Cloudsat,CALIPSO, and reconciling climate models with Earth Observations

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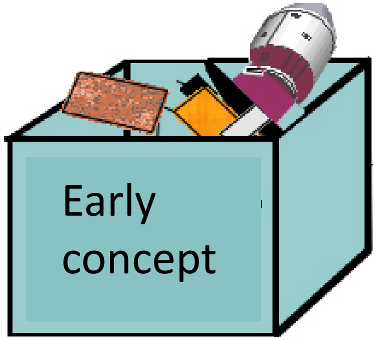
Many, many folks have contributed over many years…

Radar + lidar, Spectrometer + sub-mm radiometer +

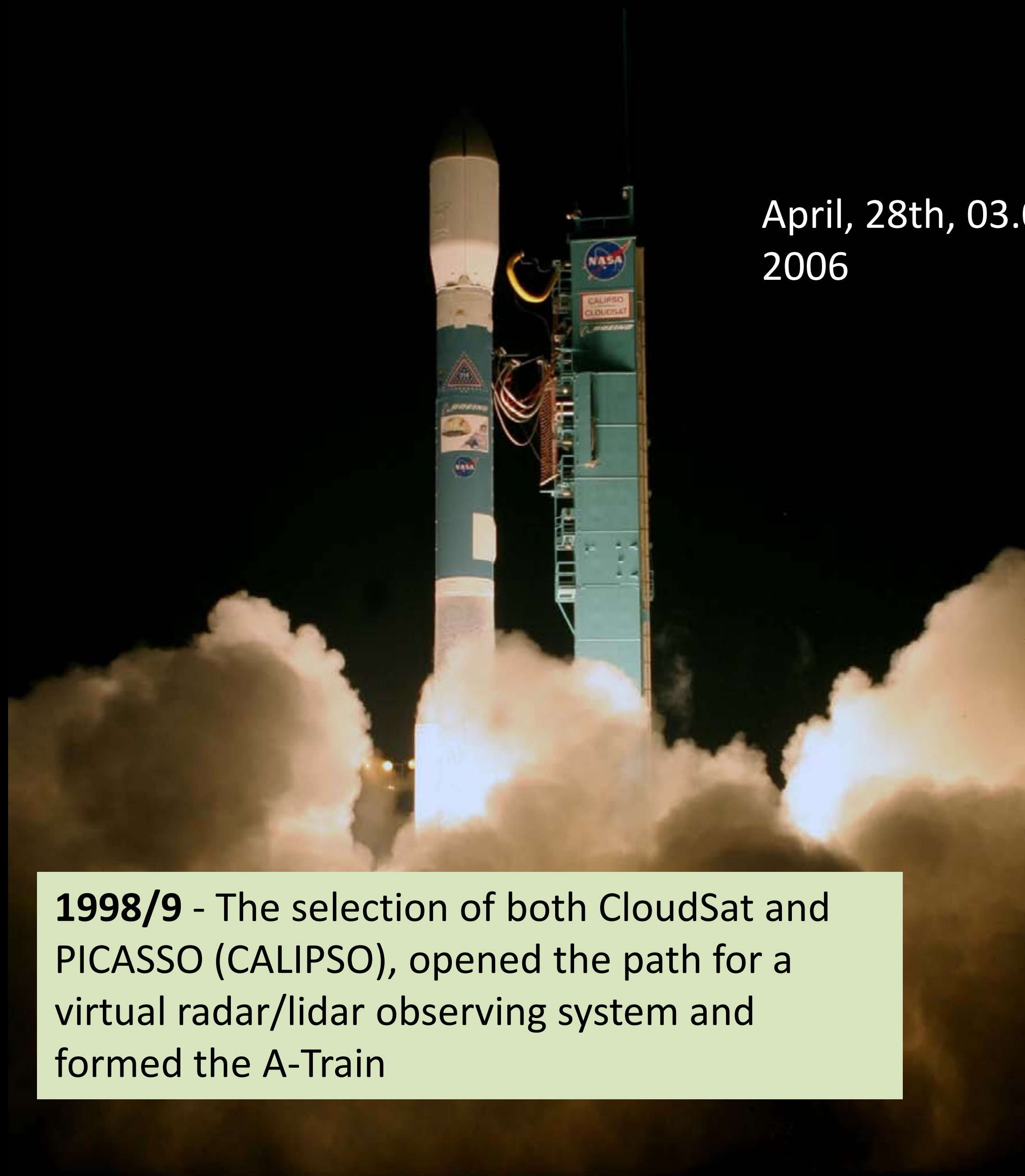


1993- 1995 - early mission concept emerged,…

Radar + spectrometer

1996- ESSP was born, missions under $90M

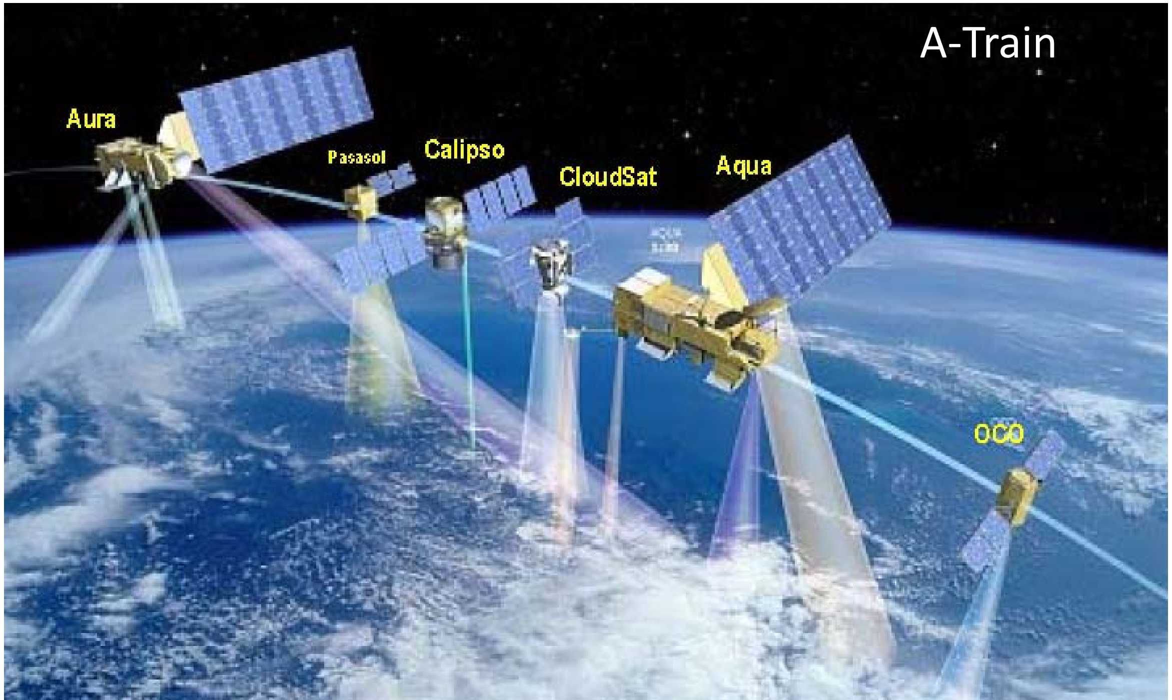
1998 - ESSP II- cap raised to $120M. This forced the separation of lidar/radar into 'competing' mission

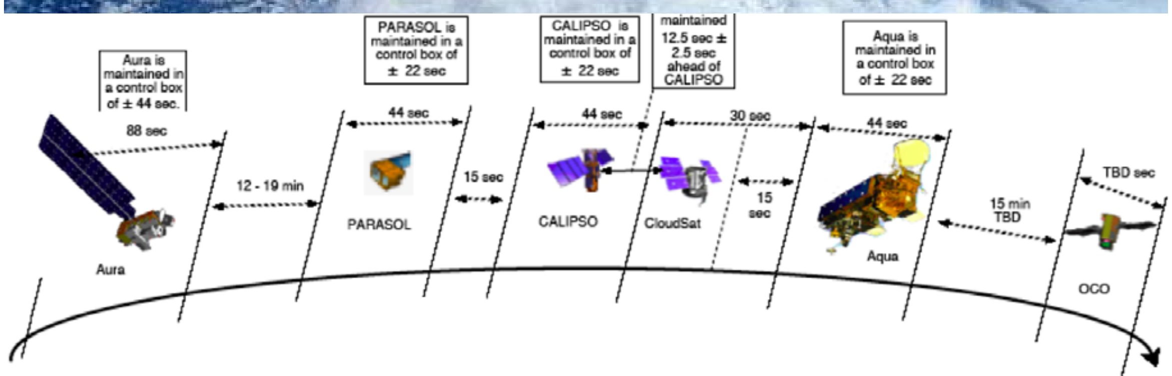


April, 28th, 03.02am
2006

1998/9 - The selection of both CloudSat and PICASSO (CALIPSO), opened the path for a virtual radar/lidar observing system and formed the A-Train

The golden age of Earth observations

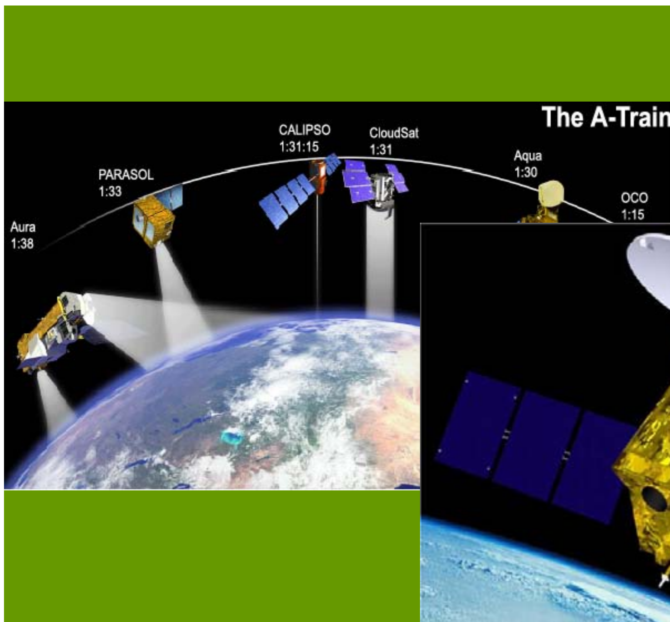




An 'observing system' that views Earth in a variety of ways – each providing different information the processes that shape out climate system

A climate record?

CloudSat and the A-Train 2014???



EarthCare – 2014? -2018?

ACE 2020???

Outline

1. CloudSat and CALIPSO

2.Some results not discussed

3.A little of the expected

4.A little serendipity and the unexpected

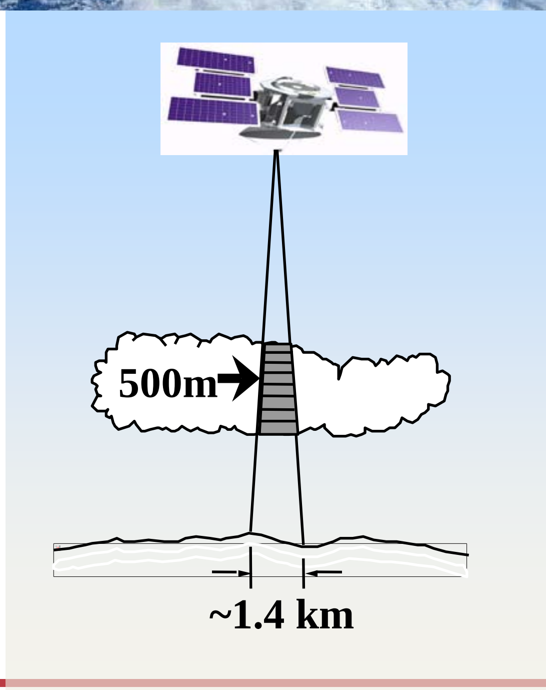
5.Simulators, model verification & assimilation

6.A little science – ‘reconciling the virtual world of climate modeling with the real world of climate physics’ —the character of rain, the properties of low clouds

7. Summary

1. CloudSat

Mission goal: 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.



The Cloud Profiling Radar (CPR)

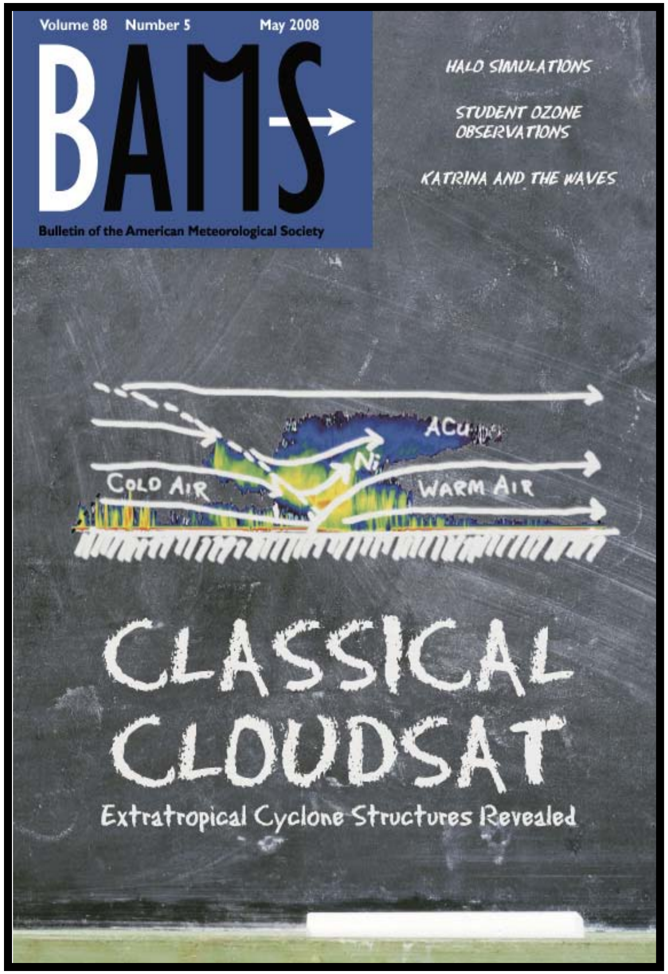
- Nadir pointing, 94 GHz radar
- 3.3μs pulse ➔ 480m vertical res, over- sampled at ~240m
- 1.7 km horizontal res.
- Sensitivity ~ -28 dBZ (-31 dBZ)
- Dynamic Range: 80 dB

We demonstrated that formation flying was indeed practical and capable of proving observations with enough precision for science – CloudSat and CALIPSO FOVs overlap 90% of the time

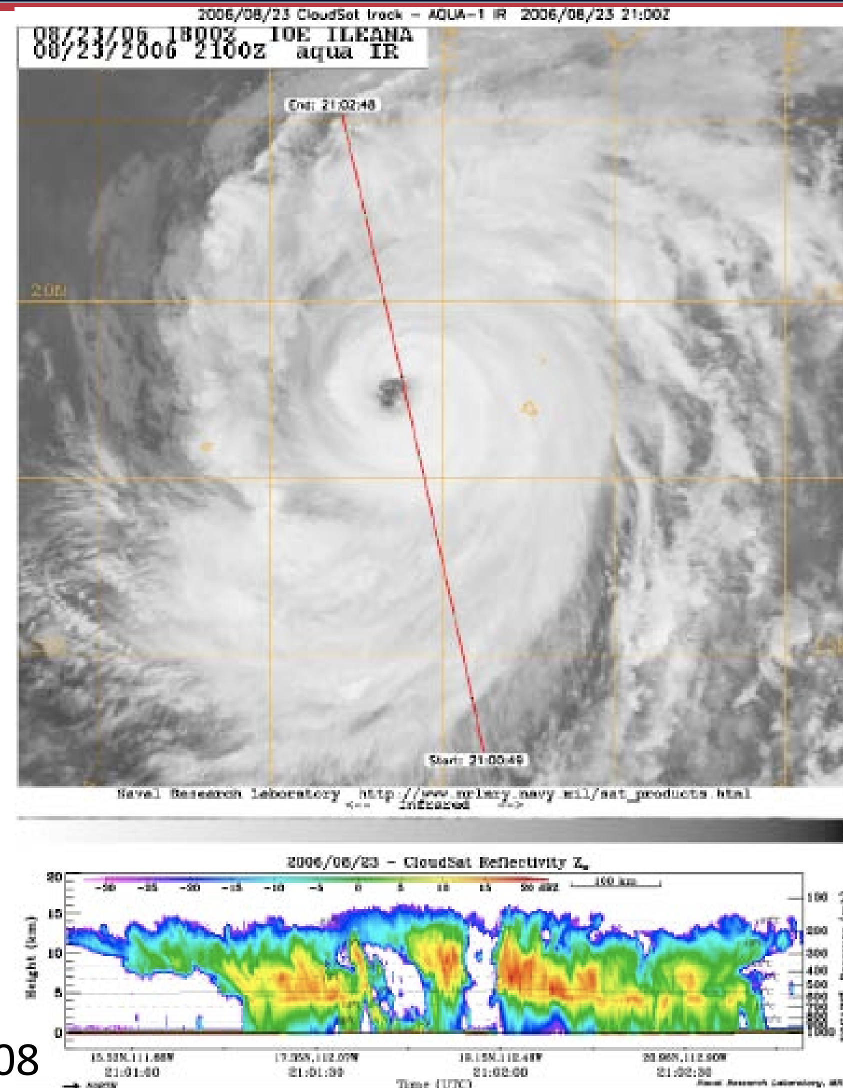
- Hardware still performing ‘nominally’
- Prime mission completed, Feb 2008
- Approved for extended mission in 2007
- Extended mission to 2011& again to 2013
- Extended mission supports ‘enhanced’ products (below)
- All standard products have been released and some precip too
- http://cira.clousdat.colostate.edu

Product ID	Description
1A-Aux	**Auxiliary data for navigation altitude assignments, raw CPR data**
1B-CPR	**Calibrated radar reflectivities**
2b_geoprof & 2B-geoprof-lidar	**Cloud geometric profile – includes a cloud mask (with confidence measure), reflectivity (significant echoes), (gas) attenuation correction, and MODIS mask**
2b-cldclass	**8 classes of cloud type, including likelihood of precipitation & mixed phase conditions**
2b-tau	**Cloud optical depth by layer, also effective radius (column) from matched MODIS**
2b-cwc	**Cloud liquid water content (2B-LWC),Cloud Ice water content (2B-IWC) -**
2b-flxhr & 2bflx-lidar	**TOA, surface and atmospheric (profile) of long and shortwave fluxes**
Ancillary and enhanced	**Various matched products including ECMWF met and other data**

Other available products include global precipitation, snow, enhanced ice microphysics, surface winds, TRMM PR matched to CloudSat, CALIPSO aerosol, MODIS cloud properties, ….



Posselt et al., 2008



Luo et al., 2008

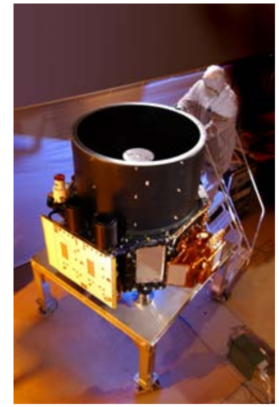
1 CALIPSO

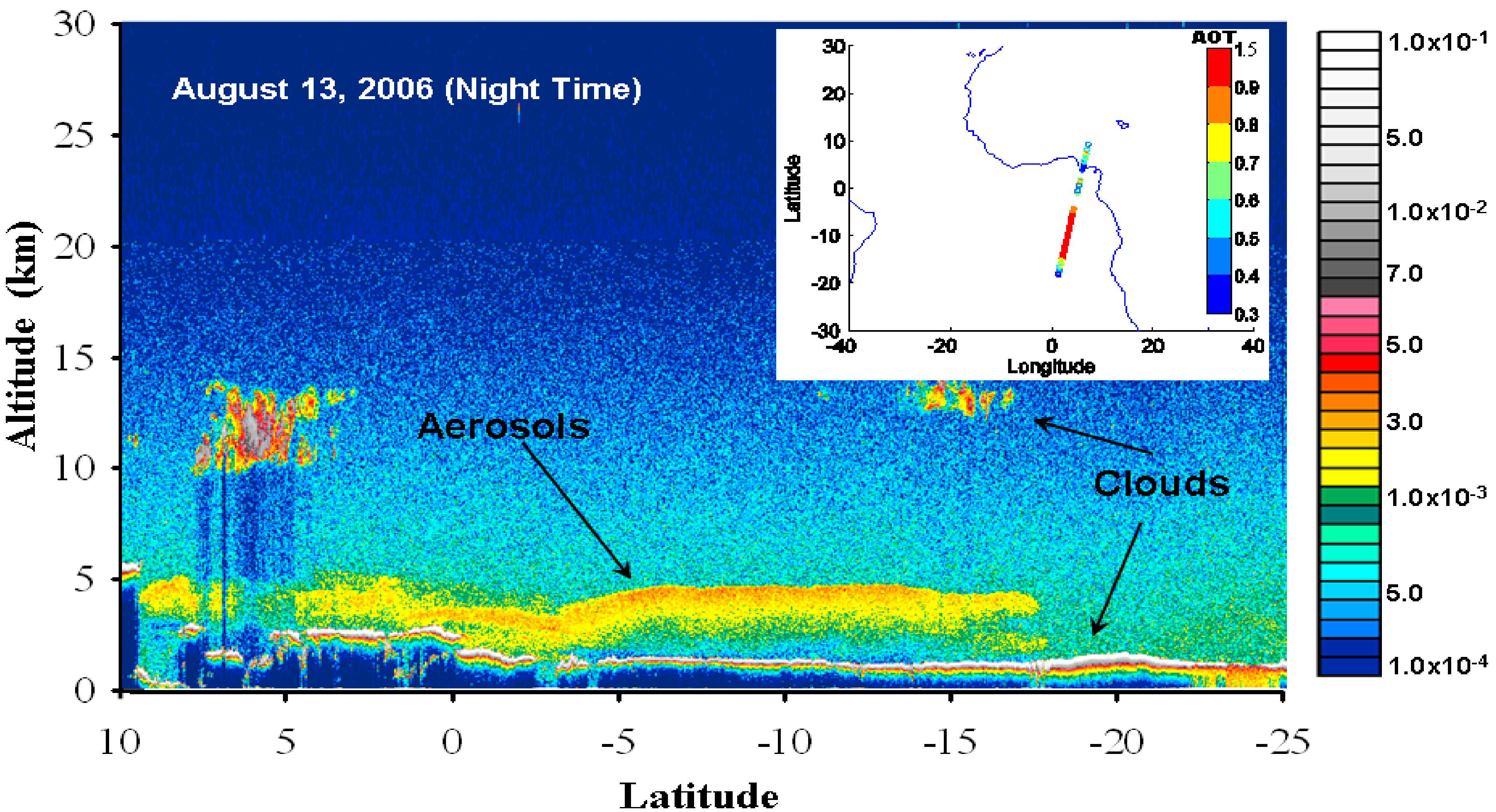
•**Objective:** Improve our understanding of and ability to predict aerosol and cloud effects on Earth's climate

Two-wavelength backscatter lidar (532 and 1064 nm)
- profile information on aerosol and clouds
- multiple channels provide information on particle size

Depolarization lidar channel at 532 nm
- discriminates between spherical and non-spherical particles (e.g. droplets/ice)

Co-aligned IR and Vis imagers
- Information on cirrus particle size
- Meteorological context





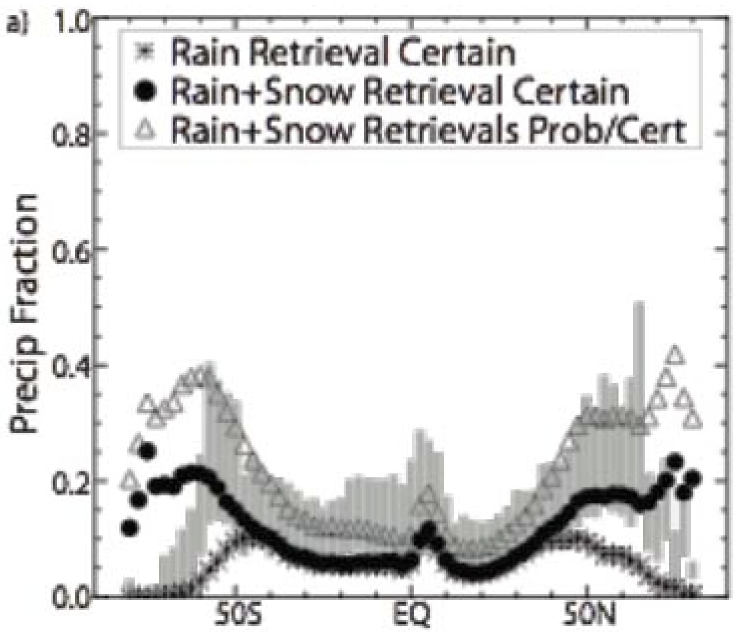
August 13, 2006 (Night Time)
Aerosols
Clouds
Altitude (km)
Latitude
30
25
20
15
10
5
0
10
5
0
-5
-10
-15
-20
-25
AOT
Latitude
Longitude
1.0x10-1
5.0
1.0x10-2
7.0
5.0
3.0
1.0x10-3
5.0
1.0x10-4

2 A few highlights not emphasized

- Deep convection – Luo et al (2008) introduce a method for determining cloud top buoyancy - 0.02% of the tropics is occupied by deep undilute convection.
- First global aerosol forcing estimates above cloud layers
- Aerosol indirect studies are beginning to reveal the influence of aerosol on precipitation (Lebsock et al., 2009, L'Ecuyer et al., 2009) and the lack of a discernible Twomey effect
- Analysis indicated the vast majority of PSCs form with larger scale synoptic weather systems (Zhang et al. 2008)
- Clouds radiatively heat the global atmosphere by ~ 8W/m2 (L'Ecuyer et al., 2008).
- We can now deduce the rate of the conversion of cloud water to rain (Stephens and Haynes, 2007; Suzuki and Stephens, 2009) and the character of this transition (Suzuki and Stephens, 2008).
- Profile information is beginning to suggest the need to re-interpretation of previous fixed ideas about cloud 'regimes' - more than half the rain from the tropics falls from multi-layered systems (not strictly deep, Haynes et al., 2008) and the deep cloud mode of ISCCP is primarily thick high over thick low clouds (Mace et al., 2009).

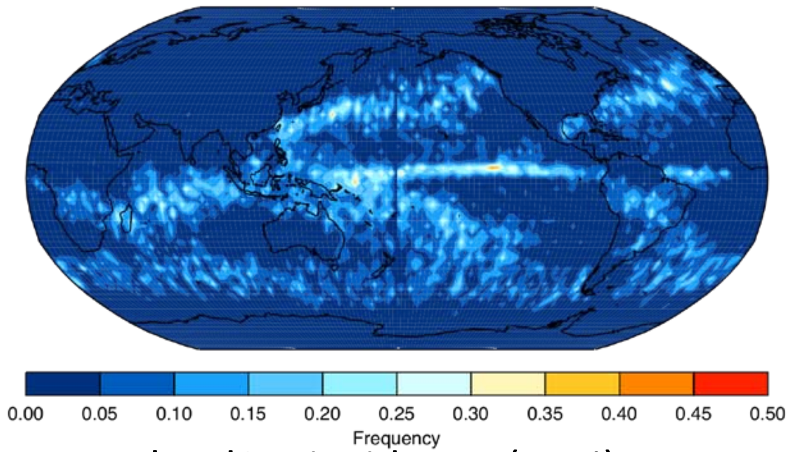
3. An expected result: first real estimate of the incidence of oceanic precipitation

Annual mean

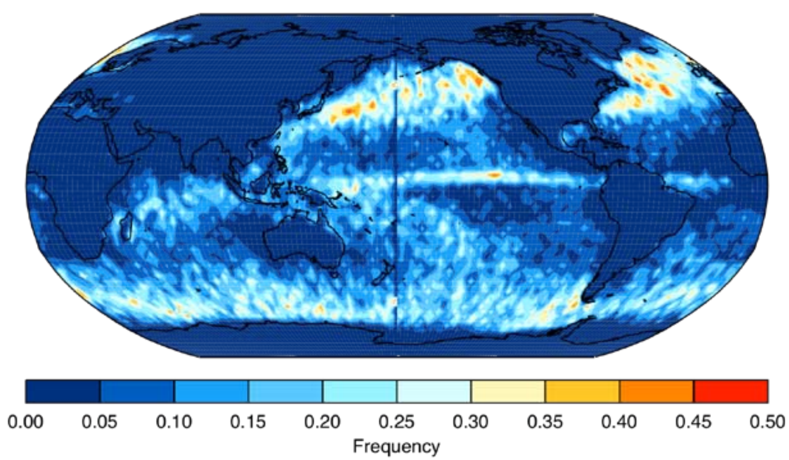


DJF, 2006/2007

AMSR-E incidence 5%

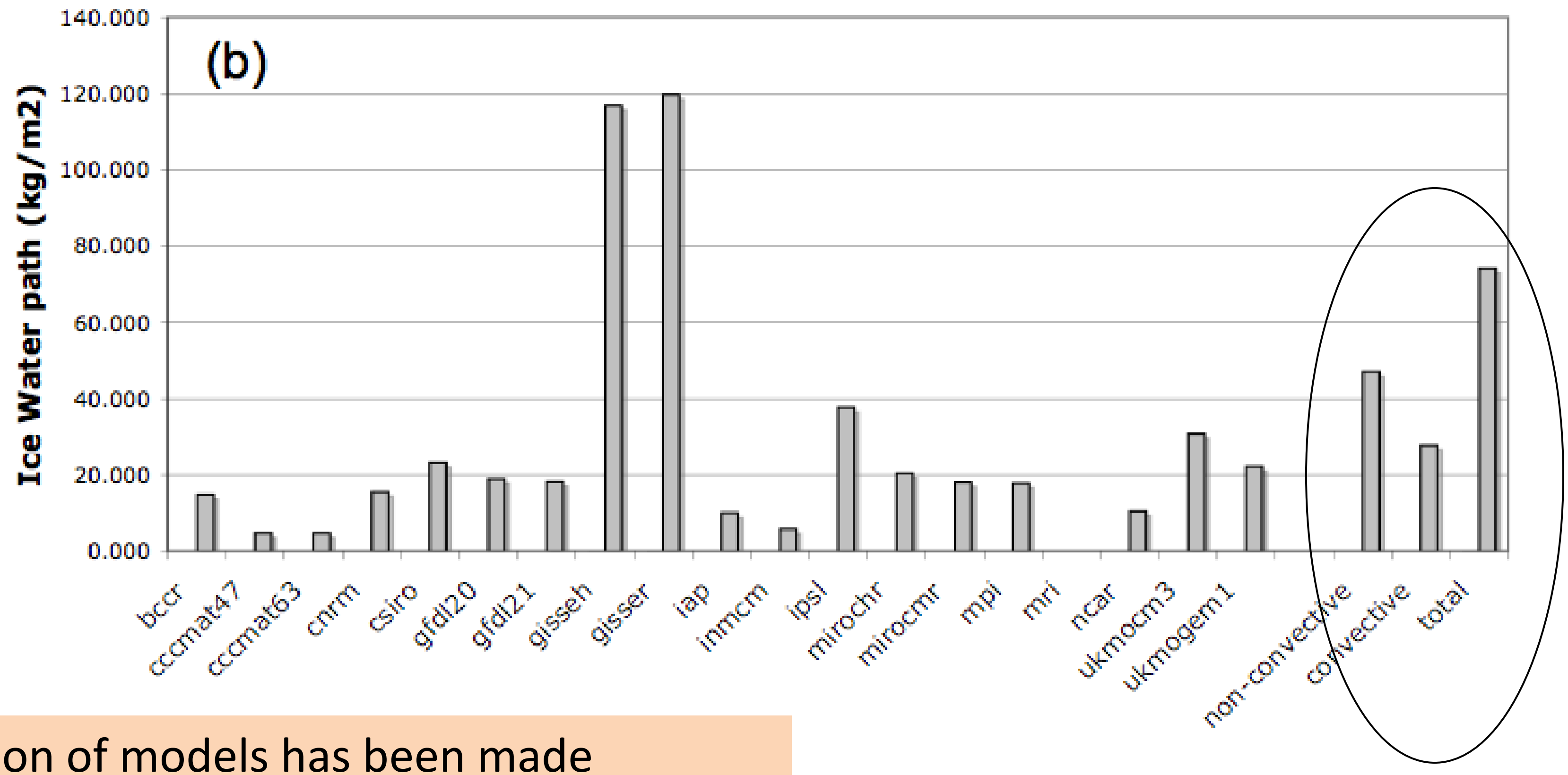


CloudSat incidence (11%)



CloudSat incidence looks like COADS surface obs (Ellis et al. 2008) but other data (e.g. microwave radiometer products) don't (Petty, 1998)

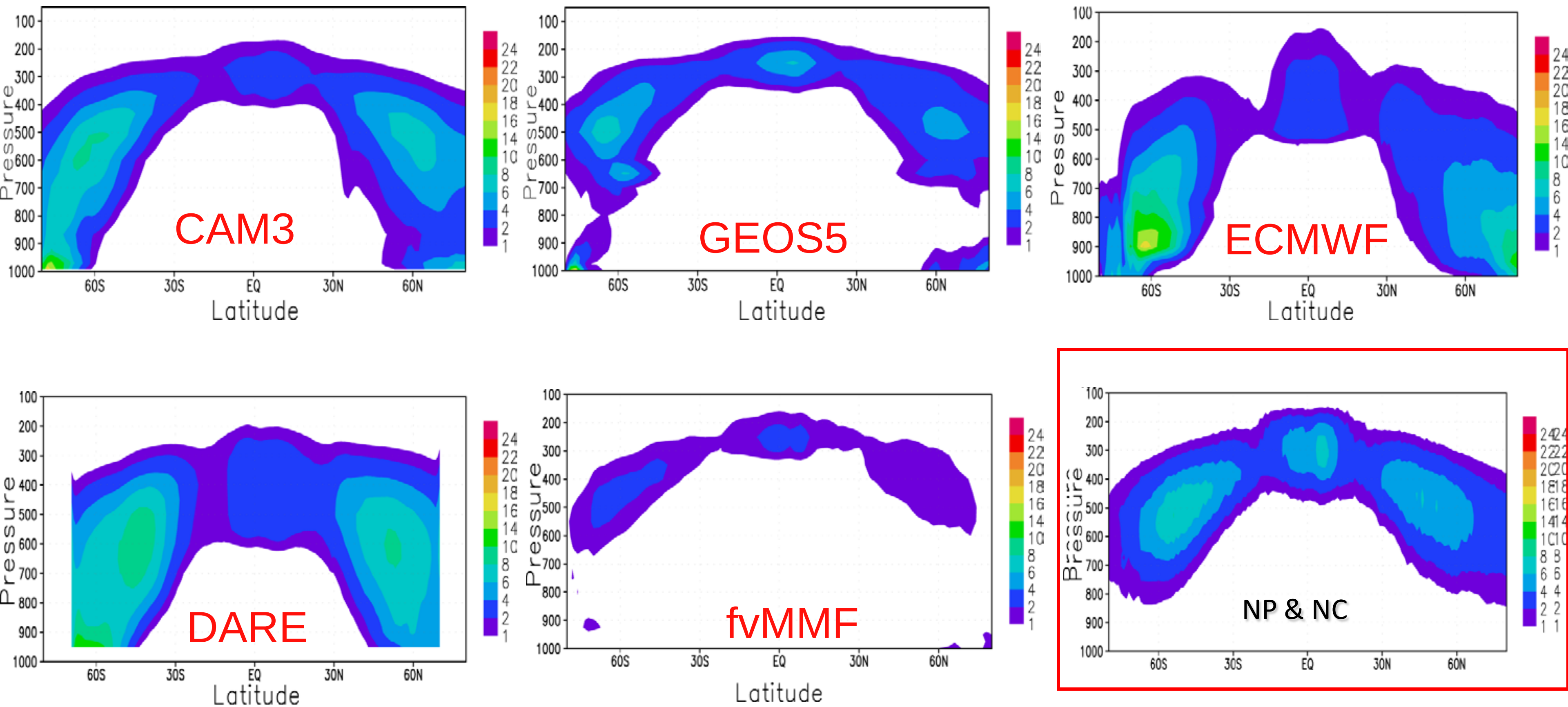
3. Expected result: ice mass suspended in the sky



Evaluation of models has been made ambiguous by the way parameterizations stitch clouds together

Stephens et al., 2008

GCM Cloud Ice Water Content (IWC)
Annual Mean Values

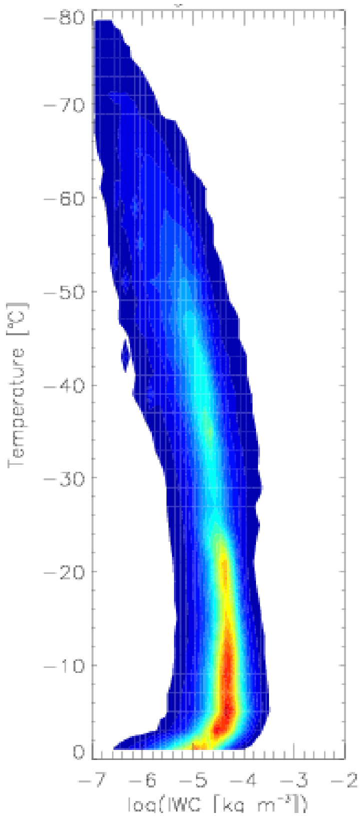


Waliser, Li and colleagues

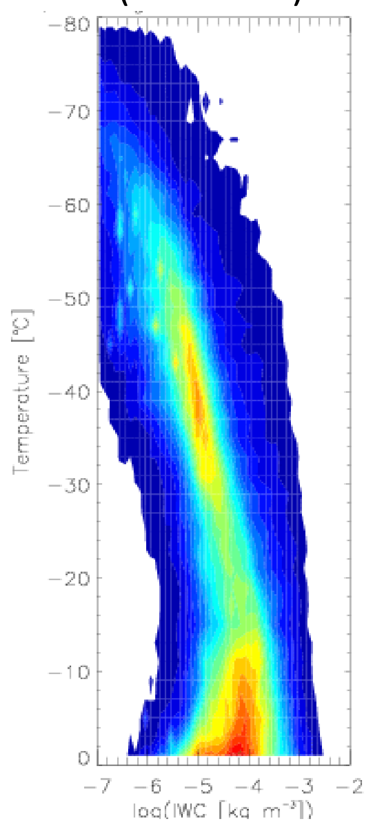
Global datasets with high resolution vertical profiles → valuable source of data to validate and to inspire model developments

EXAMPLE: Global Ice Water Content vs. T distribution -

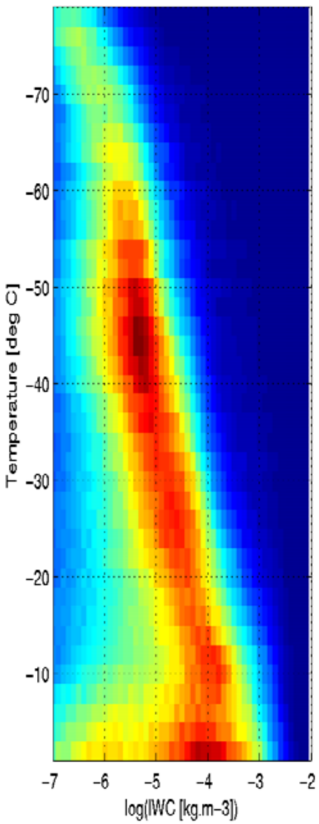
Current cloud scheme (ice)



New prognostic scheme (ice+snow)



CloudSat (3 week composite)

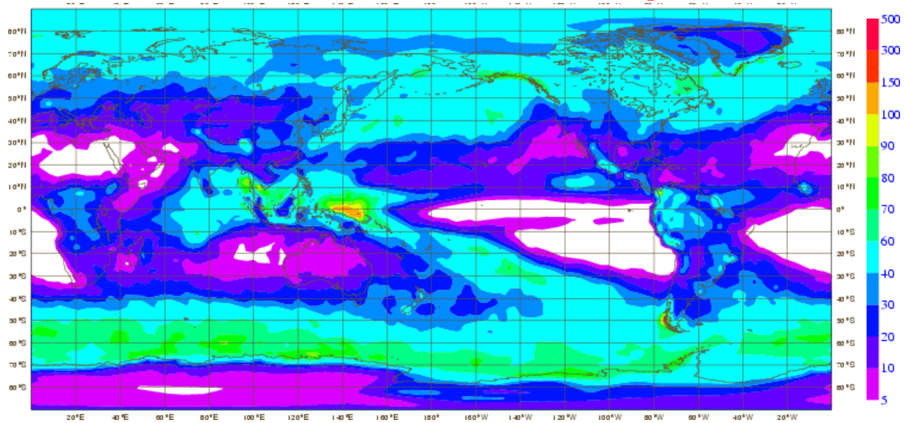


(Richard Forbes)

Model verification

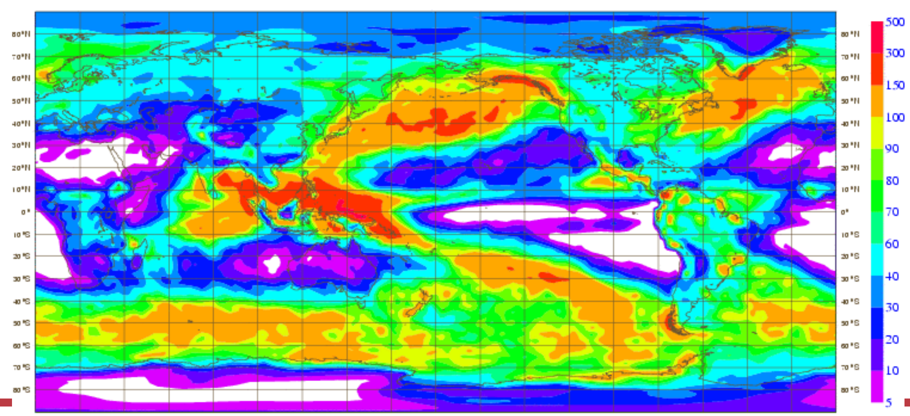
Model Ice Water Path (IWP) (1 year climate)

Current cloud scheme with diagnostic snow



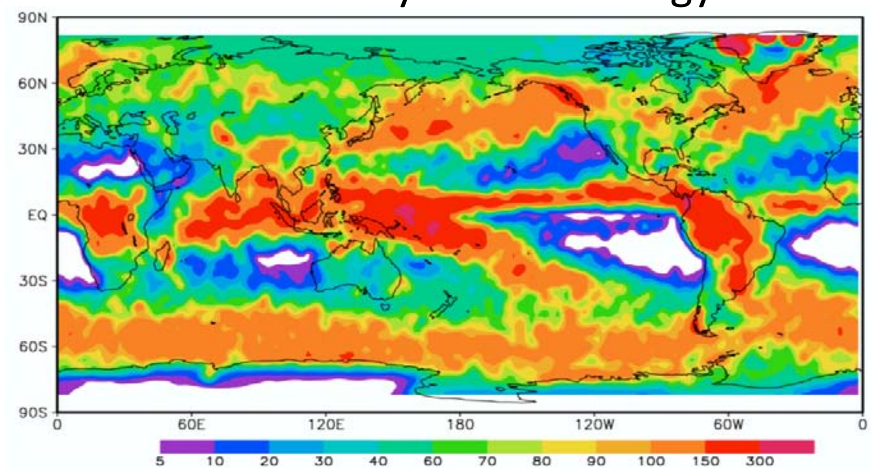
g m^{-2}

New cloud scheme with prognostic snow



Observed Ice Water Path (IWP)

CloudSat 1 year climatology



Waliser et al. (2009), JGR

The new scheme (with separate prognostic liquid and ice variables and prognostic snow included in the definition of "Ice Water Path") is closer to the CloudSat estimate. Tuning to obs has has constrained model sedimentation

(Richard Forbes)

Lidar –ocean properties

Relation between Sea Surface Lidar Backscatter γ and

Mean Square Wave Slope ($\langle s^2 \rangle$ or $\langle \tan^2\theta \rangle$)

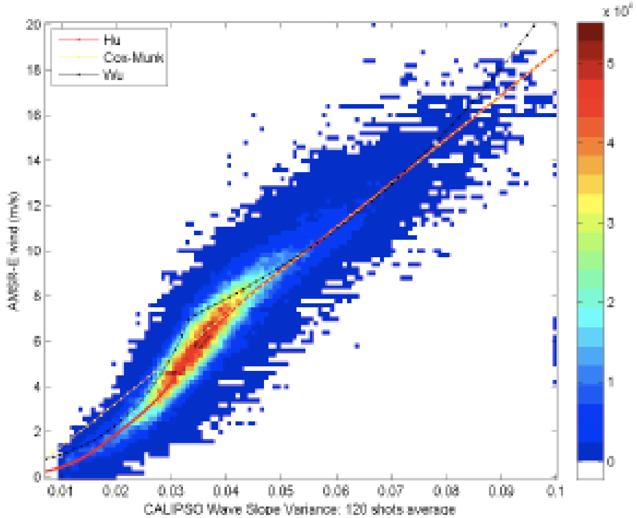
Surface Backscatter γ =

laser power * atmospheric attenuation * sea surface Fresnel reflectivity

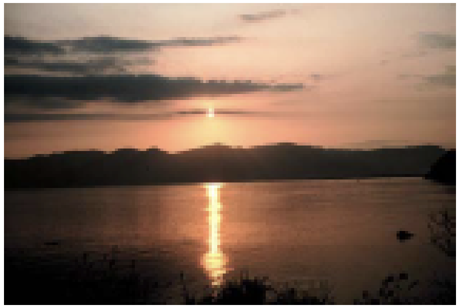
* fraction of the wave slope surfaces captured by the lidar receiver (θ=0)

$$= C^* [\ \sec^4\theta / \langle \tan^2\theta \rangle \exp(-\ 0.5 \tan^2\theta / \langle \tan^2\theta \rangle\ ]$$

$$= C / \langle \tan^2\theta \rangle$$

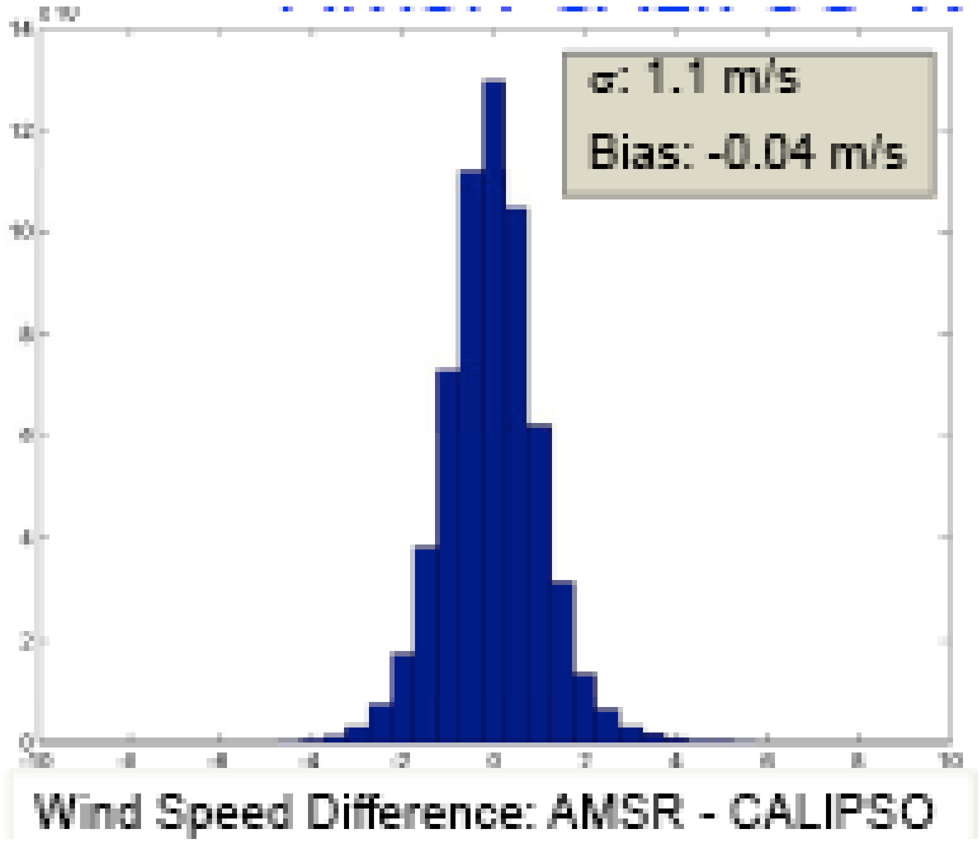


Yong Hu,
LaRC

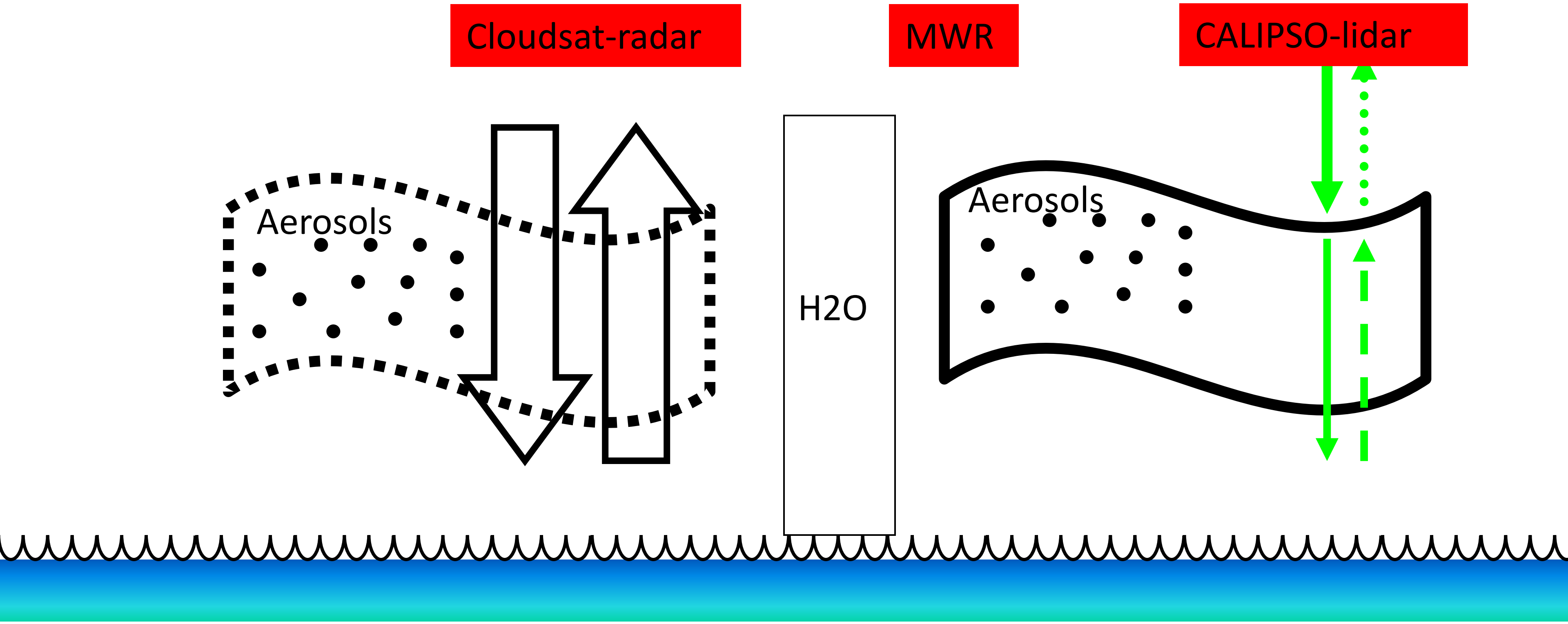


3/14/2009

Courtesy
Yong Hu, Larc



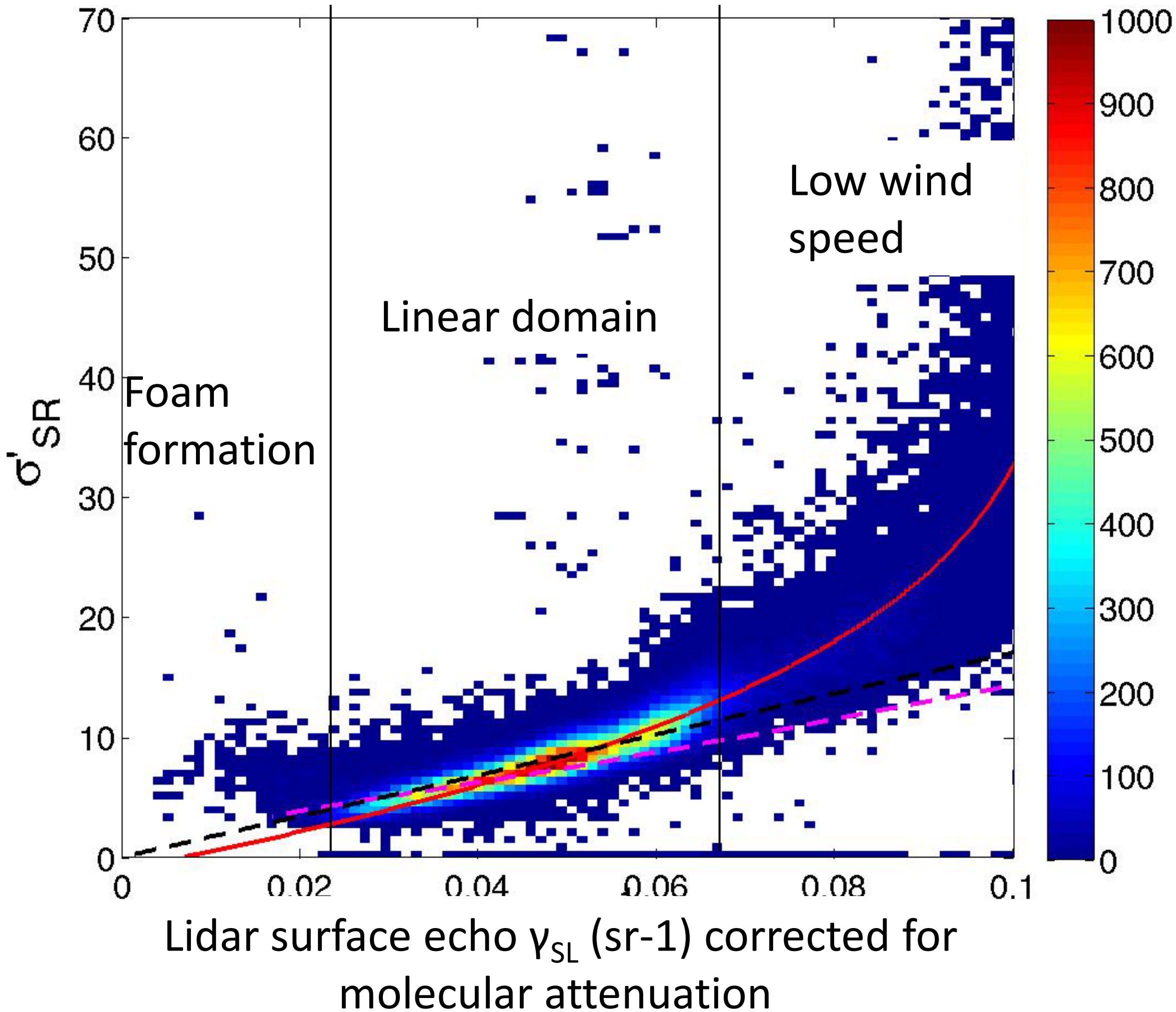
Ocean surface also can be used for lidar calibration and directly retrieve AOD



Already used for TRMM and Cloudsat CPR calibration (Tanelli et al., 2008)

- Transmittance analysis using large signal (high signal to noise ratio), no inversion
- Usable day and night

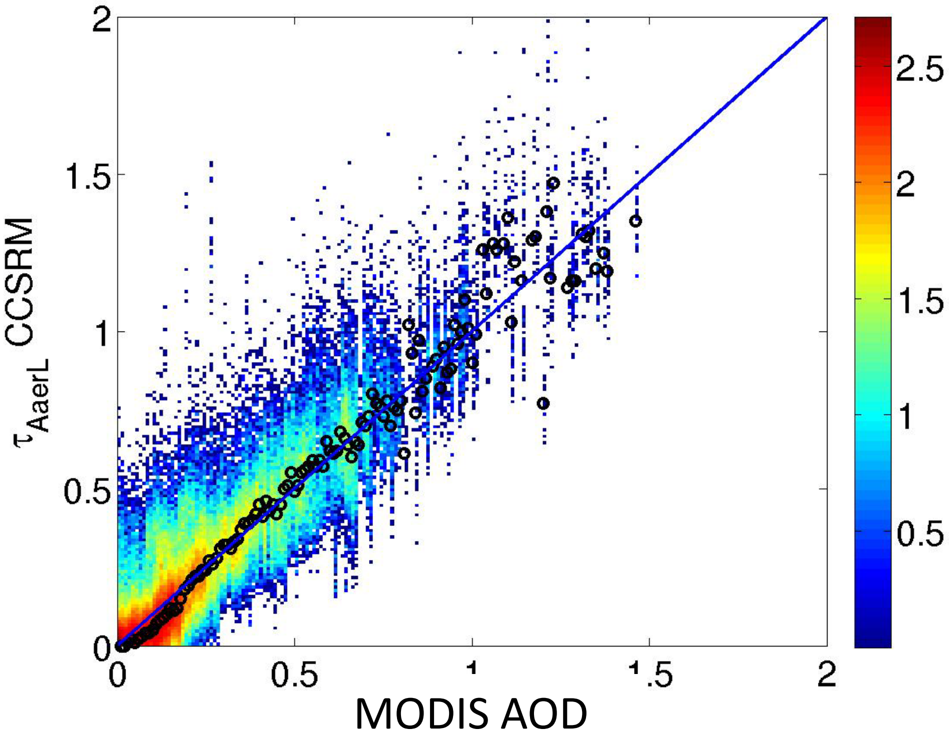
σ_0 CLOUDSAT surface echo from R04 operational product corrected for H_2O attenuation and SST variations (using AMSRE)



There is a unique relationship between CALIPSO and CLOUDSAT surface return - use Cloudsat sigma-0 to determine surface return of lidar and then derive the optical depth of aerosol ivia transmittance (exactly the same method used for cloudsat rain)

Number of occurrences (log10)

Aerosol Optical Depth CALIPSO/CLOUD SAT



1-31 August 2006 (Gulf of Guinea, fire season) CALIPSO/CLOUDSAT

Josset et al., 2009

Accurate AOD at the size of lidar spot (accurate cloud screening),
No microphysical assumptions so not affected by non sphericity problems (dust)
(main problems in MODIS retrievals Remer et al. 2005)

5. Simulators

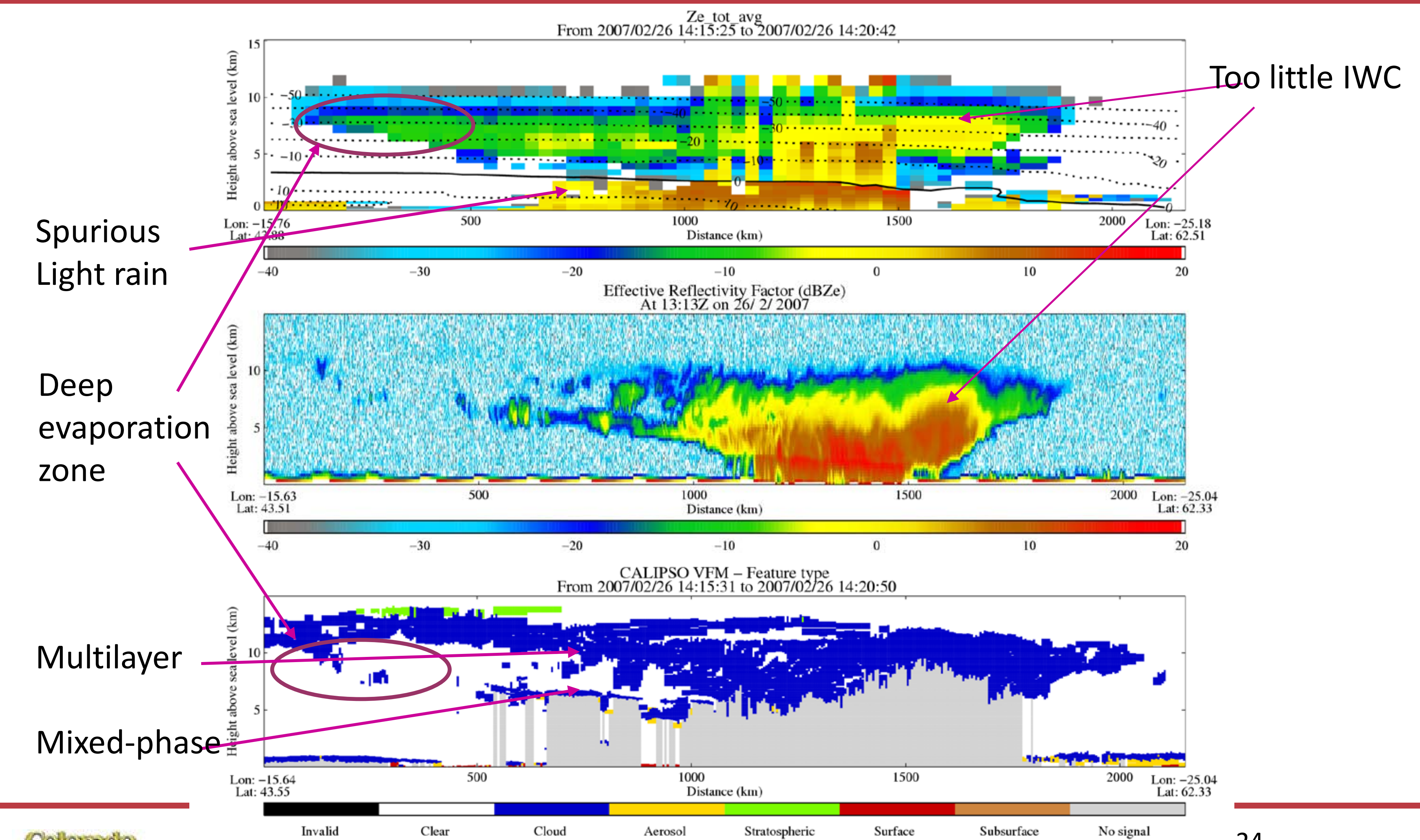
CFMIP
Cloud Feedback Model Intercomparison Project

The CFMIP Observational Simulator Package (COSP) - To facilitate the exploitation of CloudSat, CALIPSO data in numerical models,

- Model verification, data monitoring as well as data assimilation require a forward operator to match model output with observations →
  - Adaptation of existing forward operators:
    - CFMIP Observation Simulator Package (COSP)
      – to be used mainly for model validation
    - ZmVar - ECMWF reflectivity model used before for 14 and 35 GHz adapted
      – to be used for data assimilation

Simulator in the UKMO model

Bodas-Salcedo et al., 2009



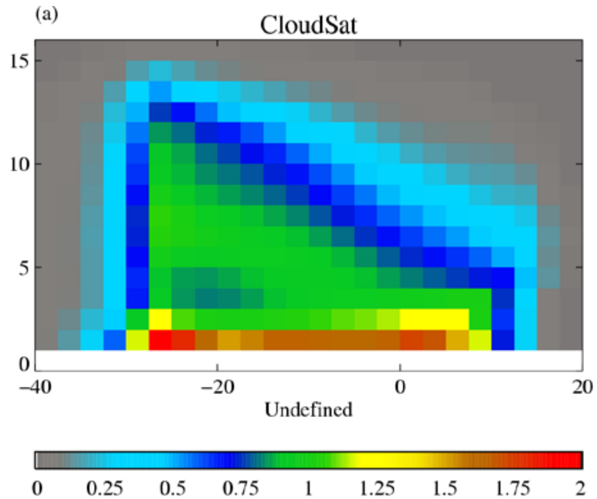
A → B

Global histograms: 2006/12 – 2007/02

CloudSat

Frequency of occurrence

Height / km

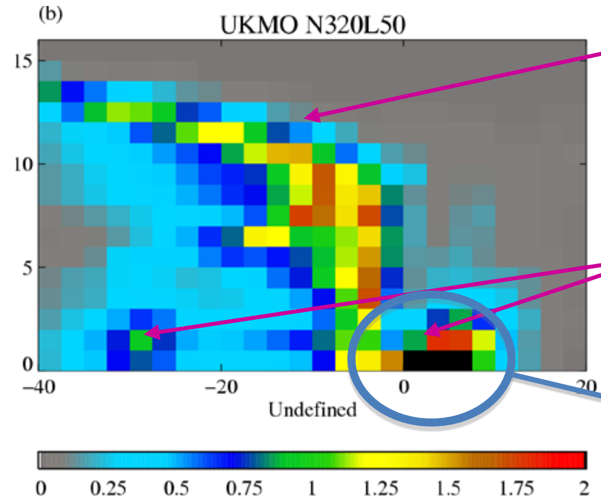


Reflectivity / dBZ

MetUM N320L50

Frequency of occurrence

Height / km



Reflectivity / dBZ

Strong dependence of N0 with T

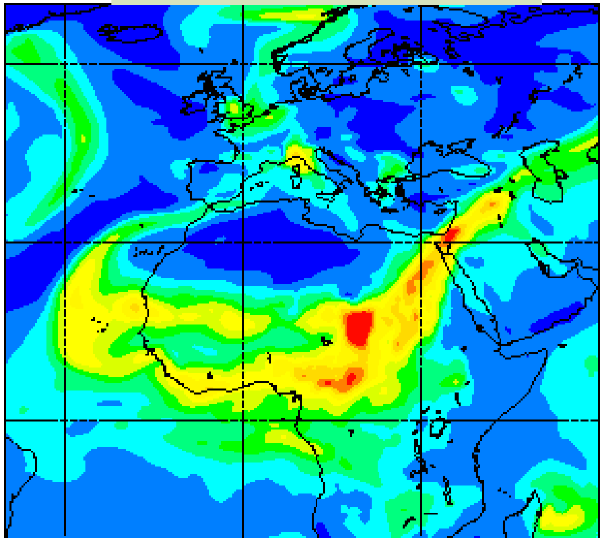
Two regimes. Rain/drizzling or not

This is for rain >0.05mm/hr

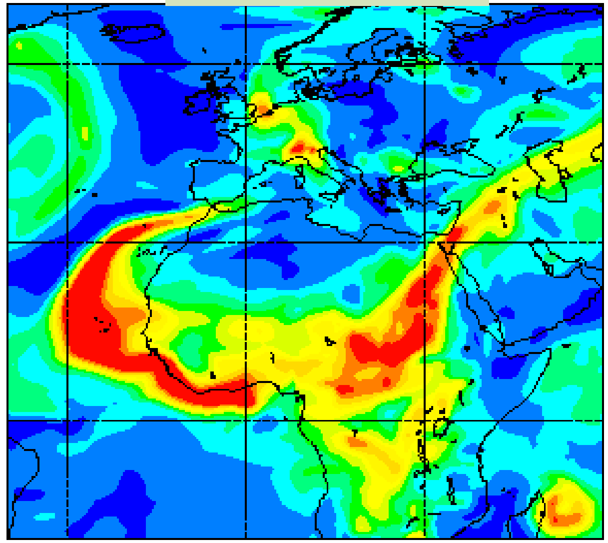
Bodas-Salcedo et al., 2008

Aerosol assimilation - Saharan dust outbreak: 6 March 2004

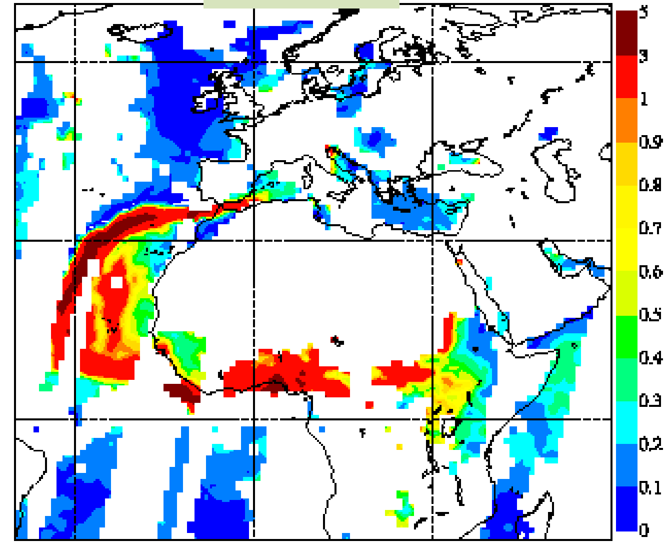
Model simulation



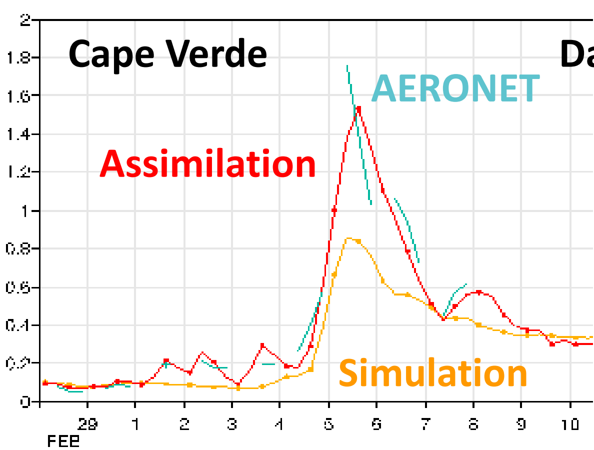
Assimilation

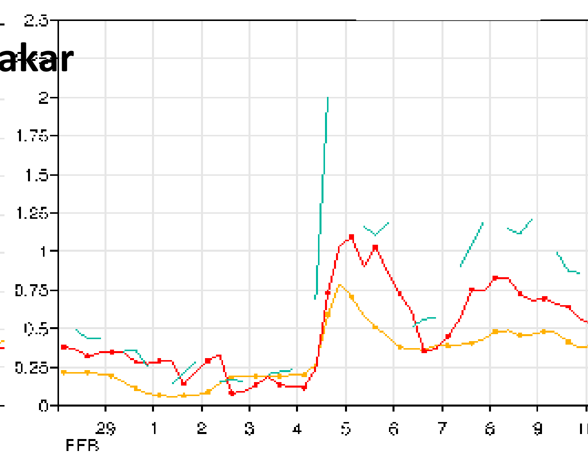


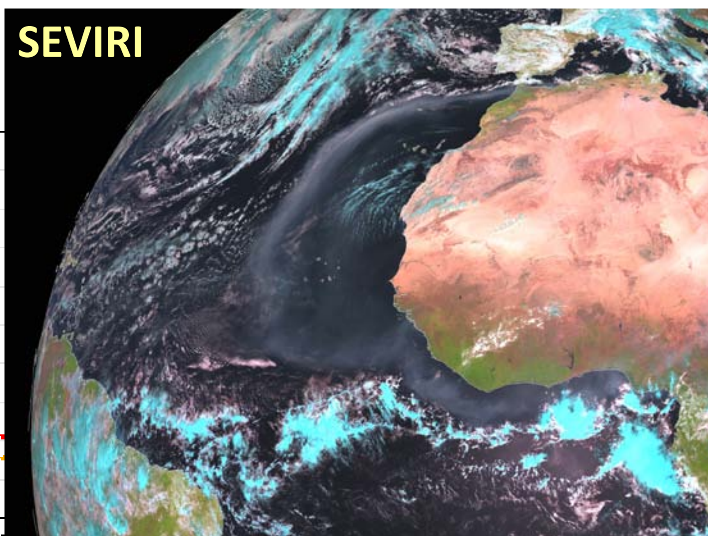
MODIS



Aerosol optical depth at 550nm (upper) and 670/675nm (lower)







Morcrette et al., 2008; Benedetti et al., 2008

CALIPSO feature classification along 9670 km of
A-Train orbit between 26/06/2007 00:36:29 and 26/06/2007 01:00:01

6. Some science- the nature of rain

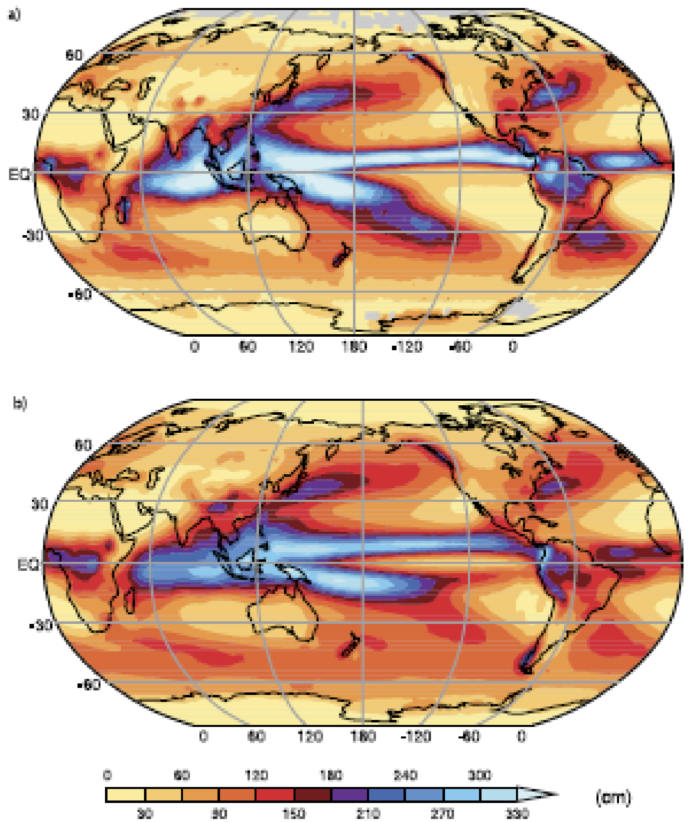
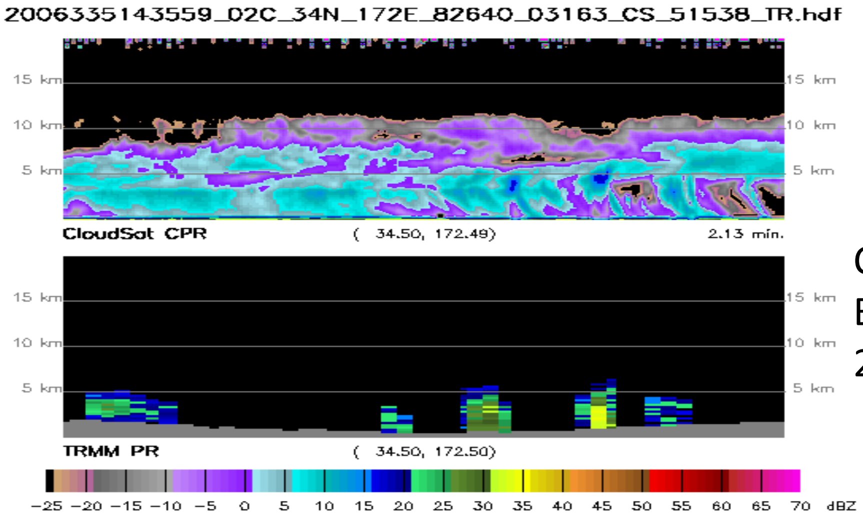


Figure 8.5. Annual mean precipitation (cm), observed (a) and simulated (b), based on the multi-model mean. The Climate Prediction Center Merged Analysis of Precipitation (CMAP; Xie and Arkin, 1997) observation-based climatology for 1980 to 1999 is shown, and the model results are for the same period in the 20th-century simulations in the MMD at PCMDI. In (a), observations were not available for the grey regions. Results for individual models can be seen in Supplementary Material, Figure S8.9.

1.Accumulation - amount of precip accumulated over some time period –typically expressed as a rain rate – in climatological applications this is the most frequently analyzed form of precip used to compare to models – the accumulated precip on large space and long time scales is controlled (constrained) by energetics - ie it has to be ~ 3mm/day globally

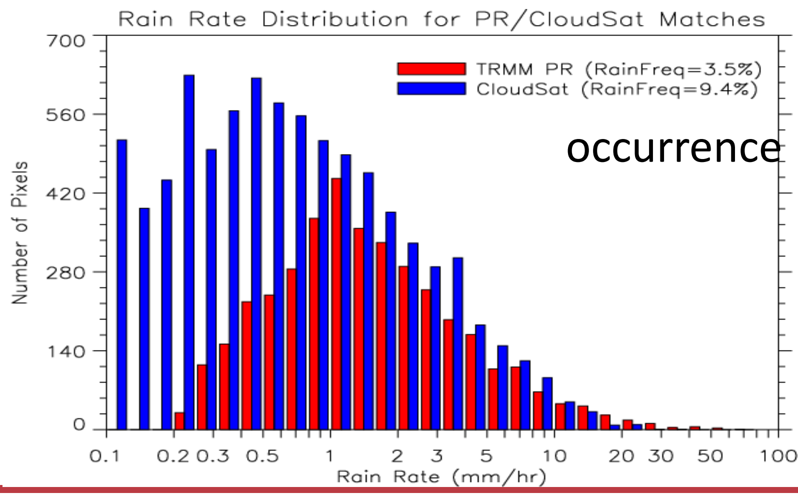
2. **Character of precipitation** (accum = frequency X intensity) much less focus but essential to most hydrological applications and to many precip-related climate processes. There is no obvious constraint on this pair of characteristics.

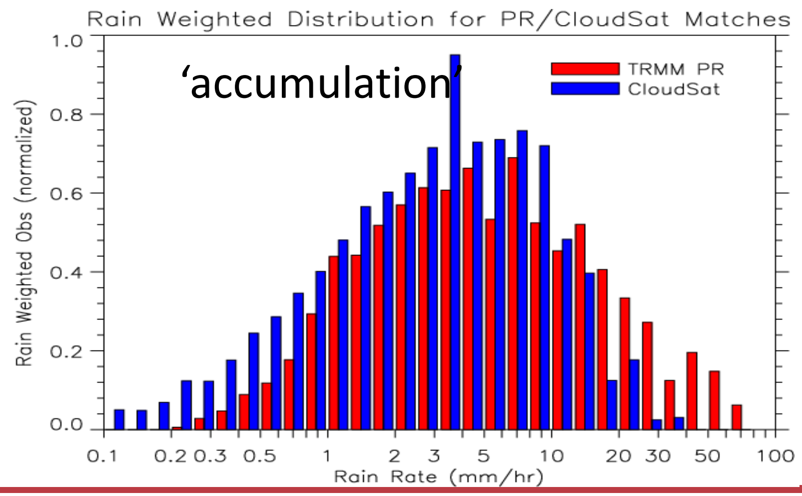
Intensity: CloudSat AN-PR



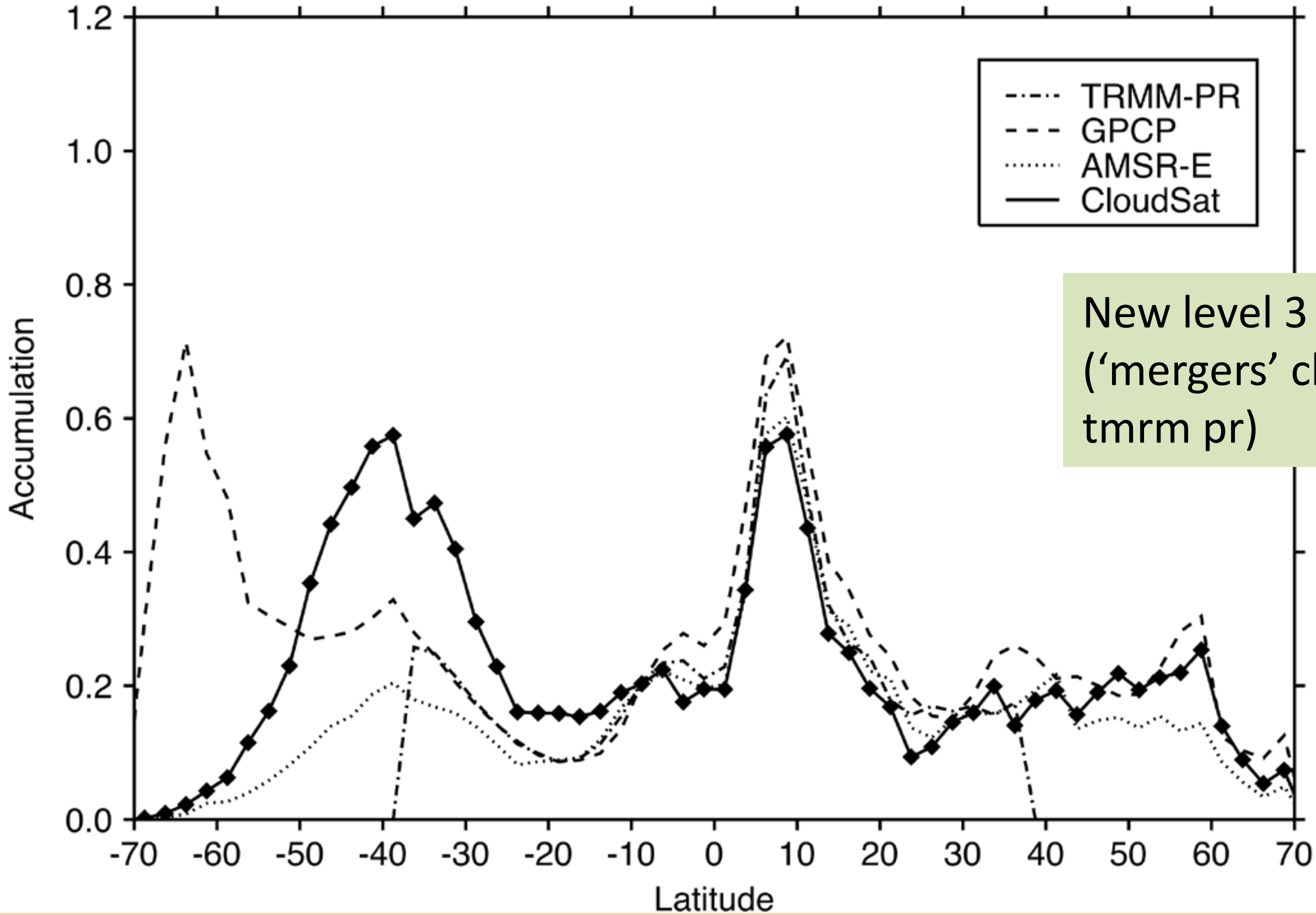
More than 3000 orbit crossings between CloudSat and TRMM (& growing) in the CloudSat AN-PR

Comparison of 2c-precip-column (already released) - Berg and L'Ecuyer (in preparation) also Ellis et al. 2009





JJA Oceanic accumulation (m/area)



New level 3 rain product ('mergers' cloudsat and tmrm pr)

We are seeing much more frequent rain and much higher accumulations in the winter hemisphere than has been evident in other data bases – is this true?

Comparison to models

- We use CloudSat observed frequency and intensity for JJA (2006)
- Special experiments performed using ECMWF forecast model (JJA 2006), UMKO climate model (JJA 5 yr seasonal) and early versions of AM3 and CAM
- Upscale CloudSat (1.7km) to model resolution (ECMWF, 0.5 degree, UKMO 1.25 degrees, 2 degrees for other two models) via averaging along track
- Compare to model properties employing the lower CloudSat threshold of 0.05mm/hr also up-scaled to relevant model resolution

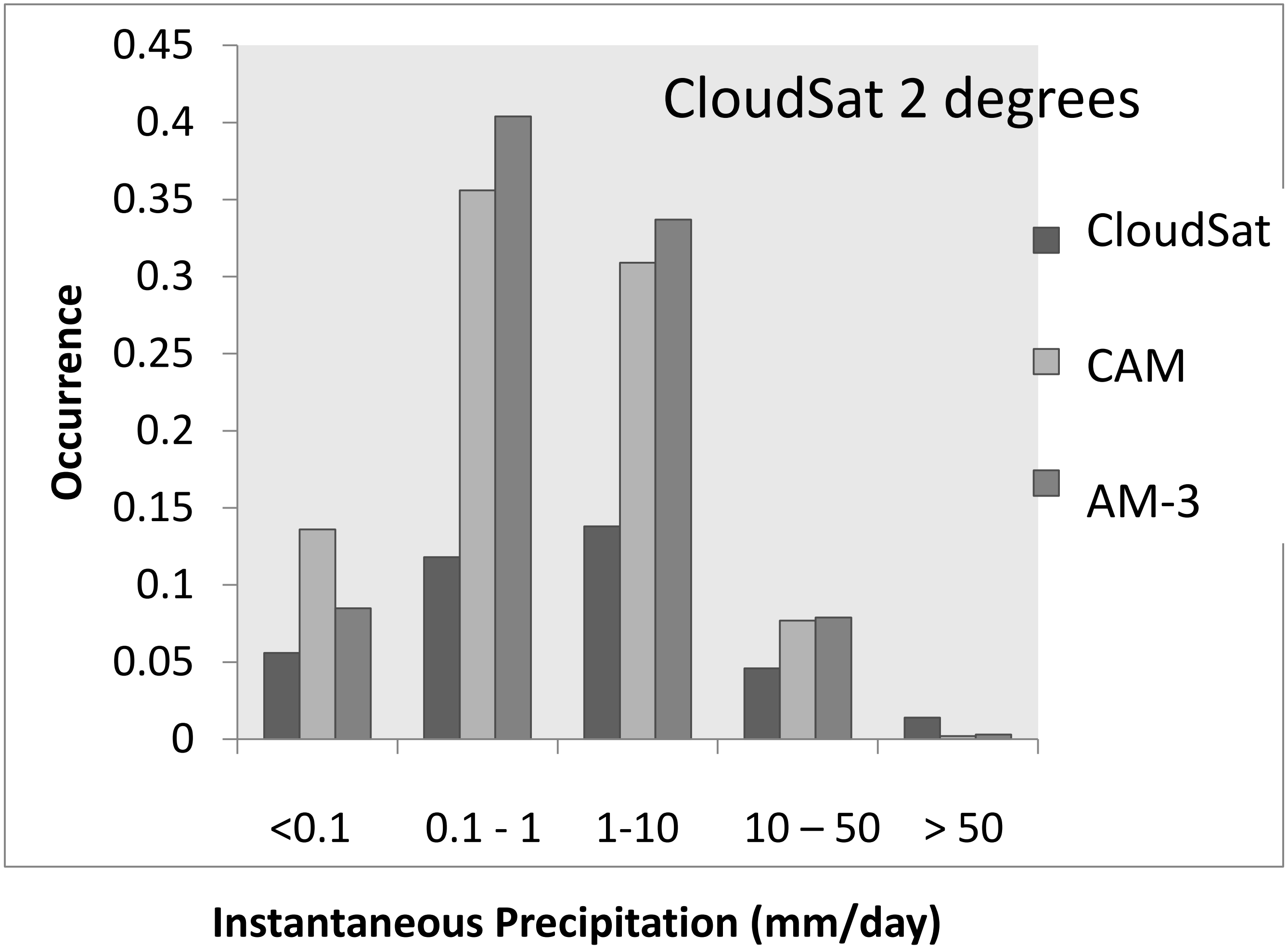
Work in progress

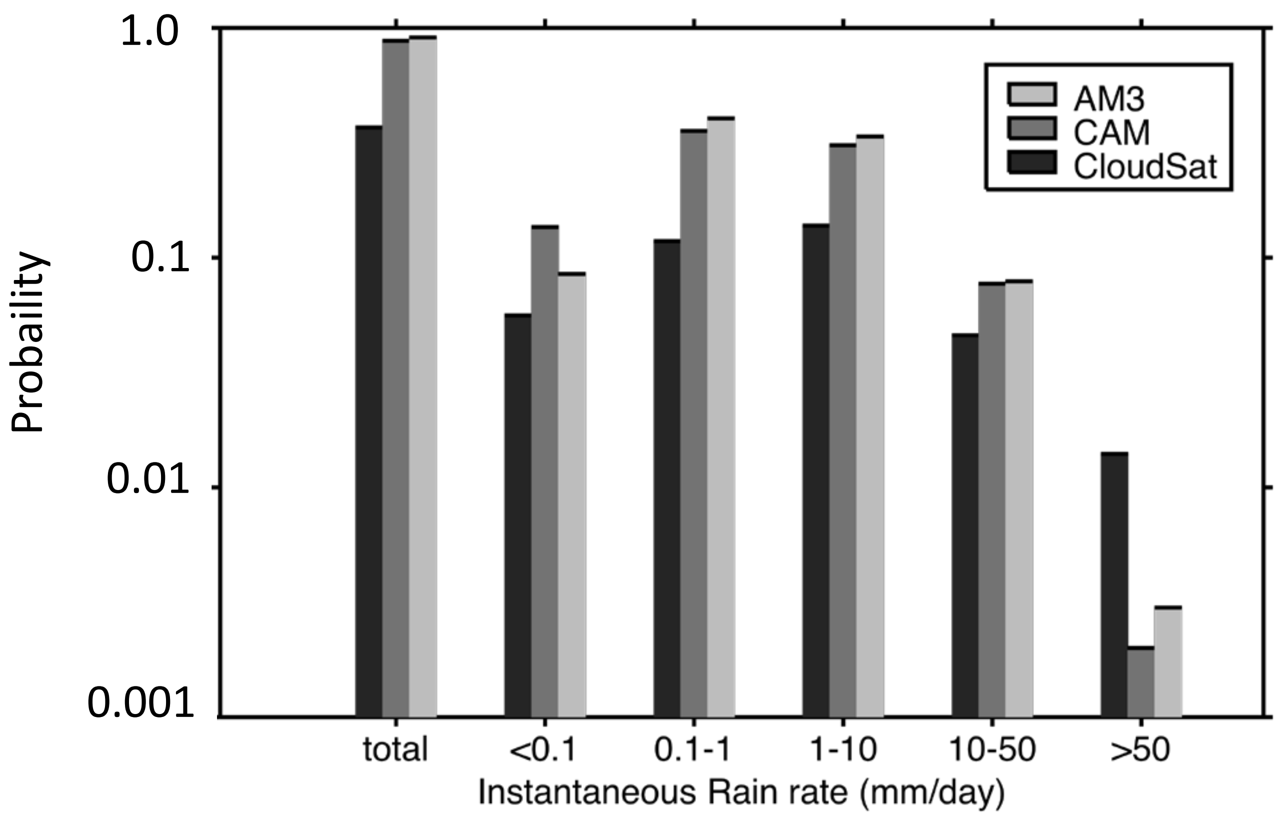
JJA Oceanic Precipitation Model Comparison Summary

In progress

Data Source	Incidence	Mean Rain rate mm/day
CloudSat (native)	0.11	2.86
CloudSat (0.5)	0.212	
ECMWF	0.679	2.83
CloudSat (1.25)	0.309	
UKMO	0.493	2.65
CloudSat (2)	0.372	
CAM	0.880	2.71
AM-3	0.908	2.94
CloudSat		
NICAM (7km)	0.27	
NICAM (14km)	0.34	

accumulation


CloudSat 2 degrees
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Occurrence
<0.1
0.1 - 1
1-10
10 – 50
> 50
CloudSat
CAM
AM-3
Instantaneous Precipitation (mm/day)


1.0
0.1
0.01
0.001
Probaility
AM3
CAM
CloudSat
total
<0.1
0.1-1
1-10
10-50
>50
Instantaneous Rain rate (mm/day)

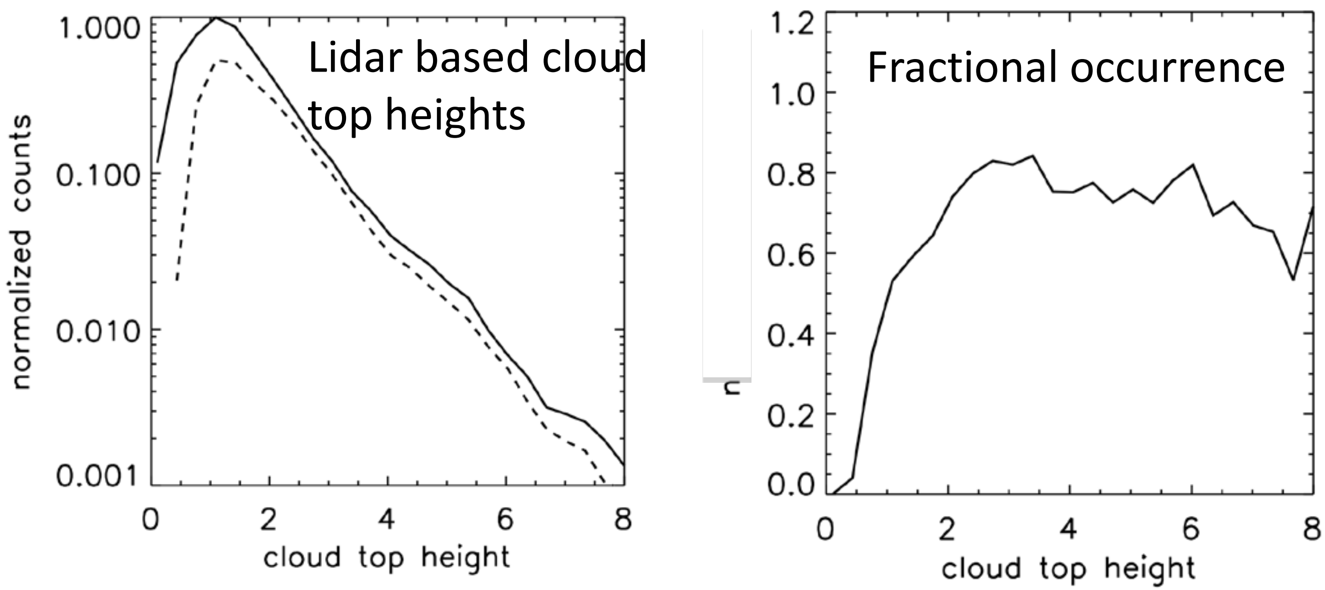
Is this merely a consequence of apples n oranges? Ie studies have show how the predictive skill of regional forecast models is not apparent on scales less than ~10Δx

or

are there a fundamental issues in the way rain processes are represented in global models?

6. More science - Low oceanic clouds

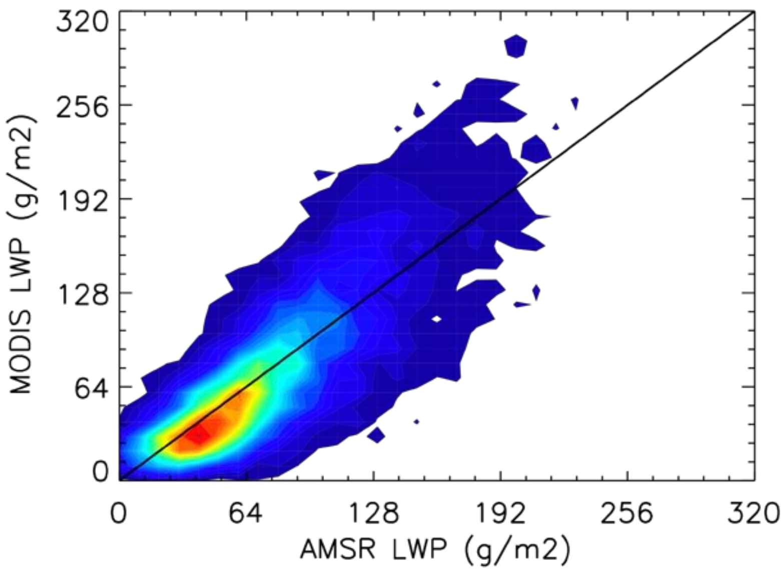
- Low oceanic clouds = identified by MODIS low cloud mask (uses cloud top temp and other properties)
- Only single layer clouds (as determined by lidar info) analyzed
- Statistics accumulated over one JJA and one DJF seasons



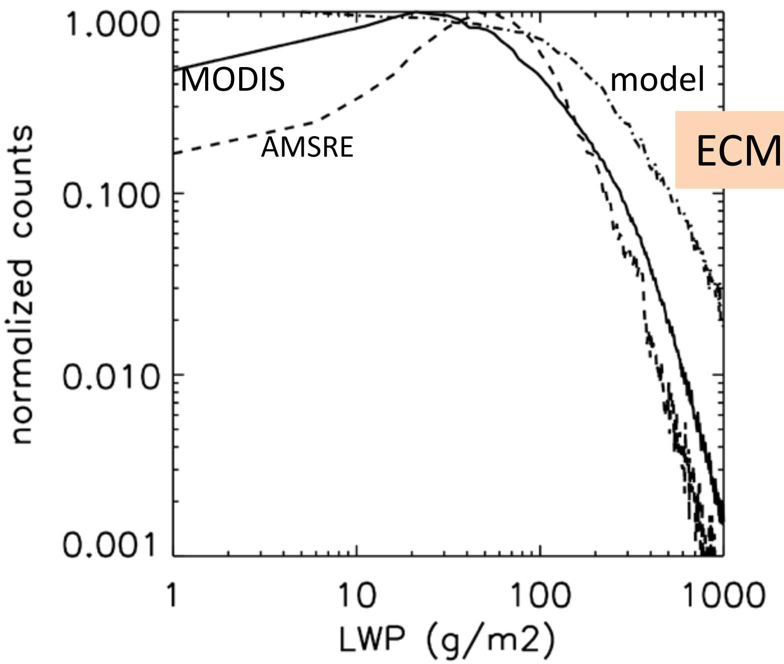
- The low clouds accumulated primarily lie below 4km

In-cloud LWP statistics

Overcast MODIS averaged to AMSRE FOVs



Mean ~ 110 g/m2
Model 200 g/m2



ECMWF

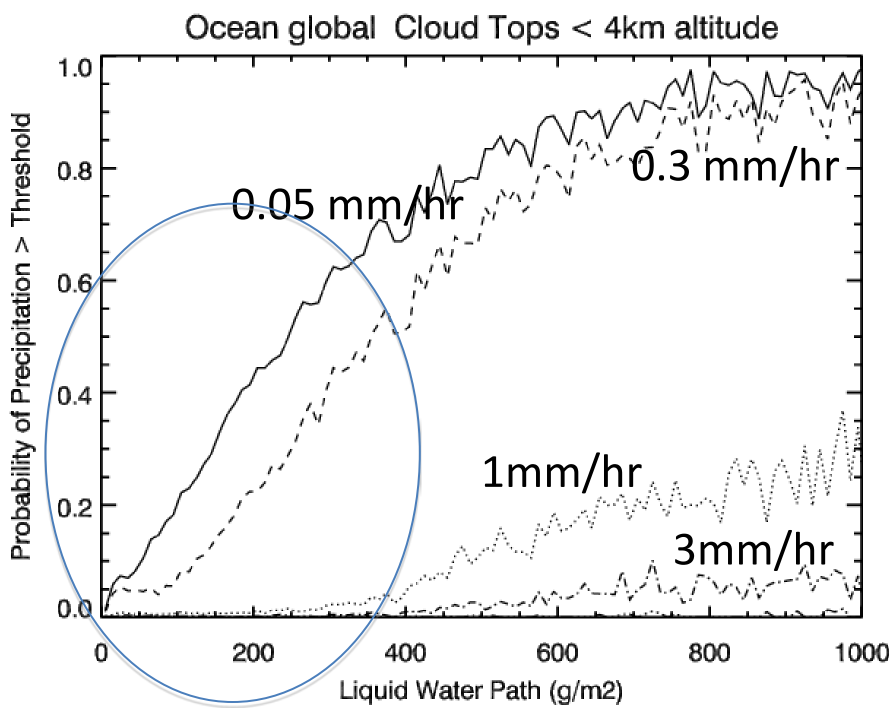
For the sampling applied, LWP derived from two different approaches methods agree over the range 20 - 200 g/m2

Water contents not only of ECMWF AR4 models are too large ?????

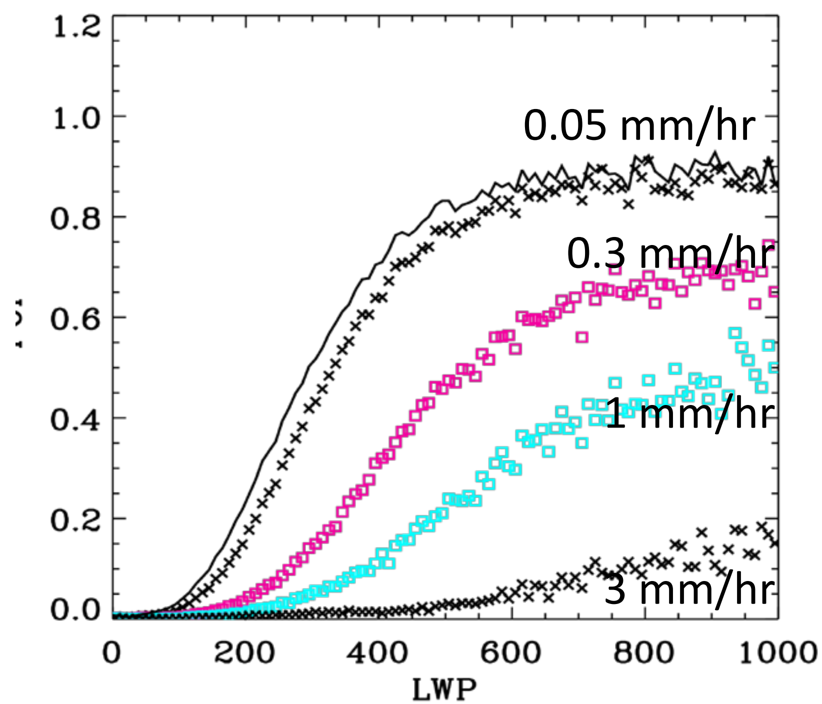
Probability of rain in warm clouds

Modal rainfall probability is ‘bi –modal’ very light or ‘heavy’

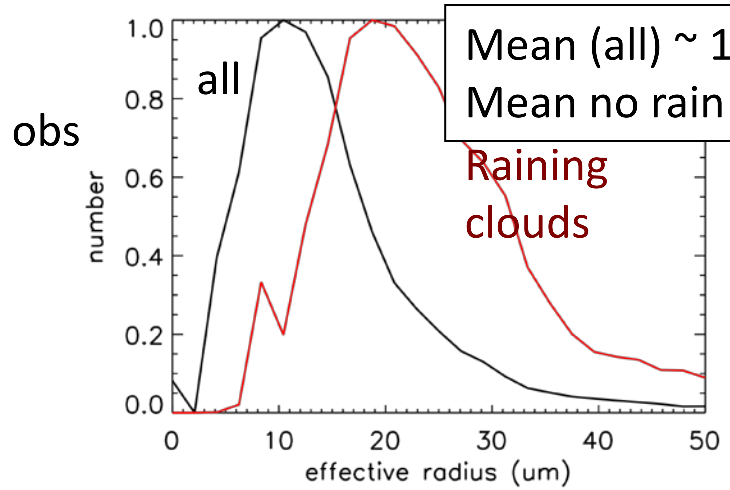
Model

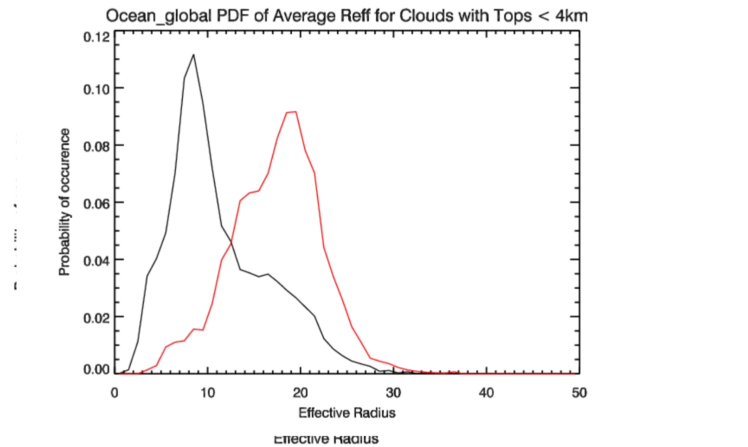


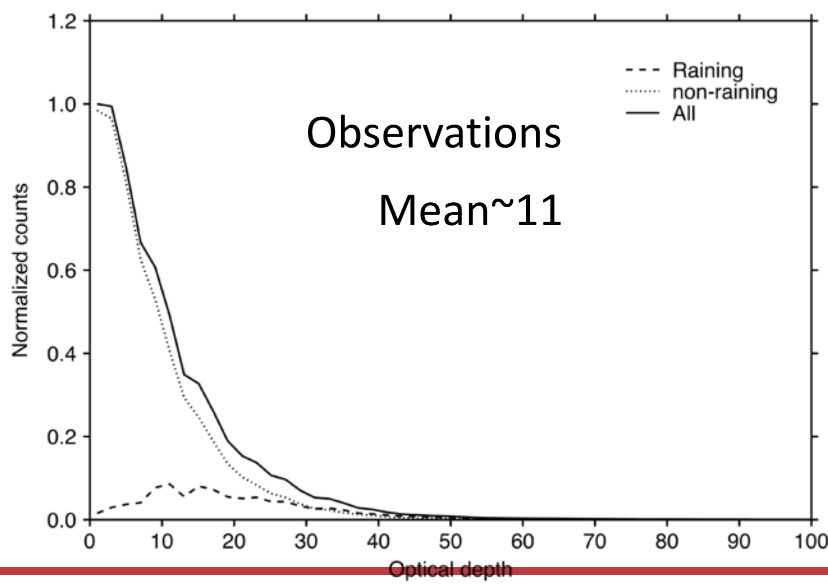
Observations



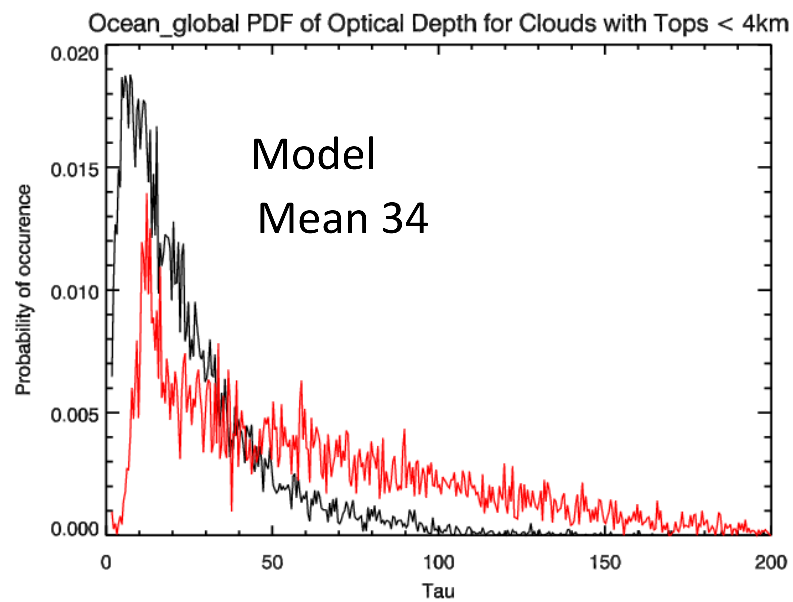
Low cloud Optical depth







$$\tau = \frac{3}{2}\frac{W}{r_e}$$



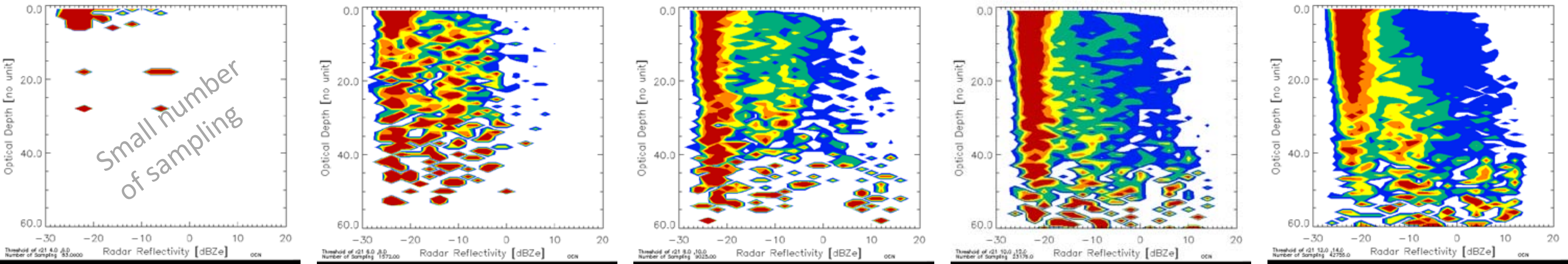
Breckenridge - 2009

Contoured Frequency by Optical Depth Diagram (CFODD) for several R21 ranges (OCEAN)

Sampled only Tau_modis>1

Nakajima, Suzuki, Stephens (2009) in progress

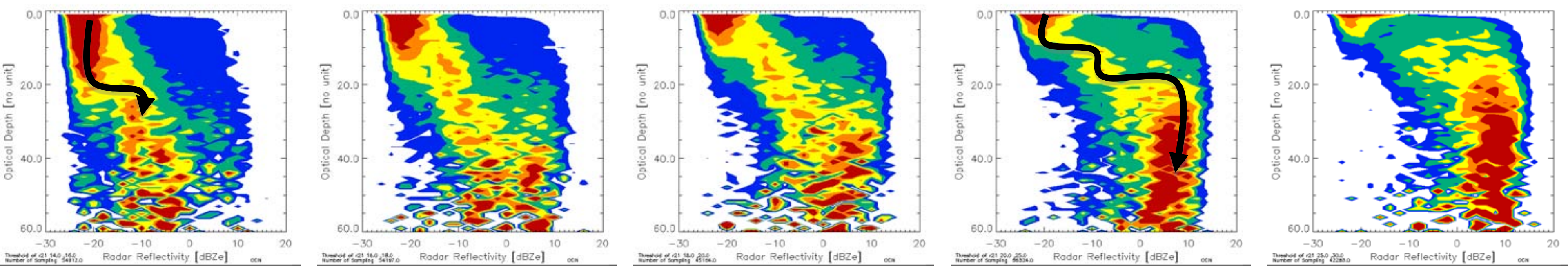
4<R21<6µm | 6<R21<8µm | 8<R21<10µm | 10<R21<12µm | 12<R21<14µm



Condensation growth

R21=14µm

14<R21<16µm | 16<R21<18µm | 18<R21<20µm | 20<R21<25µm | 25<R21<30µm

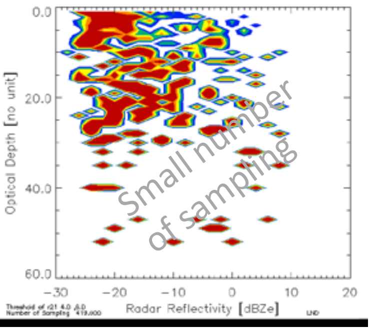


Drizzling → Drizzle to Rain → R21=20µm → Rain → Decay

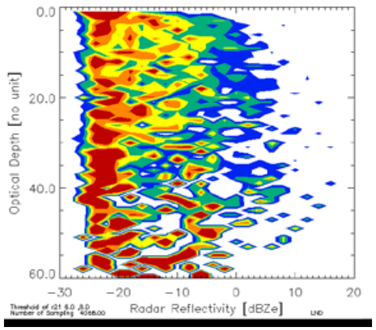
Sampled only Tau_modis>1

Contoured Frequency by Optical Depth Diagram (CFODD) for several R21 ranges (LAND)

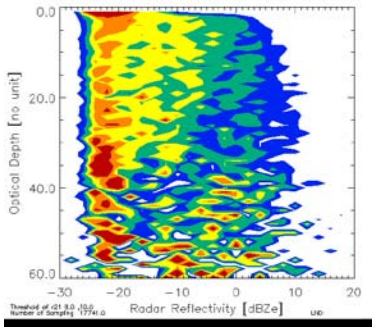
4<R21<6µm



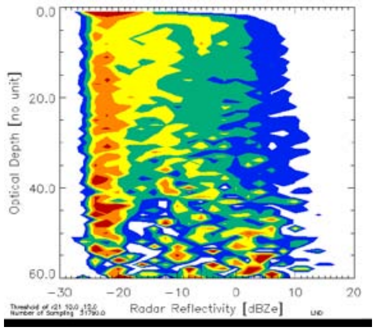
6<R21<8µm



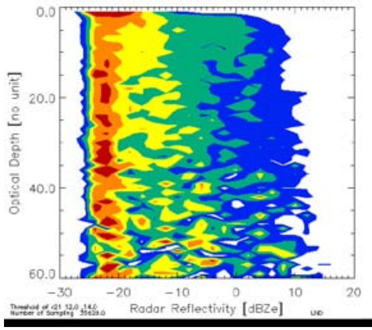
8<R21<10µm



10<R21<12µm

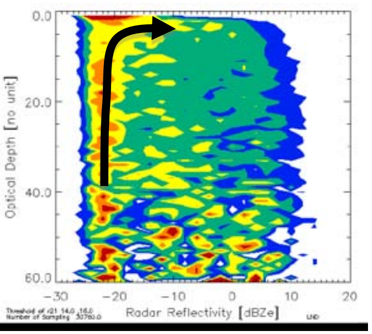


12<R21<14µm

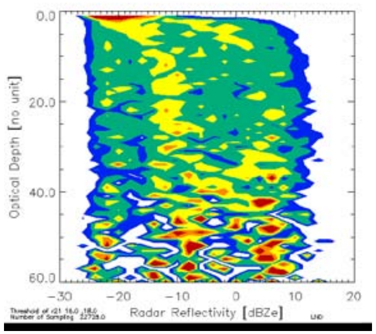


Condensation growth → R21=14µm

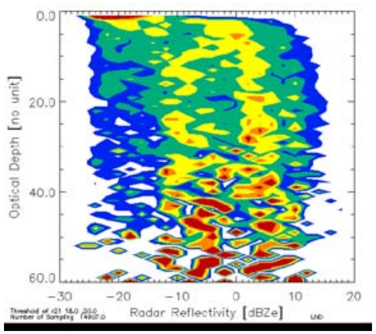
14<R21<16µm



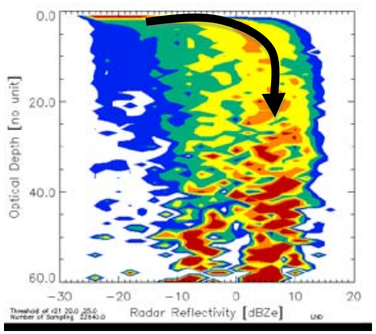
16<R21<18µm



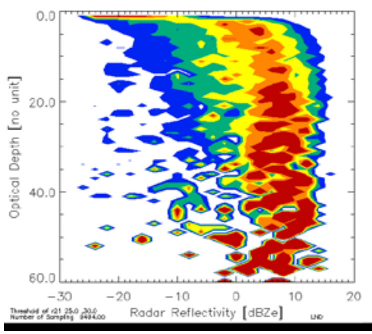
18<R21<20µm



20<R21<25µm



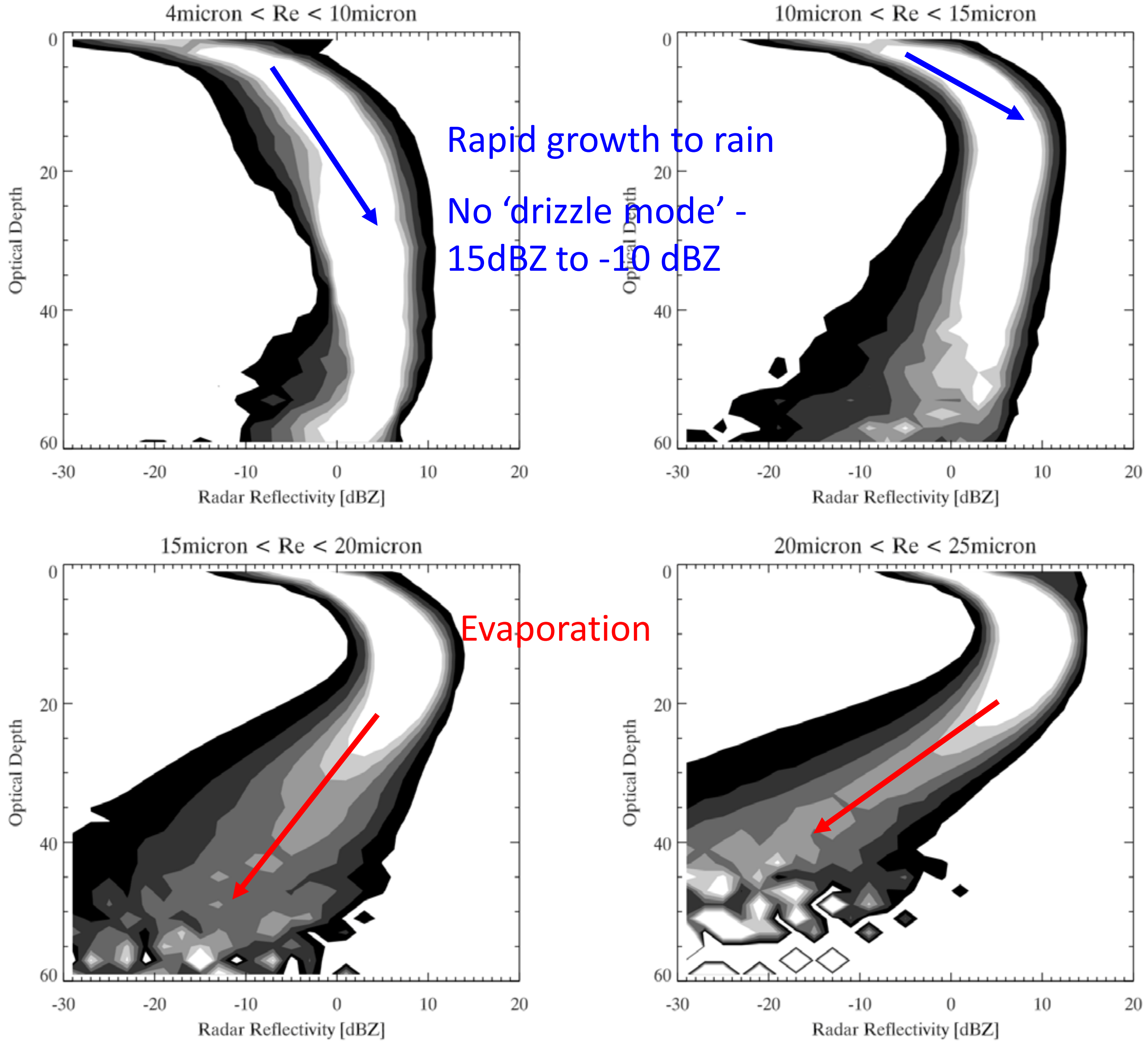
25<R21<30µm



Drizzling → Drizzle to Rain → R21=20µm → Rain → Decay

Nakajima, Suzuki, Stephens (2009)

NICAM-SPRINTARS



7. Summary

Models lack a third drizzle mode clearly evident in the observations of both particle size and in the radar reflectivity

What is emerging

Clouds

Too frequent, too light

Precipitation

Too wet, too bright

The consequences

No drizzle mode in radiative properties, too little low cloud, no optical depth Feedback (e.g. Colman et al., 2001) , unrealistic microphysics and aerosol influences

Unrealistic filtration & runoff, unrealisitic wet deposition and rain out, weak diabatic heating & storm development

7. Summary

A consistent picture is emerging on the topic of (warm) rain and its representation in models- it appears that by digging into the processes, we can conclude that models make rain too rapidly that falls out too readily with the end result that rain occurs too frequently (and by inference too lightly) compared to the real world.

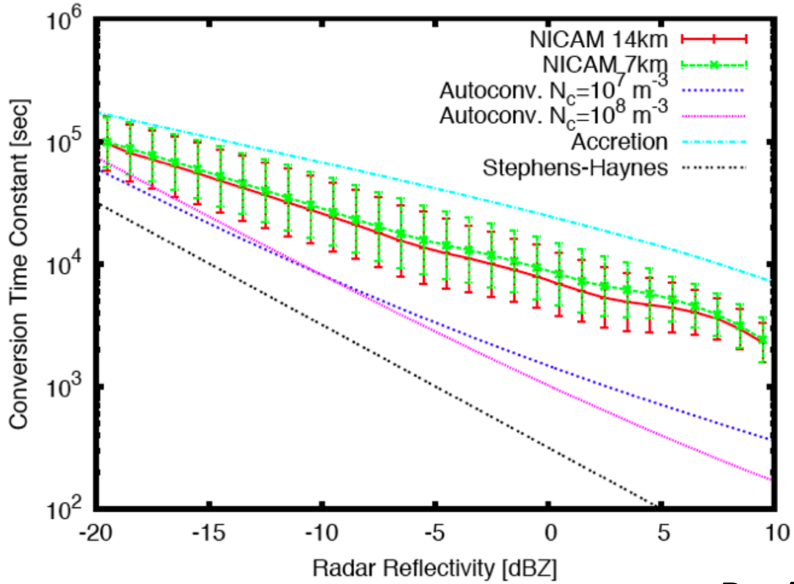
Thus the entire character of model precipitation differs from reality.

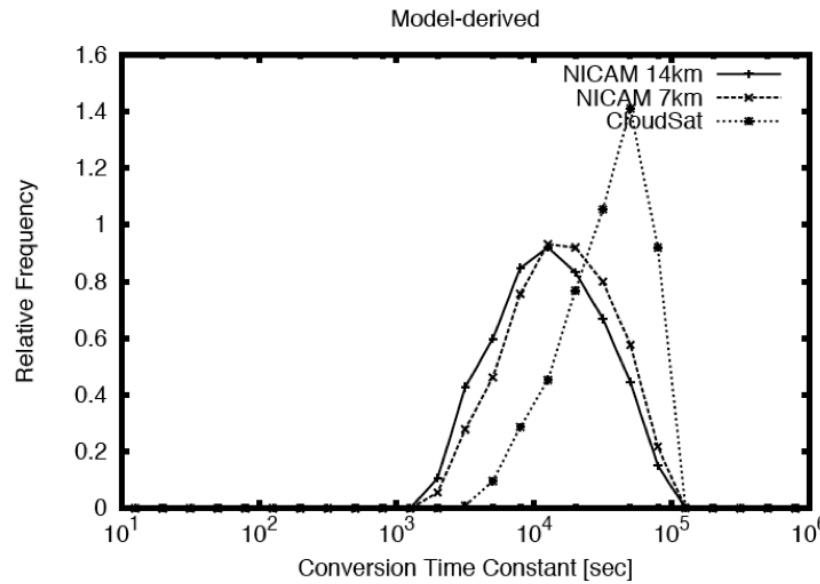
An obvious next step is to develop the parameterization of the coalescence process that maintains a presence of drizzle and that is expressible as a function of particle size

This past 3+ years has been an amazing journey

Thanks

Processes: warm rain – timescale of coalescence





Basic message is the mean reflectivity of the cloud layer is related to time scale of coalescence

Stephens and Haynes, 2007
Suzuki and Stephens, 2008

Summary:

1)Low clouds dominate the global TOA CRE via their influence on sunlight reflected to space.

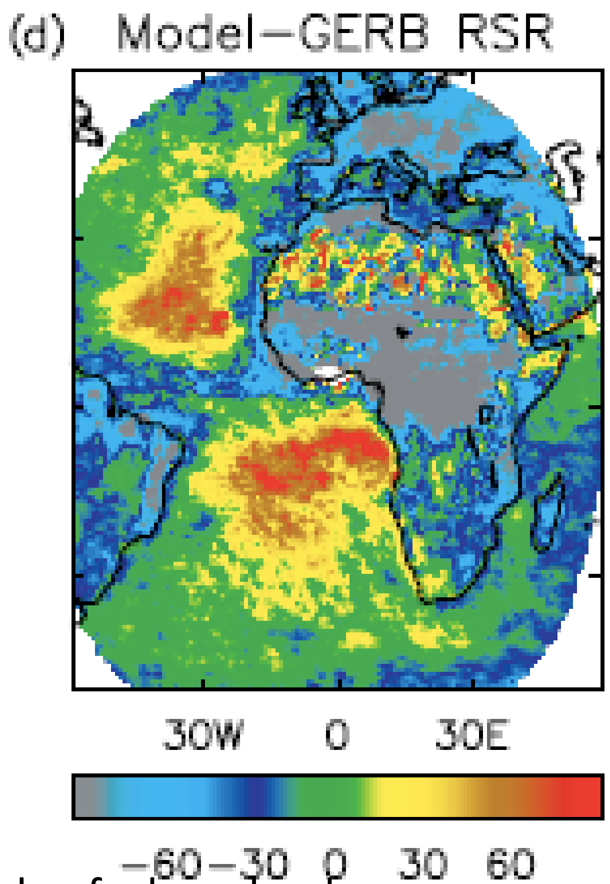
2)The reflection of solar energy by a cloudy atmosphere is controlled by cloud amount, the water path and particle size and changes to these properties underlie hypothesized cloud-climate feedbacks.

3)The presence of drizzle in low clouds is prevalent enough that it has an observable consequence on the *mean* radiative properties of clouds (e.g. 18 µm mean particle size).

4)There are preliminary hints that the representation of low cloud radiative effects in models may be significantly biased high (water contents too large, particle sizes too small, optical depths too large and the amount of sunlight reflected by a given volume of cloud too large).

Model comparisons (preliminary)

UM

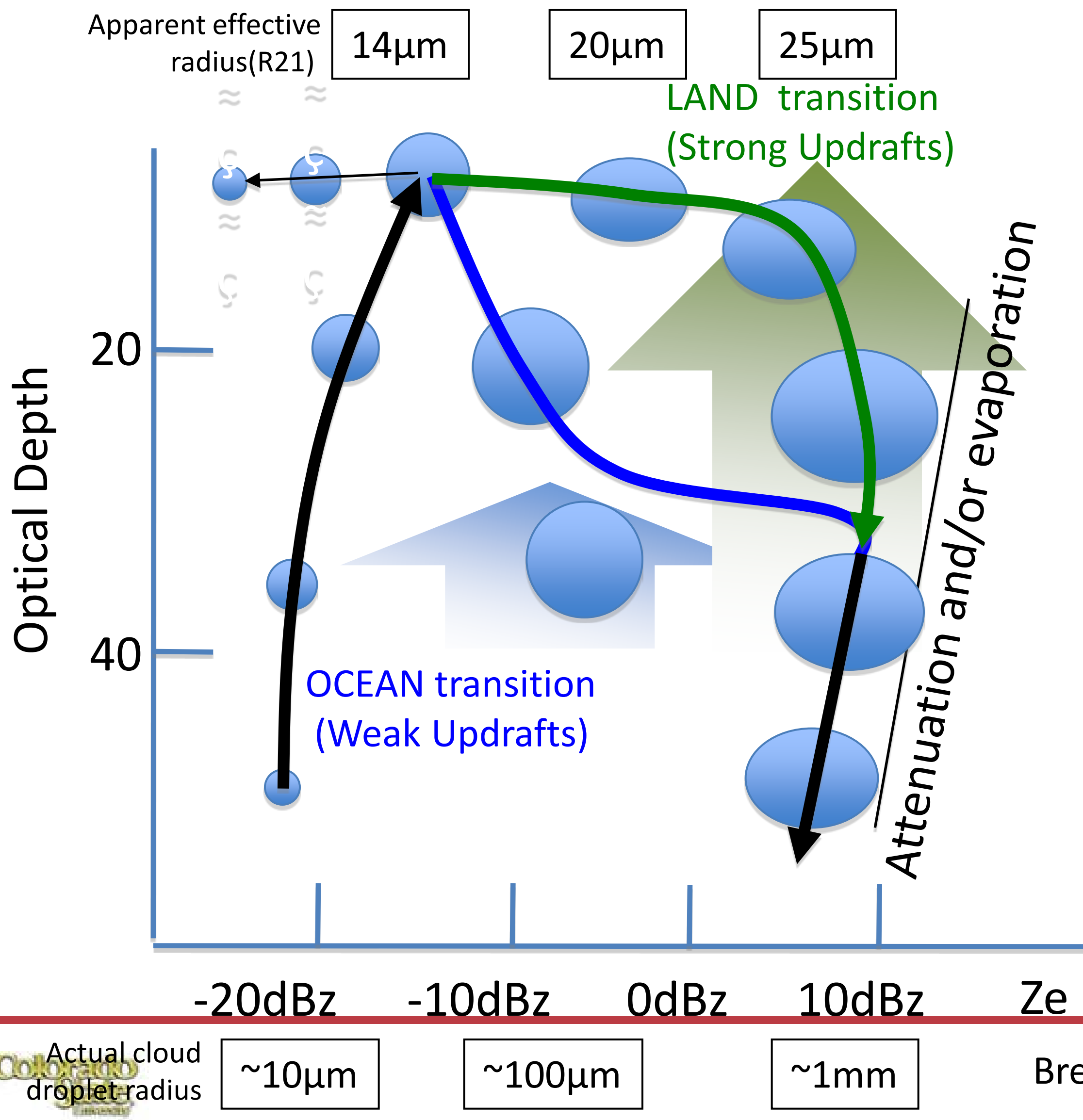


Example of a low cloud albedo bias (Allan et al., 2007)

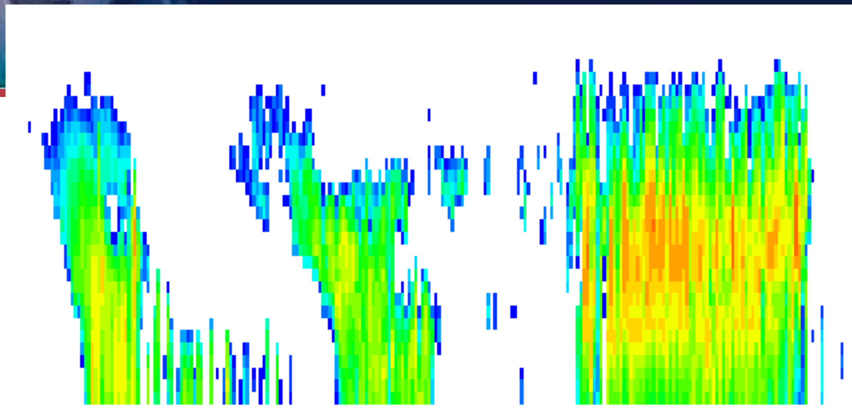
I speculate these low cloud biases may be common to most models

(e.g. in cloud AR4 model LWP ~ 200 g/m2)

Suggested interpretation



1D-Var assimilation of cloud-related observations – very preliminary



CloudSat observations

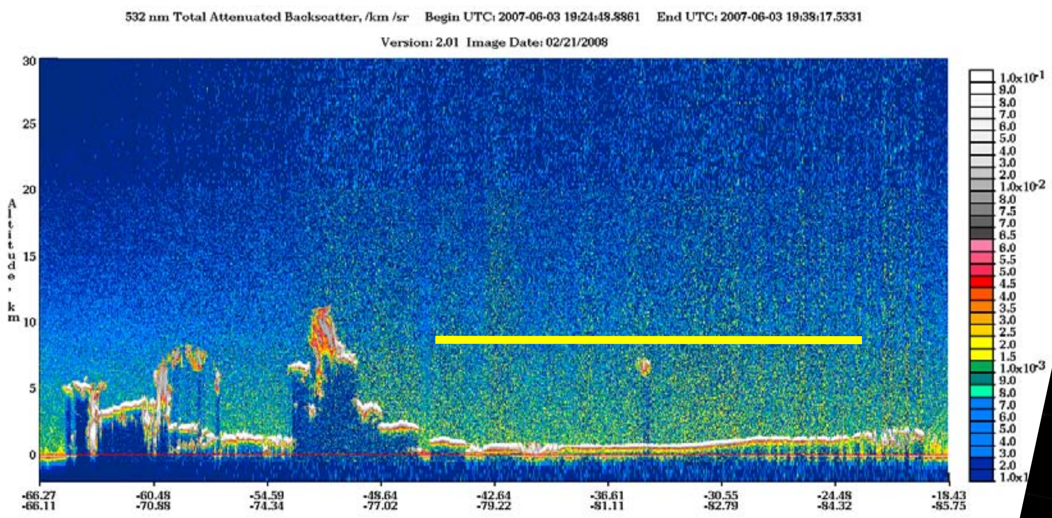
- Cloud reflectivity from 94GHz radar

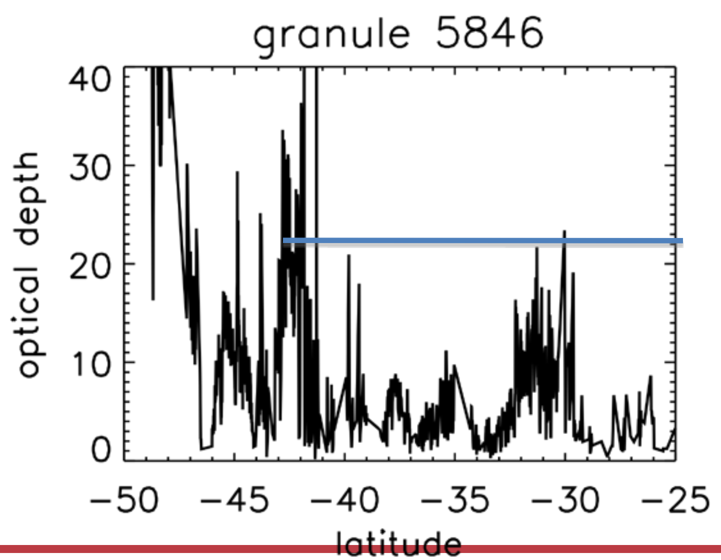
Period: 7 February 2008, 3:37 – 3:50 UTC

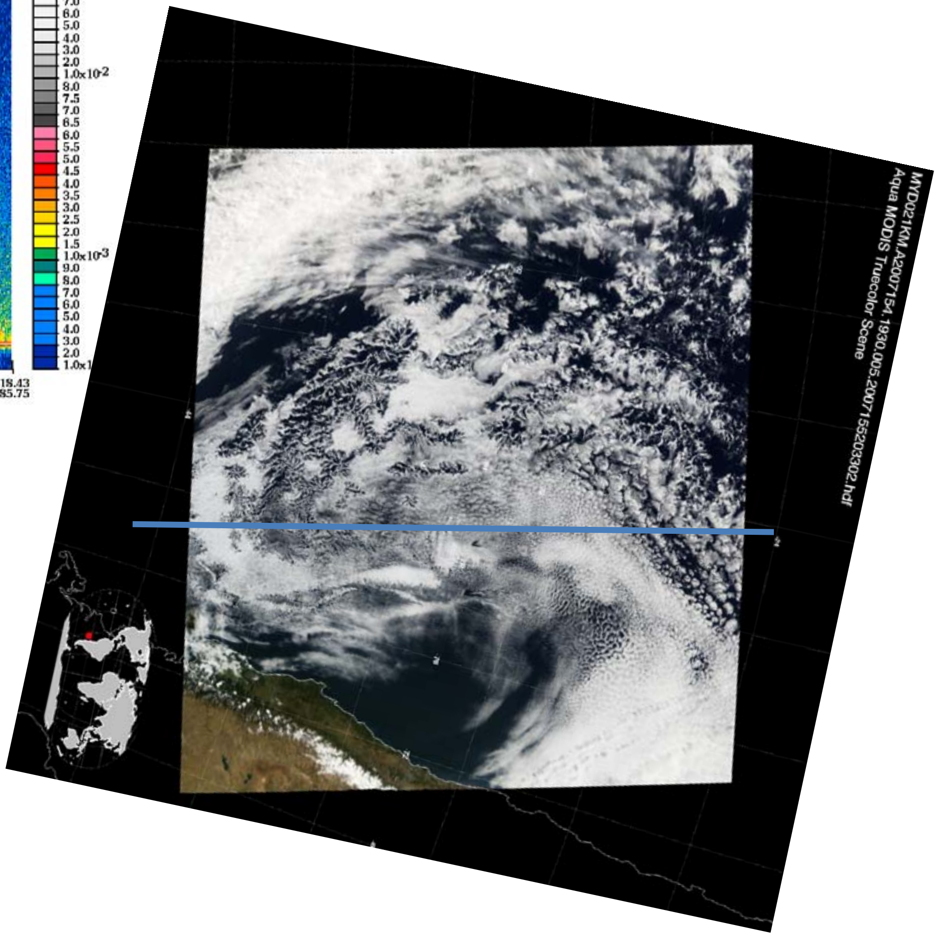
> 20 dBZ
15 dBz < Z < 20 dBz
10 dBz < Z < 15 dBz
5 dBz < Z < 10 dBz
-5 dBZ < Z < 5 dBz
-10 dBz < Z < -5 dBz
-15 dBz < Z < -10 dBz
-20 dBz < Z < -15 dBz
< -20 dBZ

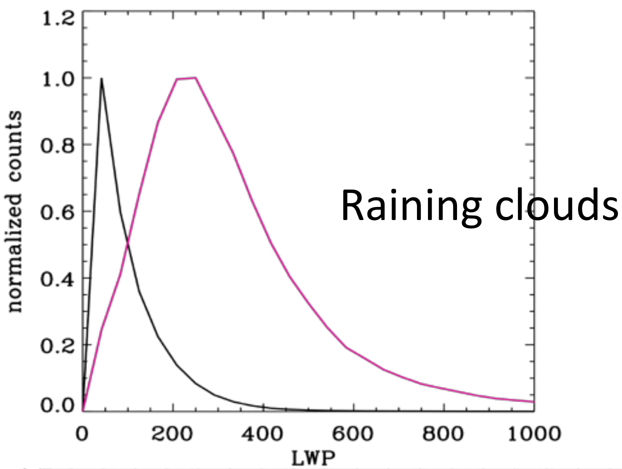
Cloud reflectivity in dBz

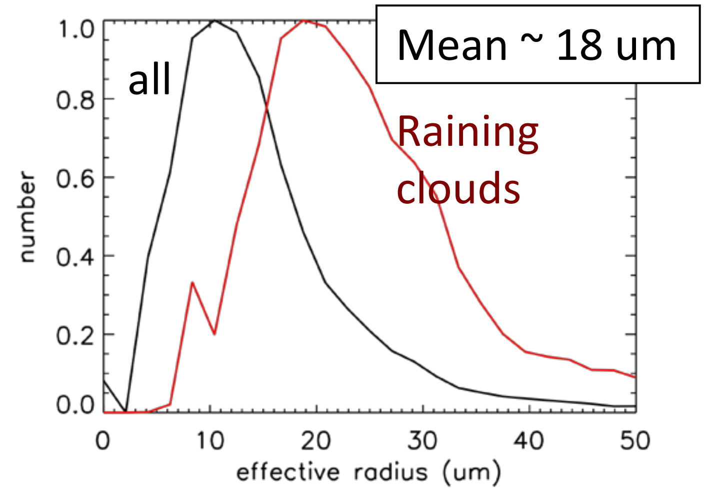
Example orbit

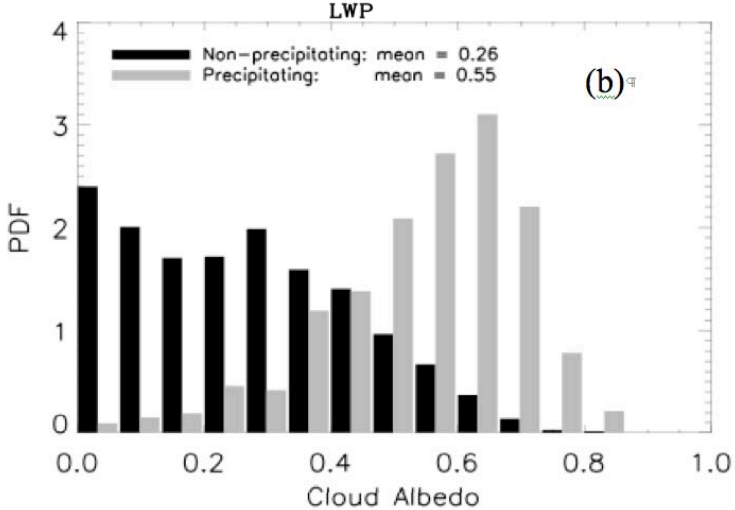


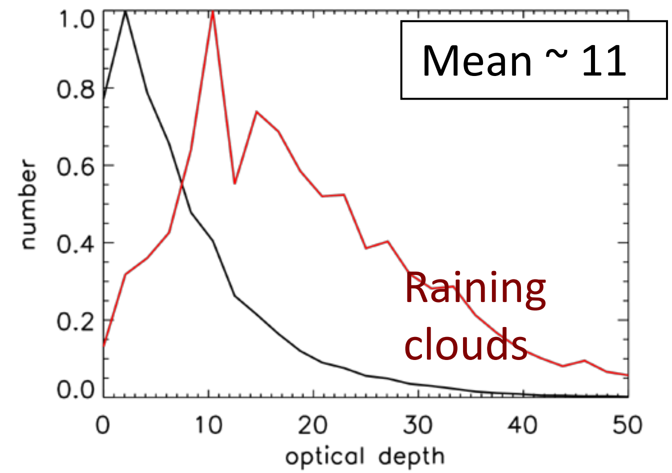












Drizzling/raining low clouds are wetter, contain larger particles are optically thicker and and reflect significantly more solar energy than non-raining low clouds

Core (Standard) & Enhanced Products

Standard Product ID	Description
Level 1 (Since June 2006)	
1A-AUX	Auxiliary data from navigation, altitude and sensing systems, raw CPR data
1B-CPR (RELEASED)	Calibrated radar reflectivities
Level 2 (Since June 2006, Except 2B-GEOPROF-LIDAR)	
2B-GEOPROF (RELEASED)	Cloud geometric profile including cloud mask (with confidence measure), radar reflectivity (significant echoes), gas absorption correction, and MODIS mask
2B-GEOPROF-LIDAR (INDEV)	Merged radar and lidar cloud masks
2B-CLDCLASS (RELEASED)	8 classes of cloud type, including likelihood of mixed phase conditions
2B-TAU (RELEASED)	Cloud optical depth by layer, also effective radius (column)
2B-CWC (RELEASED)	Cloud liquid water content (2B-LWC) Cloud ice water content (2B-IWC)
2B-FLXHR (RELEASED)	Atmospheric radiative fluxes and heating rates
Level 3 (Under Development)	
3B-zonal-mon 3B-zonal-sea	Zonally averaged distributions of cloud derived from averaging 2B products for

Standard Product ID	Description
Auxiliary Data Products (Since June 2006)	
MODIS-AUX	MODIS radiances and cloud mask subset
AN-MODIS	MODIS 1B radiances and 2B products subset to the CloudSat footprint
AN-SSF	CERES Single Satellite Footprint (SSF) product matched to CloudSat ground track
AN-State variables	Subset along track of various forecast model state variables, e.g., fluxes, etc.
Enhanced Products (Proposed)	
2B-Rain Precipitation (liquid)	Surface rain rate, profiles of liquid water content in precipitation
2B-snow Precipitation (solid)	Profiles of snow particle size distribution parameters and snowfall
2B-CC-ICE	Profiles of number concentration, particle size and ice water content
AN-PR	TRMM PR reflectivities and rainfall products matched to CloudSat reflectivity and rainfall products
AN-AMSRE	AMSR-E radiances and products matched to the CloudSat ground track
Special Products (Under Development)	
TC-CloudSat	Hurricane passes observed

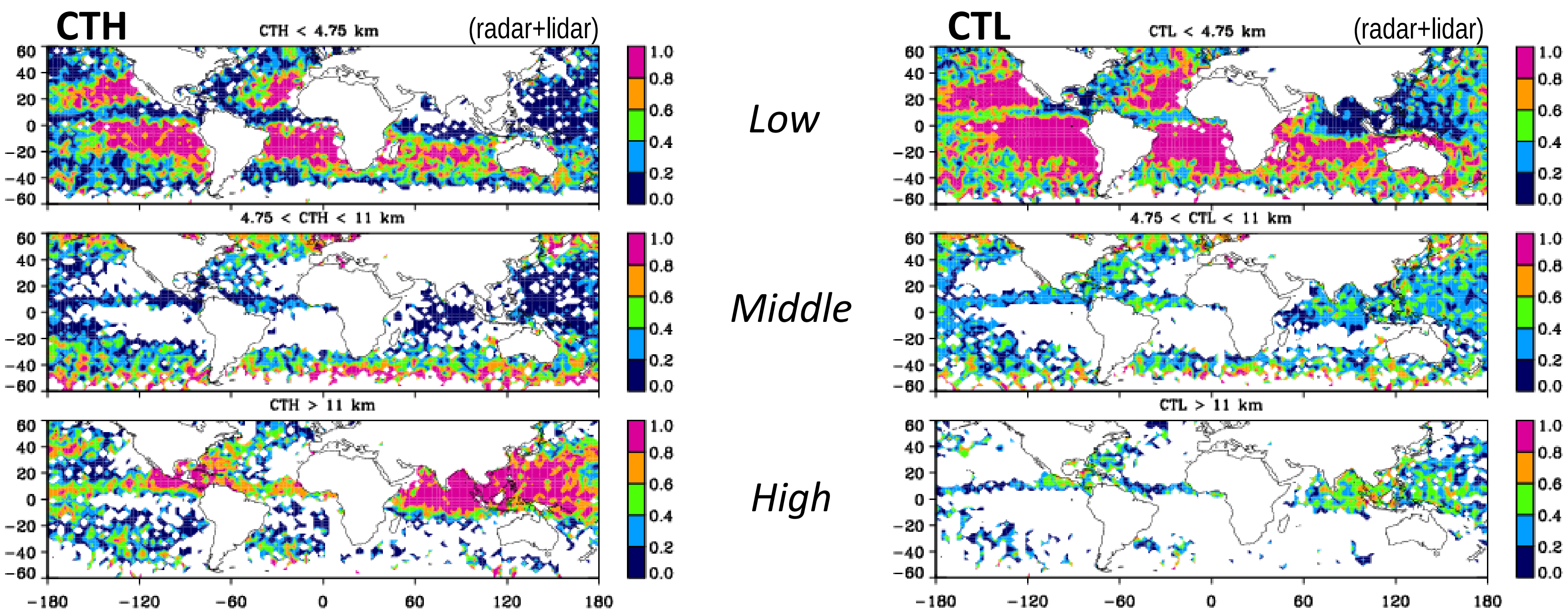
2B-flxhr-lidar under development

All 2B (non enhanced) products have been available for some time- as are the AN products

Precipitation Incidence

Precipitation Incidence by CTL/CTH, JJA 2007

Seasonal totals, 2.5° grid boxes

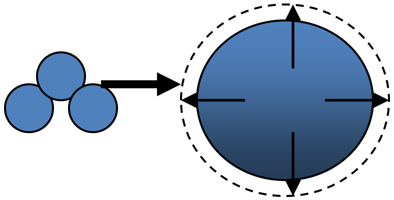


- Low cloud: Stratus regions
- Middle clouds: higher latitudes (probably an effect of a lower tropopause)
- High clouds: ITCZ, entire Indian and West Pacific basin

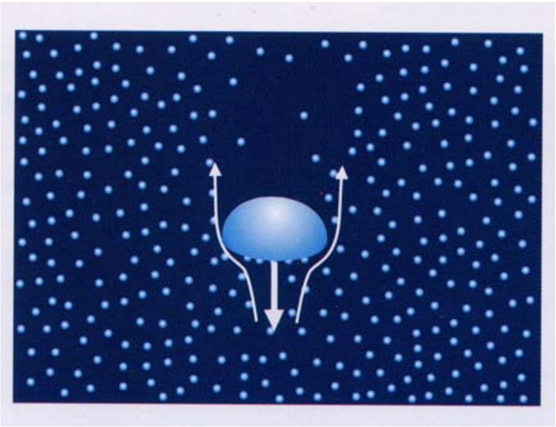
A new perspective on the same picture: low clouds dominate much of the tropics and subtropics

⇒ Differences are due to **multiple cloud layers**. Particularly in west Pacific and Indian basin, where cirrus are ubiquitous

Processes: warm rain – the transition from cloud to rain



When droplets grow by vapor deposition, the mass increases but not the number concentration



When coalescence occurs, big drops grow by collecting little drops - that is the total droplet number concentration is reduced but the total mass of water doesn't change

The differing sensitivity of the various A-Train observations to particle size, when brought together are now revealing new insights on the warm rain process

Suzuki and Stephens, 2008

Processes: The warm rain transition

The observables

Z_e: layer-mean radar reflectivity

$$R_e = \frac{3}{2}\frac{1}{\rho_w}\frac{LWP(\text{AMSR-E})}{\tau_c(\text{MODIS})}$$

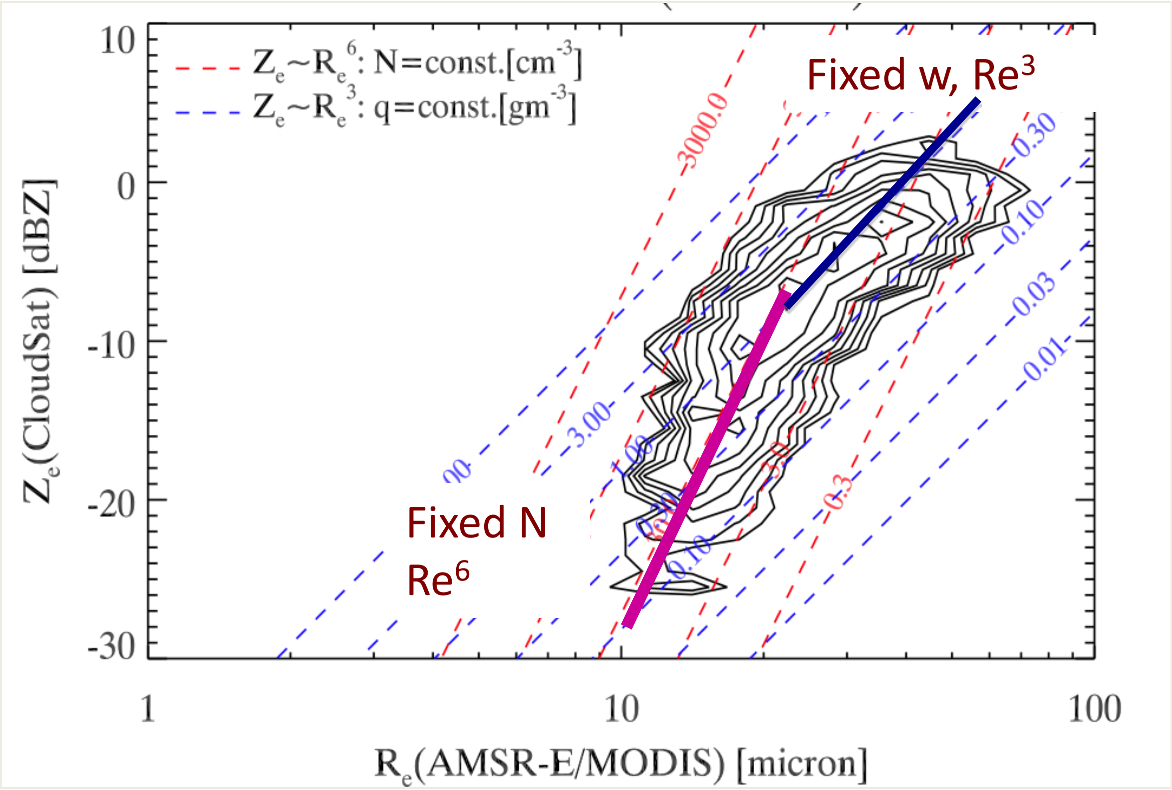
(Masunaga et al., 2002a,b; Matsui et al., 2004)

The relationships

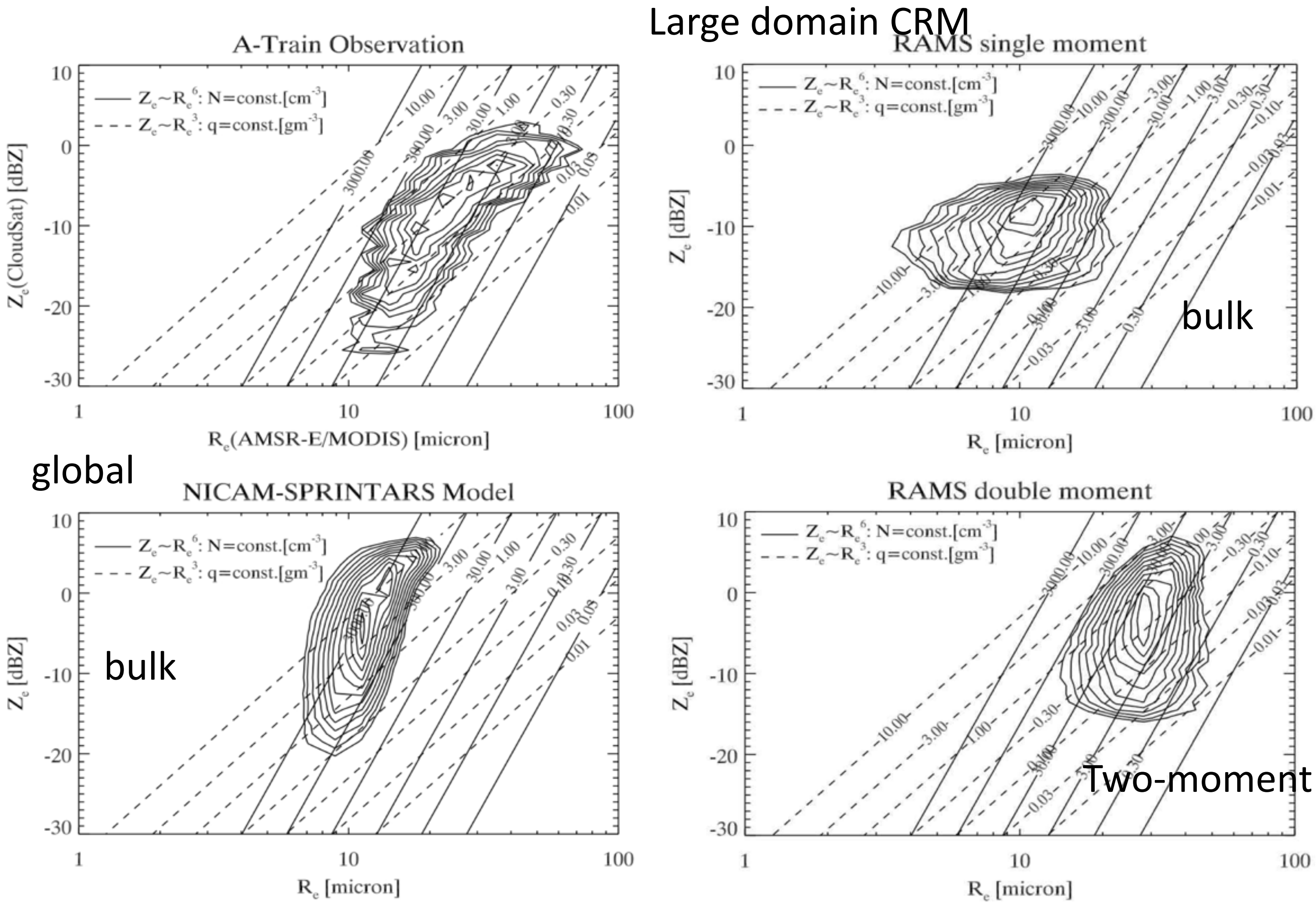
$$Z_e \approx 64 N R_e^6$$

$$Z_e \approx \frac{48}{\pi \rho_w}(w) R_e^3$$

Suzuki and Stephens, 2008



Processes: suspended rain water is almost entirely missing in models…..



Contoured Frequency by Optical Depth Diagram (CFODD) for several R21 ranges (OCEAN)

Sampled only Tau_modis>1

Nakajima, Suzuki, Stephens (2009) in progress

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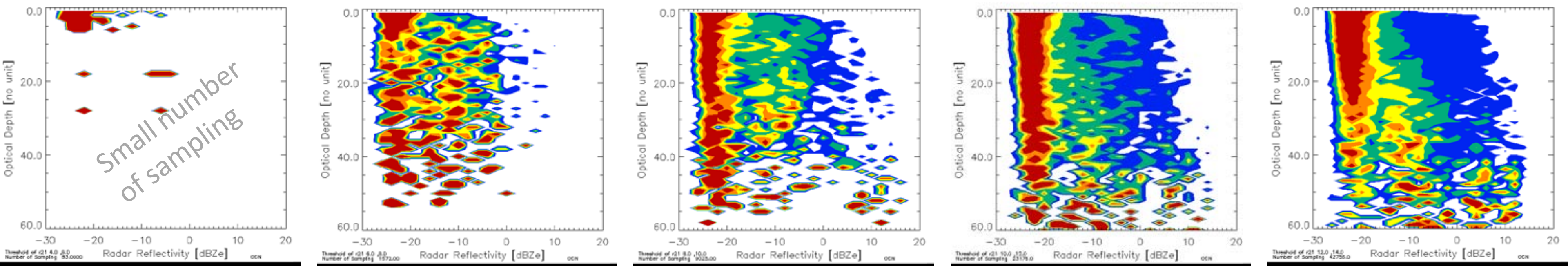

Condensation growth → R21=14μm

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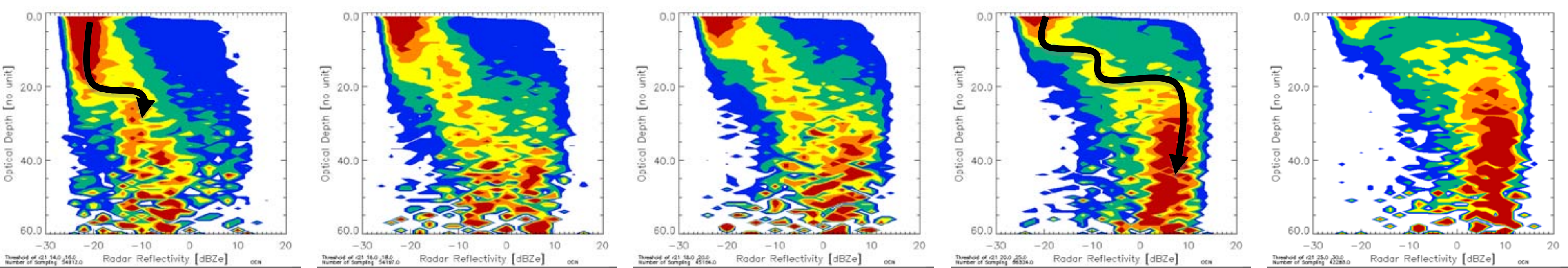

→ Drizzling → Drizzle to Rain → R21=20μm → Rain → Decay

Sampled only Tau_modis>1

Contoured Frequency by Optical Depth Diagram (CFODD) for several R21 ranges (LAND)

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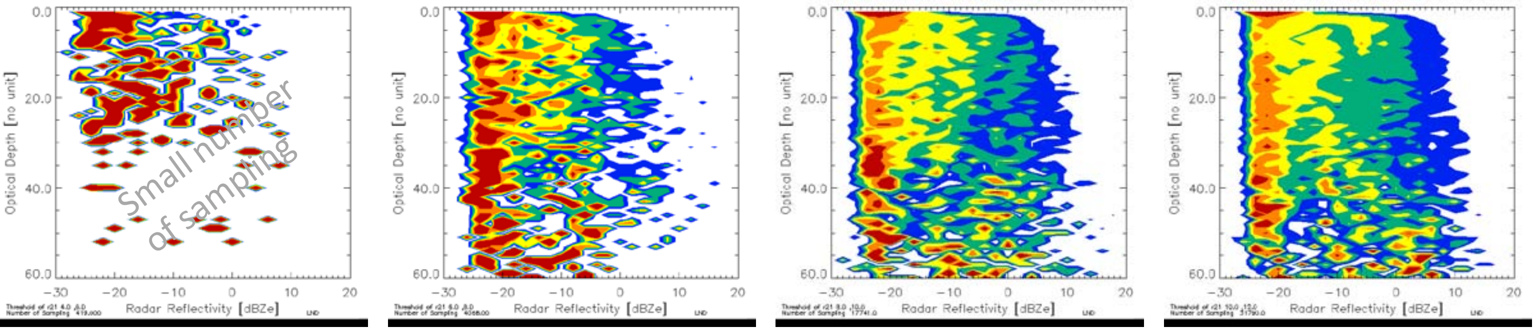

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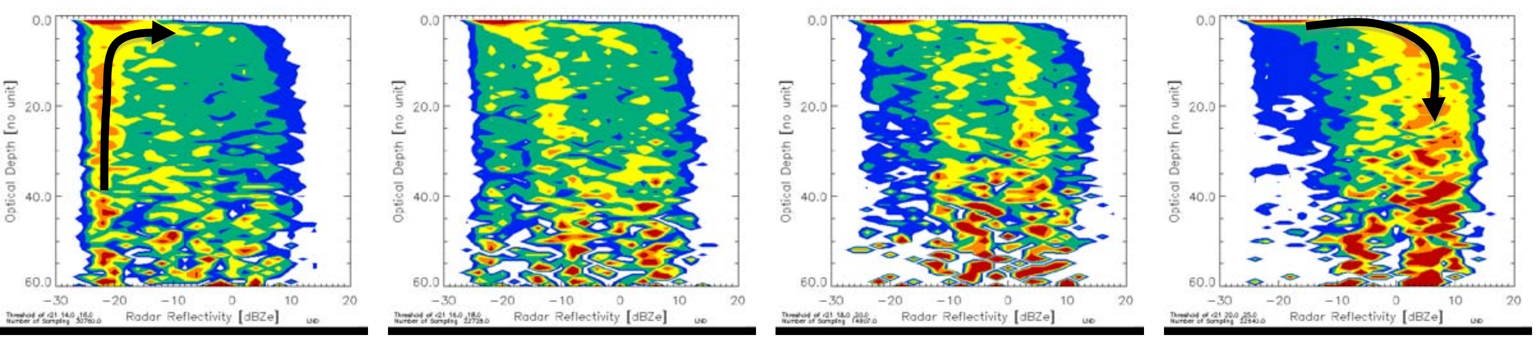
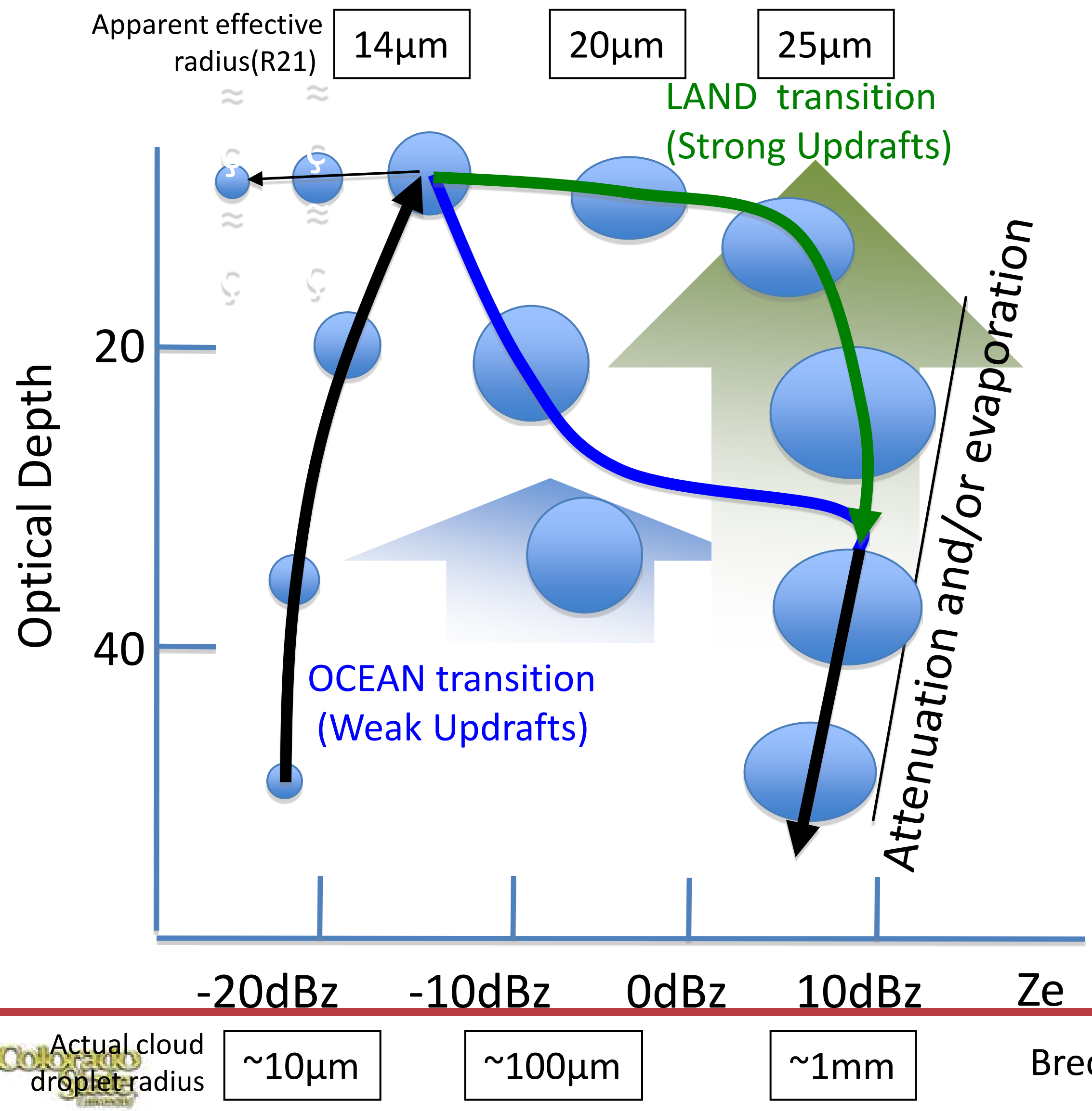


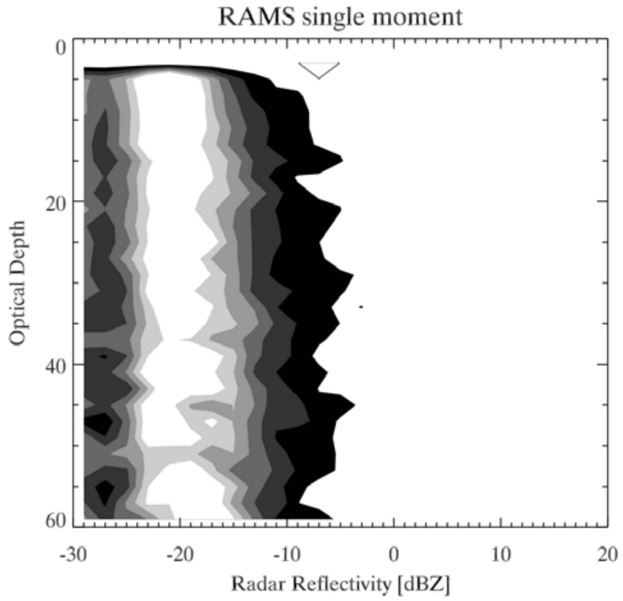
Drizzling → Drizzle to Rain → R21=20µm → Rain → Decay

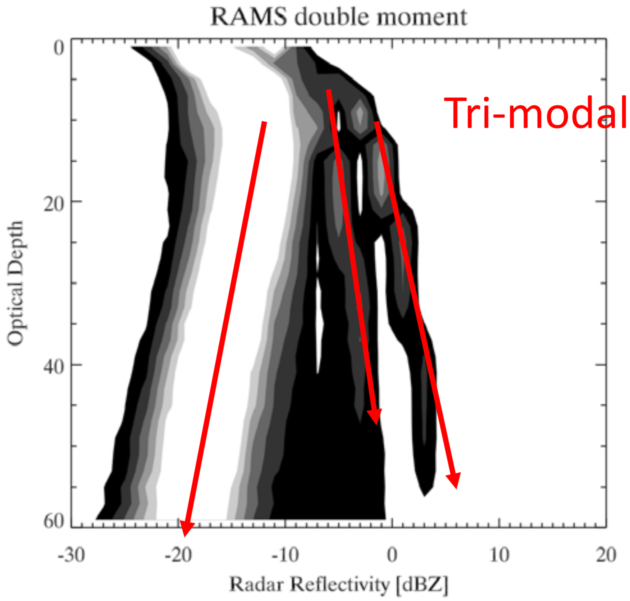
Nakajima, Suzuki, Stephens (2009)

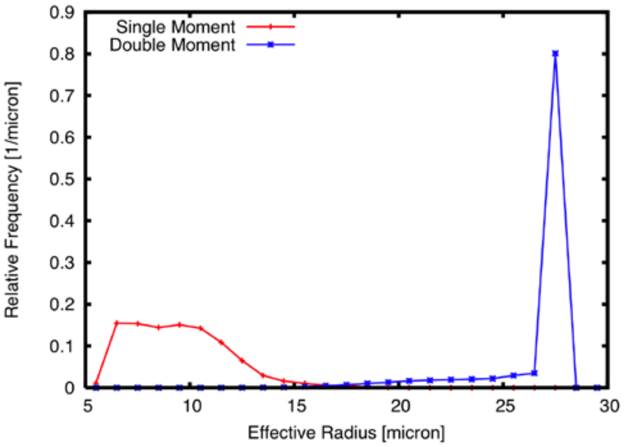
Suggested interpretation

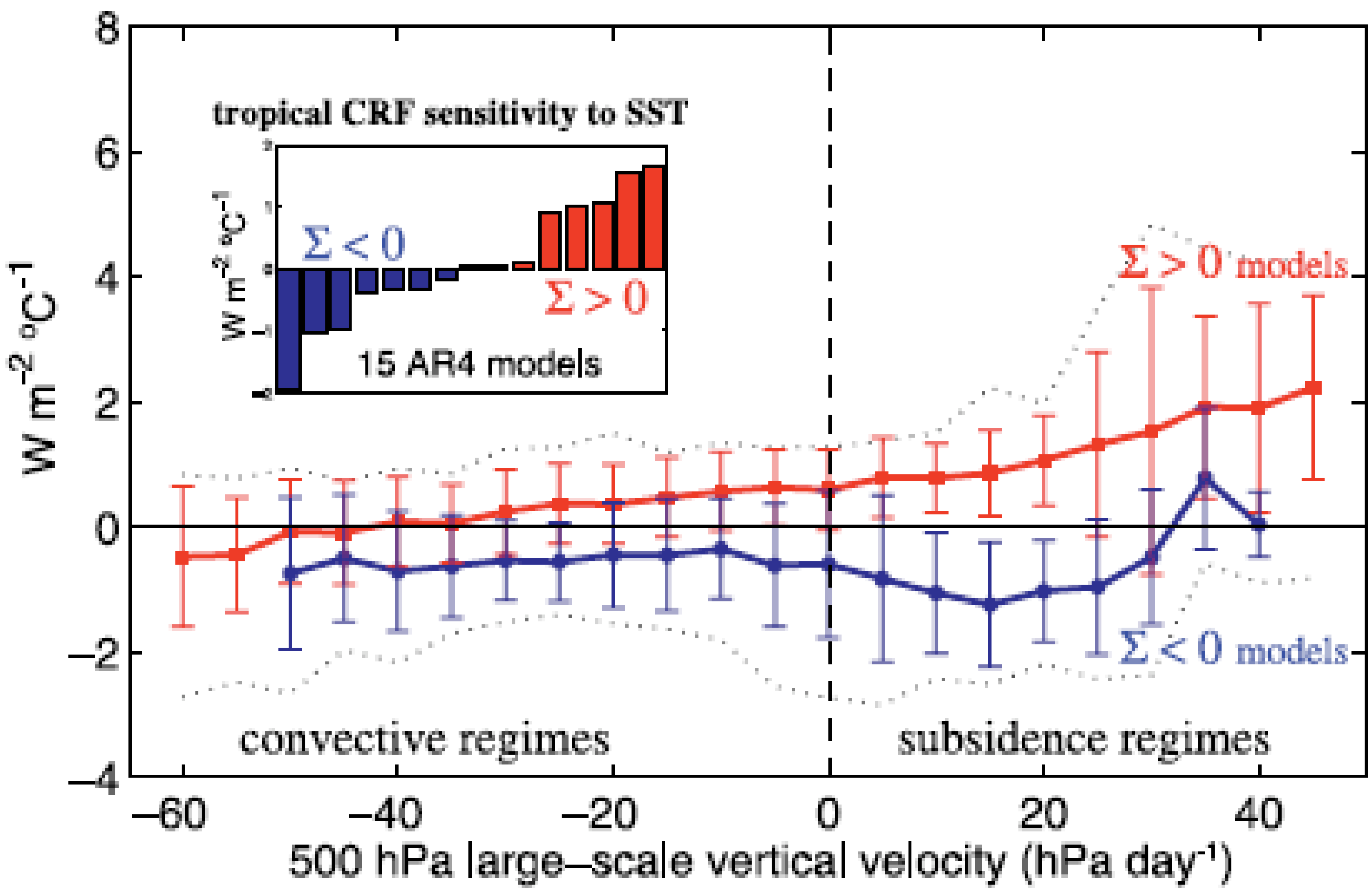


Cloud resolving model simulations



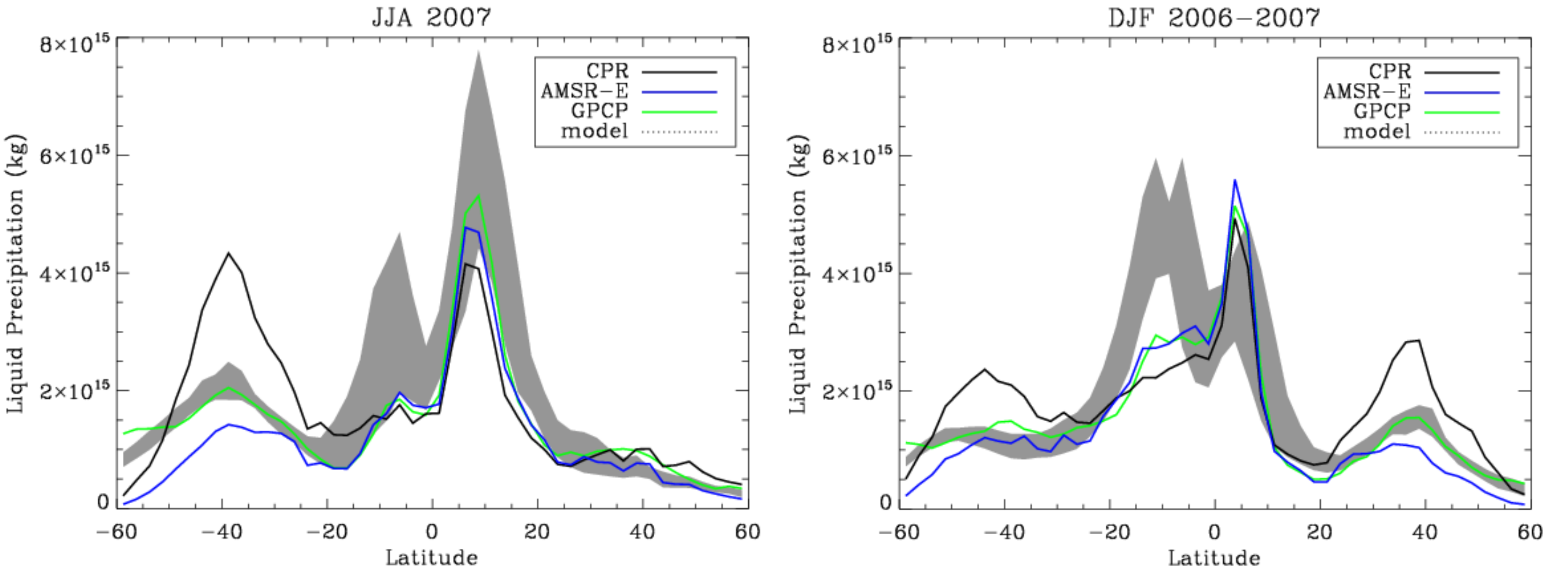






Greatest 'spread' associated with low cloud

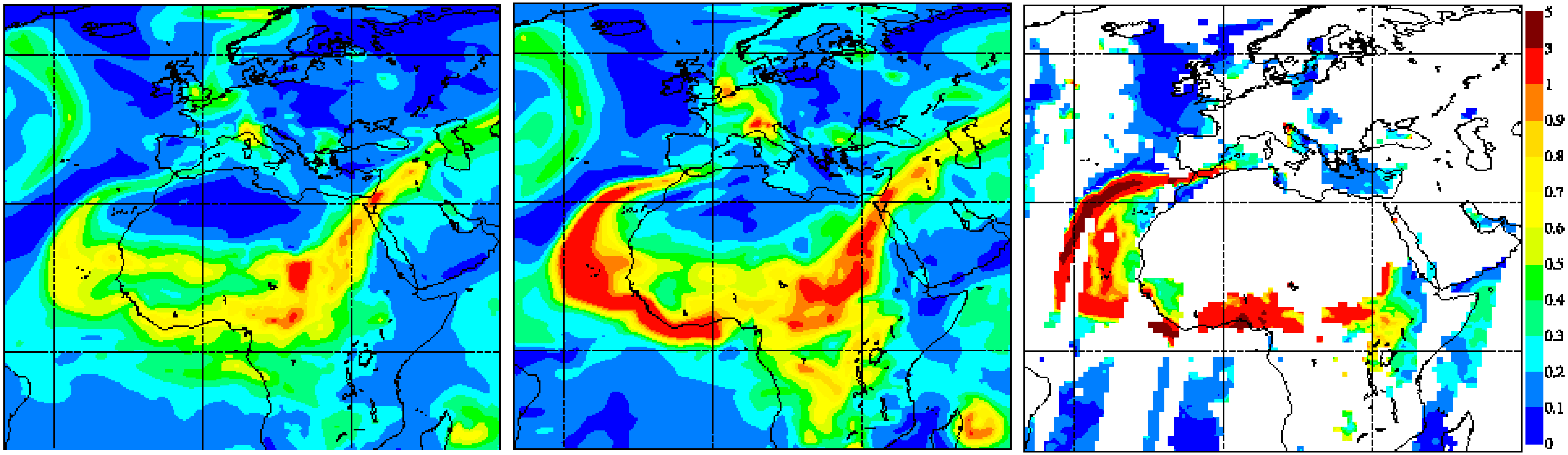
Total Seasonally Accumulated Precipitation



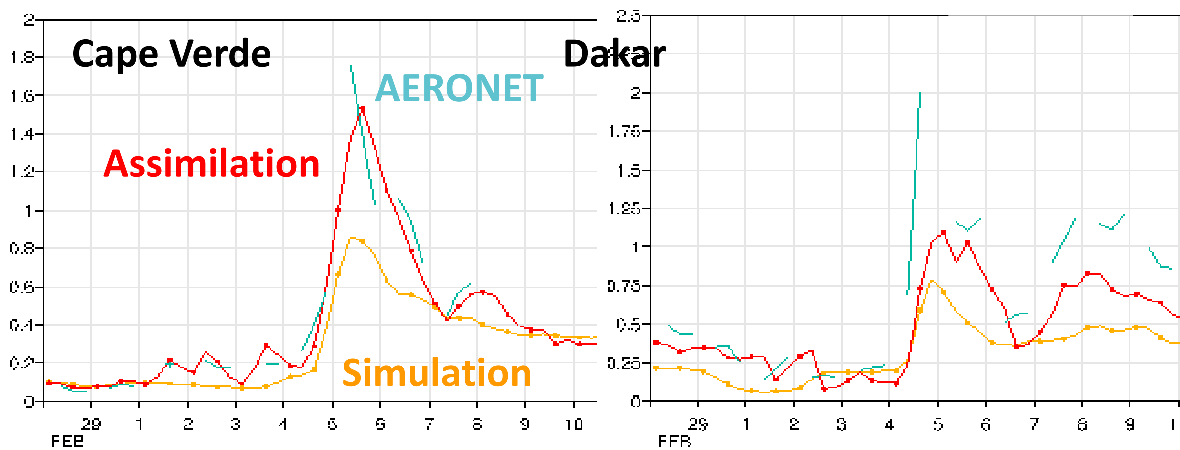
The new results suggest that it rains more (in amount as shown) and frequency(not shown) than other observations indicate or is predicted by climate models, especially in the winter season.

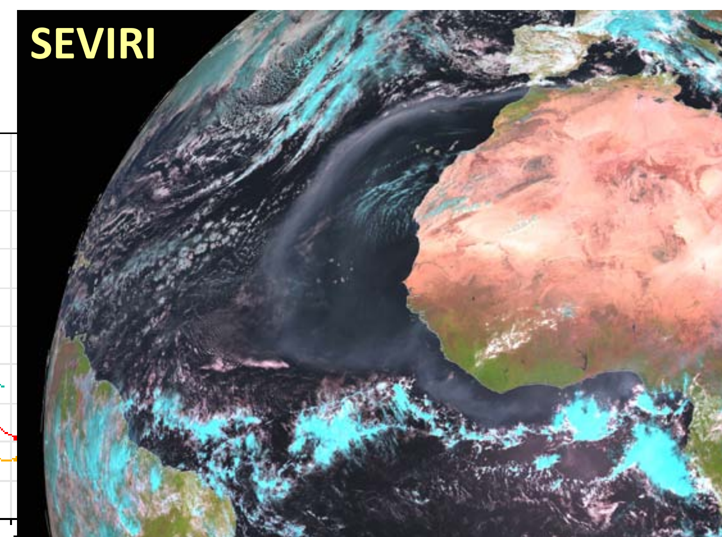
Saharan dust outbreak: 6 March 2004

Model simulation | Assimilation | MODIS



Aerosol optical depth at 550nm (upper) and 670/675nm (lower)





Morcrette et al., 2008; Benedetti et al., 2008

CALIPSO feature classification along 9670 km of
A-Train orbit between 26/06/2007 00:36:29 and 26/06/2007 01:00:01

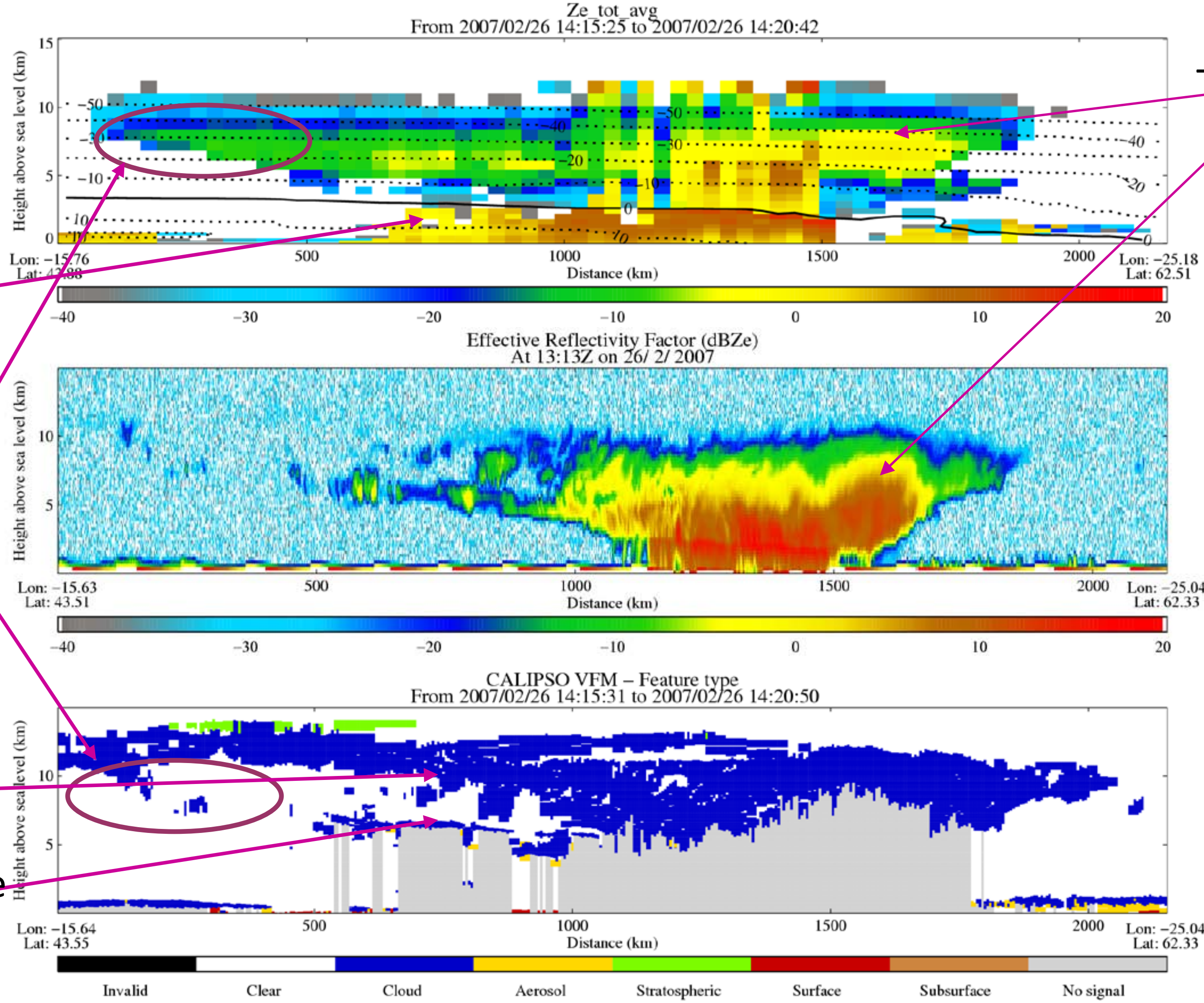
Too little IWC

Spurious Light rain

Deep evaporation zone

Multilayer

Mixed-phase



A

B

The CFMIP Observational Simulator Package (COSP)

To facilitate the exploitation of CloudSat, CALIPSO data in numerical models, we are developing a system that allows to simulate the signal that CloudSat/CALIPSO would see in a model-generated world. It is a flexible tool to simulate active instruments in models (climate, forecast, cloud-resolving). The ISCCP simulator is also included in the package.

There are several groups involved in the project:
Met Office Hadley Centre
LMD/IPSL (Laboratoire de Météorologie Dynamique/ Institut Pierre Simon Laplace)
LLNL (Lawrence Livermore National Laboratory)
CSU (Colorado State University)
UW (University of Washington)

Prime mission completed, Feb 2008

Approved for extended mission in 2007

Extended mission to 2011

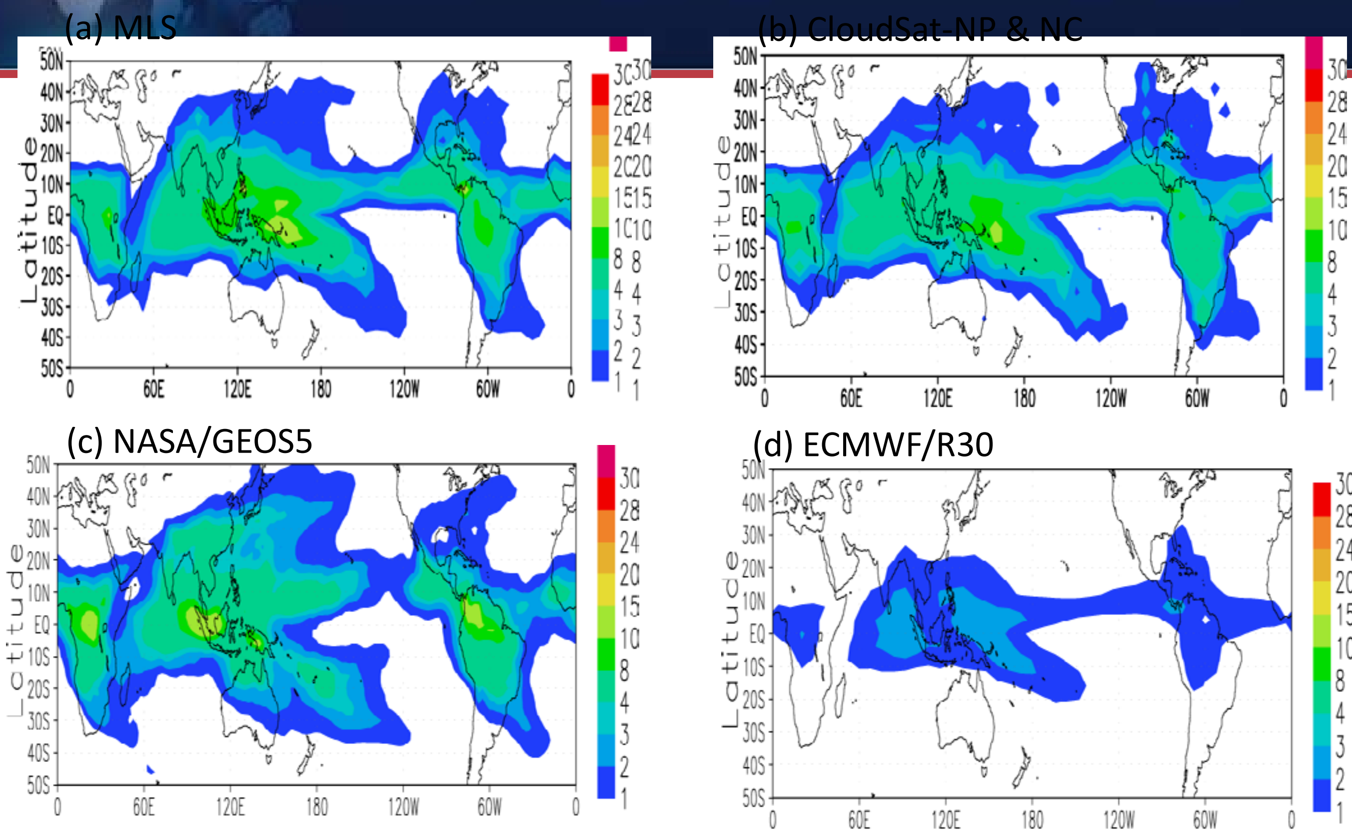
Extended mission to support 'enhanced' products

All standard product have been released

Precipitation products near release (ocean-wide attenuation based product is ready - ocean is 'easy')

Product ID	Description
1A-Aux	**Auxiliary data for navigation altitude assignments, raw CPR data**
1B-CPR	**Calibrated radar reflectivities**
2b_geoprof & 2B-geoprof-lidar	**Cloud geometric profile – includes a cloud mask (with confidence measure), reflectivity (significant echoes), (gas) attenuation correction, and MODIS mask**
2b-cldclass	**8 classes of cloud type, including likelihood of precipitation & mixed phase conditions**
2b-tau	**Cloud optical depth by layer, also effective radius (column) from matched MODIS**
2b-cwc	**Cloud liquid water content (2B-LWC),Cloud Ice water content (2B-IWC) -**
2b-flxhr	**TOA, surface and atmospheric (profile) of long and shortwave fluxes**
Ancillary and enhanced	**Various matched products including ECMWF met and other data**

Update MLS



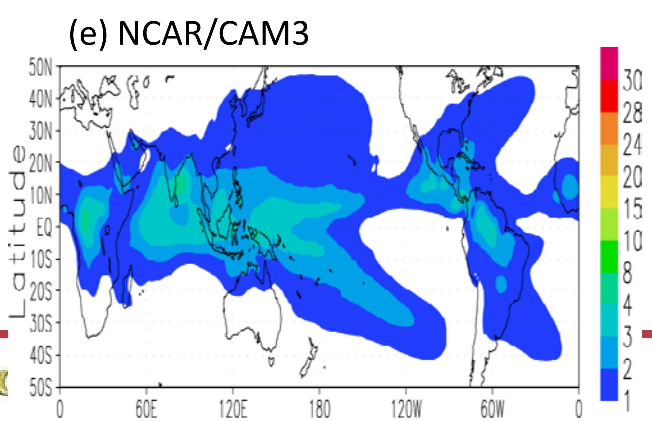


Figure 16. Mean annual IWC (mg m^{-3}) at 215 hPa for MLS (a; 2007), CloudSat values flagged as either Non-Precipitating (NP) or Non-Convective (NC) (b; 8/2006-7/2007), GEOS5 (c; 1/1999-12/2002), ECMWF analysis R30 (d; 8/2005-7/2006), and NCAR CAM3 (e; 1979-1999).

(Waliser et al, 2008, JGR)

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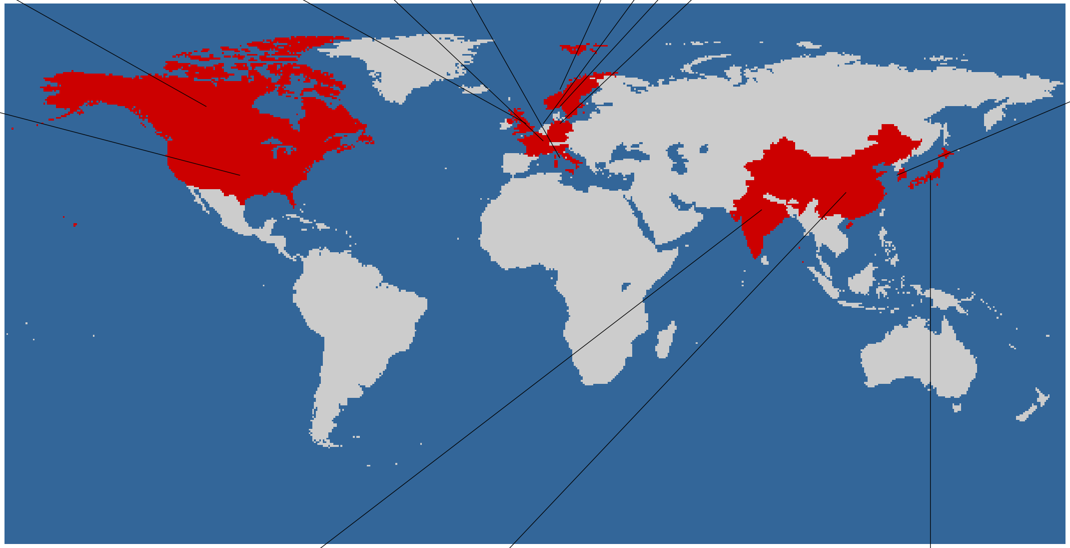

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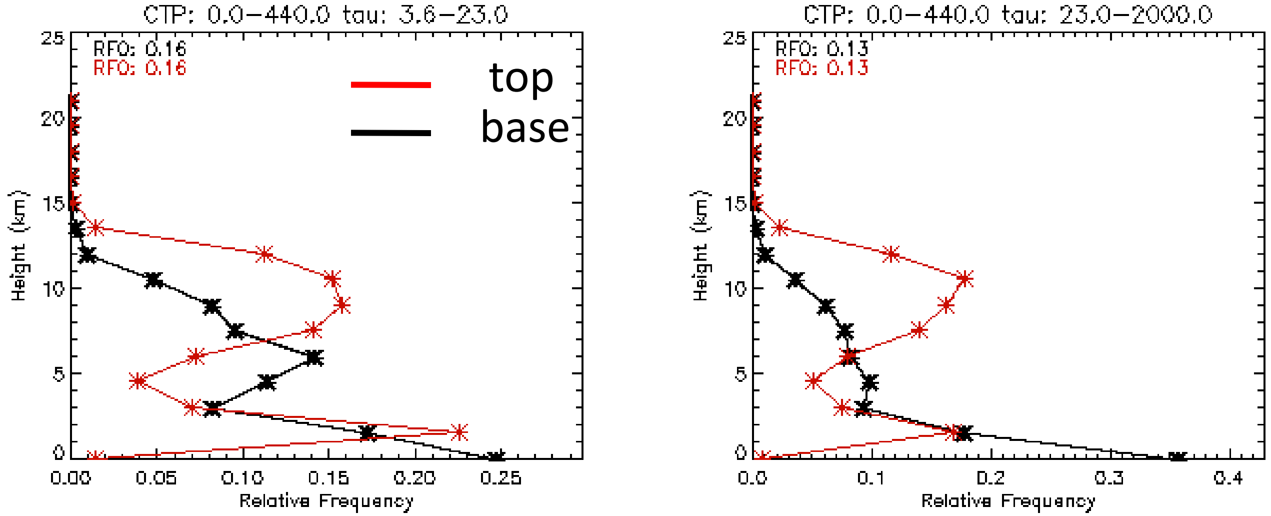
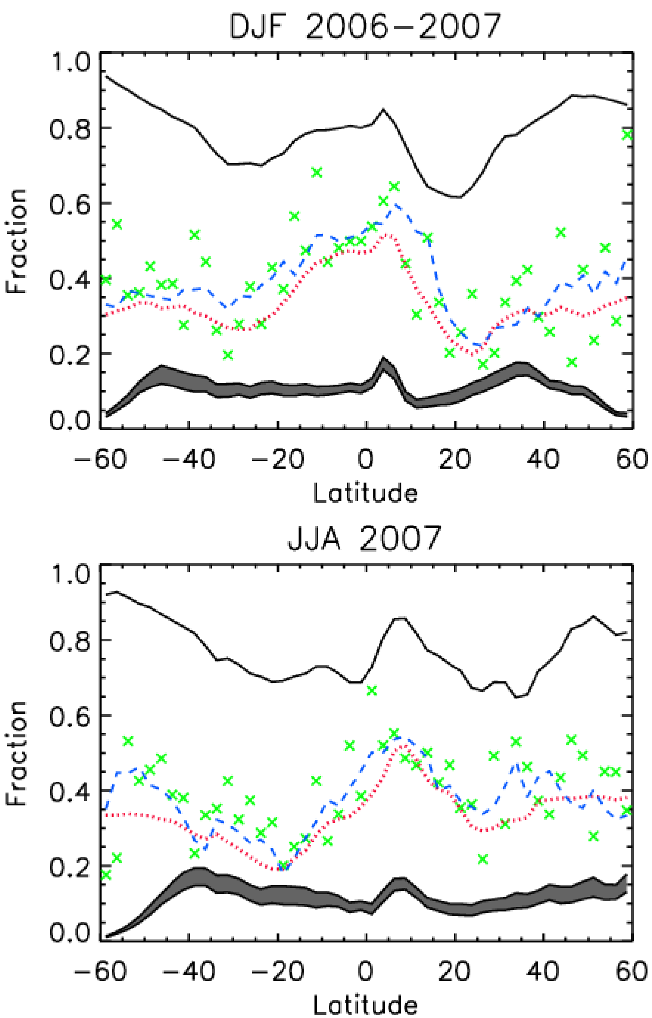
A new dimension to Earth Observation: ISCCP example



Multiple Layered Cloud Systems

How often does oceanic precipitation fall from multiple layered systems?



(—) … cloudy scenes
(......) … cloudy scenes that are multi-layer
(- -) … precipitating scenes that are multi-layer
(x) … CloudSat accumulation from multi-layers
( ) … cloudy scenes with precipitation

- Area weighted precipitating cloud fraction about 0.10 for both seasons
- Multi-layer cloud systems are most prevalent in the tropics (dominated by cirrus) —> 50% of rain occurrence is from these systems
- Between 40 and 60% of the total CPR accumulated water in the tropics falls from these cloud systems (*)
- Multi-layer systems are less frequent, and with less fractional contribution to rain accumulation, in higher latitudes (cirrus are less common)