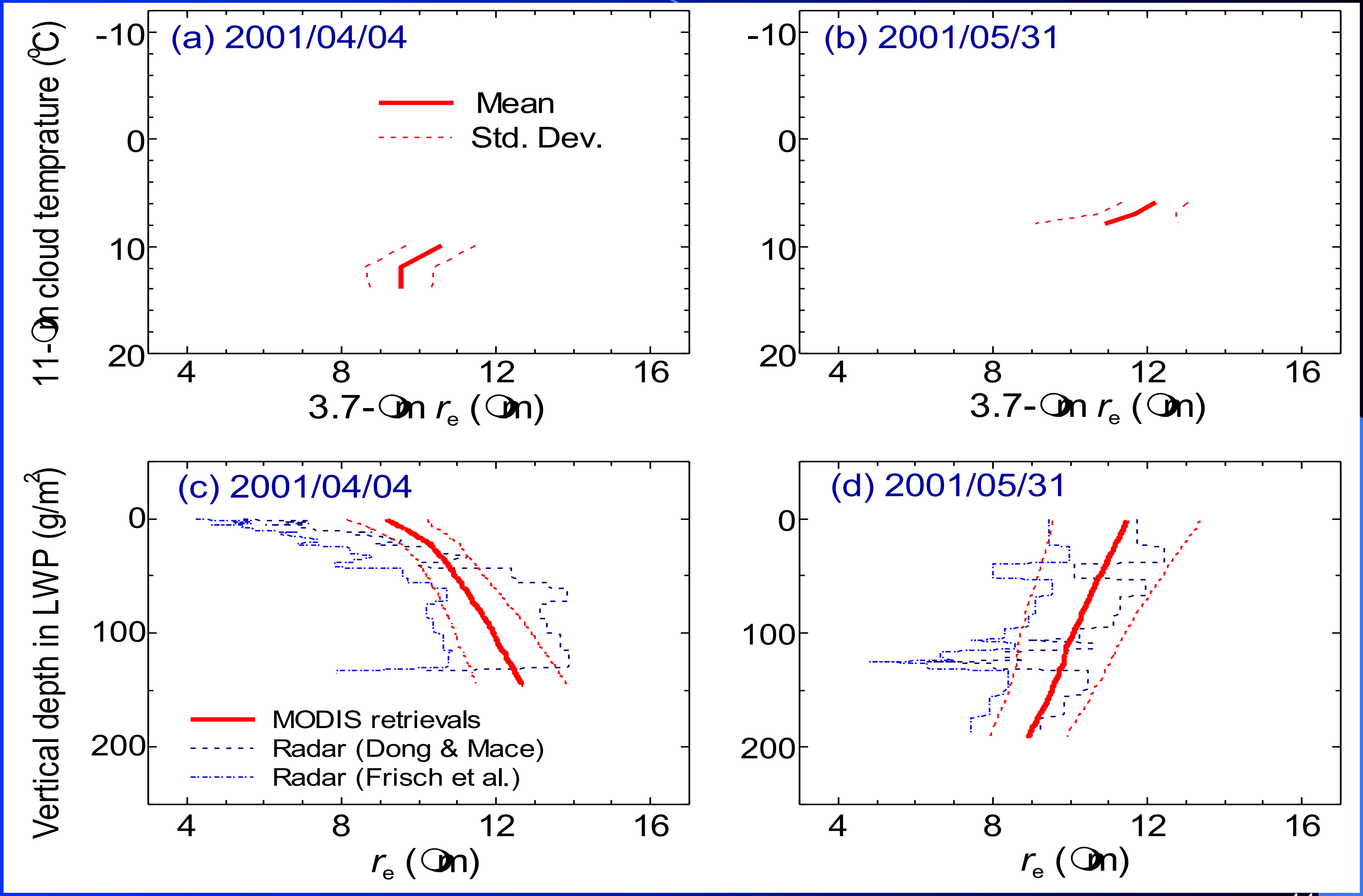
Rosenfeld

Retrieval of the DER Profile and the Conventional Cloudtop DER



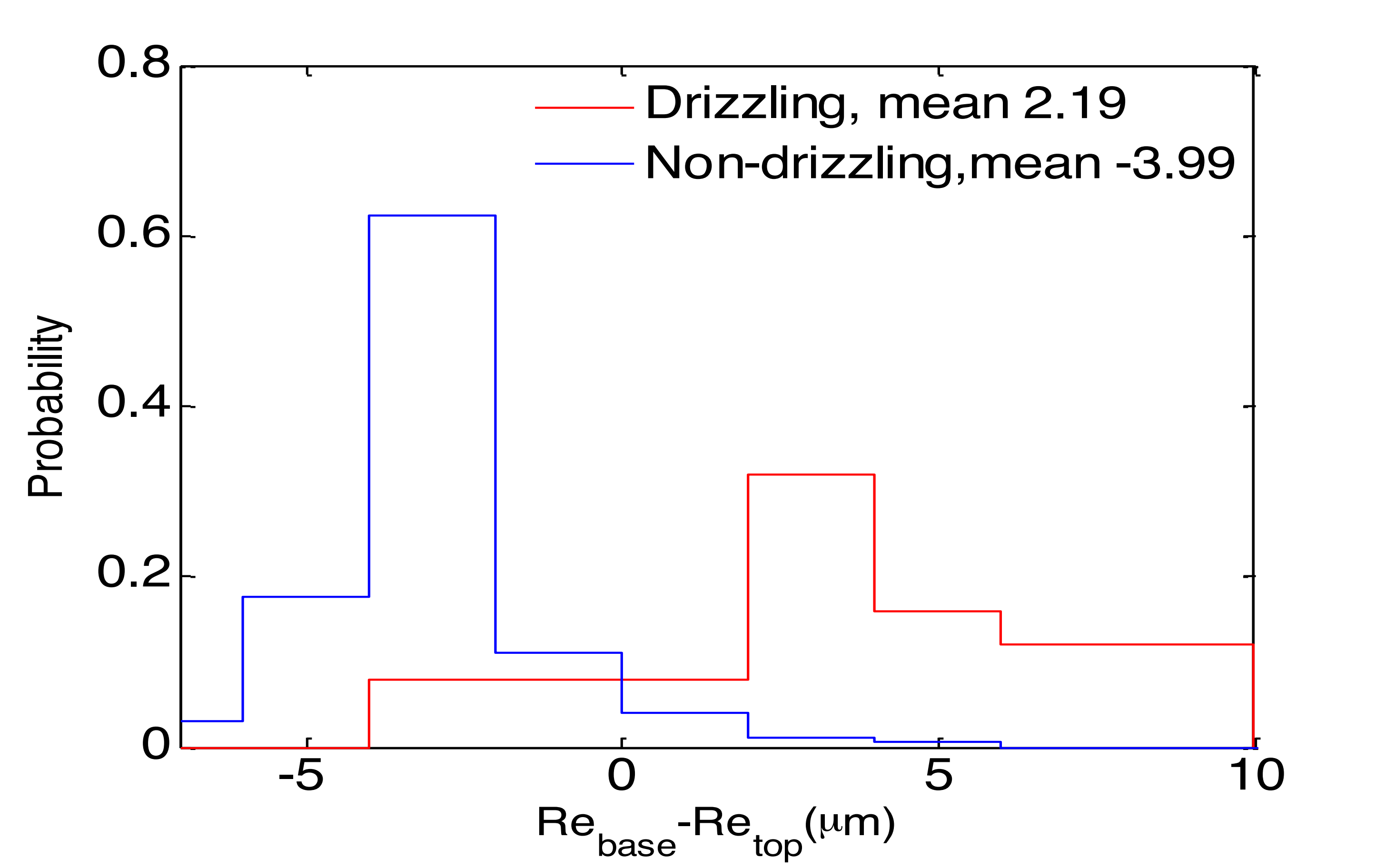
Chang and Li (2002,2003)

Retrieval of vertical profile of cloud droplet size from MODIS

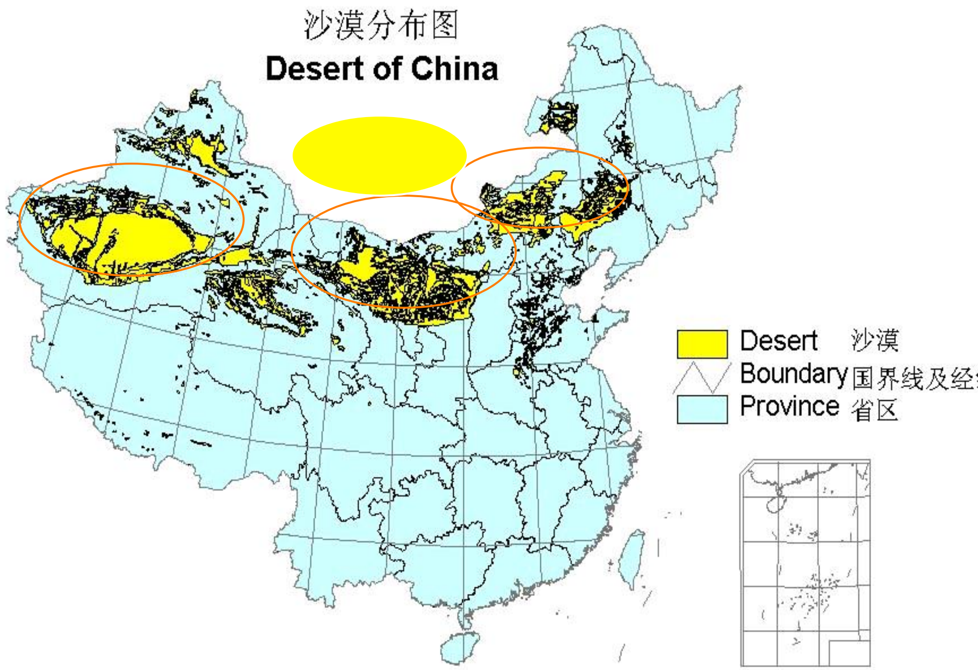


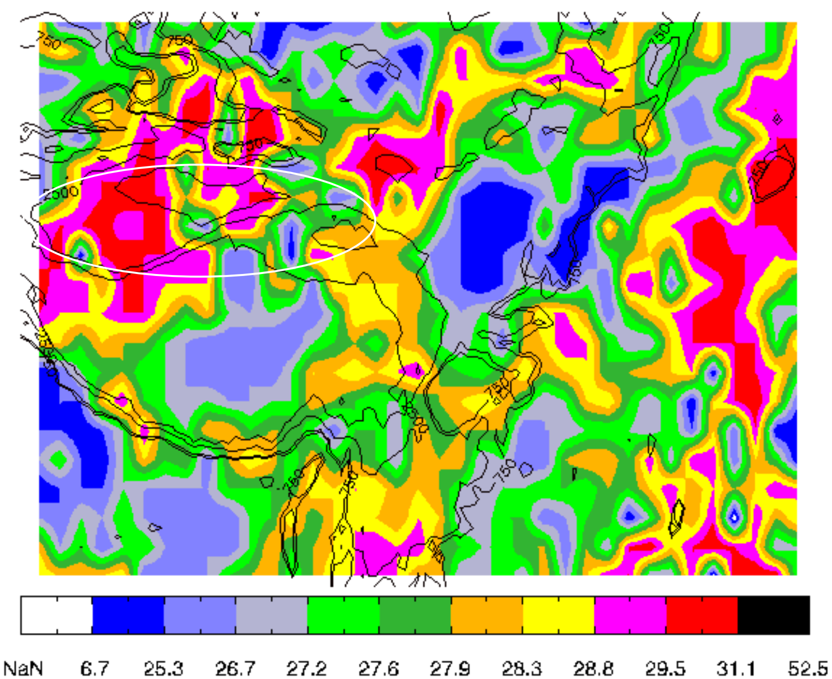
Chang and Li (2003)

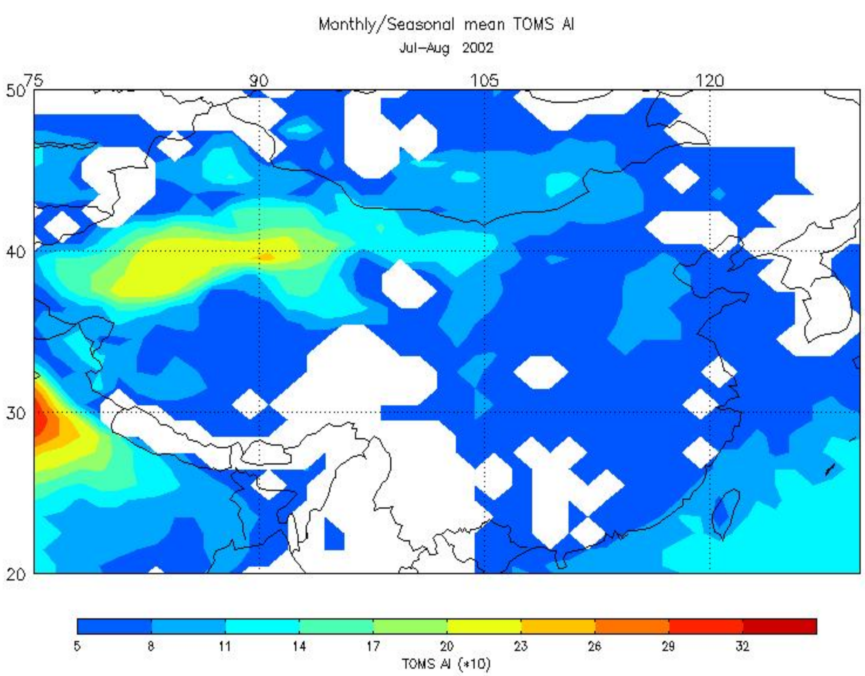
Use of DER profile for Drizzle Detecting



Chen et al. (2008)







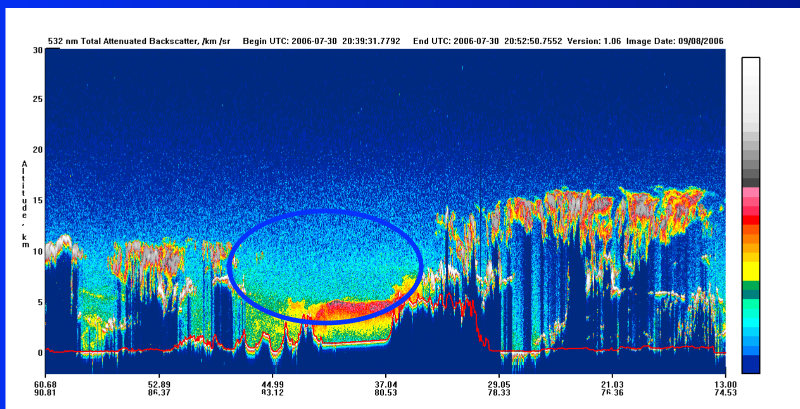
Features to notice

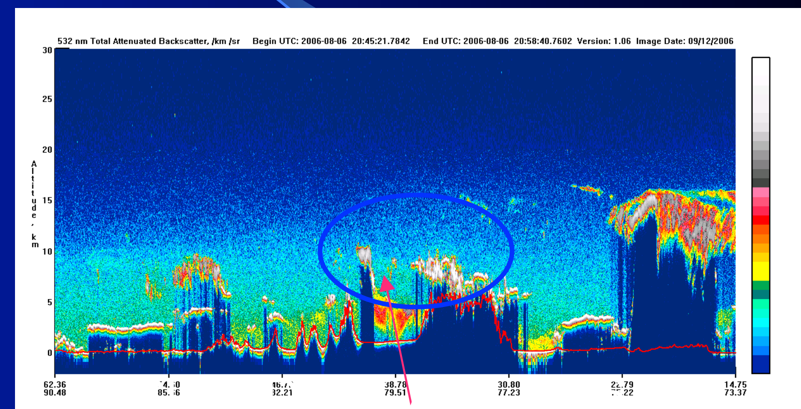
- Correspondence between areas with large AI value and desert distribution
- In Northwestern China and southern Mongolia there is a band of area with large ice particle sizes
- There's an established land-sea contras in terms of DER size

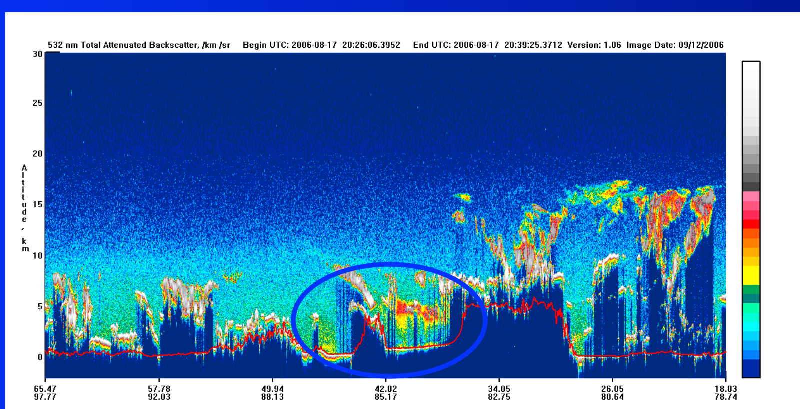
Persistent Elevated dust layers over Taklamakan desert

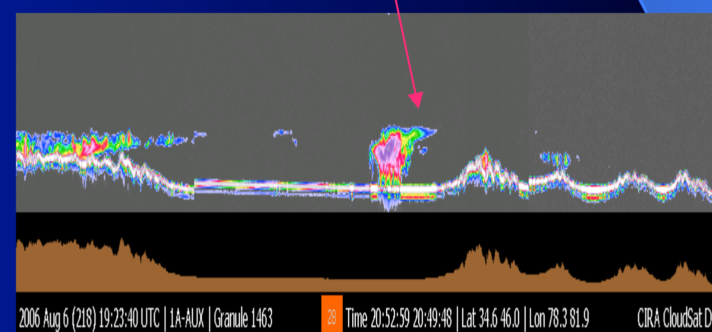
CALIPSO, July 30, 2006

CALIPSO, Aug 6, 2006









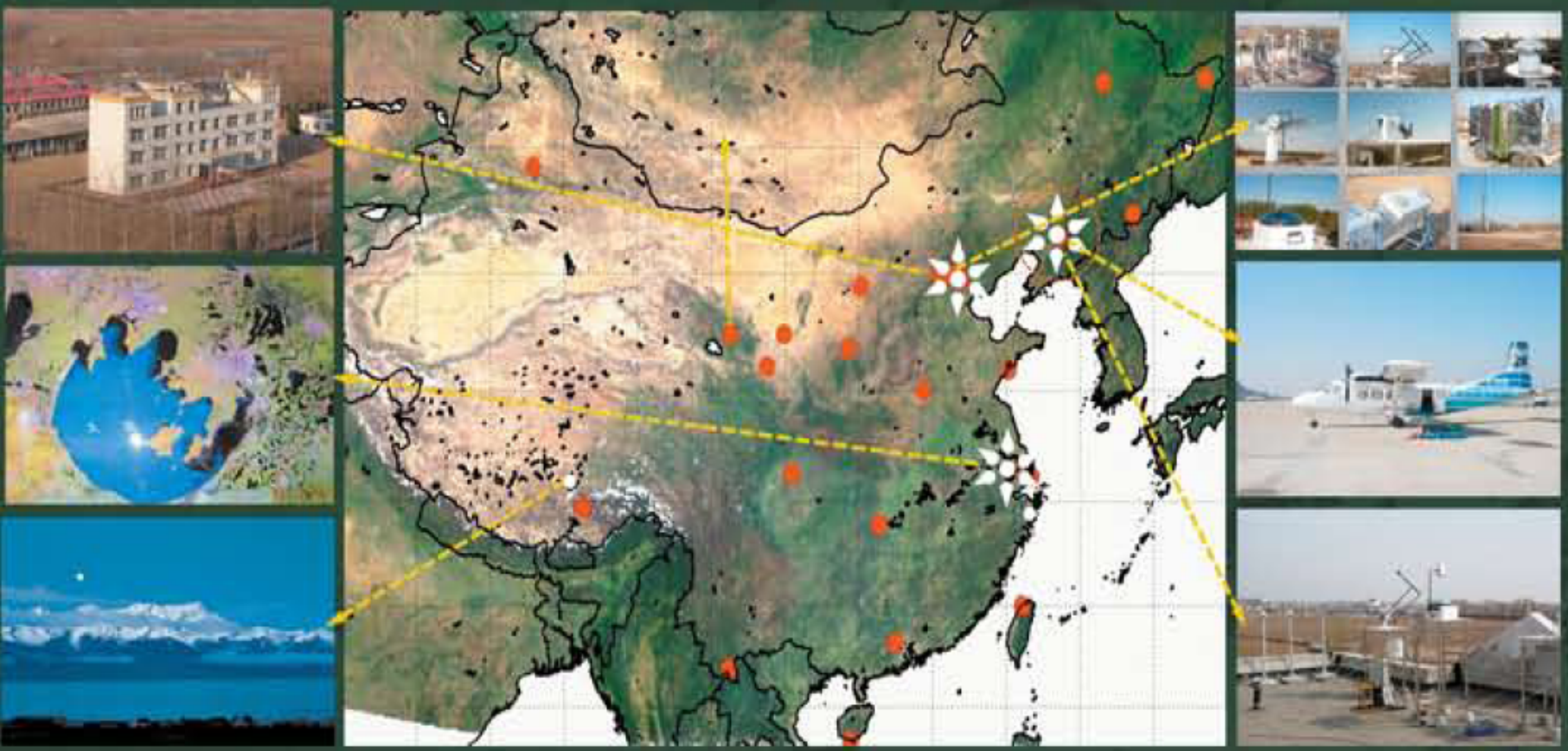
Summary (2)

- Care must be exercised in using satellite data to study AIE
- Real effects and artifacts may be separated by combined use of satellite, in-situ and ground observations.
- For fair-weather Cu AIE efficiency may be either positive or negative based on the satellite analysis
- Different environmental factors like aerosol type and air humidity may affect AIE
- A lot more in-depth studies are required to further sort of various issues

East Asian Study of Tropospheric Aerosols:

An International Regional Experiment (EAST-AIRE)

Cover of JGR special section 2007



Xianghe Farmland- AAF

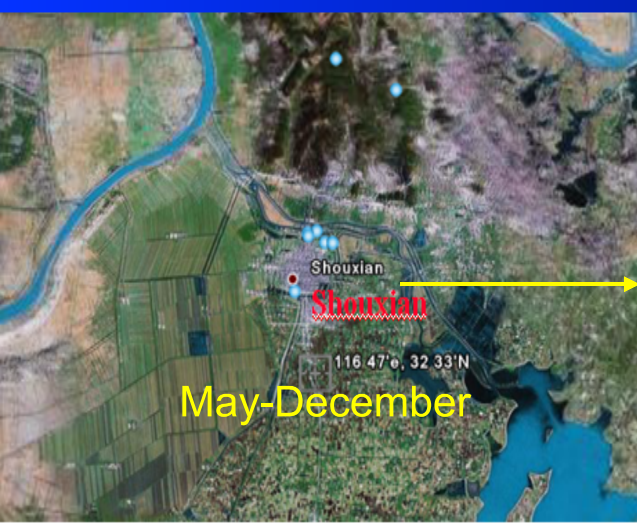
Deployment: July 10 – Oct 31. 2008
Location: 39º45’14”N, 116º57’43”E
Elevation: 36 m
Cities Nearby: Beijing and Tianjin
Annual Rainfall: 571.9
Annual Cloud Amount: 45%
Mean aerosol optical depth: 0.82

Zhangye Desert - AAF

Deployment: Apr 7 – June 23, 2008
Location: 39º06’N, 100º16’E,
Elevation: 1456 m
Cities nearby: Zhangye (26 km)
Annual Rainfall: 87.7 mm
Annual Cloud Amount: 45%

Taihu Lake – Ancillary

Deployment: March – December 2008 Location: 31.702ºN, 120.358ºE
Elevation: 10 m
Cities nearby: Wuxi, Suzhou, Shanghai, Hangzhu, Nanjing
Annual Rainfall: 1184.4 mm
Annual Cloud Amount: 62%
Mean aerosol optical depth: 0.78



Shouxian – AMF site

Location: 116º47’ E, 32º33’ N
Deployment: May-December
Cities nearby: Hefei, Bengbo
Annual rainfall: 886 mm
Mean cloud cover: 59
Mean aerosol optical depth: 0.55

Shouxian Climate Observatory: AMF

AMF Baseline Measurements

Measurement	Instrument
Surface Radiation Balance	• Up- and down-looking pyranometers and pyrgeometers • Sun-shaded pyranometer and pyrgeometer using solar tracker • Normal incidence pyrheliometer • Up- and down-looking 9-11μm narrow-field-of-view radiometers
Surface Meteorology	• Temperature and relative humidity sensor • Barometer • Optical rain gauge • Propeller vane anemometer • Present weather detector
Cloud Properties	• Micropulse lidar (523 nm) • Ceilometer (7.5 km maximum range) • W-band cloud radar • Total Sky Imager
Aerosol Optical Depth	• Multi-filter rotating shadow band radiometer (total, direct, and diffuse irradiance in six 10-nm channels)
Column Water	• Dual channel (23.8 and 31.4 GHz) microwave radiometer
Atmospheric profiling	• Balloon Borne Sounding System (BBSS) • Microwave radiometer profiler (MWRP)

- Surface radiation balance
- Surface meteorology
- Cloud properties
- Column water
- Atmospheric profiling
- Aerosol properties and optical depth


Taihu Observatory (2005-Now)
NUIST Joined in 2008



radiometrics
CORPORATION



YES
YANKEE ENVIRONMENTAL SYSTEMS, INC.

Zhangye Climate Observatory

AAF Instruments

Downwelling Radiation (SKYRAD)

- Precision Spectral Pyranometer (PSP)
- Precision Infrared Radiometer (PIR)
- Shaded Black & White Pyranometer (B/W)
- Shaded Precision Infrared Pyrgeometer (PIR)
- Normal Incidence Pyrhiliometer (NIP)
- Infrared Thermometer (IRT)

Surface Meteorological Tower (SMET) Instruments

- Optical Rain Gauge (ORG)
- Anemometers (WND)
- Temperature/Relative Humidity Sensor (T/RH)
- Barometer (BAR)
- Present Weather Detector (PWD)

Upwelling Radiation (GNDRAD)

- Precision Spectral Pyranometer (PSP)
- Precision Infrared Radiometer (PIR)
- Infrared Thermometer (IRT)

Stand-Alone Instruments

- Microwave Radiometer (MWR)
- Micropulse Lidar (MPL)
- Tethered Balloon
- Atmospheric Emitted Radiance Interferometer (AERI)
- Total Sky Imager (TSI)
- Standard lamp Li-Cor

Aerosol Observation System (AOS)

- Aethalometer
- SMPS
- APS
- Nephelometer x 4
- TEOM aerosol chemistry
- TEOM-ACCU
- Trace Gas sampling
- Particle Photometer

Xianghe Obervatory

Routine observation: Sep 2004 to present

IOP observation: Feb 27 – March 27


Radiation Instruments
Aerosol Instruments
08.03.2005 14:59
Cloud Instruments