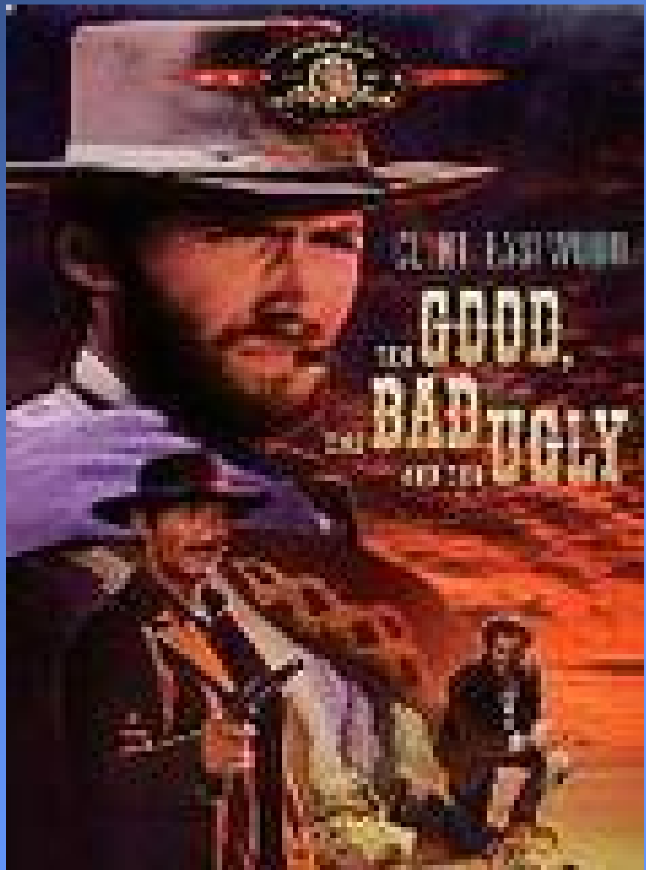
Thoughts on the old and the new satellite observations and the cloud parameterization problem

The old: limitations and motivation for the new

Preliminary results from the new era of observations

Thoughts on the workshop ‘questions’


GOOD,
BAD
UGLY

CloudSat

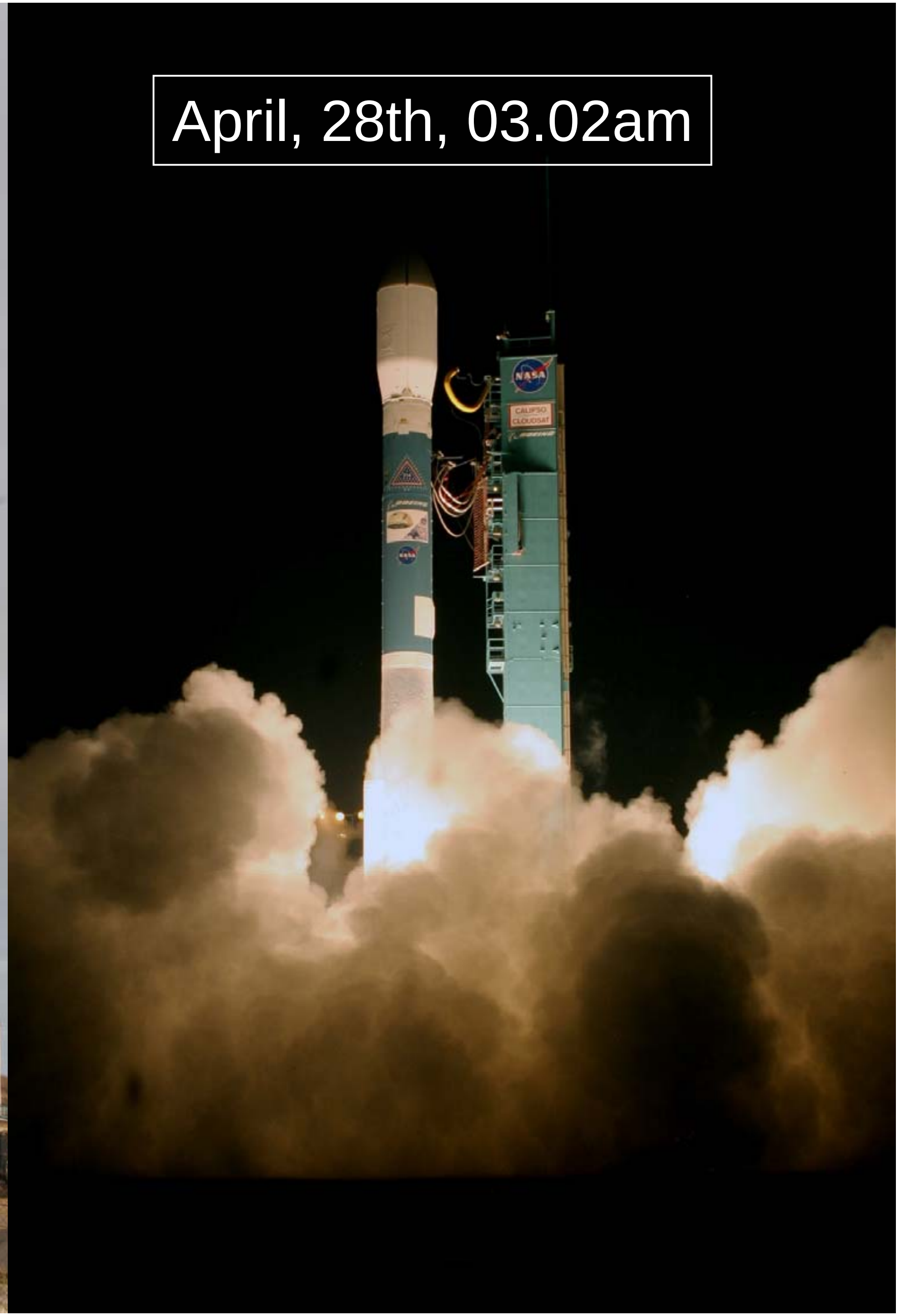
Comments on the mission and data availability

Early results on global cloud distributions

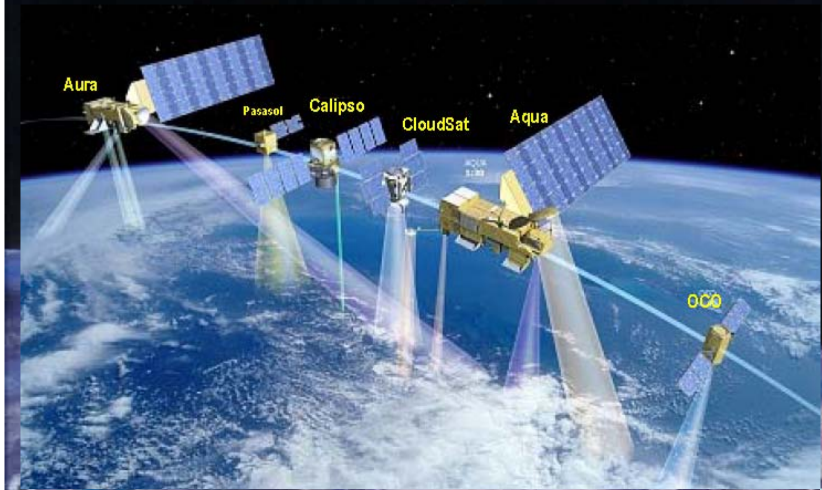
Early results on comparisons with other cloud & precipitation observations - cth, ice water and MLS, AMSR-E precipitation, …..

Critical areas ripe for attention:

- Convection
- The cloud-precipitation connection- preciptation efficiency, (warm rain) auto-conversion in shallow clouds
- Ice clouds (Duane Waliser) & UTH connection

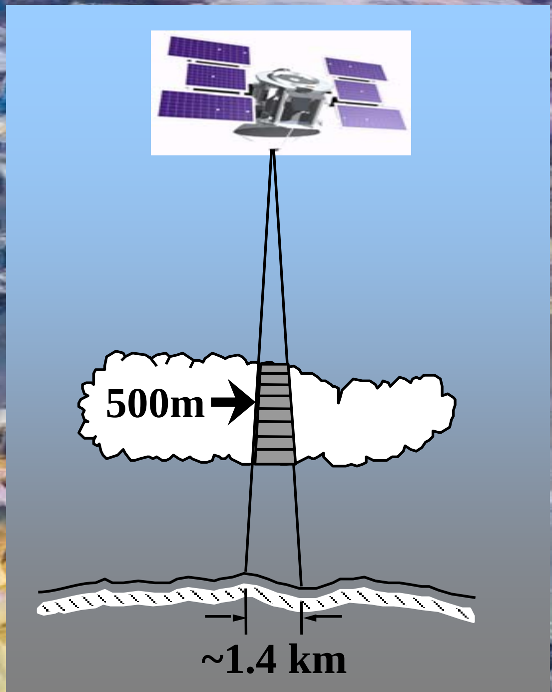

April, 28th, 03.02am

Two components to the mission design



1. Formation with the A-Train

2. The Cloud Profiling Radar (CPR)



- Nadir pointing, 94 GHz radar
- 3.3μs pulse ➔ 500m vertical res, over-sampled at ~240m
- 1.4 km horizontal res.
- Sensitivity ~ -28 dBZ (more like -32 dBZ)
- Dynamic Range: 80 dB
- Calibration to within 2dBZ

The CloudSat Mission

Primary Objective: To provide, from space, the first global survey of **cloud (& precip)** profiles and **cloud** physical properties, with seasonal and geographical variations needed to evaluate the way **clouds** (& precip) are parameterized in global models, thereby contributing to weather predictions, climate and the **cloud**-climate feedback problem.

Key highlights:

Launched on April 28th

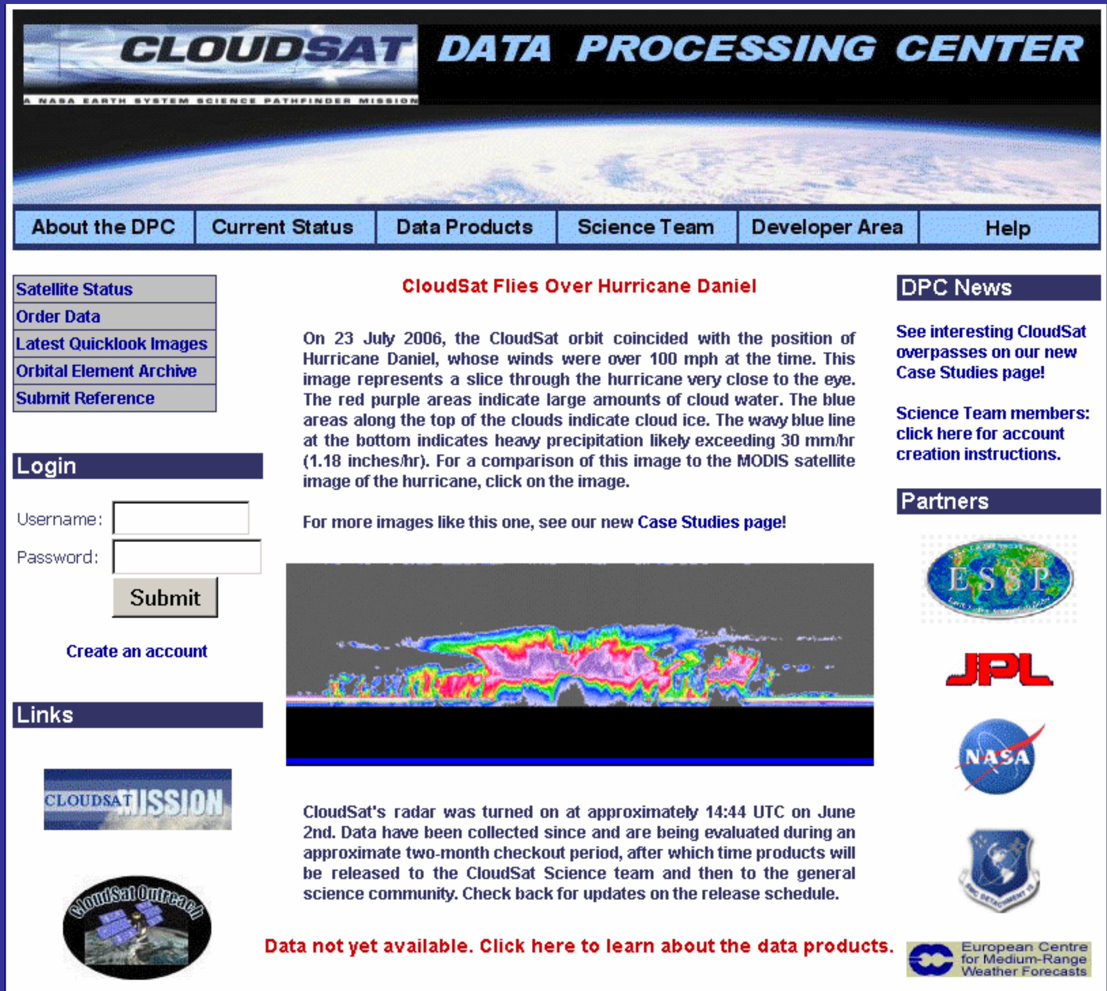
Instrument turn on May 20th (4 hour test) & operations began June 2

Calibration activities - ocean views & sfc, aircraft val experiments have confirmed radar performance - calibration within 2 dBz, minimum sensitivity (early life~-32 dBZ)

Since launch, we have ~116 passes over named tropical storms and 5 passes through the eye of trop cyclones

General *initial* data release, Nov 2006

CloudSat Data Processing Center (DPC)



http://www.cloudsat.cira.colostate.edu

CloudSat Data Products

- Level 0 (from RSC)

  0A-CPR – raw science data

  SSOH - stored (instrument) state-of-health data

- Level 1 (geolocation and time added to data)

  1A-AUX – Geolocation, time, engr. data

  1B-CPR – Calibrated CPR ±2dBZ

  1B-CPR-FL - Calibrated CPR (First Look)

- Level 2 (science data products)

  2B-GEOPROF - geometrical profile* -30 dBZ, 500m, z>1km

  2B-CLDCLASS - cloud type classification

  2B-TAU-OFF-N - cloud optical depth (off nadir)

  2B-LWC - cloud liquid water content LWP~20%

  2B-IWC - cloud ice water content IWP ~30%

  2B-FLXHR - fluxes and heating rates

  2B-E -(Precipitation) TBD

- Level 3 (summary/statistical data products)

  Summary statistics on a global 1 degree grid

*** CloudSat also is producing a lidar-radar version of geoprof that will become available as CALIPSO data becomes available**

CloudSat's cloud - precipitation activities

•Algorithms:

- PIA - precip occurrence, surface precip (relies on surface σ_o)
- Profile (slope) method of Matrosov (2-5km) extends precip > 10 mm/hr
- Bayesian vertical profile of precip using PIA, Z (but could add other obs) and implicitly accommodates the slope approach

•Strengths:

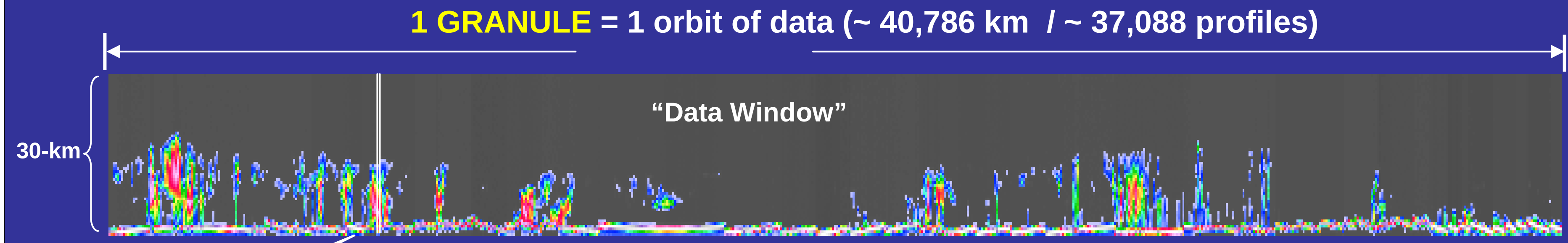
- CPR offers higher spatial resolution than other sensors that directly measure precipitation - very sensitive precip detector
- Sensitivity to continuum of ***clouds, drizzle, rainfall, and snowfall*** facilitates studying transition regions and fills gaps missed by both TRMM and GPM. Connecting cloud & precip is compelling

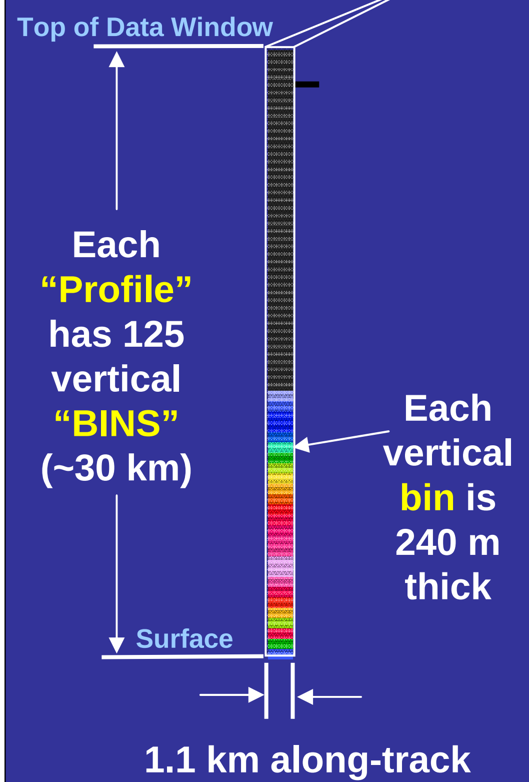
•Weaknesses:

- Strong attenuation at 94 GHz limits (PIA) retrievals ≤10 mm/hr
- Single-frequency method limits information regarding the dielectric properties of the melting layer and restricts DSD assumptions
- CPR is nadir-pointing providing only a 2D slice but it is global

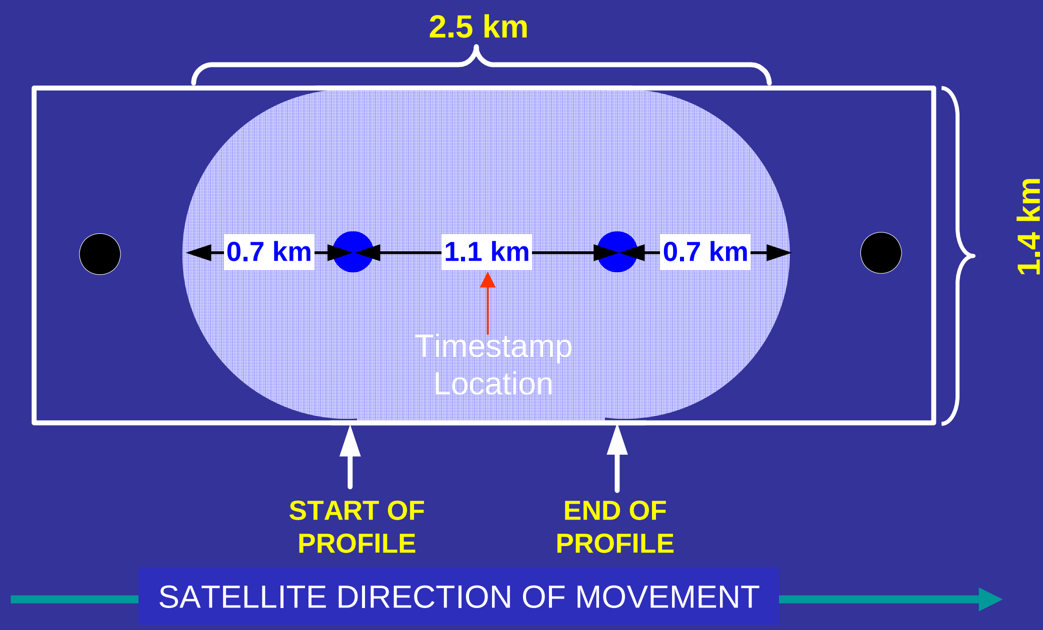
Preliminary

CloudSat DPC: CPR footprint & granule size





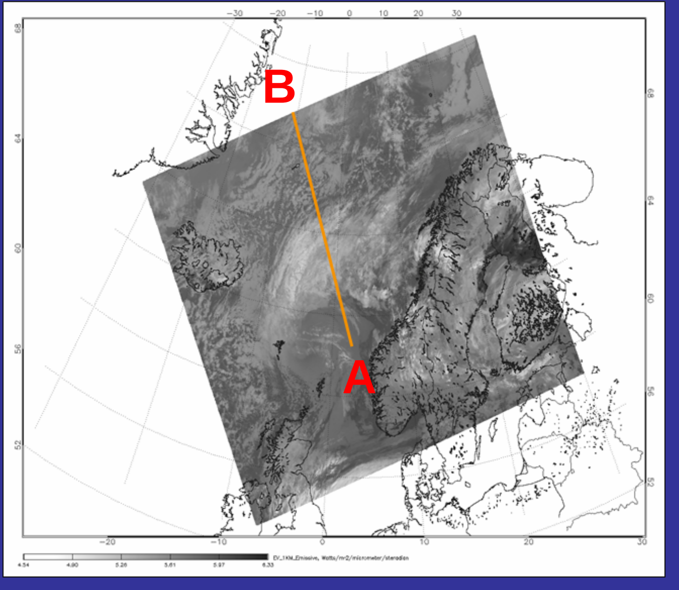
- Granule begins on descending node (night side)
- "Data Window" is 30-km high by 37,088 profiles wide



98.9 minutes per orbit 14.56 orbits/day

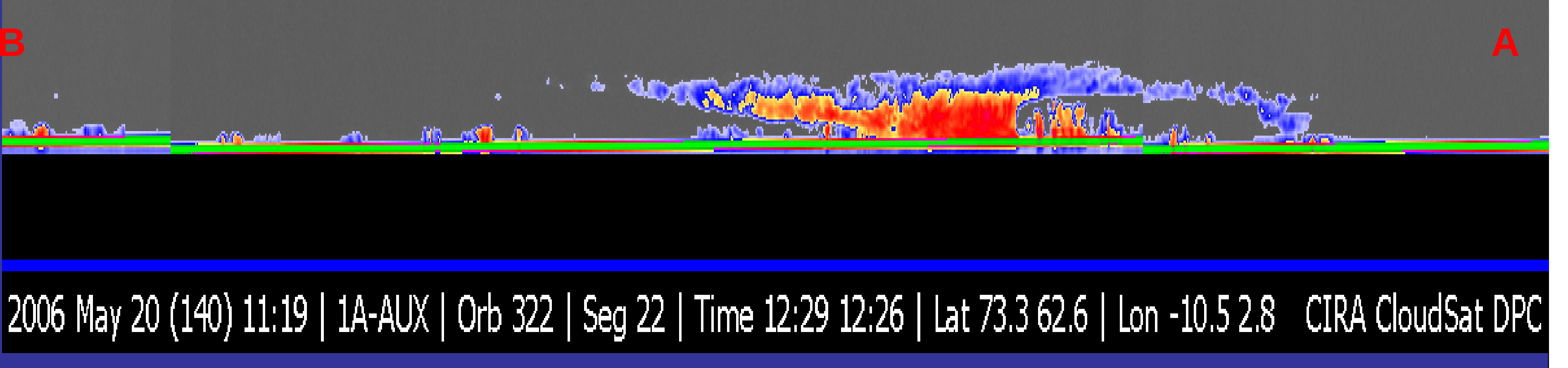
CloudSat - FIRST IMAGE

This segment was the first dump of CloudSat data - 20 May 2006 12:26-12:29 UTC

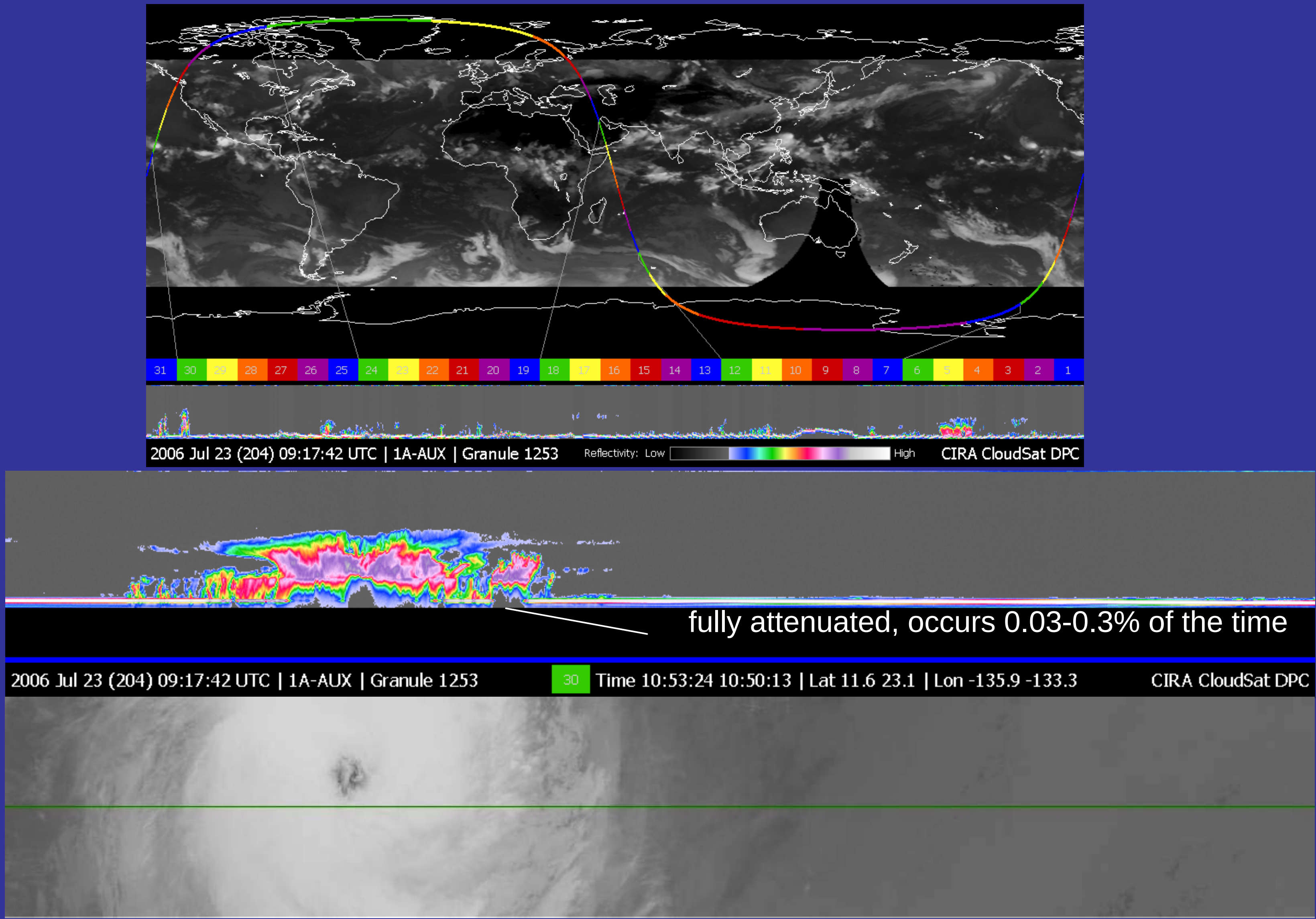


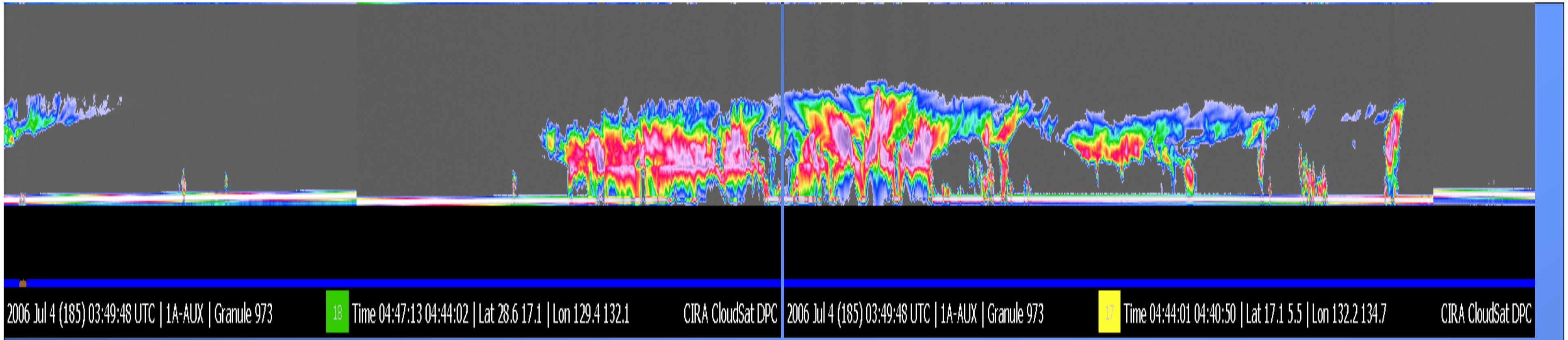
Location of CloudSat data segment on a 5-minute MODIS infrared (10.8μ) data swath.
(approx. 25 minutes prior to CloudSat overpass)

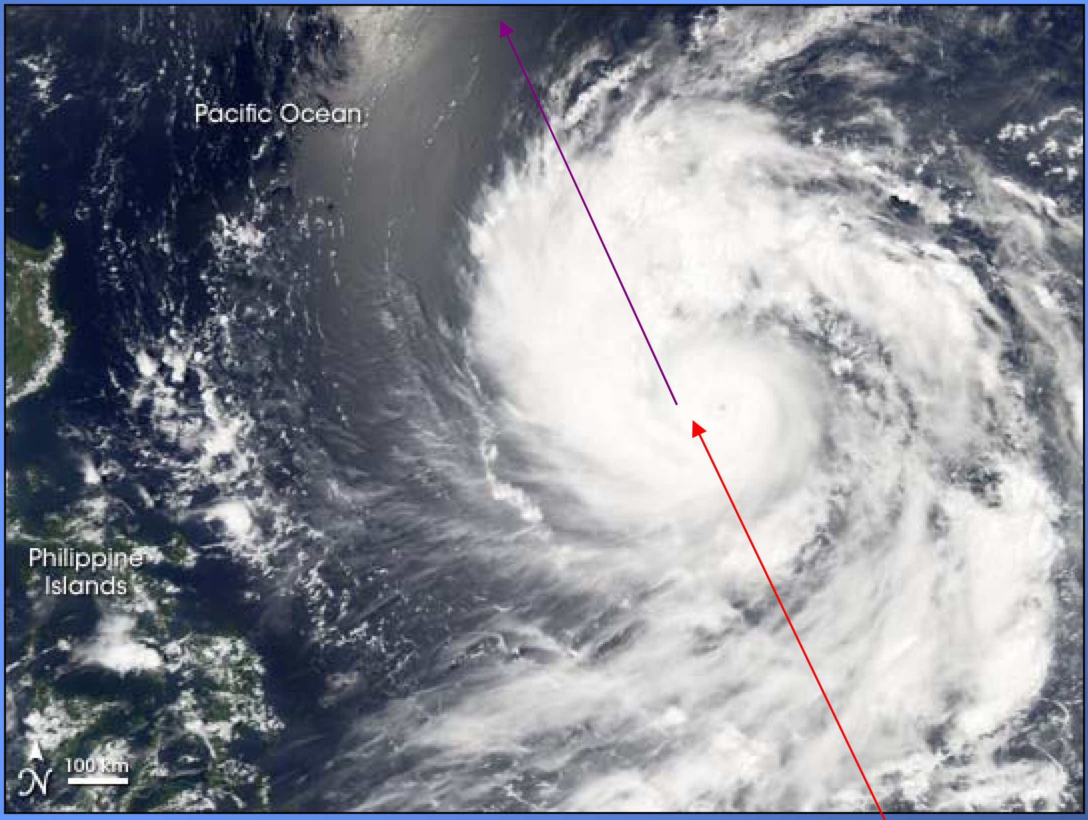
(MODIS image downloaded from Goddard DAAC)



CloudSat - Quicklook Image – Geo and MODIS imagery

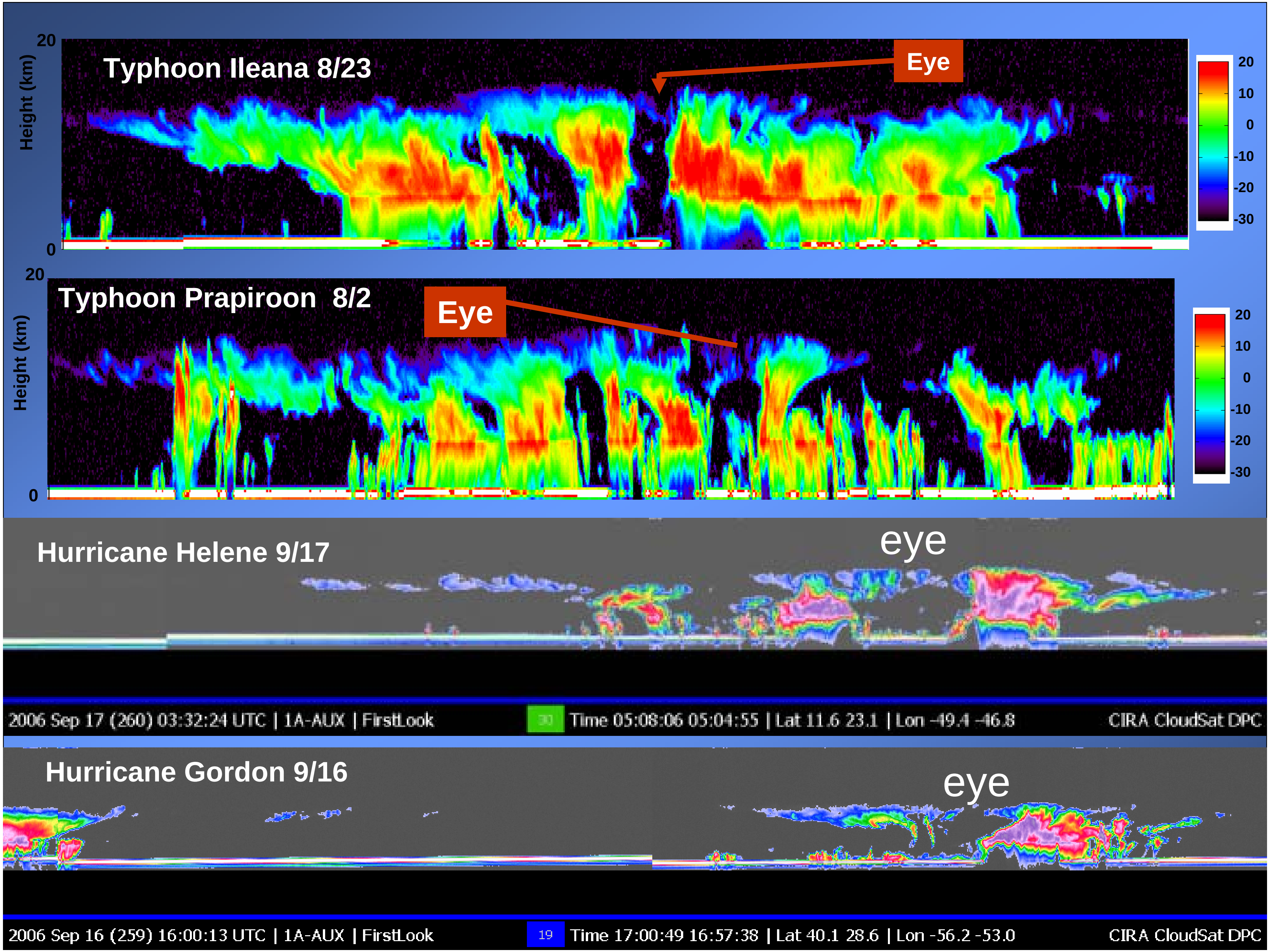






Day 185 July 4
20,130

Through the Eye of Typhoon Ewiniar


Typhoon Ileana 8/23
Eye
Height (km)
20
0
20
10
0
-10
-20
-30
Typhoon Prapiroon 8/2
Eye
Height (km)
20
0
20
10
0
-10
-20
-30
Hurricane Helene 9/17
eye
2006 Sep 17 (260) 03:32:24 UTC | 1A-AUX | FirstLook
Time 05:08:06 05:04:55 | Lat 11.6 23.1 | Lon -49.4 -46.8
CIRA CloudSat DPC
Hurricane Gordon 9/16
eye
2006 Sep 16 (259) 16:00:13 UTC | 1A-AUX | FirstLook
19
Time 17:00:49 16:57:38 | Lat 40.1 28.6 | Lon -56.2 -53.0
CIRA CloudSat DPC

The 2B Geoprof and Cldclass

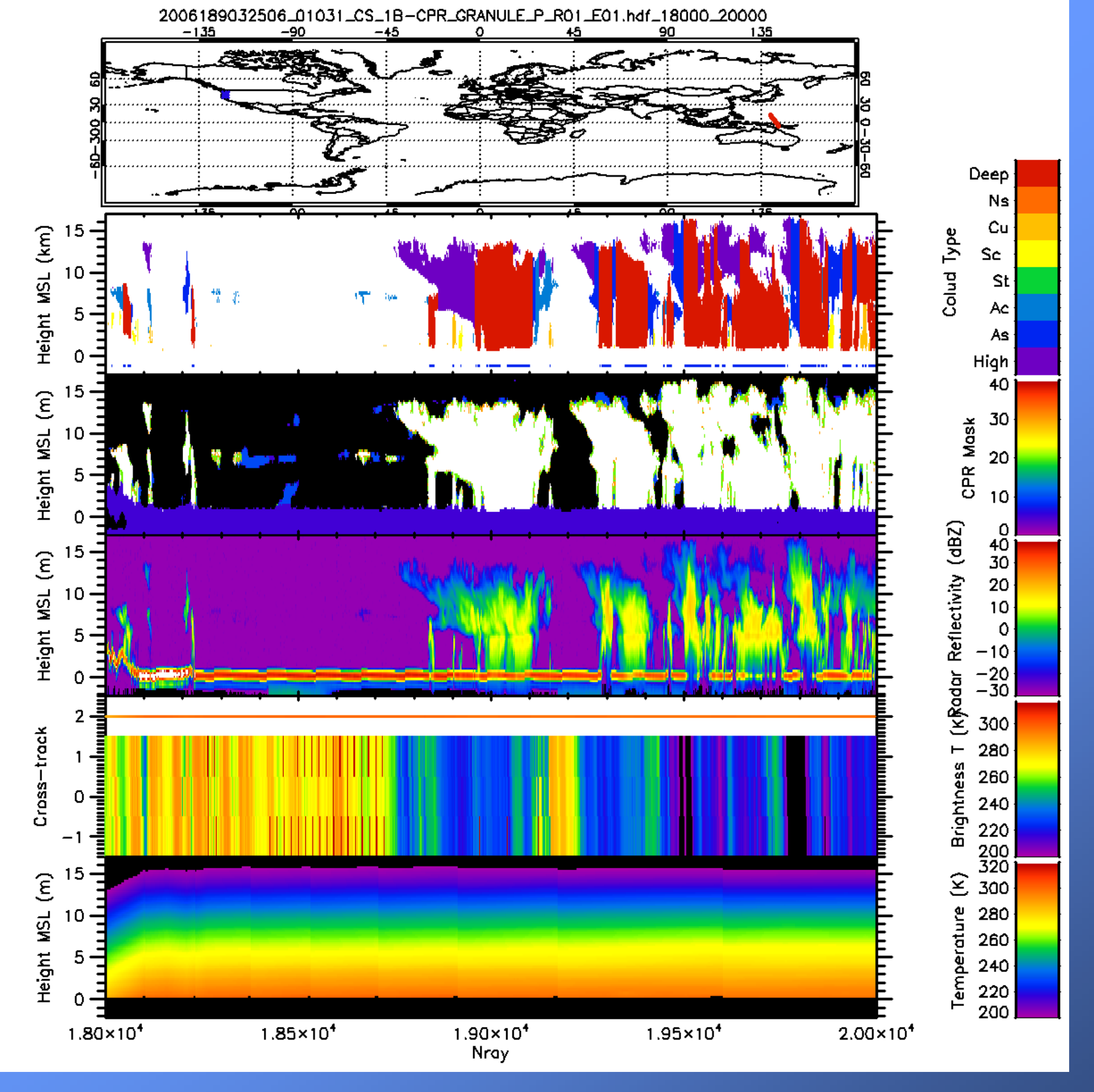
Classification (2B-CLDCLASS)

Mask (2B-GEOPROF)

Reflectivity (dBZ) (1B-CPR in 2B-geoprof)

MODIS

ECMWF T(z)

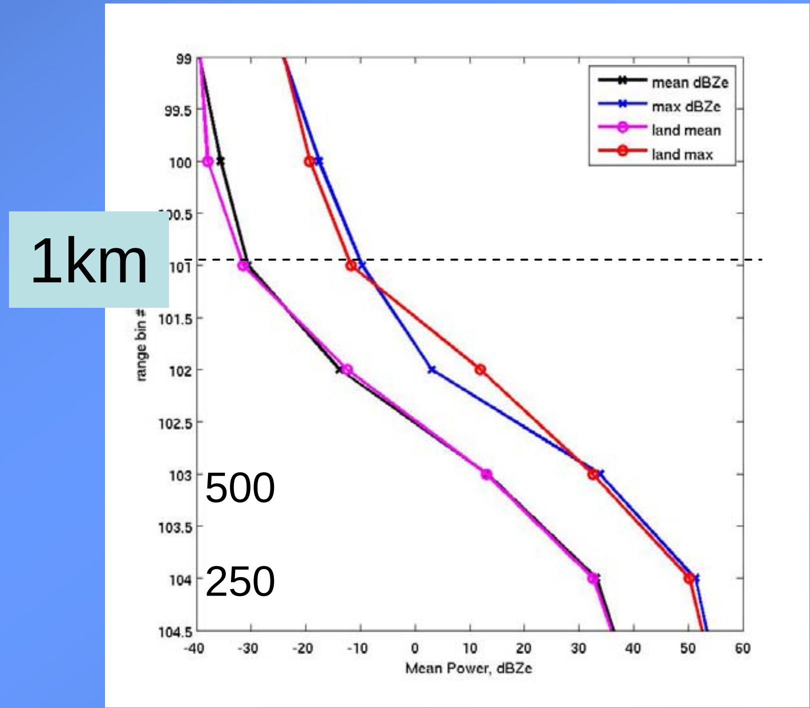


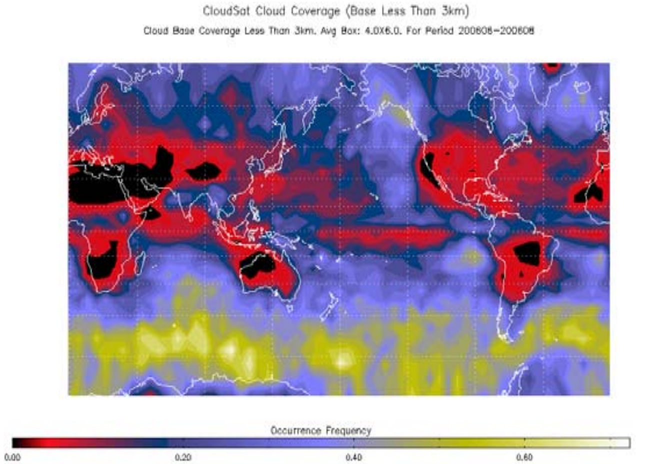
Surface reflection issues:

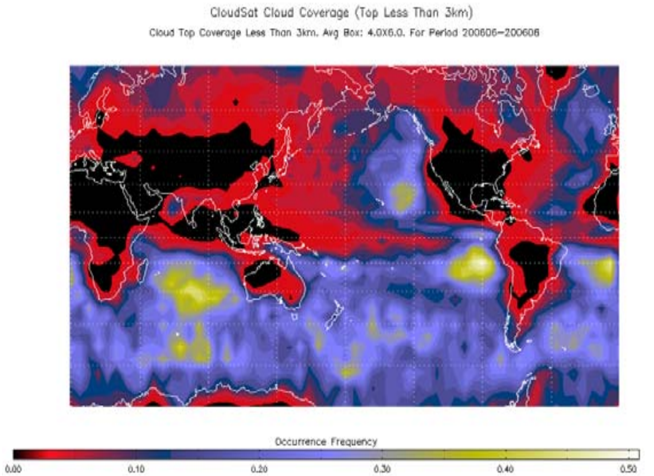
The issue: surface leakage into bottom two bins:

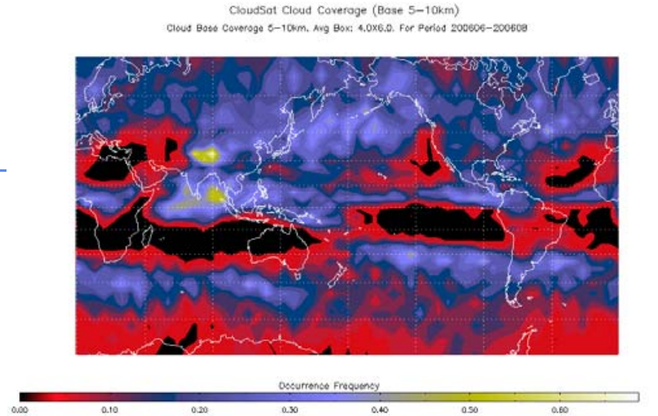
Consequence: only drizzle (and precip) will be detected in 500-1000m bin

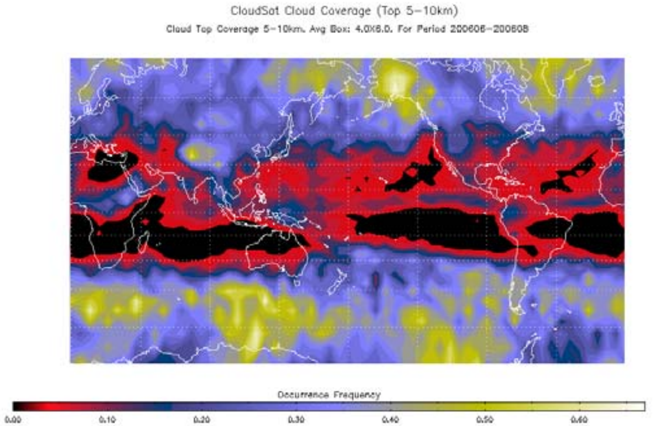
Non-precipitating low clouds (and fog below 1 km) need to be addressed using other sensors

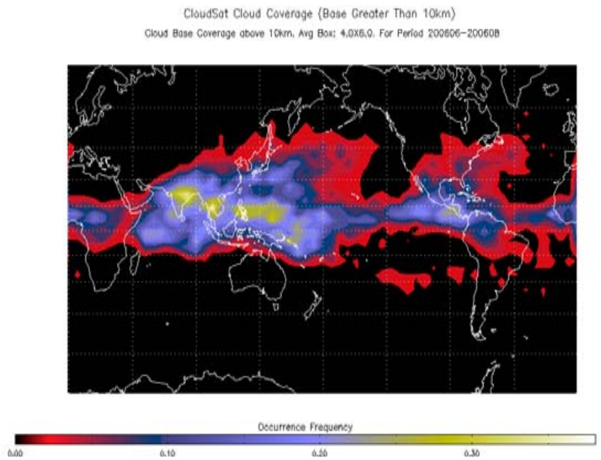


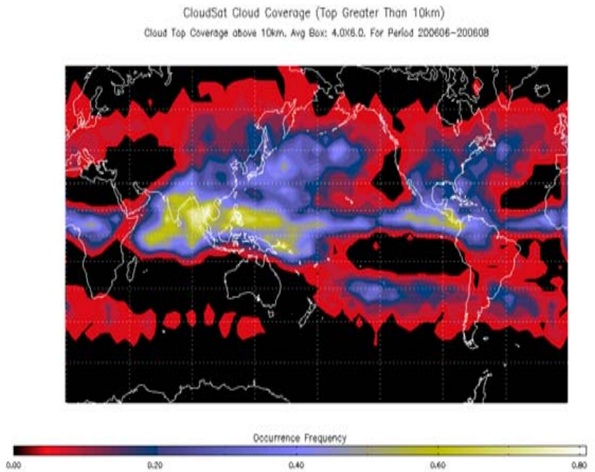

CloudSat Cloud Coverage (Base Less Than 3km)
Cloud Base Coverage Less Than 3km. Avg Box: 4.0X6.0. For Period 200606-200608
Occurrence Frequency
0.00 0.20 0.40 0.60


CloudSat Cloud Coverage (Top Less Than 3km)
Cloud Top Coverage Less Than 3km. Avg Box: 4.0X6.0. For Period 200606-200608
Occurrence Frequency
0.00 0.10 0.20 0.30 0.40 0.50

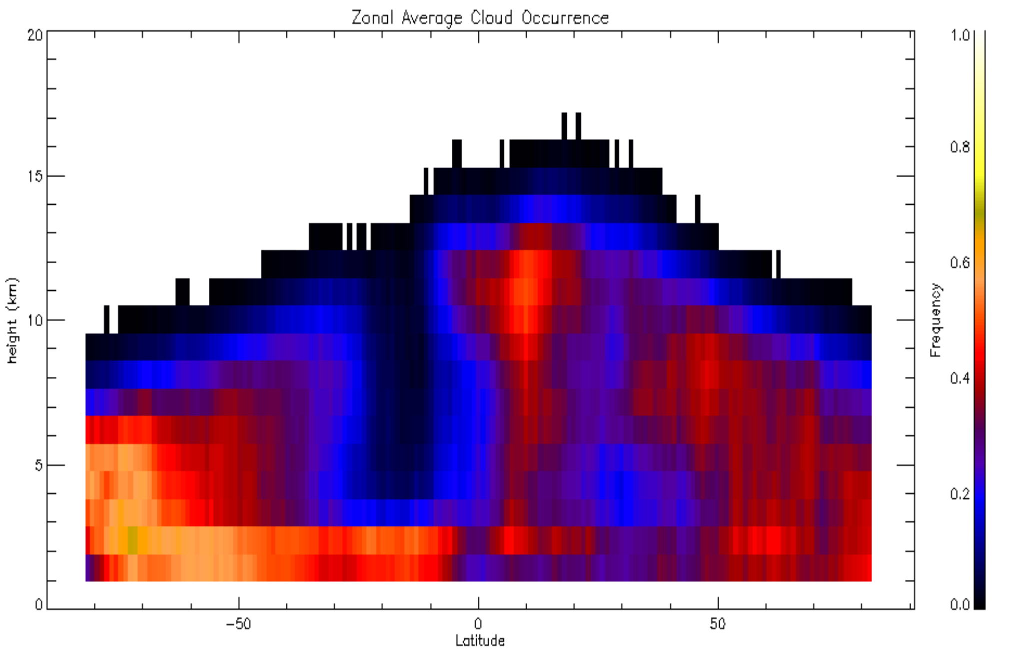

CloudSat Cloud Coverage (Base 5–10km)
Cloud Base Coverage 5-10km. Avg Box: 4.0X6.0. For Period 200606-200608
Occurrence Frequency
0.00 0.10 0.20 0.30 0.40 0.50 0.60

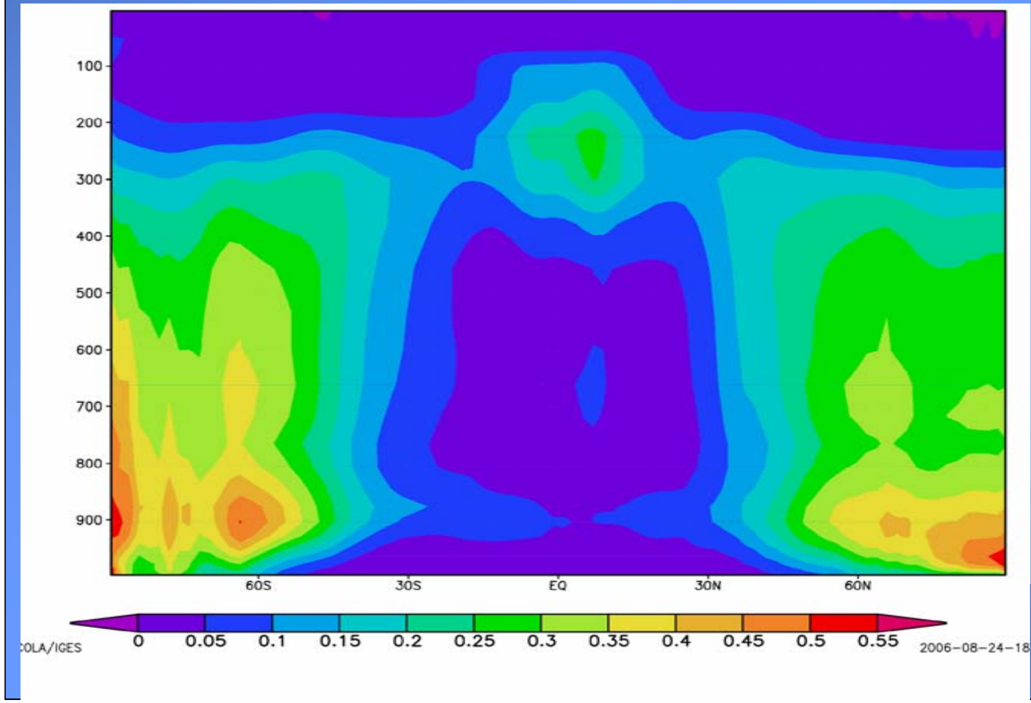

CloudSat Cloud Coverage (Top 5–10km)
Cloud Top Coverage 5-10km. Avg Box: 4.0X6.0. For Period 200606-200608
Occurrence Frequency
0.00 0.10 0.20 0.30 0.40 0.50 0.60


CloudSat Cloud Coverage (Base Greater Than 10km)
Cloud Base Coverage above 10km. Avg Box: 4.0X6.0. For Period 200606-200608
Occurrence Frequency
0.00 0.10 0.20 0.30


CloudSat Cloud Coverage (Top Greater Than 10km)
Cloud Top Coverage above 10km. Avg Box: 4.0X6.0. For Period 200606-200608
Occurrence Frequency
0.00 0.20 0.40 0.60 0.80

Mace et al





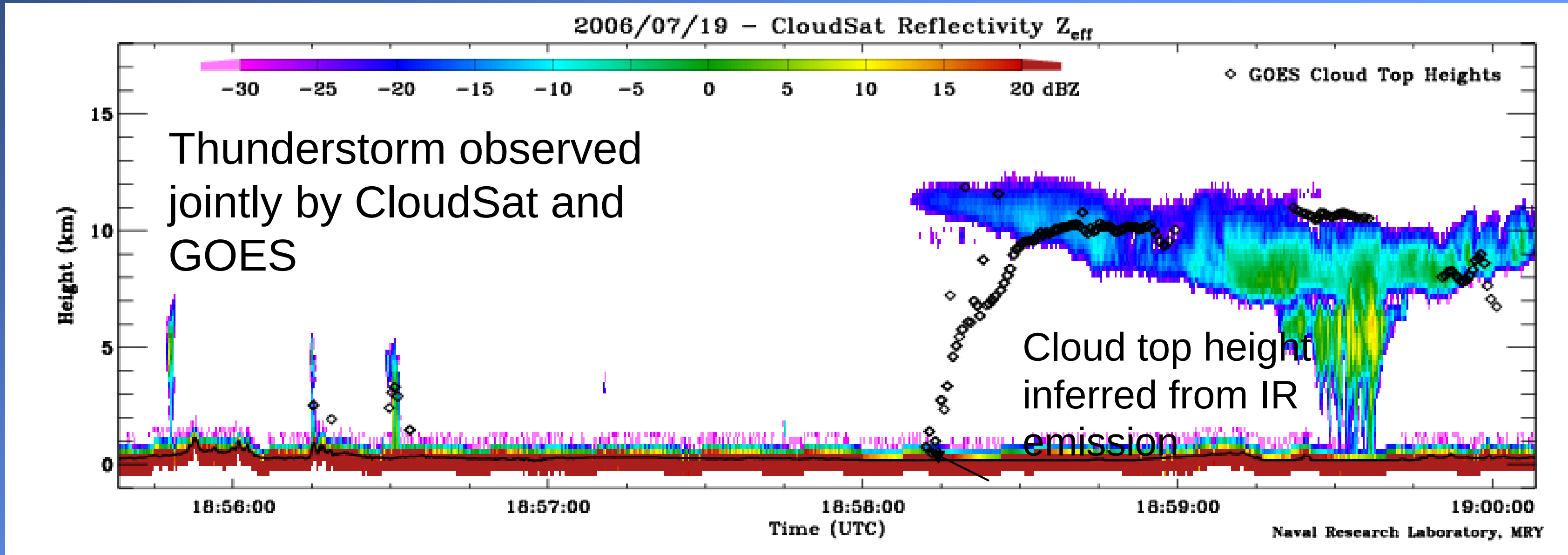
July-August zonally averaged distribution of cloudiness derived from the CloudSat 2b-geoprof mask product.

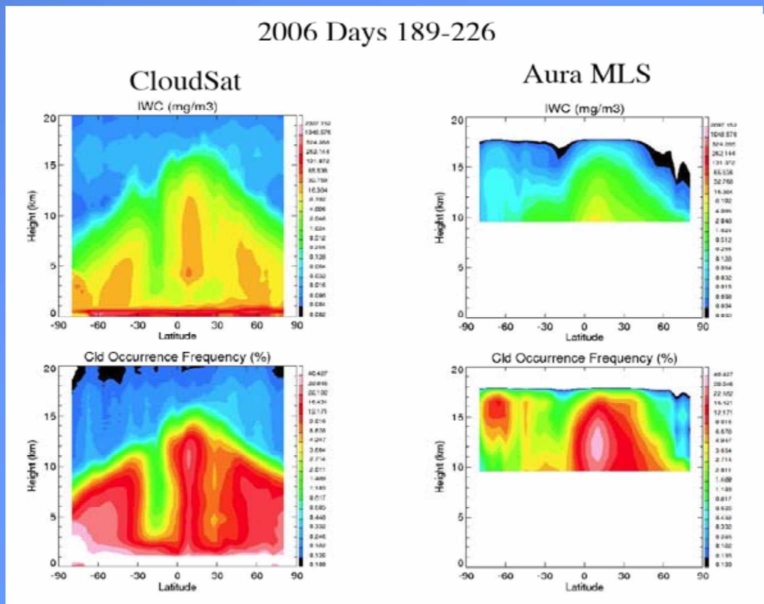
JJA zonally averaged distribution of cloudiness from one climate model-

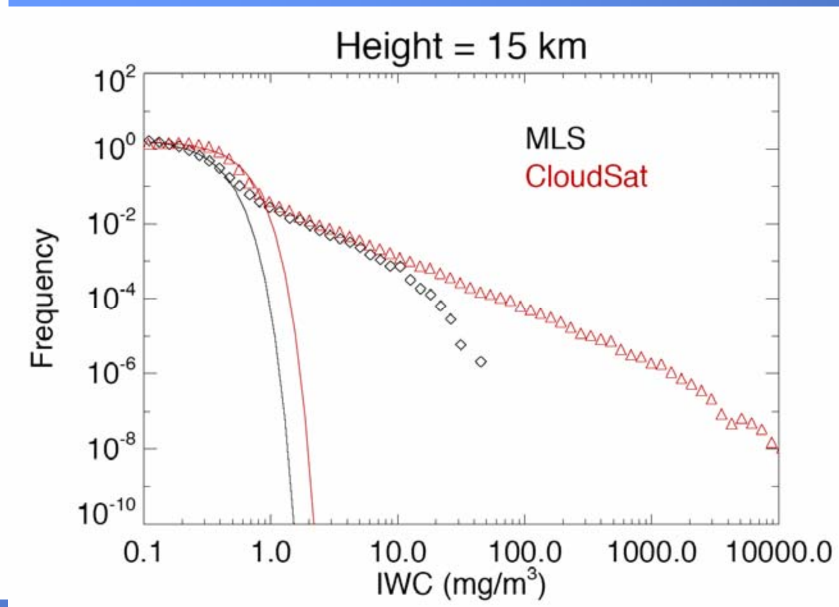
preliminary results, Mace and Klein

The point is that such comparison is not without ambiguity - e.g. how do we represent 'convective cloudiness' ,precip versus cloud

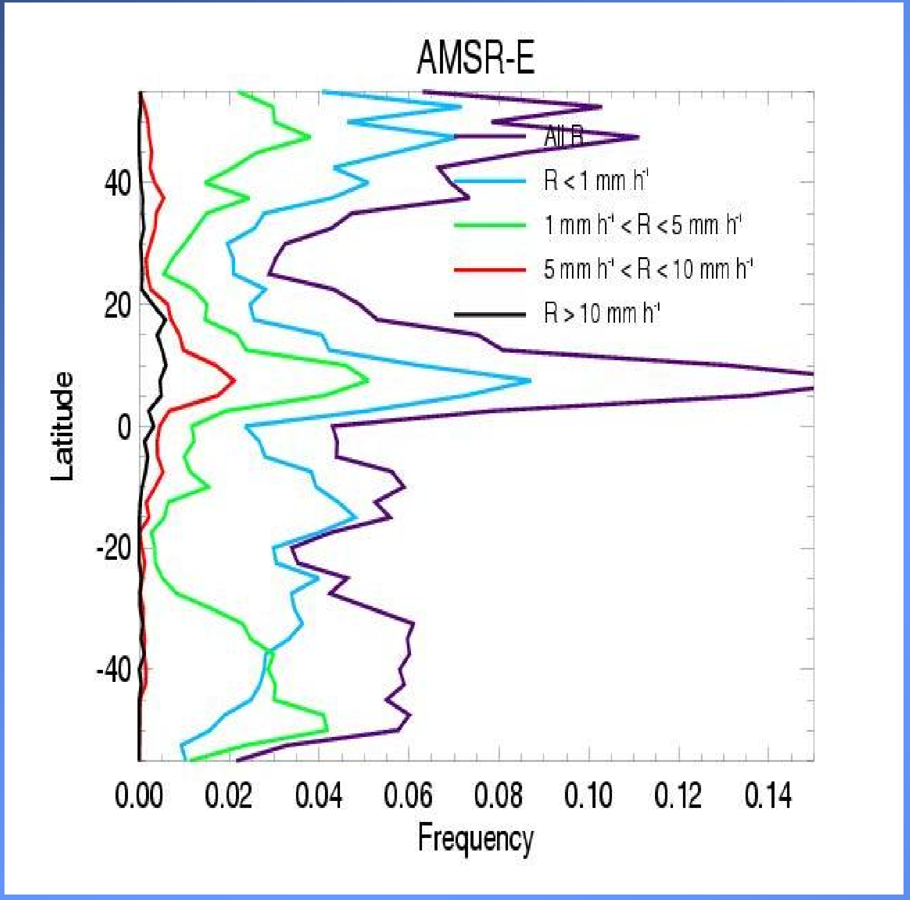
Cloud property comparisons

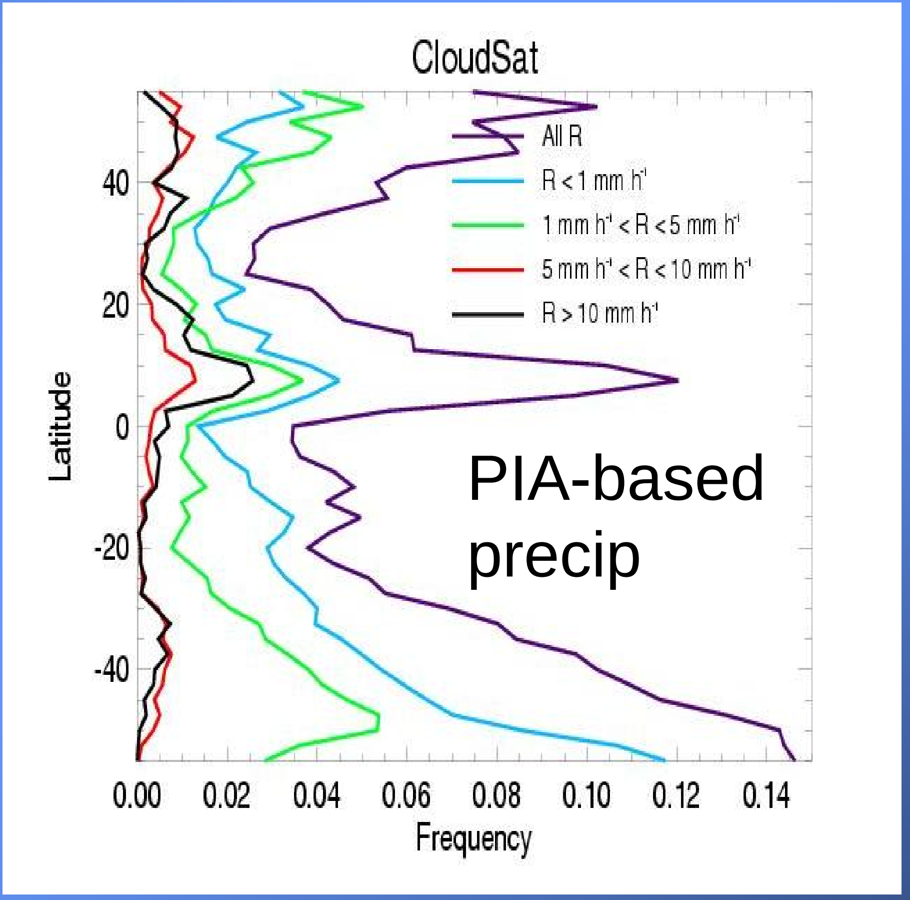






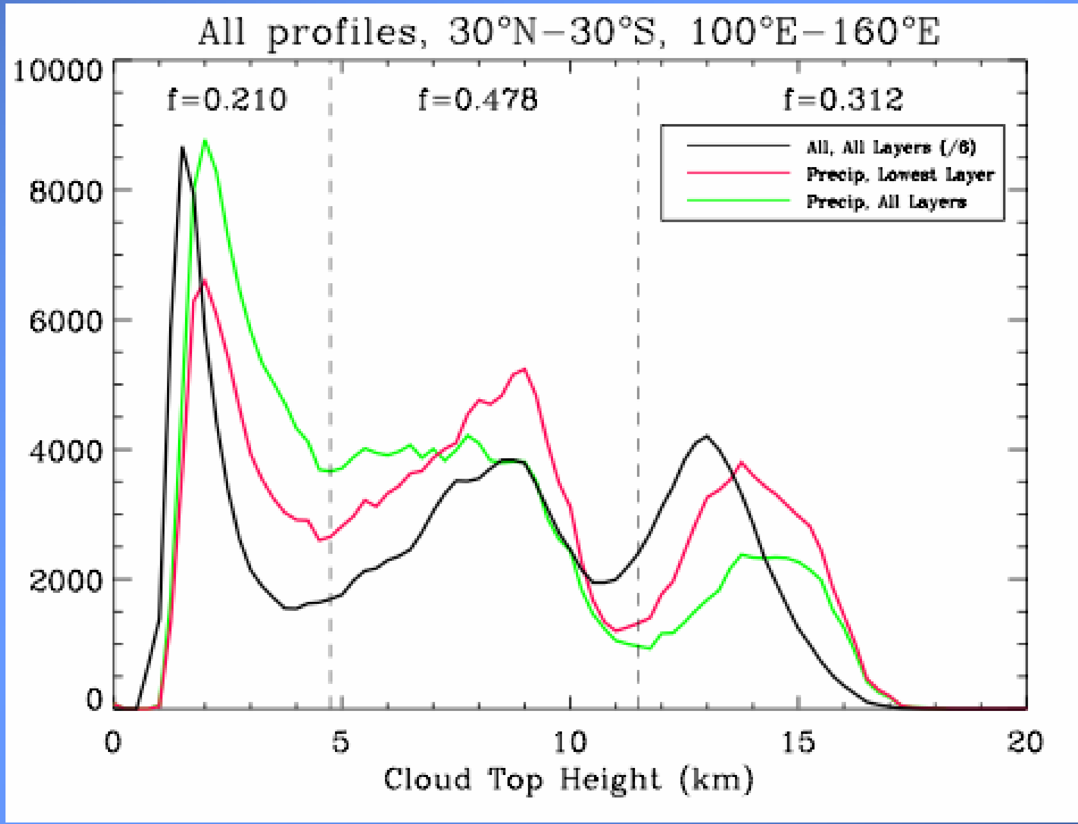
Comparison of PIA with AMSR-E





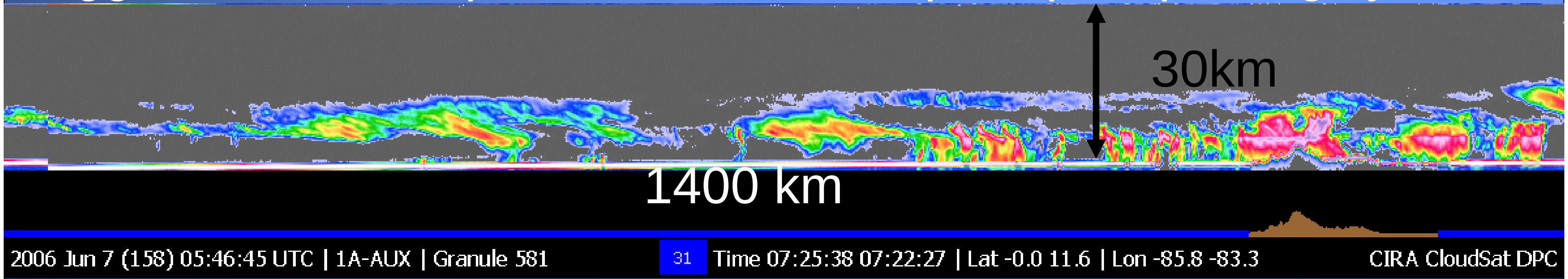
16 days of direct pixel match-ups during August 2006

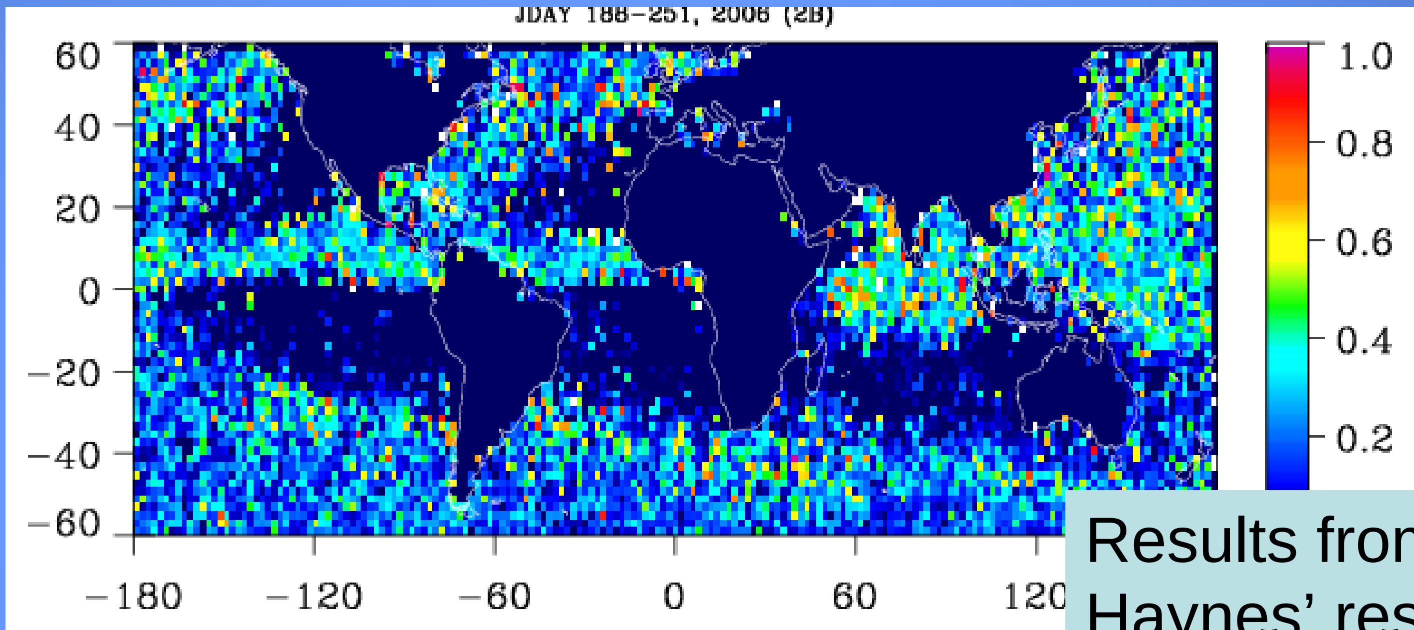
We are just beginning to quantify the properties of precipitation as a function of cloud



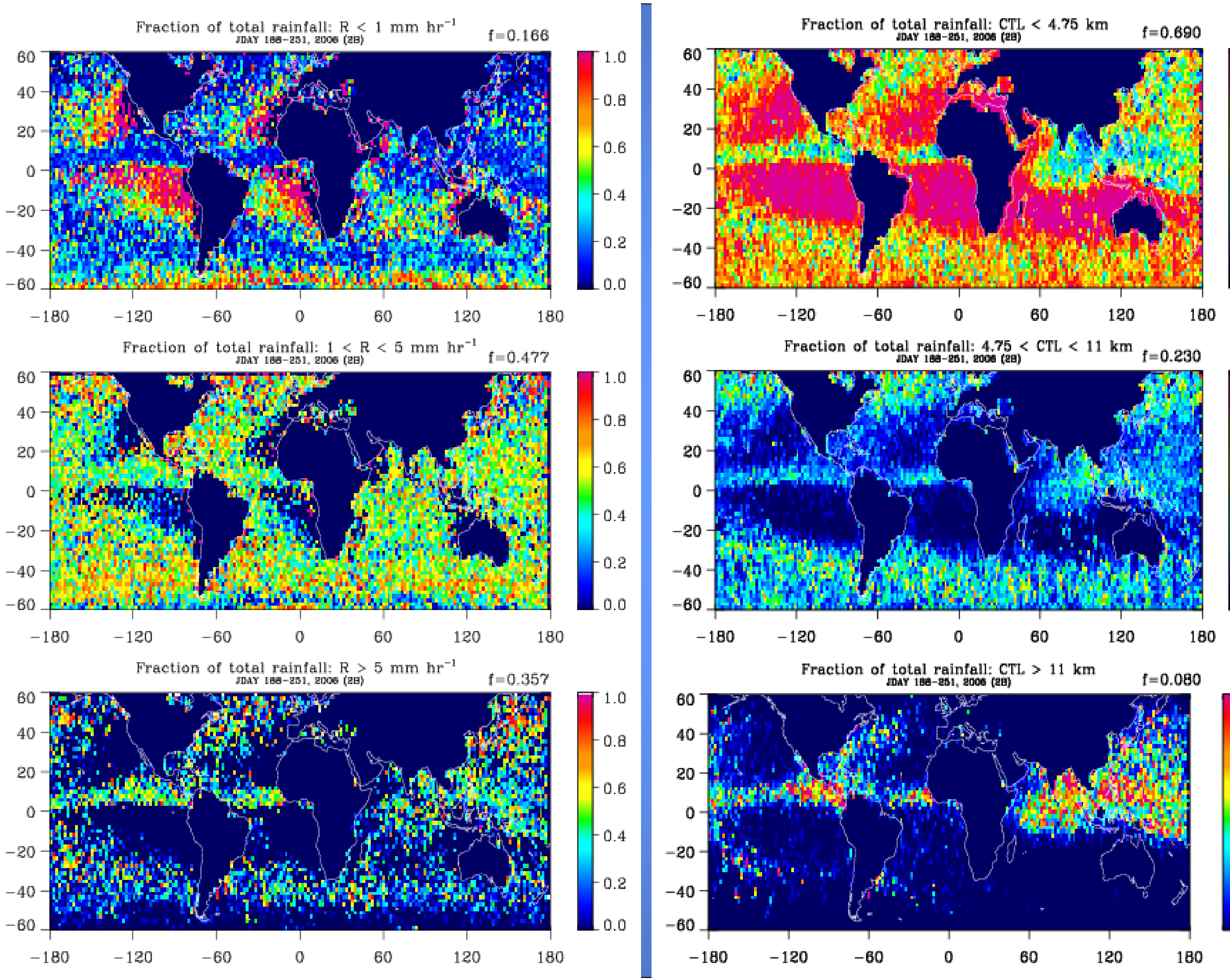
PIA based results

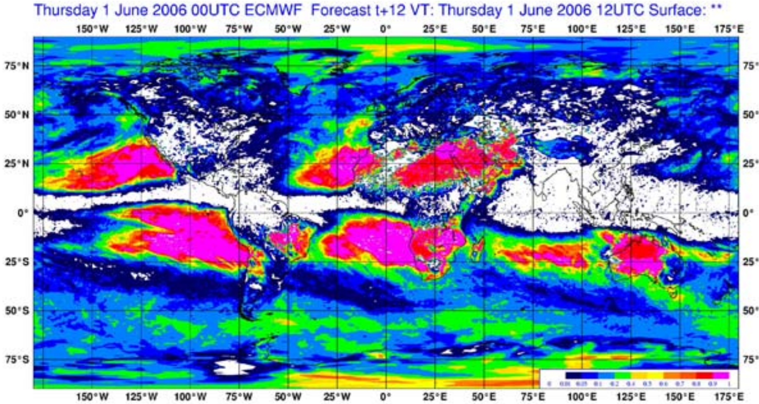
Our research using ARM observations at one tropical site reveals that tropical convective precipitation falling from multiple layered clouds is frequent and significant (~40% of total) - CloudSat also suggests it is a ubiquitous feature of tropical precipitating systems

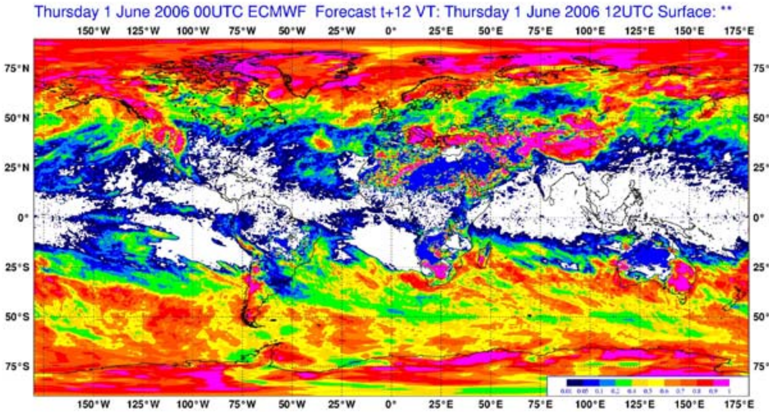


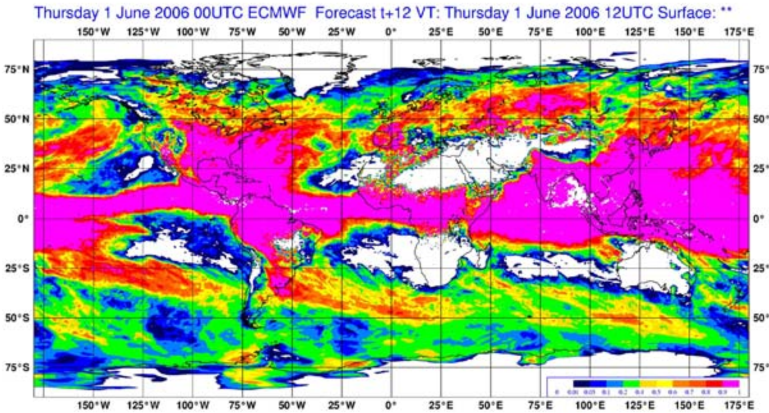


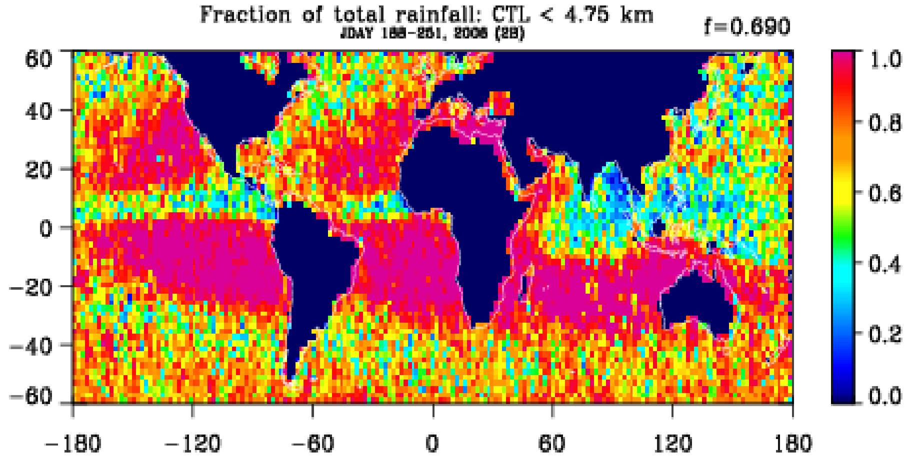
Results from John Haynes' research

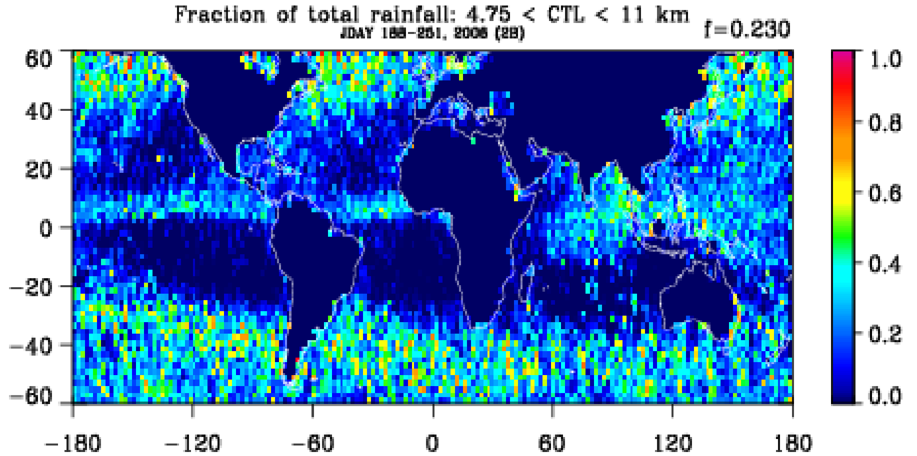

Fraction of total rainfall: R < 1 mm hr^-1
JDAY 188-251, 2006 (2B)
f=0.166
Fraction of total rainfall: 1 < R < 5 mm hr^-1
JDAY 188-251, 2006 (2B)
f=0.477
Fraction of total rainfall: R > 5 mm hr^-1
JDAY 188-251, 2006 (2B)
f=0.357
Fraction of total rainfall: CTL < 4.75 km
JDAY 188-251, 2006 (2B)
f=0.690
Fraction of total rainfall: 4.75 < CTL < 11 km
JDAY 188-251, 2006 (2B)
f=0.230
Fraction of total rainfall: CTL > 11 km
JDAY 188-251, 2006 (2B)
f=0.080

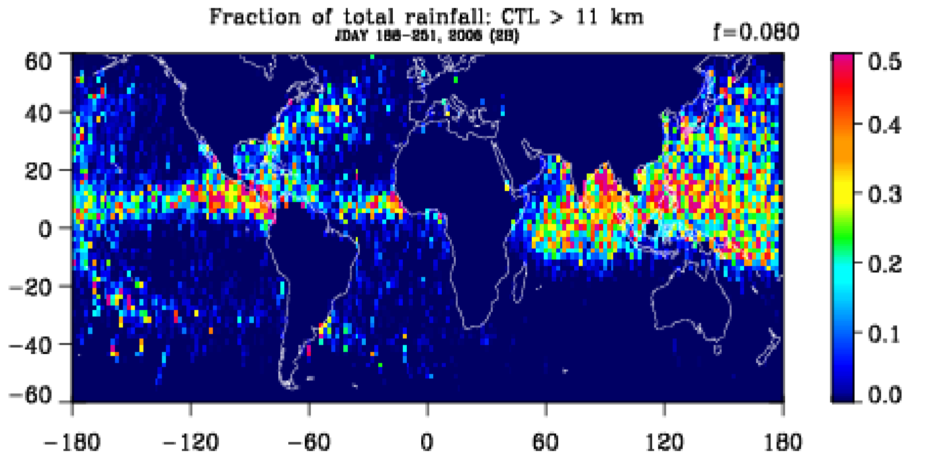

Thursday 1 June 2006 00UTC ECMWF Forecast t+12 VT: Thursday 1 June 2006 12UTC Surface: **

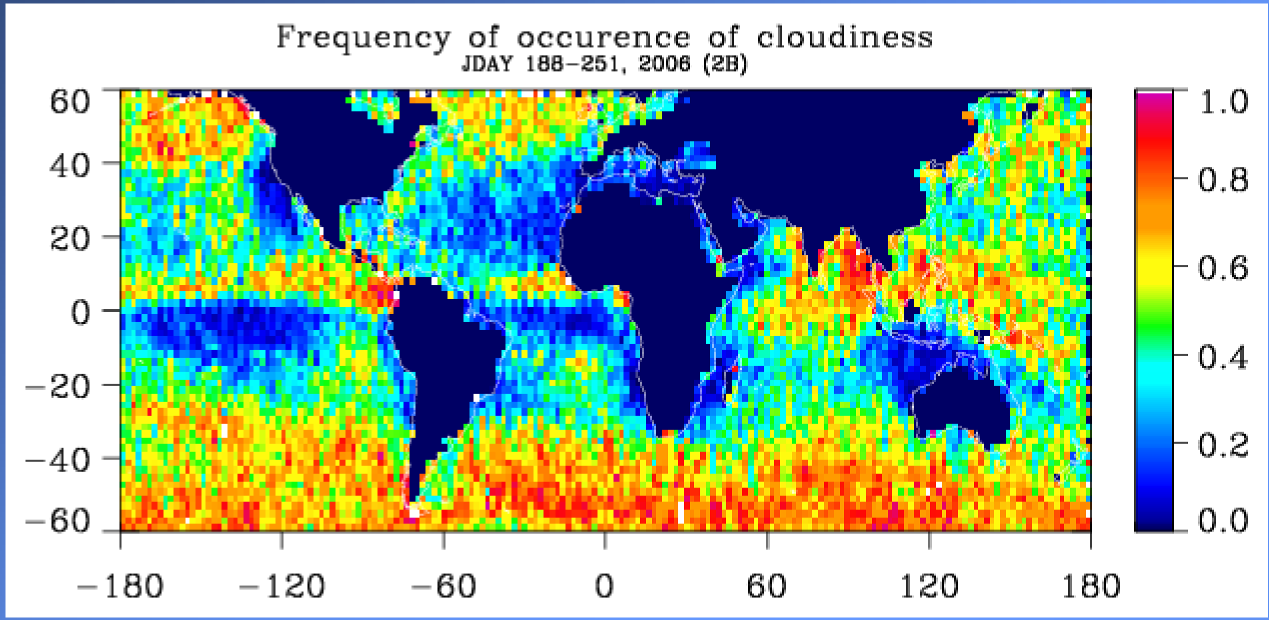

Thursday 1 June 2006 00UTC ECMWF Forecast t+12 VT: Thursday 1 June 2006 12UTC Surface: **

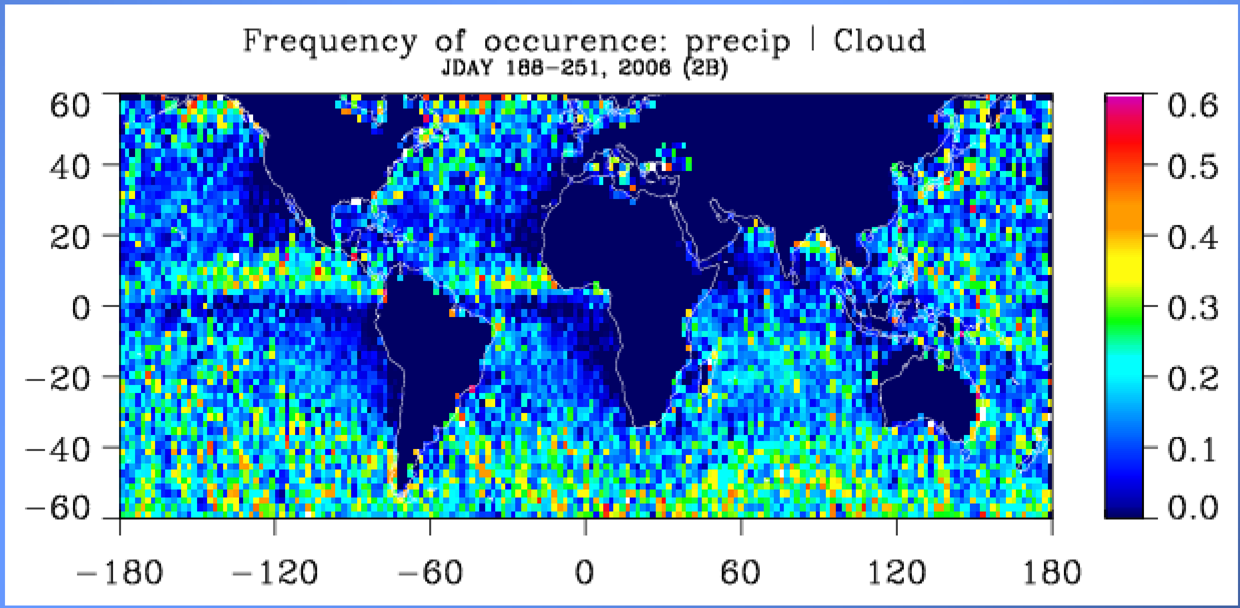

Thursday 1 June 2006 00UTC ECMWF Forecast t+12 VT: Thursday 1 June 2006 12UTC Surface: **


Fraction of total rainfall: CTL < 4.75 km
f=0.690


Fraction of total rainfall: 4.75 < CTL < 11 km
f=0.230


Fraction of total rainfall: CTL > 11 km
f=0.080





fraction=0.12

Warm cloud precipitation susceptibility

The idea - estimate the rate at which cloud water is converted to rain and examine factors that influence this conversion process

Fundamental to most of the critical cloud related problems that confront us (indirect effects, low cloud life cycle, large-scale precipitation, ….)

$$P = \int \frac{dm(R)}{dt} n(R)dR = \int n(R)dR \int n(r)m(r)K(r,R)dR$$

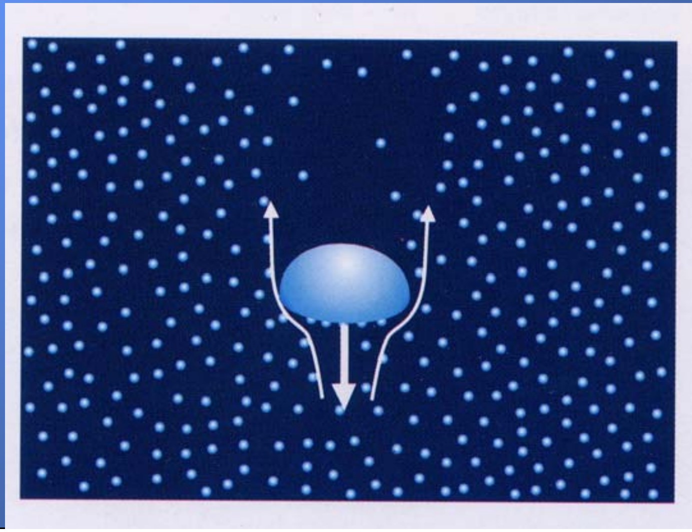
Long (1974) approximation

$$K(r,R) \sim \kappa R^6$$

$$P \sim \kappa N R_6^6 L$$

where L = LWC. Integration through cloud

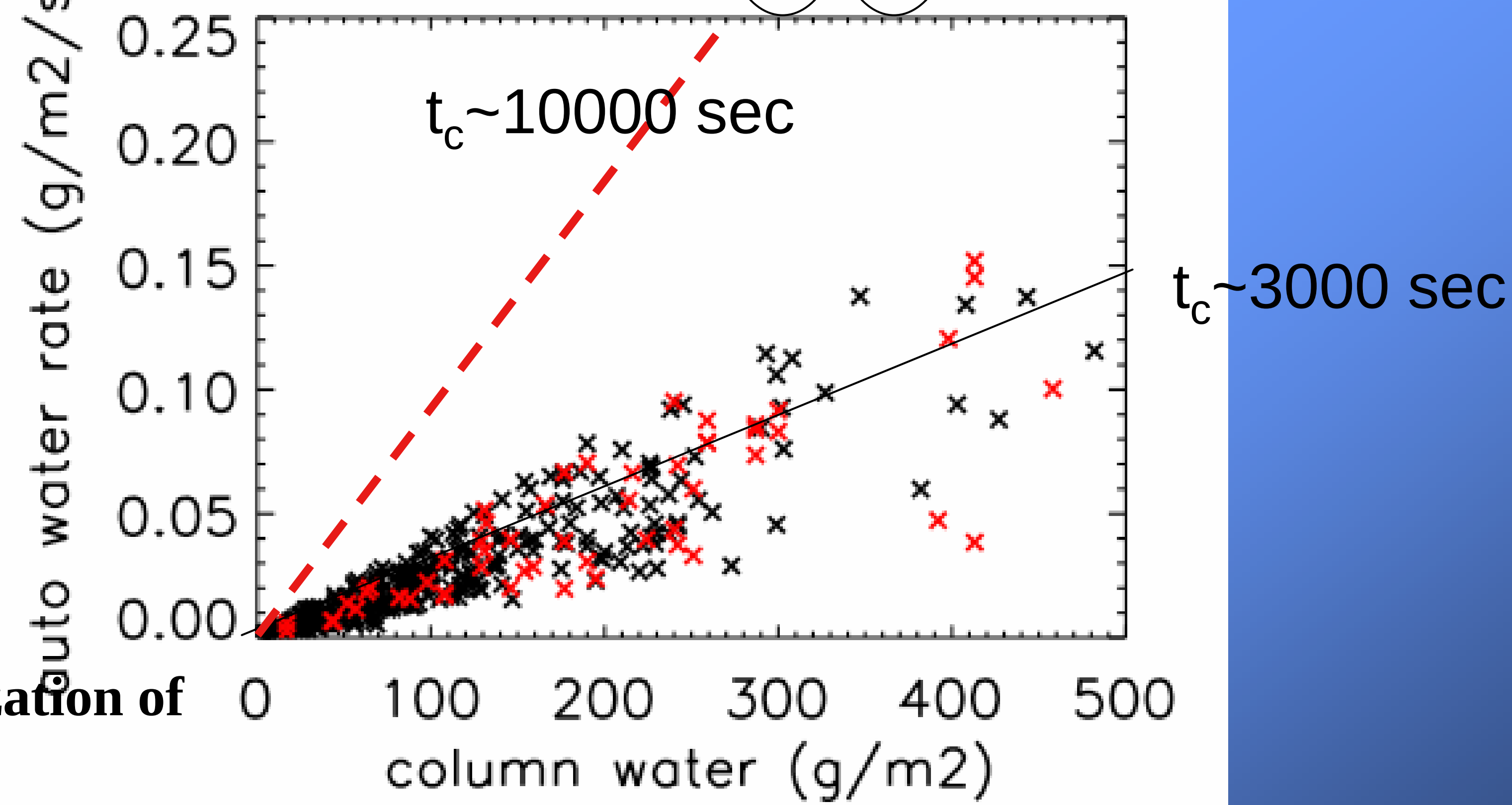
$$\mathbf{P.h} \rightarrow LWP.\overline{Z} \rightarrow \tau r_e.\overline{Z} \qquad \overline{Z} \leq -15dBZ$$



Results for low, warm clouds

$$\mathbf{P.h} \rightarrow LWP.\bar{Z} \rightarrow \tau r_e.\bar{Z}$$

MODIS CloudSat



Parameterization of Sundquist

$$\mathbf{P.h} = \frac{\mathbf{LWP}}{\mathbf{t_c}}[1 - \exp[-(L/Lc)^2]]$$

ZRAINAUT(JL)=ZZCO*(1.0_JPRB-EXP(-(ZLCLD(JL)/ZLCRIT)**2)

Preliminary 10 days of matched cloudsat-modis

Thoughts for the workshop

- Observations - what and how?
- What role CRMs?
- What role assimilation
- How do statistical approaches (pdf) connect?

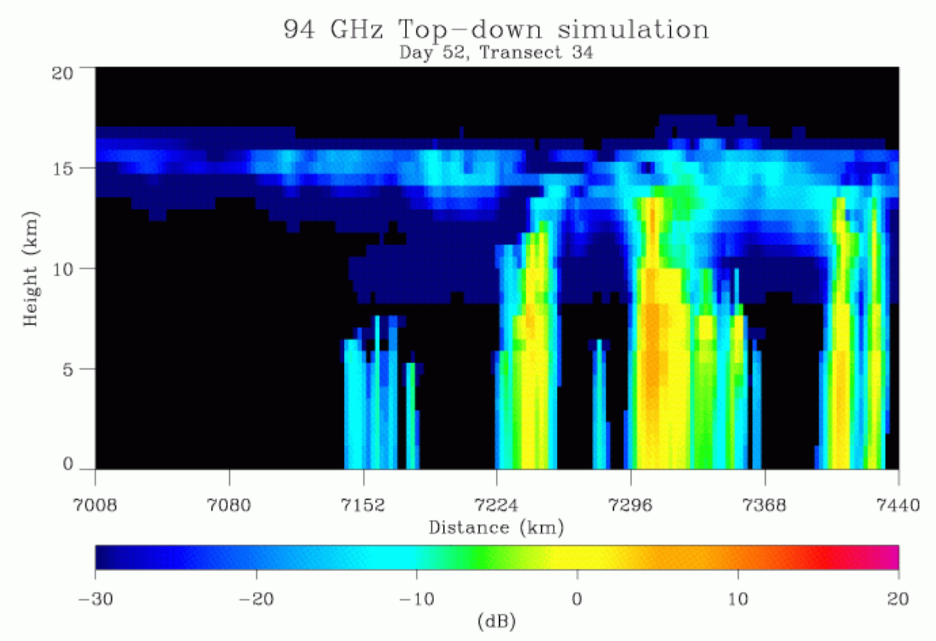
- Observations - what and how?

From the global perspective - we are in an unprecedented 'golden age' - with two space-borne radars, a lidar and a suite of radiometers providing joint information about cloud & precipitation.

I propose we begin coordinating activities around uses of these data - key topics ripe for the picking are convection, precipitation processes (warm and cold), and ice

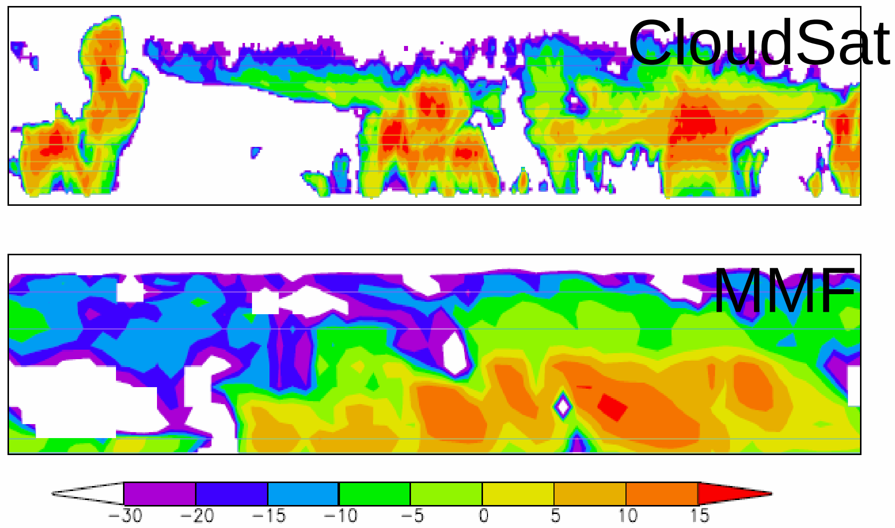
How? On multiple fronts - One such activity is the use of radar, lidar simulators - the use of such simulators is more 'direct' when applied in CRMs. Activities are underway to couple to GCMs and their 'traditional' parameterizations

Simulators in CRMs -ie it creates a Model Equivalent Geoprof product



CLOUDSAT 94 Ghz radar simulator applied to RAMS

John Haynes, CSU



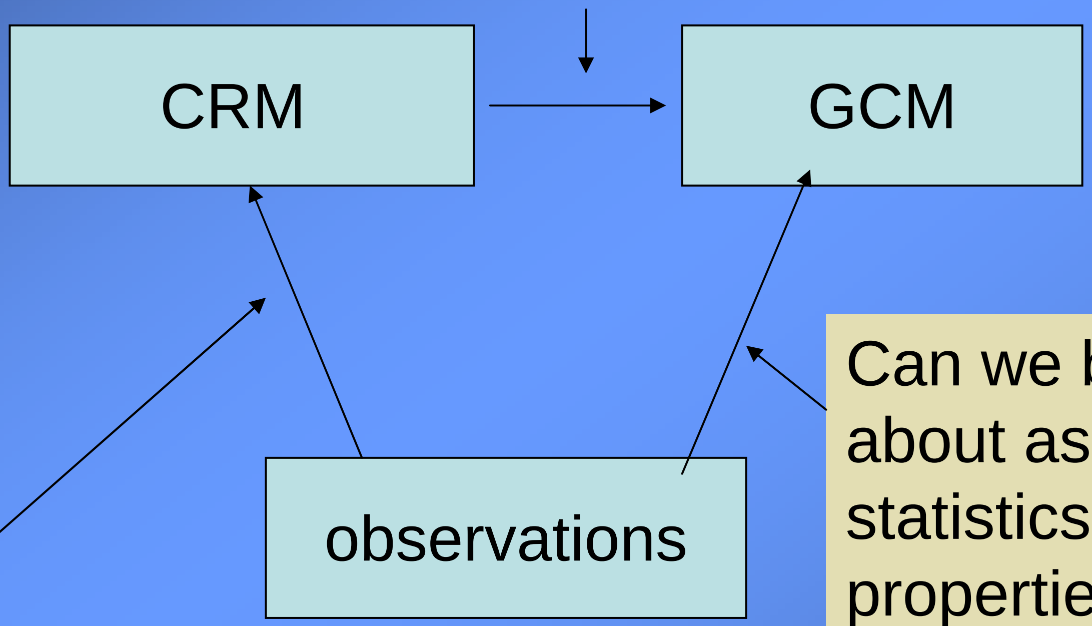
dBZ

July 16, Asian Monsoon and one grid pint of the GCM

We are developing diagnostic tools to analyze such data

What role CRMs, assimilation and statistical approaches?

Used to train parameterizations

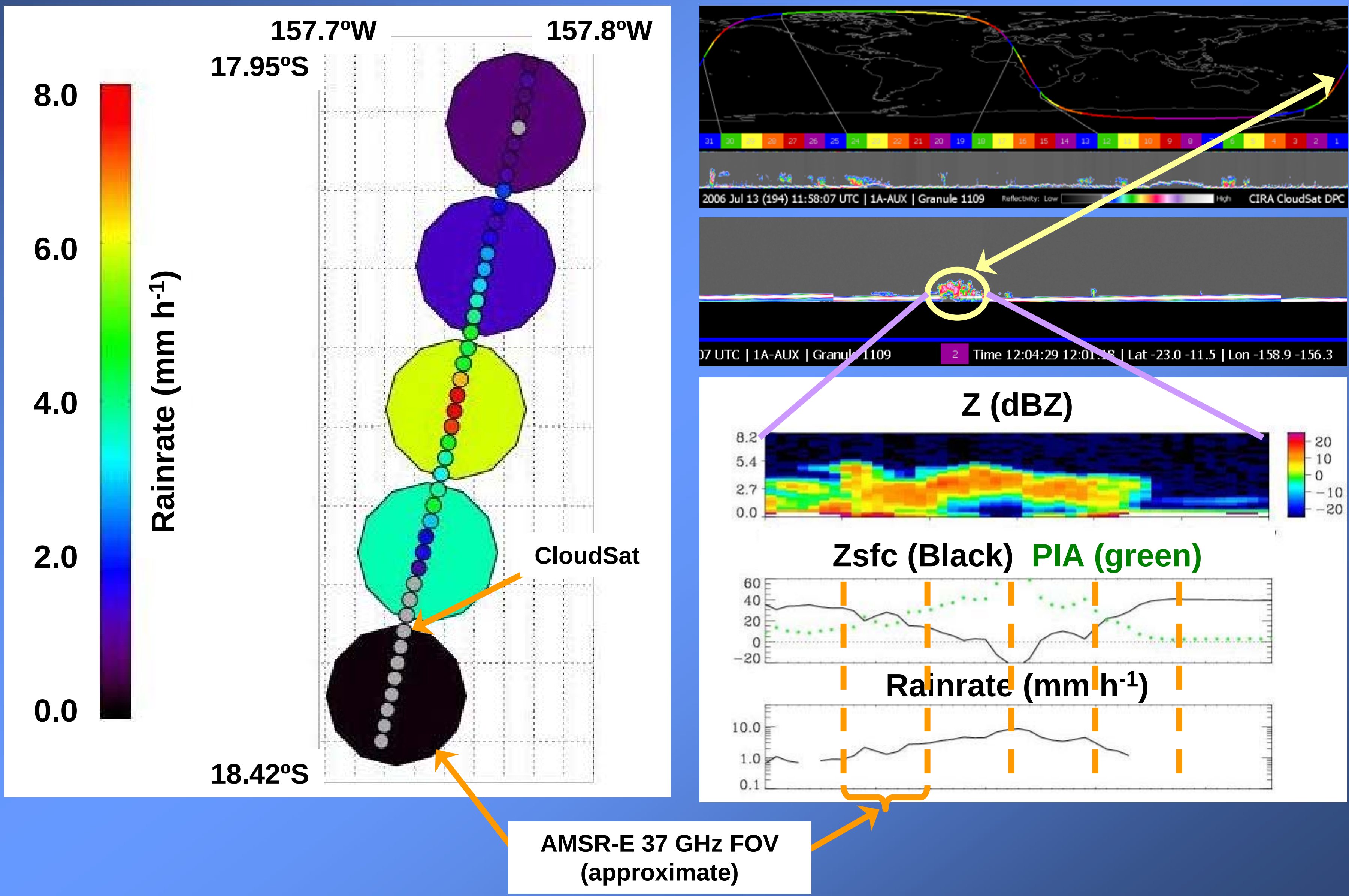


Can we begin to think about assimilation of (x,t) statistics (eg pdf properties) rather than a given cloud realization

- Constrain CRMs directly -
- Use assimilation for parameter estimation

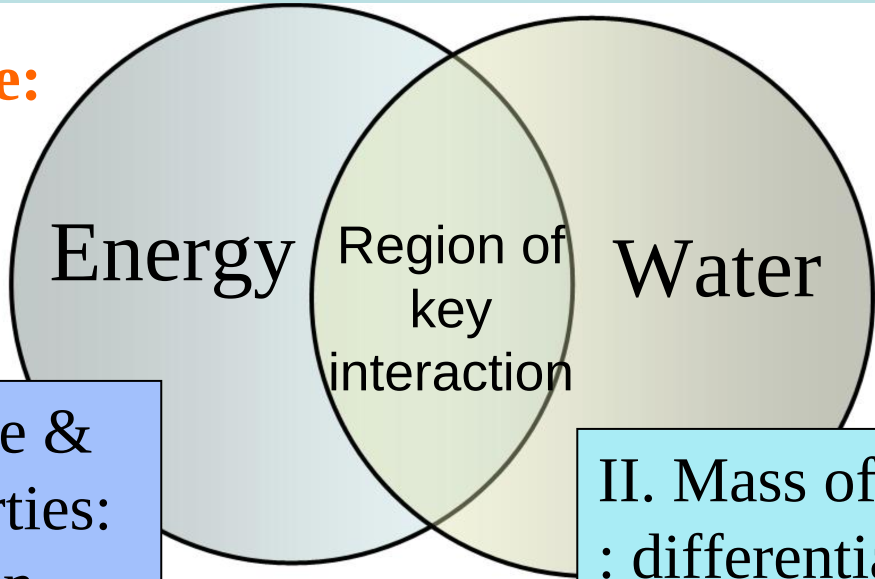
Backup

Pixel-Level Comparisons



Motivation (mine): To advance our understanding of the role of moist (atmospheric) processes in weather and climate with a goal toward improving our ability to predict the evolution of (atmospheric) ‘water systems’.

Scope:



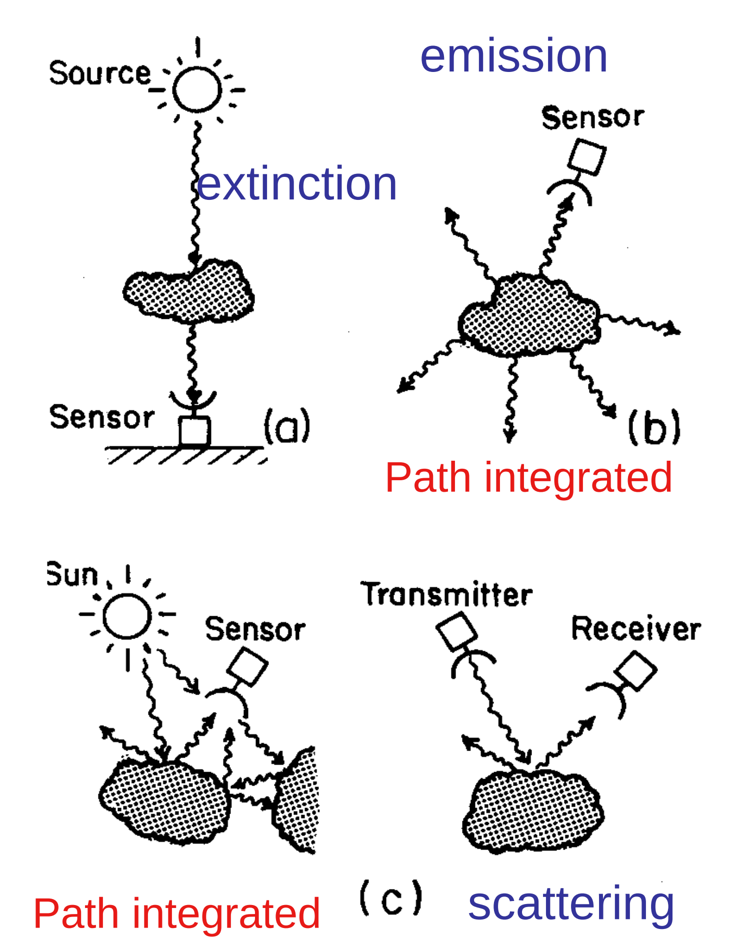
I. Radiative & Optical properties: precipitation

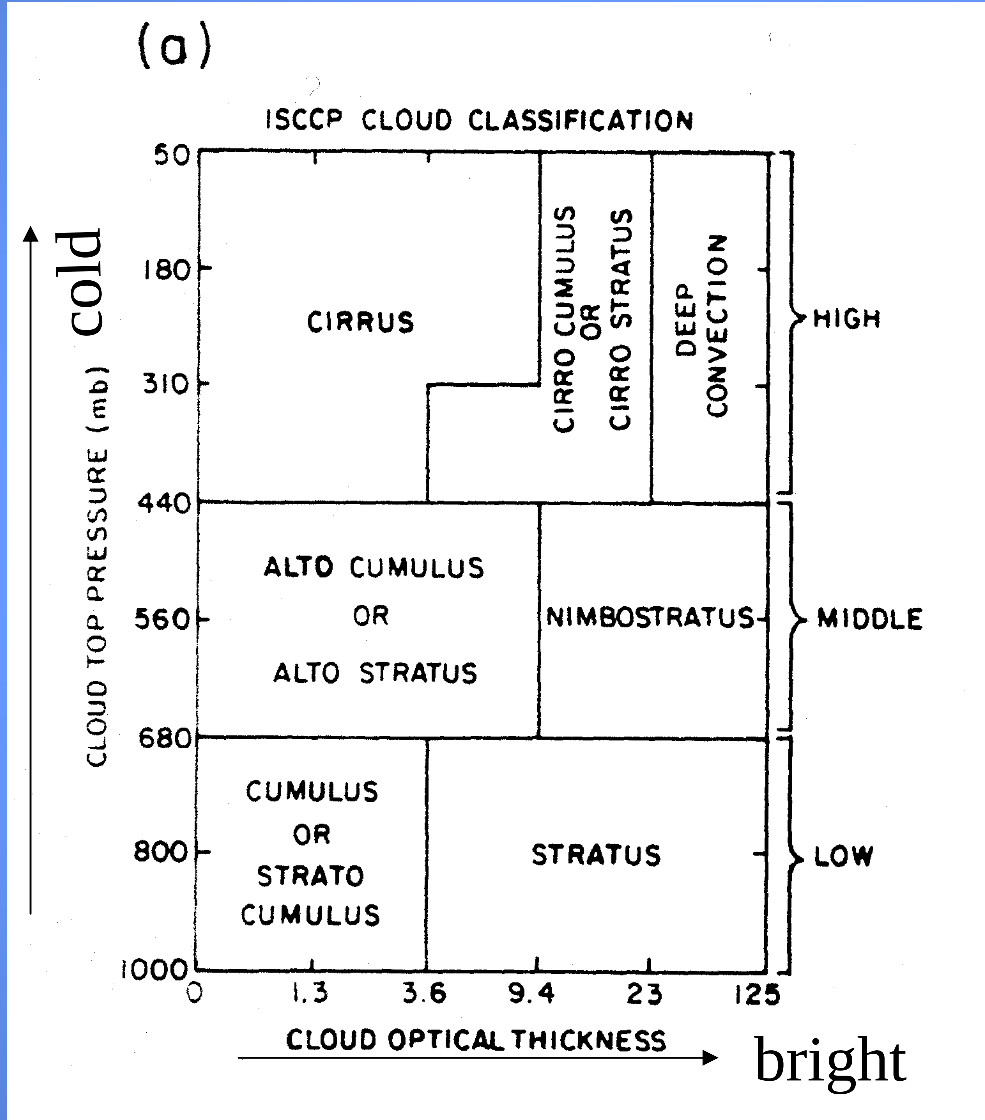
II. Mass of condensed water : differentiate phase and that which falls to Earth

III. Microphysical properties:

IV. State information, including ‘macroscopic’, aerosol and meteorology (motions large & small, thermodynamics …)

Radiometric classification of clouds





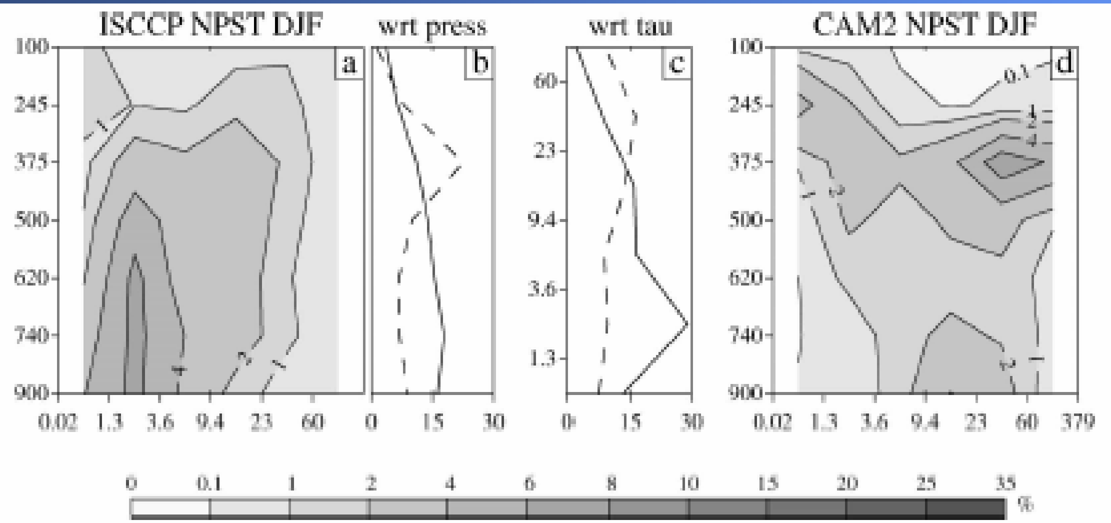


FIG. 6. (a) DJF cloud frequency stratified against cloud-top pressure (p_c) and cloud optical depth (τ) for the NP storm track. (b) Cloud frequency integrated over τ, for ISCCP (solid) and CAM2 (dashed). (c) Cloud frequency integrated over p_c for ISCCP (solid) and CAM2 (dashed). (d) Same as in (a), except from CAM2. Abscissas in (a) and (d) are optical depths, in (b) and (c) and are cloud fractions. Ordinates in (a), (b), and (d) are cloud-top pressure, and are optical depth in (c).

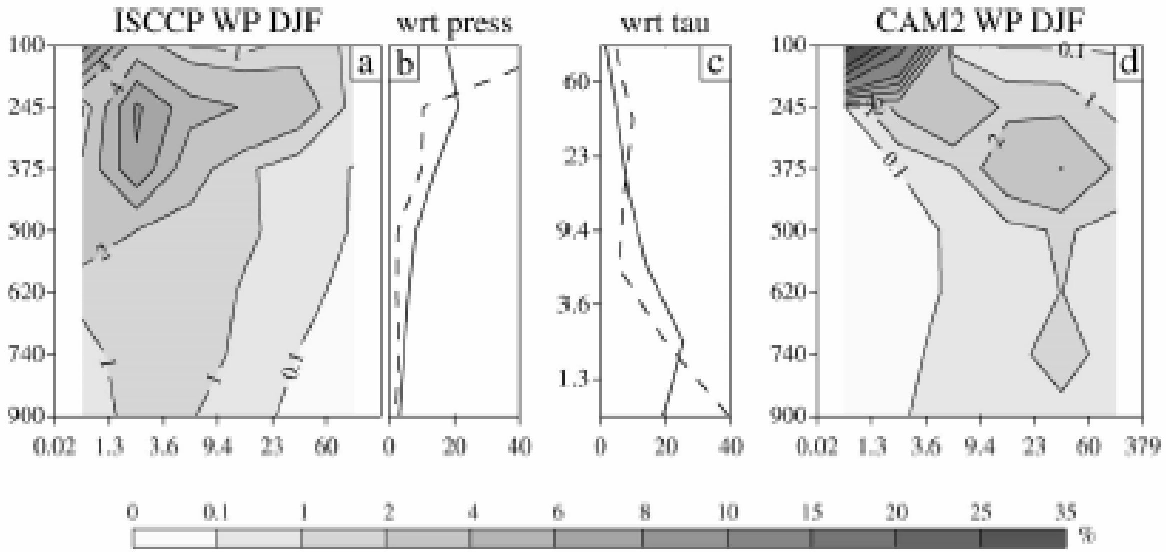
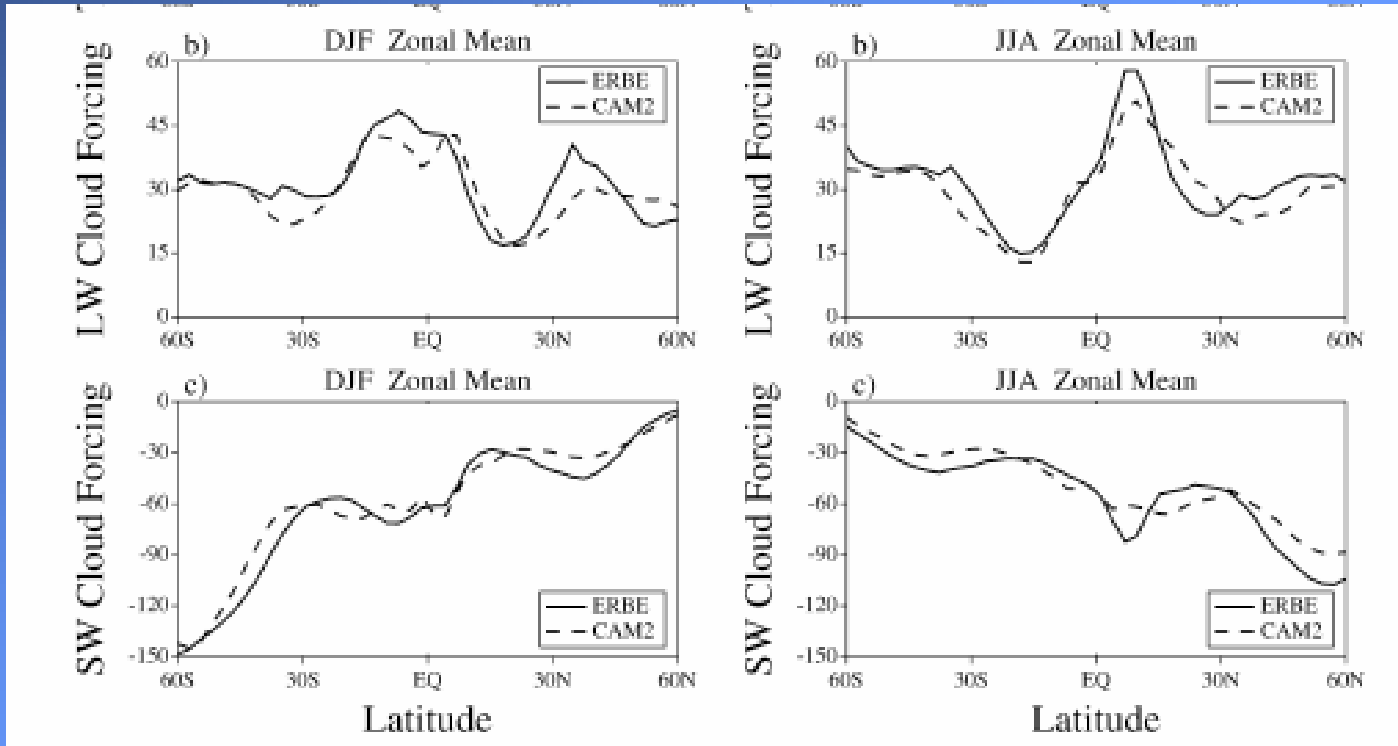


FIG. 12. Cloud frequency distribution for the WP: 10°N–10°S, 120°–150°E; same as in Fig. 6.

Lin and Zhang, 2005

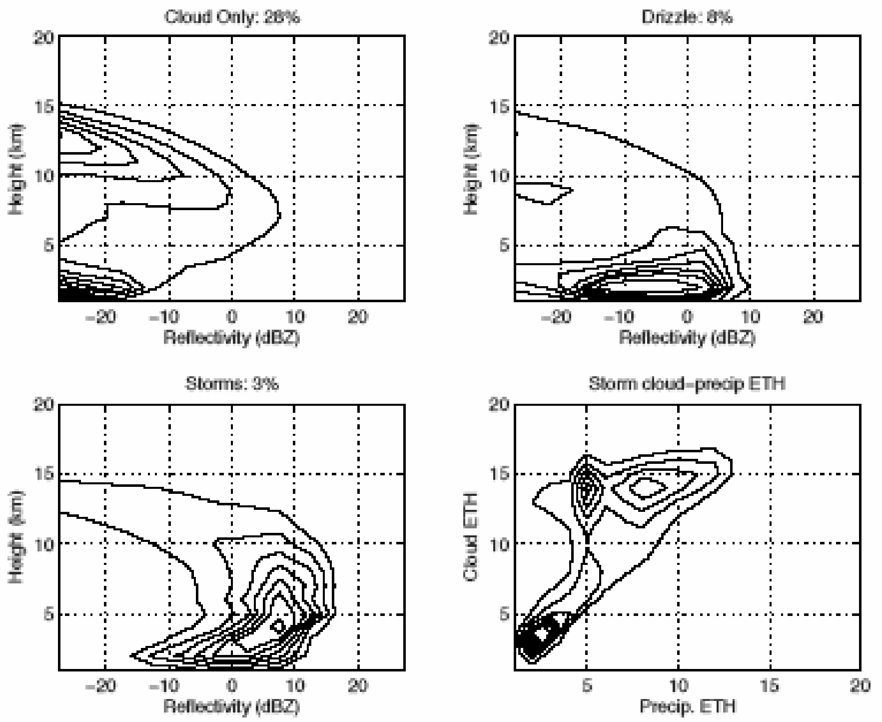
'TOA channel thinking'



We have known for many years that any given observation of TOA fluxes can be explained by many different 'macroscopic' cloud configurations.

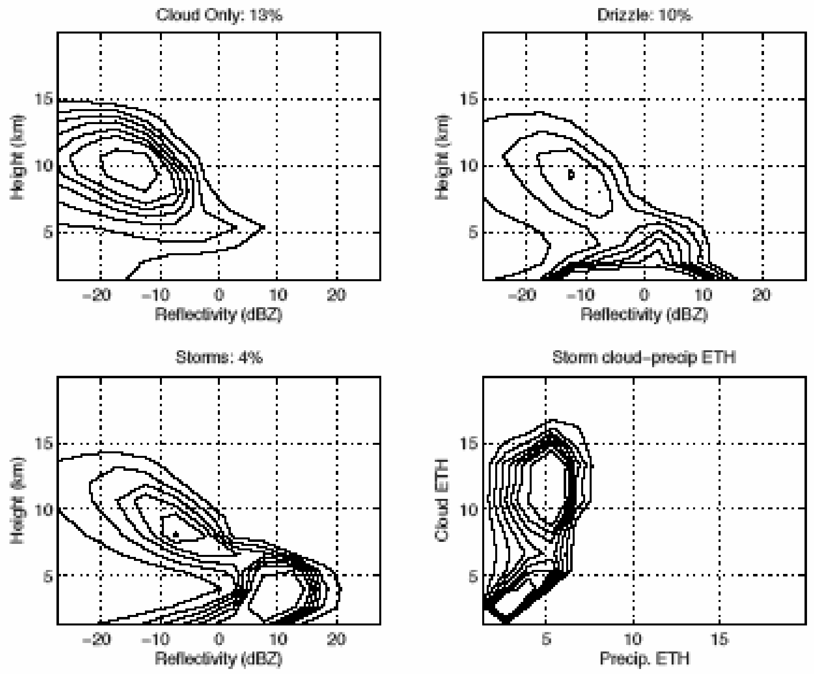
A TOA viewpoint alone often tends to channel our thinking into particular directions (e.g. low cloud) where other viewpoints (eg atmospheric rad forcing, convection and precipitation) identify (perhaps) other 'priorities'

Statistical structures of clouds and precipitation



CloudSat, 30N-30S

CAM- MMF, 30N-30S



Identifies systematic differences between the CRM and observations

- Where should our priorities lie with cloud observations?
- What timeliness is required for NWP?
- Should models be validated in both NWP modes and Climate modes?
- How can we best use the observations we already have? Should a centralized database of tests be organised?
- What role can cloud resolving models play?
- Can observations be better used in data assimilation? What is required in order to do this?

- Are statistical cloud schemes the way forward?
- If yes: What complexity of PDF is required? (Uni/bi/multi modal?)
- What are the alternative approaches?
- How will we parametrize the influence on PDF moments from other processes (microphysics/convection)?

- How do we determine what the main weaknesses are of our current cloud schemes?
- How can we gain confidence in our cloud schemes and the climate sensitivities they produce?
- What will be the future cloud parametrization priorities?

Radar Simulator Package

QuickBeam

• Produces vertical profiles of radar reflectivity given input profiles of hydrometeor mixing ratio and ambient conditions.

• Uses up to 50 species of hydrometeors, liquid and ice.

• User may specify their own size distribution: exponential, modified gamma, lognormal, or monodisperse.

• Includes Mie lookup tables for expedited operations, or can perform Mie calculations on-the-fly for greater accuracy.

• Future versions will include support for non-spherical ice crystals and a bright band/melting layer simulator.

•Activity beginning with H.C, LLNL, CSU to develop methods to integrate into 'conventional' GCMs with partial cloud covered grid boxes

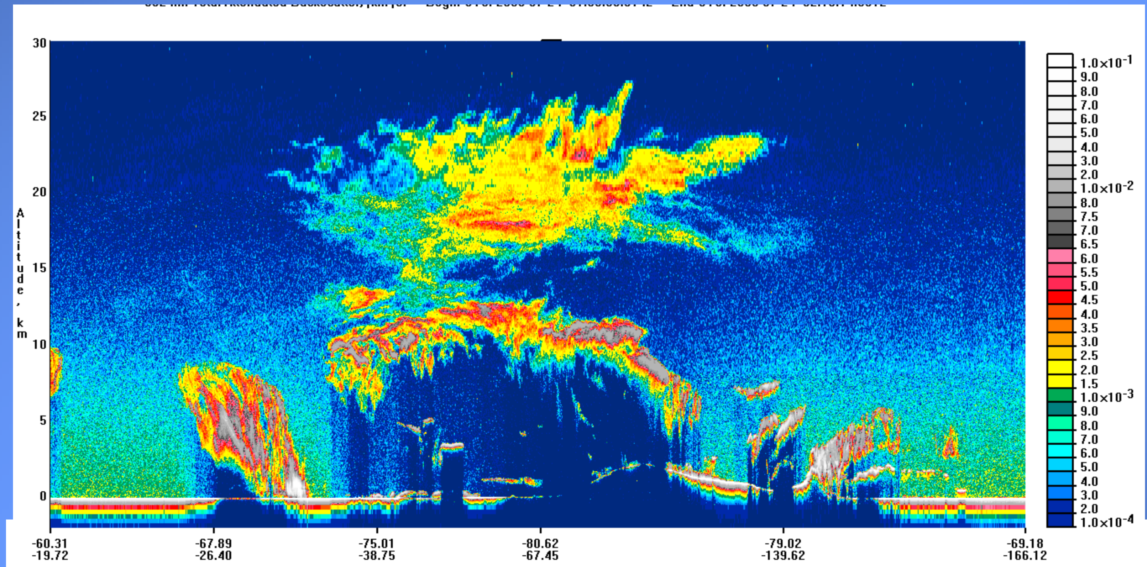
http://reef.atmos.colostate.edu/haynes/radarsim

John Haynes, haynes@atmos.colostate.edu

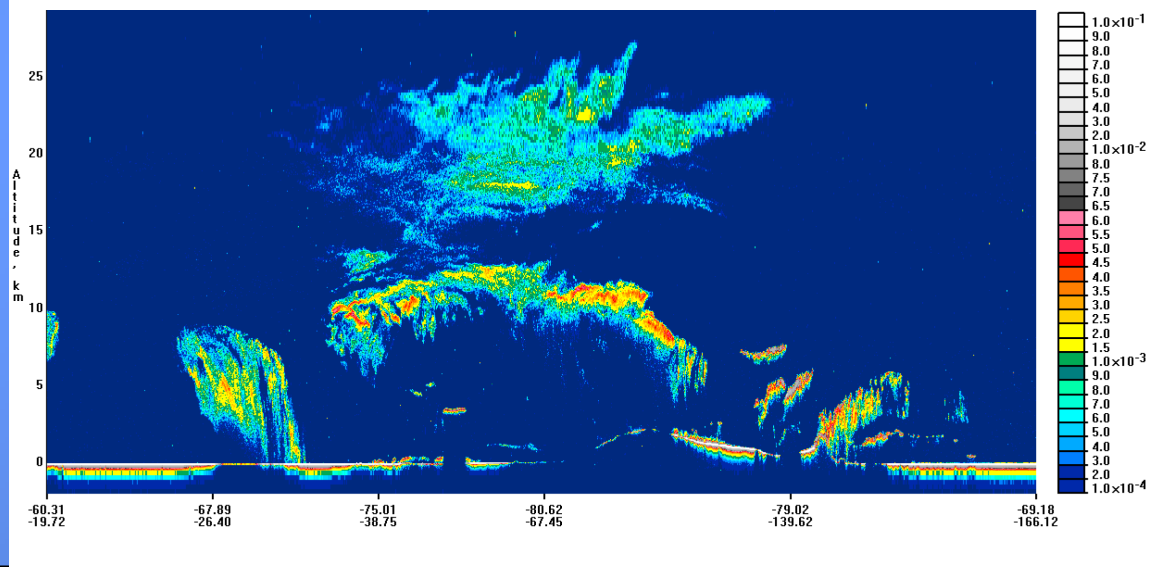
Polar Stratospheric Clouds

24 July 2006

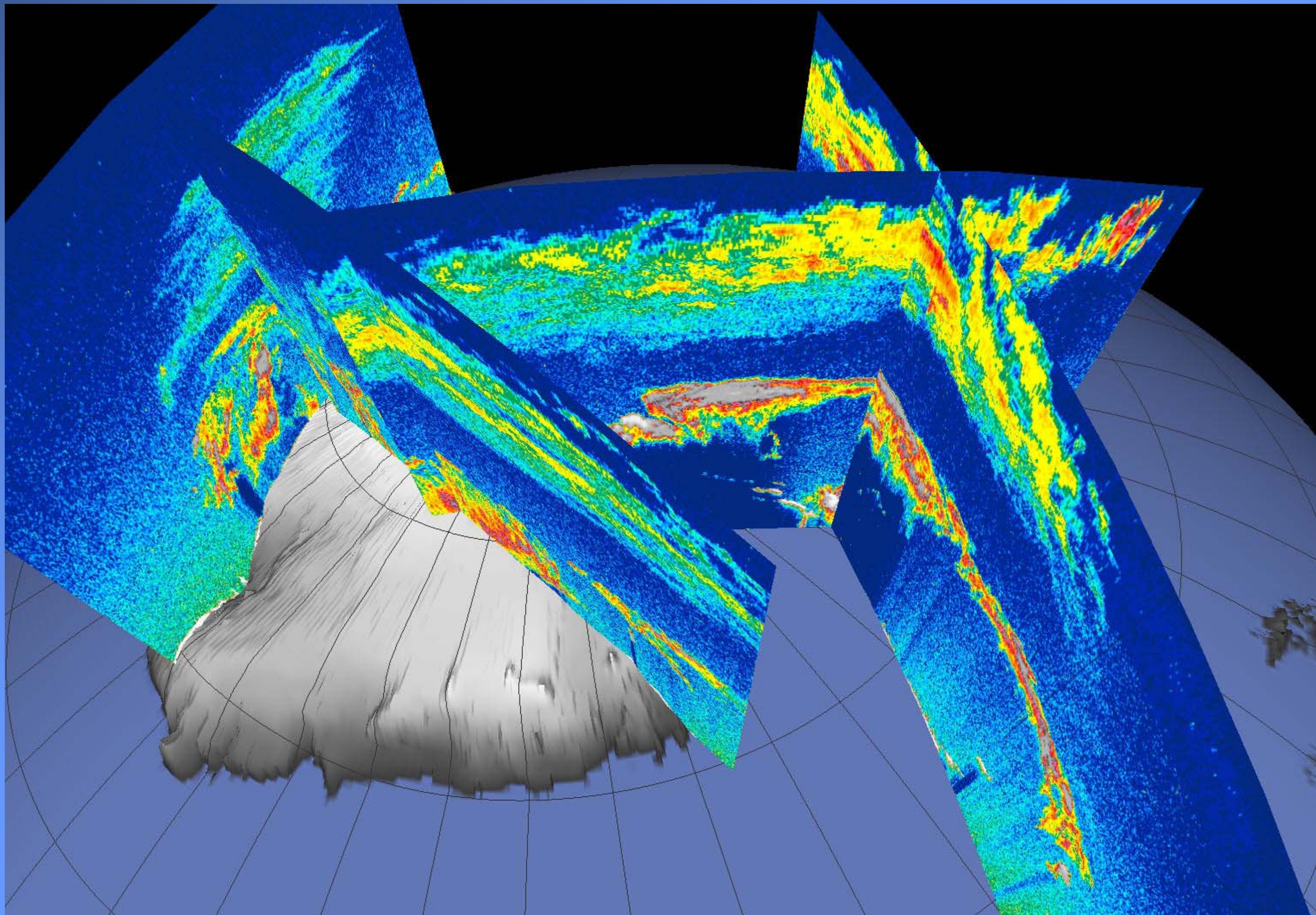
532 nm Total Attenuated Backscatter

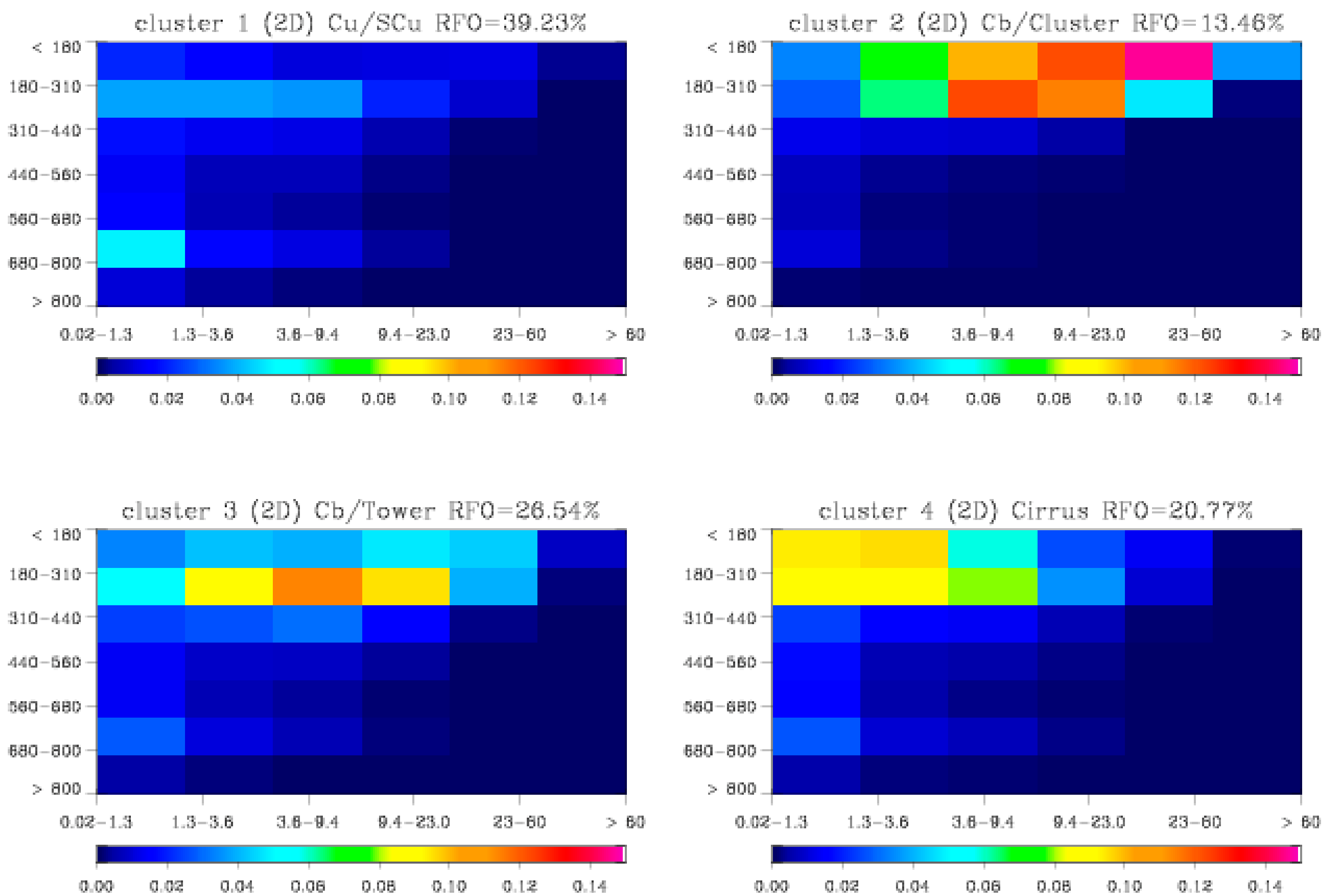


532 nm Perpendicular Attenuated Backscatter

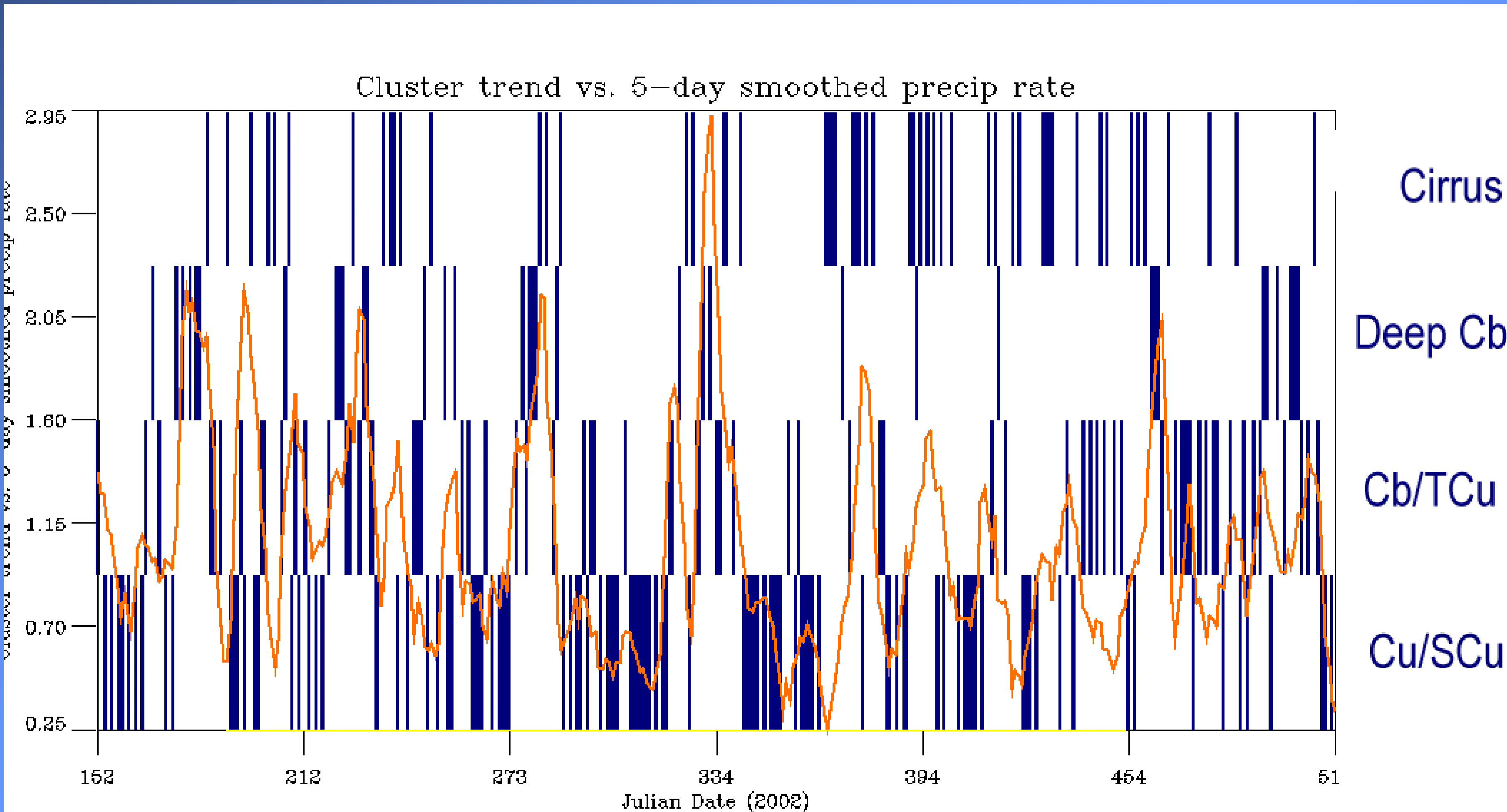


3D Polar Stratospheric Clouds !




cluster 1 (2D) Cu/SCu RFO=39.23%
cluster 2 (2D) Cb/Cluster RFO=13.46%
cluster 3 (2D) Cb/Tower RFO=26.54%
cluster 4 (2D) Cirrus RFO=20.77%
< 180
180-310
310-440
440-560
560-680
680-800
> 800
0.02-1.3
1.3-3.6
3.6-9.4
9.4-23.0
23-60
> 60
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14

Cloud cluster evolution and the MJO



1970

1980

1990

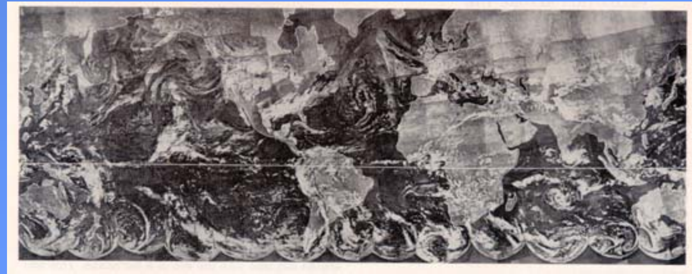
2000

The early period: the period of great imagination

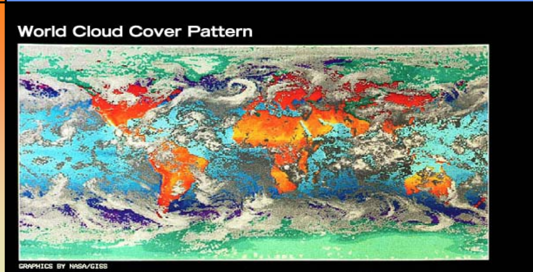
The intermediate period: the period of great information-gathering

The ‘advanced’ phase: quantifying processes

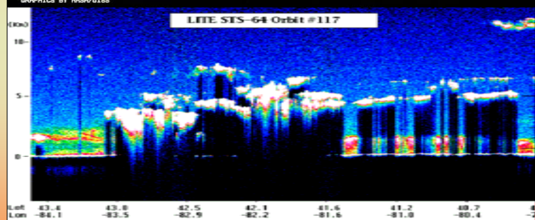
The launch of TIROS-1, April 1960



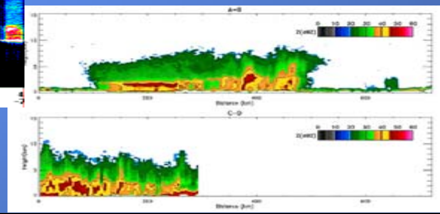
The first 24hr view of global clouds TIROS-9, February 13, 1965



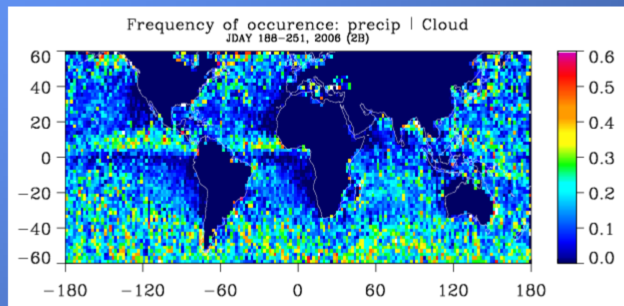
1. Global climatologies of cloud occurrence*, optical properties, 1983-present *** Cloud mask/ identification /screening**



First flight of back-scatter lidar, LITE, 1996

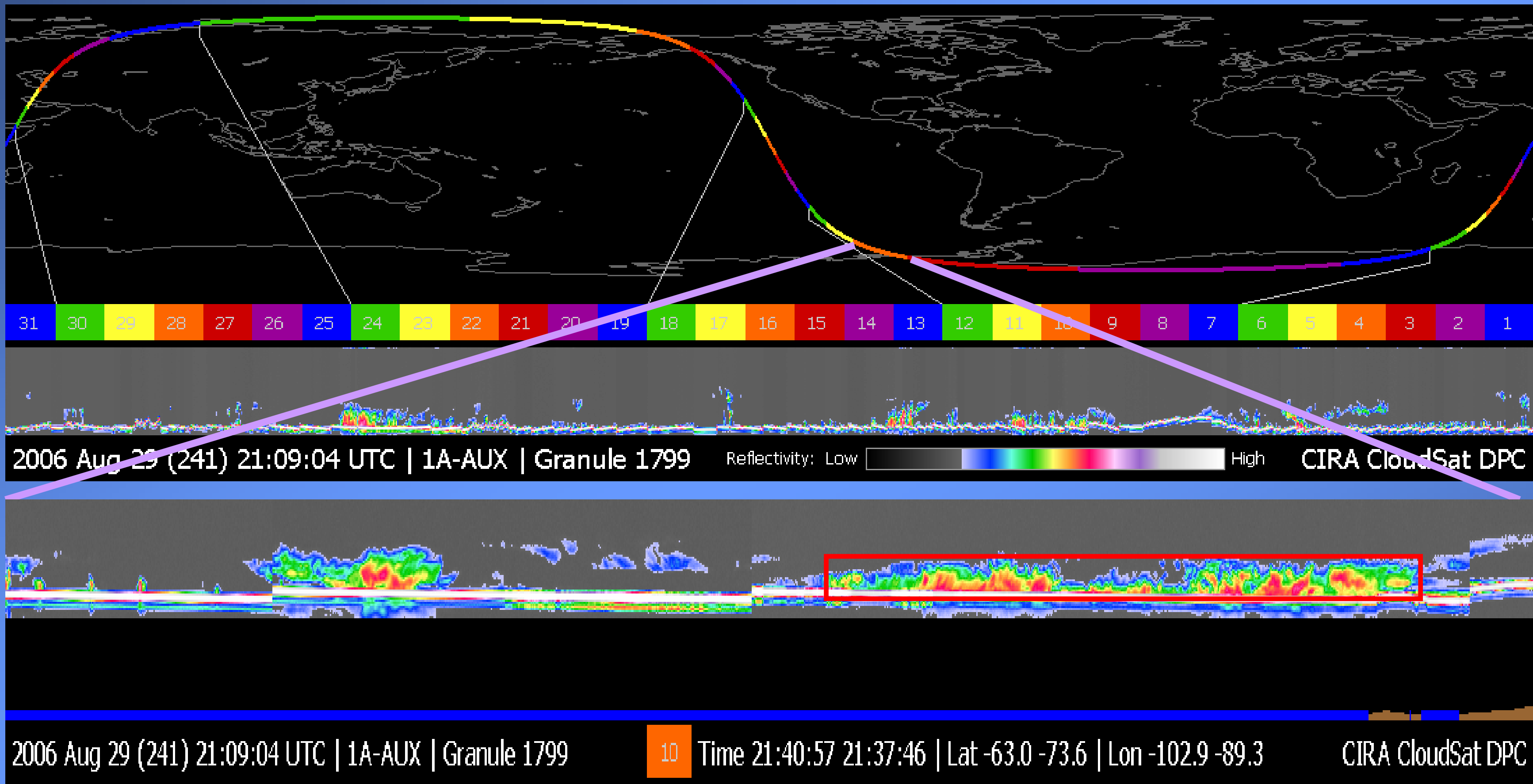


First flight of precipitation radar, TRMM, 1997



Cloud <u>and</u> precipitation

An early look at Snowfall



•CloudSat’s sensitivity makes it ideal for detecting snowfall.

•The region poleward of 60º is sampled ~4 times more frequently than an equal area region at the equator!

Radar-Only Retrieval

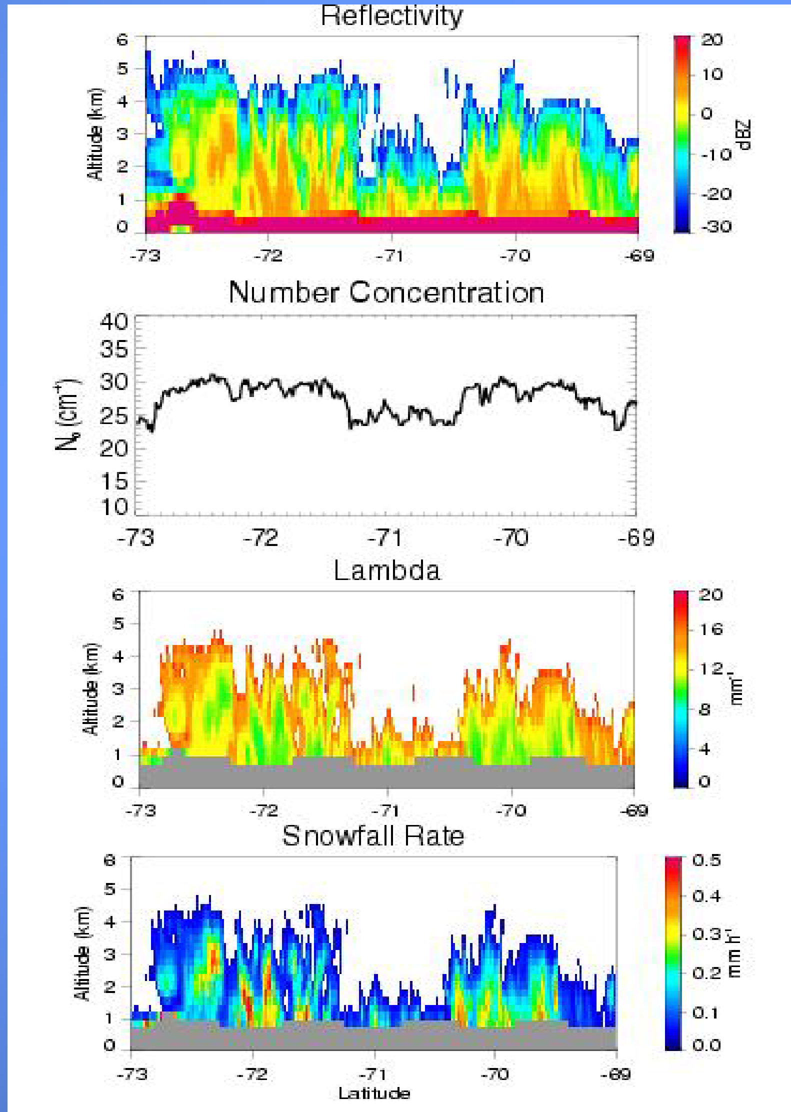
- **Very preliminary inversion of CPR reflectivities to infer snowfall rate**

- **Assumes exponential distribution of snow particles**

$$N(D) = N_0 \exp(-\Lambda D)$$

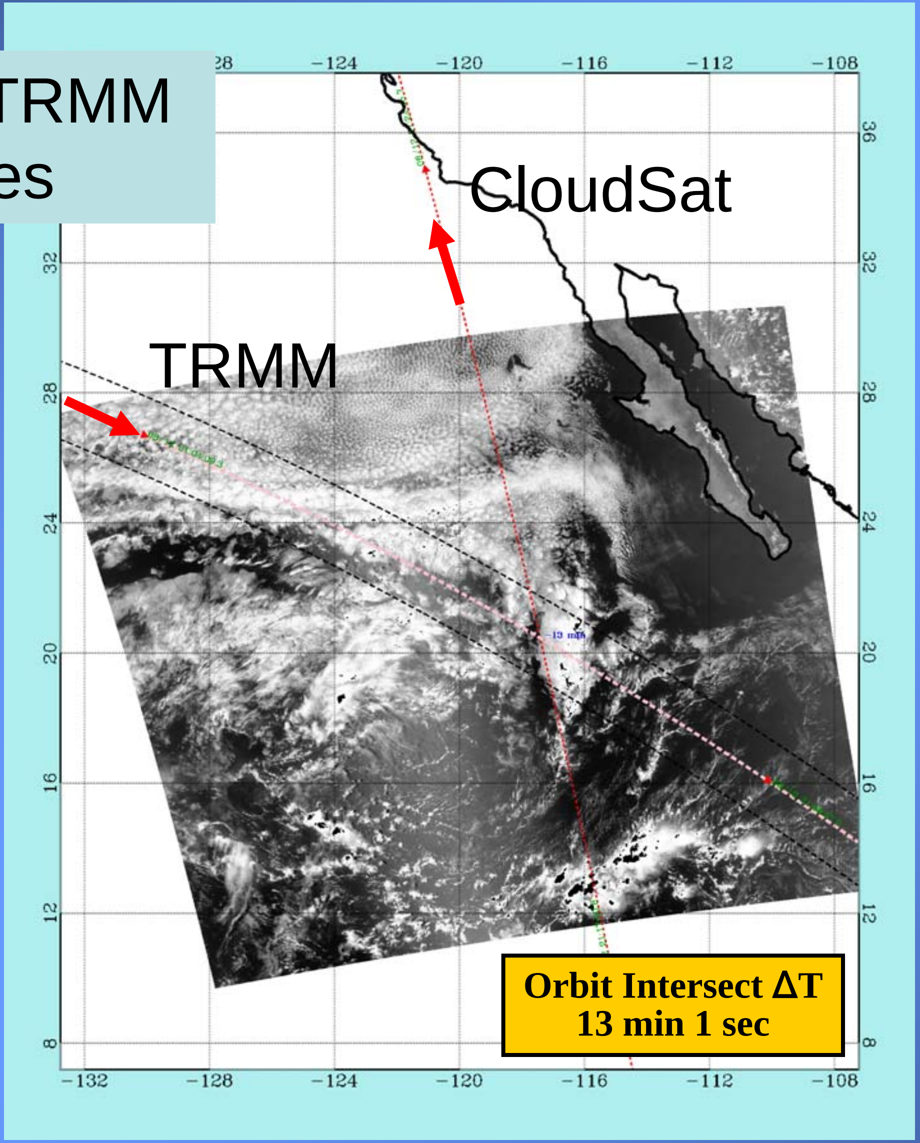
- **Similar probabilistic retrieval framework as rainfall retrieval**

- **First goal is detection and discrimination from light rainfall**



AQUA-MODIS (500 m/band 4-green)
August 12 (day 224) : 202534 UTC (~1226 MST)
(CloudSat orbit 01551)

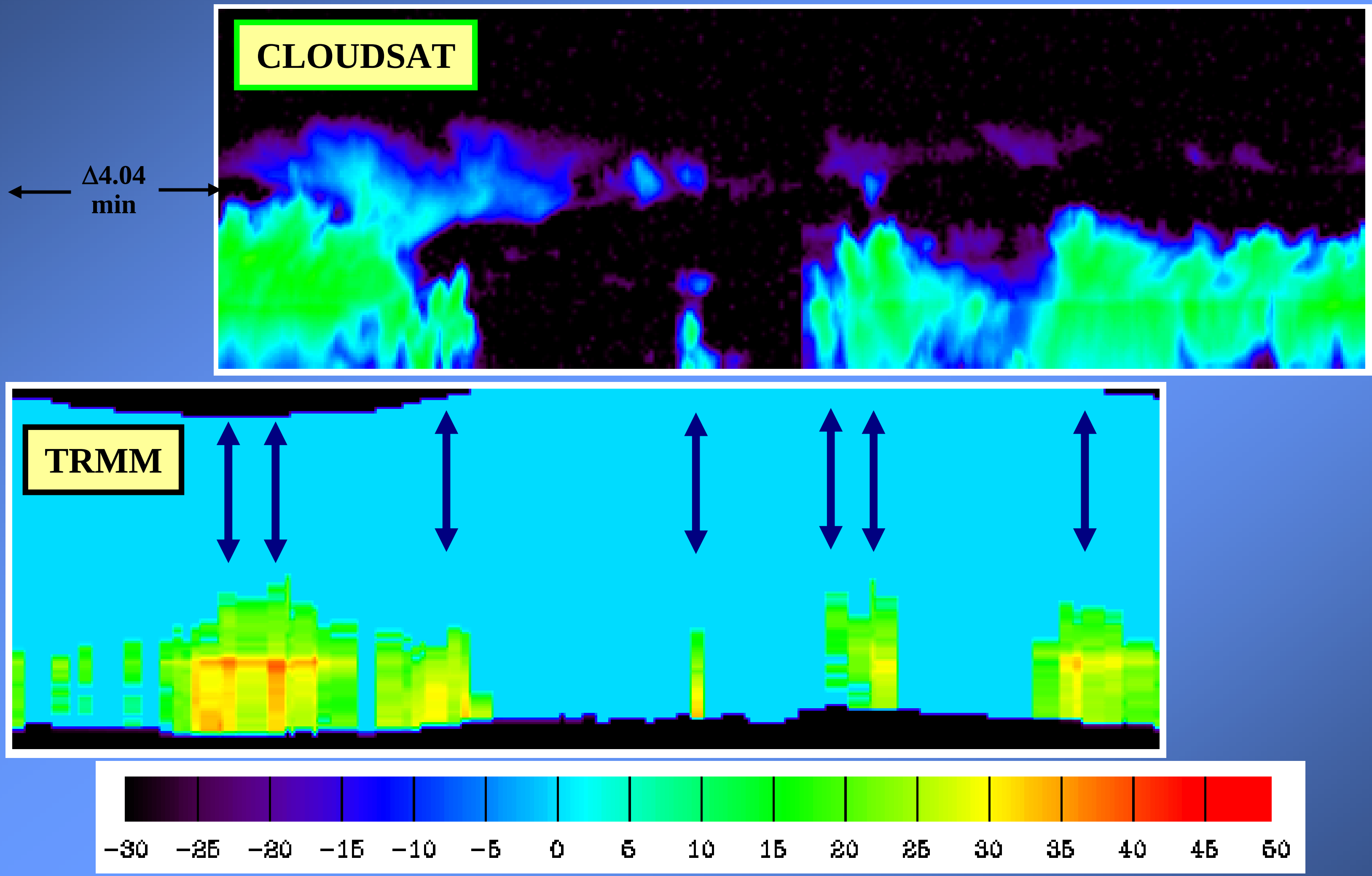
CloudSat-TRMM matches



CloudSat is supporting the development of TRMM matched data base

Courtesy, Eric Smith

Comparison of CLOUDSAT Down-track to TRMM Slant Cross-track
[25 July 2006 / ~2035 UTC (1235 MST): Intersect at 10.39ºN / 118.24ºW]



Reflectivity Factor (dBZ)