Global Precipitation

Graeme Stephens with the acknowledgement of many

Topics for discussion

Global Precipitation

- Water vapor feedback
- Precipitation & Clausius-Clapeyron
- Energy controls & expectations

New oceanic precipitation observations

- Satellite Observational capabilities/limitations
- CloudSat
- New observational resources fro studying of oceanic precipitation and surface energy balance

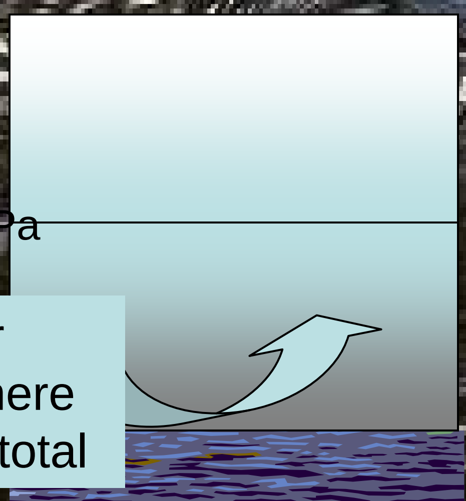
Greenhouse induced warming

Increased water vapor

Increased greenhouse effect

Increased warming

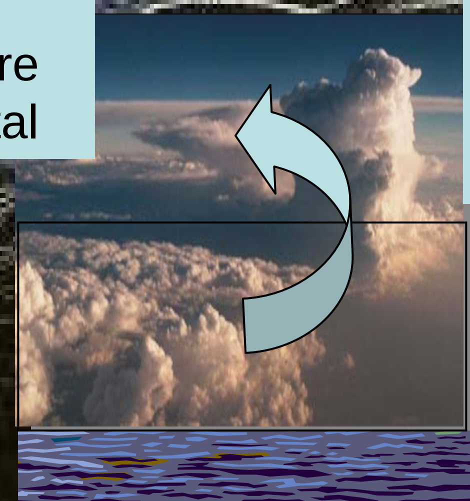
Two (related) modes to this feedback



lower troposphere ~95% of total

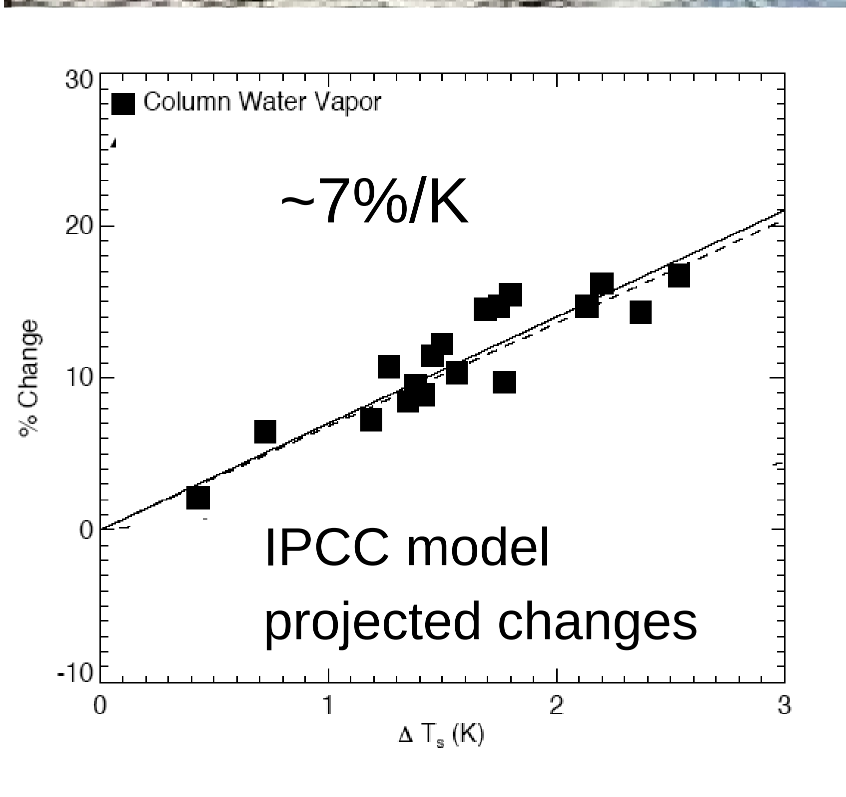
Obs ~7%/K (1988-2005) FAR models ~ 7%/K

upper troposphere ~5% of total

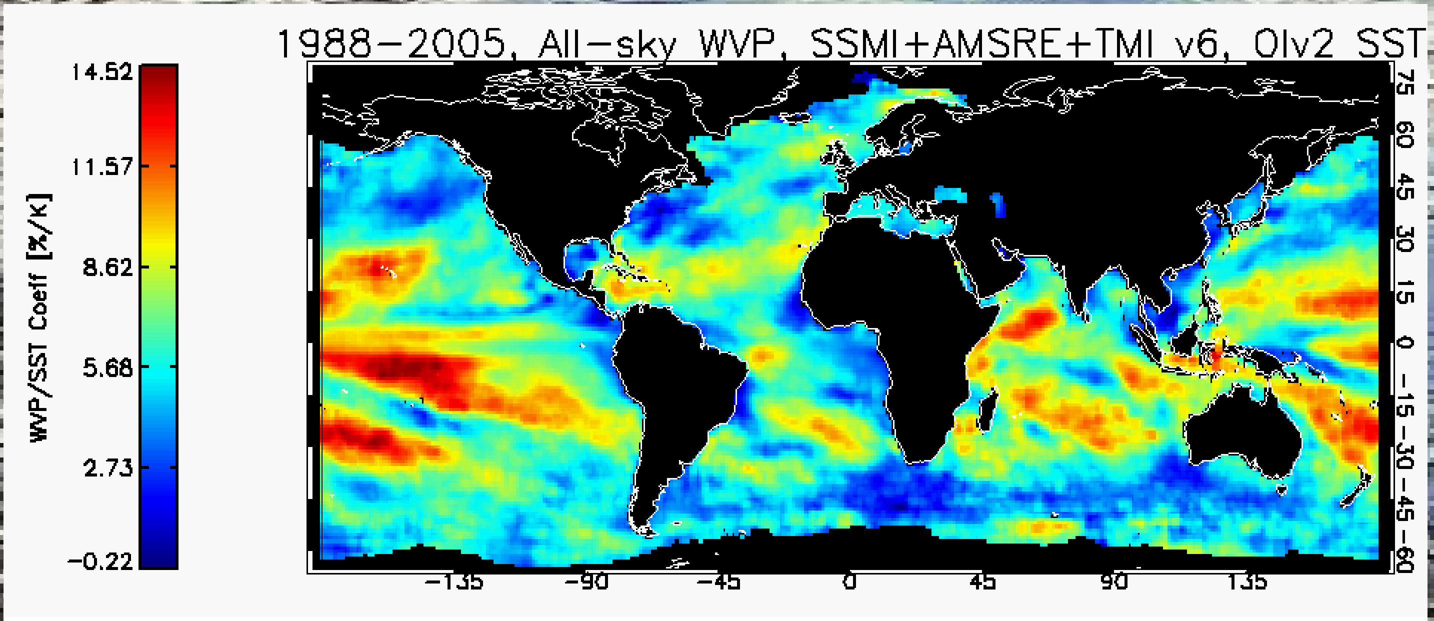


Obs~ increase FAR model > 10 %/K

Water vapor feedback



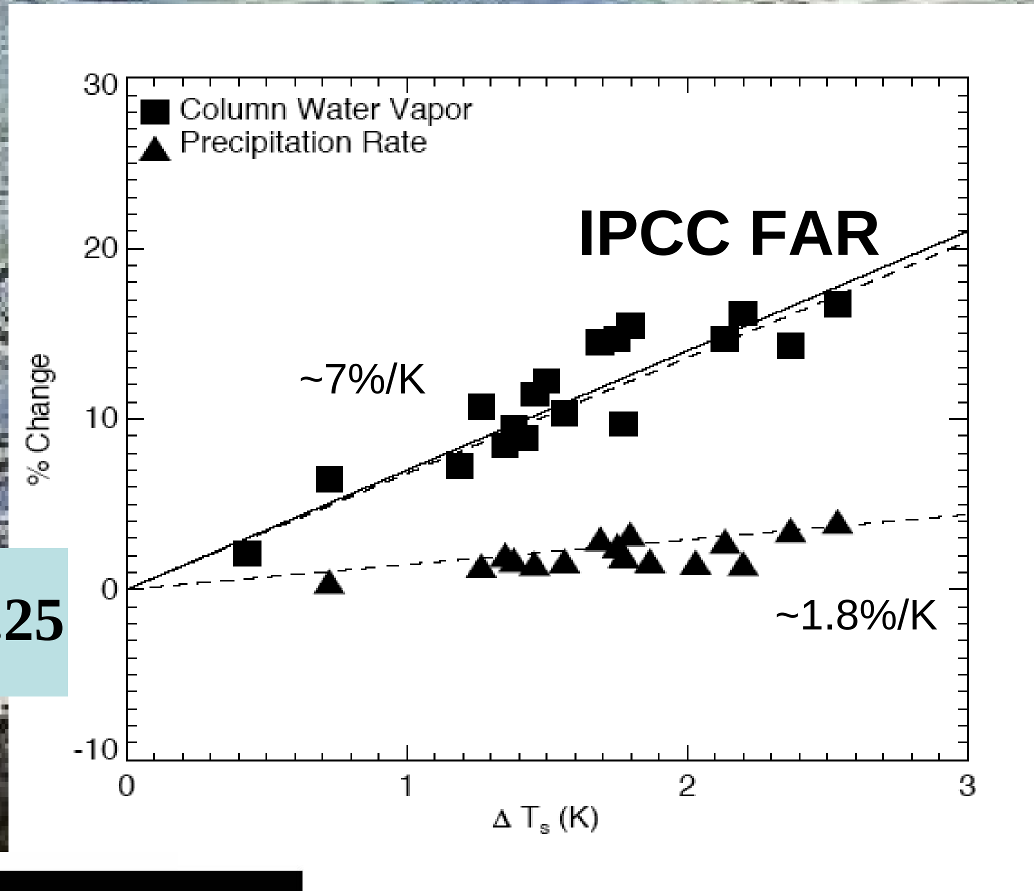
Water vapor feedback



Our satellite observations of water vapor collected over the world’s oceans since 1988 show similar rates of increase ~ 6.6 %/K

The estimated change on BOA LW flux associated with this change in water vapor ~ 0.5W/m2/decade

Precip and Clausius Clapeyron



'efficiency' $\varepsilon \sim \frac{0.018}{0.07} \sim 0.25$

Sciencexpress Report

How Much More Rain Will Global Warming Bring?

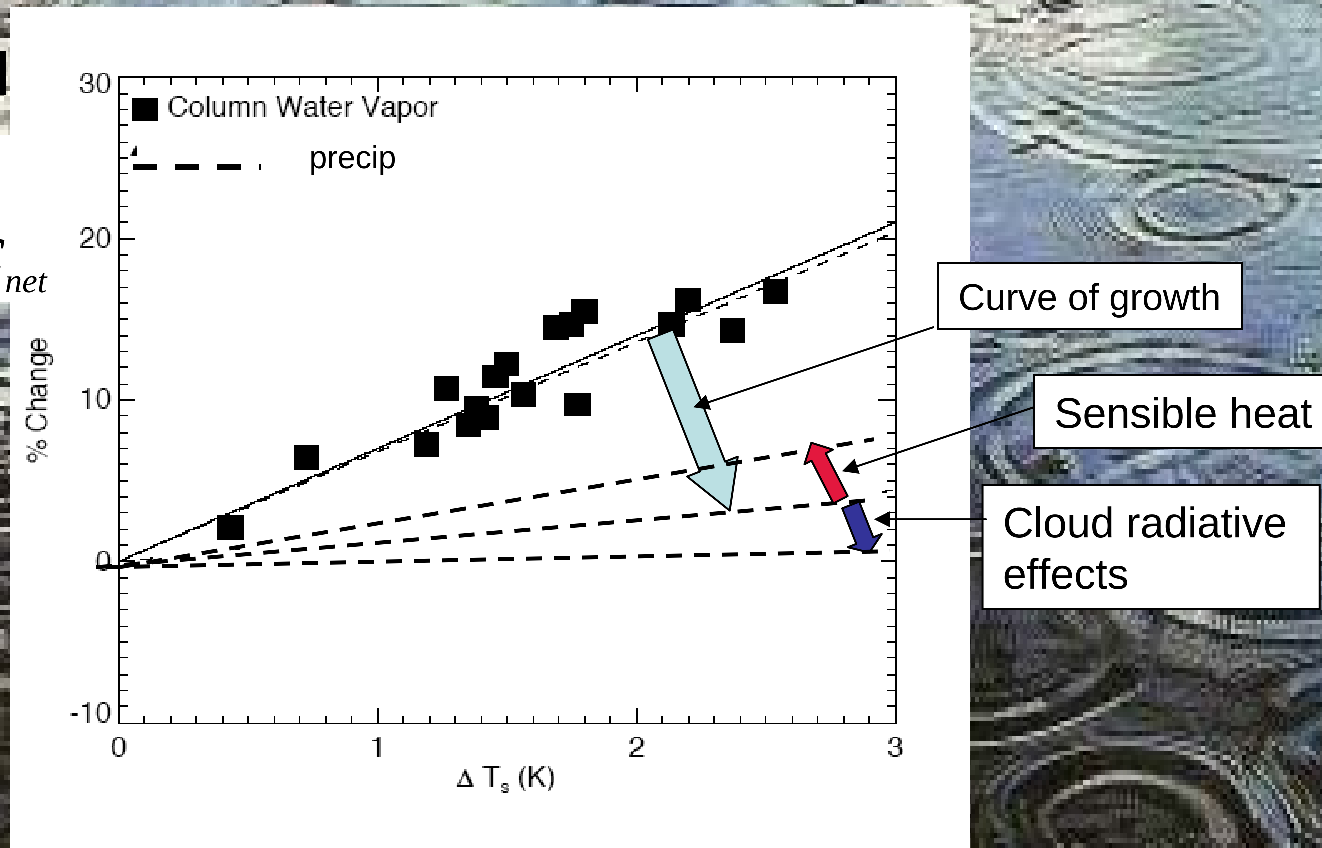
Frank J. Wentz,* Lucrezia Ricciardulli, Kyle Hilburn, Carl Mea

Simple expectations of water availability imply that the efficiency ~1 but energetics dictates otherwise (efficiency < 1)

Energy controls

$$\Delta R_{net,atm} = L\Delta P + \Delta S$$

$$\Delta R_{net,atm} = \Delta R_{net,clr} - \Delta C_{net}$$

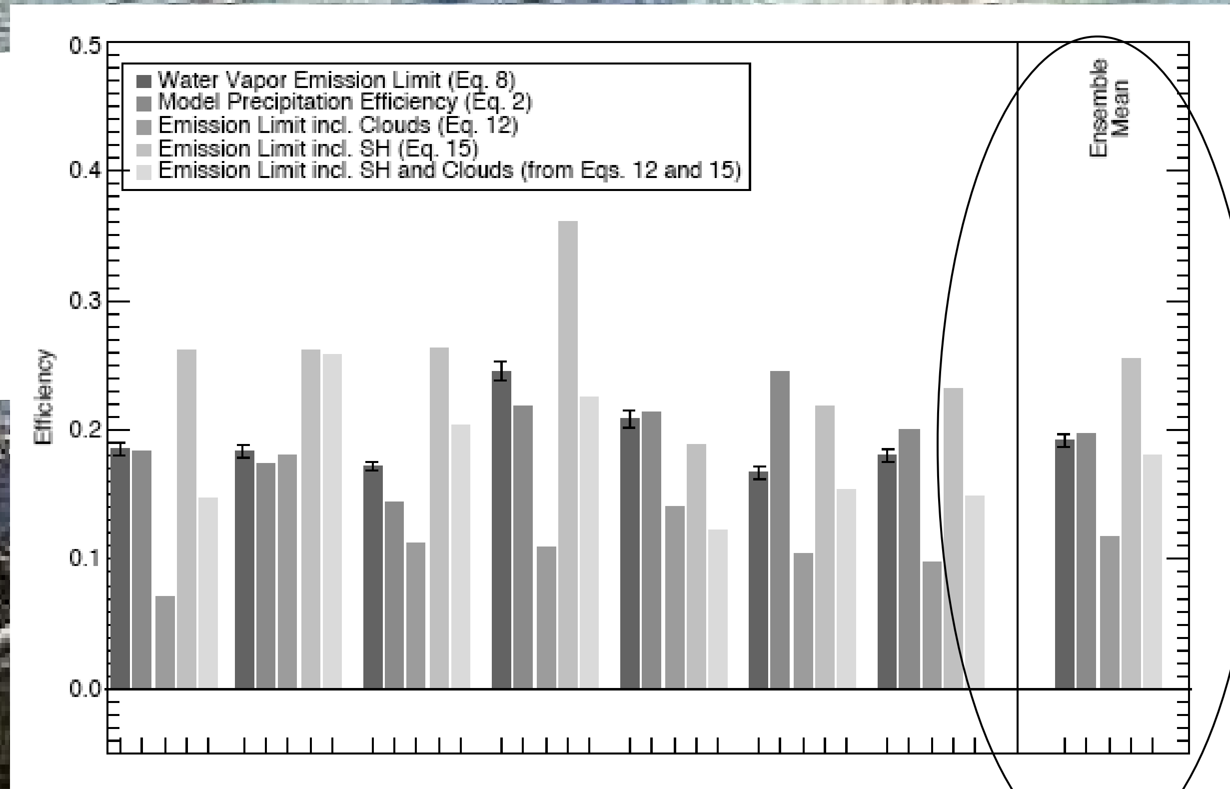


Cloud - radiative processes, sensible heating changes tug at the magnitude of the global change of precipitation set by the water vapor feedback

$$\epsilon_{wv} = b\left[1 - \frac{c_o}{R_{net,clr}}\right]$$

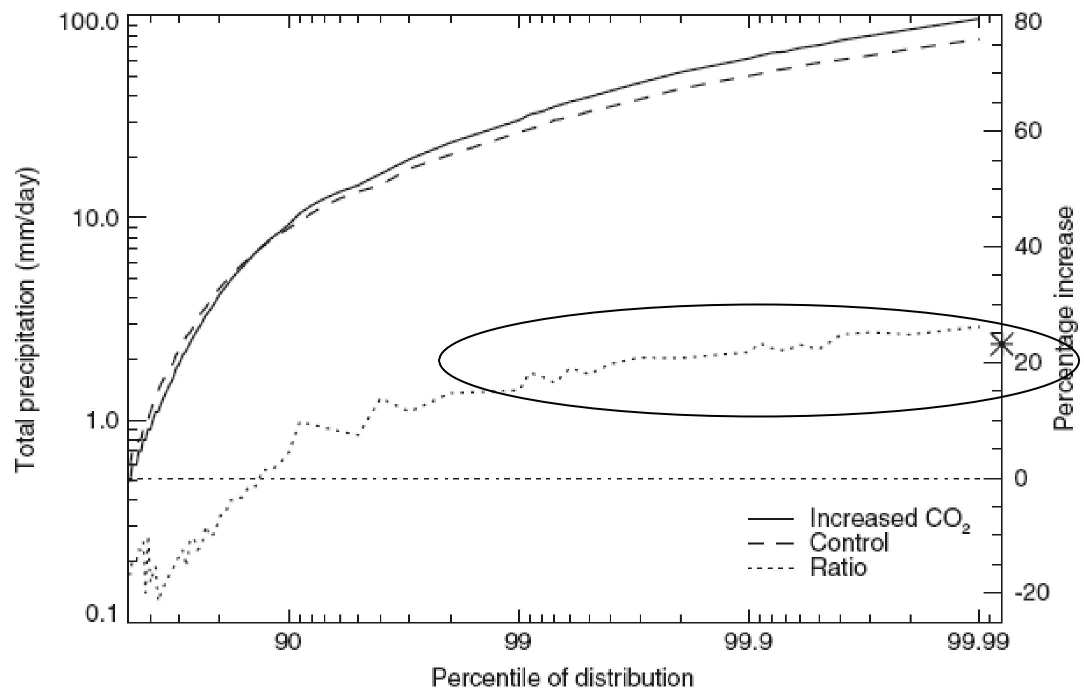
$$\epsilon_{\Delta C} \approx b\left[1 - \frac{c_o}{R_{net,clr}}\right] - \frac{\Delta C_{net}}{\Delta W}\frac{W}{LP}$$

$$\epsilon_{\Delta S} \approx b\left[1 - \frac{c_o}{R_{net,clr}}\right] - \frac{\Delta S}{\Delta W}\frac{W}{LP}$$



Stephens & Ellis, 2008

On the global mean scale, I believe gross precipitation changes are largely predictable based on predictable changes to the atmospheric energy balance - of the relevant contributions, the cloud heating term (sign,magnitude) is perhaps most uncertain



~ 7%/K

Fig. 1 After Allen and Ingram (2002), Fig. 4. Log–log plot of the change in distribution of global (all gridpoints and seasons) daily precipitation at years 2070–2100 of a transient HadCM3 climate change simulation. The *solid curve* shows the distribution in the transient simulation, where CO_2 levels have increased by a factor of approximately 2.7. The *dashed curve* shows the corresponding control simulation. Their ratio is shown by the *dotted curve* and right-hand (linear) axis. The global-mean warming is 3.6 K and the tropical-mean is 3.3 K, giving a Clausius–Clapeyron predicted limit on this ratio of about 23% as shown by the starred point. Note that Allen and Ingram (2002) *incorrectly*: stated this period as being around the time of CO_2 doubling; found a 22% Clausius–Clapeyron predicted limit; labelled the left-hand axis as 'Intensity')

Observational Challenges

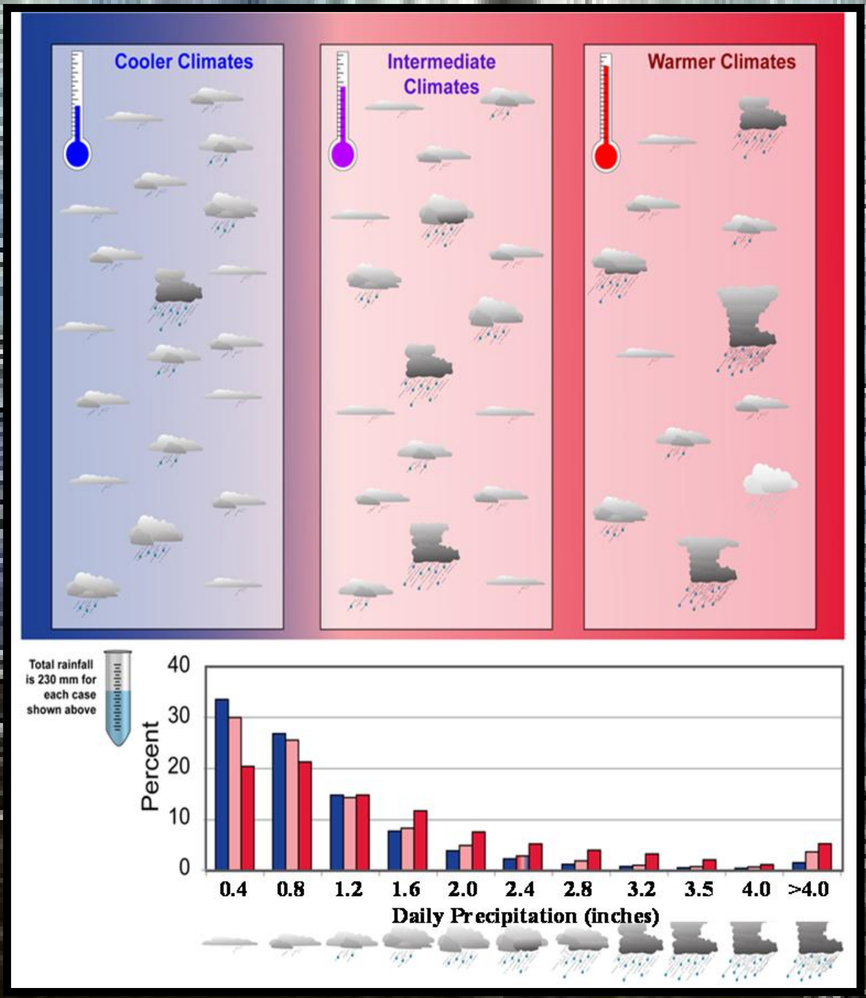
A more homogenous (land/ocean) data resource

Snowfall

Changes to rainfall pdf

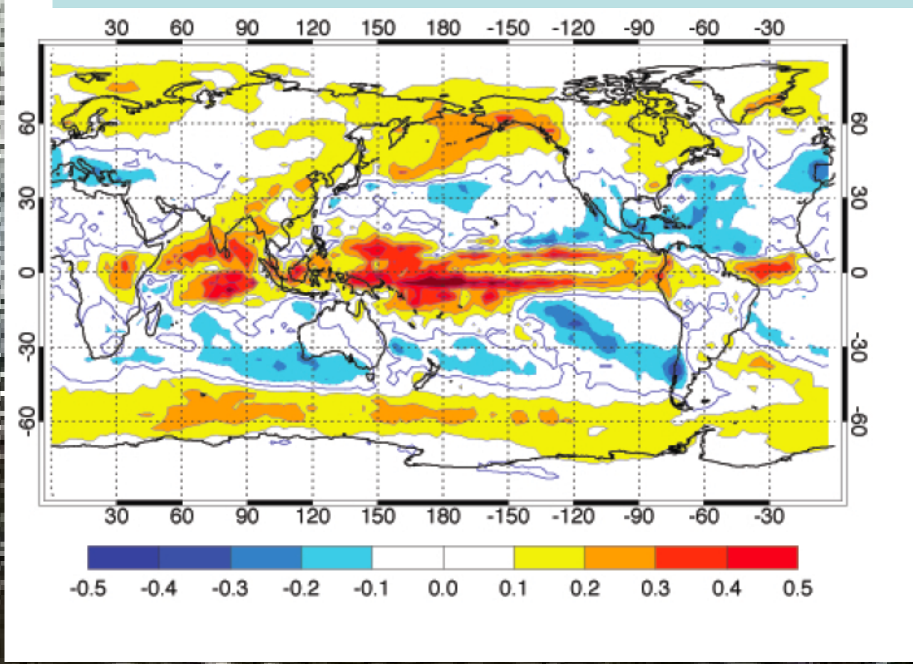
Aerosol and pollution

Continue the observing philosophy



Regional changes

Difference maps - years 60-70 minus years 1-10



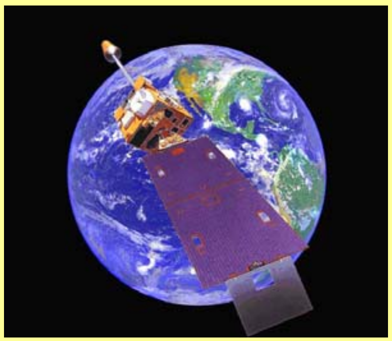
Model projections suggest that the haves receive more and the have-nots less - biggest changes over oceans

Change in precip (mm/day)

Rainfall Detection from Space

Clouds only	Clouds or rain	Rain only

INFRARED

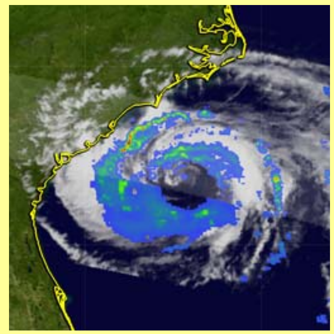


• Uses IR channel of the GOES satellites

• Counts pixels colder than a given brightness temperature threshold and associates with rain rate

• Associates cold cloud with raining clouds

PASSIVE MICROWAVE

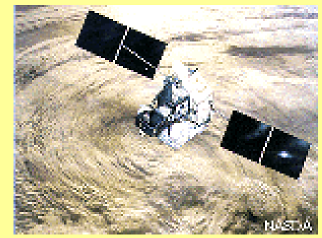


• TRMM Microwave Imager (TMI); AMSR-E

• Goddard Profiling Algorithm (GPROF, Kummerow et al., 1996)

• Based on tropical cloud resolving model database; state-of-the-art in tropics

RADAR



• TRMM Precipitation Radar (PR)

• Uses Z-R relations, corrected for attenuation, to derive rain rate

• Scanning instrument, profiles of precipitation rate

For general review, Stephens and Kummerow, 2007

Infrared: An indirect method of assessing precipitation presence; high cold cloud does not necessarily mean deep, precipitating clouds.

• Passive microwave: Relatively large field of view, rain detection problems (Berg et al., 2008), deteriorates outside the tropics, land methods are problematic

• Radar: The TRMM PR has a minimum detectable signal of 17 dBZ, and misses light precipitation and most snowfall. TRMM coverage only to ~ 37N/S

•None ‘detects’ or measures the predominant modes of snow

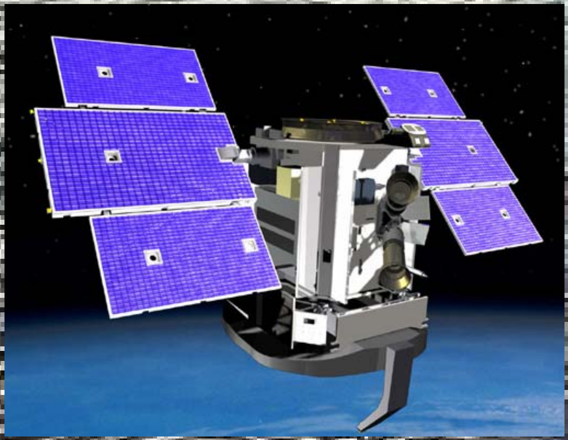
Haynes et al., 2008

CloudSat and the A-Train

CloudSat / Cloud Profiling Radar

- 82.5° orbital inclination
- 705 km above MSL
- ~1 AM/PM equator crossing time
- 16 day repeat cycle

- 94 GHz near-nadir radar system
- 240 m vertical resolution (oversampled)
- 1.4 × 1.7 km footprint
- 0.16 s integration time
- –30 dBZ minimum detectable signal



The Afternoon A-Train

- Five (soon to be six) satellite flying in formation
- Near-simultaneous observations, but all at different resolutions

For more info, see Stephens et al., 2002

What CloudSat adds

•CloudSat is a very sensitive precipitation detector because it has a small minimum detectable signal (–30 dBZ) and sensitive to the incipient stages of precipitation formation.

•CloudSat detects snow

• CloudSat has a smaller footprint than the passive microwave (O~1km, closer to the intrinsic scale of the processes of relevance) , so the information is not artificially smeared (as much)

• The CloudSat radar is an active sensor that profiles cloud boundaries simultaneously with the detection of precipitation making links to clouds more direct and thus ties to processes more apparent

• Observations extends into the middle and high latitudes

Haynes et al., 2008

Status of CloudSat

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

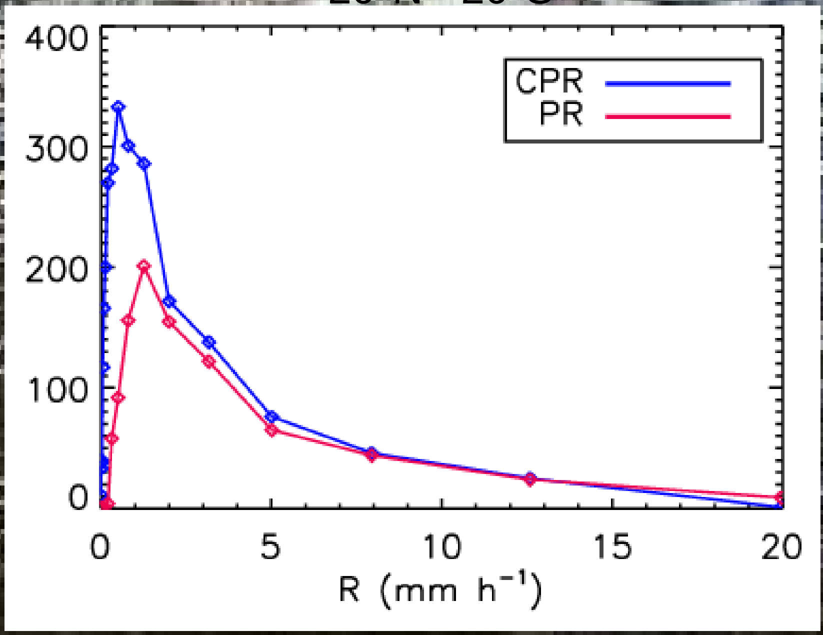
Precipitation products near release (ocean-wide attenuation based product is ready - ocean is 'easy')

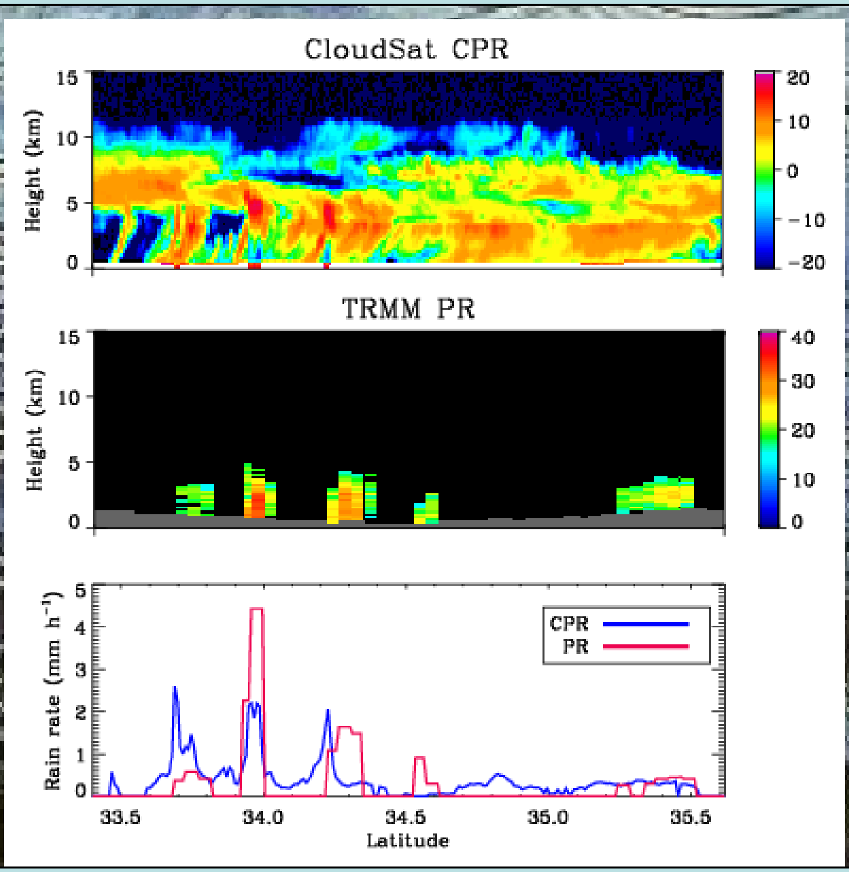
Enhanced Products (Proposed)	
2B-rain Precipitation (liquid)	Surface rainrate, profiles of liquid water content in precipitation
2B-snow Precipitation (solid)	Profiles of snow particle size distribution parameters and snowfall rate
2B-CC-ICE	Profiles of number concentration, particle size and ice water content
AN-PR	TRMM PR reflectivities and rainfall products matched to CloudSat reflectivity and rainfall products
AN-AMSRE	AMSR radiances and products matched to CloudSat ground track

Direct matchups with TRMM PR/TMI to about 35° latitude ~2 orbital crossovers per day, 1.5+ years of observations. These data (AN-PR) will soon be available at the CloudSat DPC

Matchup - within 5 min, 5 km

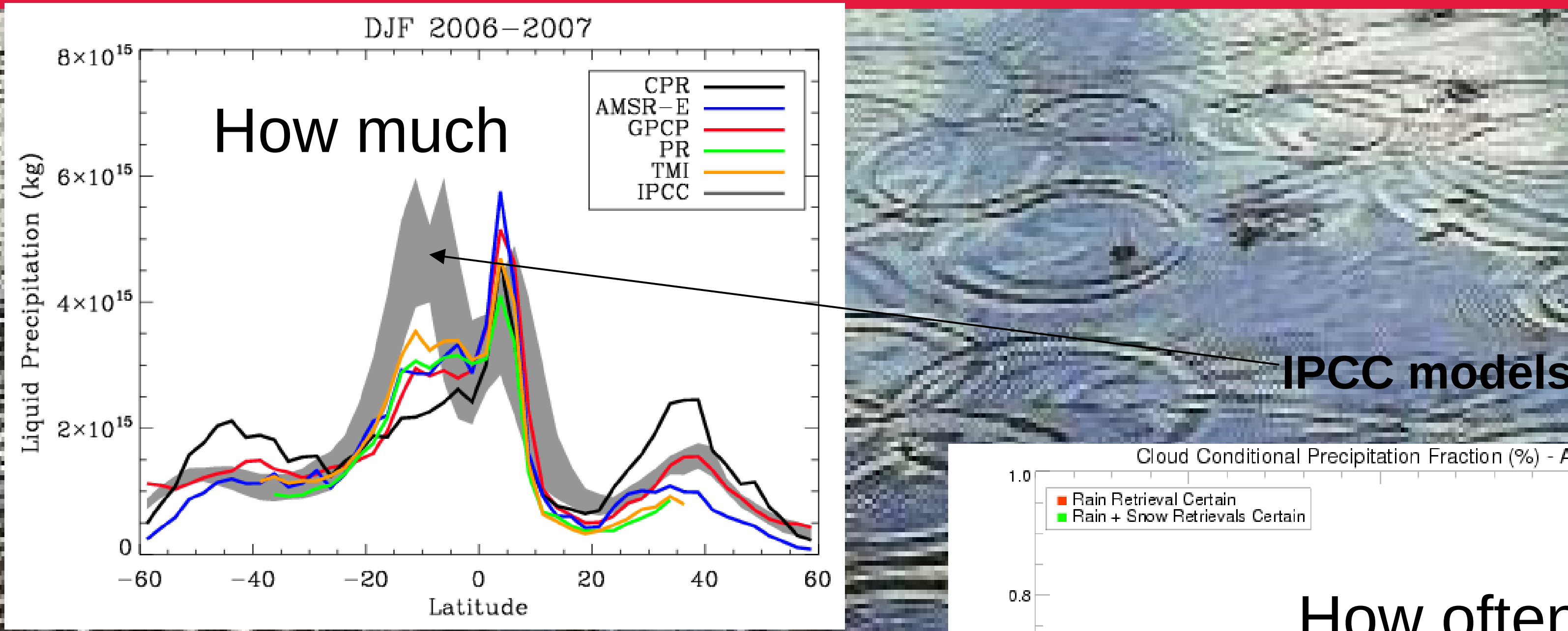
20°N - 20°S



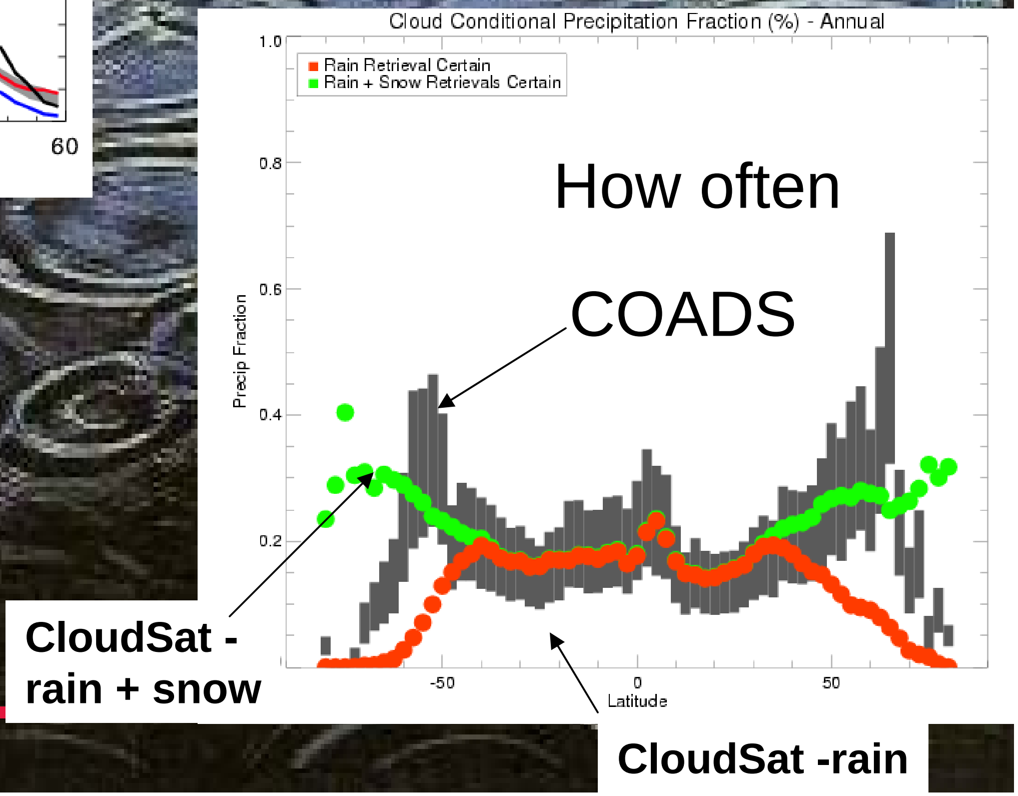


CloudSat sees more light rain than the PR - driven by differing instrument sensitivities and low-level detection capabilities

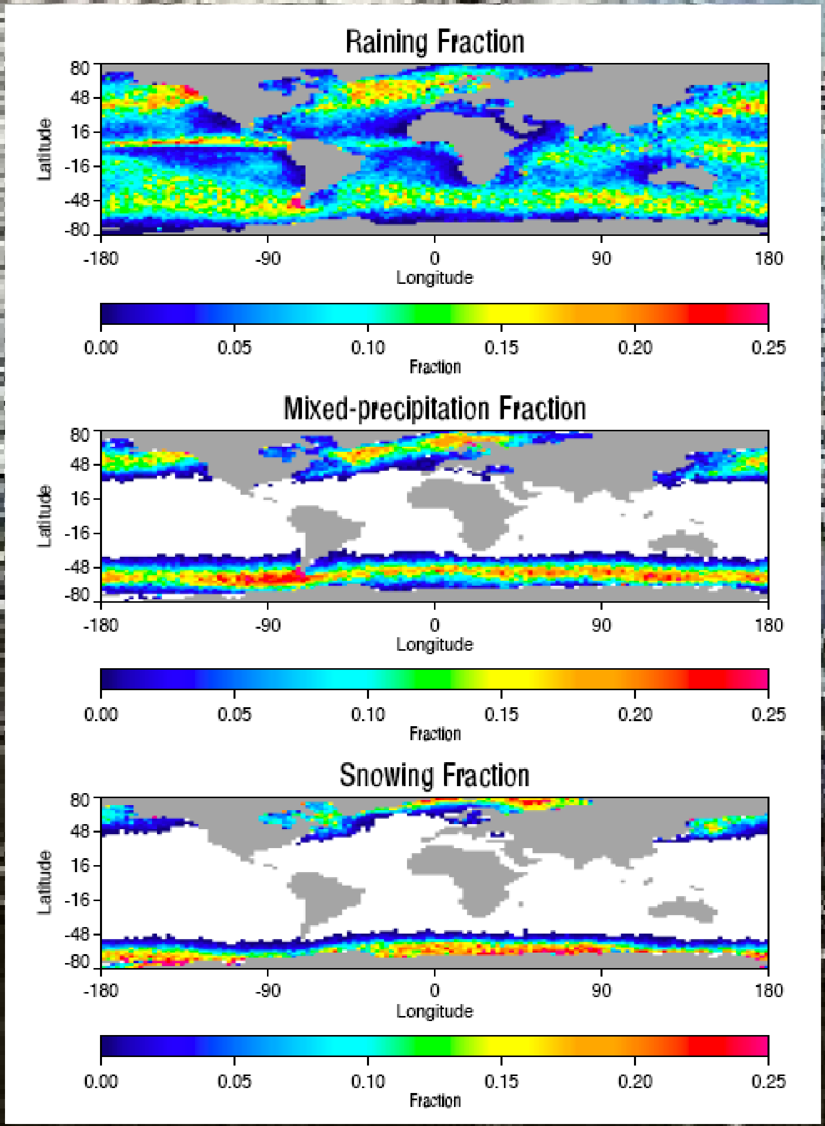
CloudSat offers the first global radar measures of precipitation

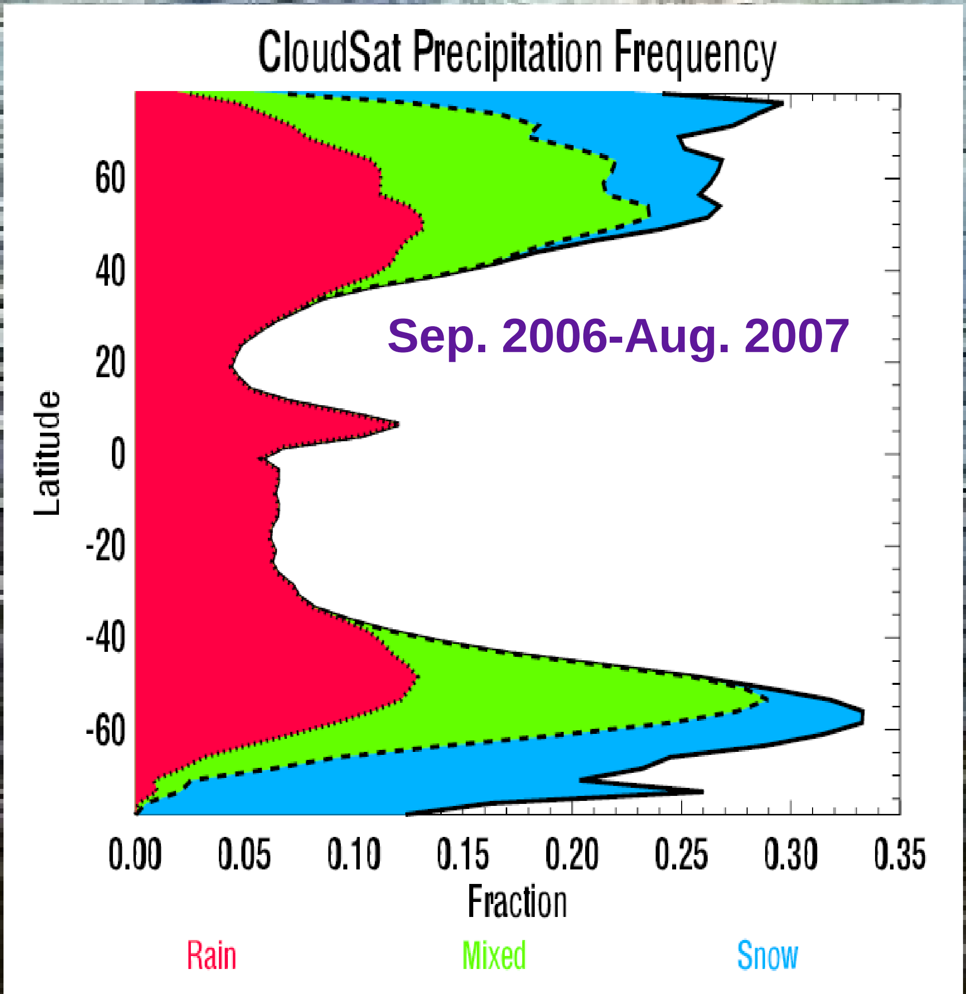


CloudSat precipitation products (incidence, amounts) are to be released in the fall



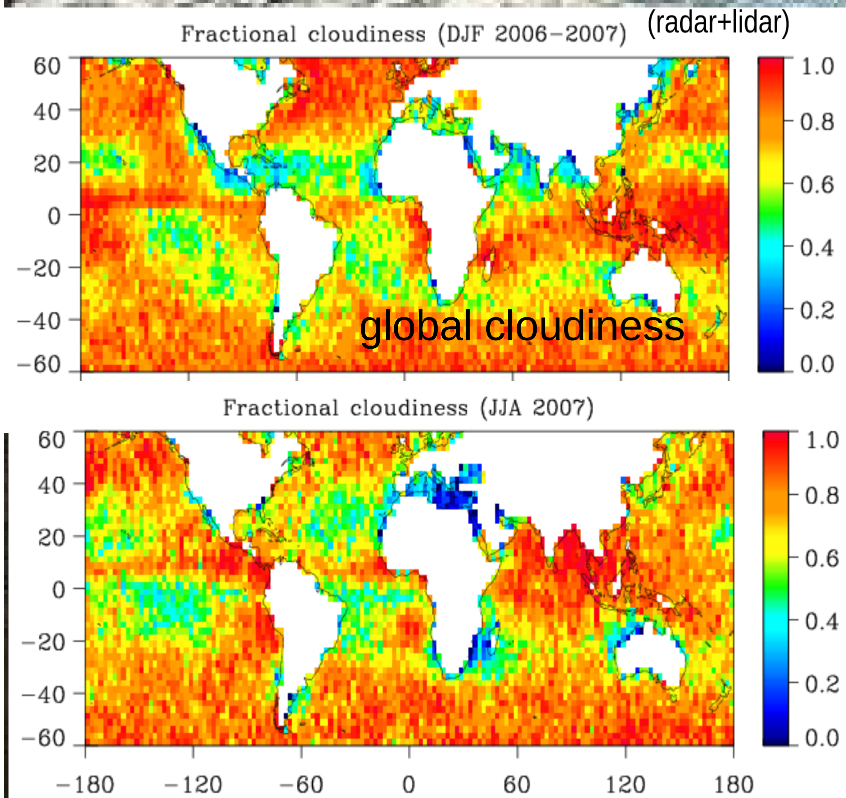
Global, oceanic incidence





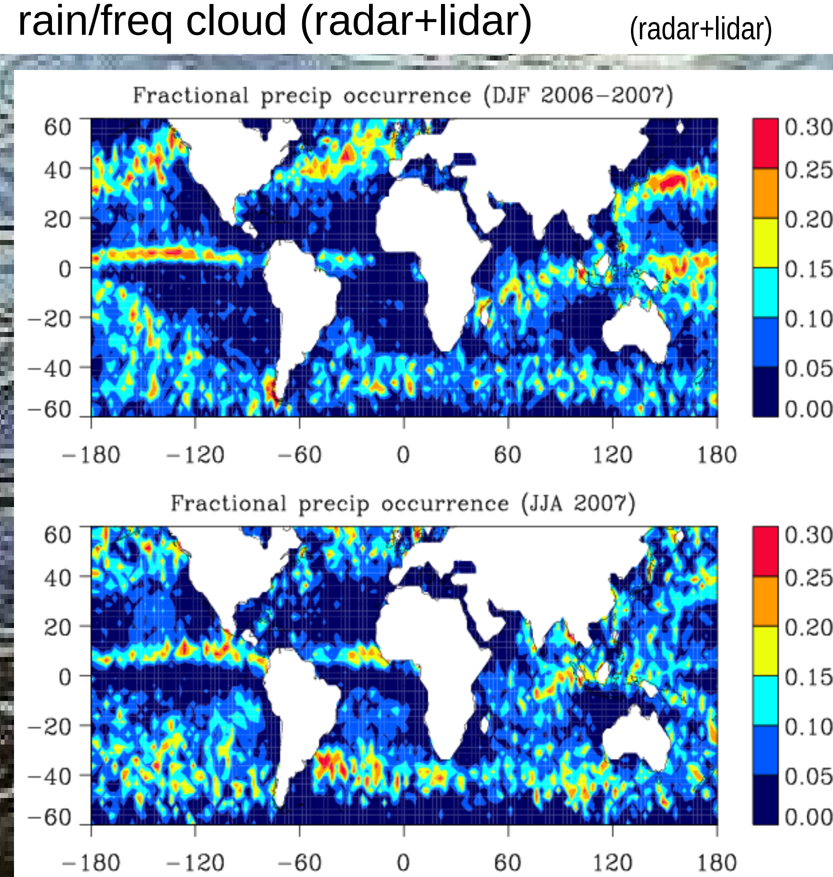
Incidence as a function of cloudiness

liquid precipitation occurrence = freq rain/freq cloud (radar+lidar)



DJF

JJA

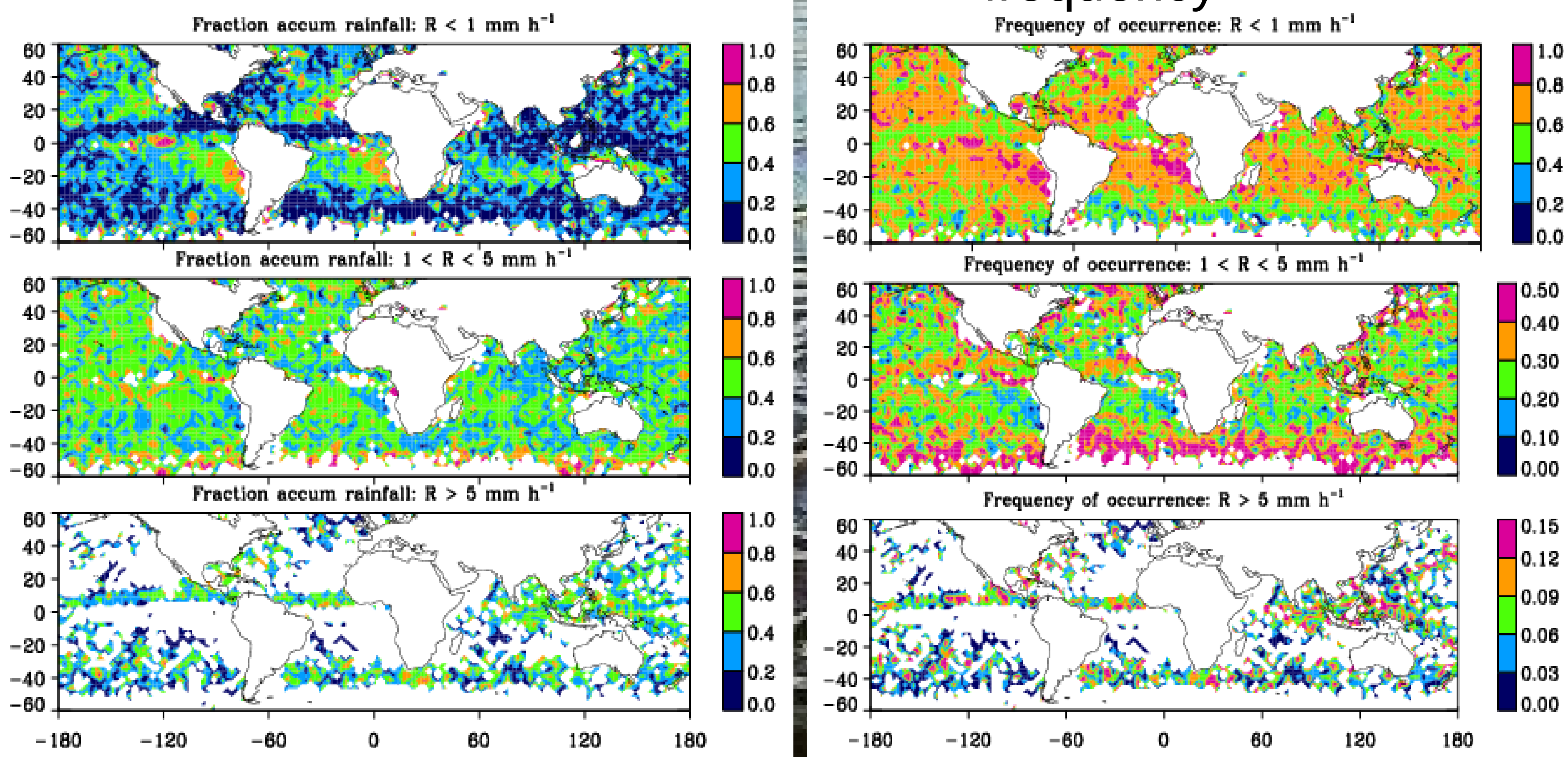


This is the first definitive estimate of the fraction of clouds on our planet that precipitate

Frequency and accumulation by intensity

accumulation

frequency



Light rain is prevalent - but the bulk of the fresh water that falls to the ocean surface occurs at rates between 1-5 mm/hr

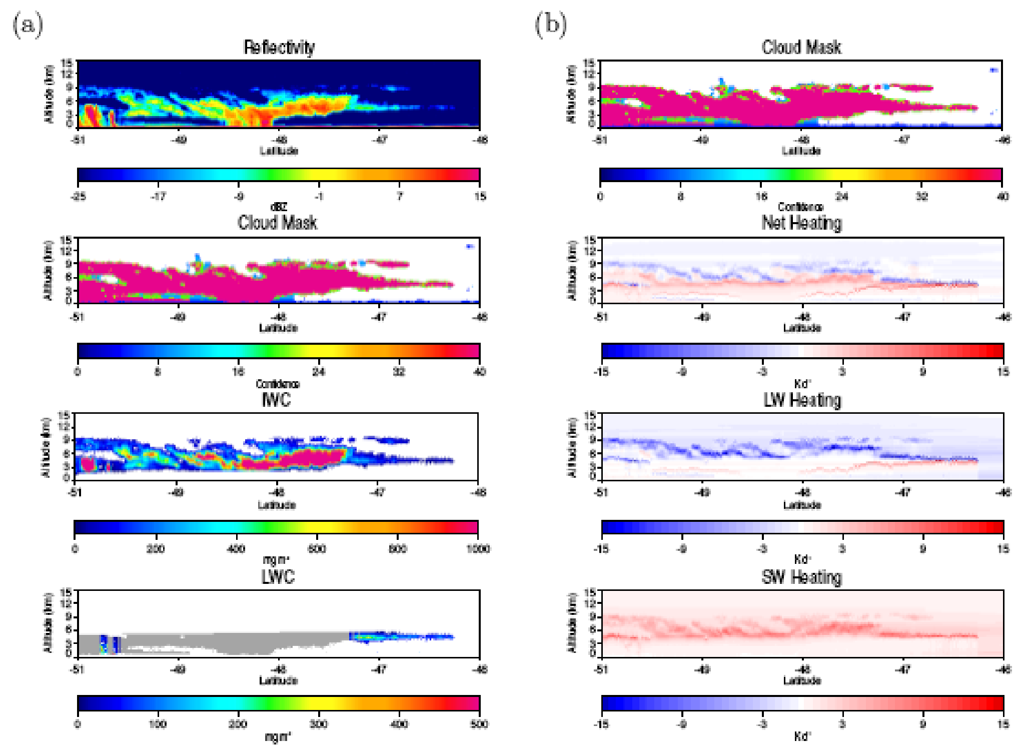
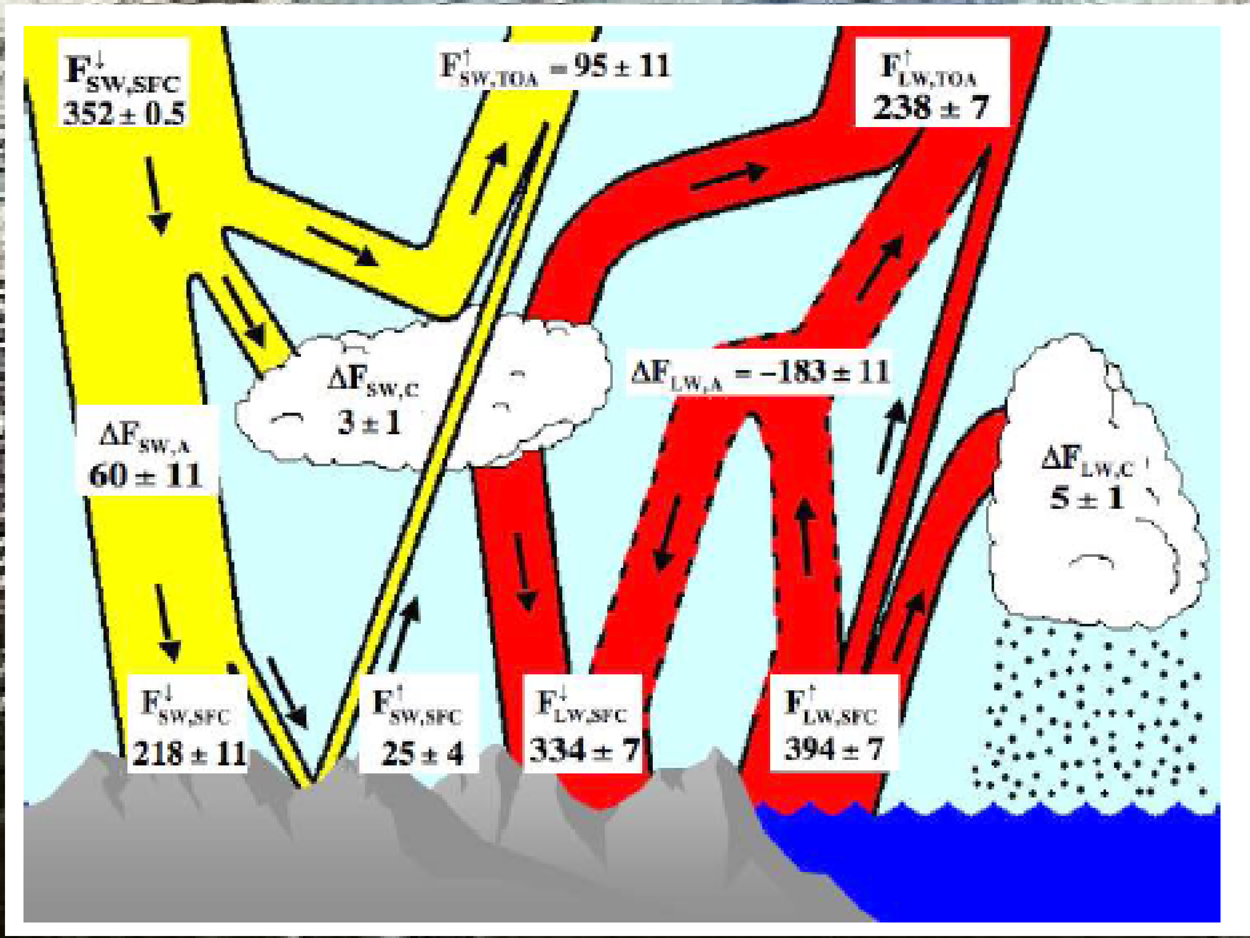


Figure 1. Inputs and outputs from the CloudSat 2B-FLXHR algorithm. From top to bottom: (a) calibrated reflectivity, 2B-GEOPROF cloud mask, IWC, and LWC, and (b) cloud mask (repeated), net heating, LW heating, and SW heating (in K d^{-1}).

Global-annual radiation budget



L'Ecuyer et al., 2008

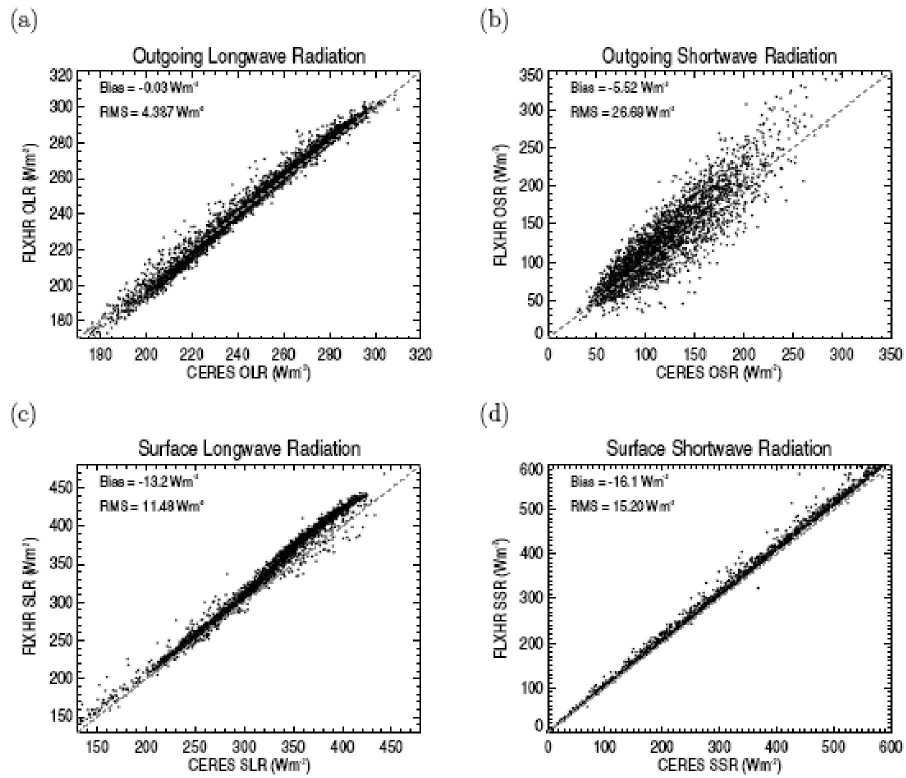
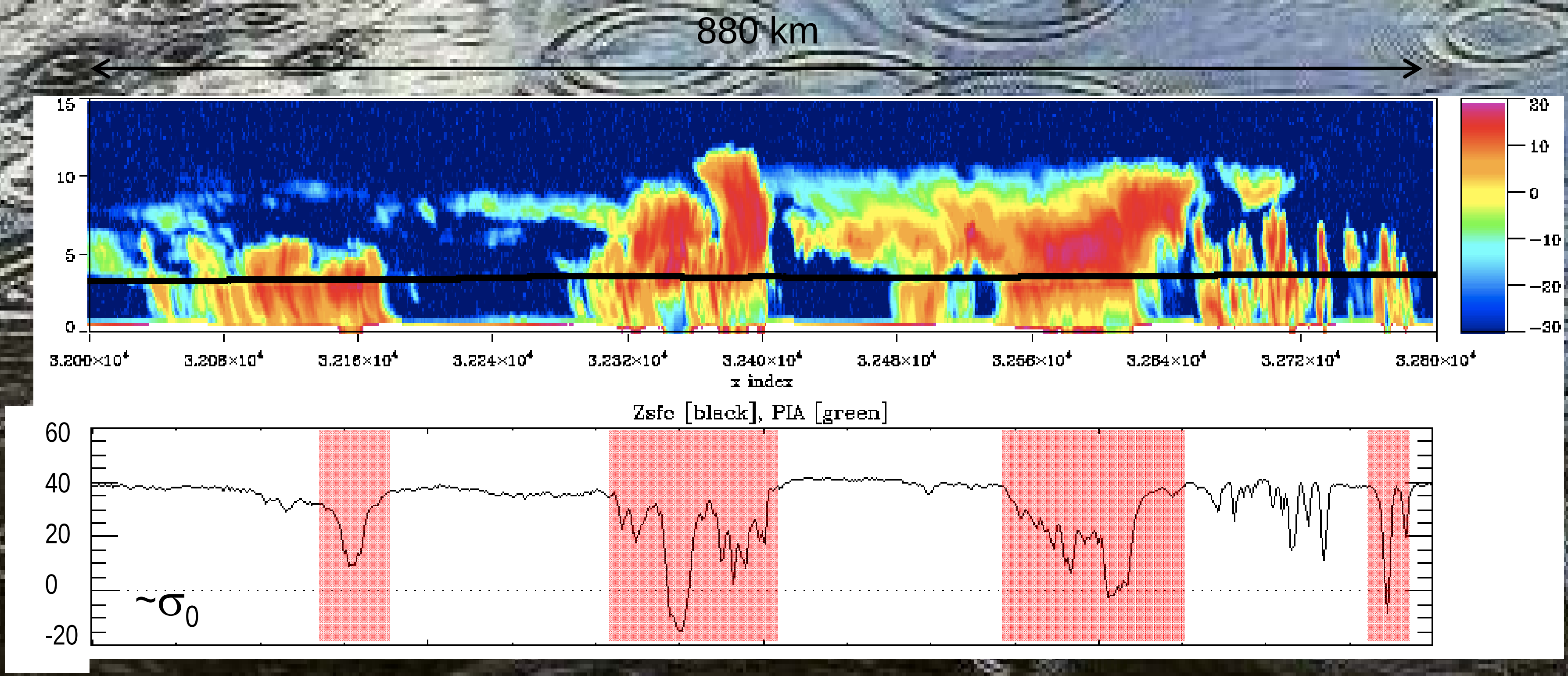


Figure 8. Comparison of monthly, 5-degree mean TOA and BOA flux estimates from the CloudSat 2B-FLXHR and CERES FLASHFlux products: (a) outgoing LW radiation, (b) outgoing SW radiation, (c) surface LW radiation, and (d) surface SW radiation.

Path Integrated Attenuation

- PIA is estimated by looking *through* the rain to the surface - attenuation in the rain will decrease the surface backscatter.



Signal significantly attenuated - Areas likely to have heavy rain

Path Integrated Attenuation

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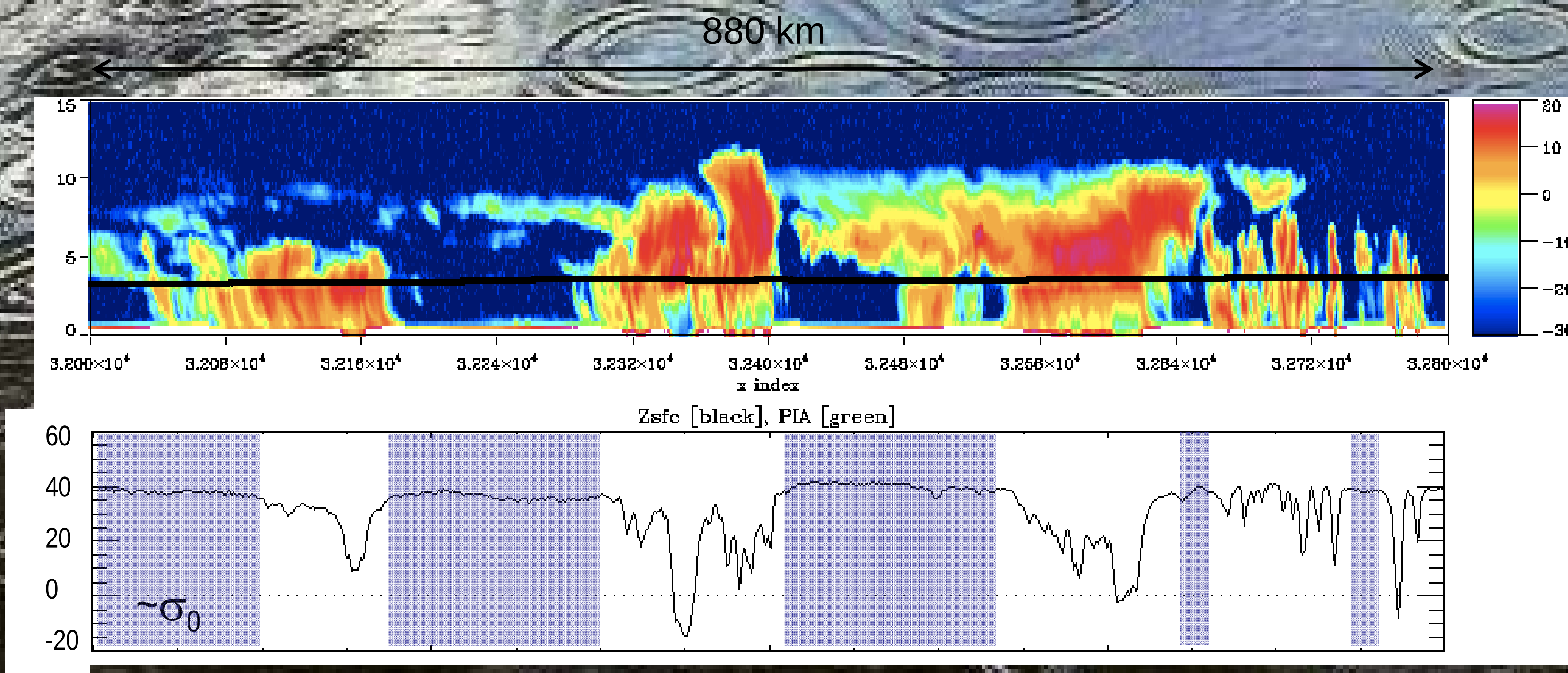

Areas where the surface backscatter is near the background value - unlikely to contain rain