Remote Sensing of Clouds

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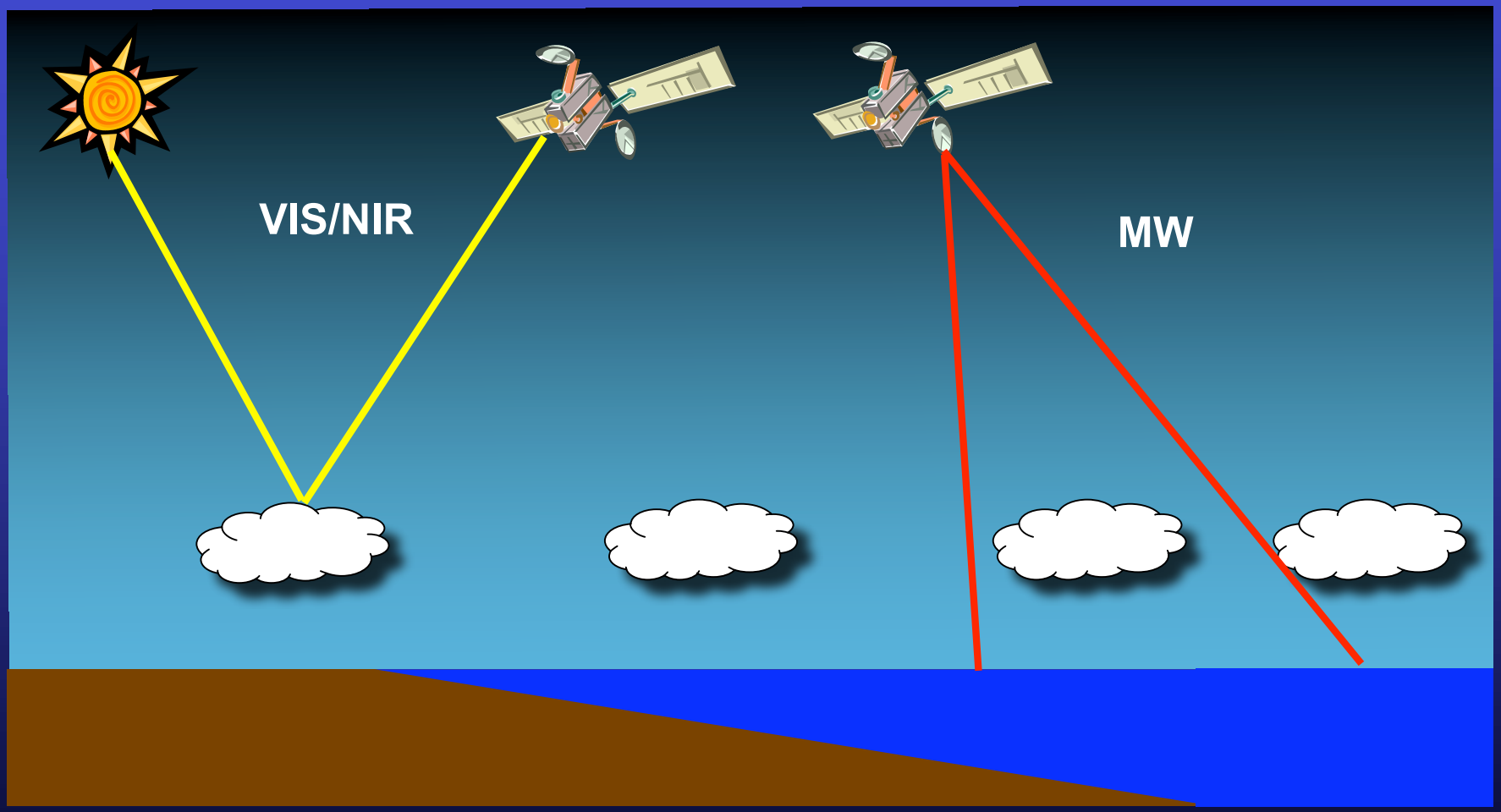
Outline

- Known knowns - Optical depth, LWP
- Known unknows - Cloud fraction, cloud top height
- Unknown unknows - Ice clouds

Known knowns - Liquid water path

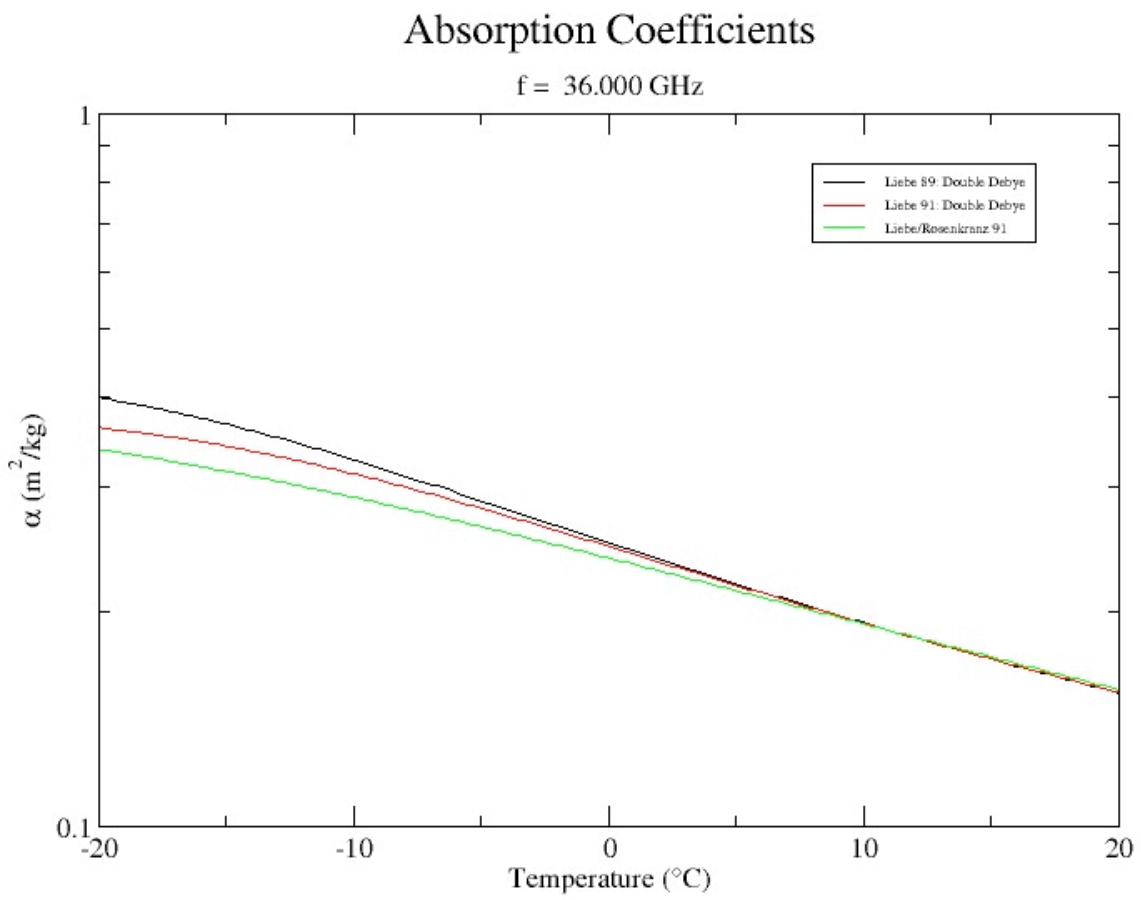


Known knowns - Liquid water path

$$\tau_{MW} = \sigma \cdot LWP$$

$$\tau_{VIS/NIR} = f \frac{LWP}{\rho_L r_{eff}}$$

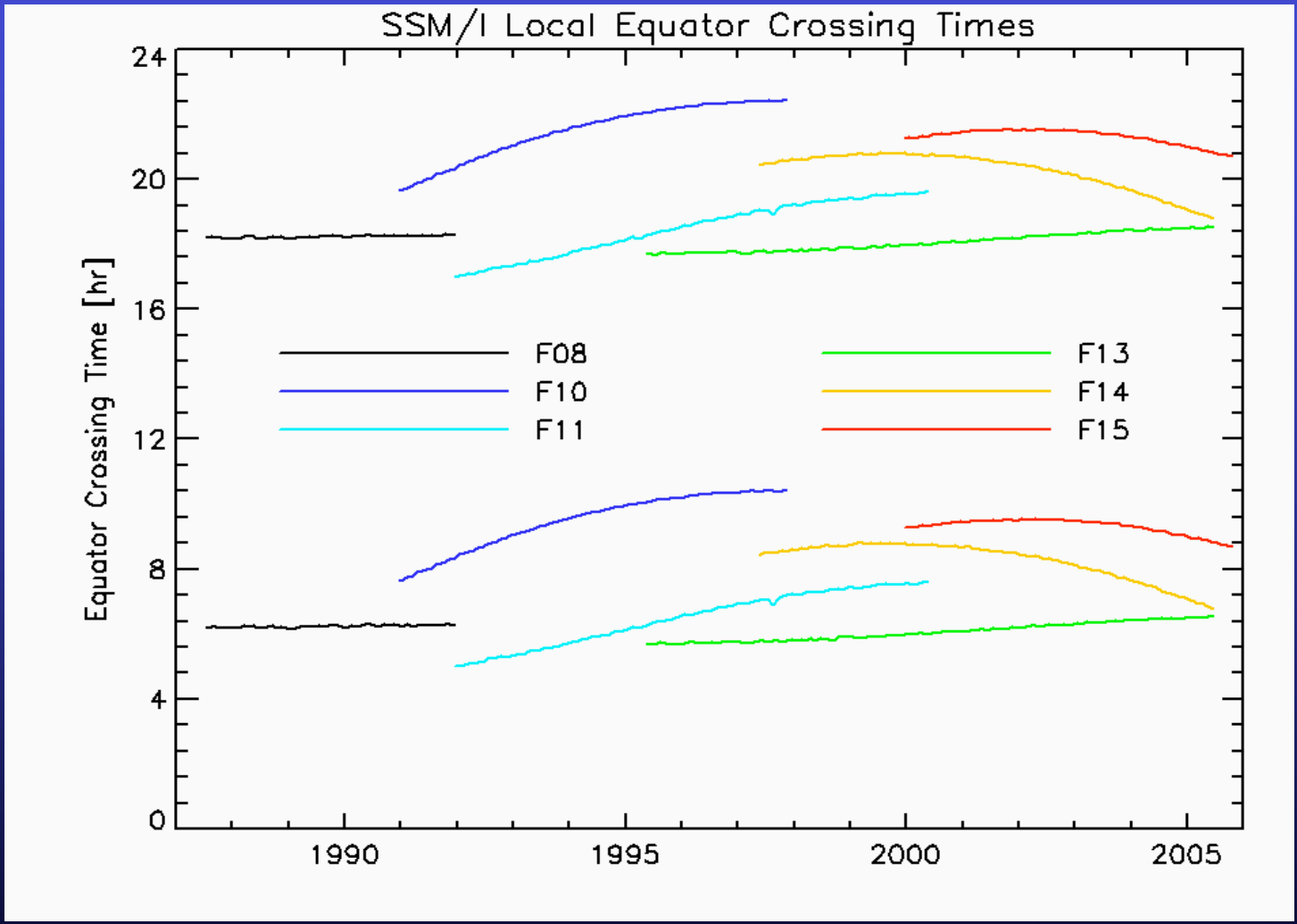
- MW: Very direct measurement. Mass absorption coefficient depends slightly on temperature
- VIS/NIR: Factor f depends on stratification of cloud (9/5 for adiabatic, 3/2 for vertically uniform)

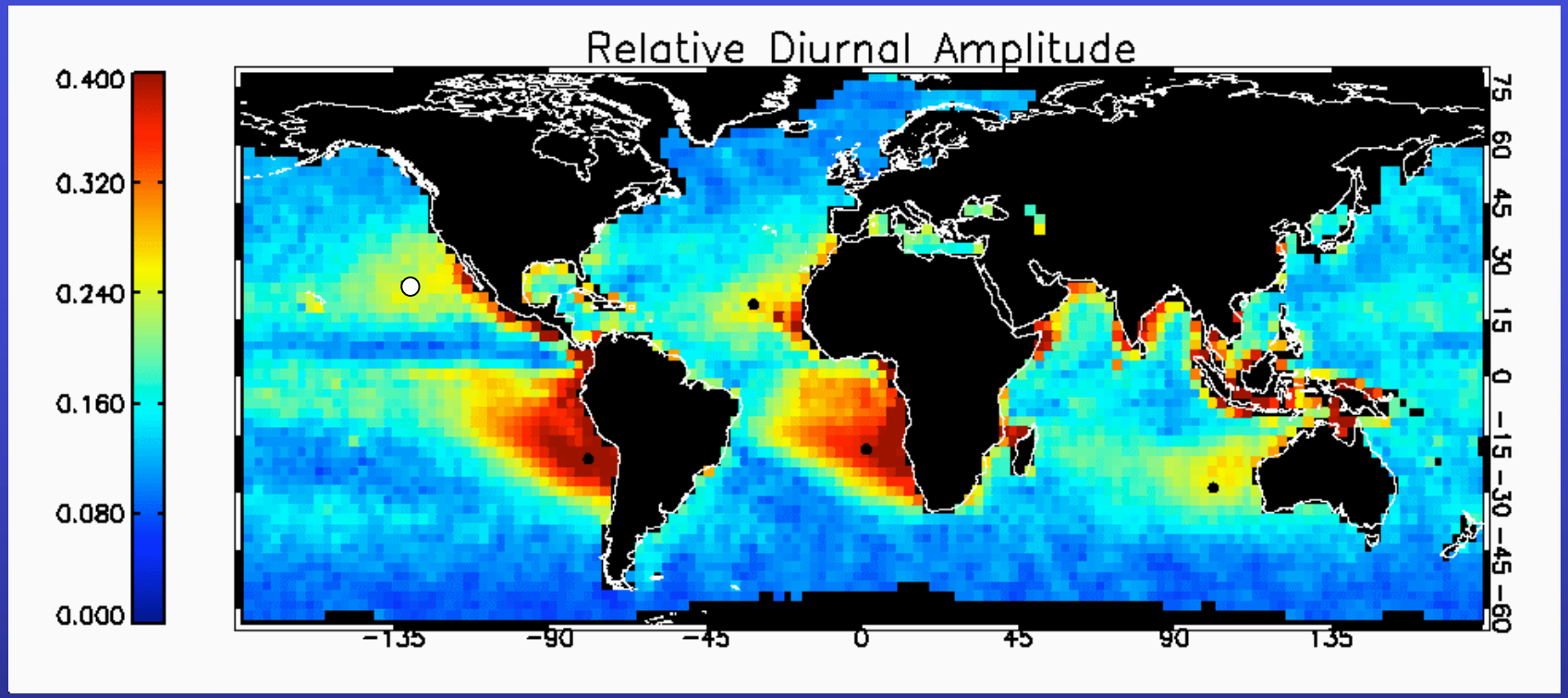

Absorption Coefficients
f = 36.000 GHz
Liebe 89: Double Debye
Liebe 91: Double Debye
Liebe/Rosenkranz 91
α (m²/kg)
1
0.1
-20
-10
0
10
20
Temperature (°C)

Cloud liquid water path climatology

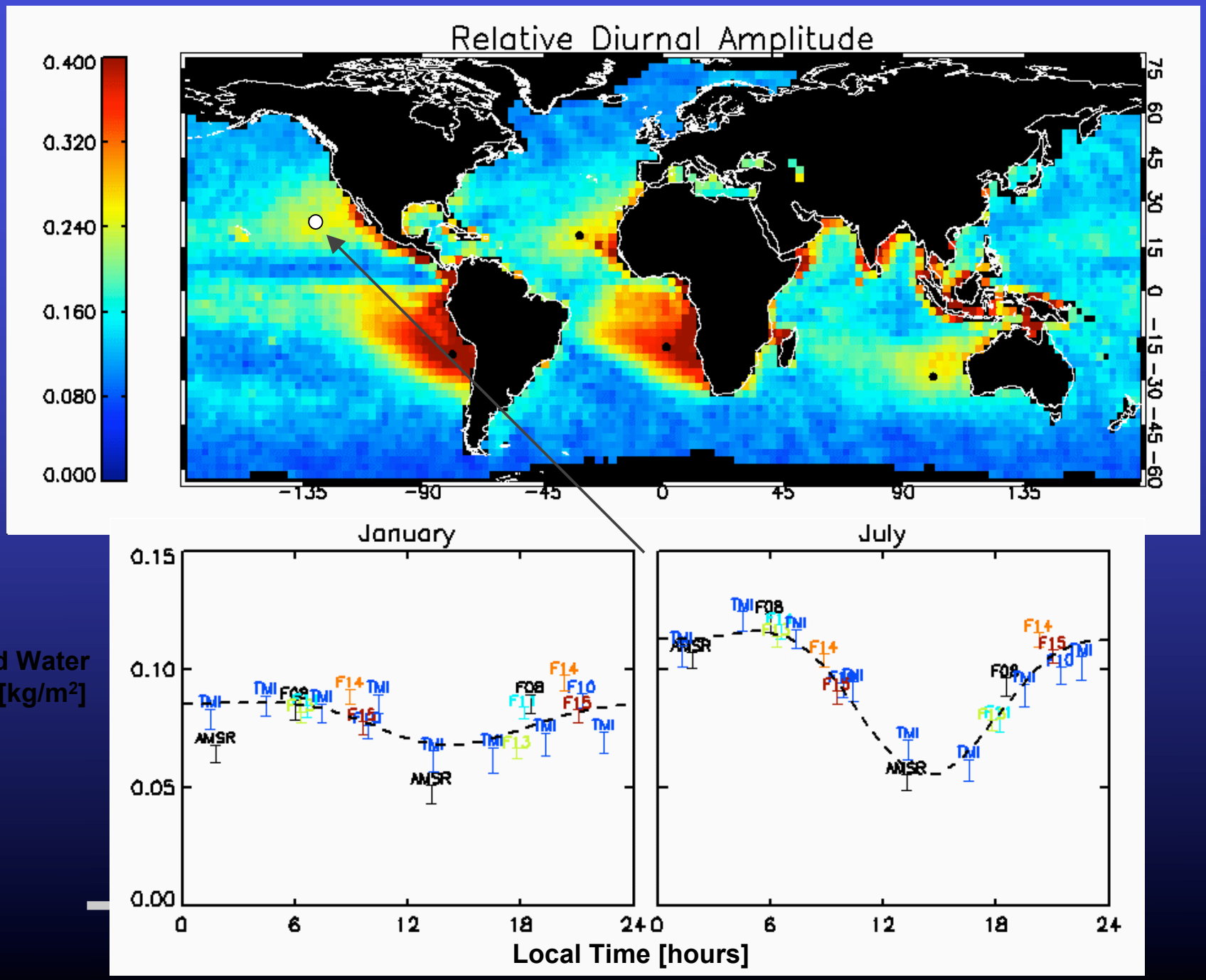
- Based on Wentz SSM/I since 1987, AMSR-E, and TMI
- Monthly diurnal mean liquid water path
- Climatological diurnal cycle
- O'Dell, Wentz, and Bennartz, J Climate, 2008

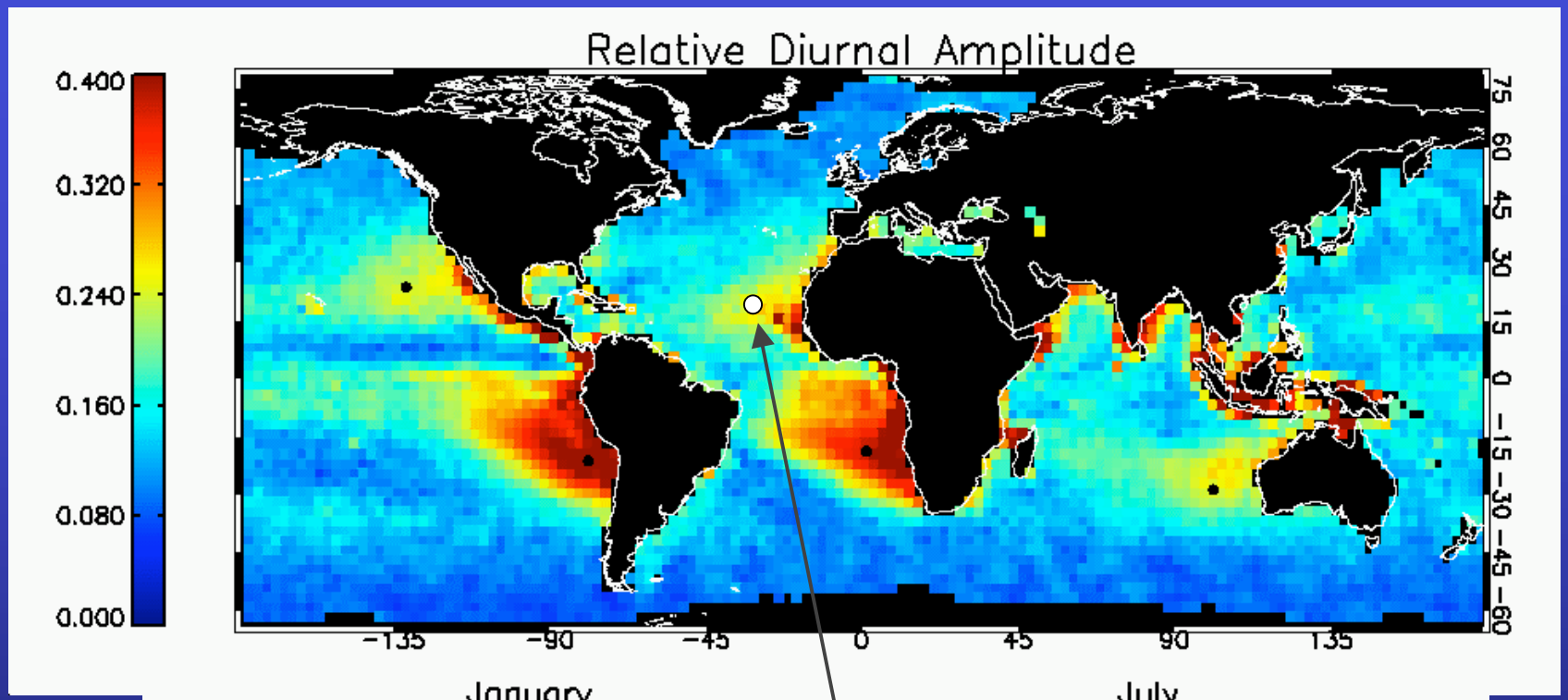
Special Sensor Microwave/Imager





Local Time [hours]


Relative Diurnal Amplitude
0.400
0.320
0.240
0.160
0.080
0.000
75
60
45
30
15
0
−15
−30
−45
−60
−135
−90
−45
0
45
90
135
January
July
Liquid Water Path [kg/m²]
0.15
0.10
0.05
0.00
0
6
12
18
24
Local Time [hours]
TMI
AMSR
F08
F14
F10
F15
F13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0
45
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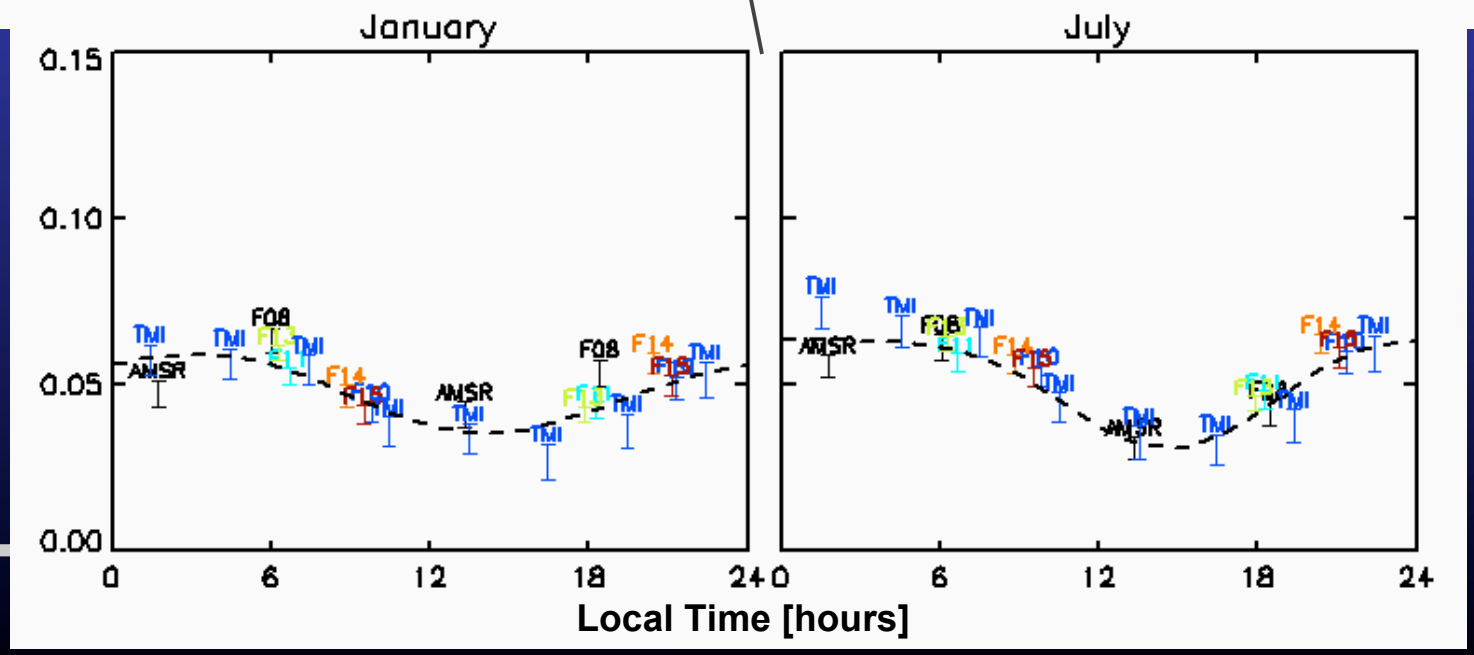
135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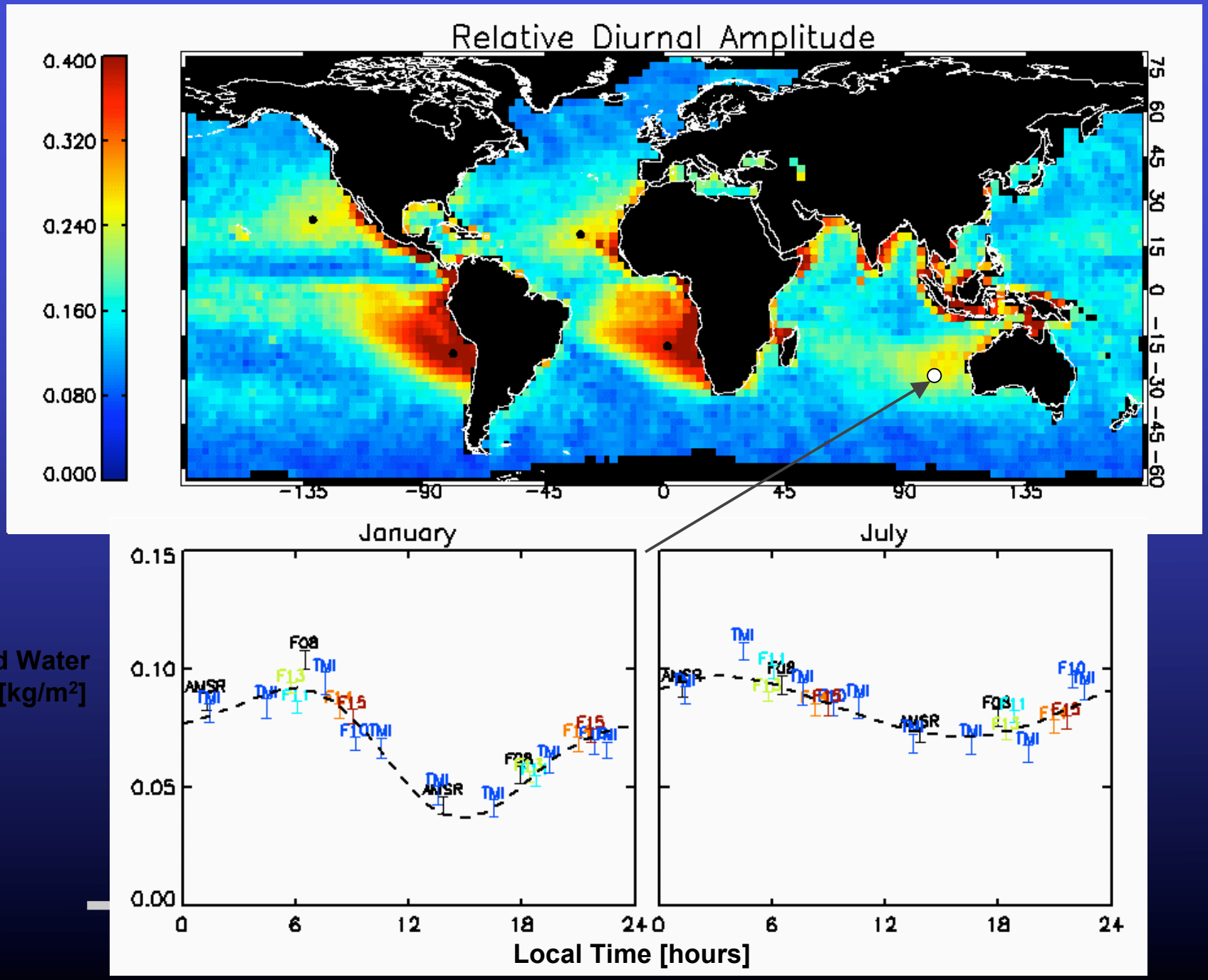
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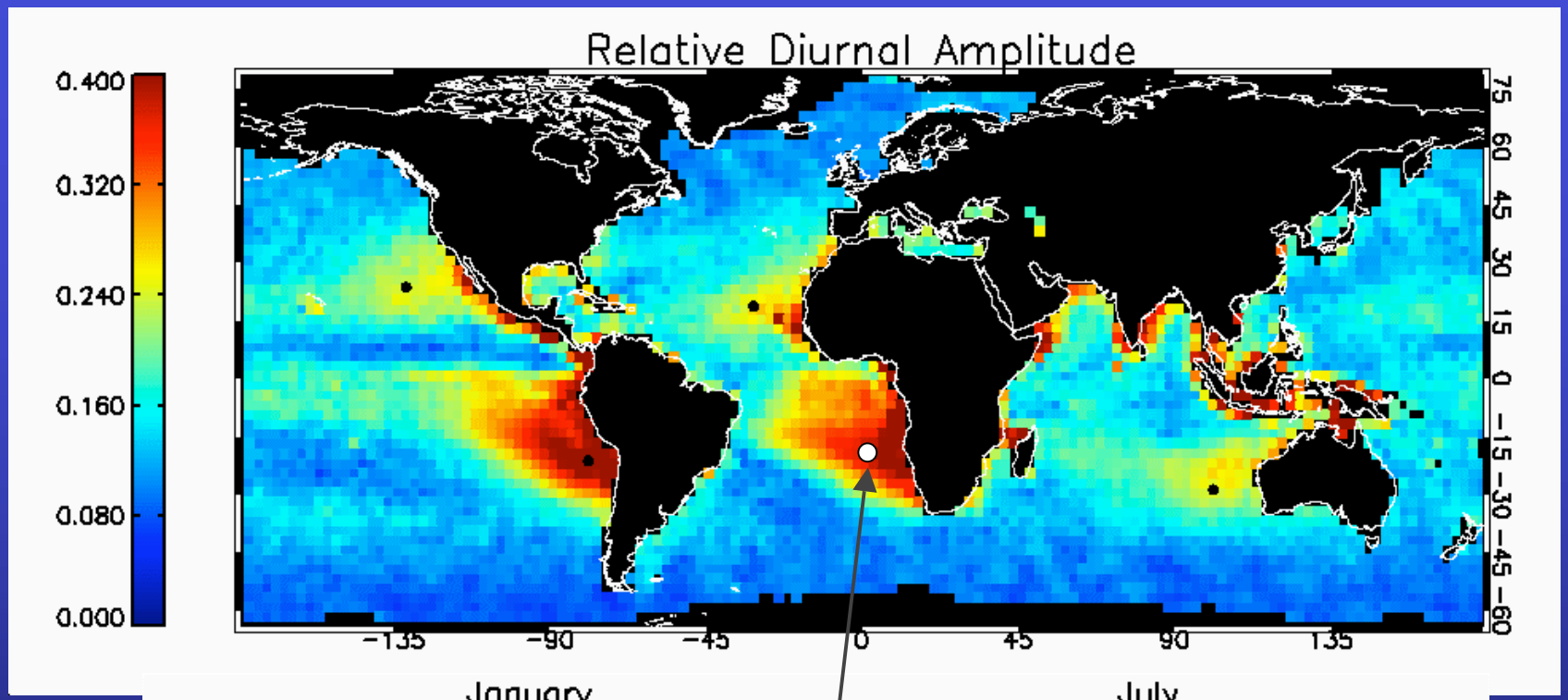
Local Time [hours]
Liquid Water Path [kg/m²]
AMSR
TMI
F08
F13
F15
F10
F03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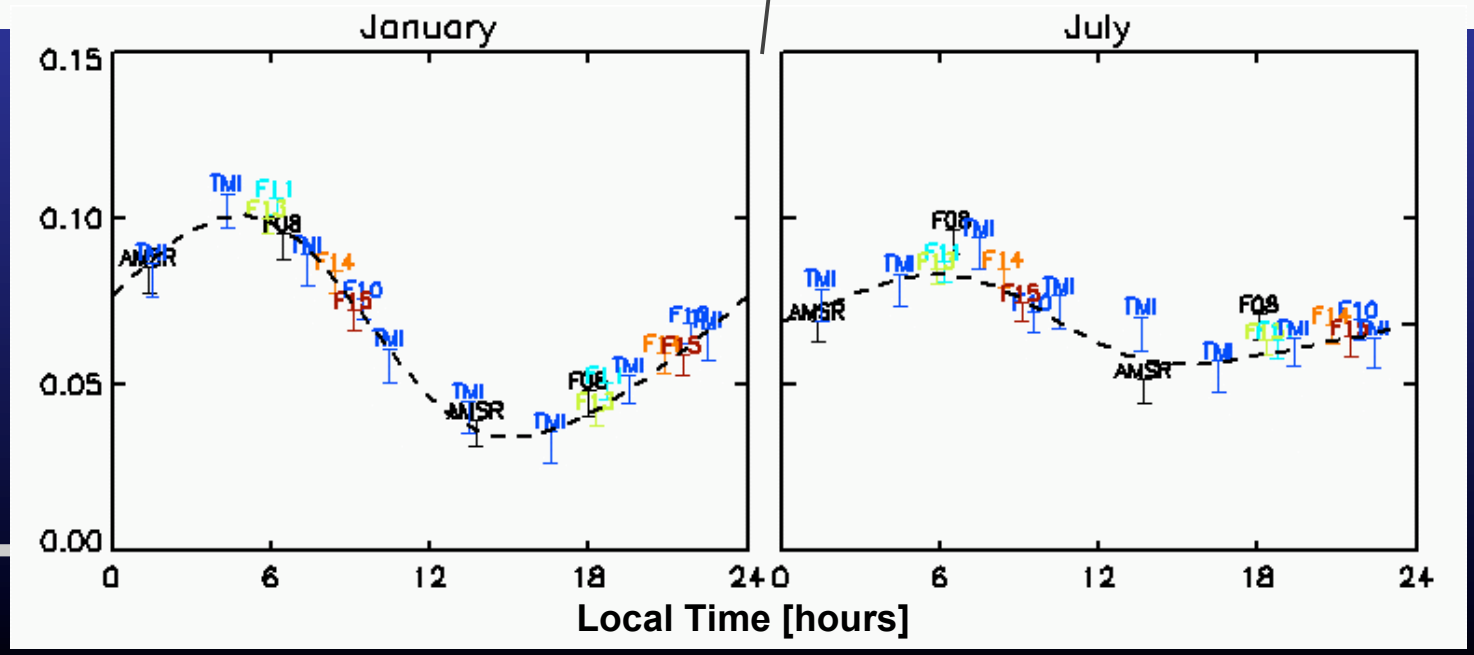
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Liquid Water Path [kg/m²]
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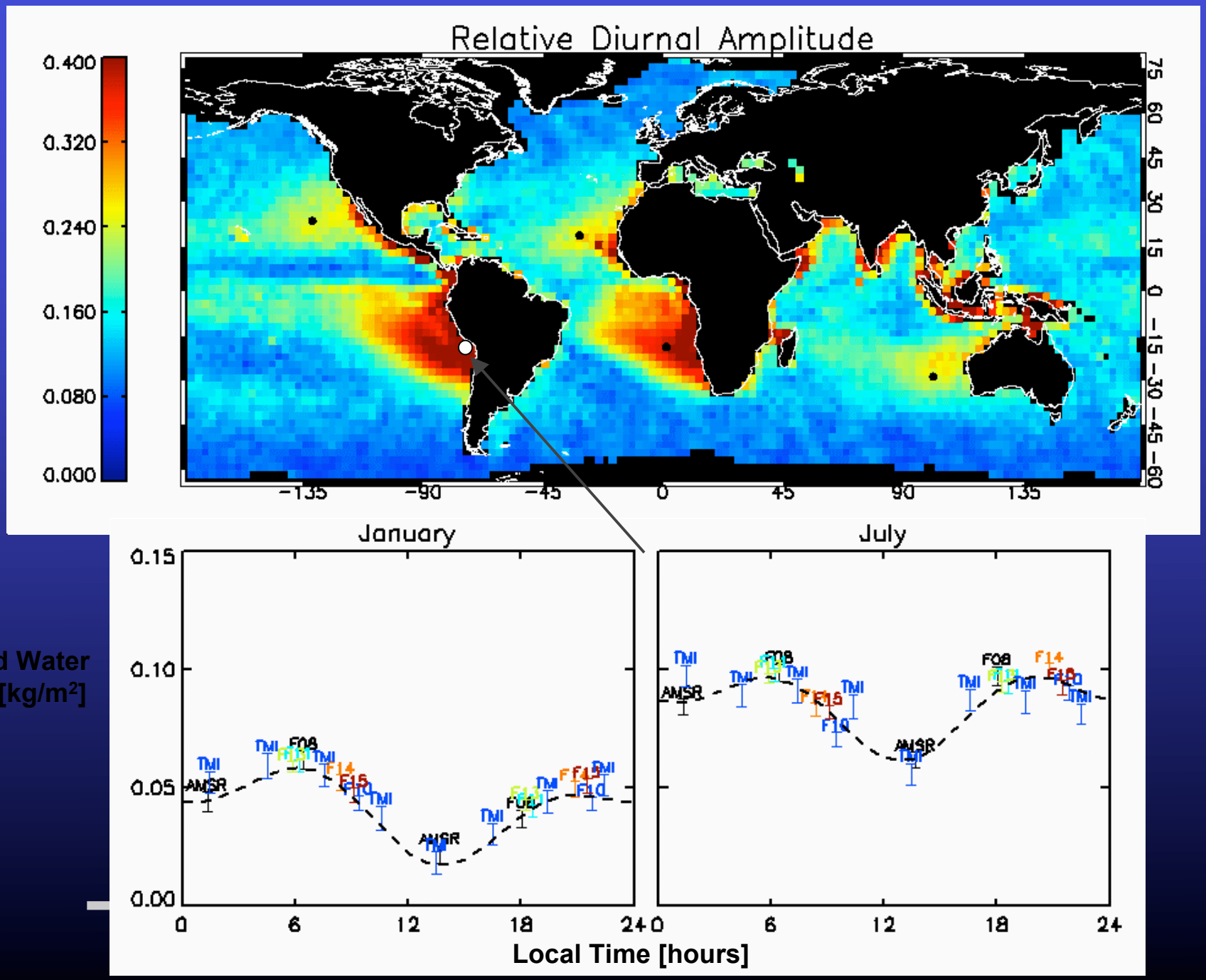
Local Time [hours]
TMI
AMSR
F08
F11
F13
F14
F15
F10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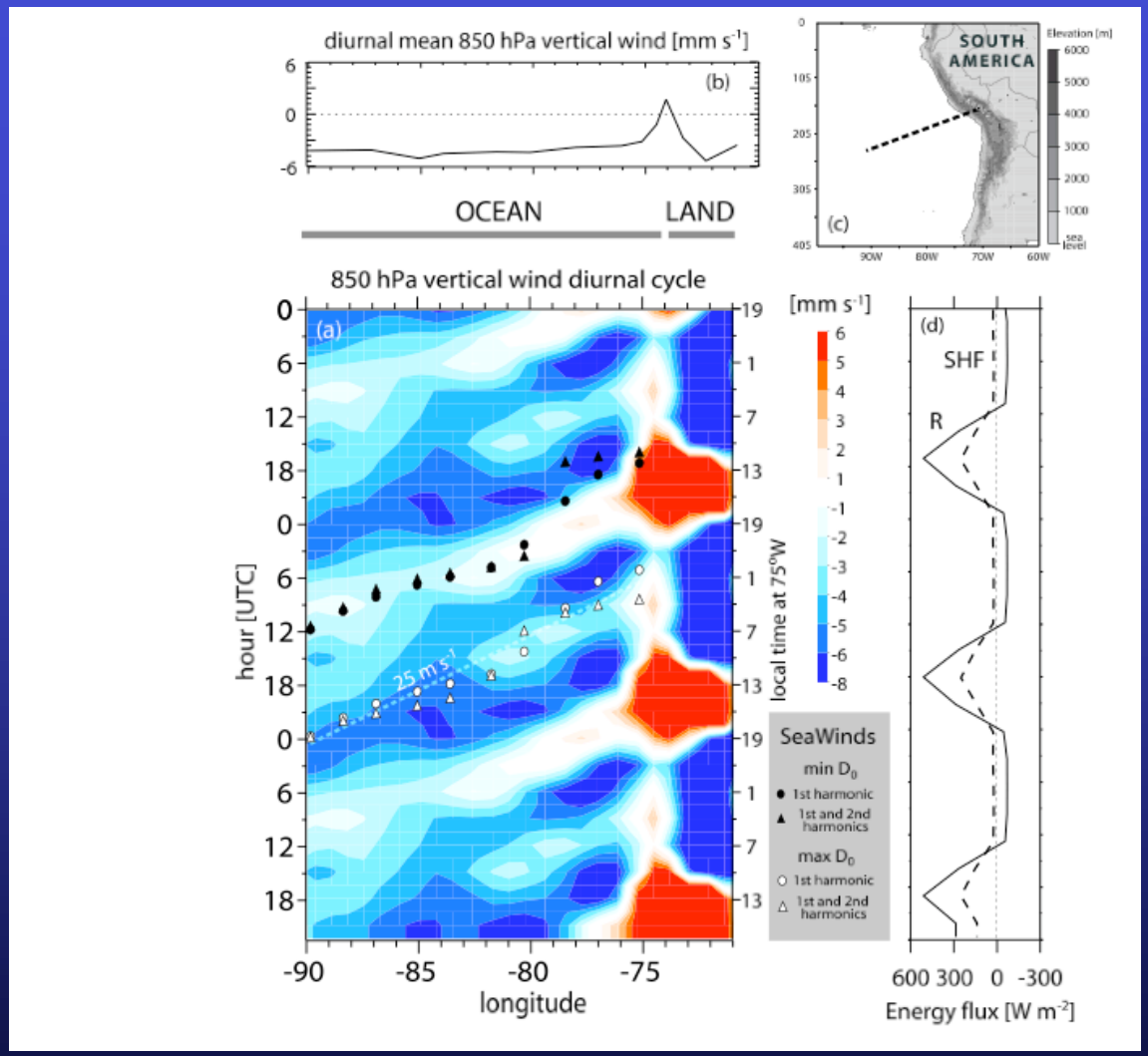
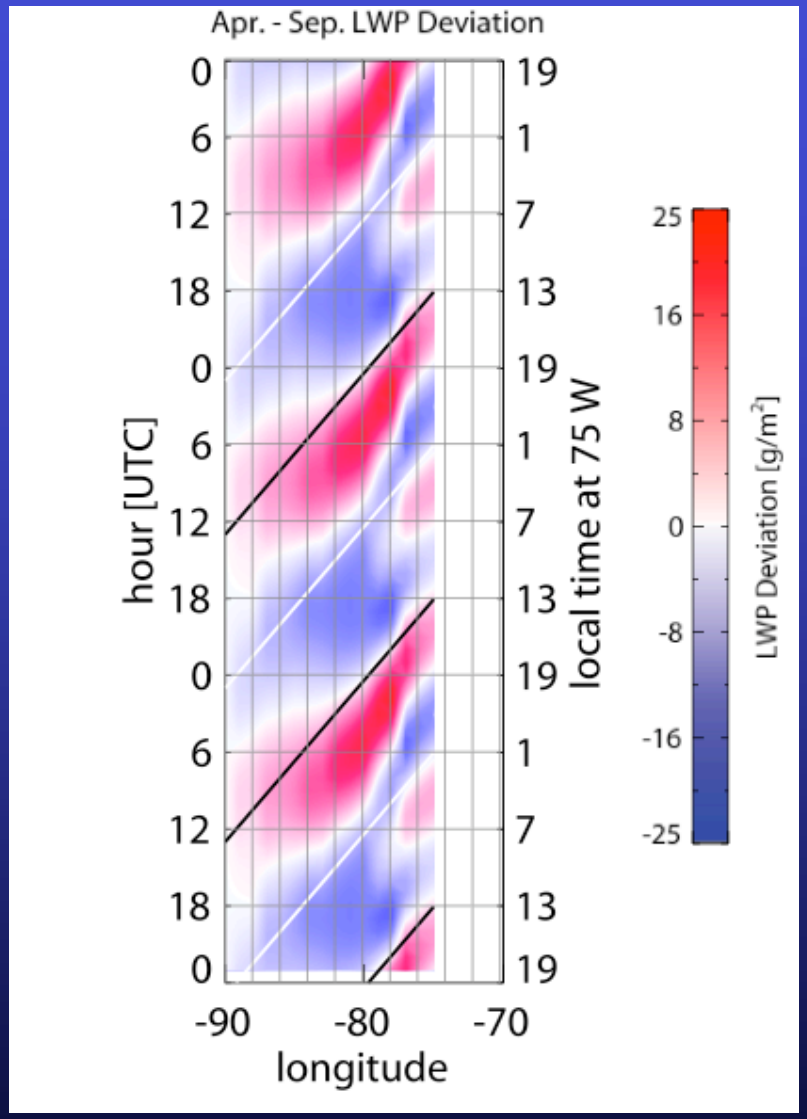


Wood, Bennartz, Koehler, O'Dell, submitted

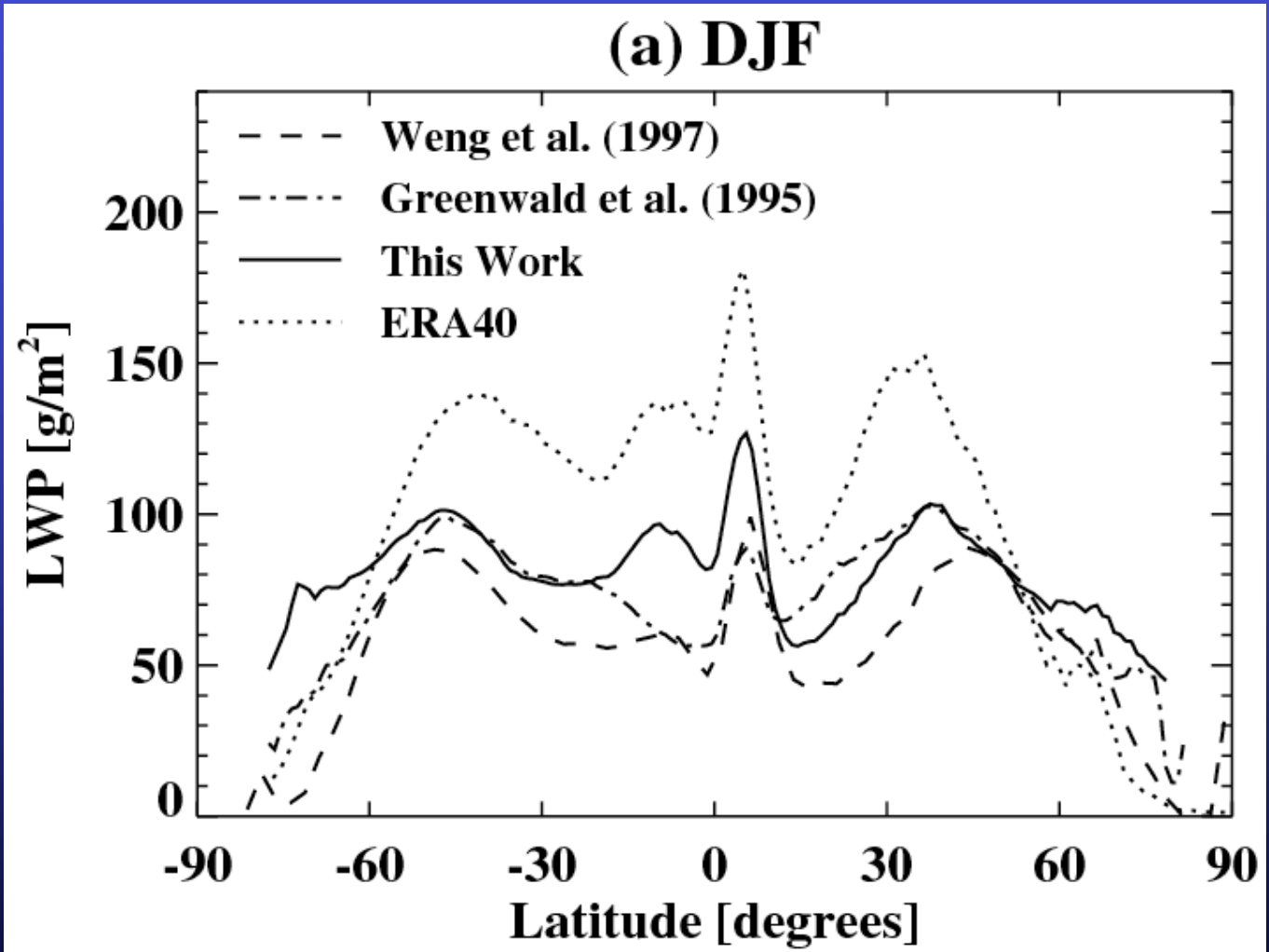
Local Time [hours]



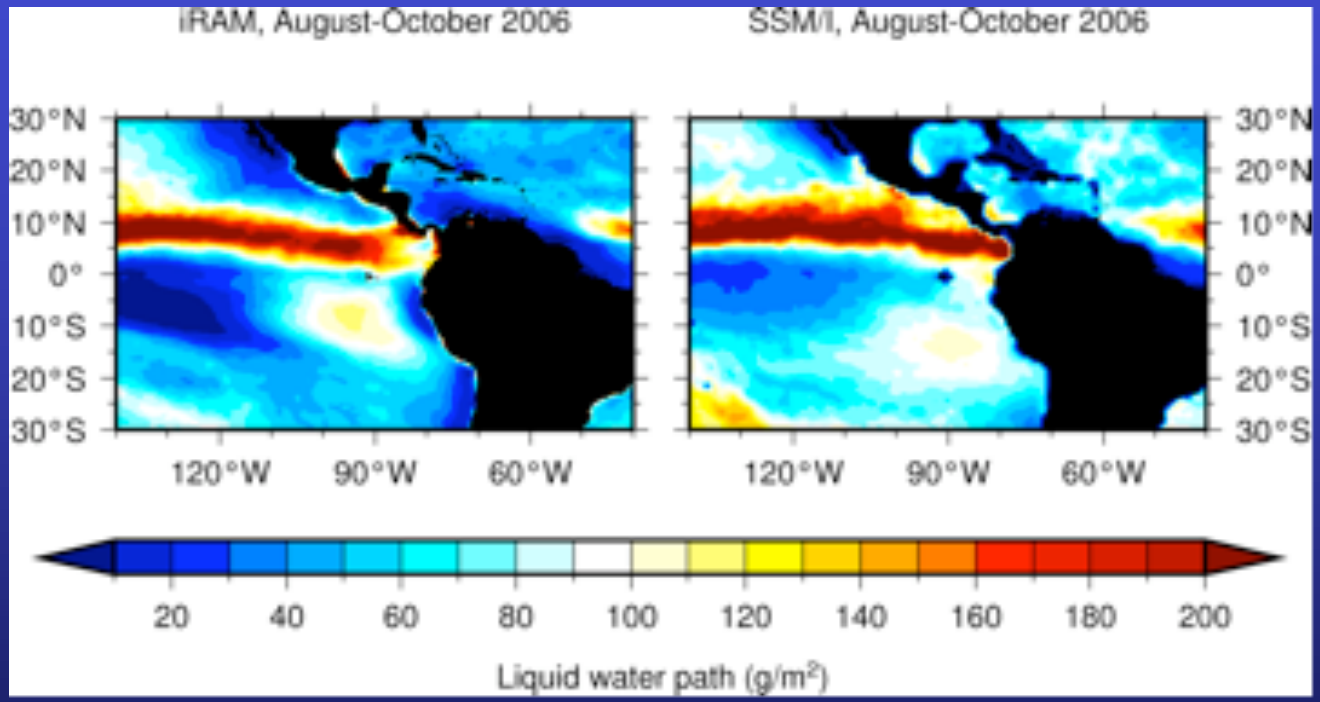
Wood, Bennartz, Koehler, O'Dell, submitted

Local Time [hours]

Mean LWP

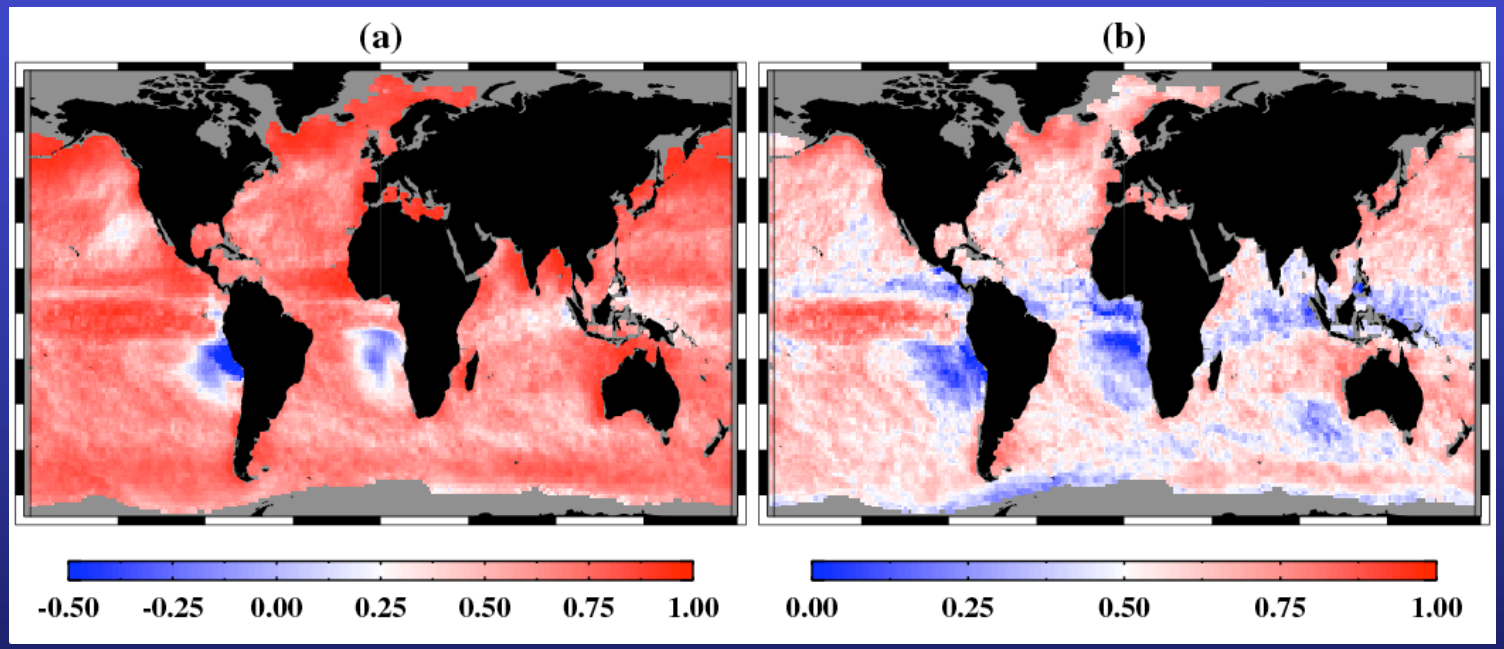

(a) DJF
Weng et al. (1997)
Greenwald et al. (1995)
This Work
ERA40
LWP [g/m^2]
200
150
100
50
0
-90
-60
-30
0
30
60
90
Latitude [degrees]

The obvious



A. Lauer

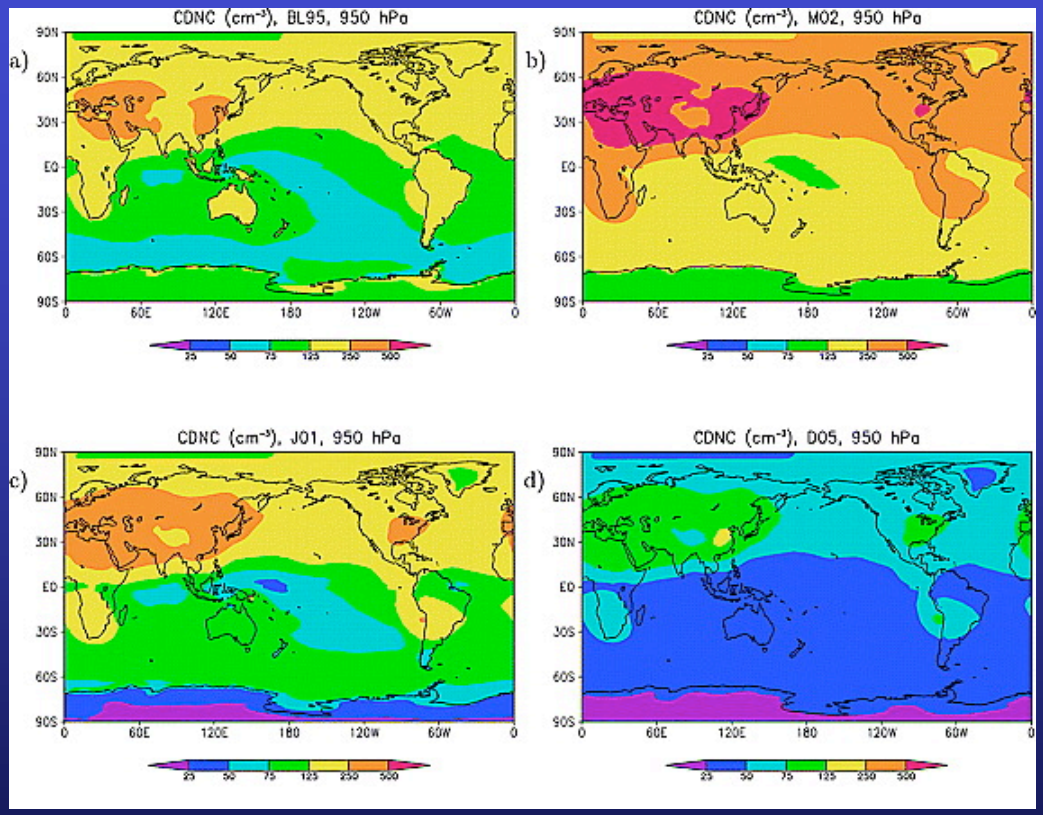
Correlation with ERA 40



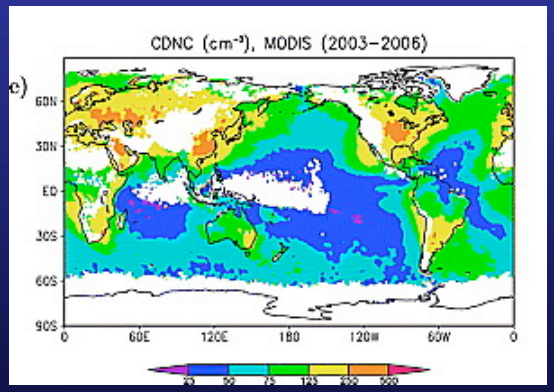
deseasonalized

O'Dell, Wentz, Bennartz, J Climate, 2008

Cloud droplet activation:

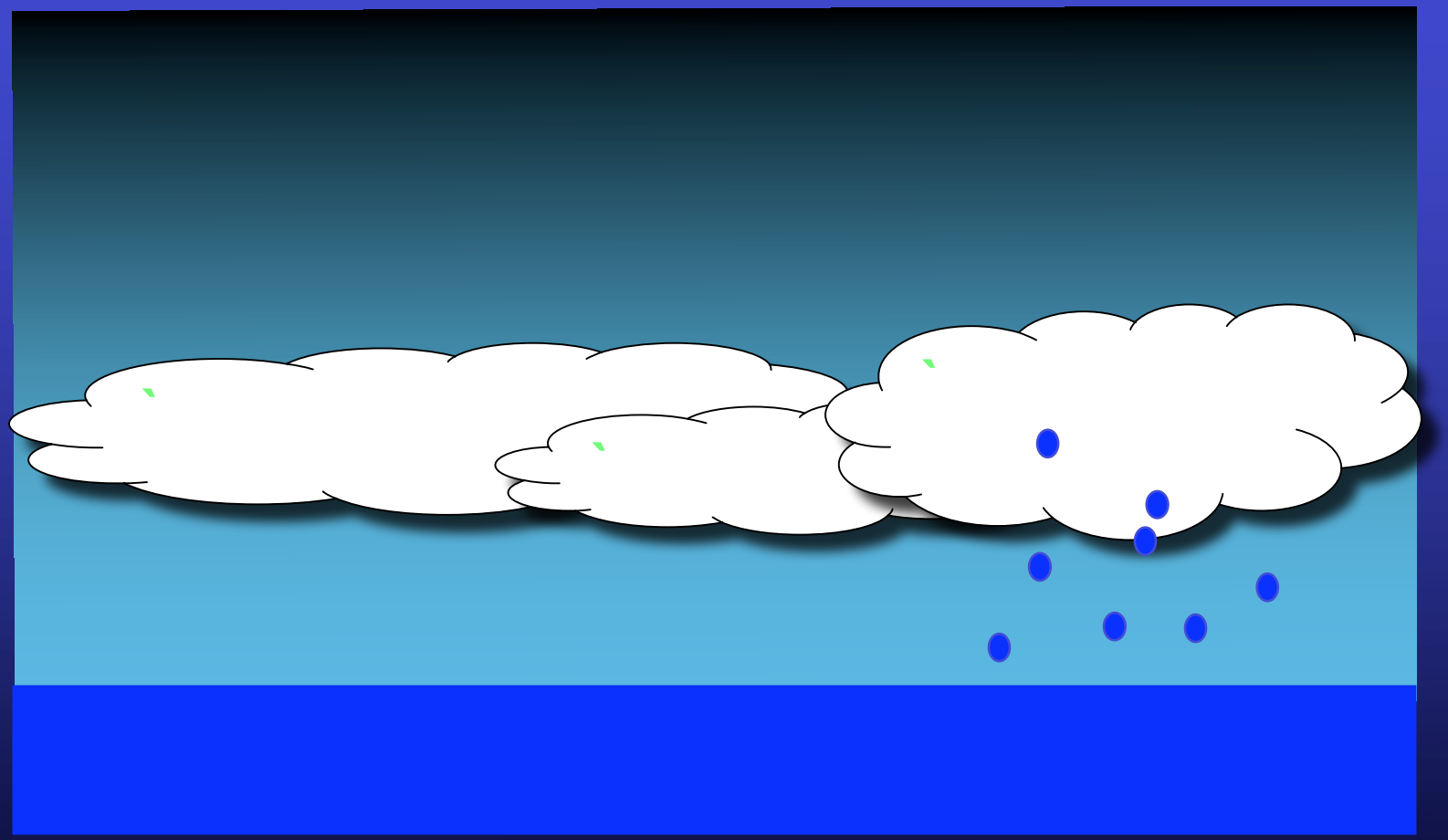


Differences in cloud droplet activation account for about 65 % (1.3 W/m^2) of the total spread in shortwave forcing (2 W/m^2) in IPCC models

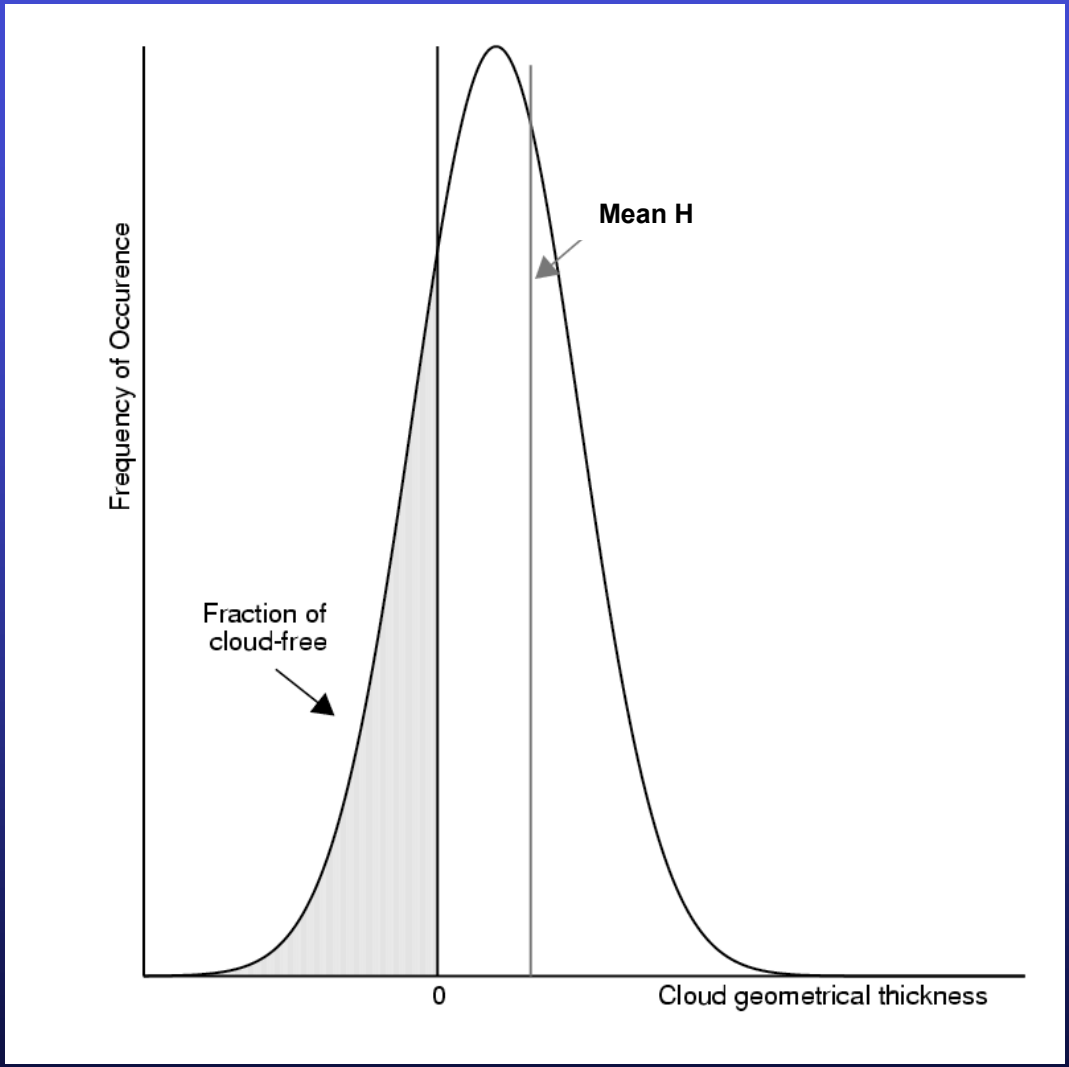


Storelvmo et al. (2009)

Processes Autoconversion/accretion

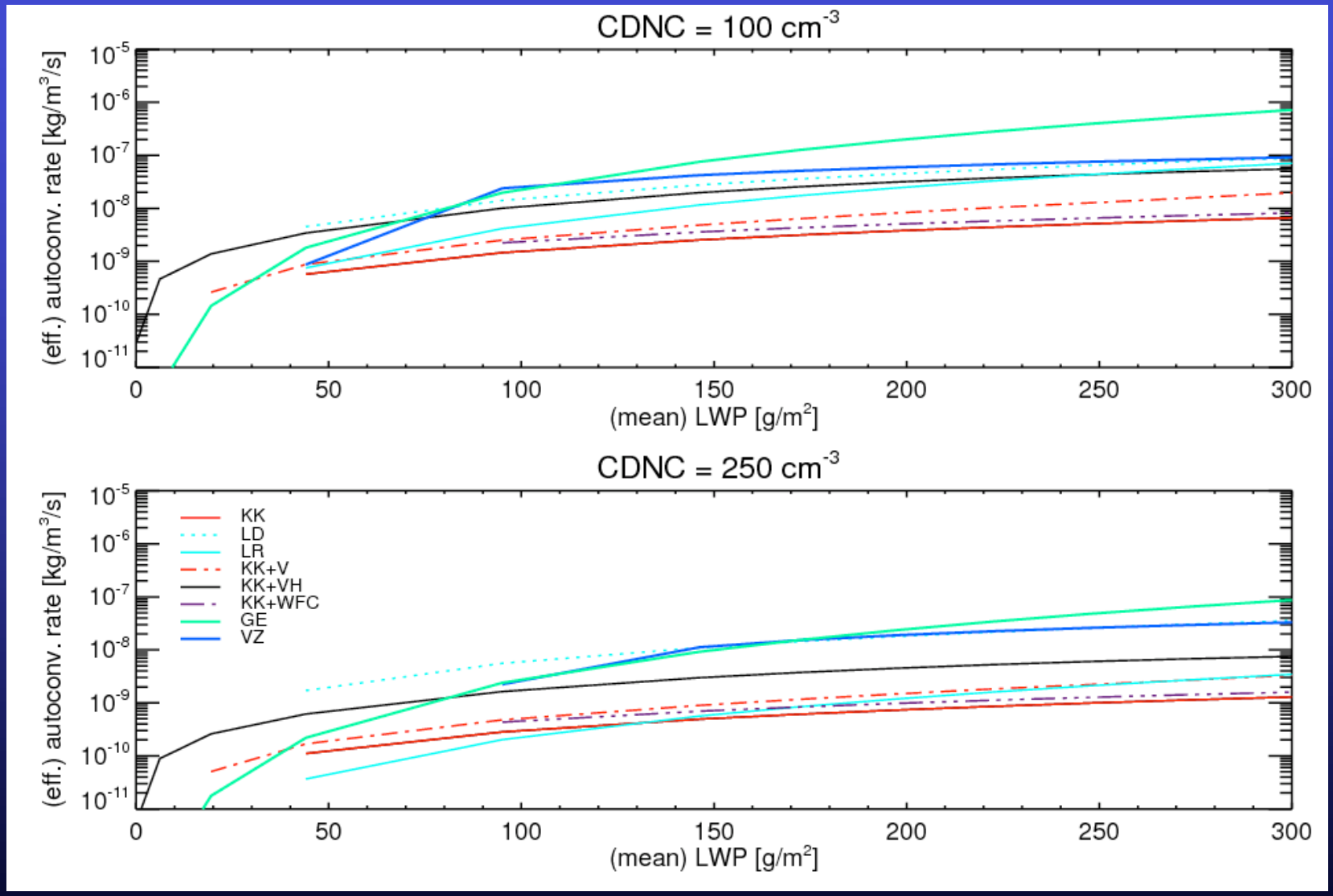


Gaussian fluctuations of cloud geometrical thickness

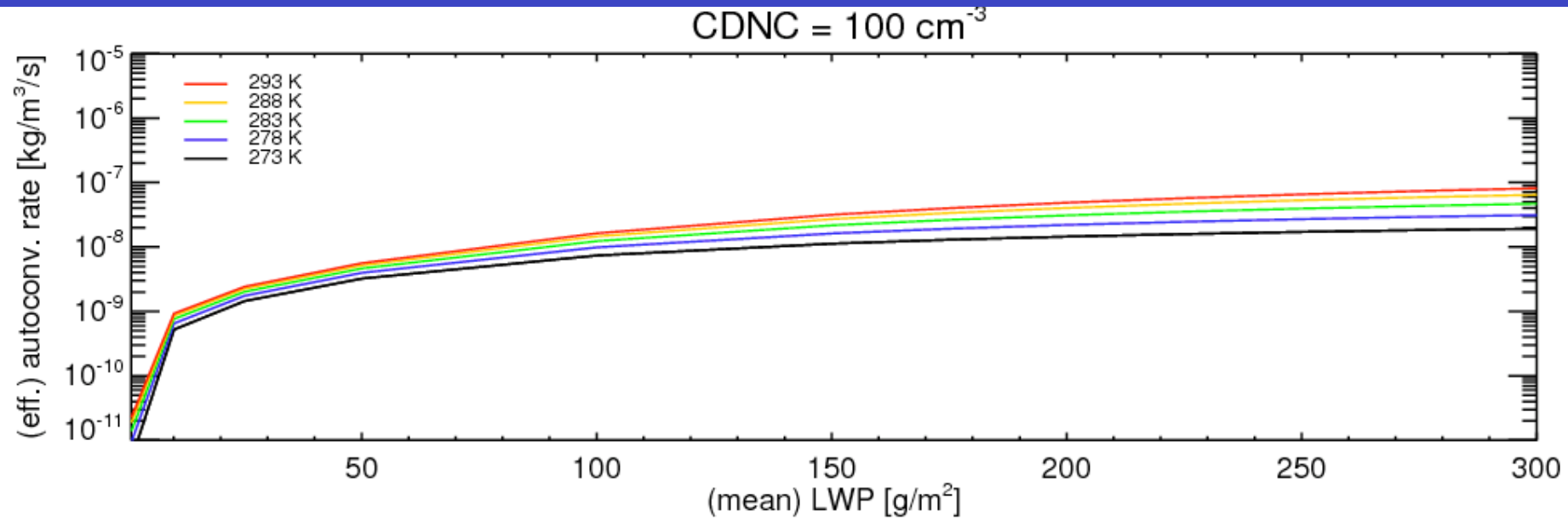


(Considine et al. 1997; Wood and Hartmann, 2006)

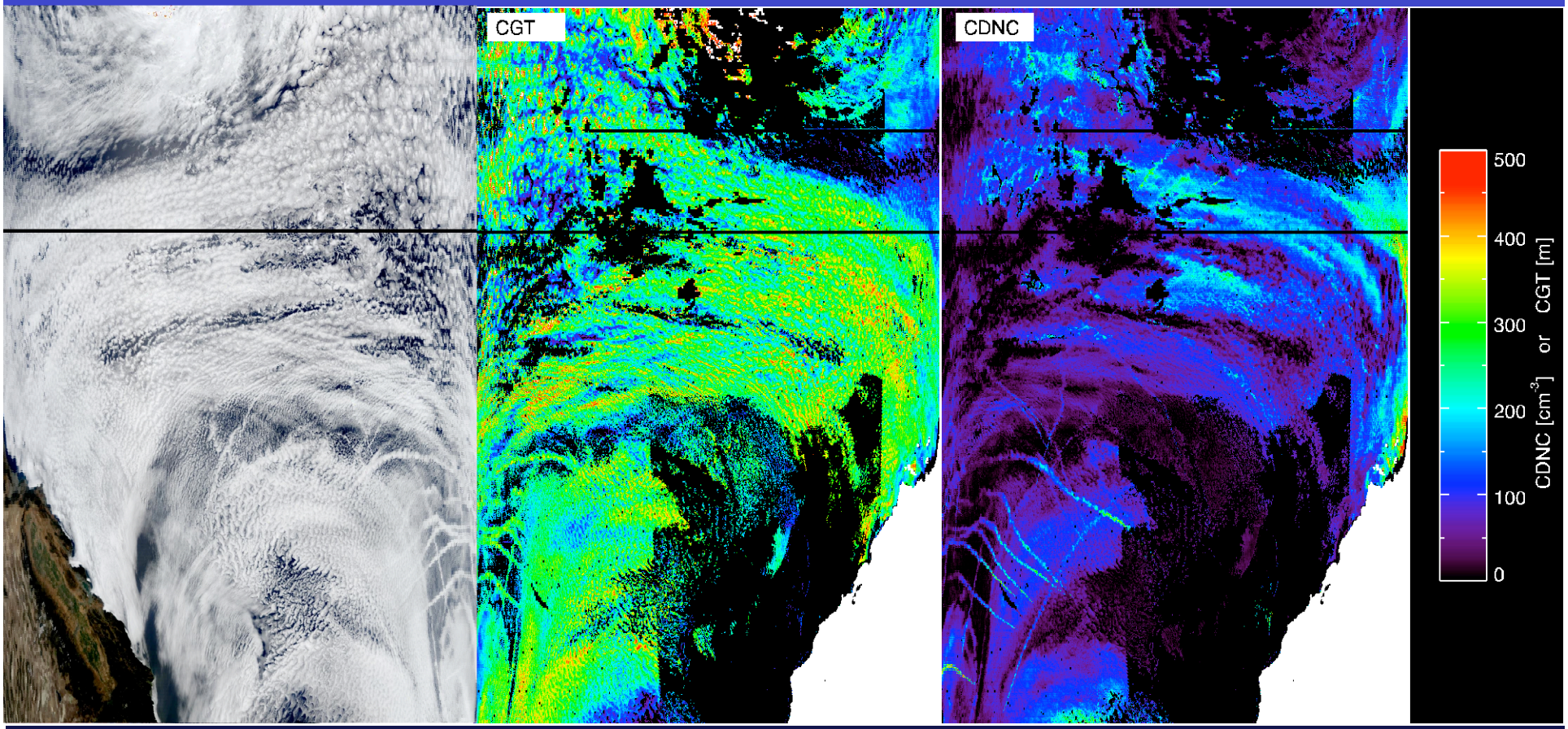
Accretion/Autoconversion



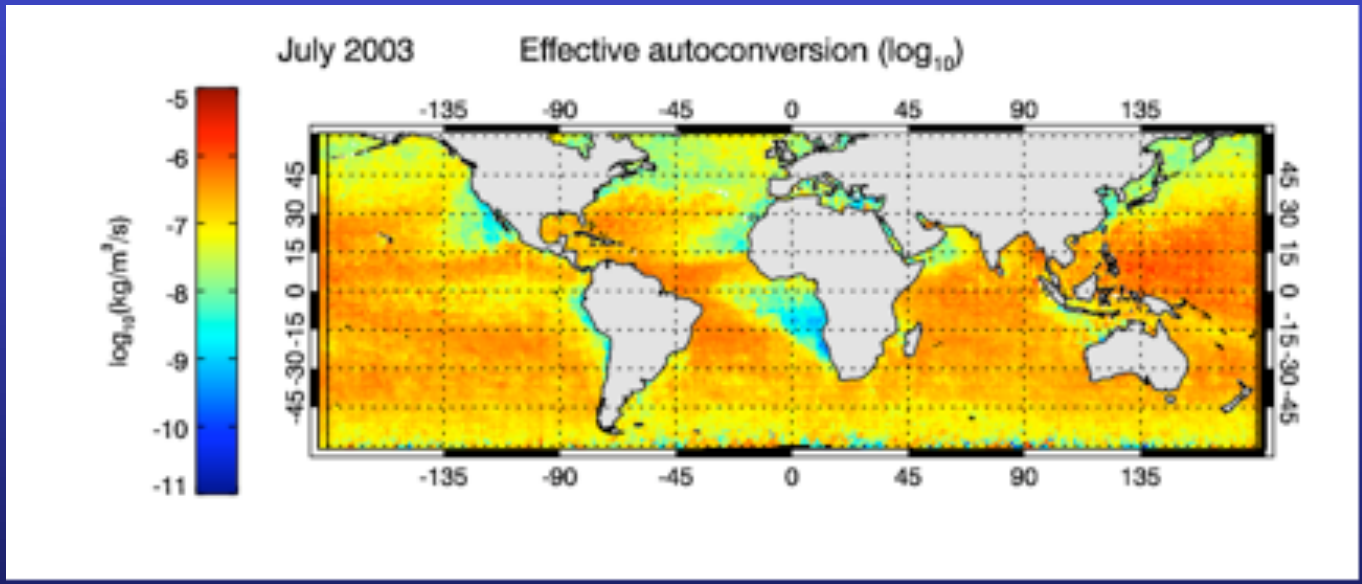
Impact of condensation rate



CDNC and geometrical thickness



Globally derived based on parameterization using CDNC, LWP and condensation rate

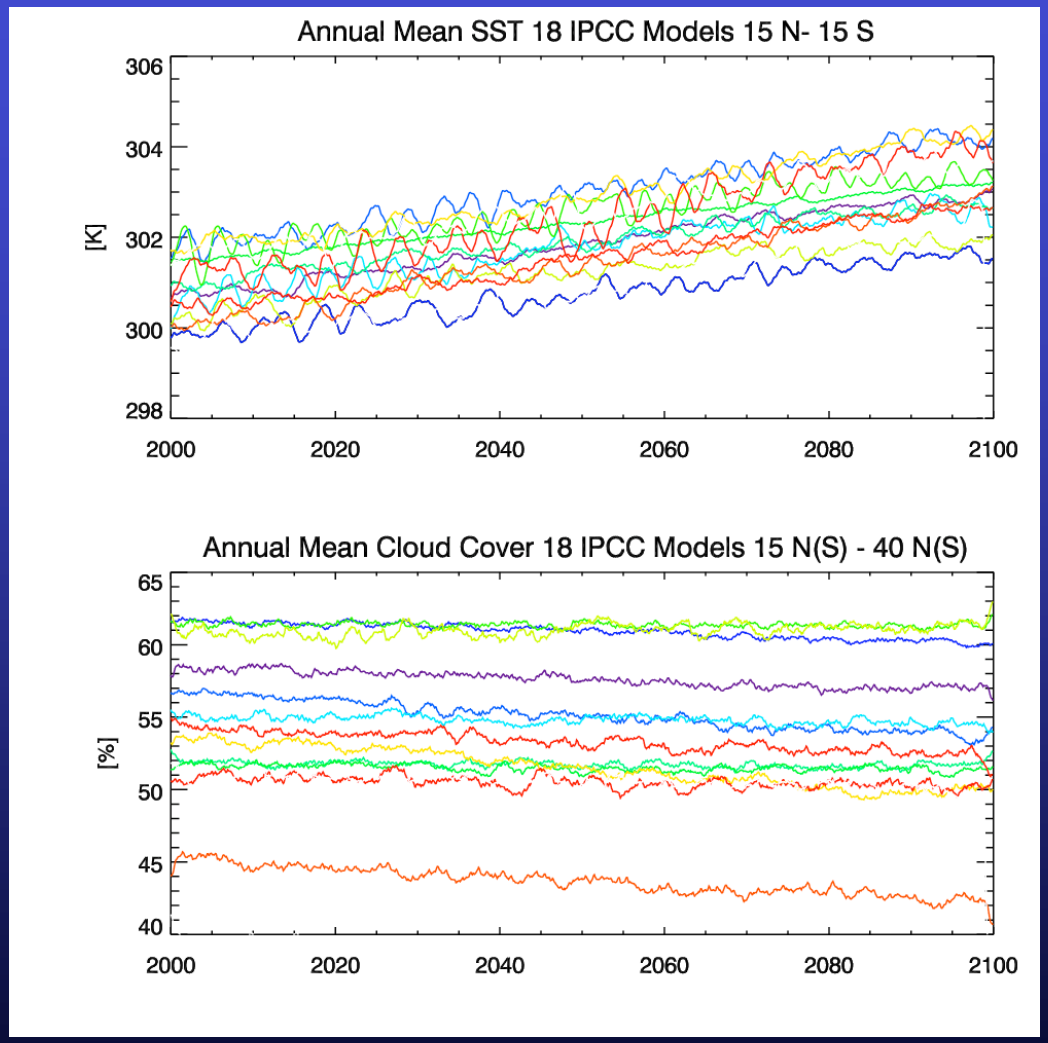


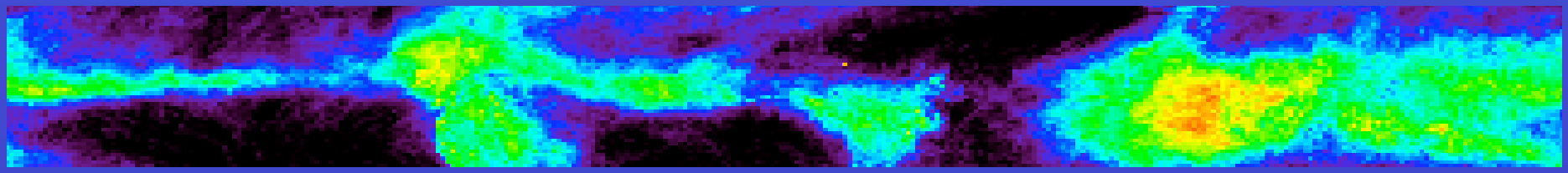
Known knowns

- Long experience with data, well-established long-term datasets (HOAPS, Wentz, Patmos)
- At a stage where we can draw conclusions both at a process level as well as in a climatological sense.
- Algorithms still can be and need to be refined.

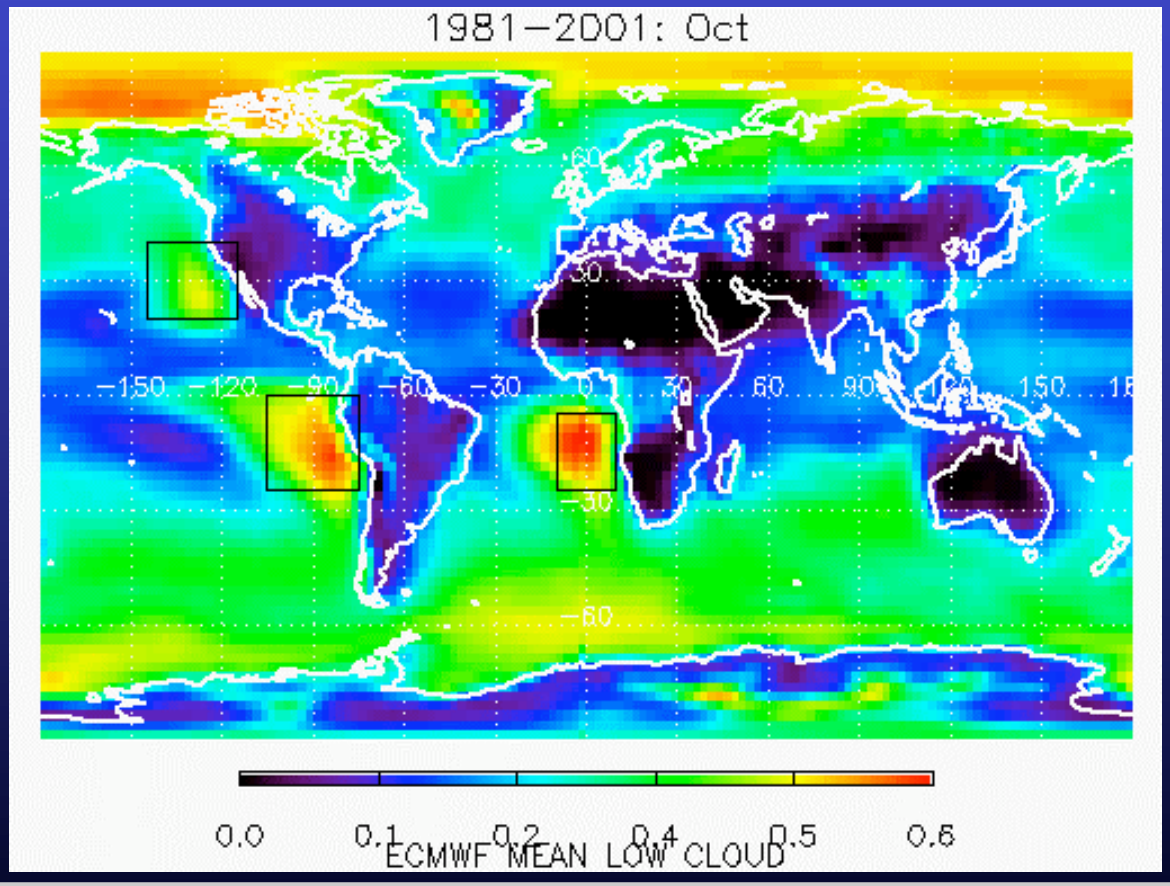
Known unknowns - cloud fraction

Cloud fraction
(18 climate models from IPCC-AR4)

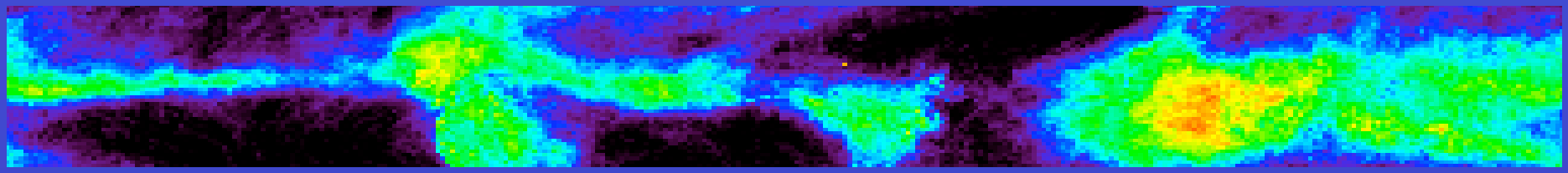




Time Series Analysis - Stratus Regions

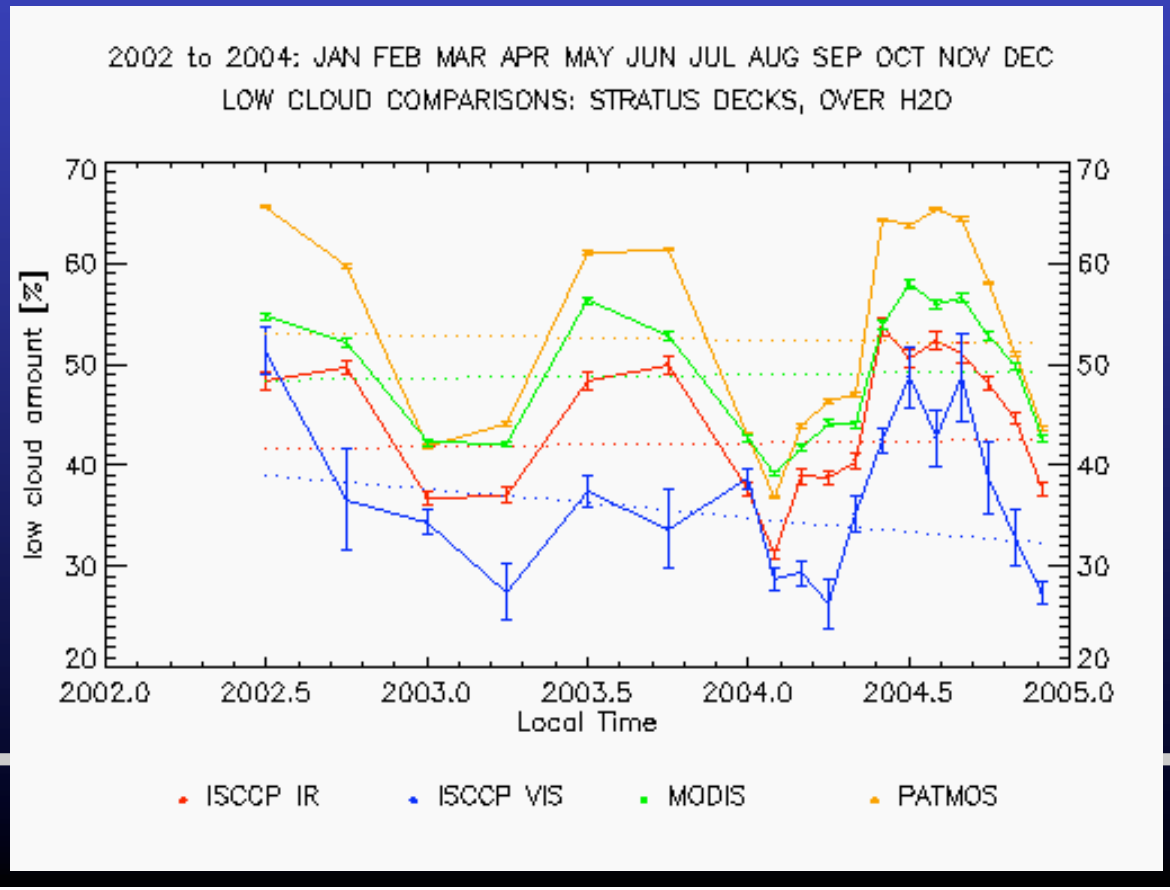


A. Evan



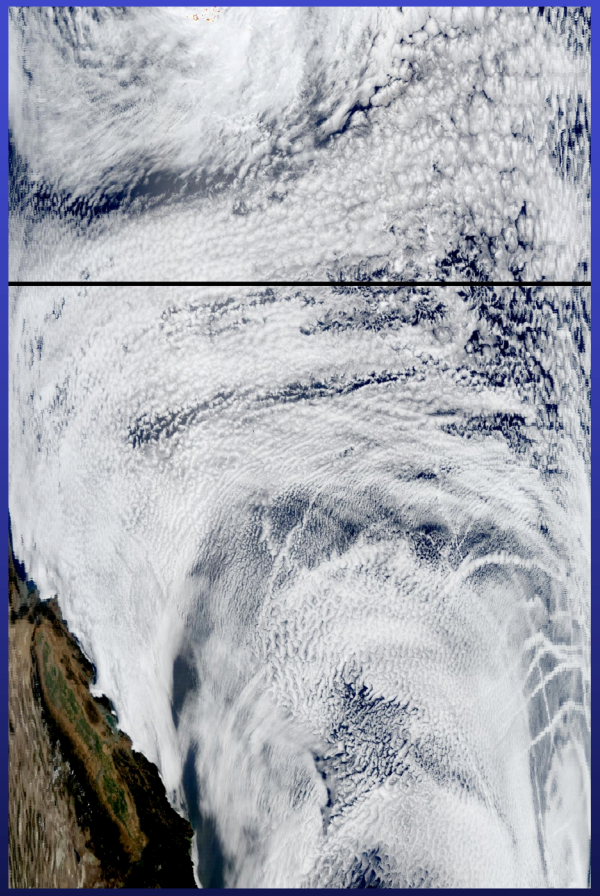
Time Series Analysis - Stratus Regions

- Low clouds
- Accounting for diurnal effects



A. Evan

Cloud fraction: MODIS Level 2 retrieval



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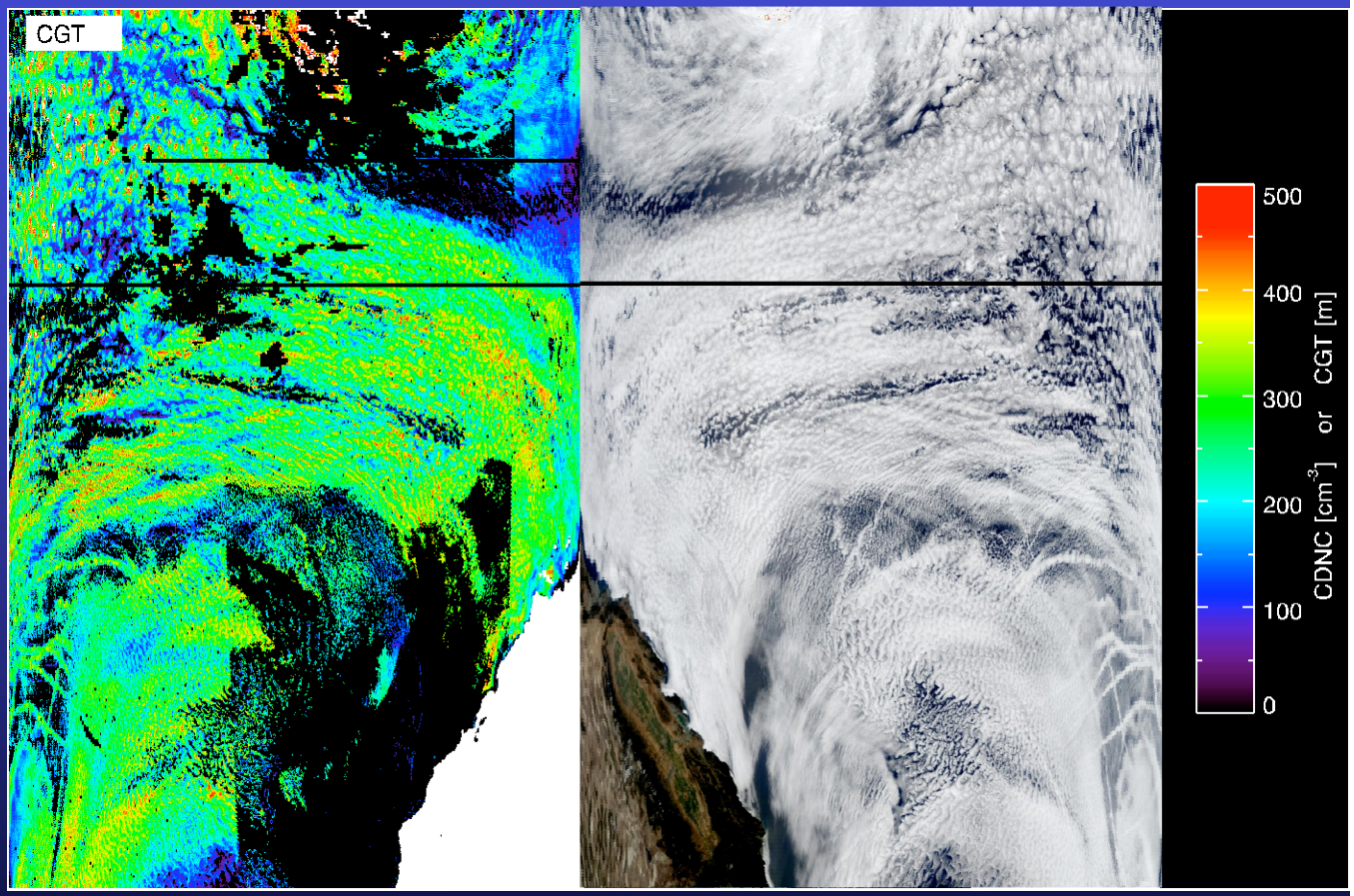
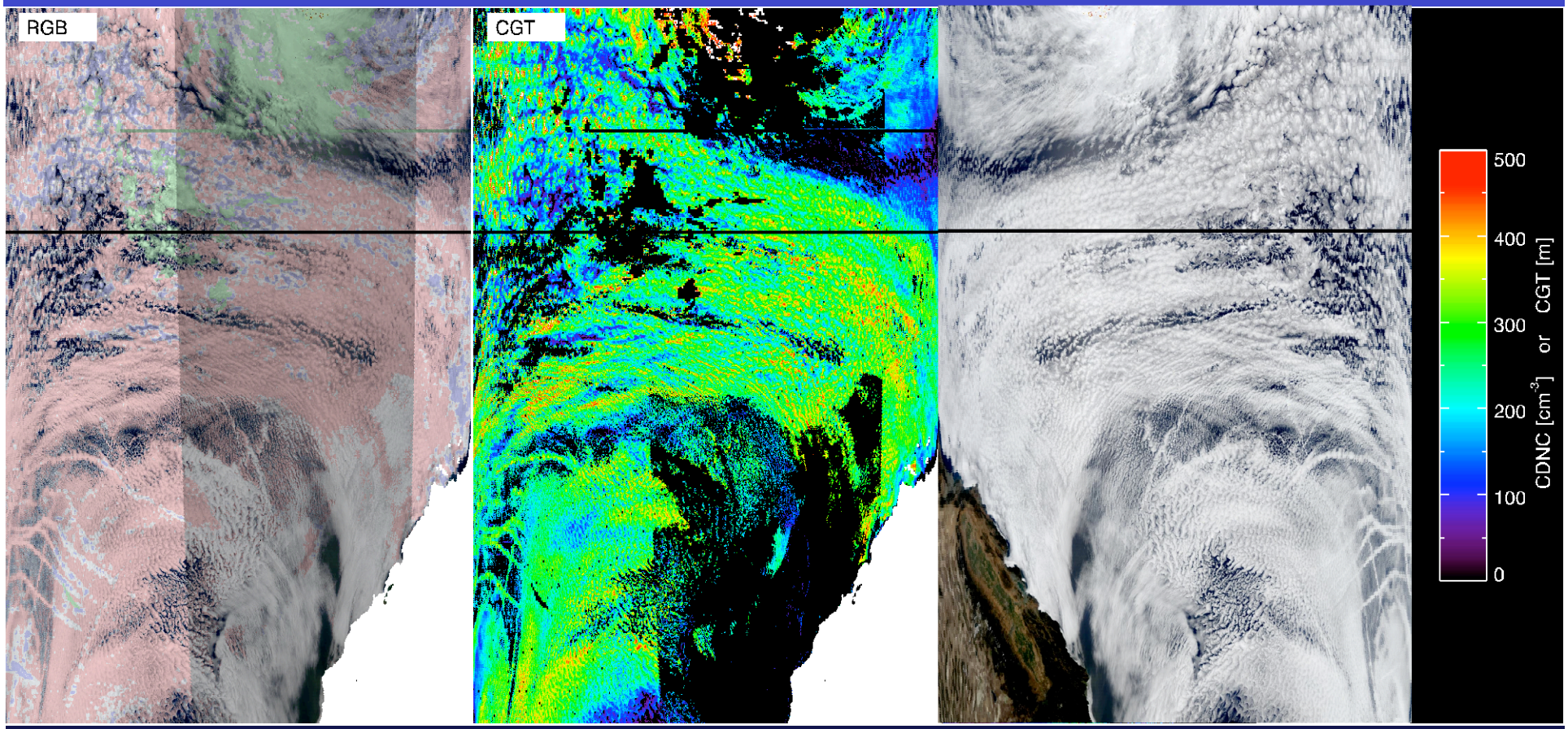
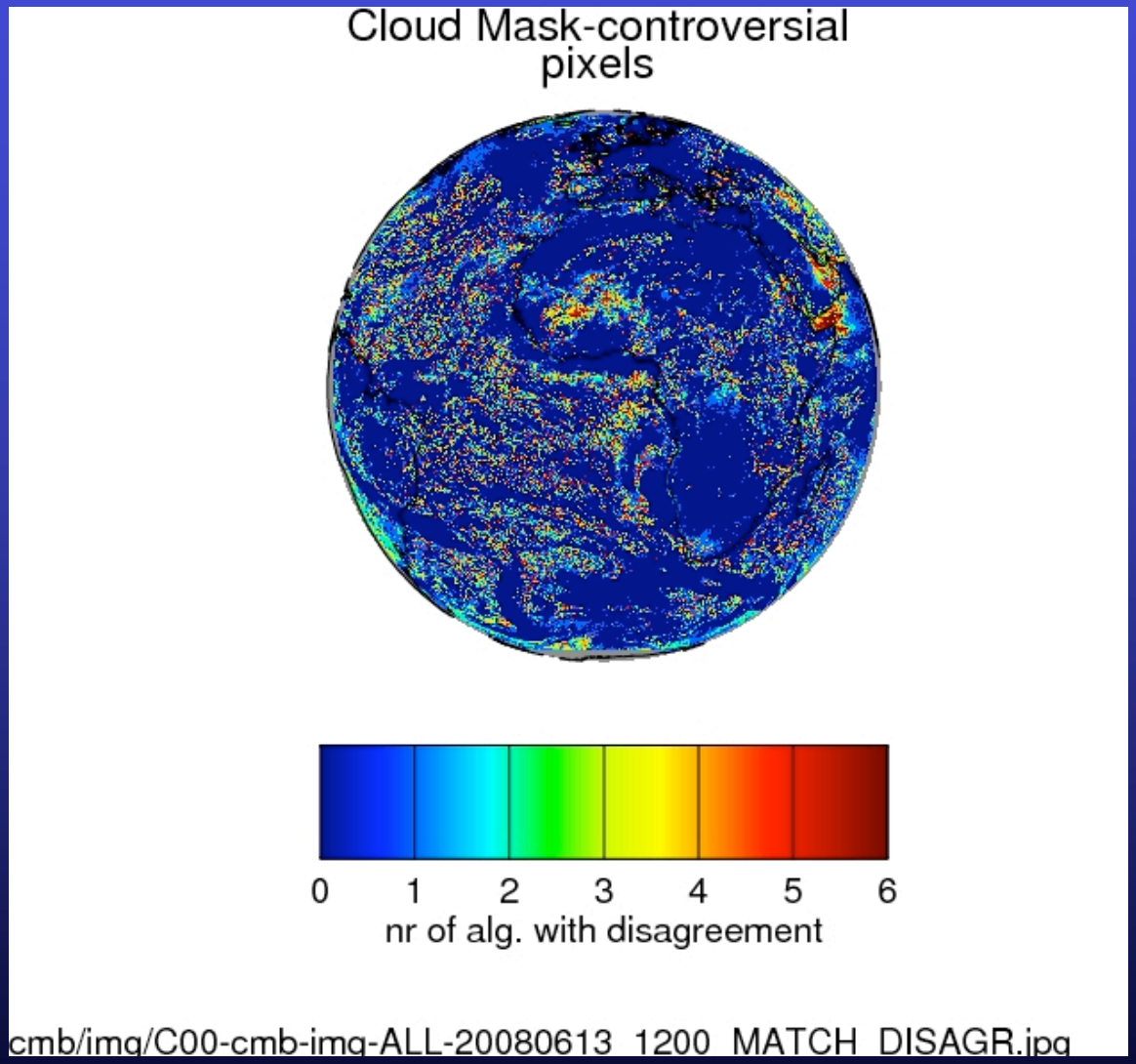


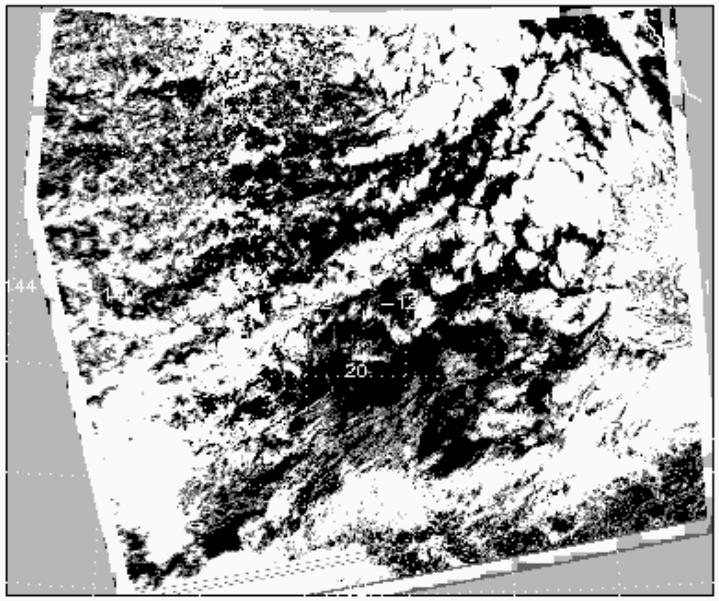
Cloud fraction: MODIS Level 2 retrieval



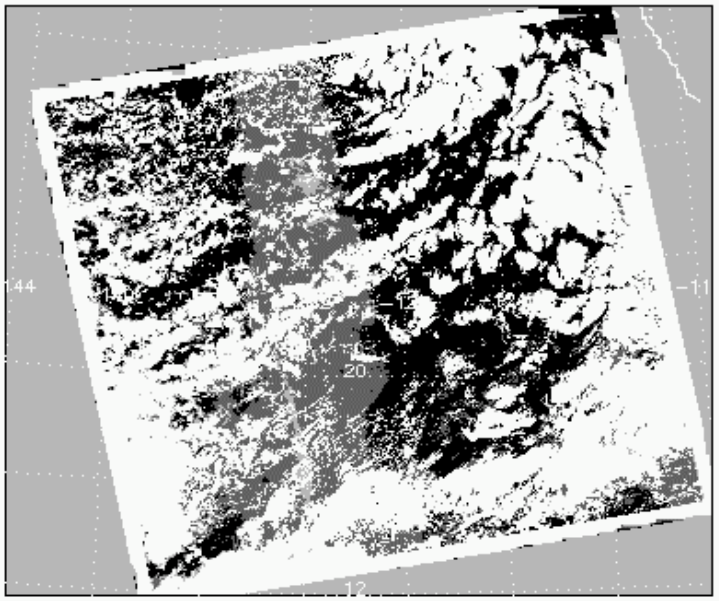
Cloud fraction: Different algorithms



A. Walther



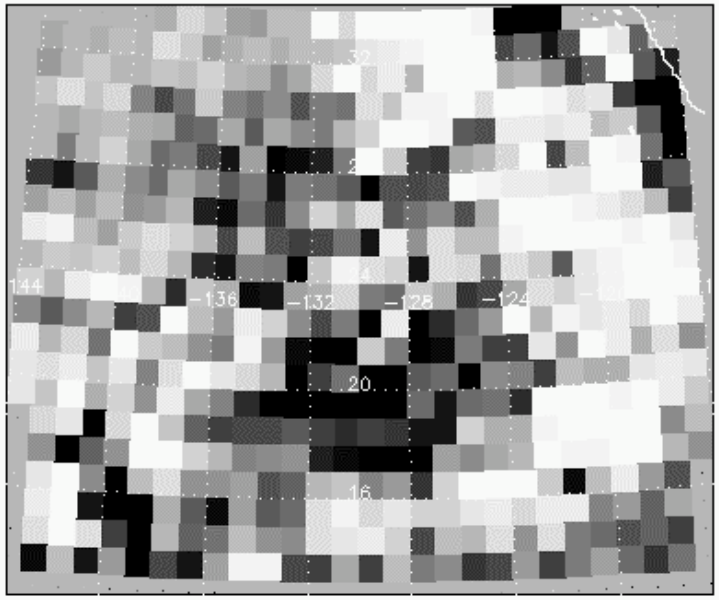
[PATMOS−x] cloud mask



[AQUA/MODIS] cloud mask

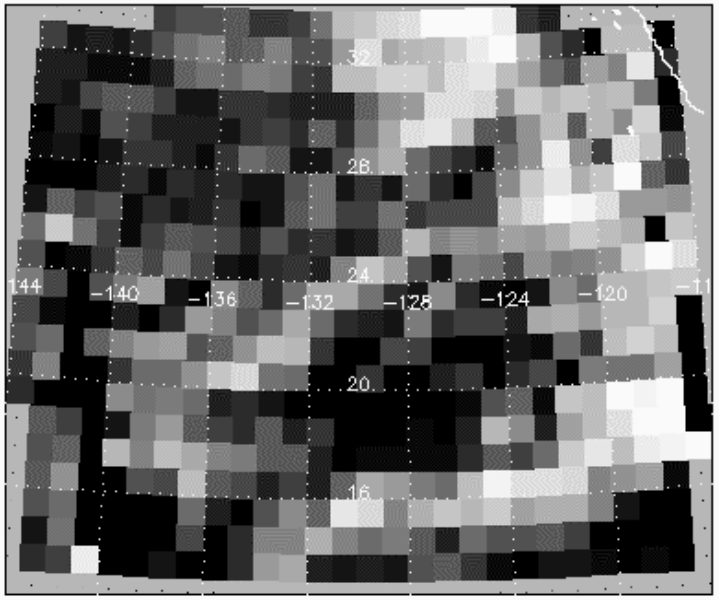
Level 2

Level 3



[PATMOS−x] liquid cloud fraction

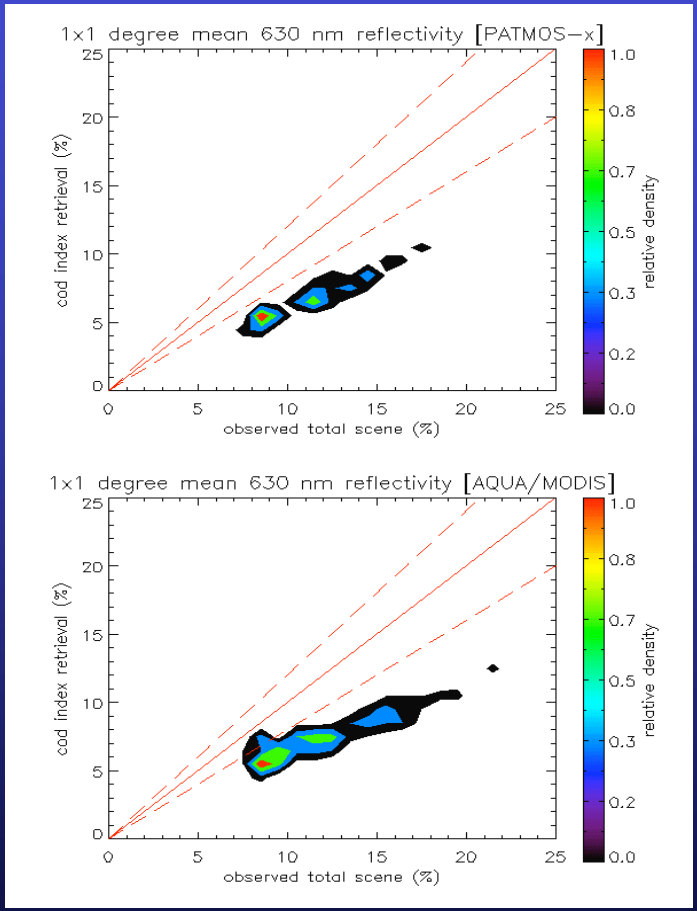
0 1



[AQUA/MODIS] liquid cloud fraction

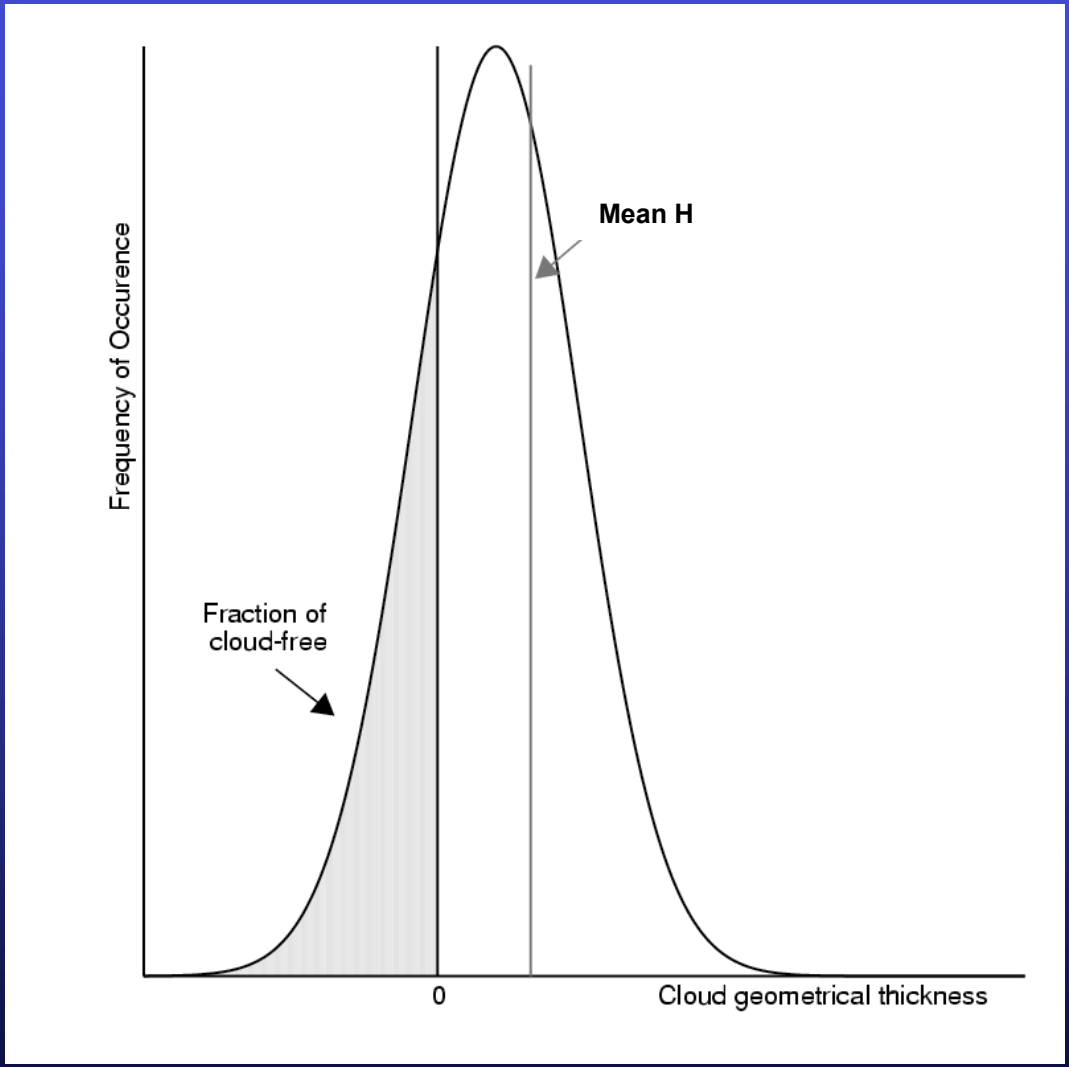
0 1

Do we conserve reflectivity?



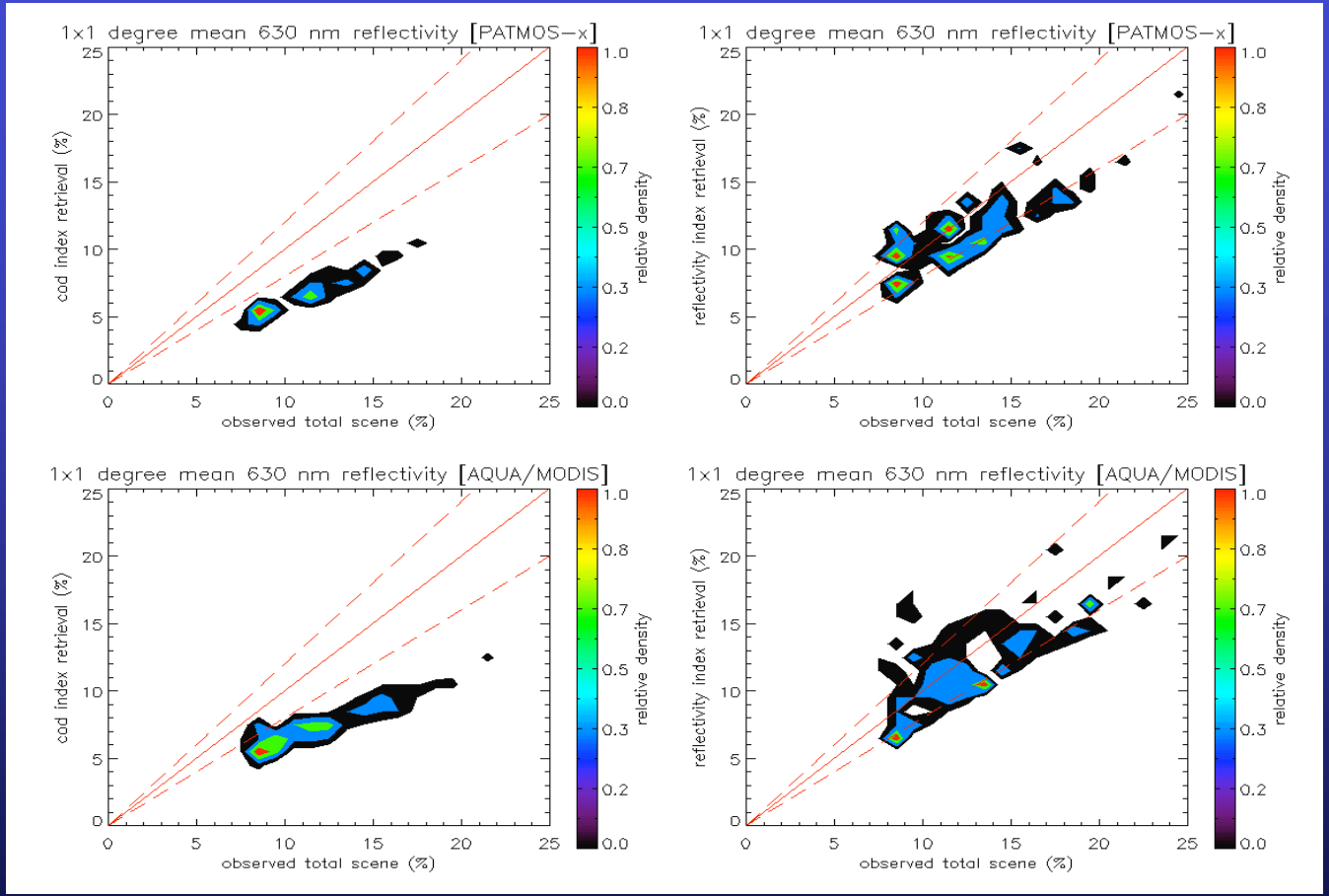
No!!!!

Gaussian fluctuations of cloud geometrical thickness



(Considine et al. 1997; Wood and Hartmann, 2006)

Conserve reflectivity



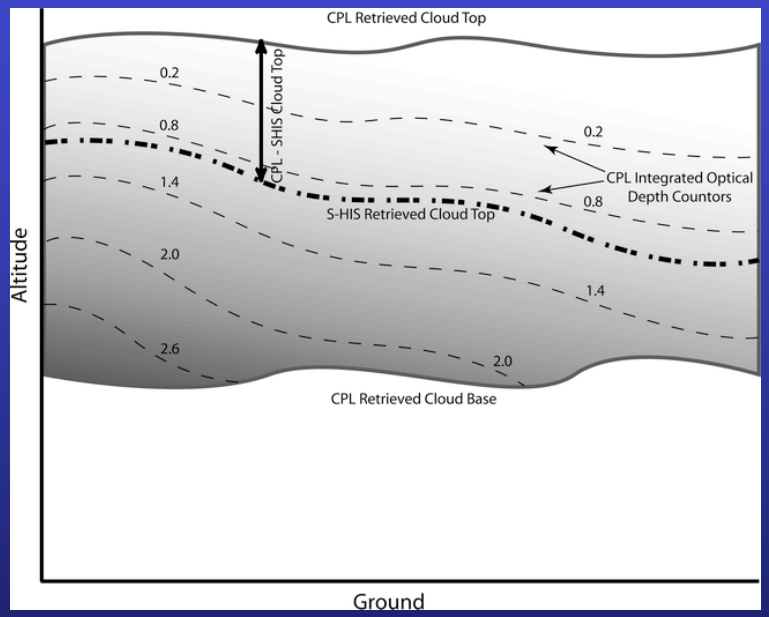
Rethinking

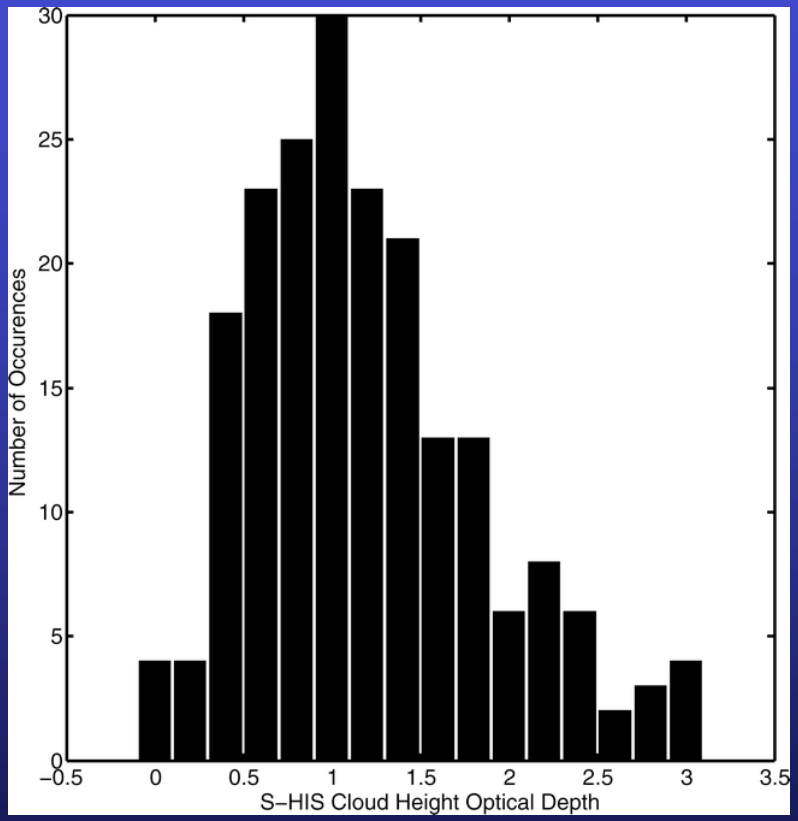
- Cloud fraction is among the hardest variables to interpret.
- We understand the reasons for disagreements very well.
- Can we come up with a better way of providing the same information?
- Physically self-consistent to the highest degree possible. E.g. conserve what the sensor actually observed also at larger spatial scales, after averaging.

Cloud Top Height/pressure

- Various techniques with different sensitivities.
- Excellent validation opportunities from active sensors.
- Physical interpretation of differences between different sensors is crucial.
- What is cloud top height?

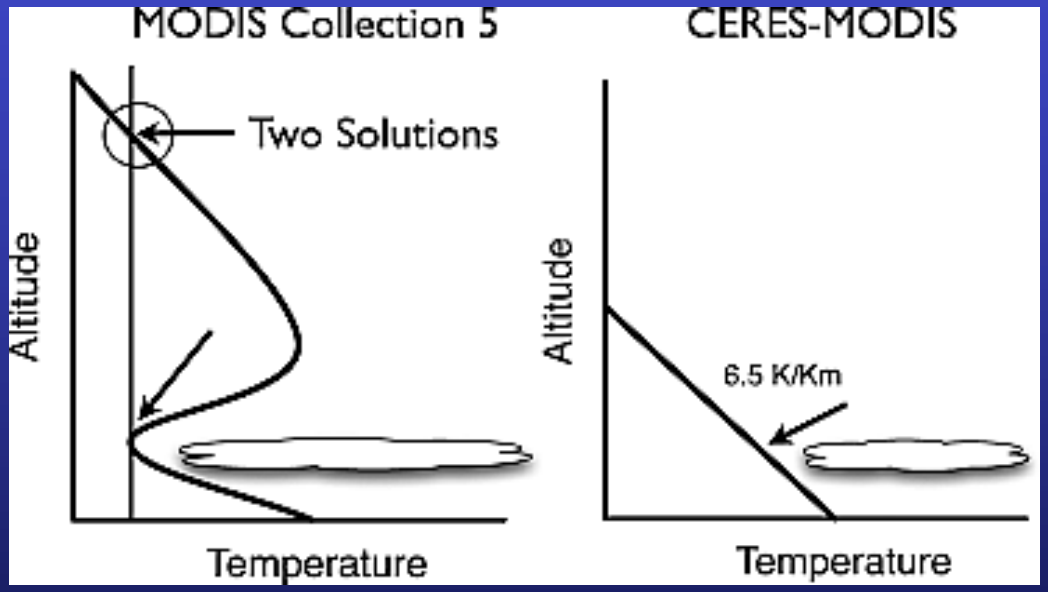
Cloud top height/pressure





R. Holz

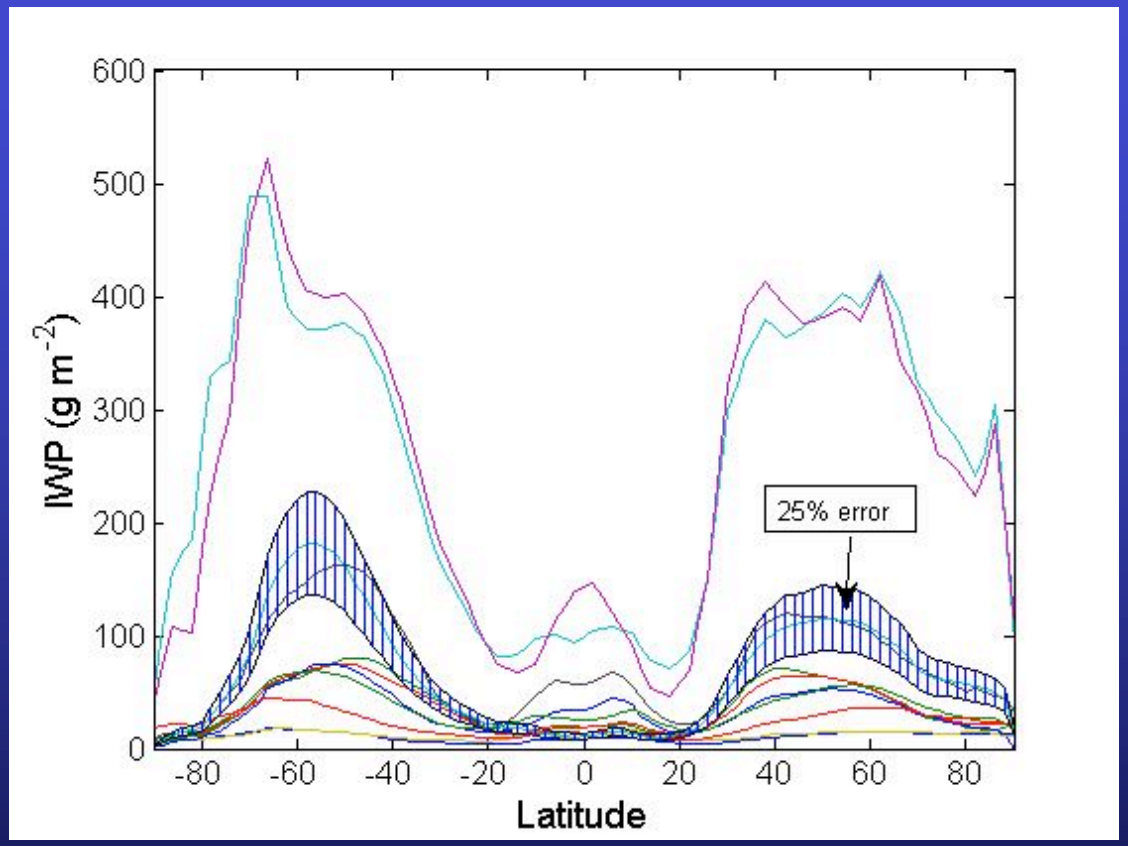
Why are there so few low-level clouds in some satellite datasets?



R. Holz

Unknown unknowns - ice cloud

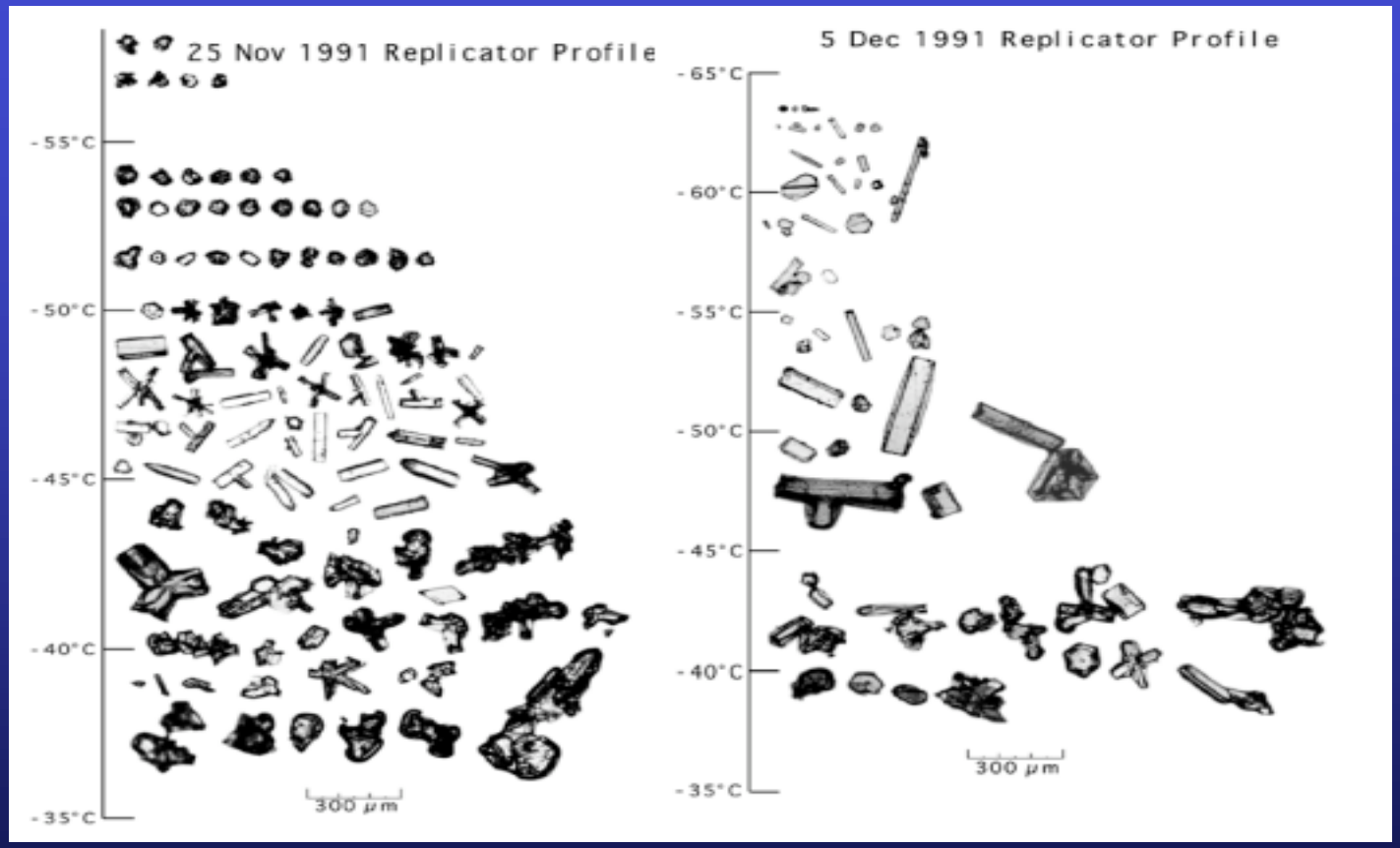
GCMs



The climatology of zonal, annual mean IWP from state-of-the-art global models

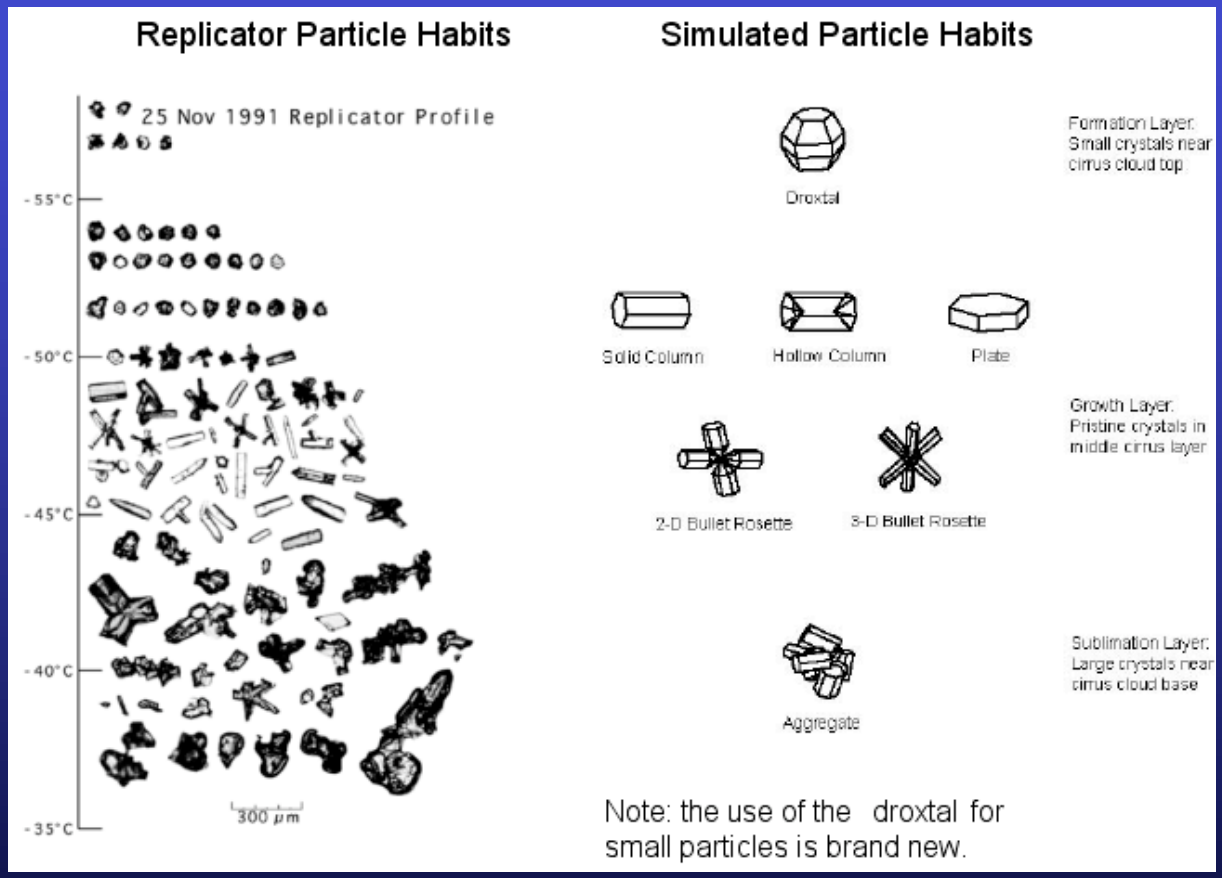
(Ackerman et al. SIRICE proposal)

Cirrus Ice particle shapes



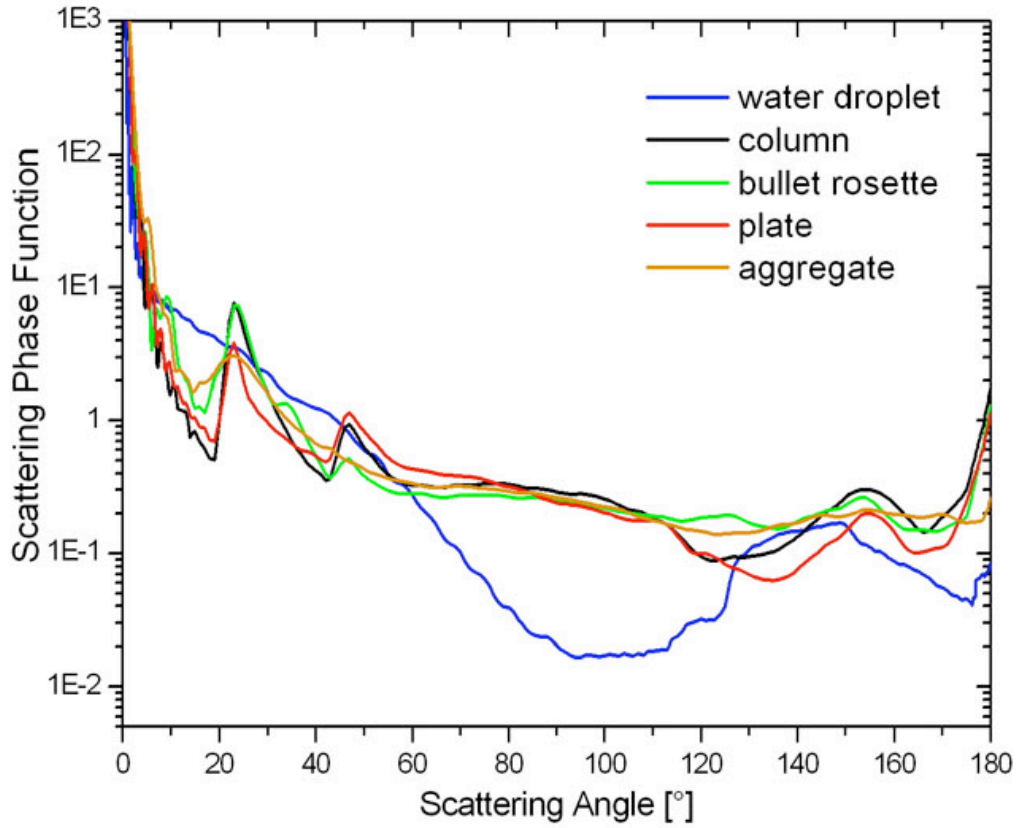
(A. Heymsfield, B. Baum et al.)

Ice particle shapes

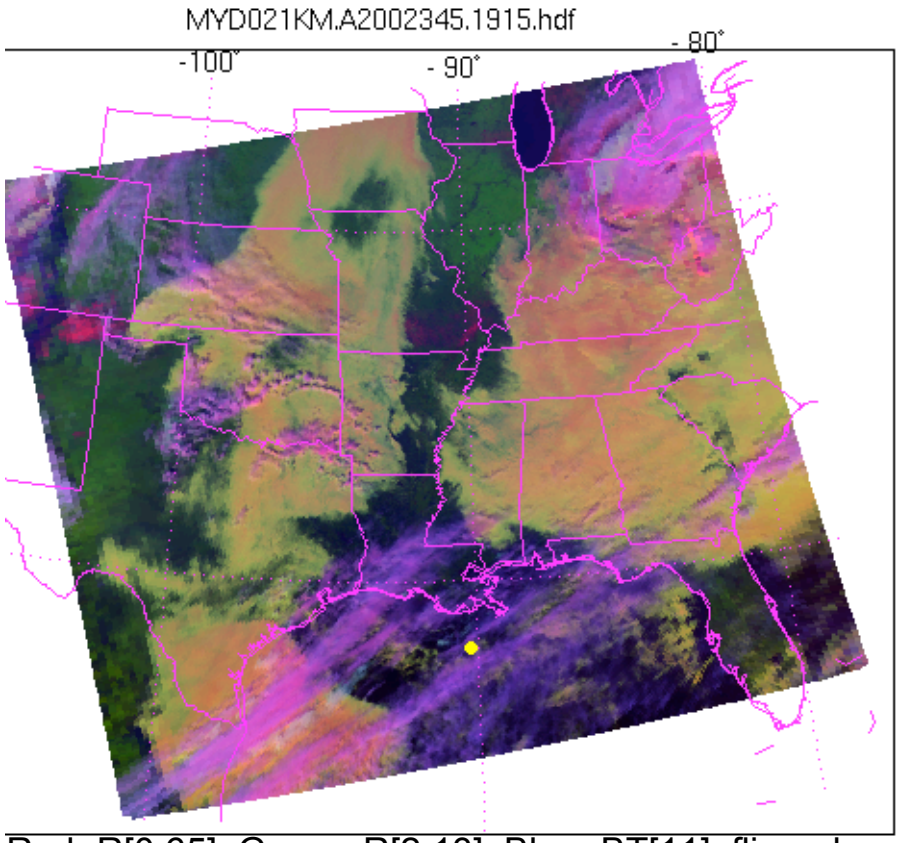


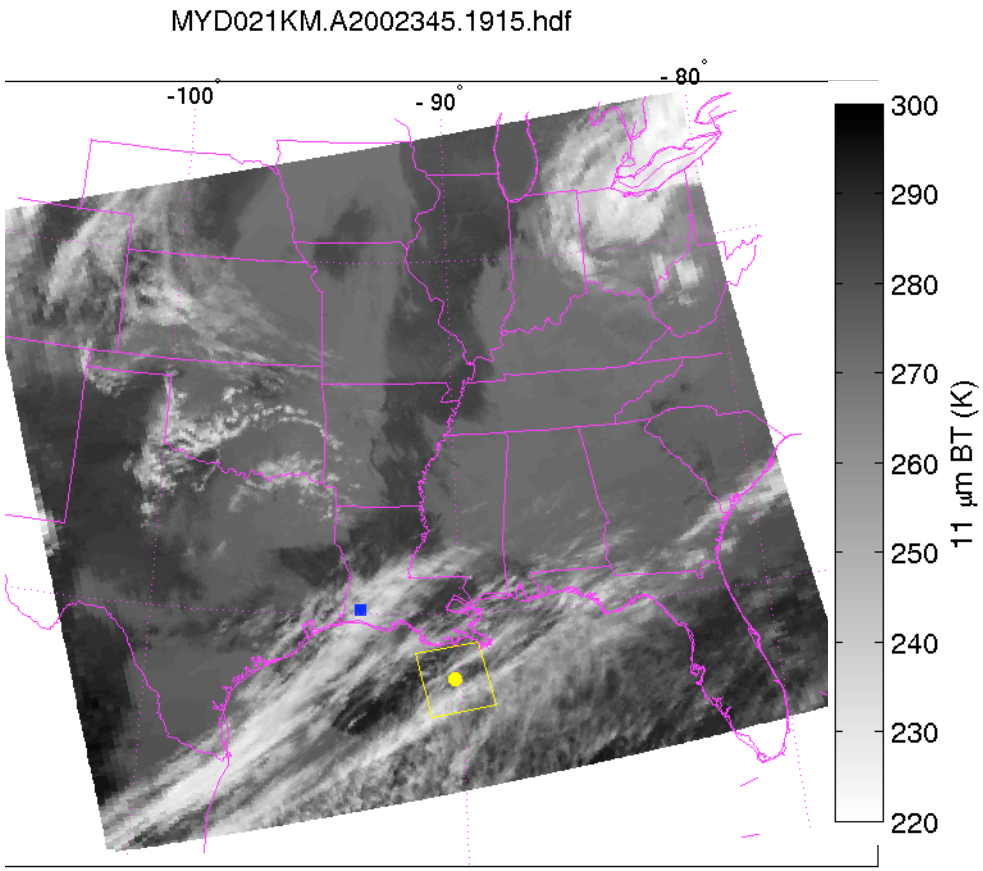
(B. Baum et al.)

Ice phase function



Overlapping Clouds in MODIS Data

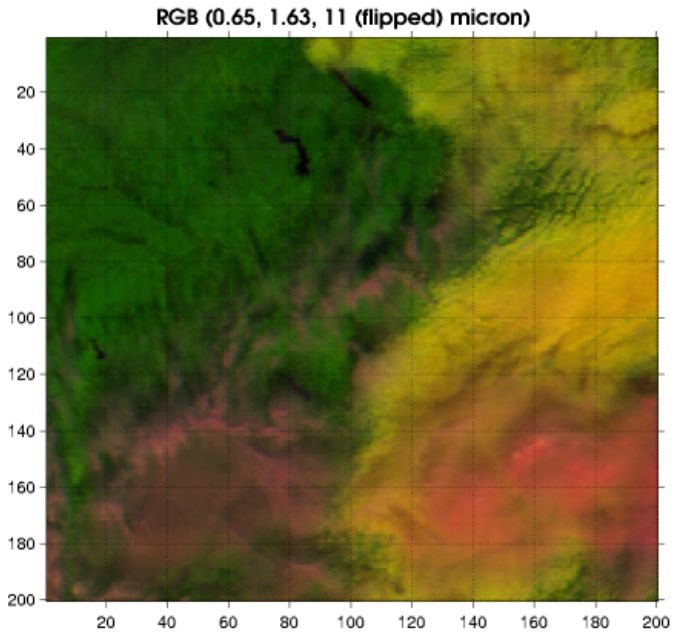


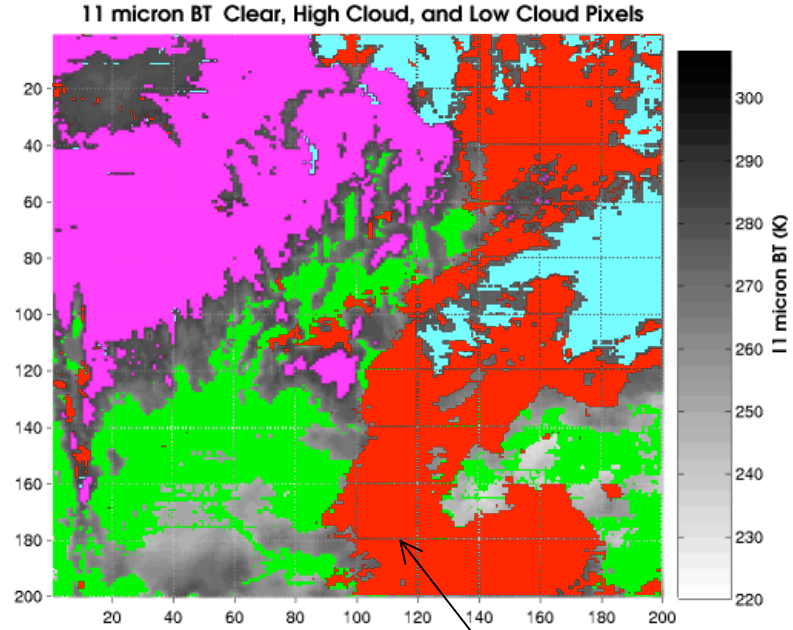


Red=R[0.65], Green=R[2.13], Blue=BT[11], flipped

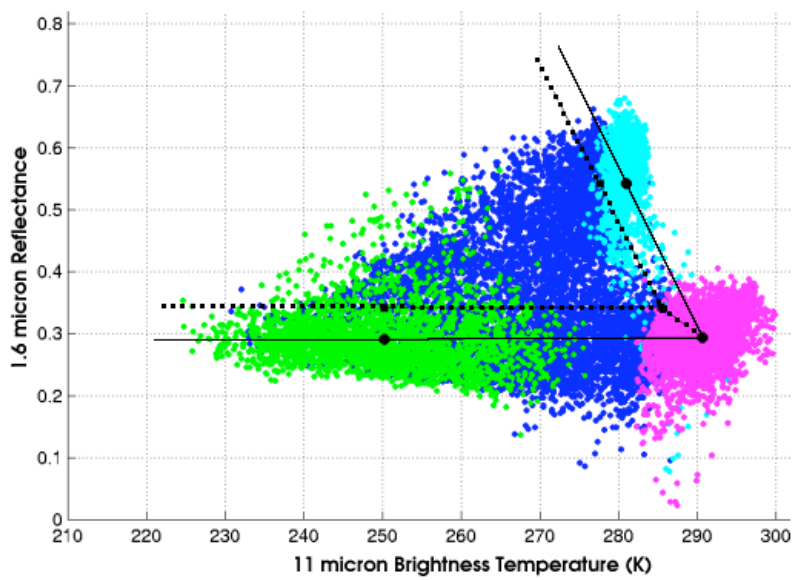
Aqua MODIS data from 11 Dec., 2002 during TX-2002 from S. Nasiri

200 by 200 pixels of Terra MODIS Data from 15 Oct. 2000 at 1725Z





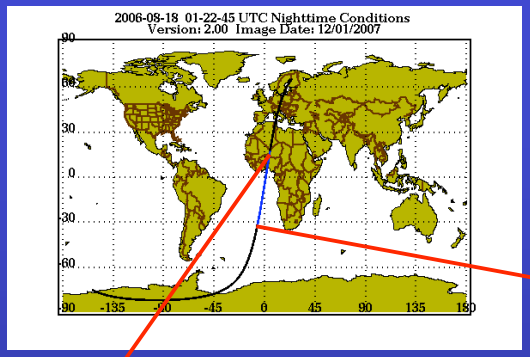
Overlap

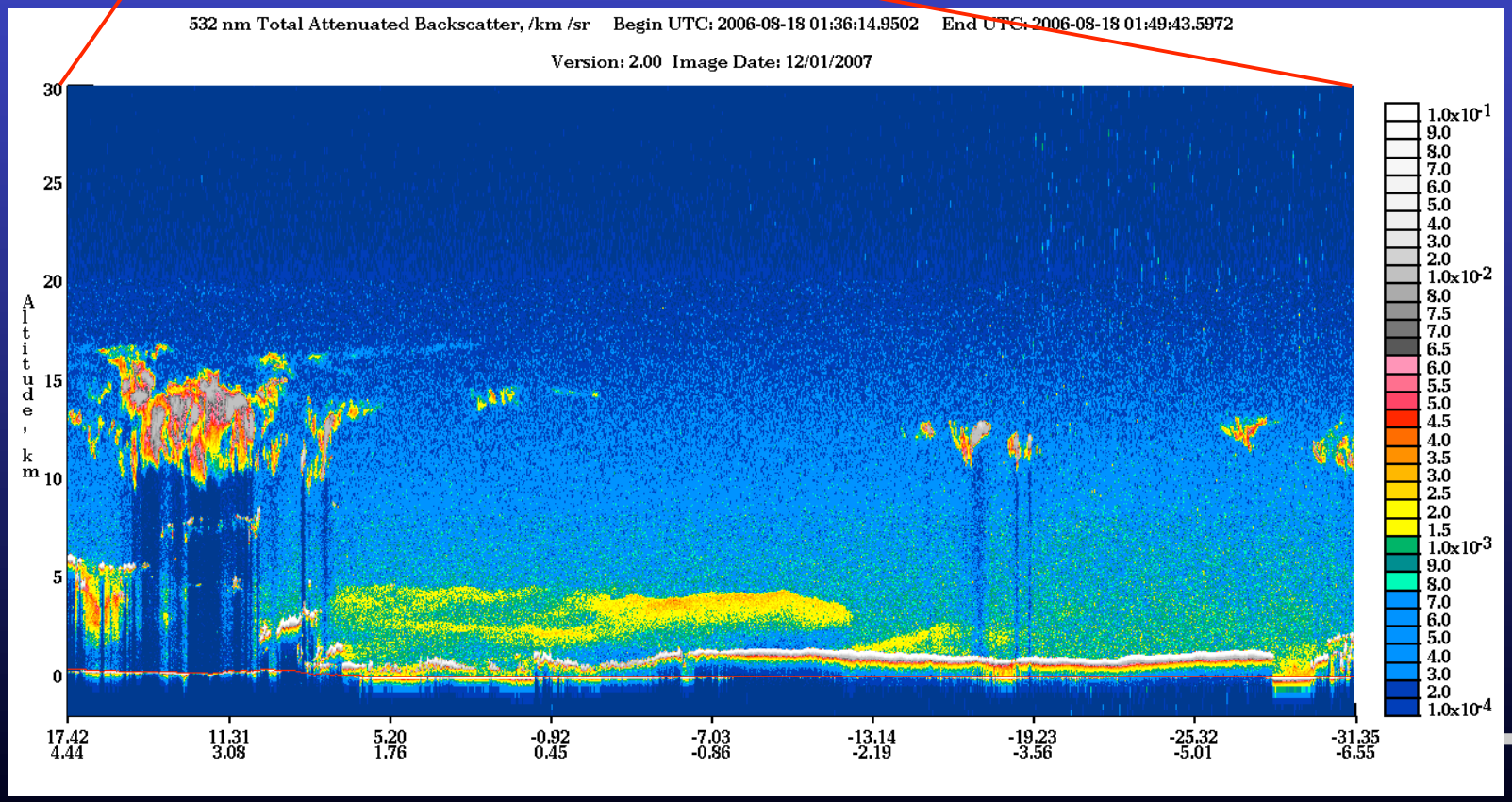


- **Water Cloud (from BTD[8.5-11])**
- **Ice Cloud (from BTD[8.5-11])**
- **Clear (from MODIS Cloud Mask)**
- **Other (to be determined)**

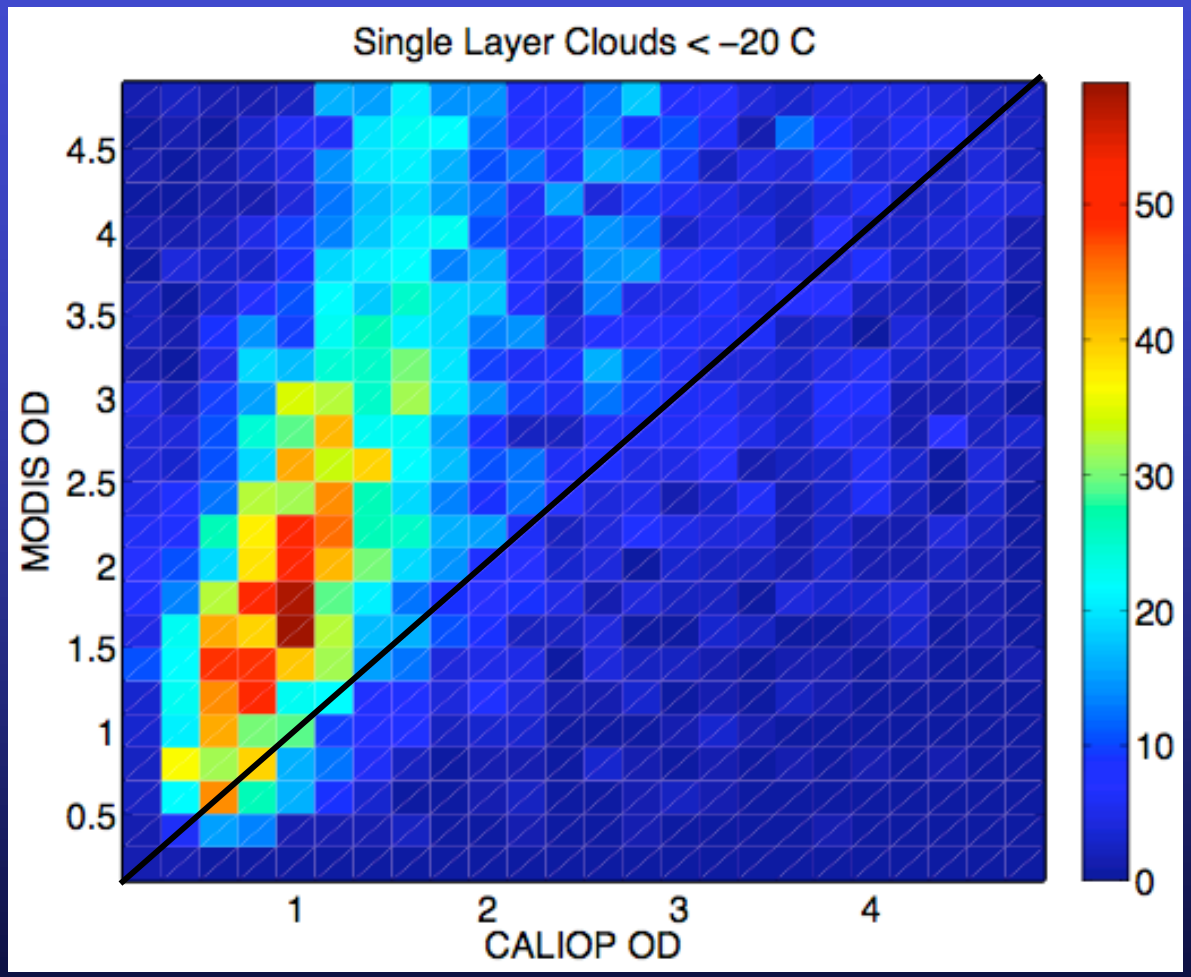
from S. Nasiri

Lidar observations of ice, aerosols, and liquid clouds



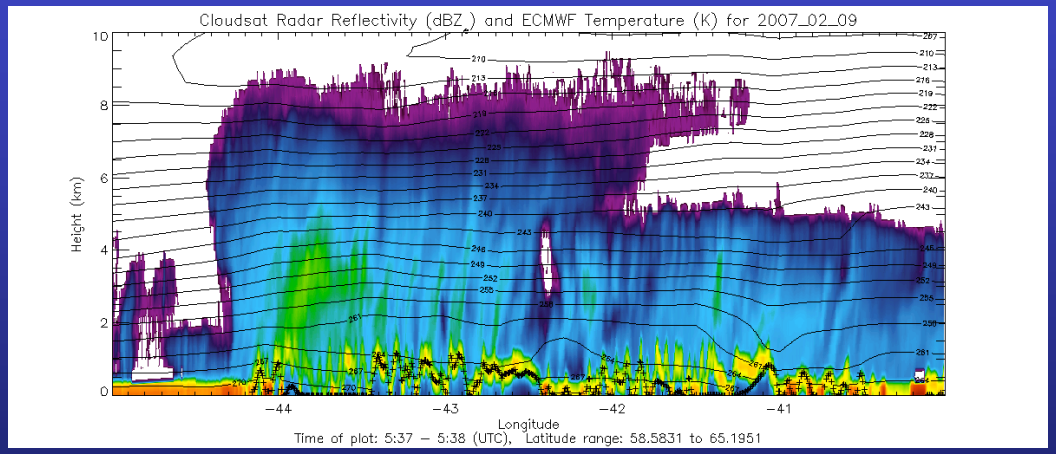


MODIS/CALIOP: Ice cloud optical depth

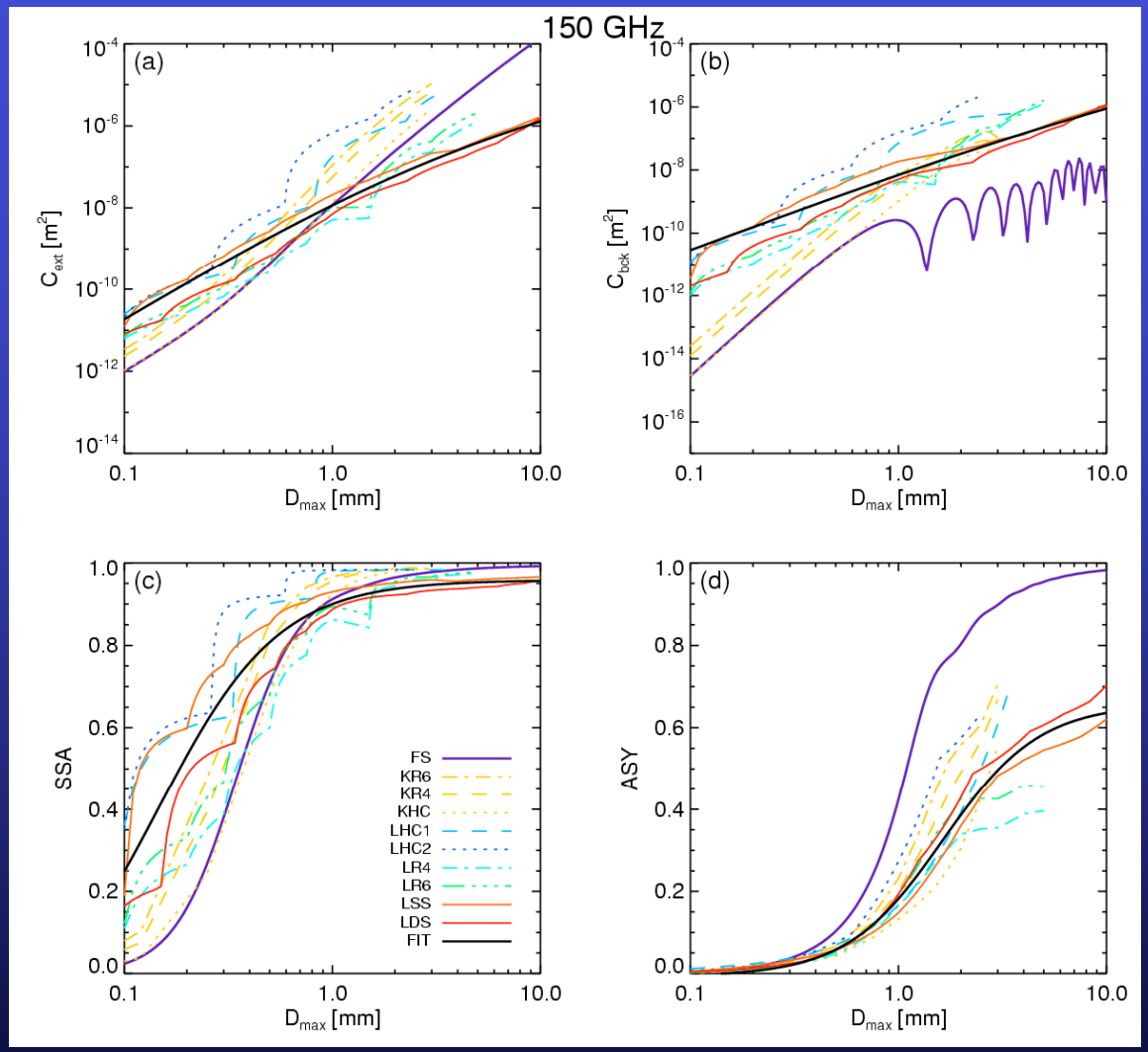


R. Holz

Microwave

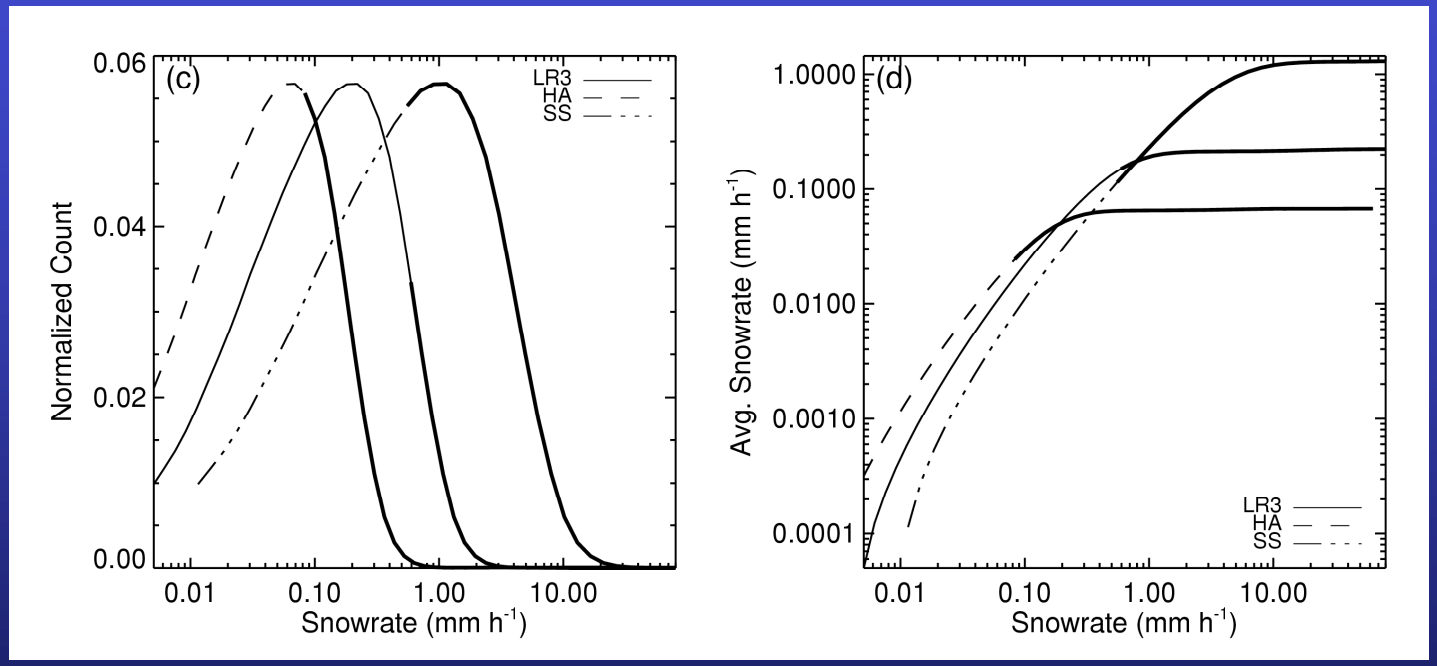

Cloudsat Radar Reflectivity (dBZ) and ECMWF Temperature (K) for 2007_02_09
Height (km)
Longitude
Time of plot: 5:37 – 5:38 (UTC), Latitude range: 58.5831 to 65.1951

Microwave



Kulie & Bennartz 2009

Microwave



Kulie & Bennartz 2009

Ice clouds

- Very difficult to assess quality of retrieved products
- Active/passive closure most promising in narrowing down uncertainties
- Lidar/radar algorithms very promising
- We need to understand the forward problem first. How well can we model/reproduce observed backscatter, radiances, and brightness temperatures? What are the limits?
- Are we asking the right question? Do GCMs have to have IWP right? What is IWP?

Rethinking

- The obvious variables are often not a good choice for comparison. For example, cloud fraction, effective radius are only of limited value.
- Model validation/evaluation: Phenomenological comparisons between models and observations are of very limited value.
- Often there are smarter ways of comparing data. Requires knowledge about both sides, models and observations.
- Forward problem.

Climate datasets

- Legacy: If we want to observe climate, we need to have long-term records. Polar orbiting imagers and passive microwave conical scanners most important.
- Transparency: We need to keep track of what is being done in each processing step. From calibration to level 3 gridding.
- Dynamics: Move away from static datasets. Need to be able to re-process entire time-series.
- SSM/I 20+ years (Schulz, CM-SAF) and AVHRR -PATMOS (Heidinger, NOAA) excellent examples.

Politics

- Agencies like to think in categories of ‘Developers’ versus ‘Users’. Useful on a management level but counterproductive at science level.
- Processing should reside with scientists, wherever possible. Reprocessing capabilities are crucial for successful products.
- Data access