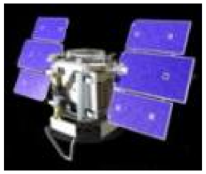


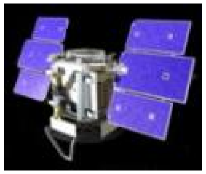
Early Results from CloudSat

Graeme Stephens

Cast of many

- incredible dedicated teams, JPL, Ball, algs, DPC, etc

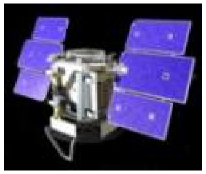
ARM



CloudSat Partners

NASA — CLOUDSAT — A NASA EARTH SYSTEM SCIENCE PATHFINDER MISSION — Colorado State University

- CIRA — Data processing
- JPL — Mission management & payload development
- Ball — Spacecraft
- Canadian Space Agency — Radar subsystem development, algorithms, validation, analyses
- Space Test Program — Ground operations system + Northrupp Grumman
- CRL — 94 GHz EIK engineering model development
- calipso / PICASSO-CENA — Formation flying
- ARM Atmospheric Radiation Measurement Program — Algorithms, validation and analyses
- + Universities/agencies in USA, Japan, Europe & Canada — Algorithms, validation and analyses



Science background

How we got to where we are today

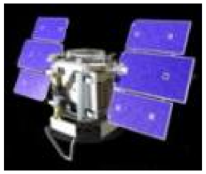
Preliminary results

What's new

Challenges & a look to the future

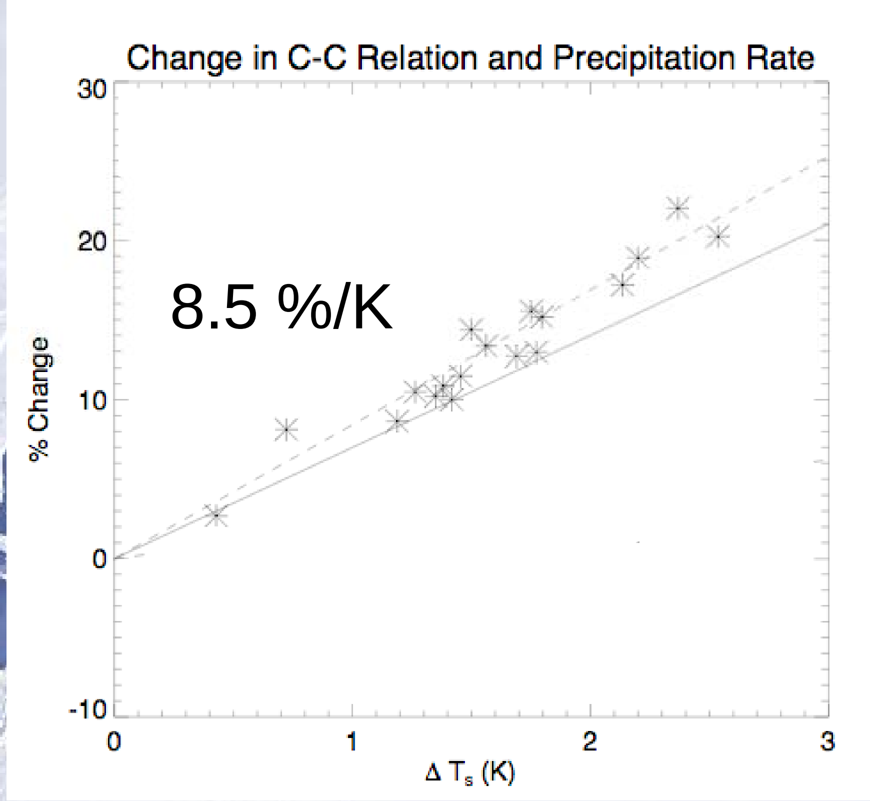
The mission science and aspirations parallel those of ARM

ARM provides a critical anchoring of the information at fixed sites, CloudSat and the A-Train then spreads this knowledge globally.

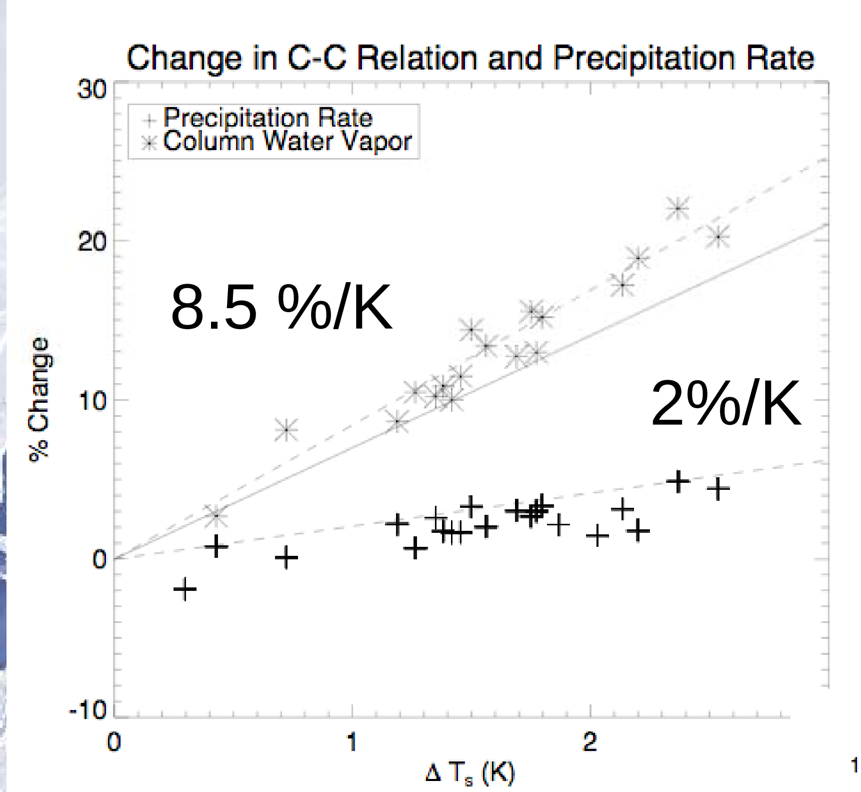


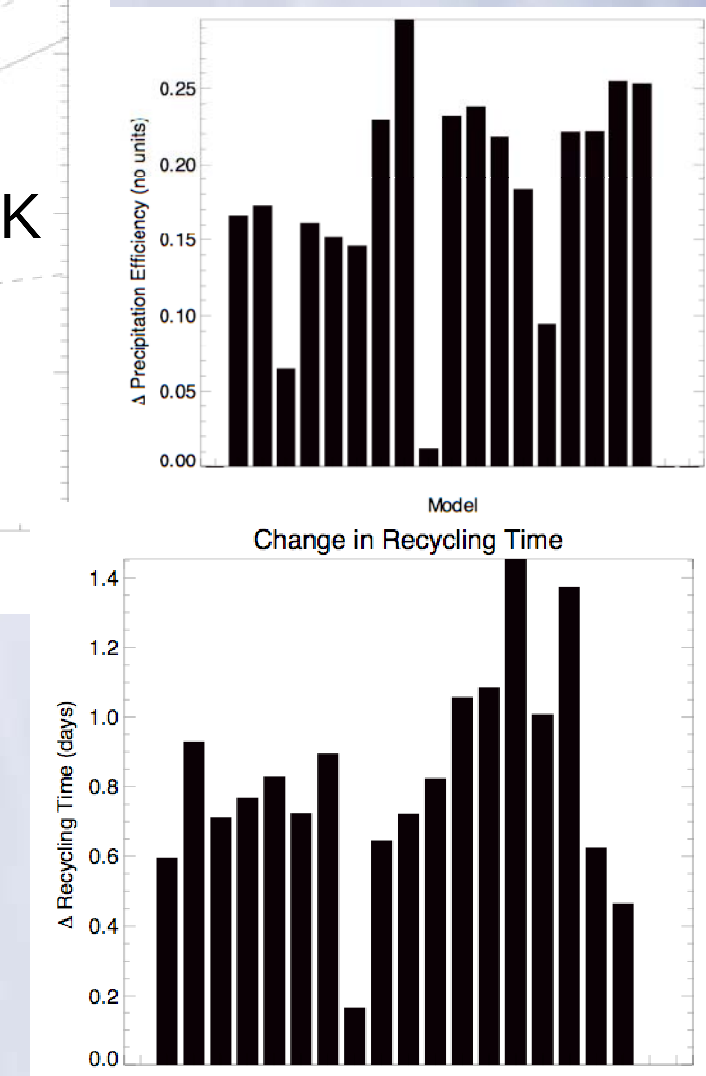
1. Science background

Column Water Vapor change year 70 minus year 1



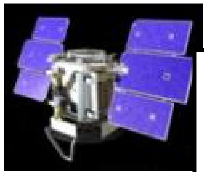
IPCC, FAR Stephens and Ellis, 2007

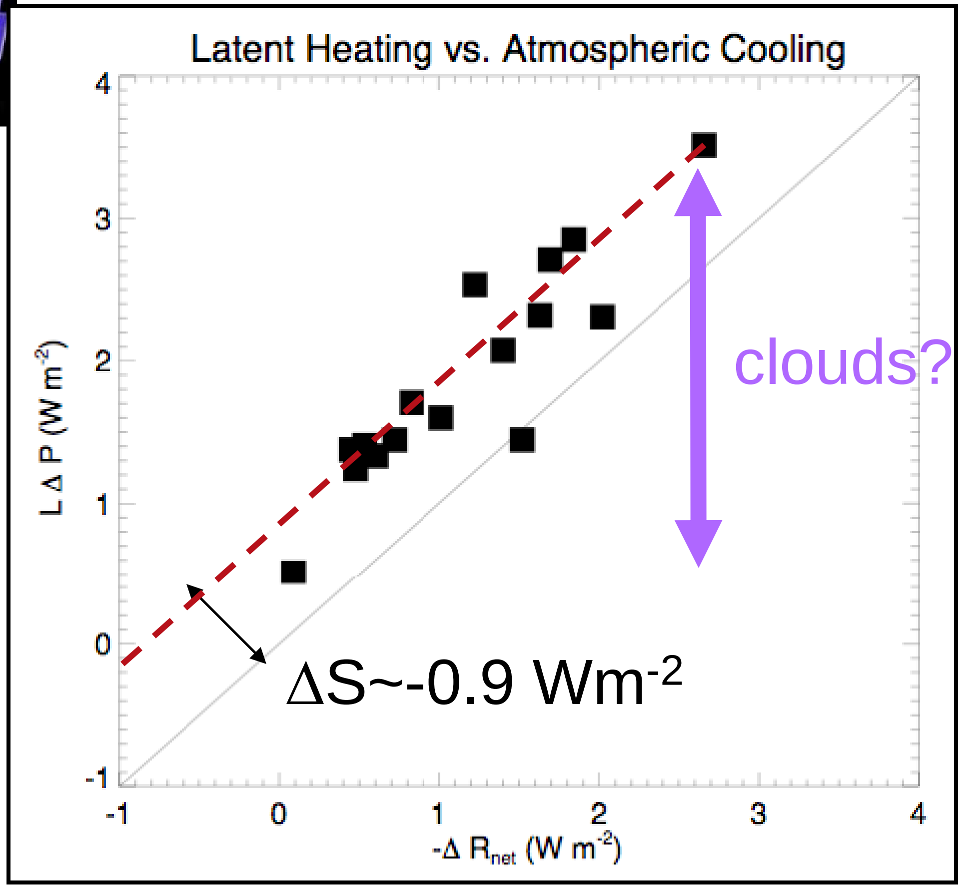




Models predict water vapor accumulating at a rate that exceeds the models ability to precipitate it out - implies a ‘slowing’ of the hydrological cycle

IPCC, FAR Stephens and Ellis, 2007



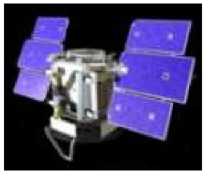


Atmospheric radiative heating, clouds and precipitation

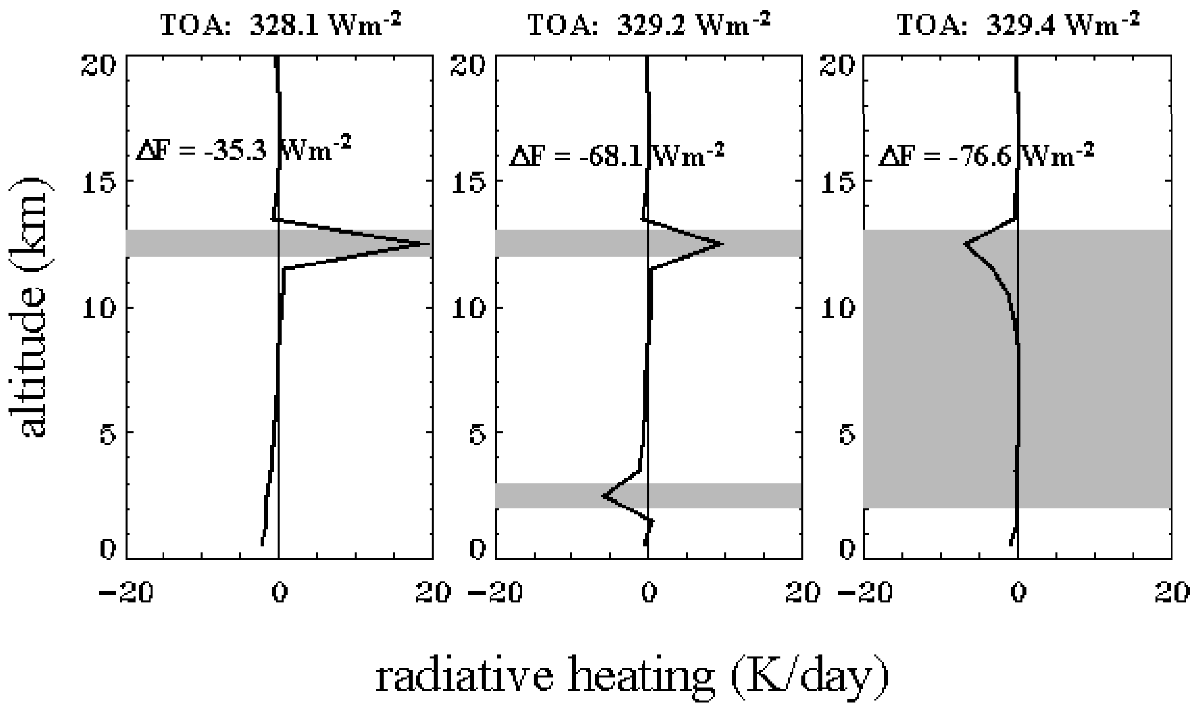
$$\Delta R = L\Delta P + \Delta S$$

It is energy that controls the gross global changes to precipitation - changes to the column-wise radiative heating grossly influence (ie control) of the global precipitation response -

The uncertain effects of clouds on this heating is one potential and significant cause for model spread in precip



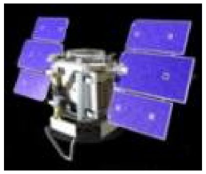
Cloud vertical structure and heating

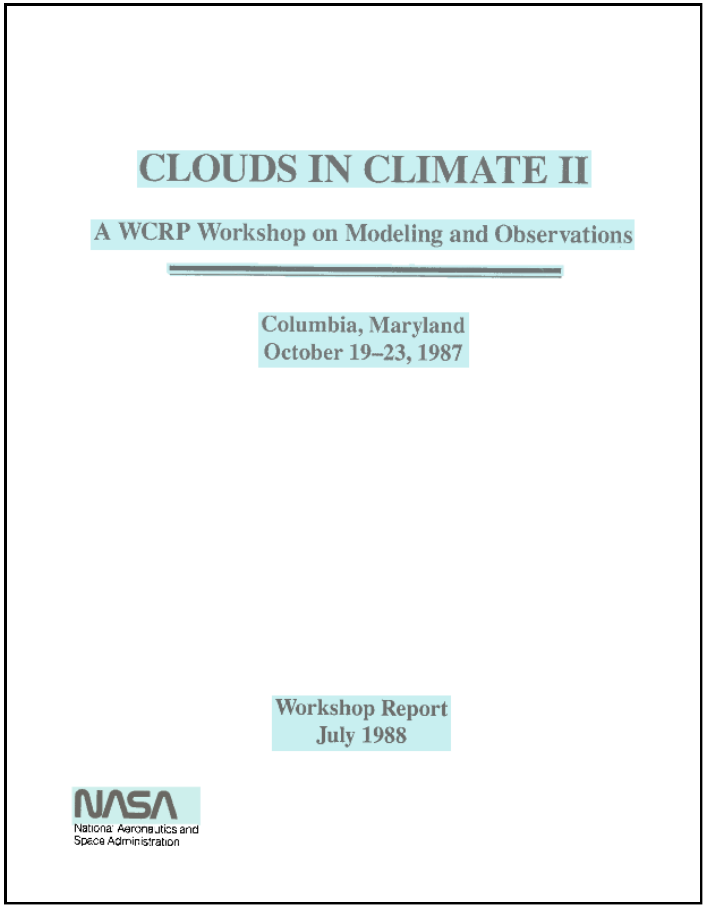


Slingo & Slingo, 1988

The ***amount*** of column heating by clouds is grossly influenced by vertical structure of clouds

The ***profile*** of heating too is fundamentally governed by cloud profile





CLOUDS IN CLIMATE II

A WCRP Workshop on Modeling and Observations

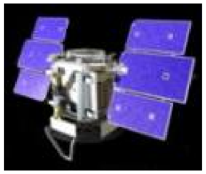
Columbia, Maryland
October 19–23, 1987

Workshop Report
July 1988

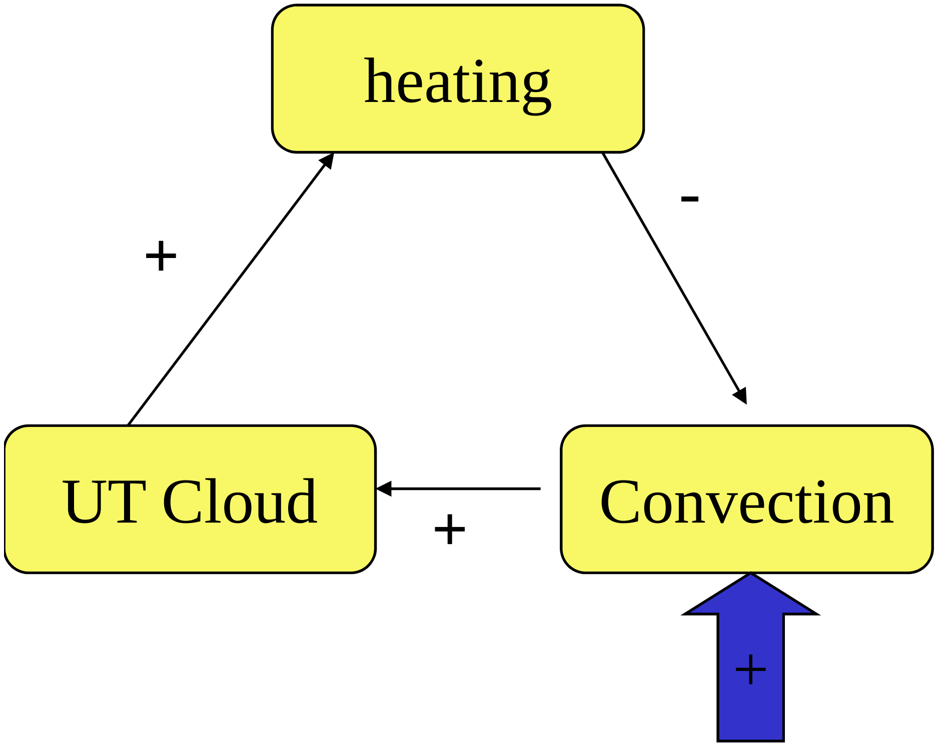
NASA
National Aeronautics and
Space Administration

Workshop identified profiles of diabatic heating, water & ice contents as critical issues for climate modeling.

Subsequent workshops circa 1990s appealed specifically for better ice info

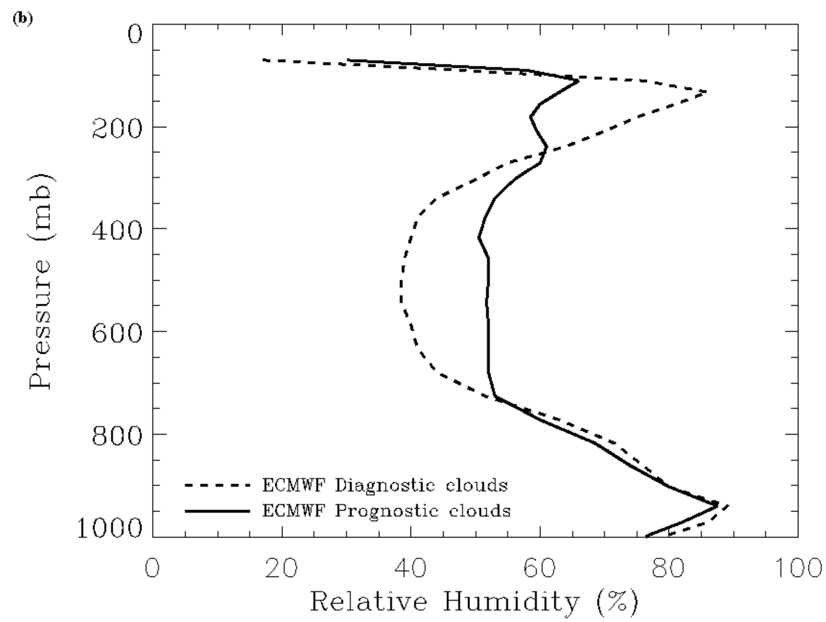


The effects of clouds on the vertical profile of radiative heating and on moisture

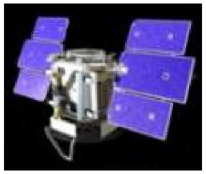


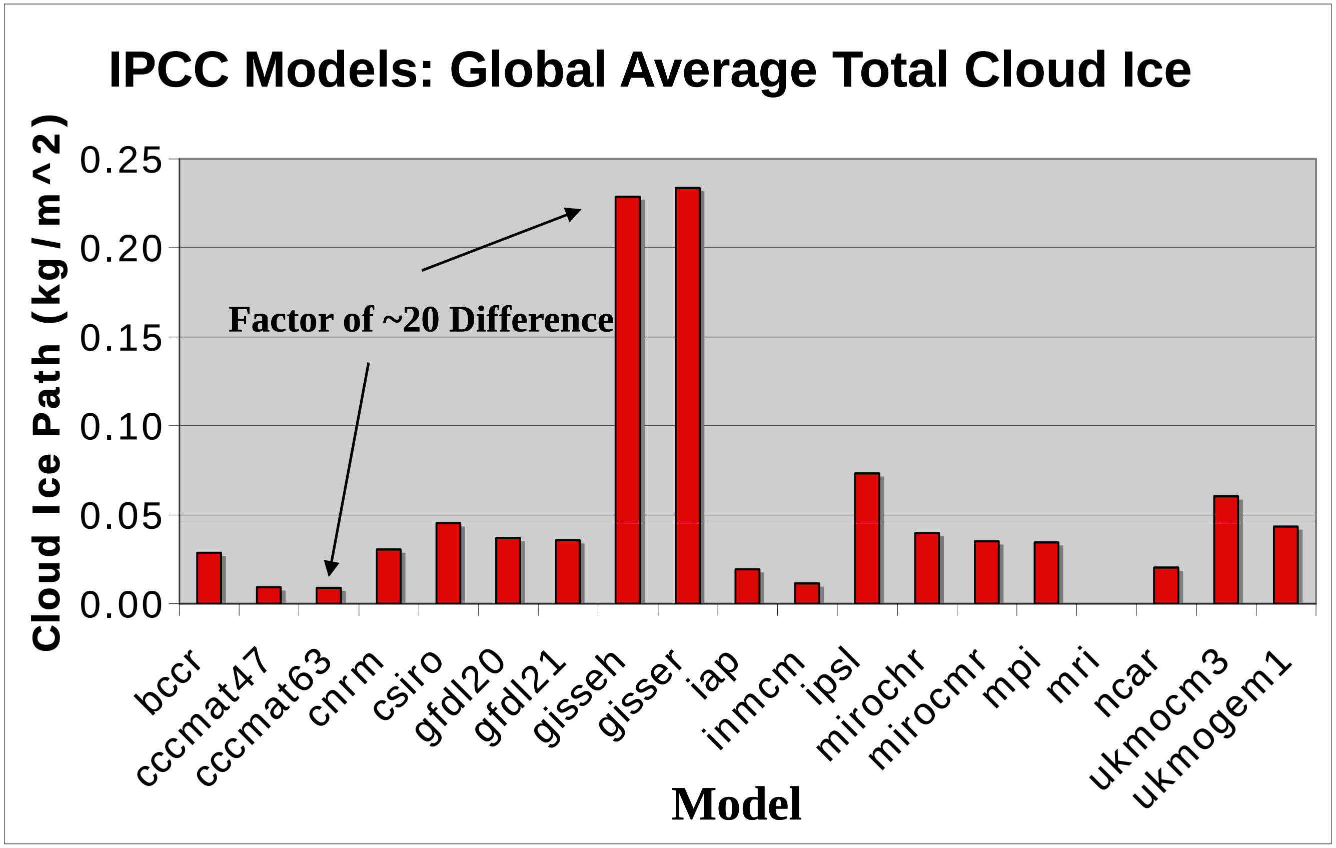
Numerous model studies point to the importance of this feedback

[Treatment of falling ice grossly influenced the UT humidity of the forecast model]



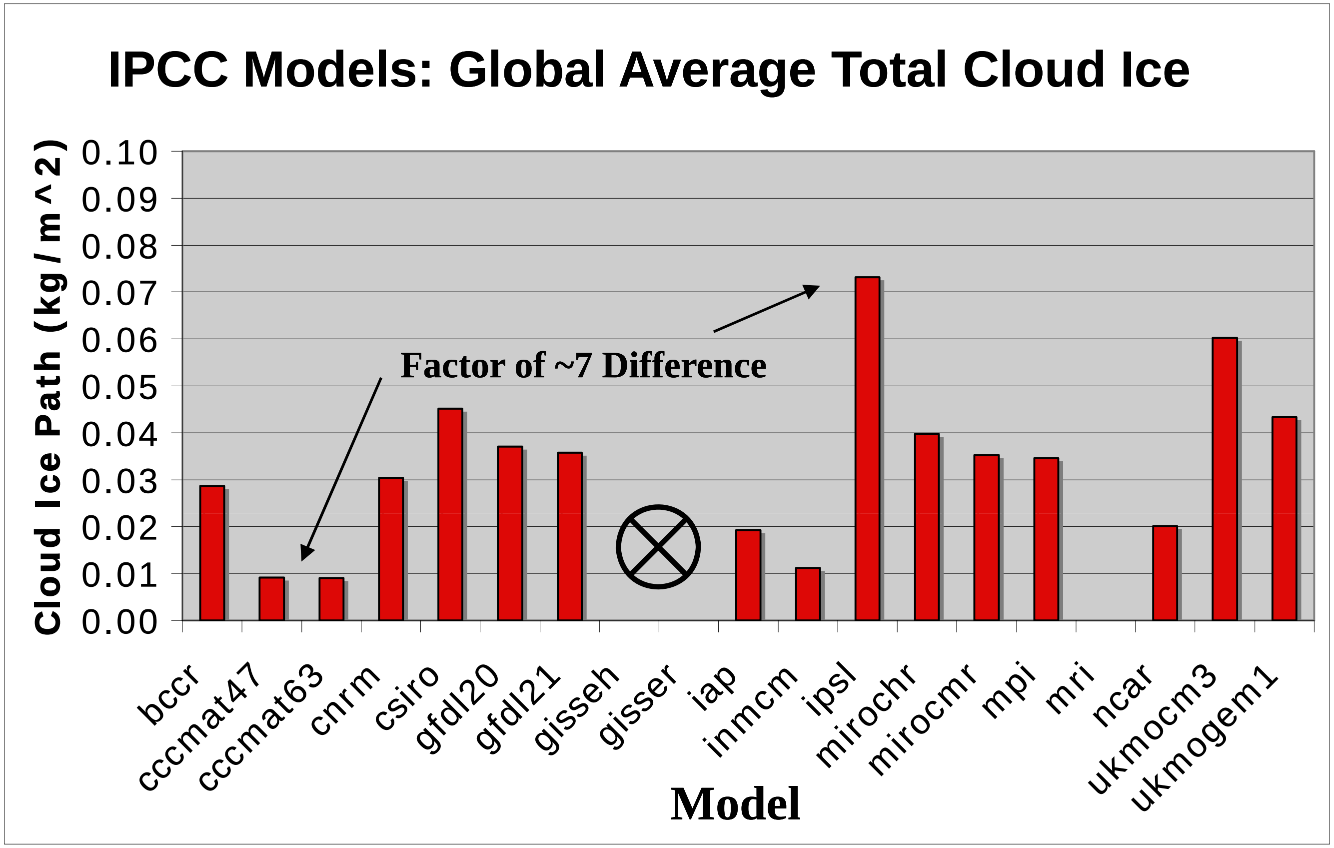
Modeling Implications: IPCC GCMs



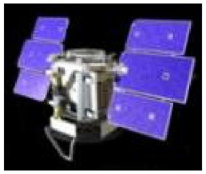


Modeling Implications: IPCC GCMs

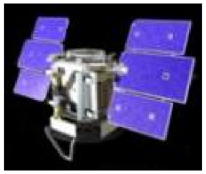
Courtesy Duane Waliser & JPL colleagues



Cloud Ice water content - modelers last line of defense against measured TOA fluxes (Tony Del Genio)



The emergence of the CloudSat science objectives



CloudSat Objectives

Provide, from space, the first global survey of cloud profiles (height, thickness) and cloud physical properties (water, ice, *precipitation*) needed to evaluate and improve the way clouds, moisture and energy are represented in global models used for weather forecasts and climate prediction.

A prevailing theme that emerged during this time was an emphasis on the notion that clouds and precipitation are part of a continuum of connected processes. Much understanding is thwarted through a general artificial separation of cloud science and precipitation science

•Products

•Geometrical profiles =Radar profiles *Mace& Marchand*

=Hydrometeor profiles

•Cloud incidence *ditto*

•Cloud type *Zhien Wang*

•Cloud physics = water content profiles *Austin*

•Cloud contribution to atmospheric radiative heating - derived from geometric profiles, cloud physics, T,q analysis *L'Ecuyer*

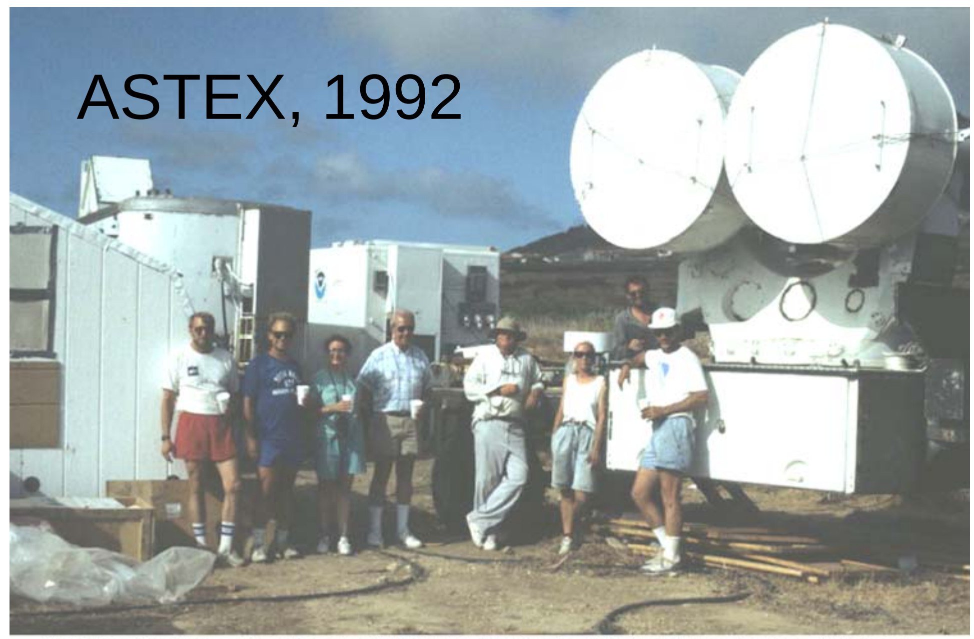
•Precipitation incidence *Wang, Haynes*

•*Quantitative precipitation Mitrescu, Miller,L'Ecuyer*

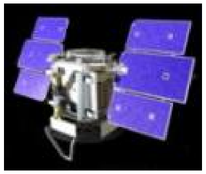
How the mission evolved

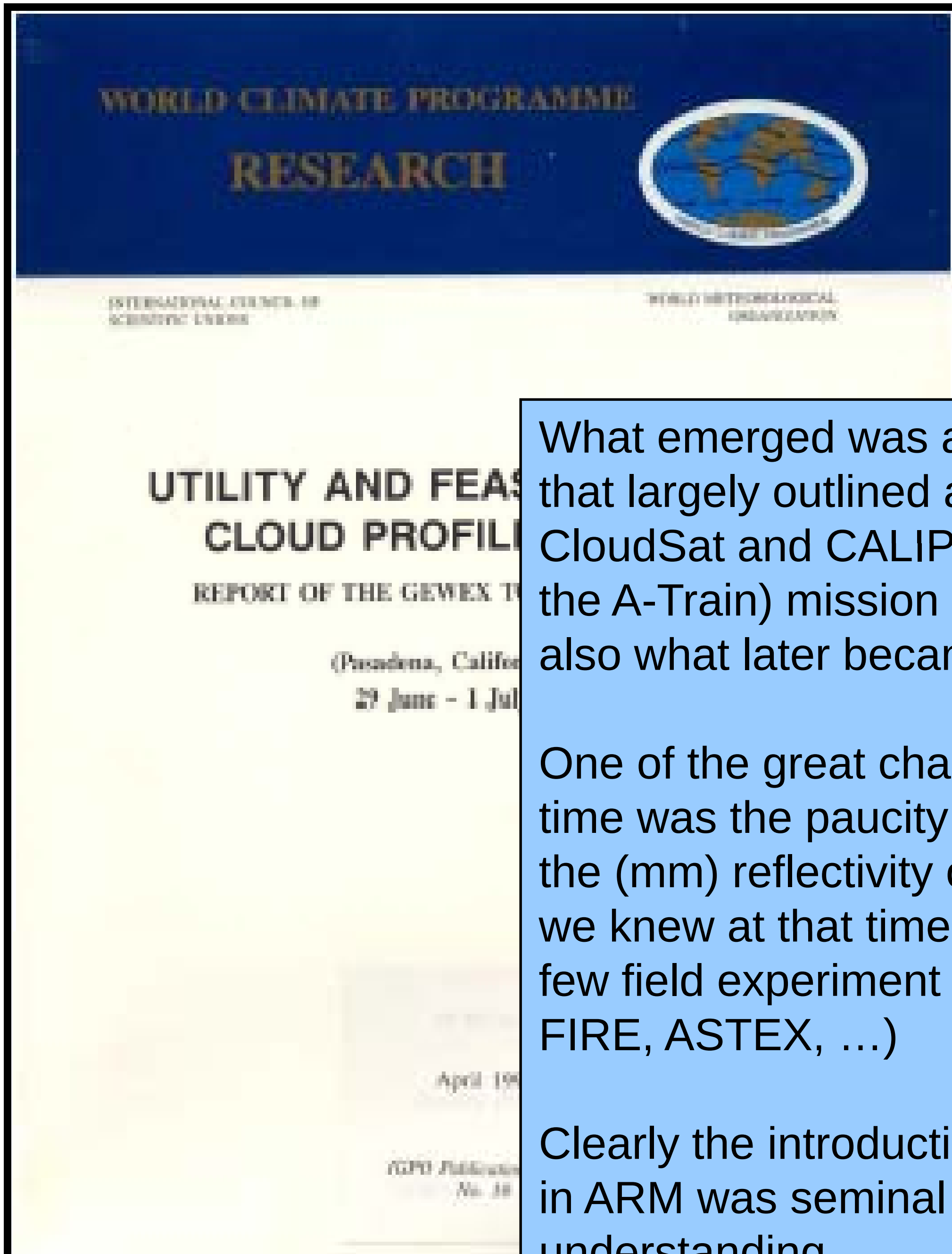
Mm radars have become a key tool to study clouds

Coffeyville
KANSAS



M.J. Post, Bob Banta, Lisa Oliver, Jack Snider, Shelby Frisch, JanGibson, Bruce Bartram, Bob Kropfli with lidar, radiometer and Ka-band radar on Porto Santo Island, Maderia Islands of Portugal, ASTEX, 1992

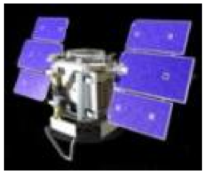



WORLD CLIMATE PROGRAMME
RESEARCH
INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS
WORLD METEOROLOGICAL ORGANIZATION
UTILITY AND FEAS
CLOUD PROFIL
REPORT OF THE GEWEX T
(Pasadena, Califo
29 June - 1 Jul
April 19
IGPO Publicatio
No. 18

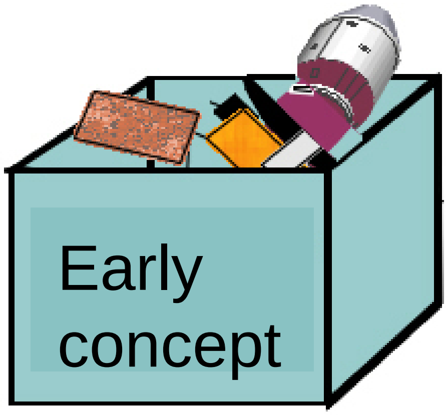
What emerged was a satellite concept that largely outlined a combined CloudSat and CALIPSO (with some of the A-Train) mission elements and also what later became EarthCare.

One of the great challenges at that time was the paucity of information on the (mm) reflectivity of clouds - what we knew at that time was limited to a few field experiment activities (e.g. FIRE, ASTEX, …)

Clearly the introduction of the MMCR in ARM was seminal to this understanding

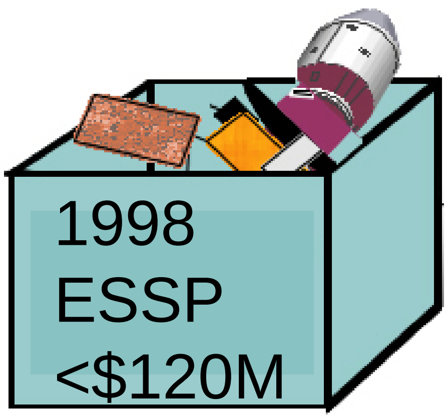


Radar + lidar, Spectrometer + sub-mm radiometer +

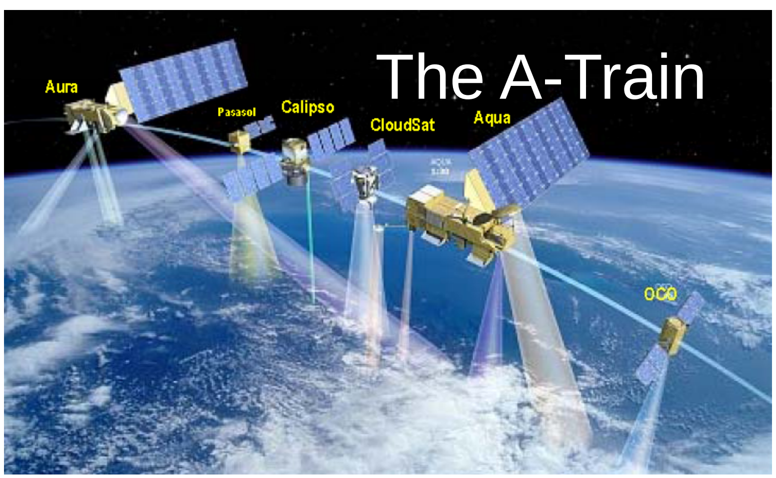


1995 - early mission concept emerged,…

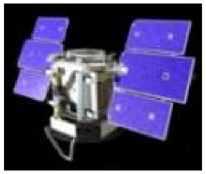
Radar + spectrometer



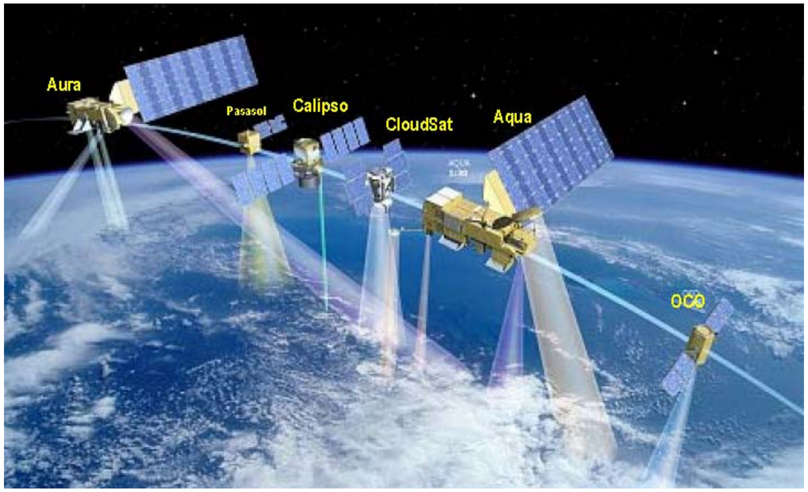
1996- ESSP was born, missions under $90M
1998 - ESSP II- cap raised to $120M. This forced the separation of lidar/radar



The selection of both CloudSat and PICASSO (CALIPSO), opened the path for a virtual radar/lidar observing system



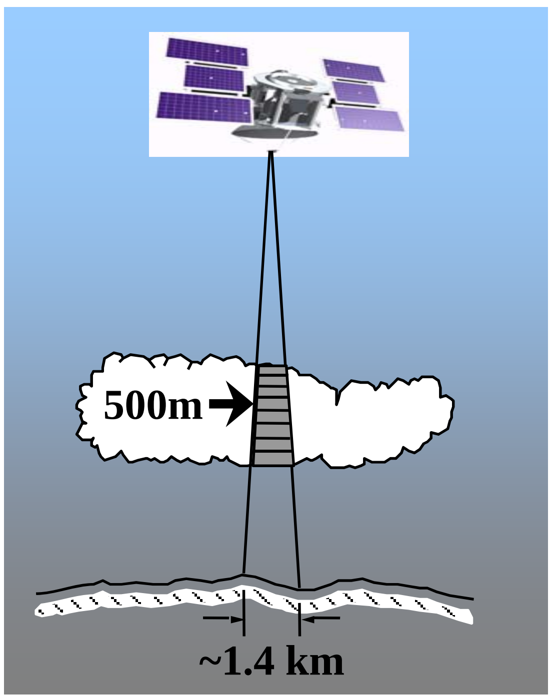
Two key components to the mission design



1. Formation with the A-Train

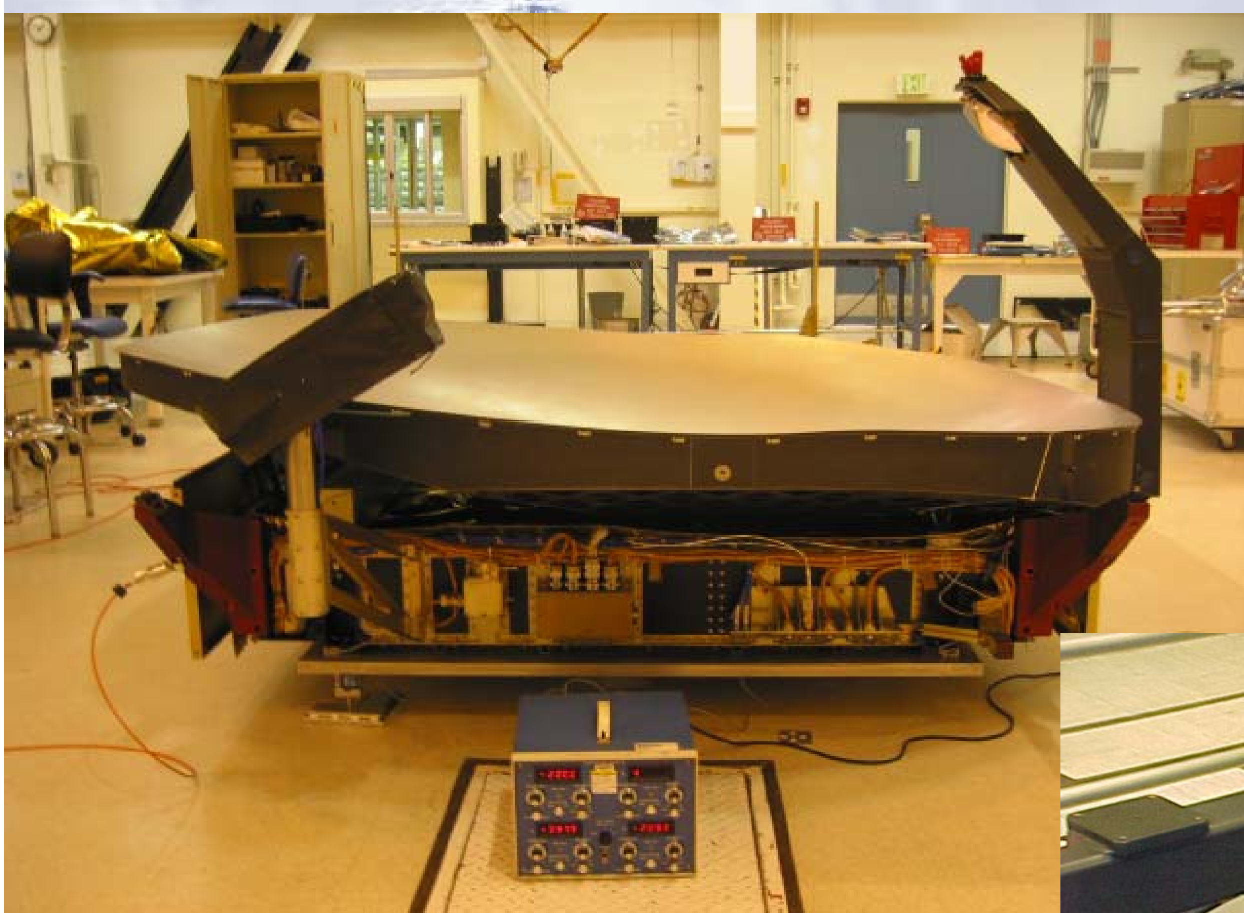
2. The Cloud Profiling Radar (CPR)

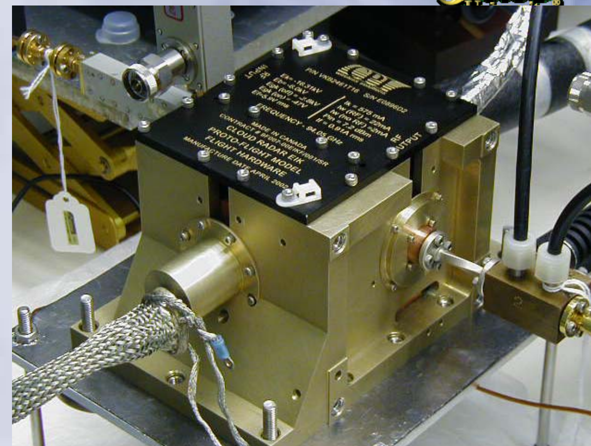
- Nadir pointing, 94 GHz radar
- 3.3μs pulse ➔ 480m vertical res, over- sampled at ~240m
- 1.4 km horizontal res.
- Sensitivity ~ -28 dBZ (-31 dBZ)
- Dynamic Range: 80 dB



CloudSat is a pathfinder mission - a step in a journey

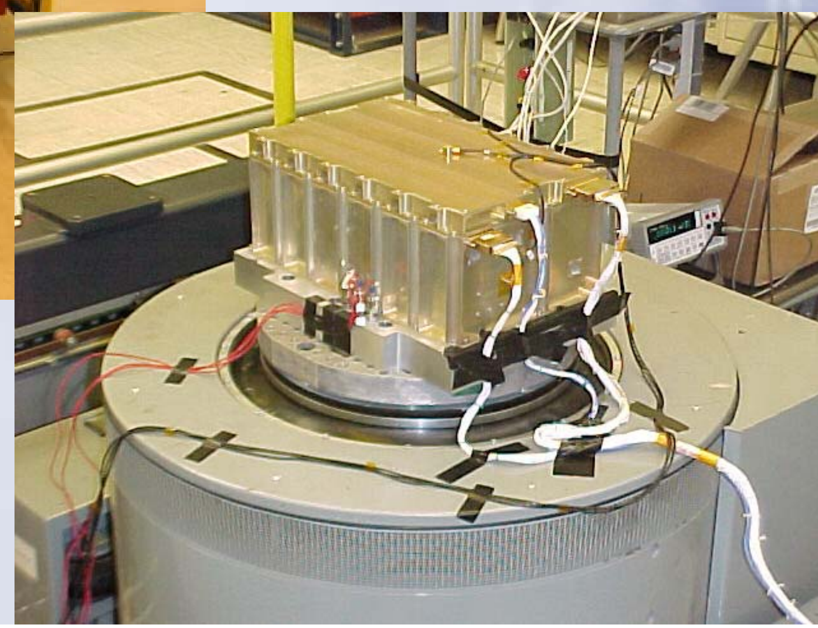
CloudSat is the FIRST spaceborne 94 GHz radar - millimeter wave technology



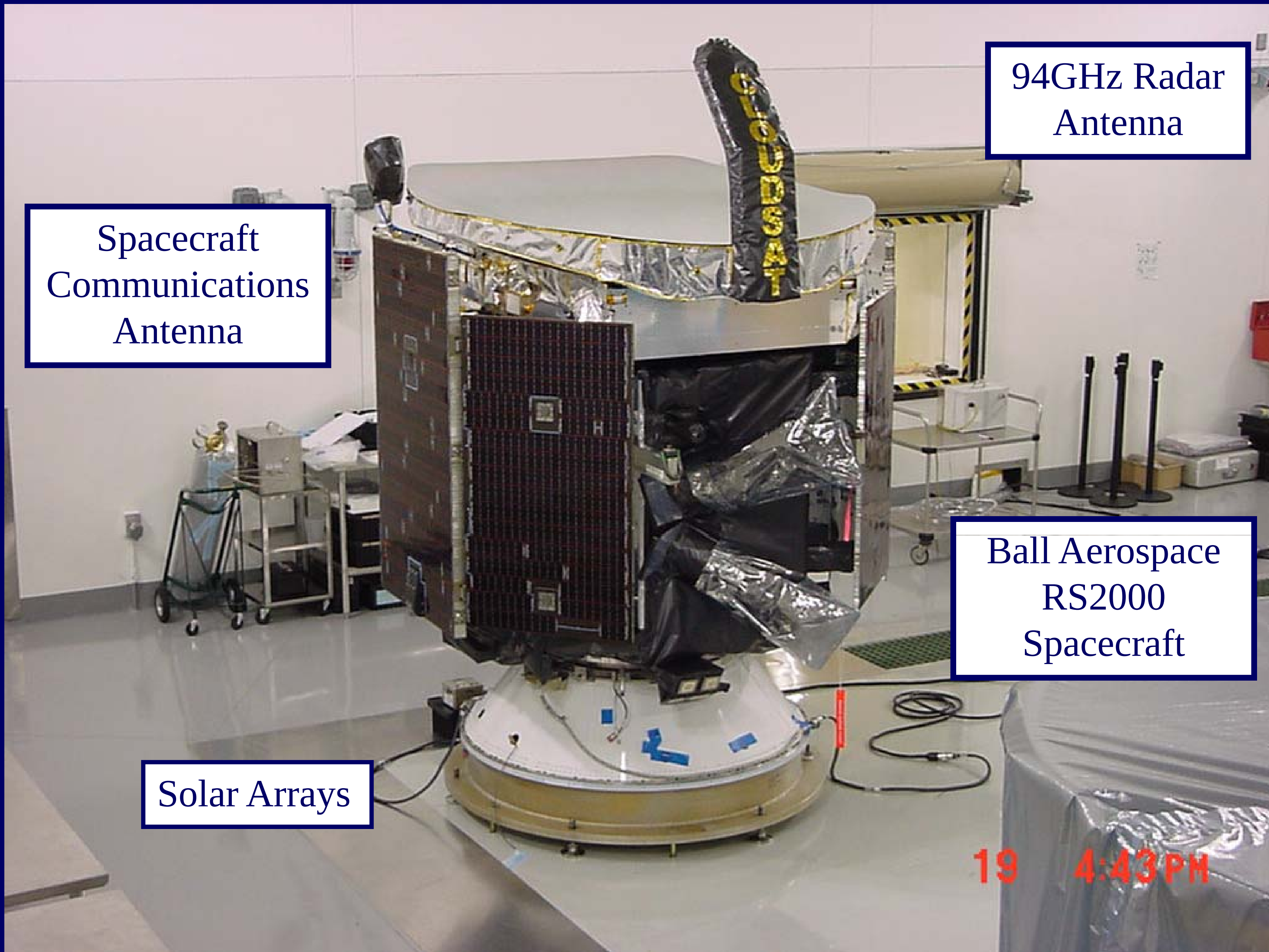


EIK contributed by the Canadian Space Agency

20 kV power supply developed by JPL



Colorado


94GHz Radar Antenna
Spacecraft Communications Antenna
Ball Aerospace RS2000 Spacecraft
Solar Arrays
CLOUDSAT
19 4:43PM

2+ years after initial proposed launch

April, 28th, 03.02am


NASA

A few highlights

•May 20, 2006 - CPR switched to Operate Mode for the first-time to check out science data collection functions and performance

•June 2, 2006 - CPR switched to operate mode and CloudSat science data acquisition phase began

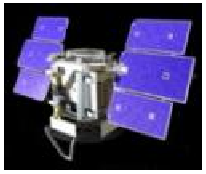
•June 6, 2006 - First CPR 10˚ clear-ocean Calibration exercise - these reinforce the calibration assessment

•July First Validation project (CCVEX)

• Nov 2006 release of selected data products followed in Jan 2007 by full release

•Feb 2007 Senior review proposal for continued operations

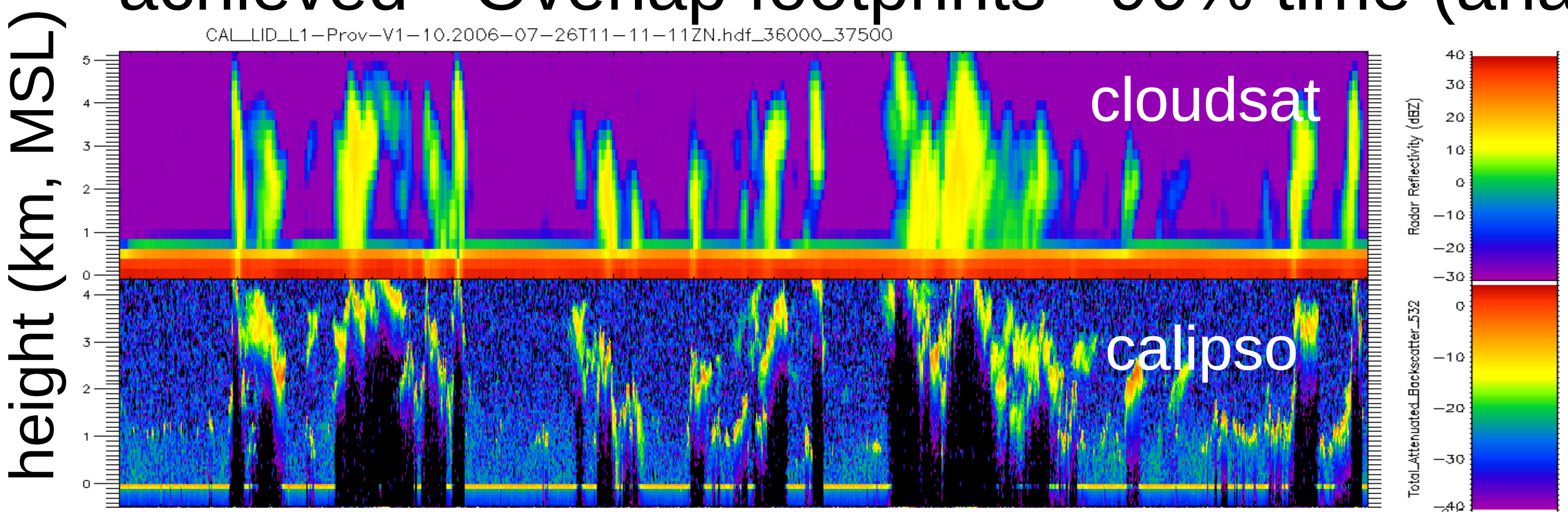
• March 2007 - first science papers



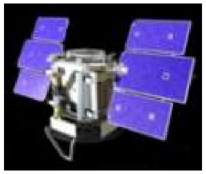
1. Formation with the A-Train

Goal - overlap ~50%

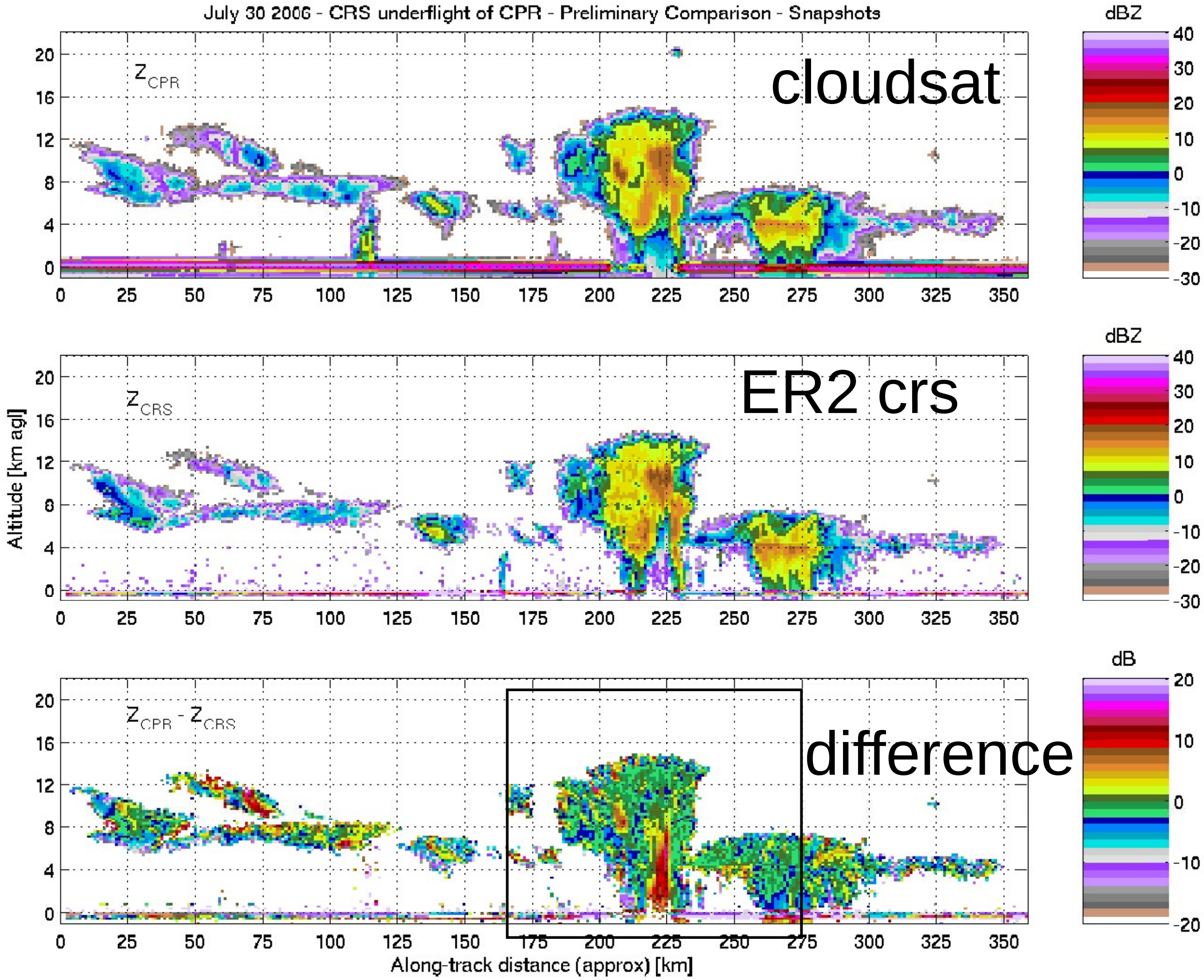
achieved - Overlap footprints ~90% time (analysis)



This is a remarkable technical achievement that has clearly demonstrated the viability (for science) of precision formation flying as a future EO strategy



2. The Cloud Profiling Radar (CPR)
Requirement - BOL ~ -28dBZ
calibration < ~-2dBZ
Δz~ 500m (480m subsampled at 240m)



Calibration within 2dBZ

Multiple scattering in rain > 5mm/hr

Validation

Validation is an endeavor that can only ever declared as 'done' under two circumstances:

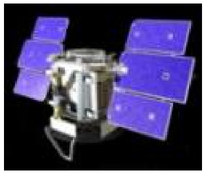
Death

Walk away in frustration

Field expts

NAMMA, CCVEX, C3VP, …TC4,

Systematic obs, ARM, …



Early Results

•*Measure vertical structure of clouds, quantify their ice and water contents as a step toward improved weather prediction and understanding of climatic processes*

What are the fundamental vertical structures of global clouds?

How do structure & properties differ in the presence of precipitation?

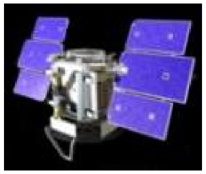
What fraction of clouds of Earth precipitate?

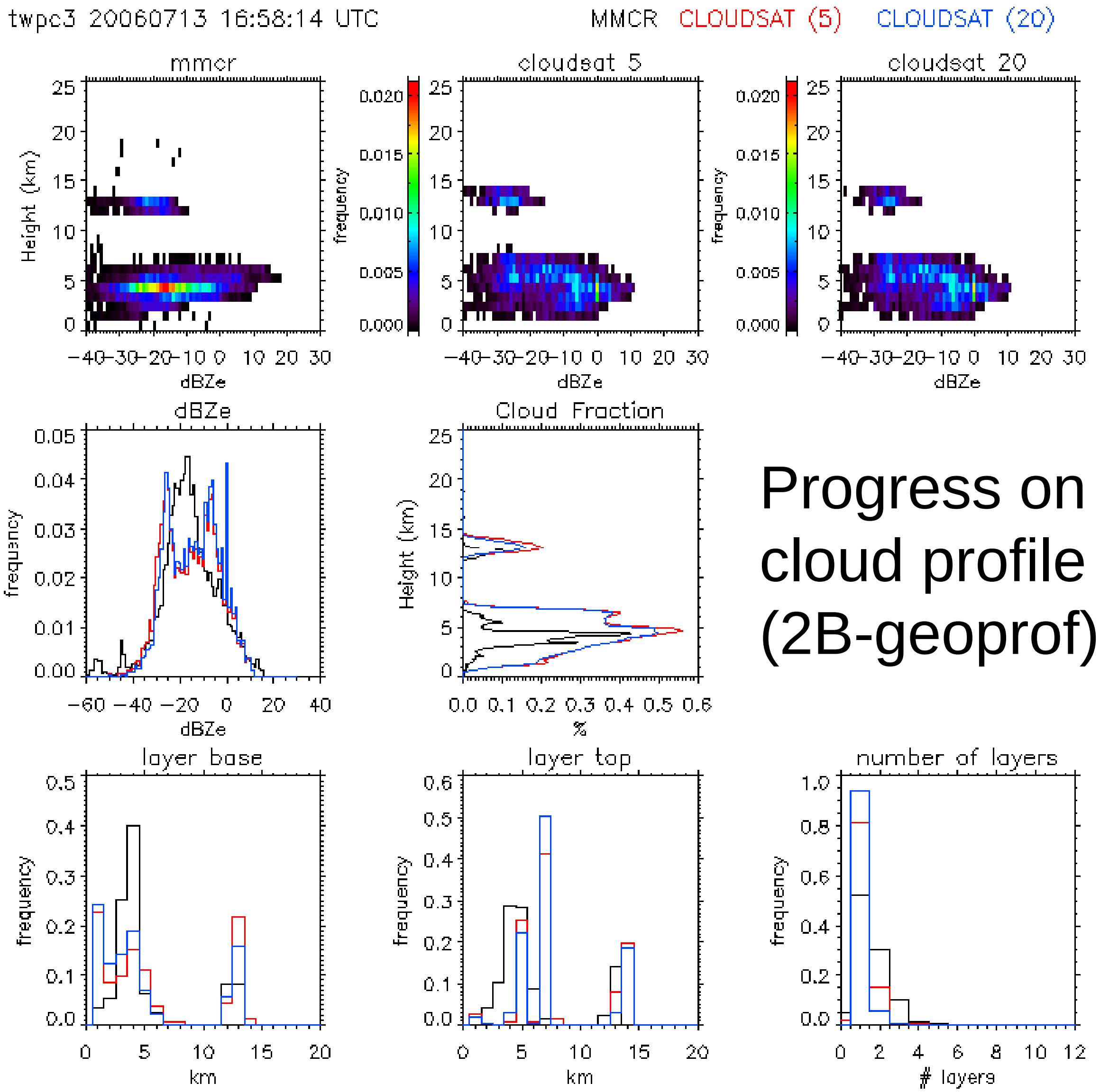
What is the mass of ice suspended in the atmosphere?

•*Quantify the relationship between cloud profiles and the radiative heating by clouds*

Do clouds heat or cool the atmosphere (relative to clear skies)?

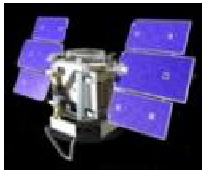
Do the radiative properties of precipitation and non-precipitating clouds differ?





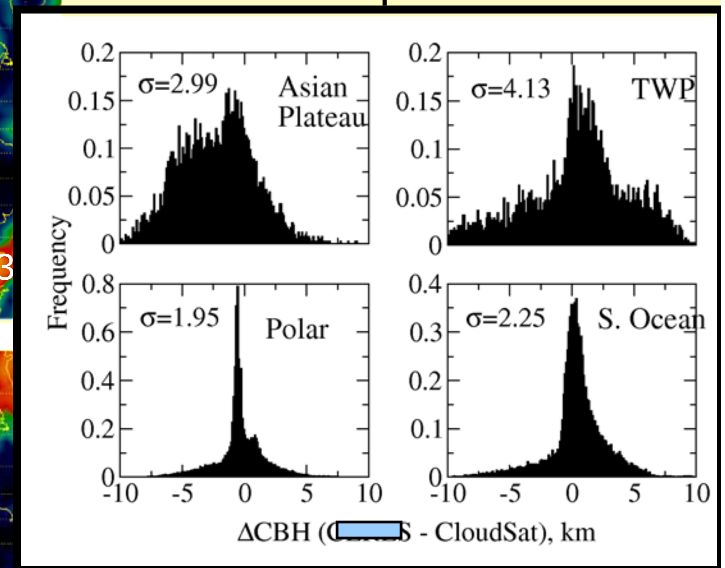
Progress on validating the cloud profile information (2B-geoprof) using ARM

Courtesy, Jay Mace

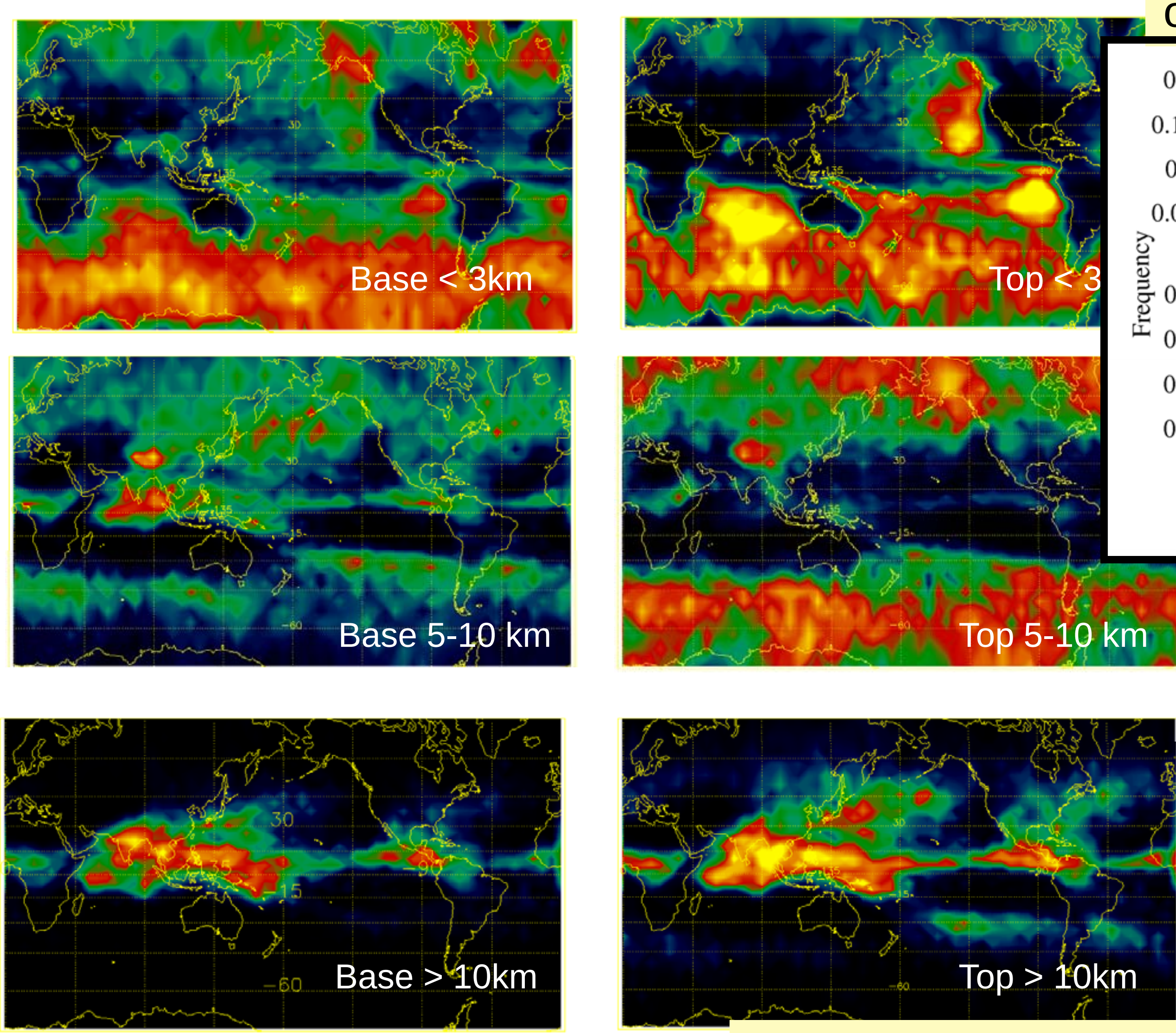


What are the fundamental vertical structures of global clouds?

Cloud base differences from other satellite products



rms differences 2-4 km
500m ~ 5-10 W/m2



Mace et al, 2007

How do structure & properties differ in the presence of precipitation?

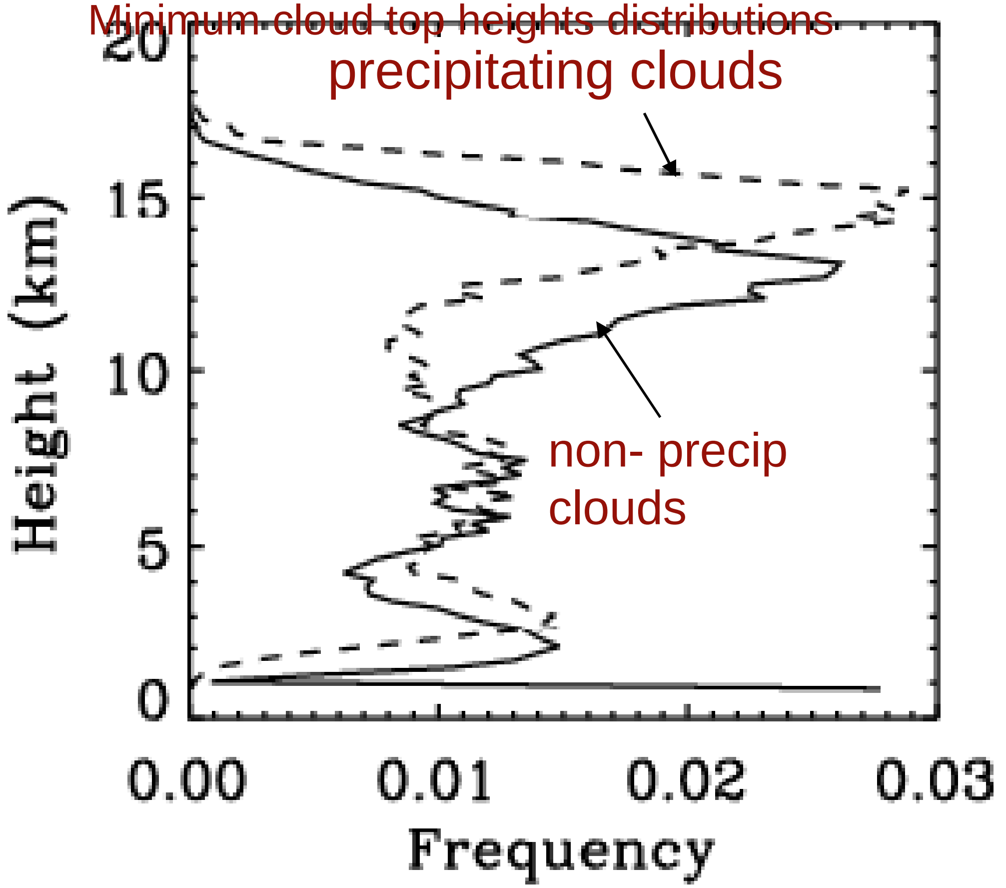
Of note:

•Trimodality (quadra-modal) heights

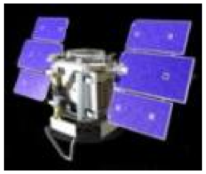
• precipitating clouds are deeper than non precipitating clouds

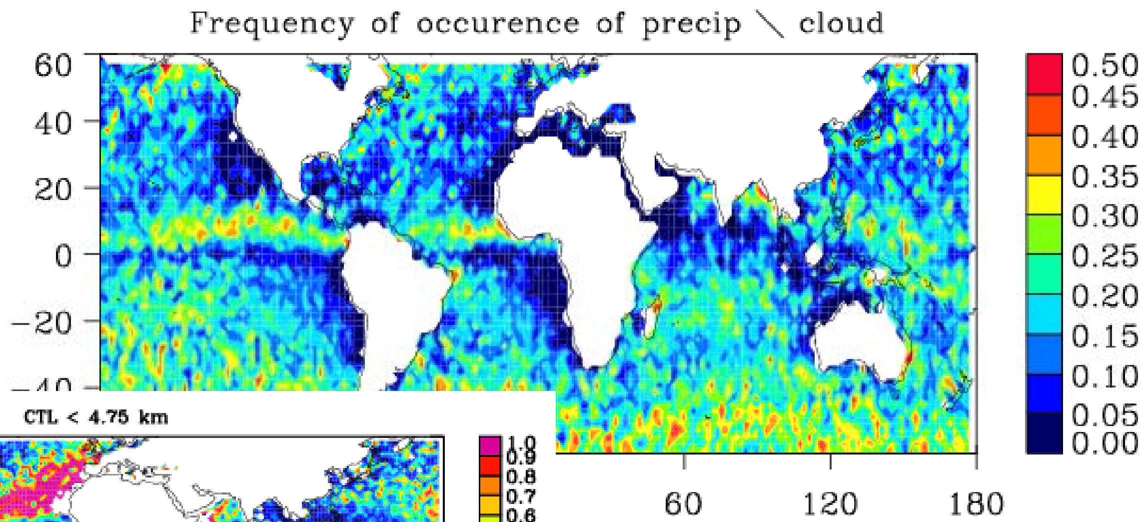
Composite vertical profile for west pac, JJA

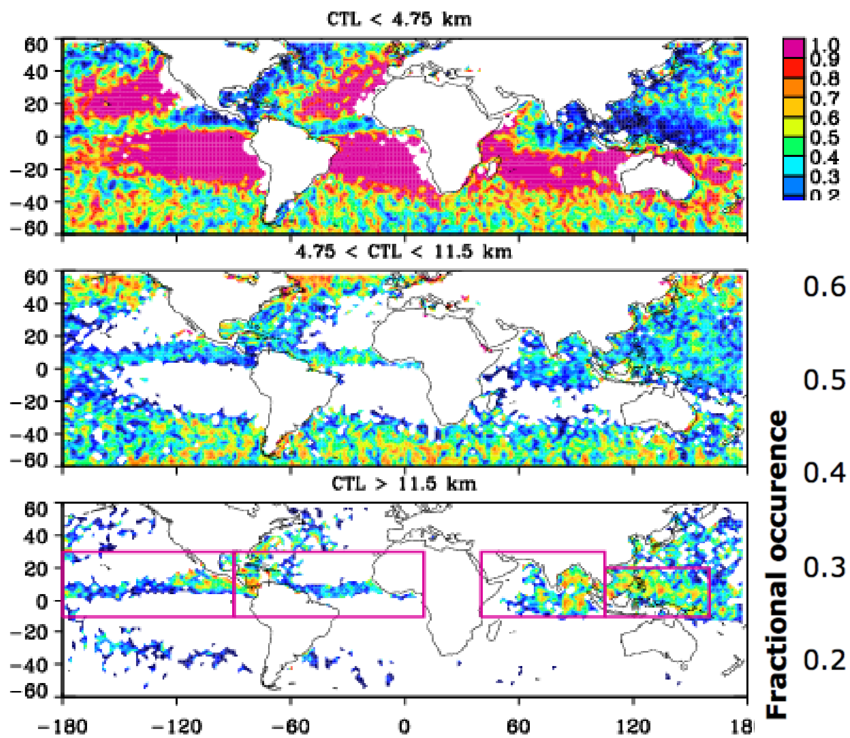
Minimum cloud top heights distributions

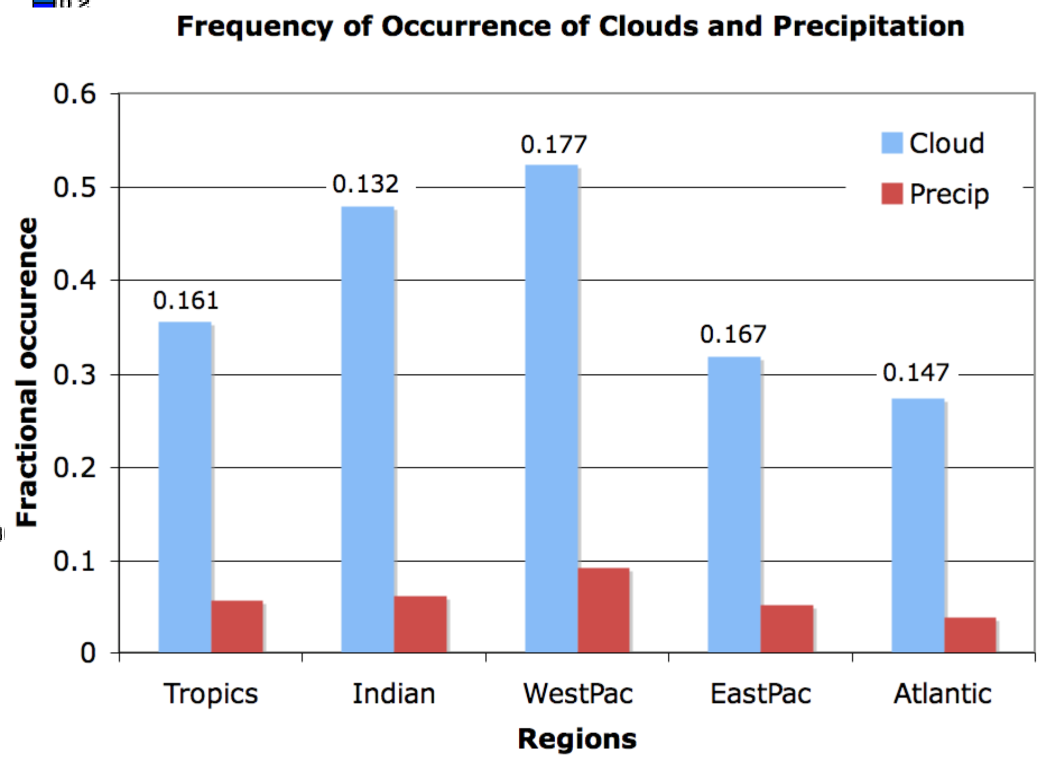


Haynes and Stephens, 2007

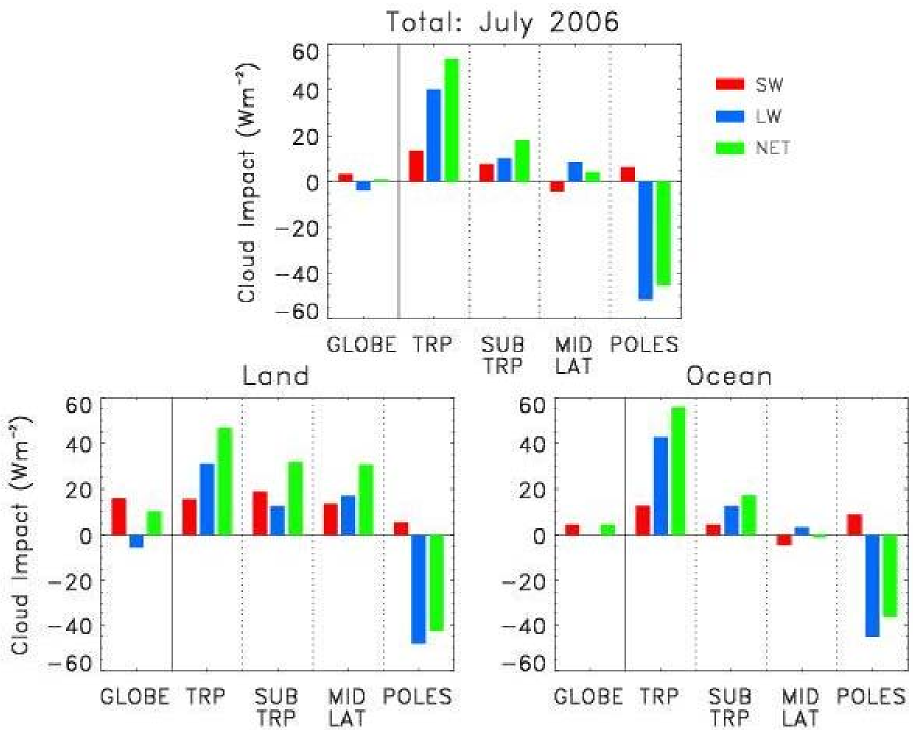






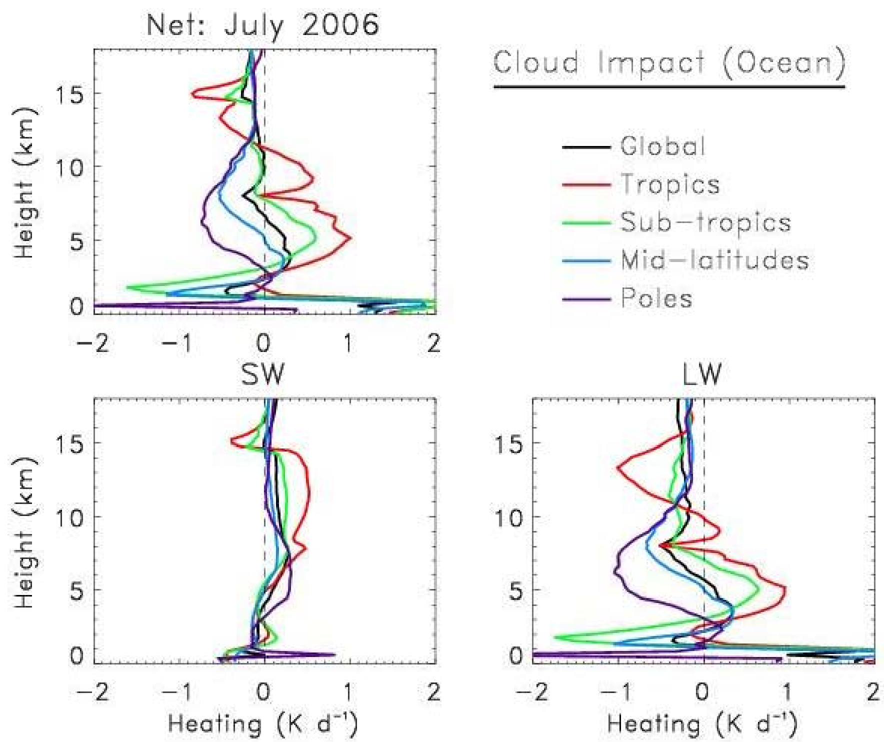


Haynes & Stephens, 2007

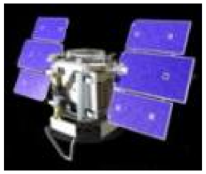


•*Quantify the relationship between cloud profiles and the radiative heating by clouds*

Do clouds heat or cool the atmosphere (relative to clear skies)?



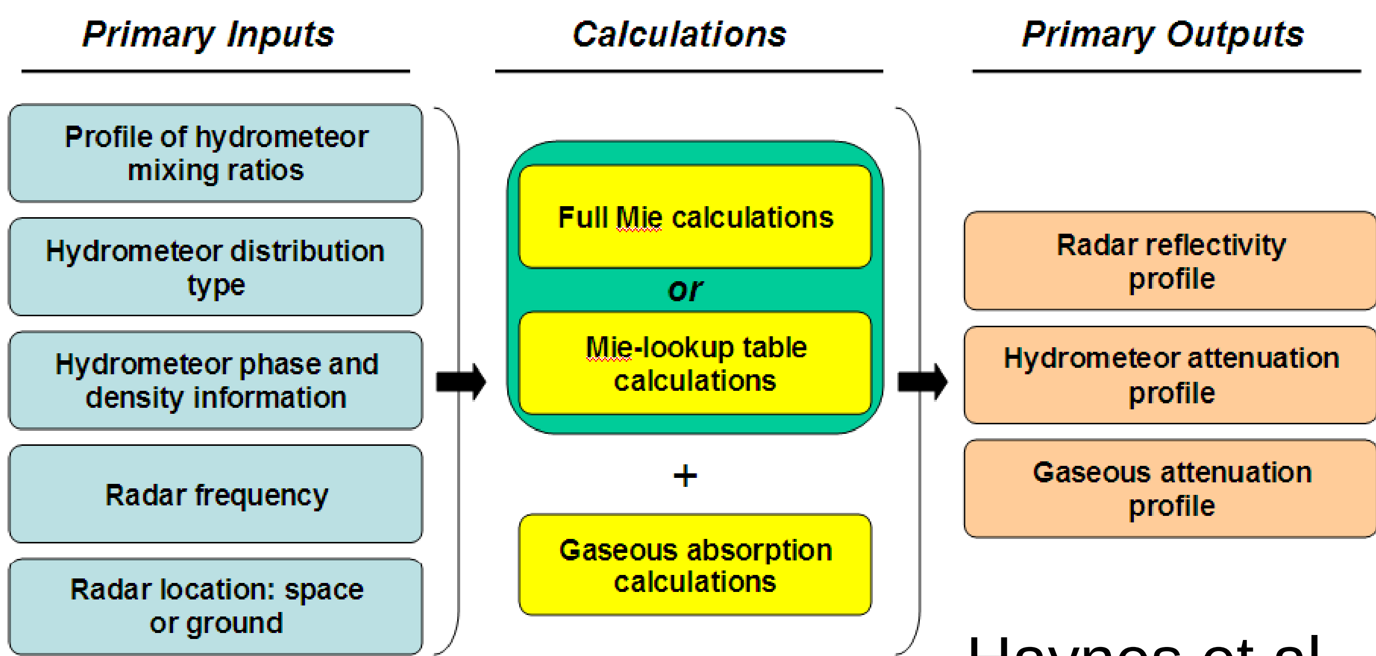
L'Ecuyer & Stephens, 2007



Steps toward improving representation of clouds related processes in models ---- Model evaluation

CloudSat simulator activity

- CloudSat simulator (Quickbeam)
  - Emulates observations (in the spirit of ISCCP simulator)
  - Requires Cloud **and** Precipitation as input
  - Has been integrated into certain versions of global models
  - Being adapted to more ‘conventional’ low-resolution models.
- Sub-grid sampling



Haynes et al., 2007

The simulator in NWP, courtesy Alejandro Bodas

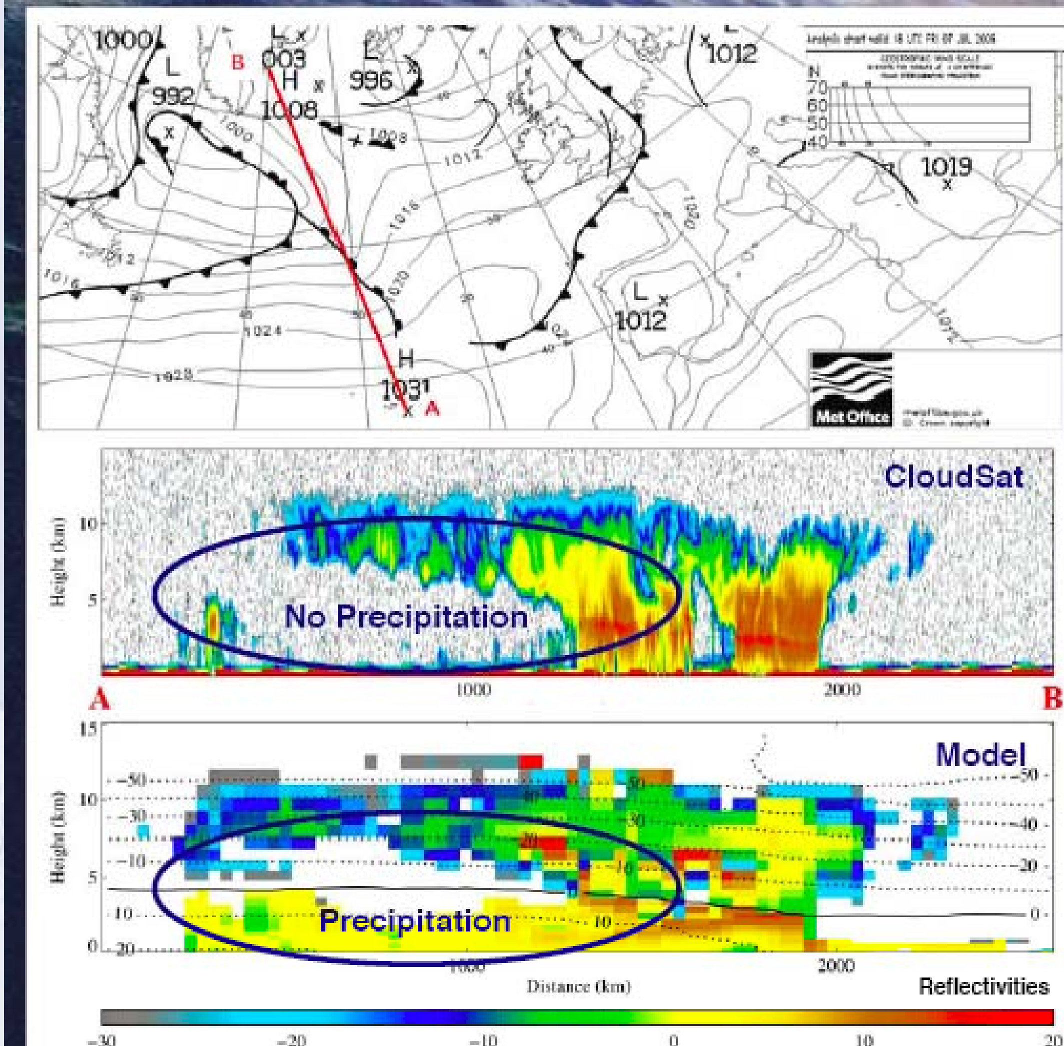
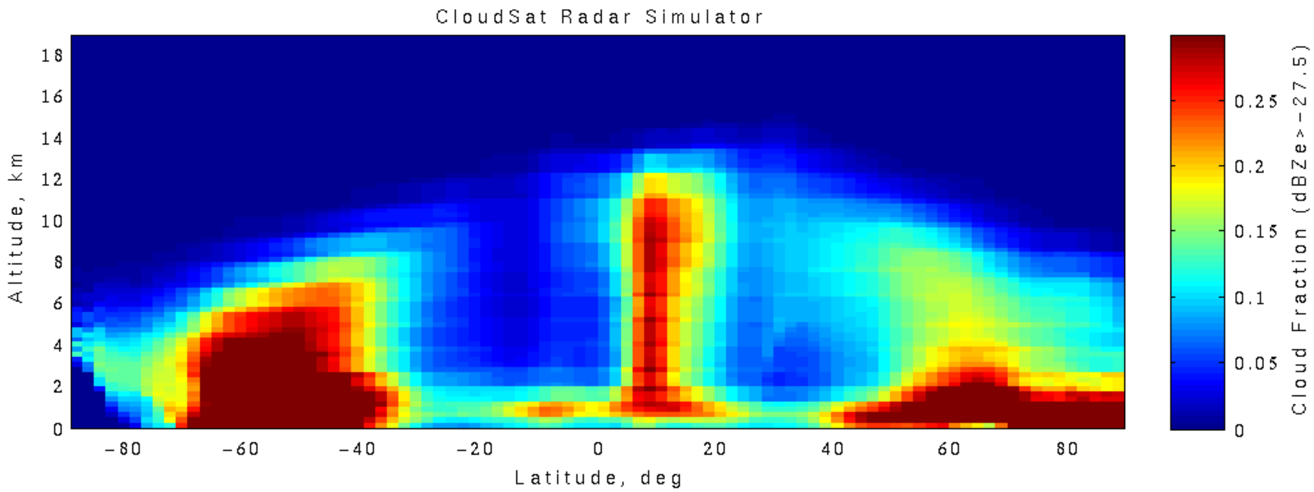
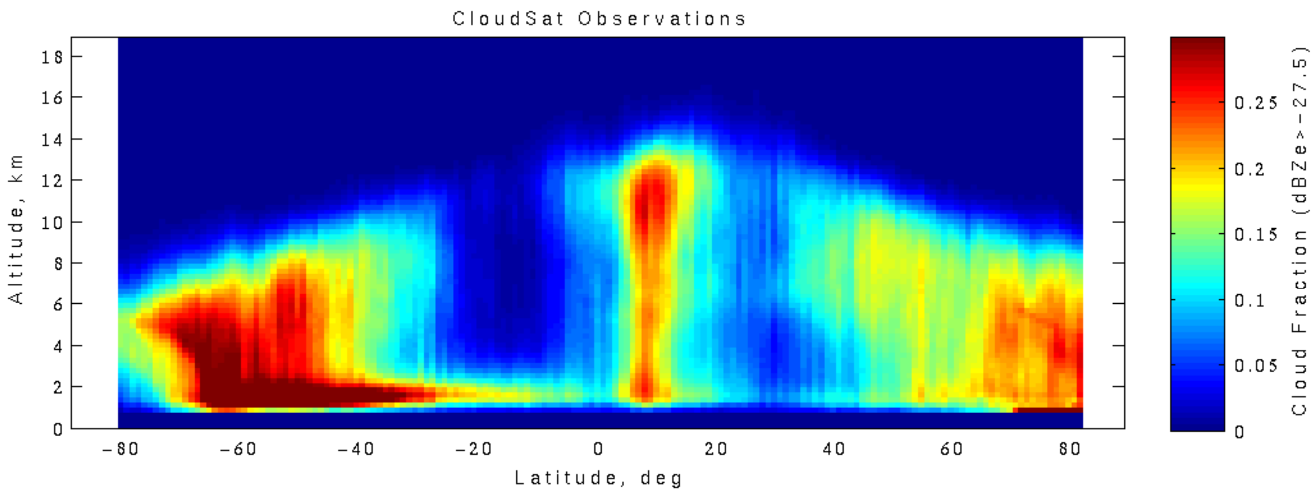


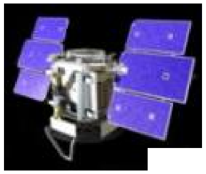
Figure B: A comparison of CloudSat data (middle panel) through a warm, mid-latitude front (top panel, line from A to B) and the simulated CloudSat observations (bottom panel) derived from the UK Met Office model forecast using the CloudSat instrument simulator. The model forecast produces wide-scale light precipitation not observed by CloudSat. The extent that this is a systematic problem in the forecast-model physics is under investigation (courtesy, M. Ringer, UKMO).

July

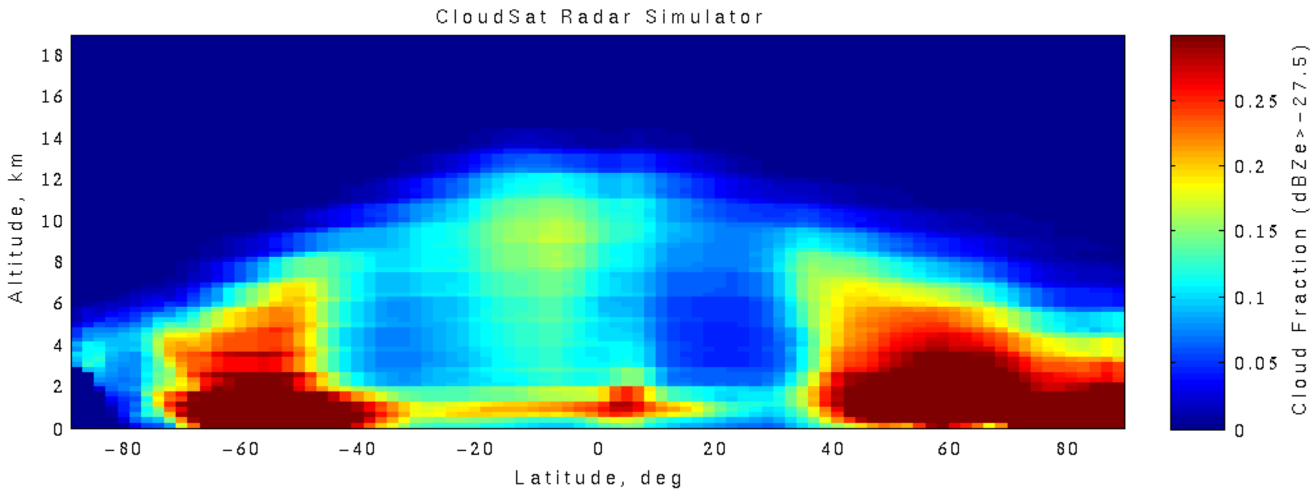


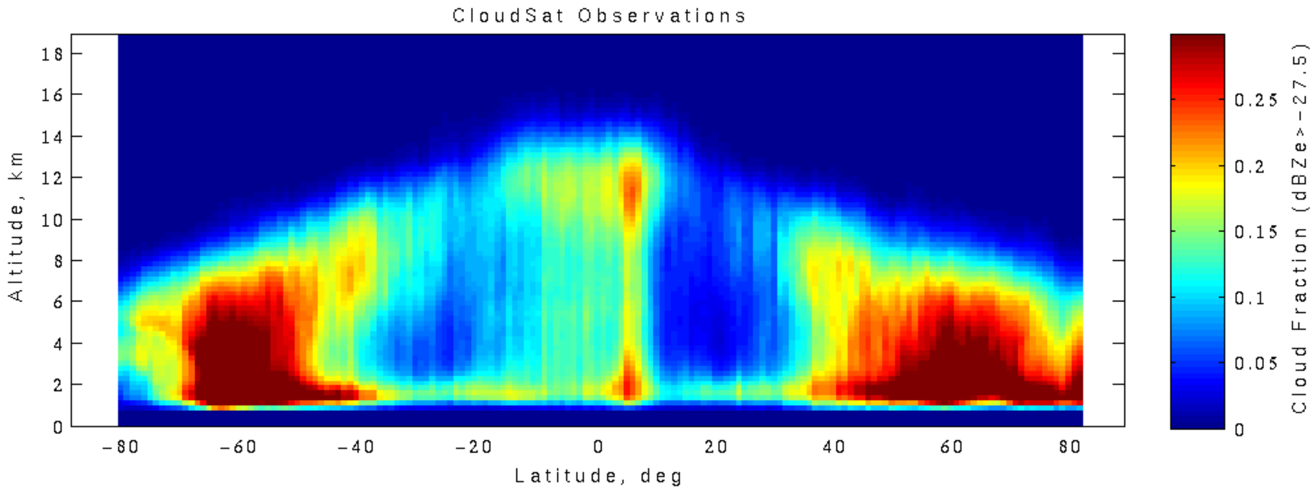


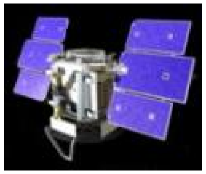
The simulator in MMF, courtesy of Roj Marchand



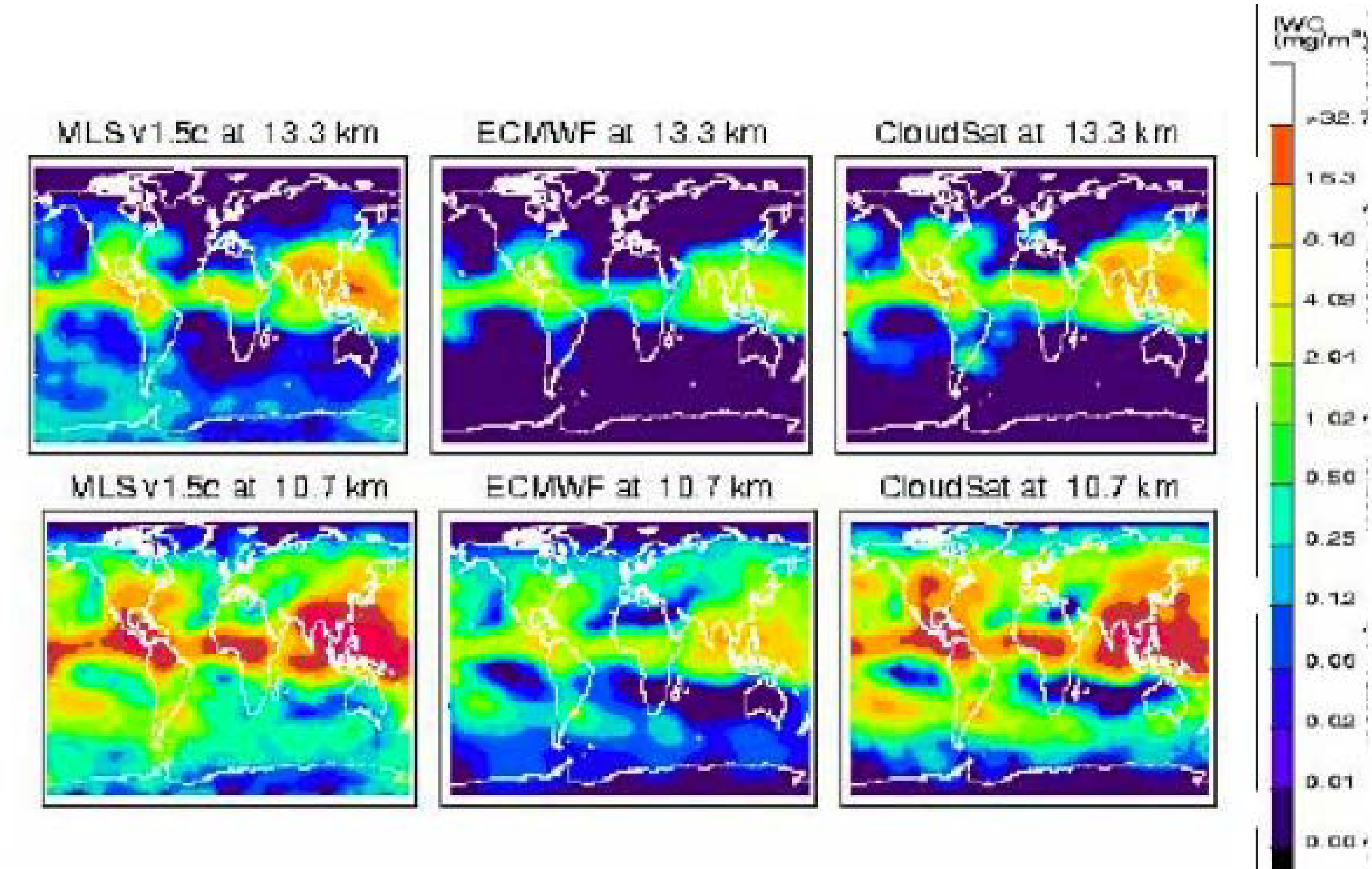
December


CloudSat Radar Simulator
Altitude, km
Latitude, deg
Cloud Fraction (dBZe>-27.5)
18
16
14
12
10
8
6
4
2
0
-80
-60
-40
-20
0
20
40
60
80
0.25
0.2
0.15
0.1
0.05
0


CloudSat Observations
Altitude, km
Latitude, deg
Cloud Fraction (dBZe>-27.5)
18
16
14
12
10
8
6
4
2
0
-80
-60
-40
-20
0
20
40
60
80
0.25
0.2
0.15
0.1
0.05
0



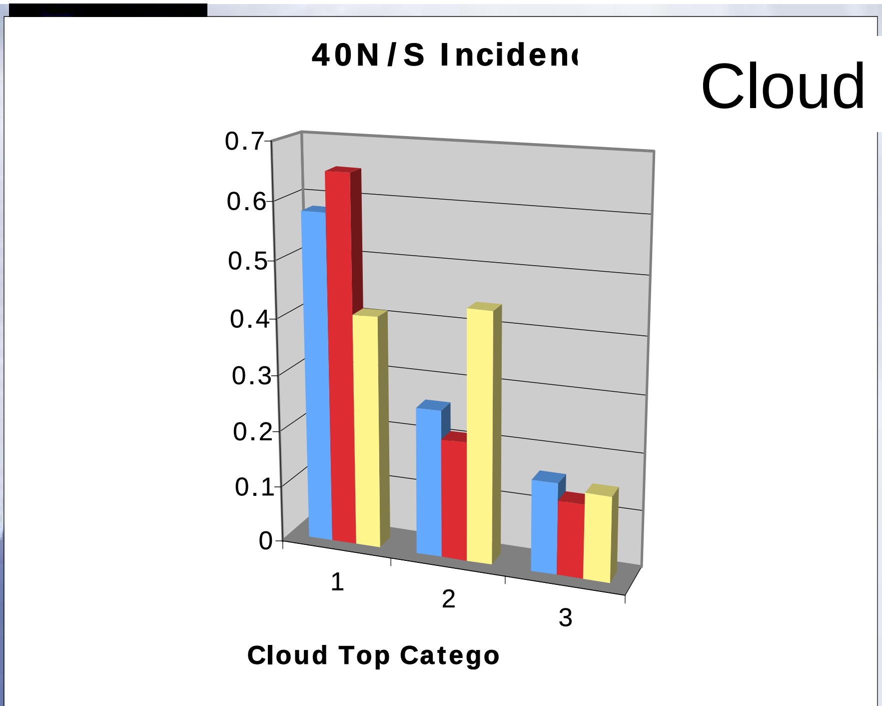
Cloud Ice water content *(2B-CWC)*



MLS ECMWF CloudSat

[1] Tony DelGenio

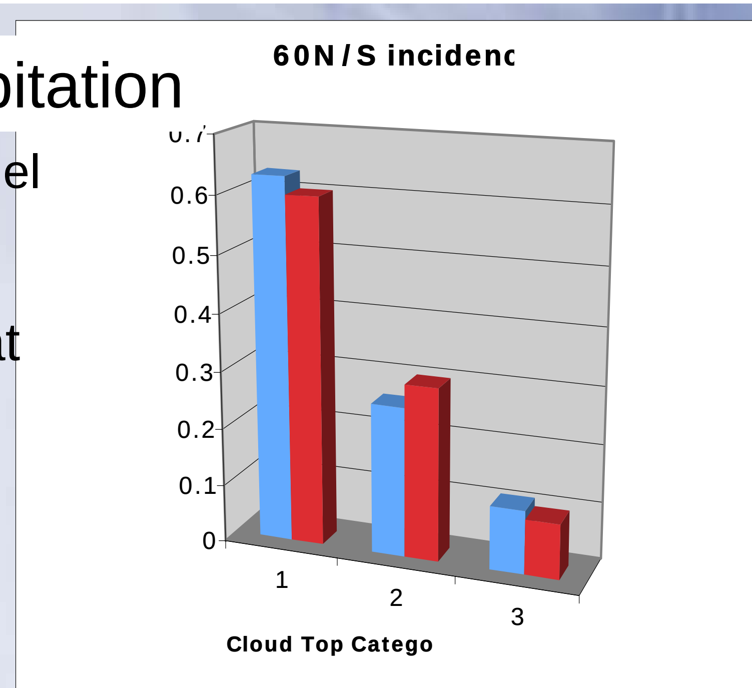
Cloud & precipitation

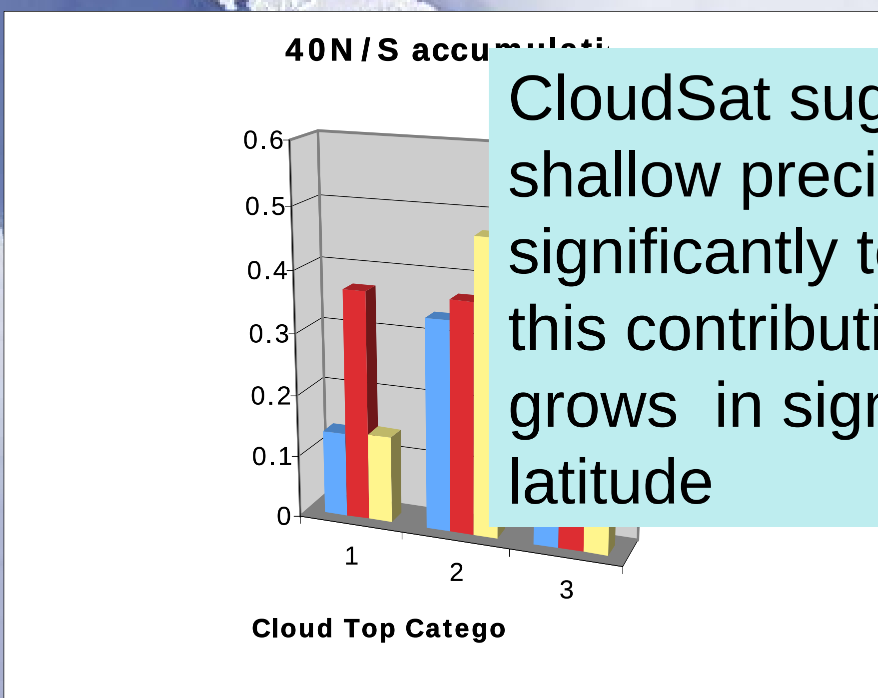


NWP model

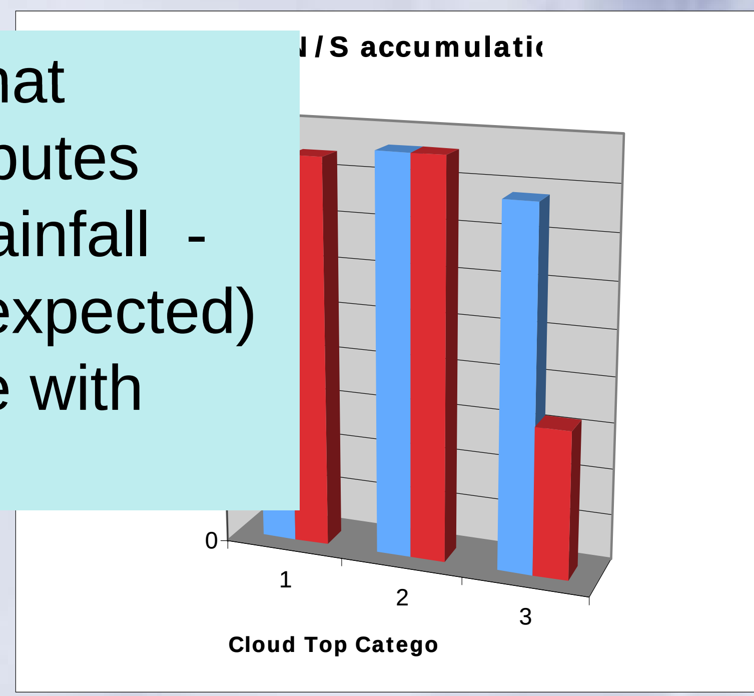
CloudSat

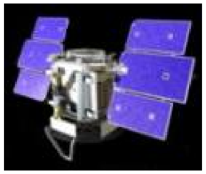
TRMM TMI



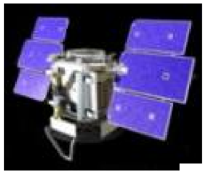


CloudSat suggests that shallow precip contributes significantly to total rainfall - this contribution (as expected) grows in significance with latitude

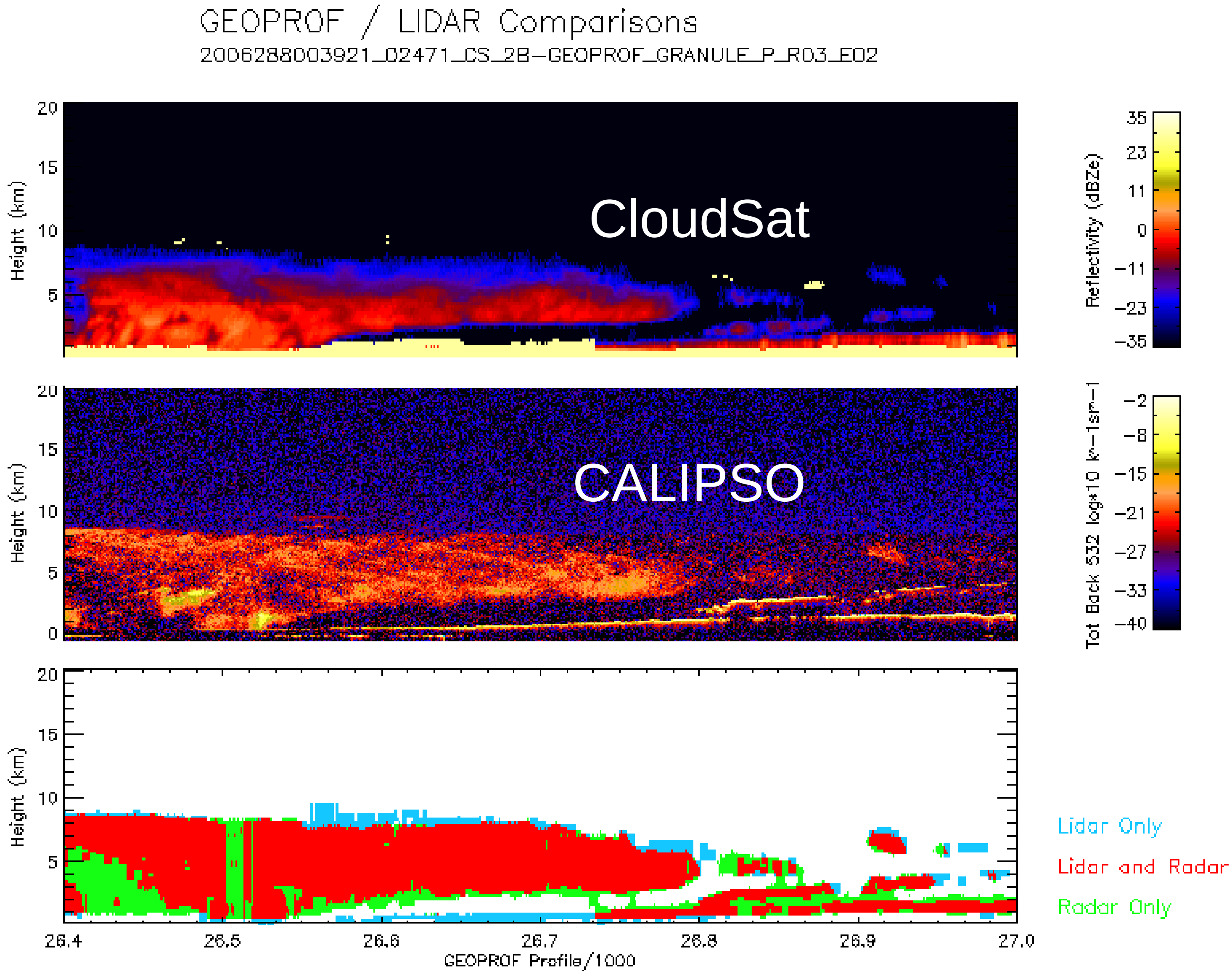




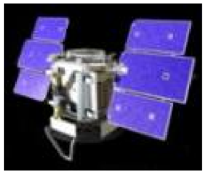
Whats new



1. What's new: 2B-Geoprof-lidar

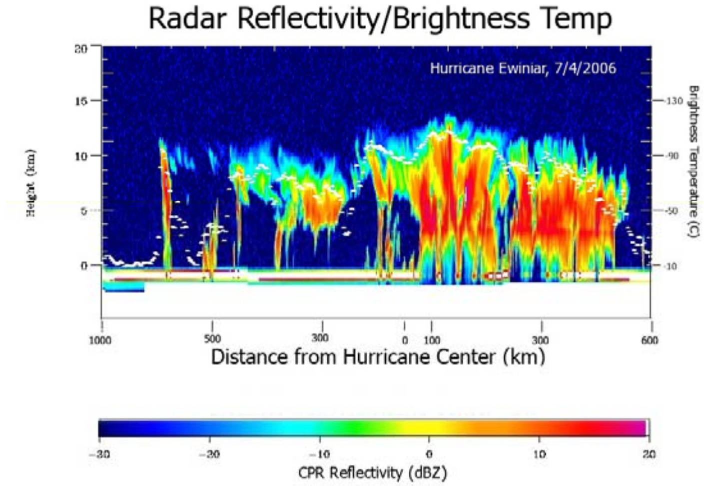


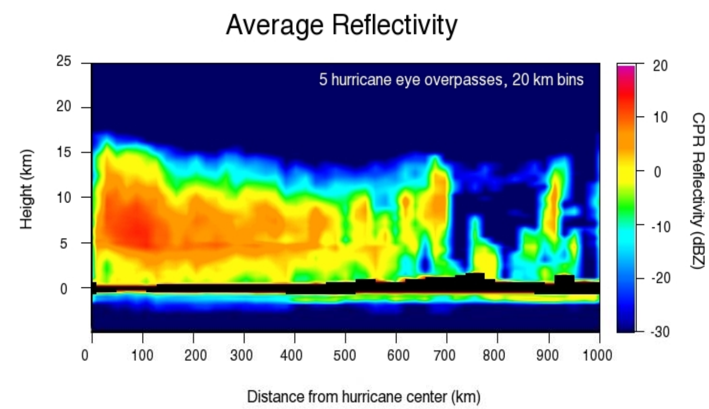
Polar cloud example

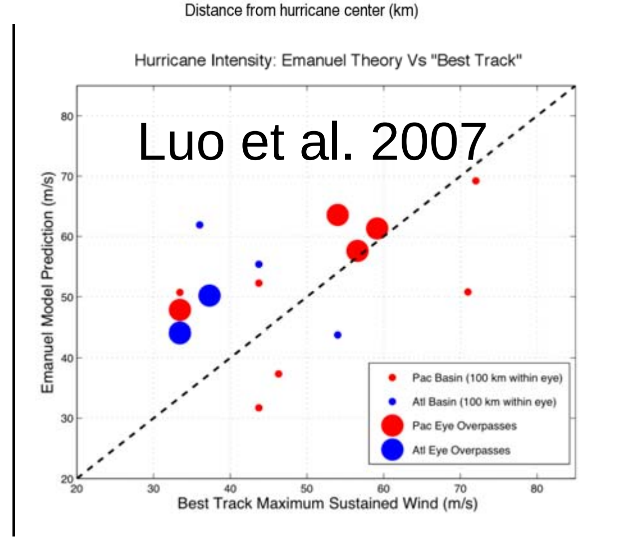


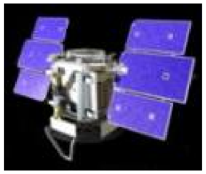
2. What's new: Tropical storm data base

- More than 170 passes over named storms
- For each storm overpass:
- (A) Storm specific variables
  - lat, lon, mslp, max winds, SST's
- (B) Radial/Azimuthal Data
  - Brightness Temperature (MODIS 11 um)
  - MODIS Cloud top height, pressure and temperature
  - AMSR-E SST, Wind Speed, LWP/IWP, Precipitation
- (C) Numerical Weather Prediction Analyses (Naval Operational Global Atmospheric Prediction System (NOGAPS™)
  - Temperature and Moisture Profiles
  - Wind Vector Profiles
- (D) CloudSat CPR Data
  - L2 GEOPROF Radar Reflectivity Profiles
  - L2 LWC/IWC Profiles

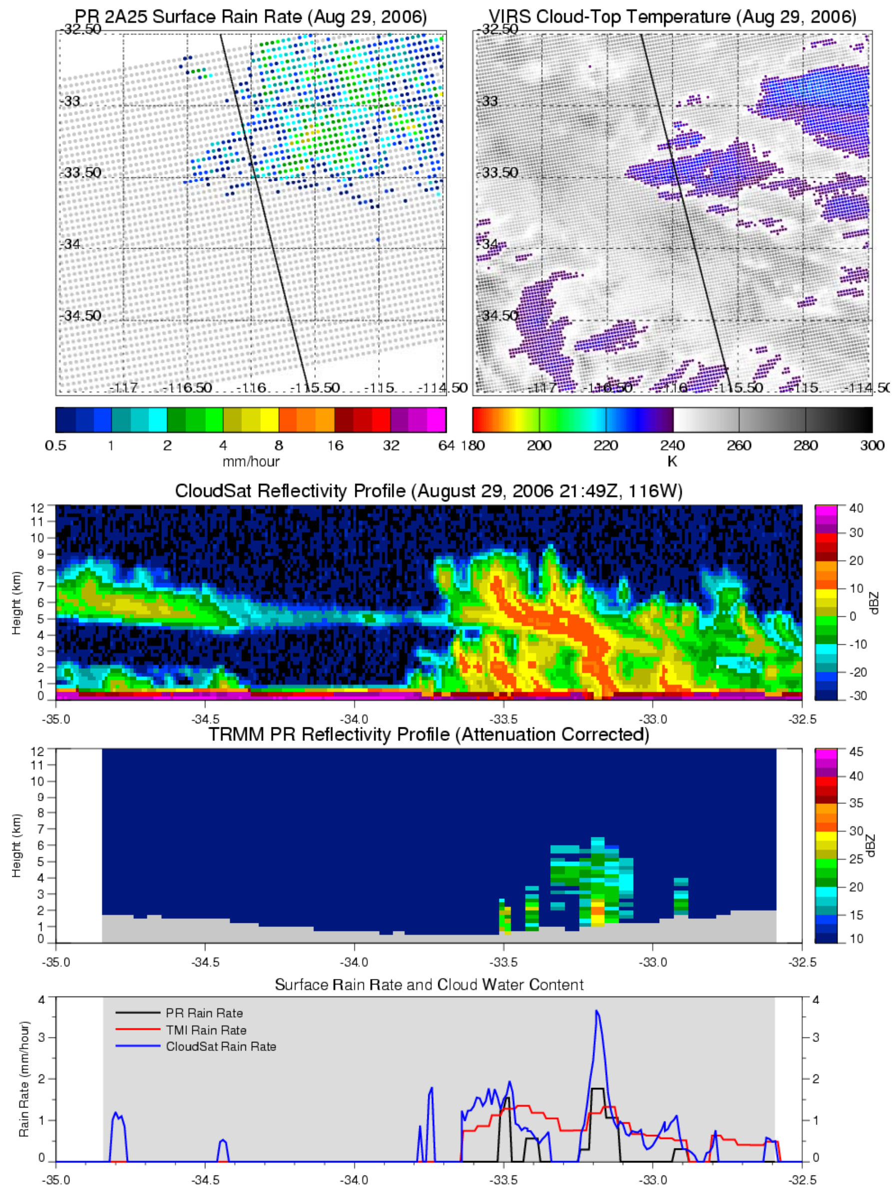






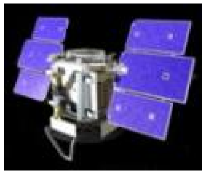


3. What's new: A TRMM-CloudSat data base

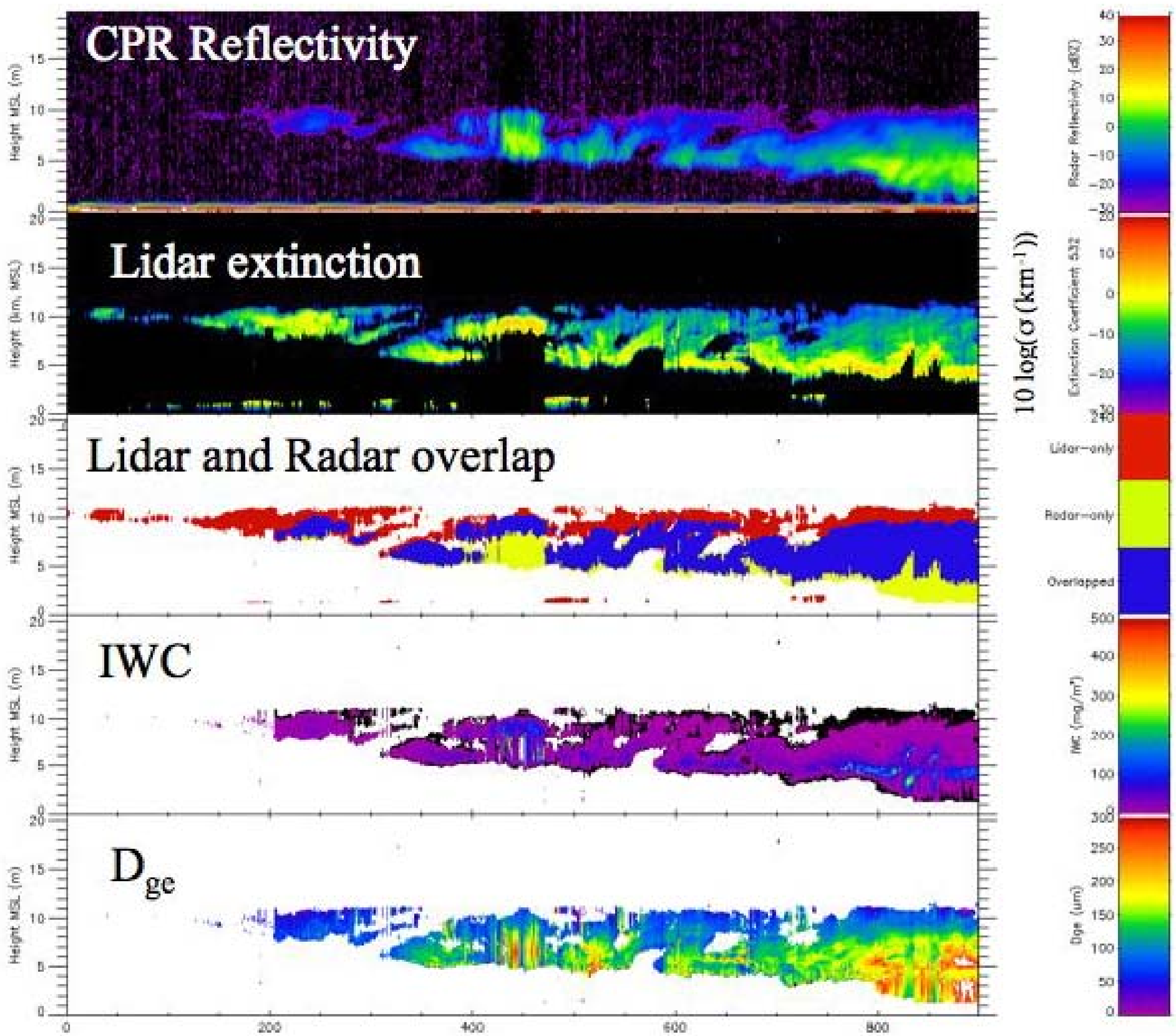


CloudSat

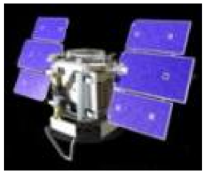
TRMM PR



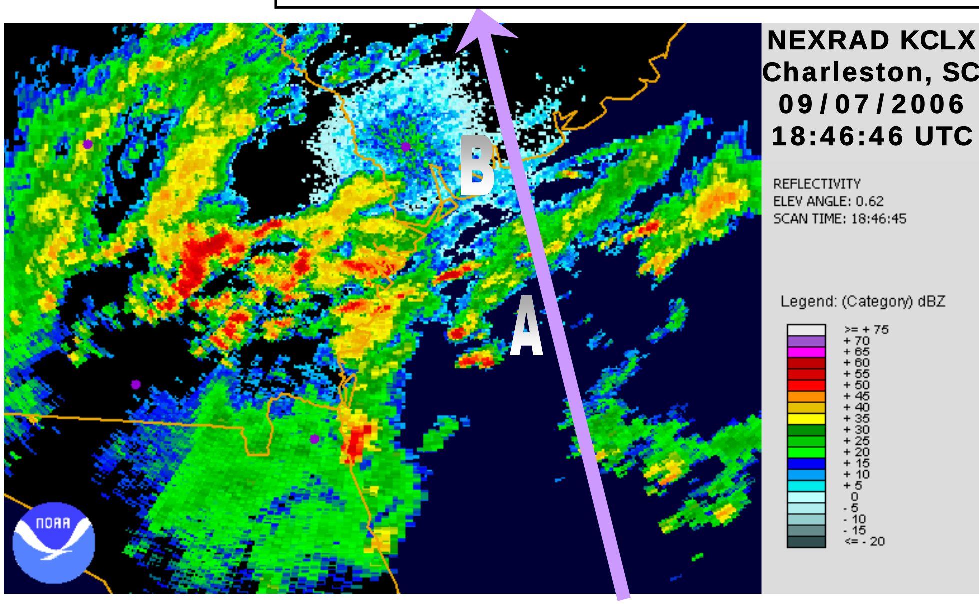
4. What's new: lidar/radar combined ice microphysics   Mace & Wang -

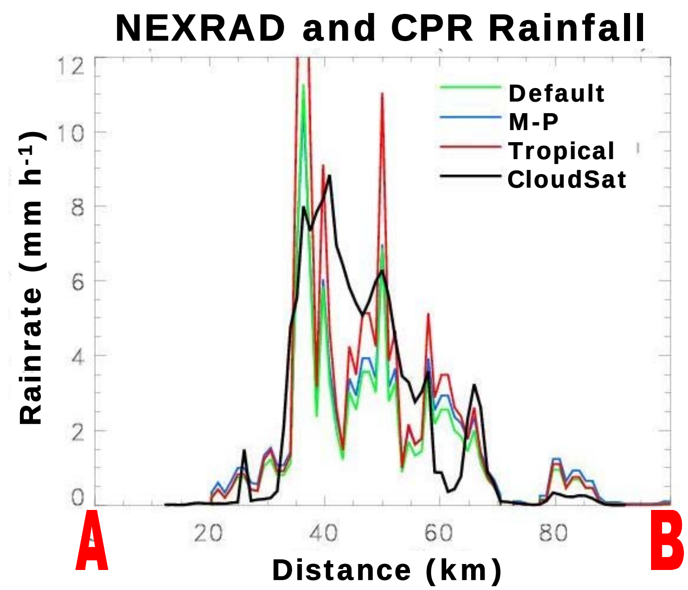


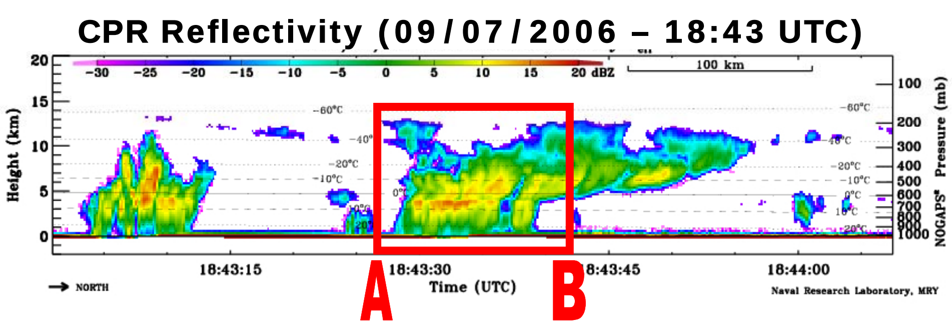
Preliminary example from Zhien



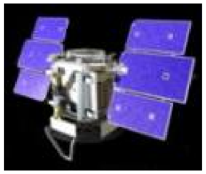
5. What's new: Precipitation profiling product (includes snow)





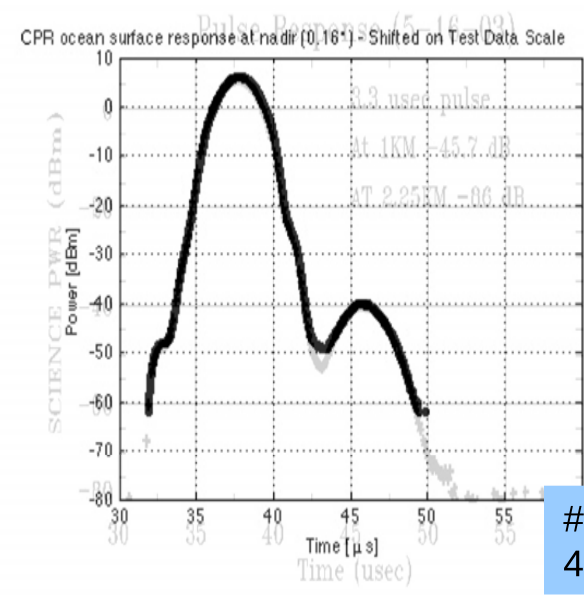


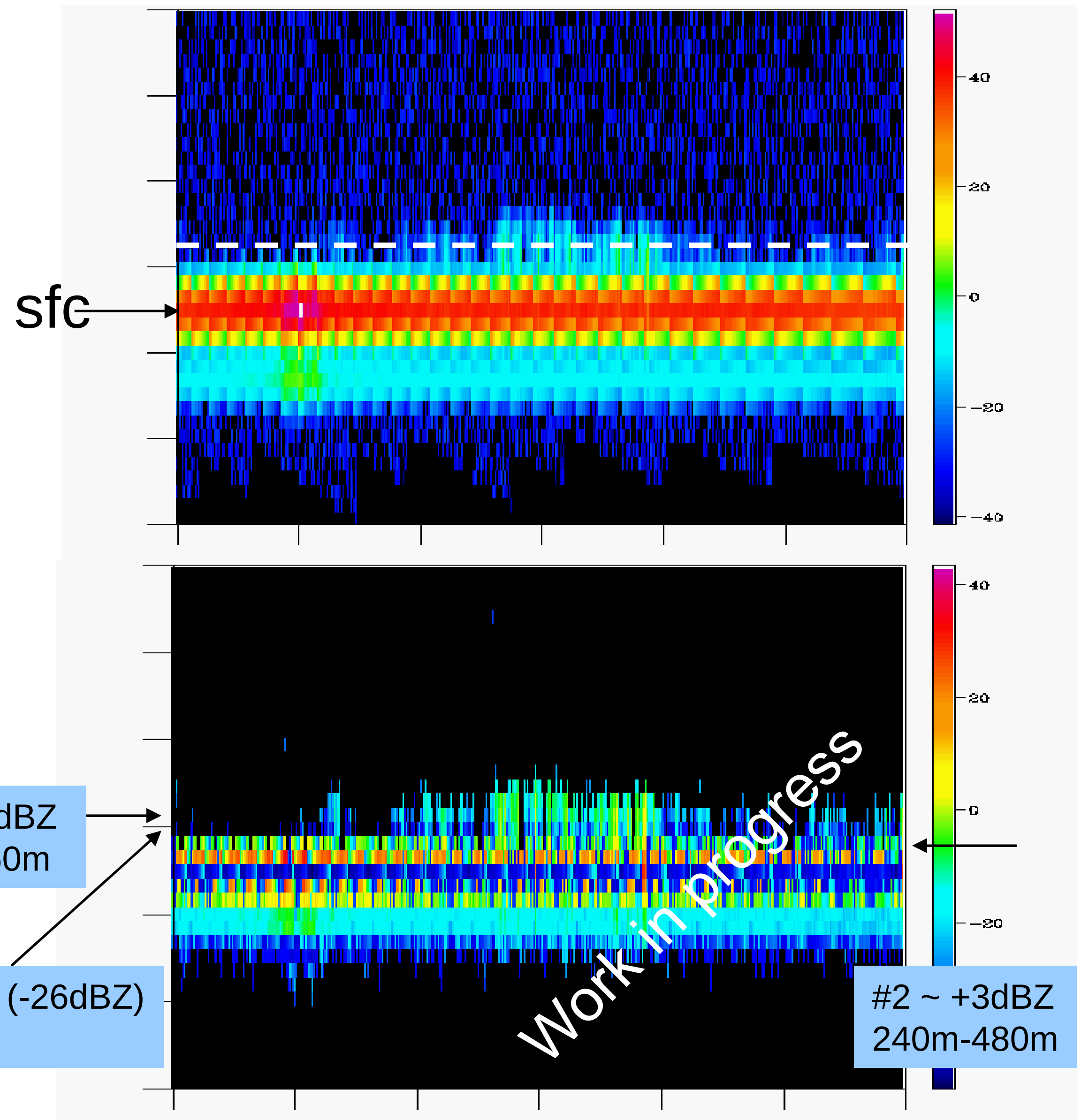
Mitrescu et al

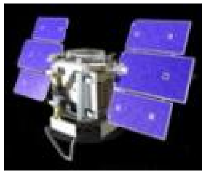


6. What's new: Surface Clutter fixes (reprocessing , July 2007)

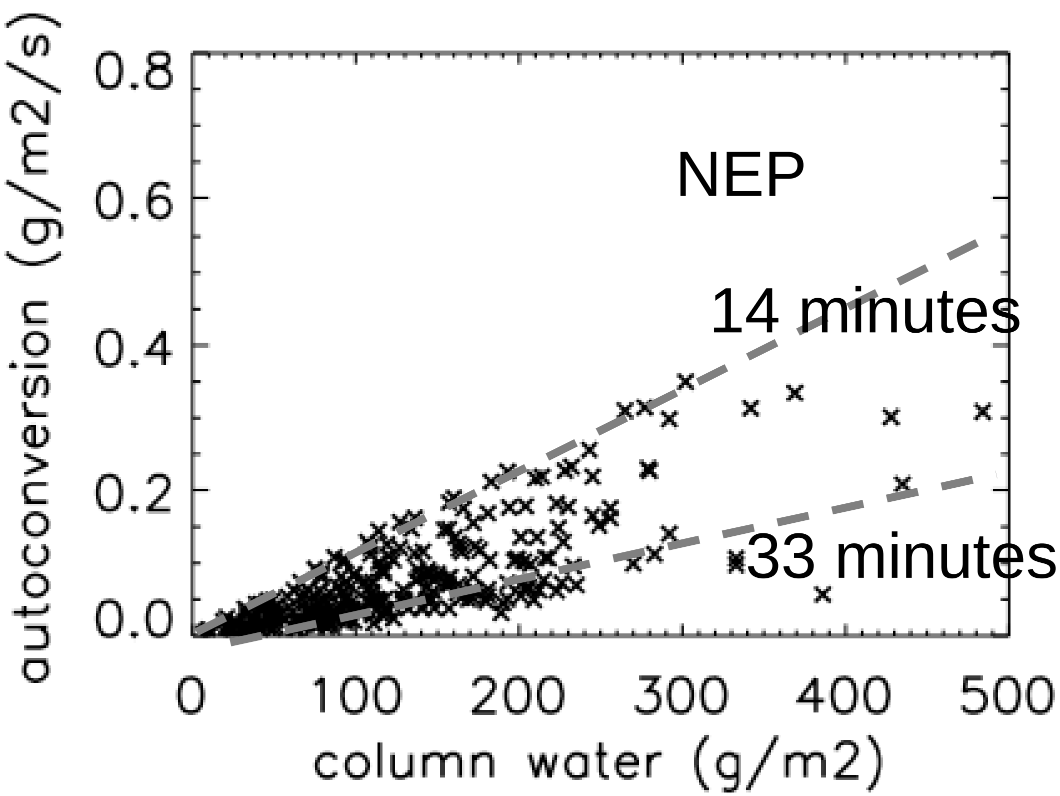
- Receiver bandwidth 350 kHz results in finite rise time, which causes clutter in bins above surface (rise time ~ 1/B)
- Actual performance (surface return) matches pre-launch tests
- These results indicate that 3 bins above ocean surface are contaminated; at least 2 were expected from EM test data.







7. Whats new: Matched CloudSat and MODIS cloud products



The combination of active and passive cloud information offers the potential for deriving ‘new information’

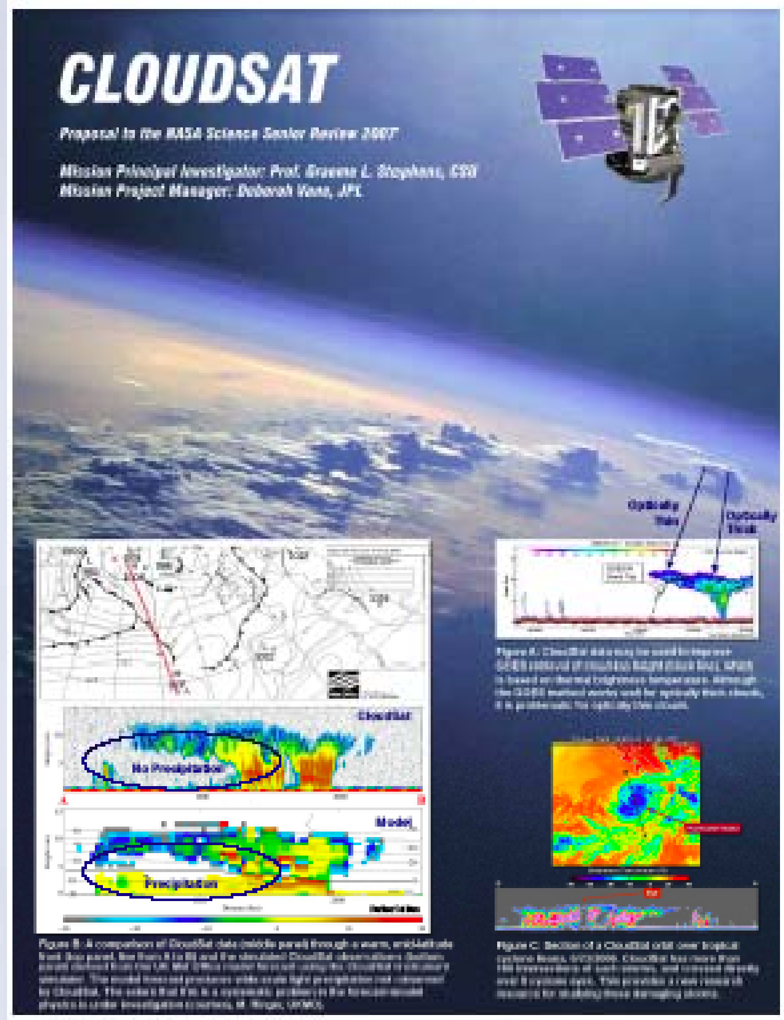
Stephens and Haynes, 2007

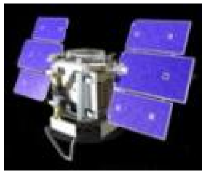
Challenges &outlooks

Many challenges -
Water contents of
Mixed phase clouds,
Deep complex clouds
Detailed, quantitative validation
….. and science that matters

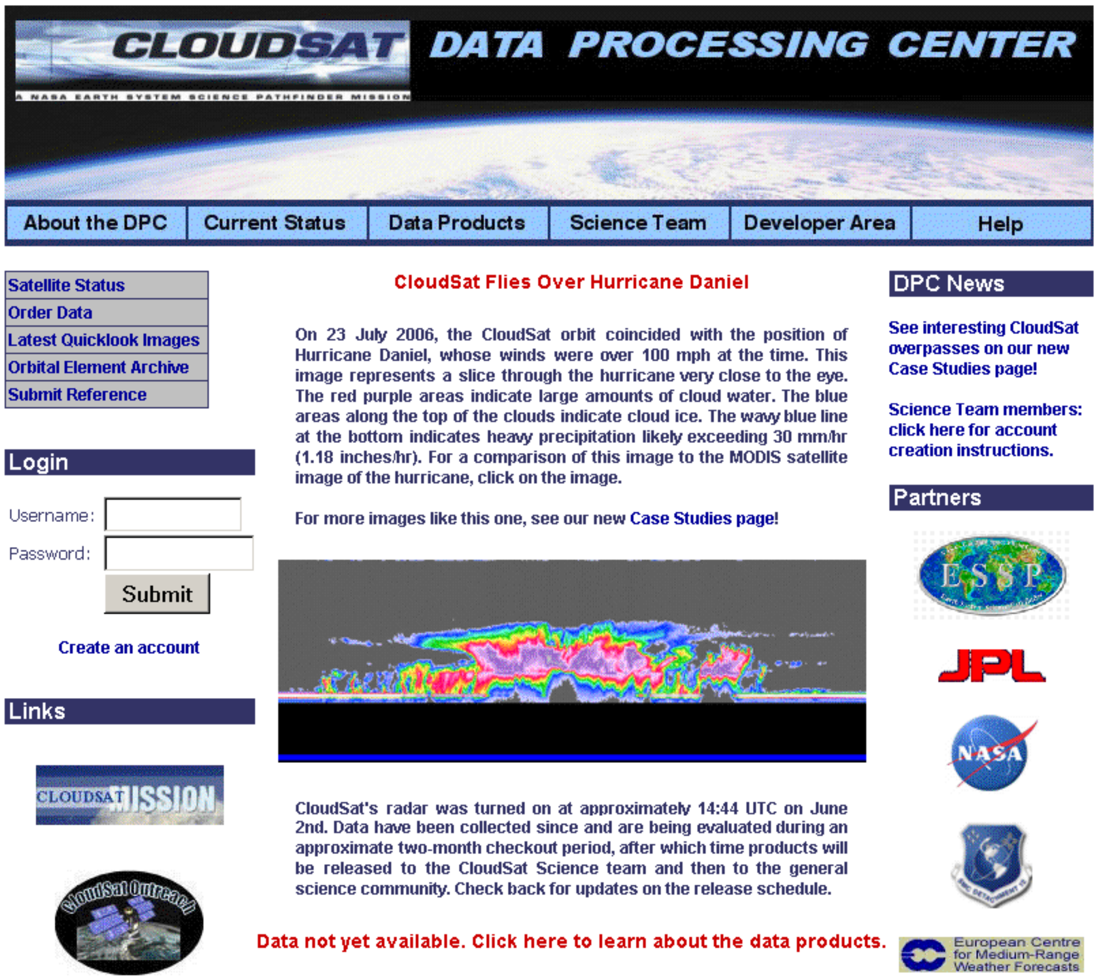
Senior review - proposal to continue CloudSat & A-train beyond 2008 to 2011..

The next step of the journey
… stay tuned



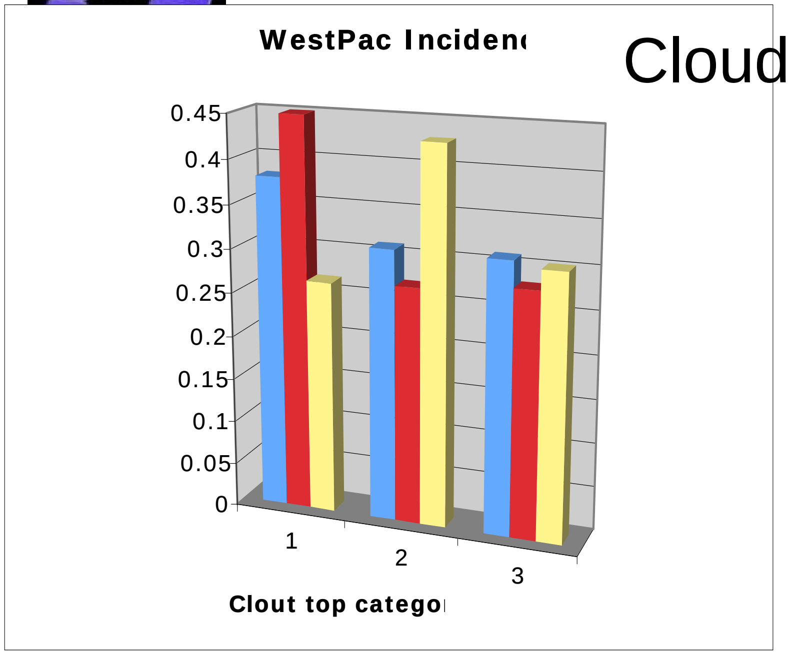


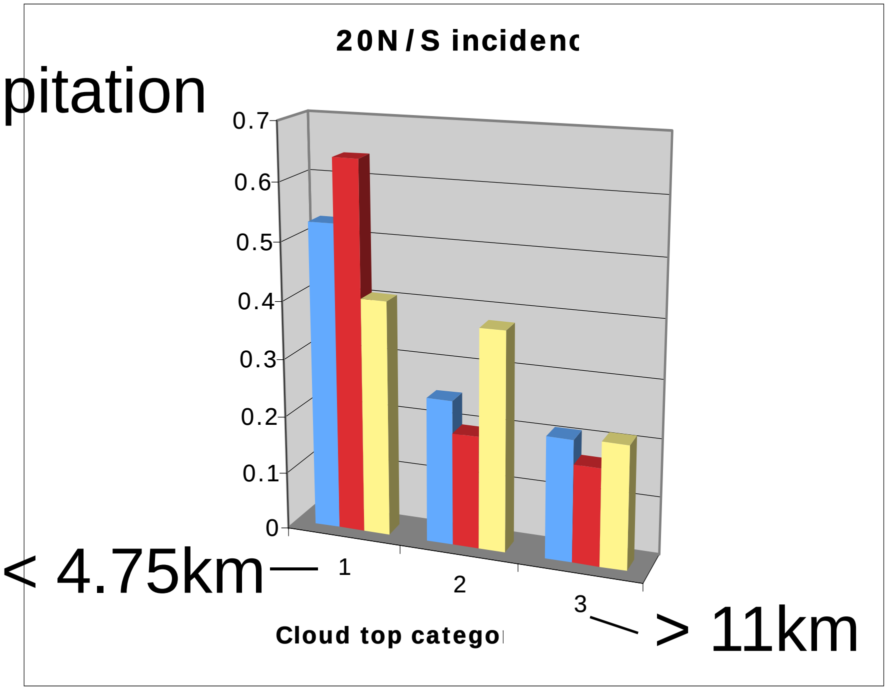
CloudSat Data Processing Center (DPC)



www.cloudsat.cira.colostate.edu

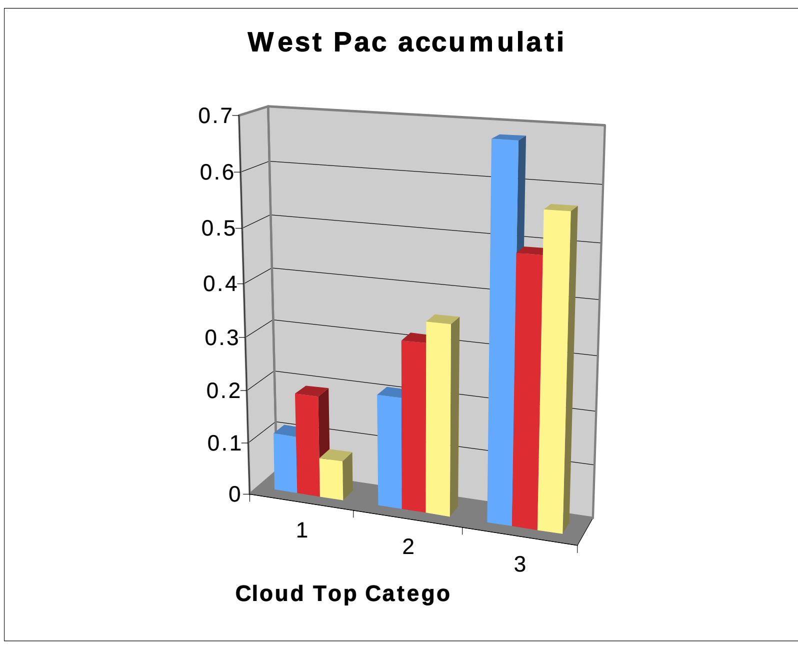
Cloud & precipitation





< 4.75km

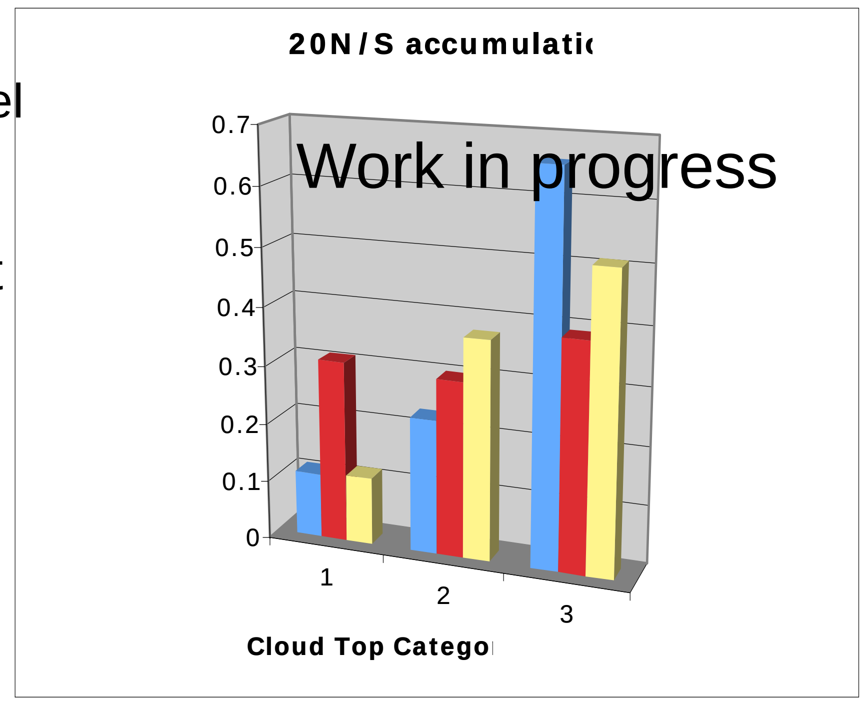
> 11km



NWP model

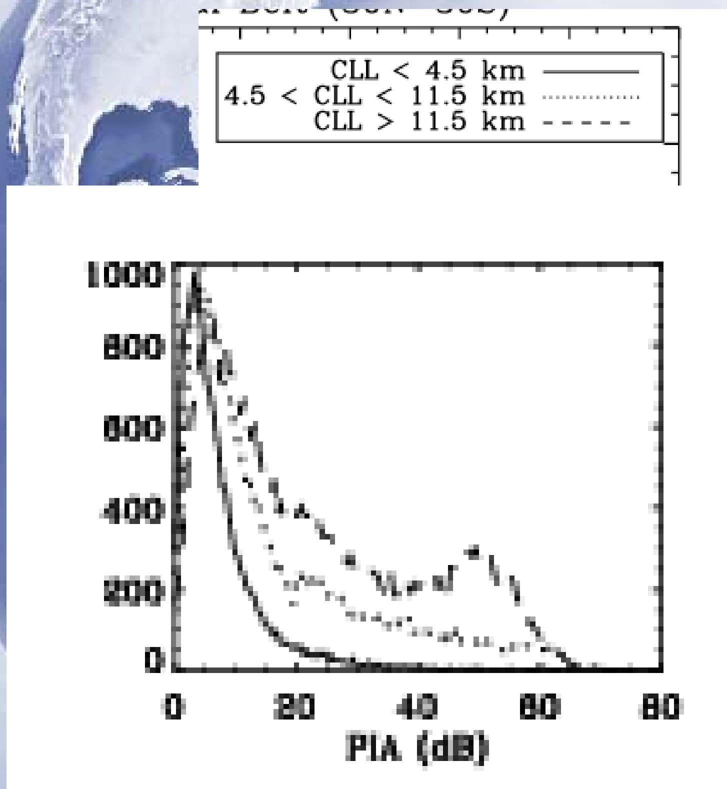
CloudSat

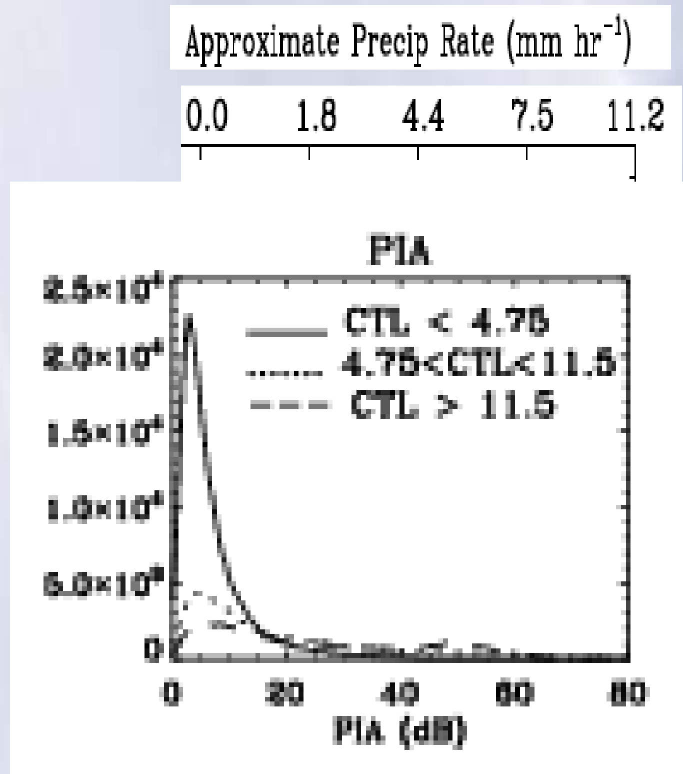
TRMM TMI



Work in progress

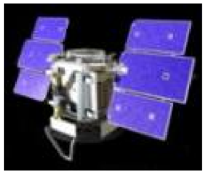
Revealing the bimodality of tropical precipitation





West pac

Global tropics



CloudSat FLXHR Algorithm

Reflectivity

Cloud Mask

Cloud Type

Initial Water Content

Optical Depth

Constrained Water Content

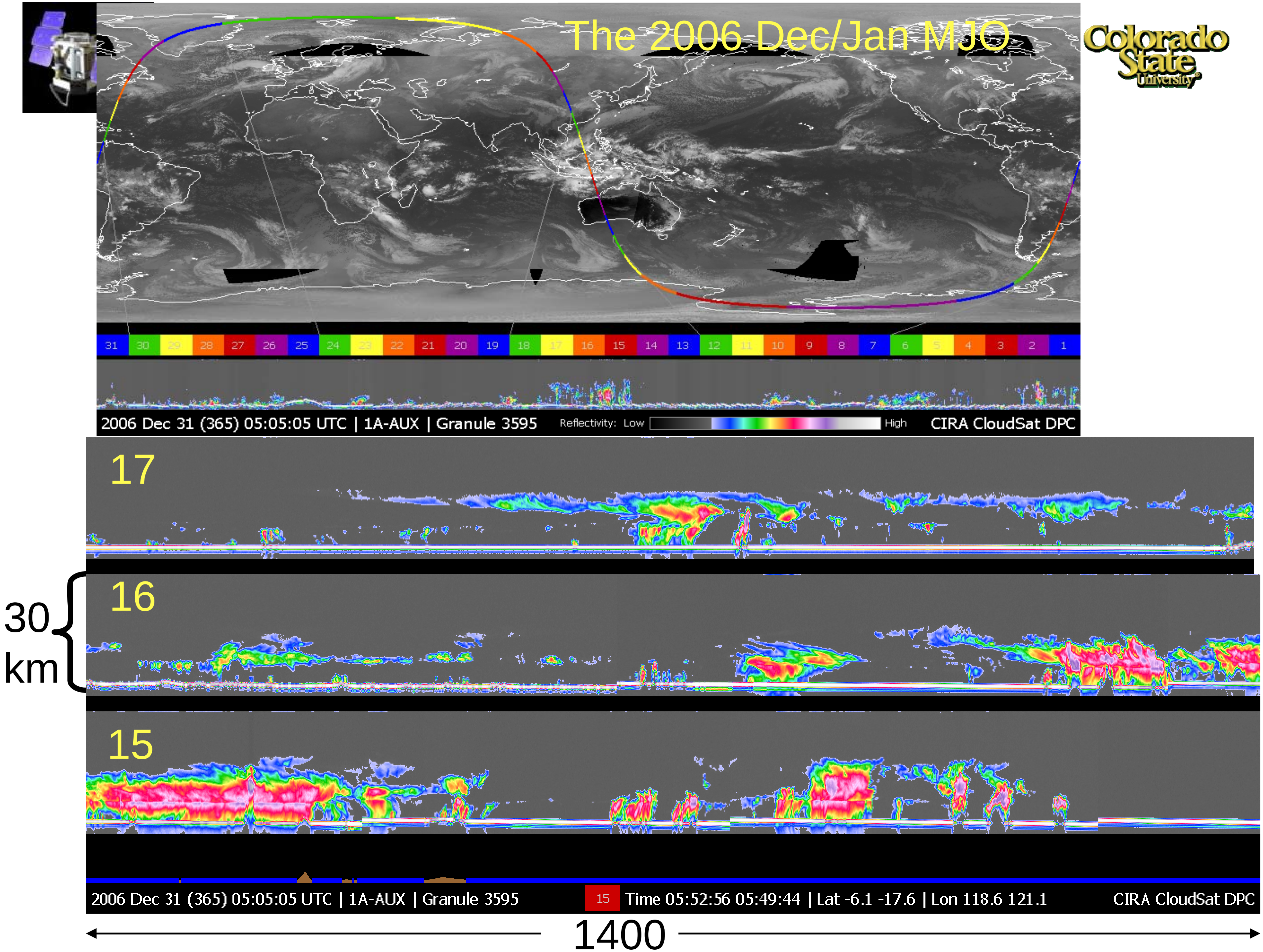
Fluxes/Heating Rate

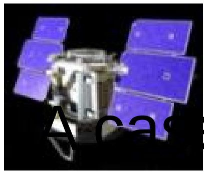
- Inputs (blue):
  - LWC/IWC profiles from CloudSat level-2B algorithms
  - Gas extinction profiles from ECMWF analyses
  - Surface albedo, solar zenith angle, etc. from ancillary datasets
- Procedure:
  - Composite geophysical parameters
  - Run broadband RT model (BUGSrad)
  - Compute heating rate profiles
- Outputs (green):
  - Output consists of vertical profiles of upwelling and downwelling LW and SW fluxes at CPR resolution.
  - Profiles of radiative heating.

ARM, Wood et al., 2007

CERES/ssf (‘validation’)

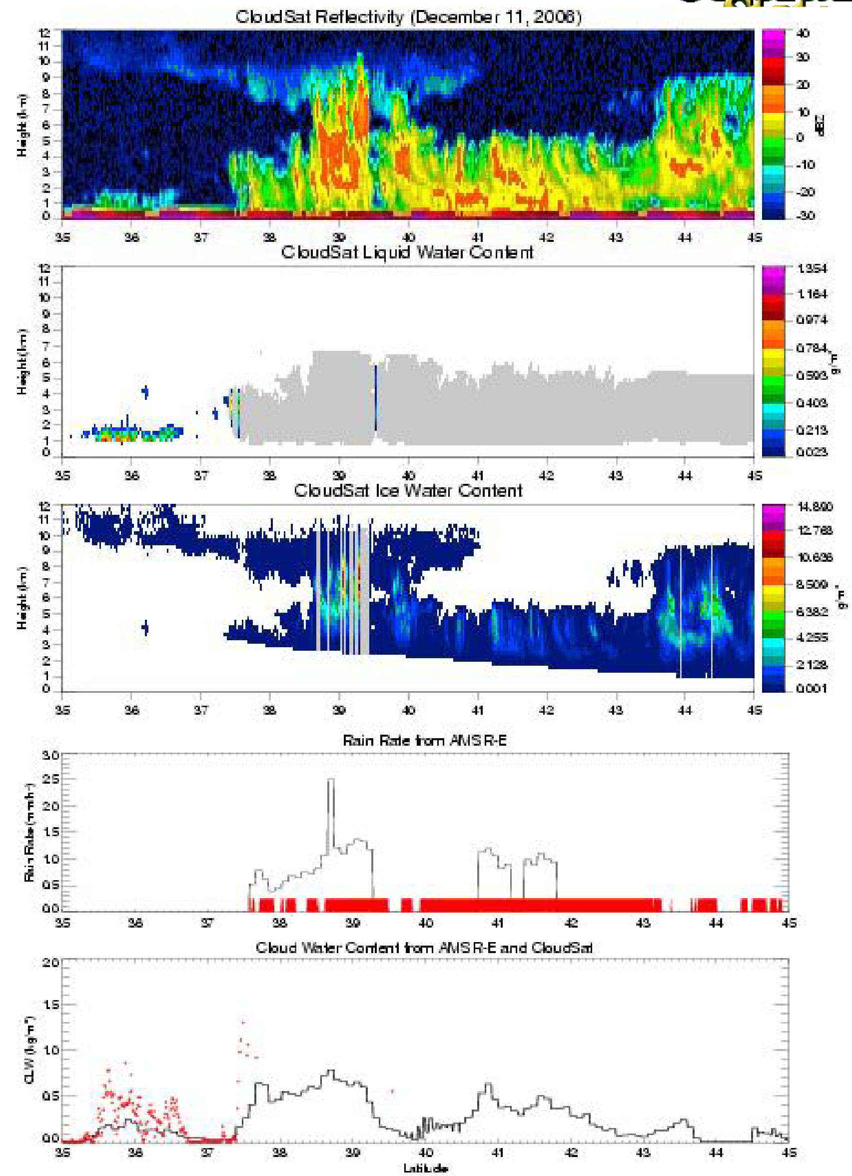
The 2006 Dec/Jan MJO





A case study example of comparison between CloudSat and AMSRE -

passive microwave methods are missing significant fractions of light precipitation



2. Comparison AMSR-E