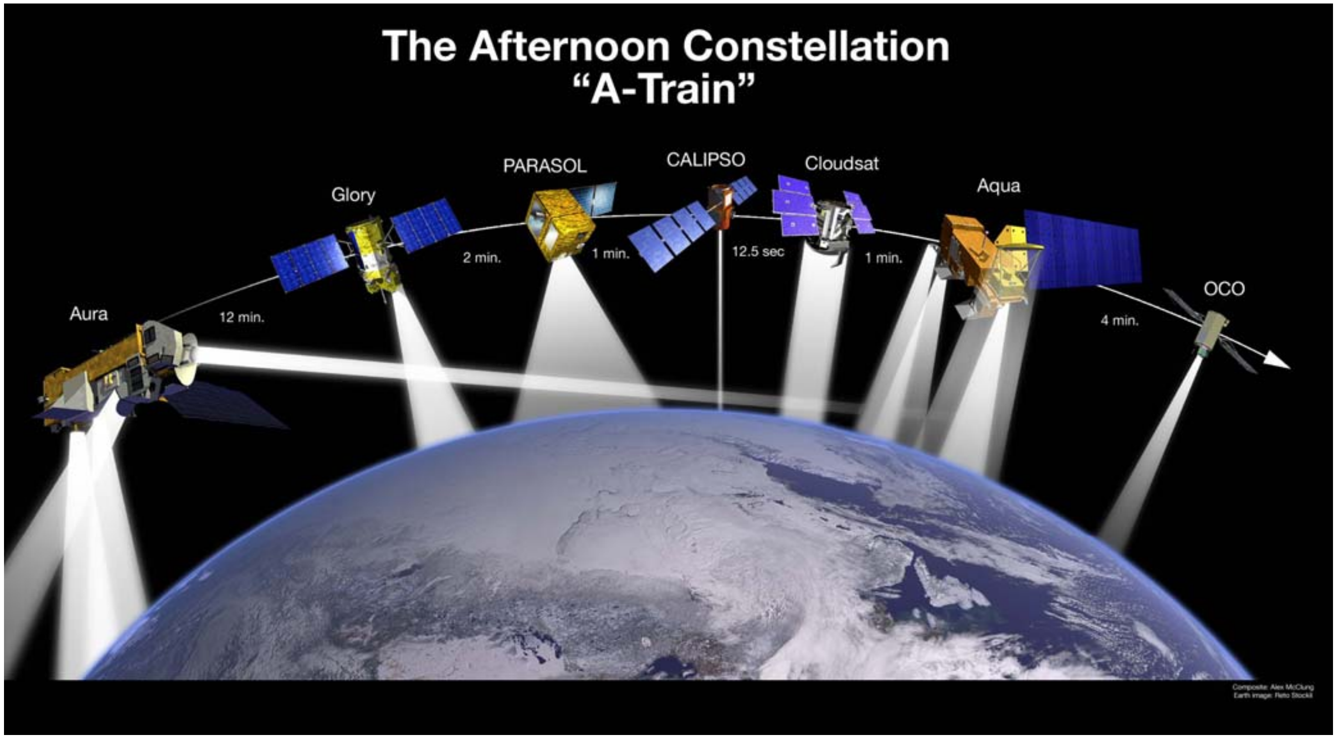
CloudSat … making measurements of critical relevance to weather and climate

Prof. Graeme Stephens, principal investigator, CloudSat mission; university professor, Colorado State University, Fort Collins, Colo.

Launch, April 28, 2006

The "A-Train" Gives Us Unprecedented Capabilities For Observing Earth



The new A-Train observations tell us much more about weather and climate-sensitive processes than can possibly be gleaned from any one instrument alone.

CloudSat Partners

Colorado State University — Science leadership & data processing — CIRA

JPL — Mission management & payload development

Ball — Spacecraft

Canadian Space Agency — Subsystem development,validation, (CONTRIBUTION)

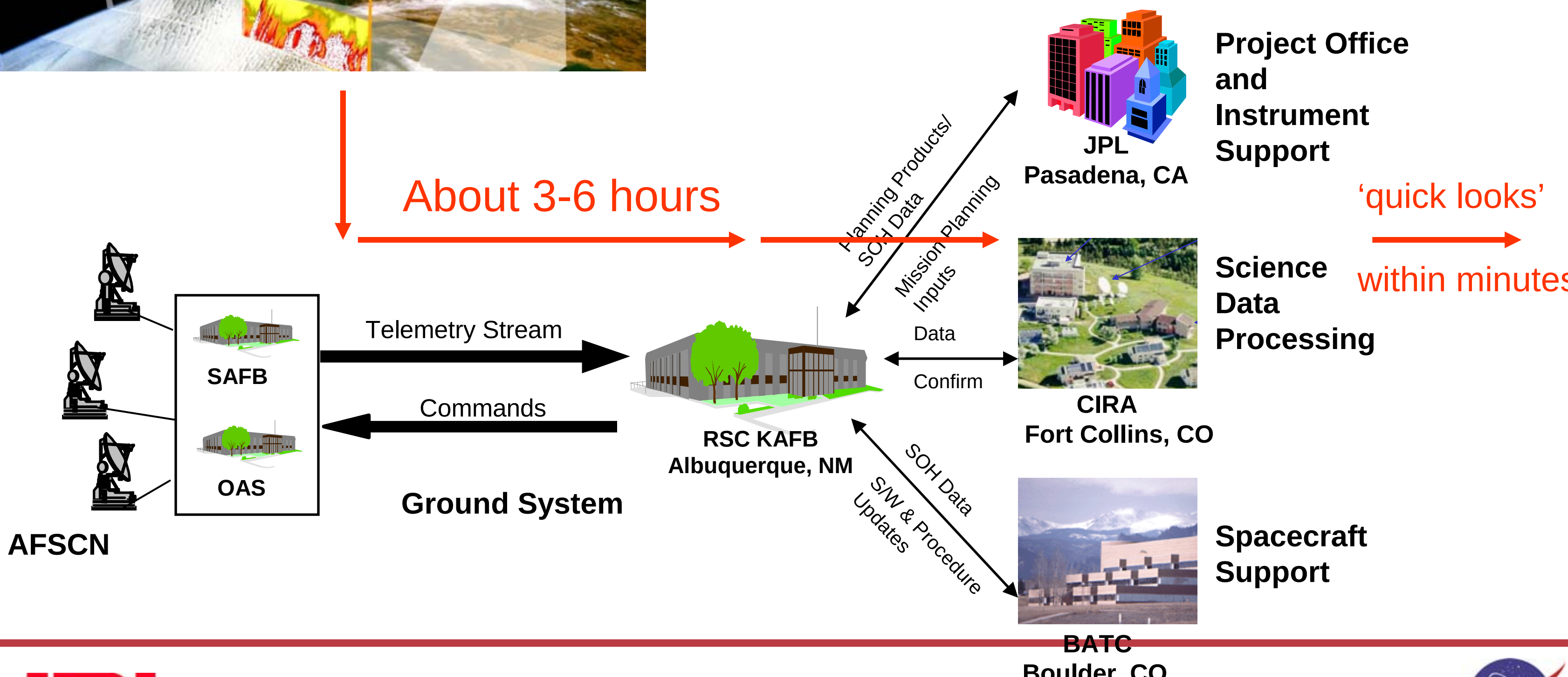
USAF — Ground operations system (CONTRIBUTION)

Calipso — Formation flying (CONTRIBUTION)

ARM Atmospheric Radiation Measurement Program DOE — Science, validation and analyses (CONTRIBUTION)

Universities world-wide,
Weather centers
Major climate groups - part of the next IPCC process
NASA funded investigtors ~O(70)

Mission elements

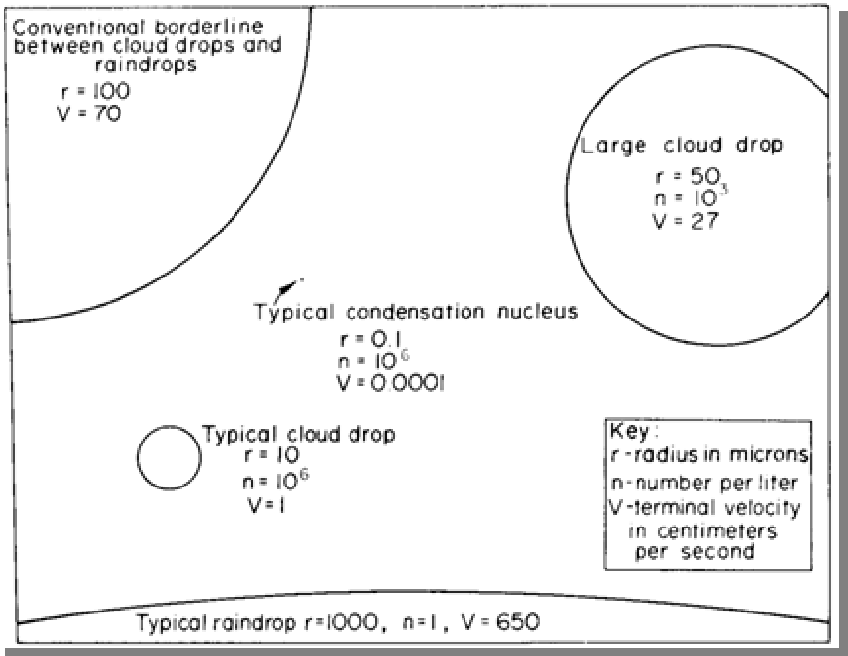


Data acquisition performance

	Requirement	Performance
CloudSat Project	85%	96.93%
CPR	96%	99.17%
Spacecraft	96%	98.52%
RSC	94%	99.21%
CIRA	98%	100%

From June 06-Oct 07

Why W-band?



Conventional borderline between cloud drops and raindrops
r = 100
V = 70
Large cloud drop
r = 50
n = 10^3
V = 27
Typical condensation nucleus
r = 0.1
n = 10^6
V = 0.0001
Typical cloud drop
r = 10
n = 10^6
V = 1
Key:
r - radius in microns
n - number per liter
V - terminal velocity in centimeters per second
Typical raindrop r = 1000, n = 1, V = 650

Why W-band?

Visible λ's:
too much attenuation

S-band λ's :
too little sensitivity

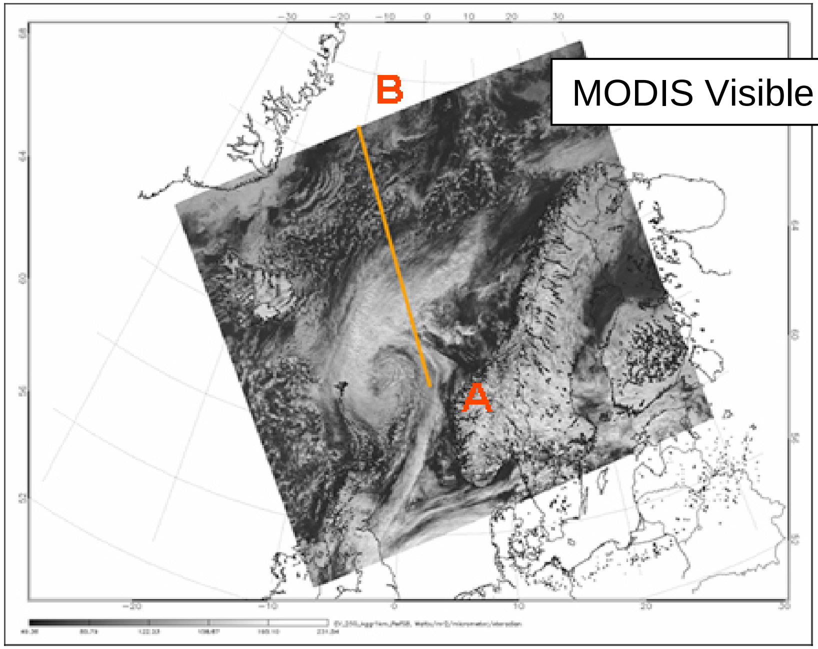
Transmitter	Advantage	Disadvantage
Laser (visible, infrared wavelengths; 0.5-10 X 10^{-6} m)	Sees* all particles of a few 0.1 X 10^{-6} m and greater, able to provide high resolution	Attenuates heavily in moderately thick cloud, multiple scattering confuses ranging (from space)
Mirowave mm wavelength (e.g. 3mm)	Sees* all particles of a few ~5 X 10^{-6} m (most cloud particles) and greater. No multiple scattering effects	Attenuation in moderate to heavy rainfall Some multiple scattering in heavy rain
cm wavelength (1-10 cm)	Less attenuated under heavy rain	Unable to see majority of cloud

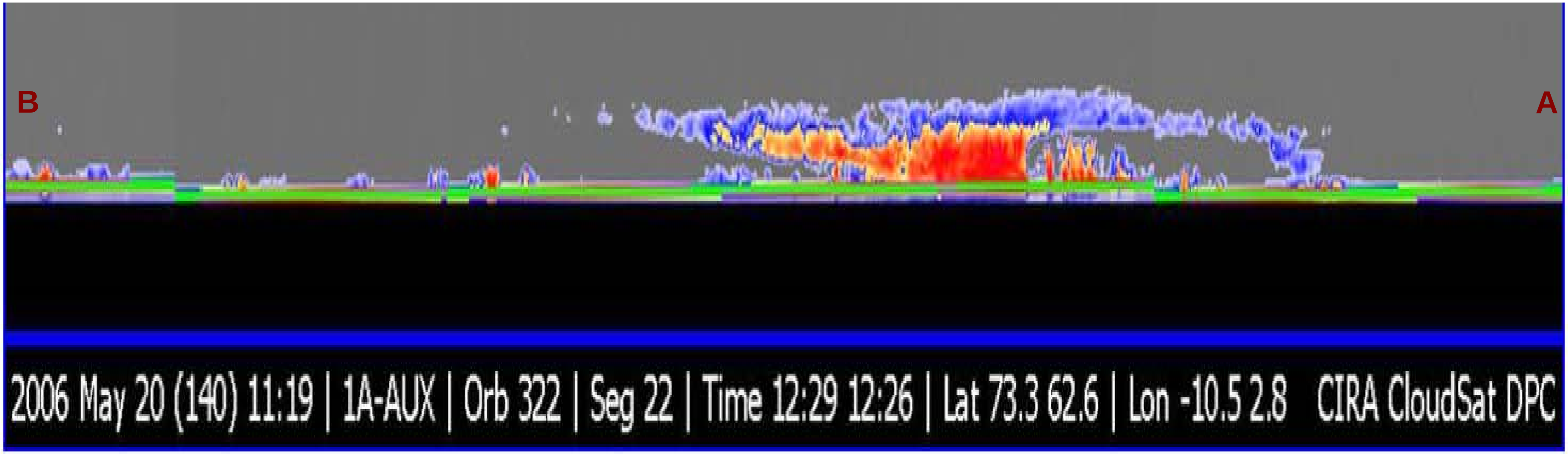
* Depends also on volume concentration of particles sees ice and water particles with almost equal sensivity

The radar reflectivity fundamentally relates to the water and ice contents of clouds and their vertical profiles - these in turn govern most of the salient properties of clouds as relevant to weather and climate.

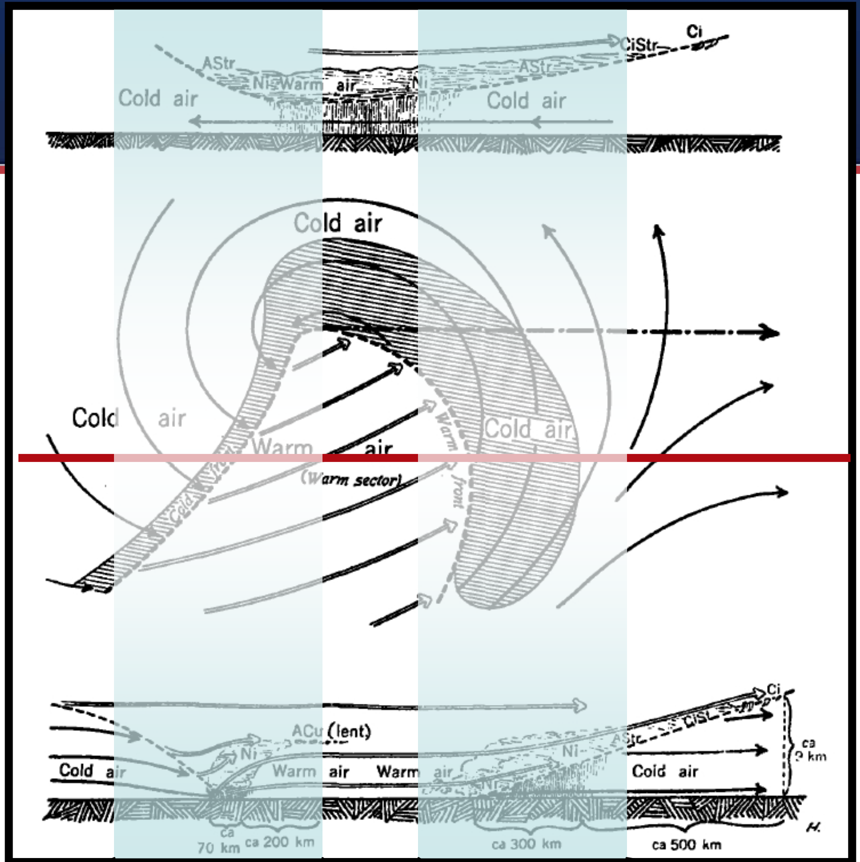
Historic First Images of CPR on May 20, 2006

Warm Front Storm Over the Norwegian Sea: 12:26-12:29 UTC





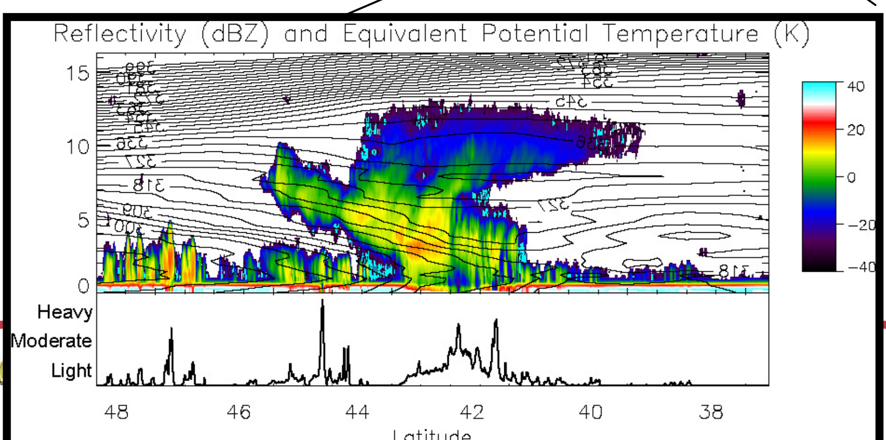
Revisiting history
The Norwegian Cyclone Model
Circa, 1923

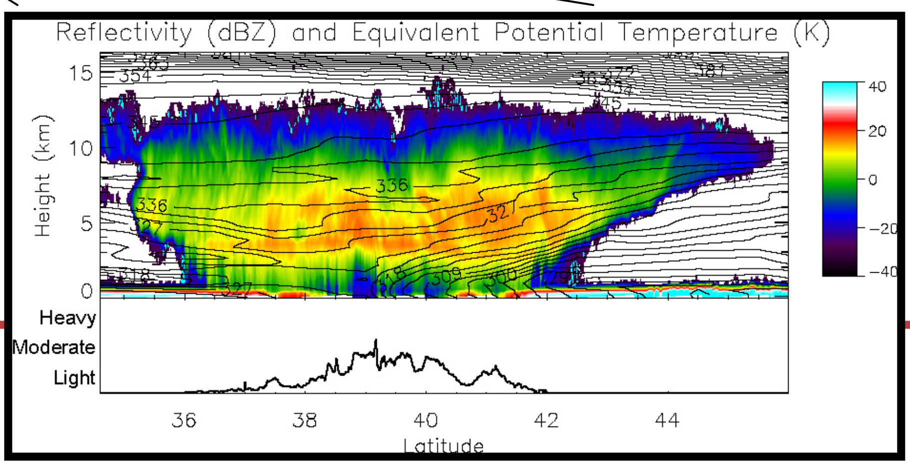


Posselt et al., 2007

Cold front

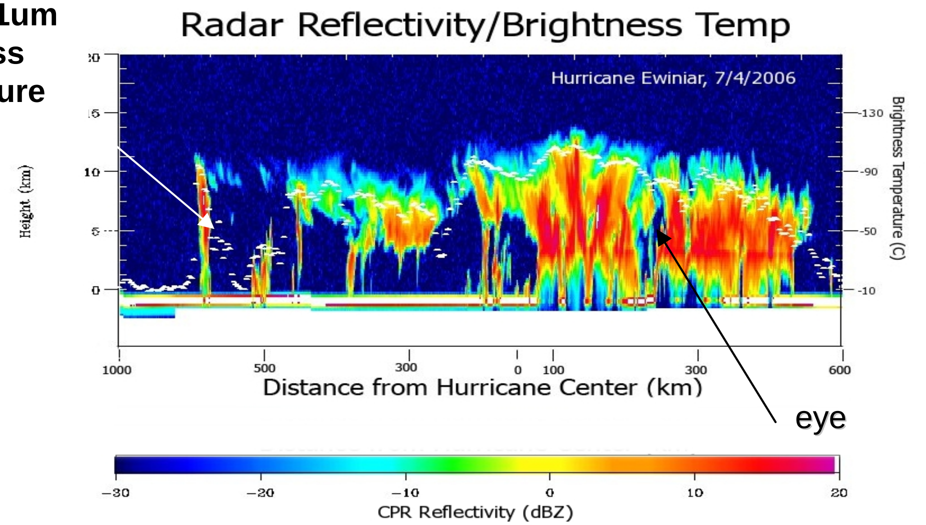
Warm front +





Fundamental tests of a theory of hurricane

MODIS 11um brightness temperature



Three unique pieces of information

1. CloudSat provides a direct measure of the altitude of clouds as part of hurricanes (z_{top})

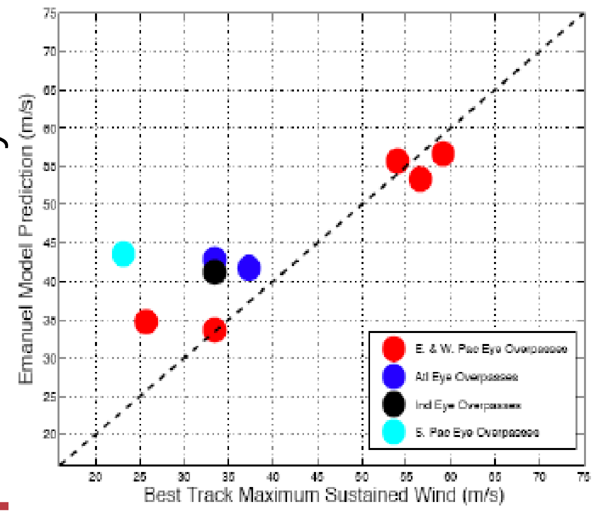
2. MODIS provides a measure of the emission temperature from tops of clouds (T_0)

3. CloudSat provides a view of the internal structures of convection in hurricanes - identifies ‘undilute’ convective cores

These three pieces of information combine to test the Emanuel theory predicts:

$V_{max} = f(z_{top}, T_0, SST)$

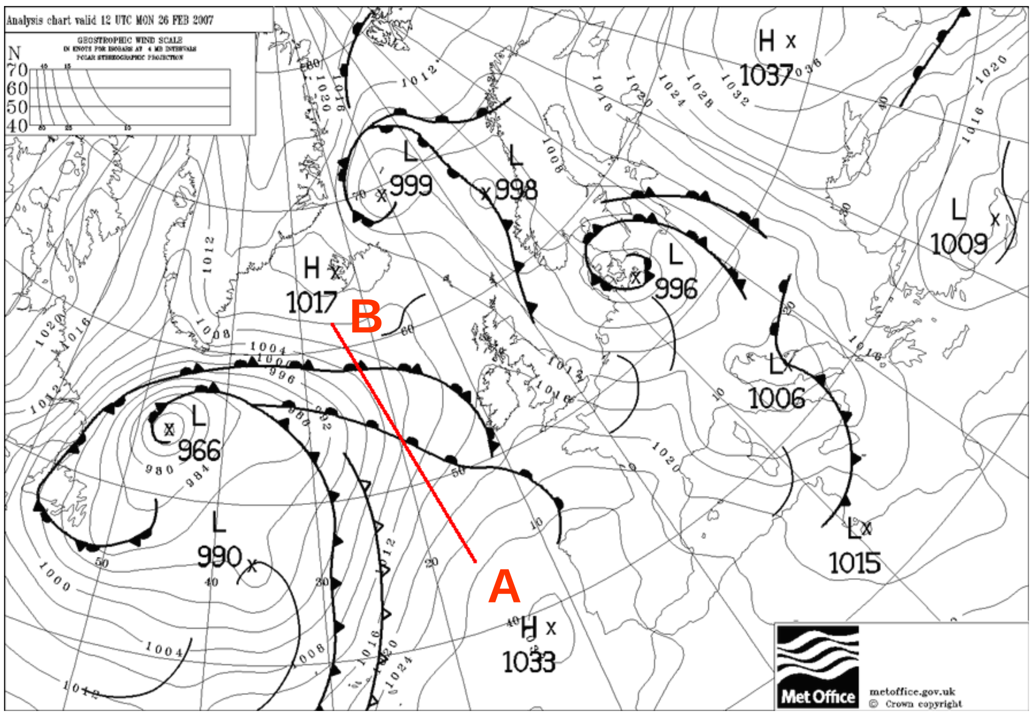
Cloudsat+MODIS data - the Emanuel theory



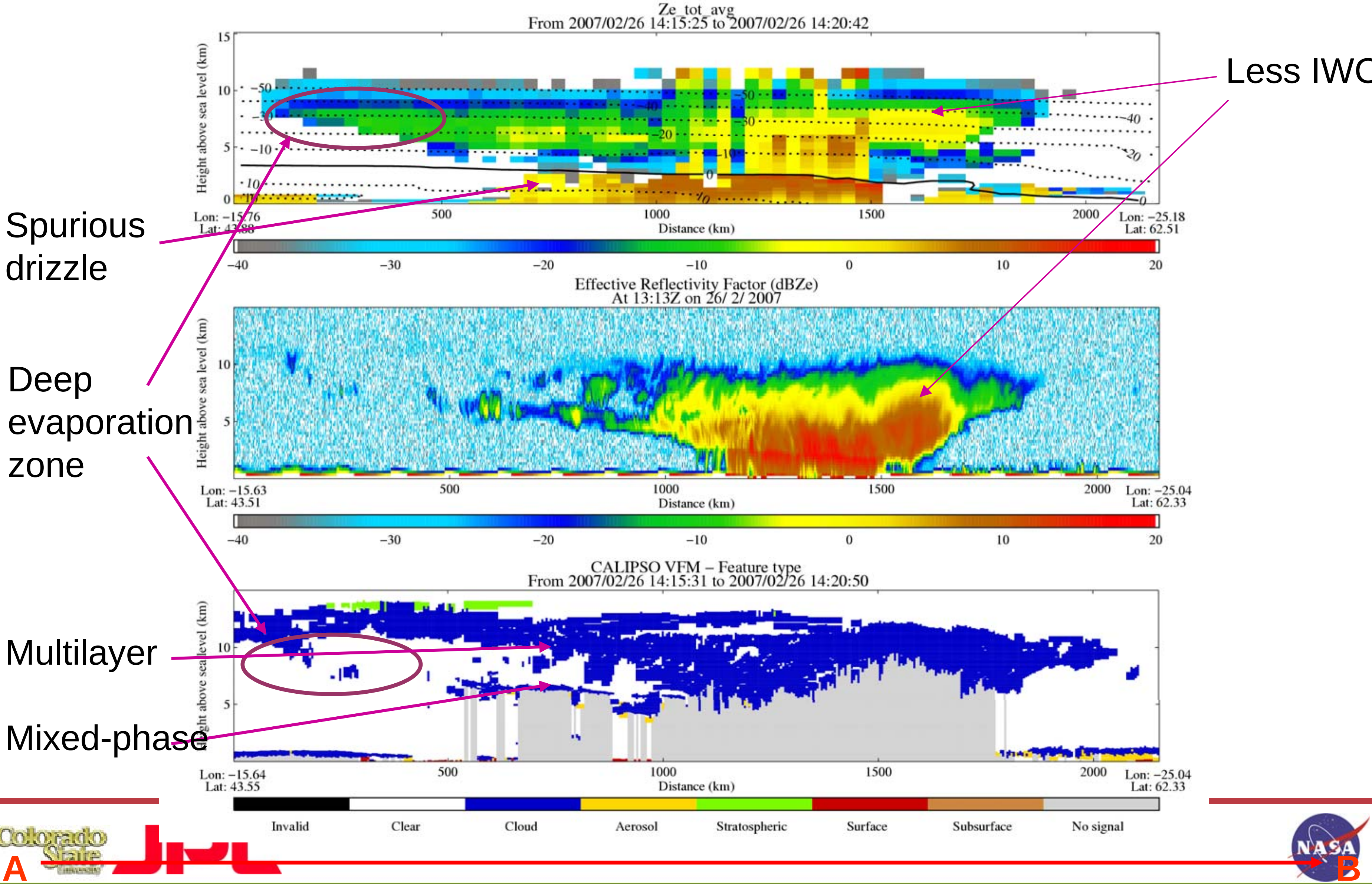
Luo et al., 2007

Case study example : 26 February 2007

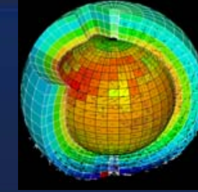
- **Analysis chart valid at 12 UTC**
- **CloudSat overpass at ~14:15 UTC**



The weather centers of the world are using the data to improve model performance



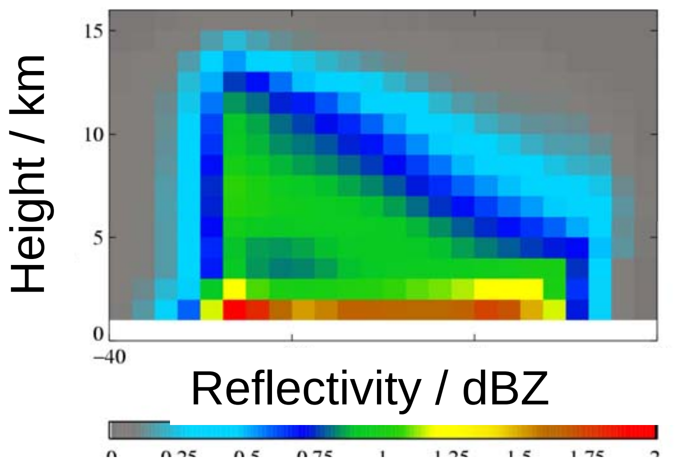
Less IWC
Spurious drizzle
Deep evaporation zone
Multilayer
Mixed-phase
Ze_tot_avg
From 2007/02/26 14:15:25 to 2007/02/26 14:20:42
Height above sea level (km)
Distance (km)
Lon: −15.76 Lat: 43.88
Lon: −25.18 Lat: 62.51
Effective Reflectivity Factor (dBZe)
At 13:13Z on 26/ 2/ 2007
Lon: −15.63 Lat: 43.51
Lon: −25.04 Lat: 62.33
CALIPSO VFM – Feature type
From 2007/02/26 14:15:31 to 2007/02/26 14:20:50
Lon: −15.64 Lat: 43.55
Lon: −25.04 Lat: 62.33
Invalid
Clear
Cloud
Aerosol
Stratospheric
Surface
Subsurface
No signal
A
B



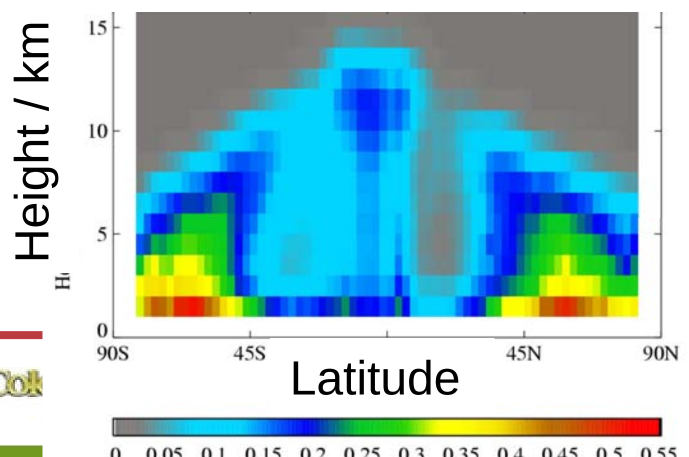
Global histograms: 2006/12 – 2007/02

CloudSat

Frequency of occurrence

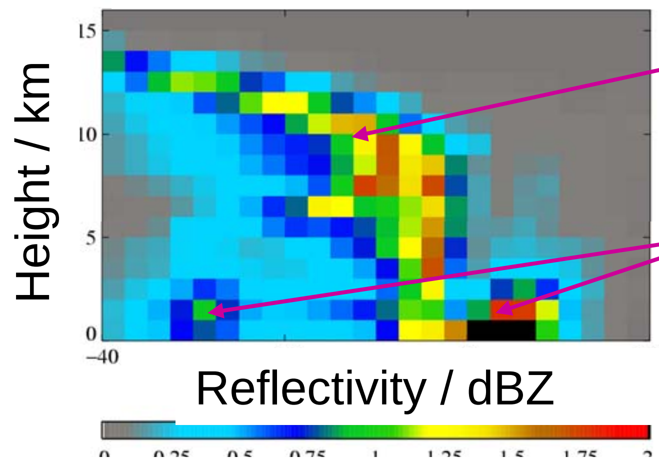


Occurrence of Z > -27.5 dBZ

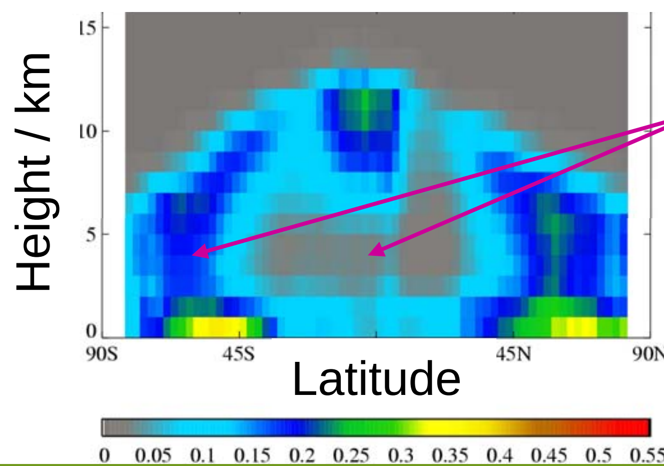


MetUM N320L50

Frequency of occurrence



Occurrence of Z > -27.5 dBZ

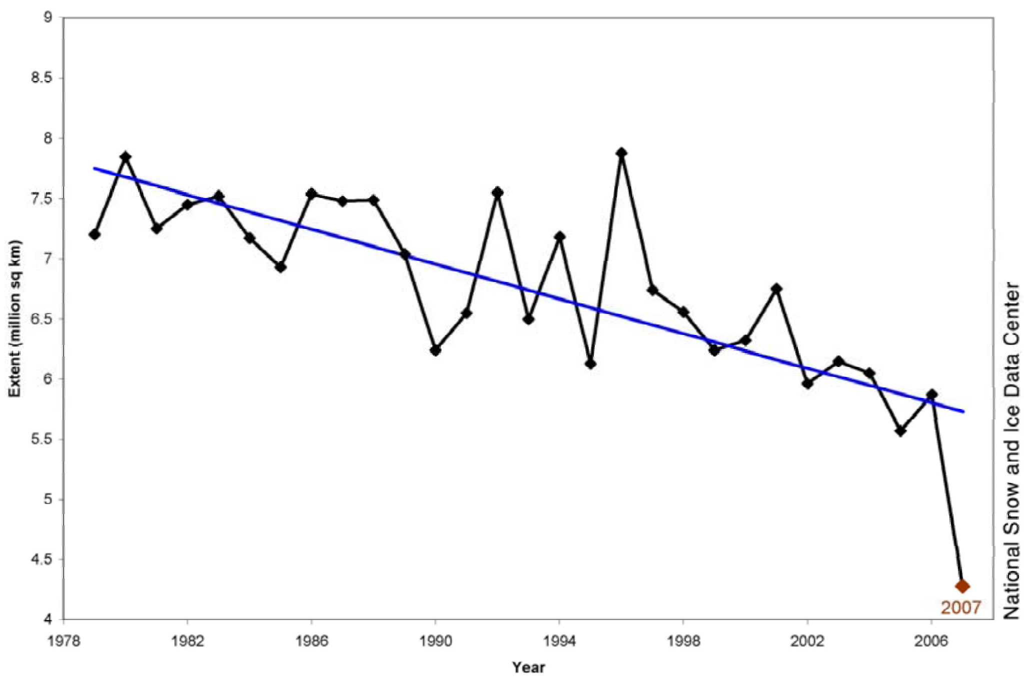


Strong dependence of N0 with T

Two regimes. Drizzling or not drizzling cloud?

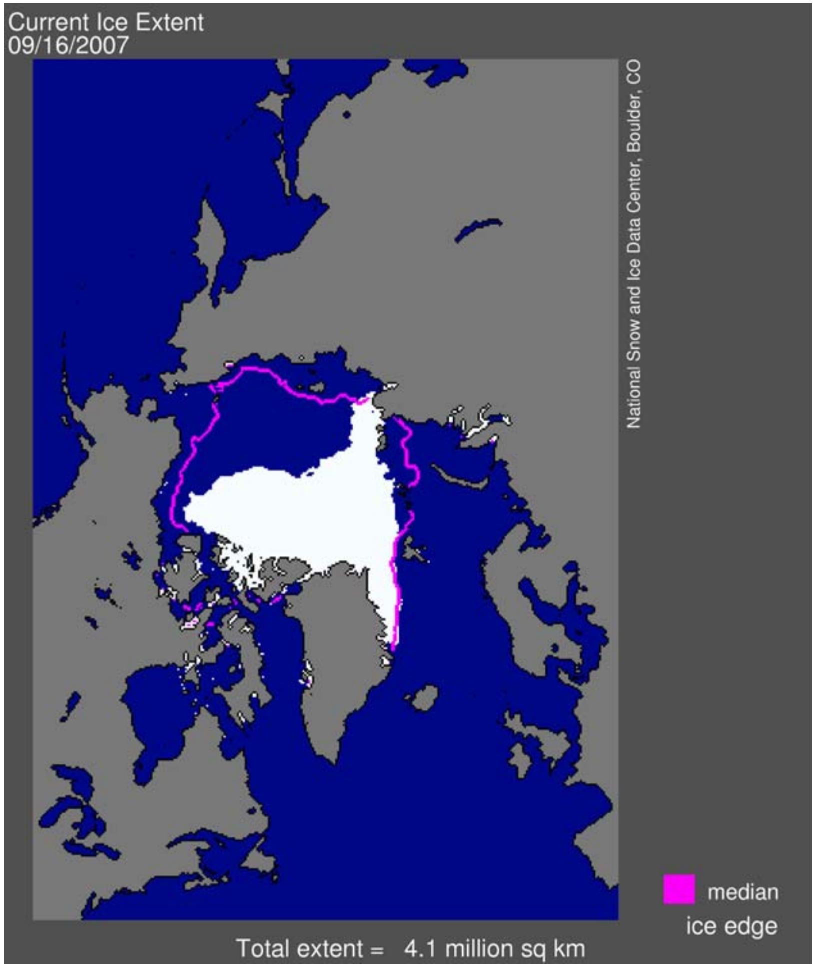
Lack of mid-level cloud

The Disappearance Act of 2007



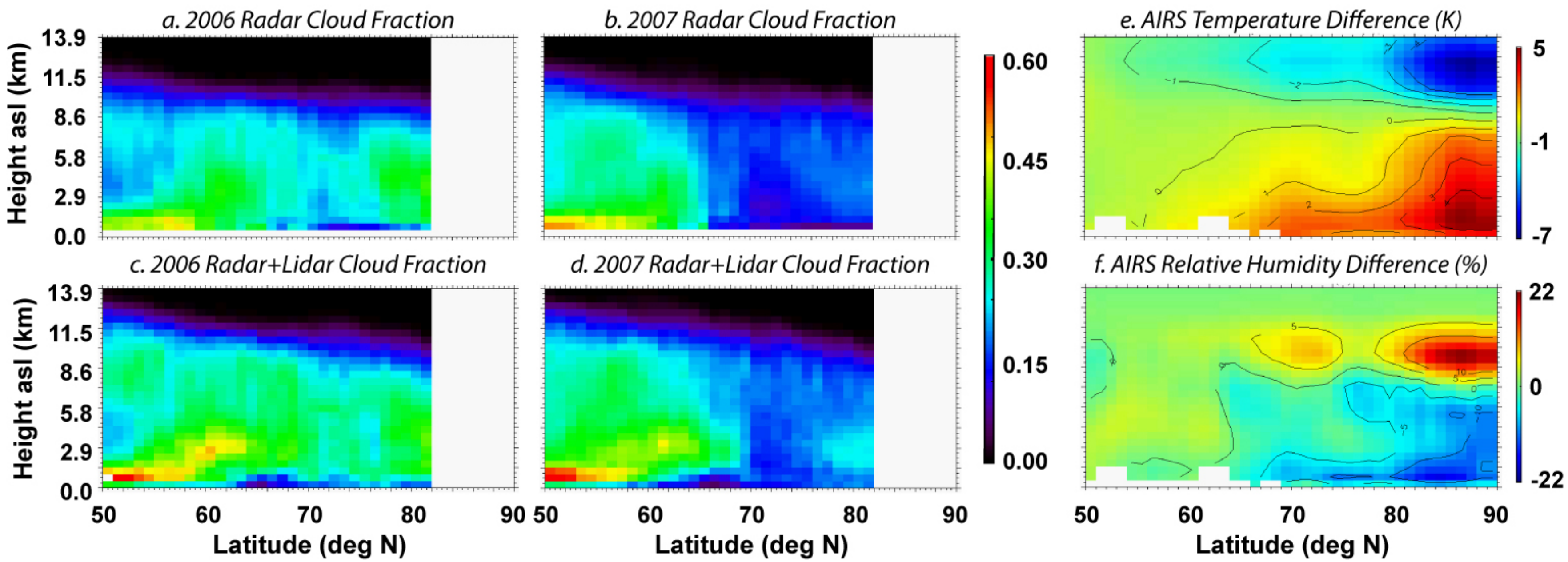
Sea Ice Minimum Extent Time Series

Kay et al., 2007
Source: National Snow and Ice Data Center



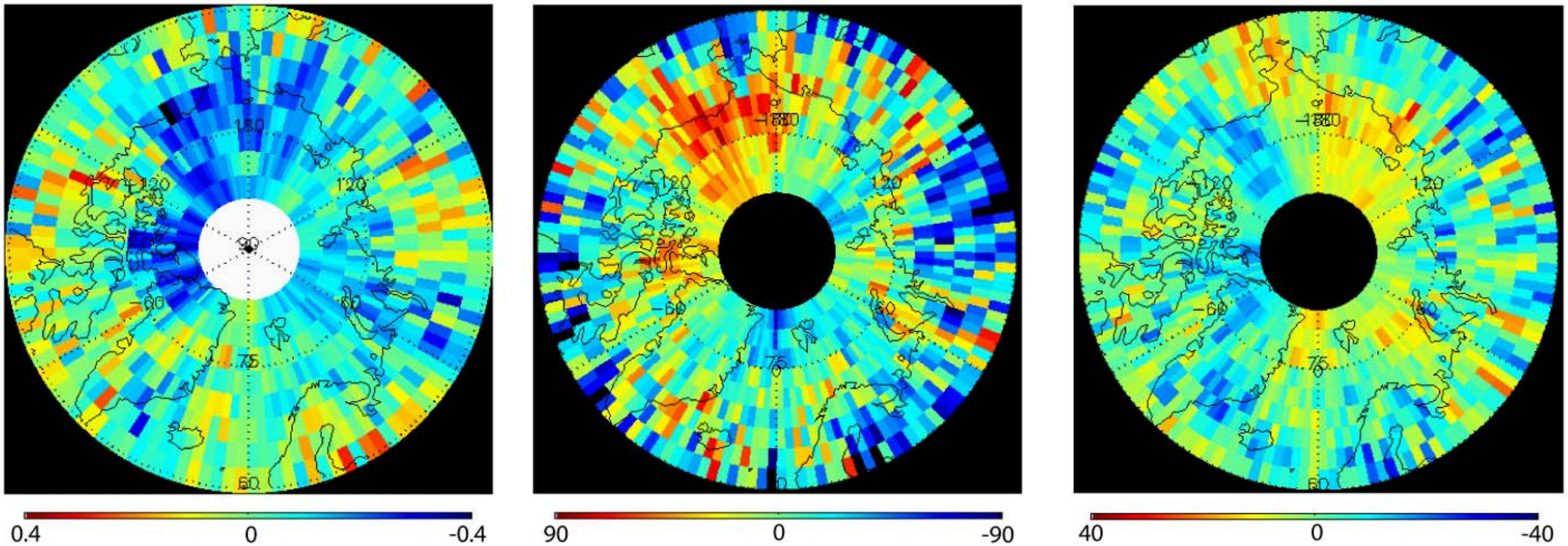
New Record Minimum - Sept. 2007

A-Train Data Reveal Dramatic Reductions in 2007 Melt Season Cloudiness



These Arctic cloud reductions are associated with anomalous weather patterns.
We see drying, warming and large cloud reductions
Kay et al. (2007)

2007-2006 Cloud and Surface Radiation Differences



Cloud Fraction

Downwelling Solar Radiation (W m^{-2})

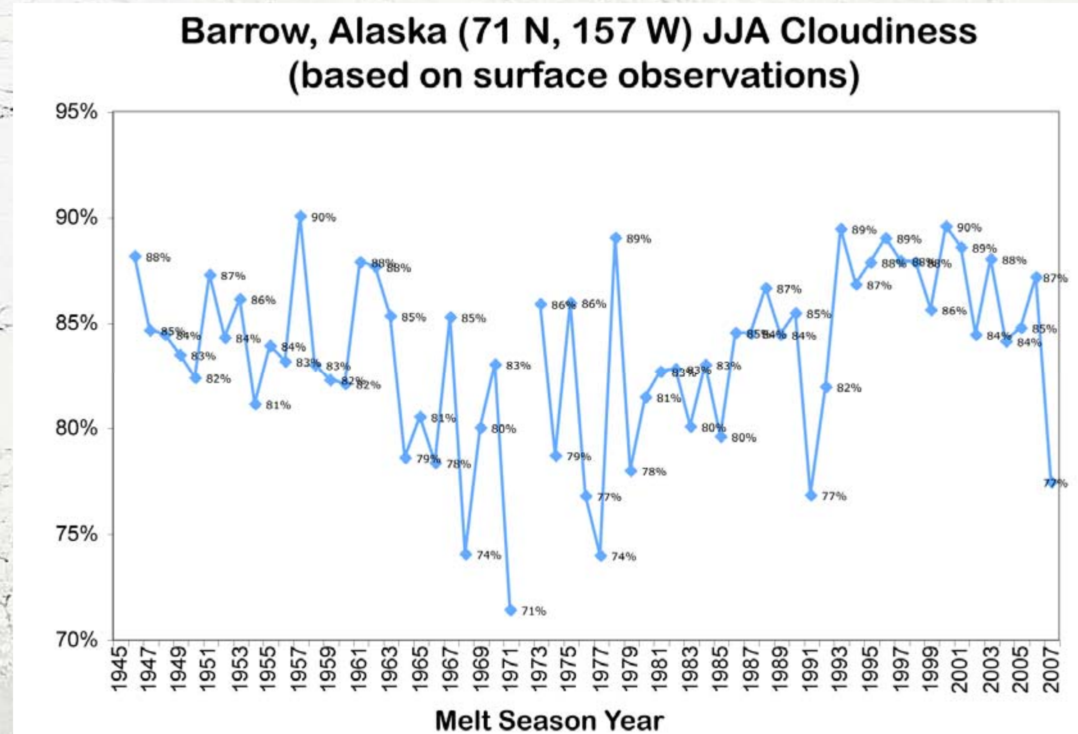
Downwelling Longwave Radiation (W m^{-2})

Radiation Calculations by T. L'Ecuyer (CSU).

These radiation differences alone could melt ~0.3 meters of sea ice and increase ocean mixed layer temperatures by ~2.4 degrees Kelvin.

Thinning Sea Ice is Vulnerable to Year-to-Year Weather Variability

The summer 2007 observed cloud decreases are anomalous but not unprecedented.

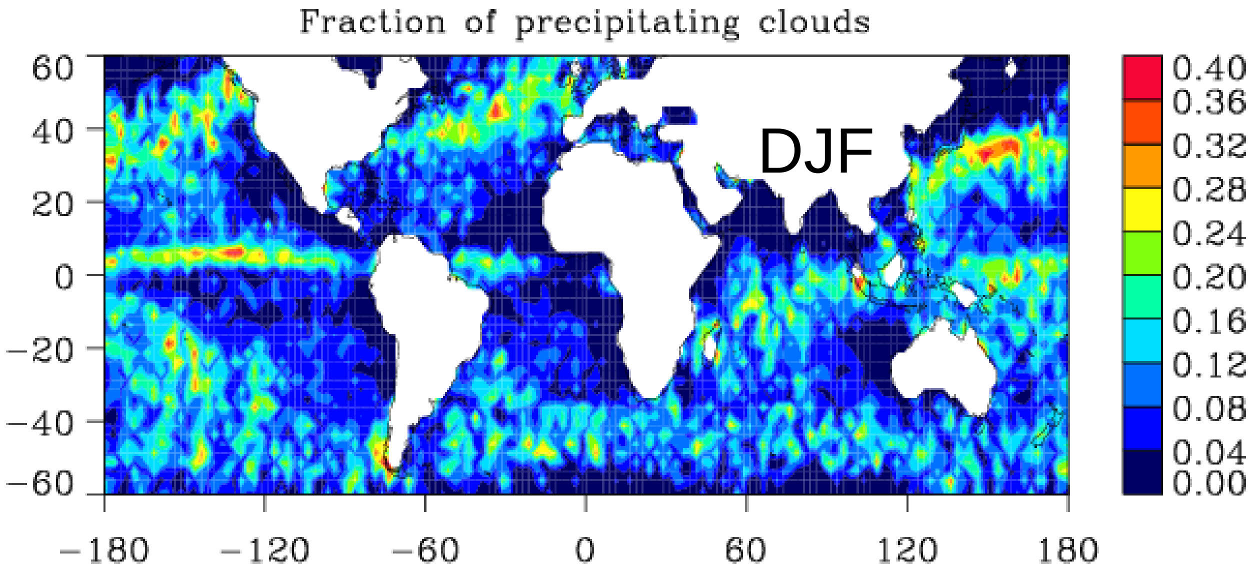


MODIS - June 2, 2007

How Often Does it Rain (Over the Oceans) ?

CLOUDSAT

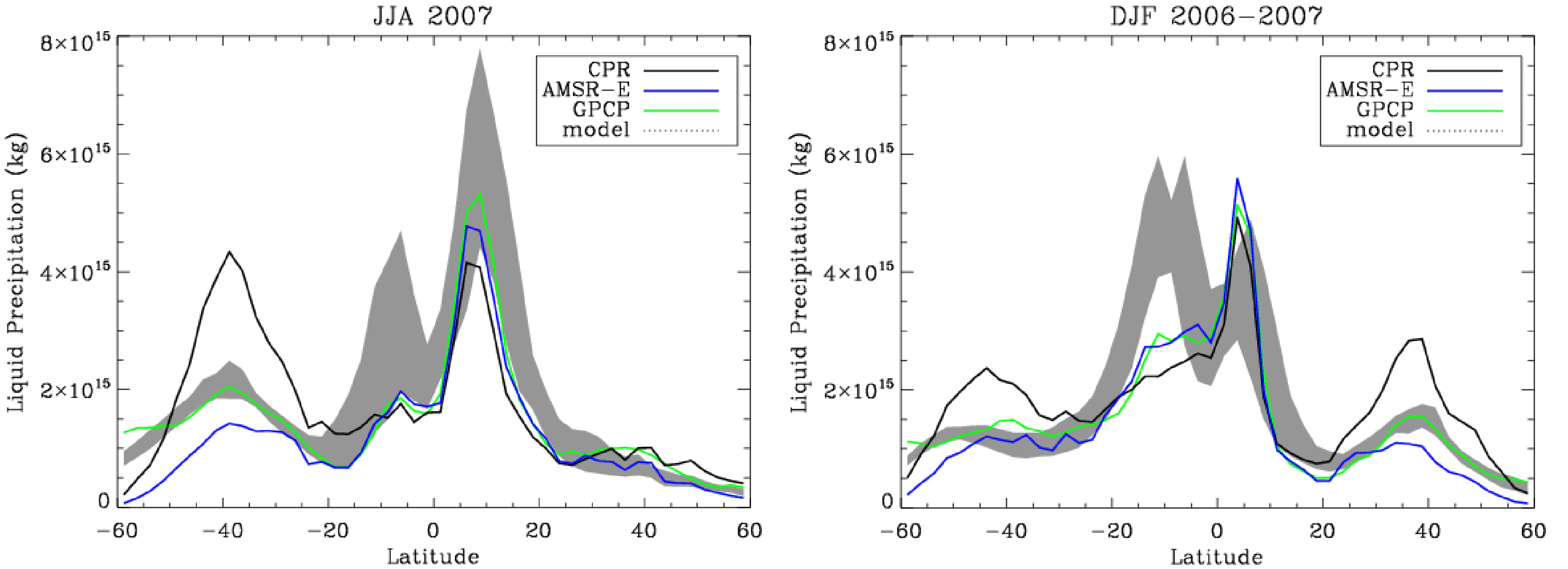
The Fraction of Oceanic Clouds That Precipitate



The global mean value is ~0.12, i.e., on average, about 12 percent of the clouds observed over our oceans at any time are producing rain. This fraction is much higher than previously speculated (0.08).

Haynes et al., 2007

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.

DoD Advocacy

CLOUDSAT

DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
MONTEREY, CALIFORNIA 93943-5006

IN REPLY REFER TO
3914
Ser 7500/044
2 March 2007

Dr. Michael Freilich
NASA Headquarters
Washington, DC 20546

Dear Dr. Freilich,

On behalf of the Naval Research Laboratory (NRL) Marine Meteorology Division, I would like to express our resolute advocacy for the continuation of the NASA CloudSat mission beyond its nominal 22-month lifetime. In the eight months since 'first light' from the Cloud Profiling Radar, we have already gained a valuable new perspective on the vertical complexity of the Earth's cloud systems—a single orbit of the CPR has provided a greater breadth of information than the aggregate of airborne cloud radar flights conducted over many years of dedicated field programs. Several of our scientists feel that an extended CloudSat mission (i.e., spanning several seasonal cycles) holds the potential to provide significant insight into one of the most challenging arenas of the climate problem: the non-linear role of cloud feedback processes in the earth/atmosphere system.

NRL has processed CloudSat data in near real-time since June 2006, thanks to the coordinated efforts of JPL, the CloudSat Data Processing Center, and Kirtland Air Force Base to supply NRL with a "First-Look" dataset. CloudSat cross sections through tropical cyclones are available at ~6 hr latency alongside other research and operational sensors on our Tropical Cyclone Web Page—a resource used by researchers and forecasters to monitor and track these systems globally. To date there have been over 1000 CloudSat passes near tropical cyclones, including ~10 direct 'eye crossings'. We also demonstrate CloudSat capabilities on our NexSat Web Page, geared toward educating users on future sensor capabilities. We are using CPR datasets to study light rainfall/drizzle regimes (where CloudSat provides sensitivity) and cloud/aerosol/precipitation feedbacks—important yet poorly understood and observed components of the hydrological cycle. We have begun using CloudSat for validation of our mesoscale and global NWP models, and in support of research programs that requires details on cloud vertical structure. Although the CPR is a nadir-only sensor, these measurements provide operationally relevant information (particularly in the data-sparse/void areas where many DoD flight operations often occur) when proper horizontal spatial correlations are applied. All the efforts mentioned above would clearly benefit from an extended CloudSat mission.

As you begin to consider the options for the future of CloudSat, we hope you will keep in mind the many important benefits this mission is currently providing to both research and operational centers. Every additional day that this technology continues to operate provides a wealth of new and unique information. If there is any further information we can provide you concerning this matter, please do not hesitate to ask.

Best Regards,

SIMON W. CHANG
Superintendent

Cc:
Don Anderson, NASA HQ
Hal Maring, NASA HQ
Steve Volz, NASA HG
Graeme Stephens, CSU
Deborah Vane, JPL
Diane Evans, JPL
Randy Friedl, JPL

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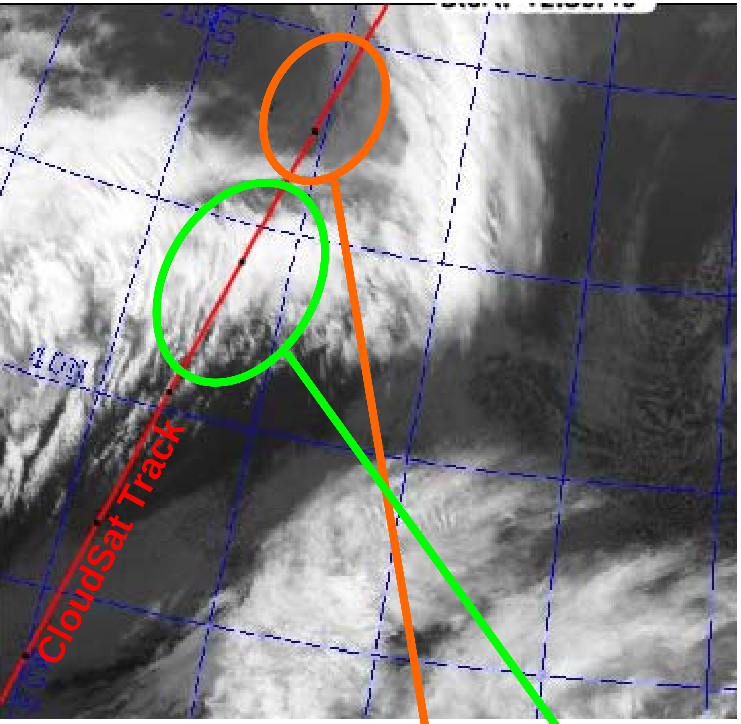
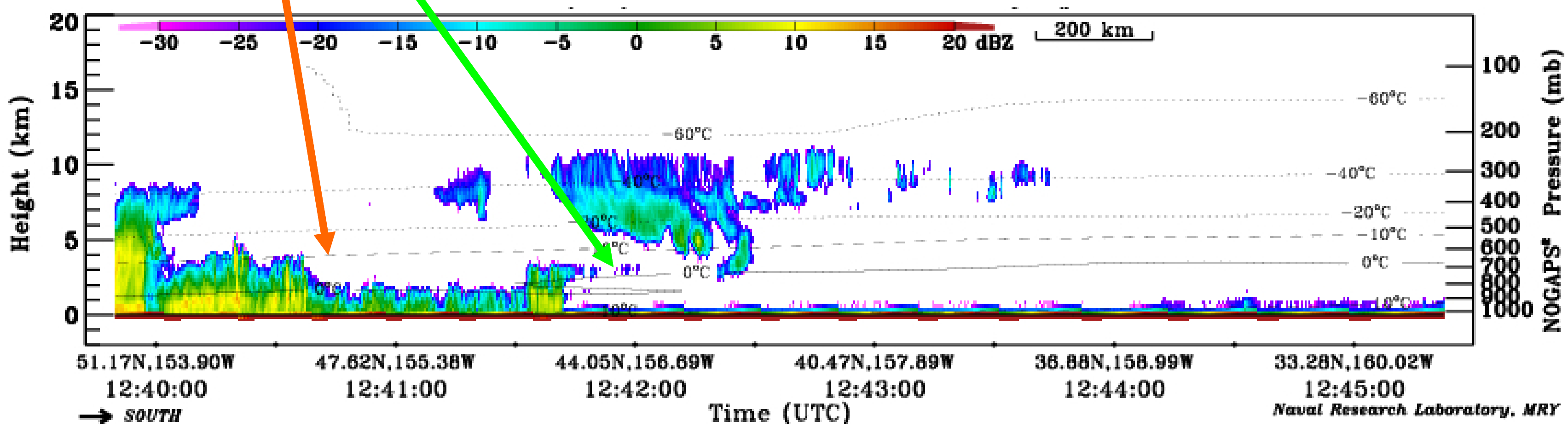
…these measurements provide operationally relevant information (particularly in the data-sparse/void areas where many DoD flight operations often occur).

U.S. Coast Guard Support

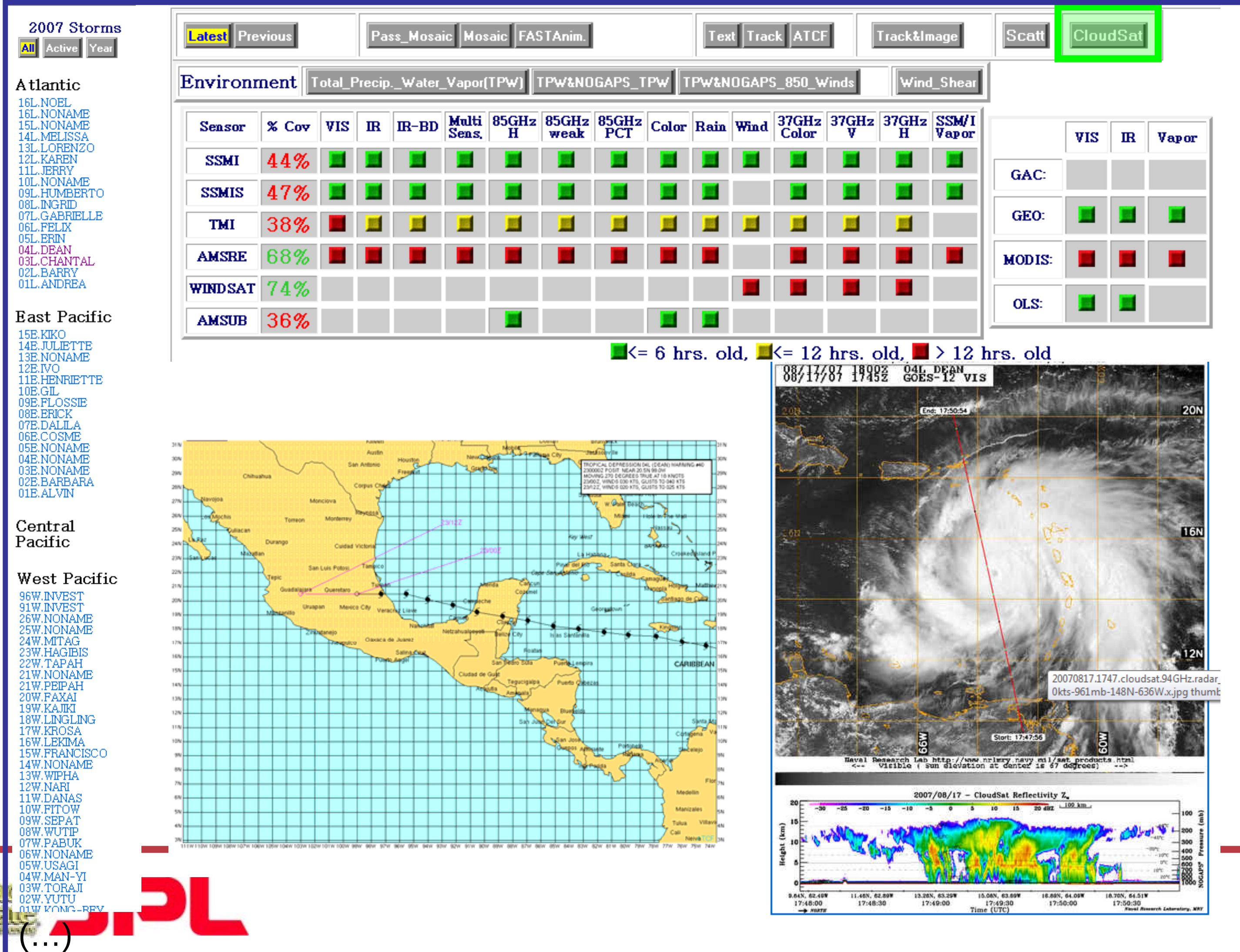


- Summer/Fall 2006, U.S. Coast Guard aircraft flew patrols for unlicensed fishing boats over the North Pacific.
- Operations were challenged by cloud obscuration (blocking pilot's view of surface).
- Conventional satellite imagery provides a view of the top-most cloud layer, but no information on cloud base height (ceilings) or multi-layered structures for clear line-of-sight to the surface.
- CloudSat was used to identify regions where cloud ceilings permitted/prohibited Coast Guard patrol operations.



Global Tropical Cyclone Tracking and Characterization

- The NRL/FNMOC Tropical Cyclone Web Pages, serving both DoD and Civilian user communities, feature near real-time 'first-look' CloudSat data.



(…)

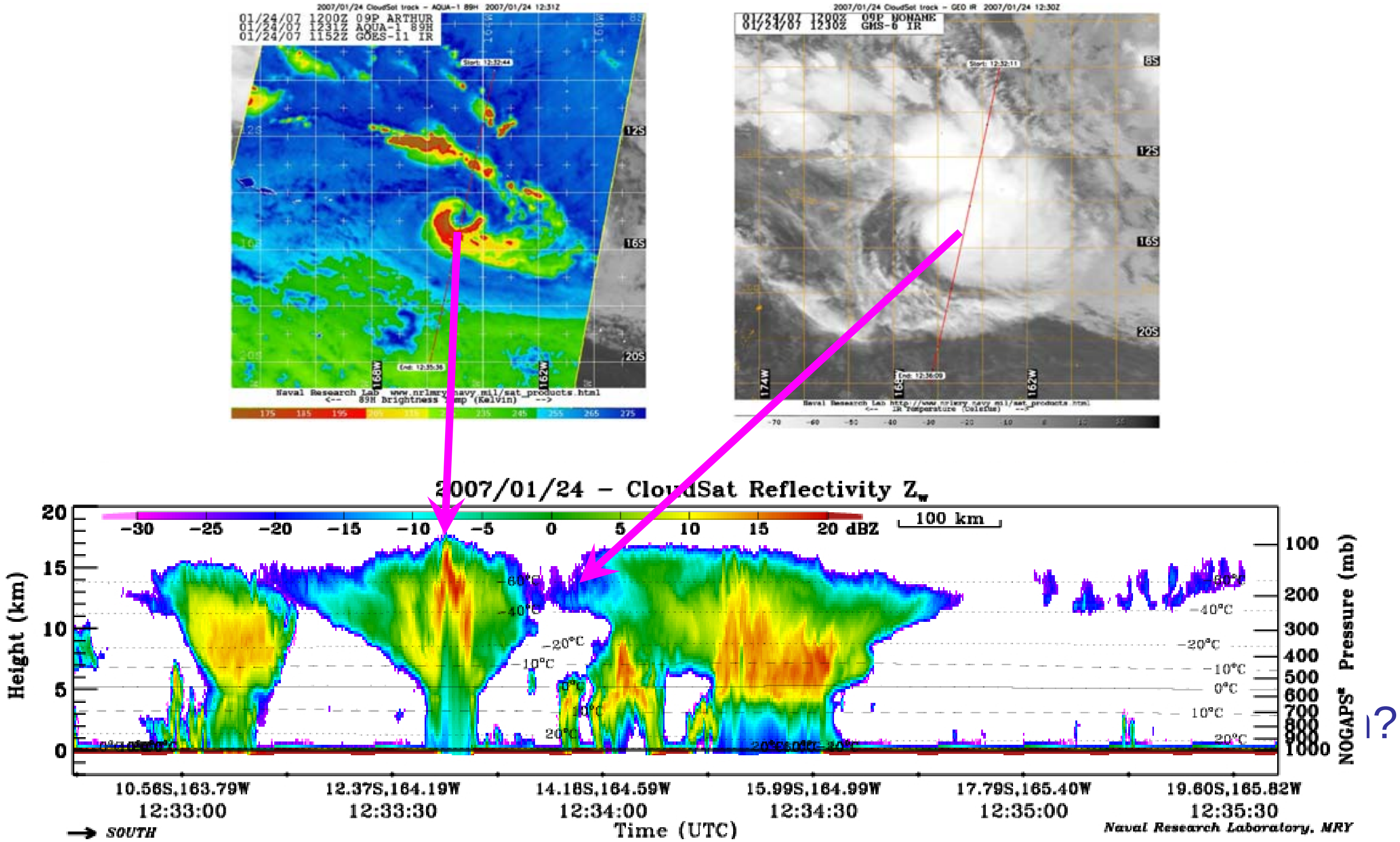
FNMOC

NHC

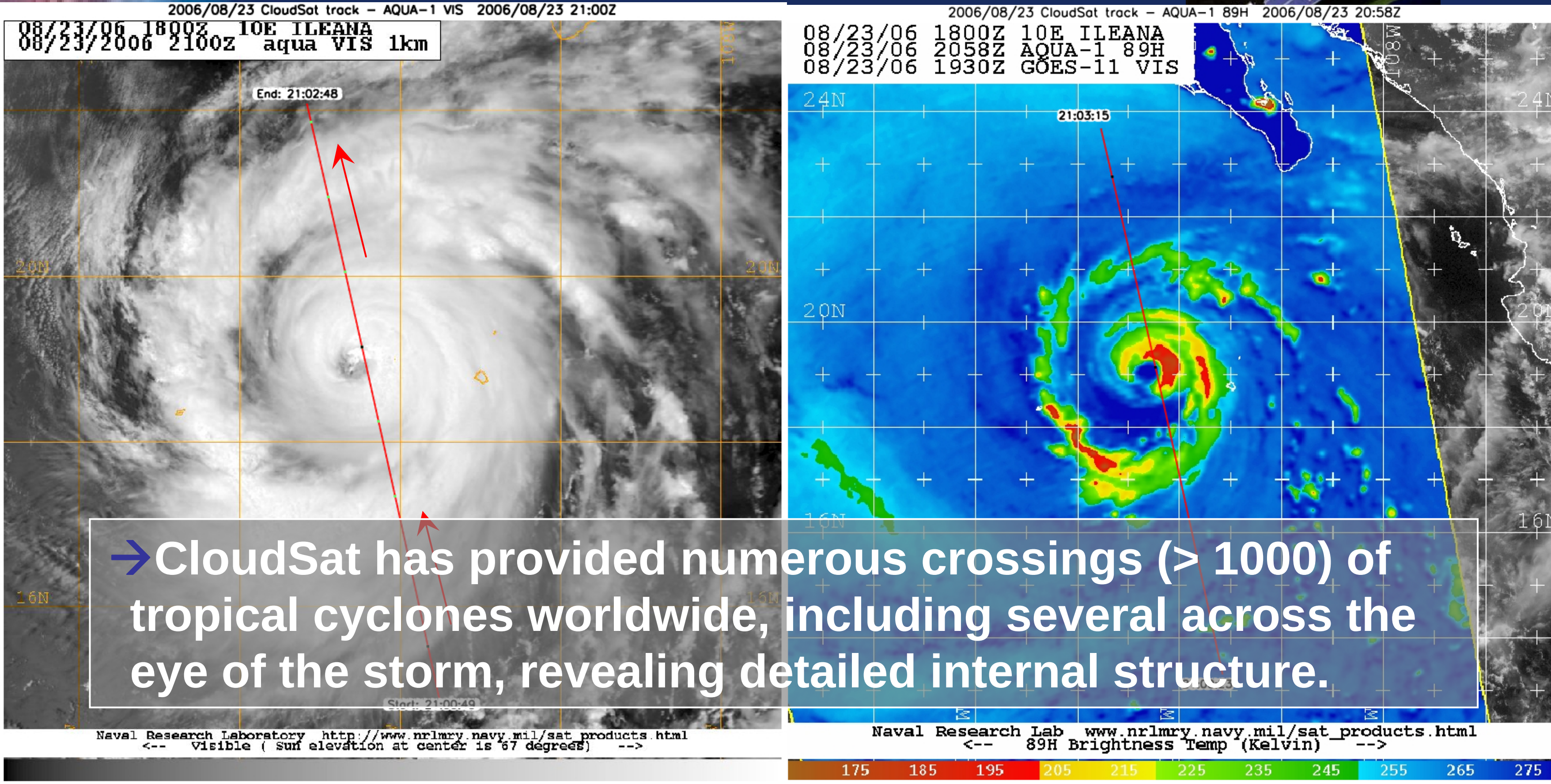
JTWC

TC Web Example: Typhoon Arthur

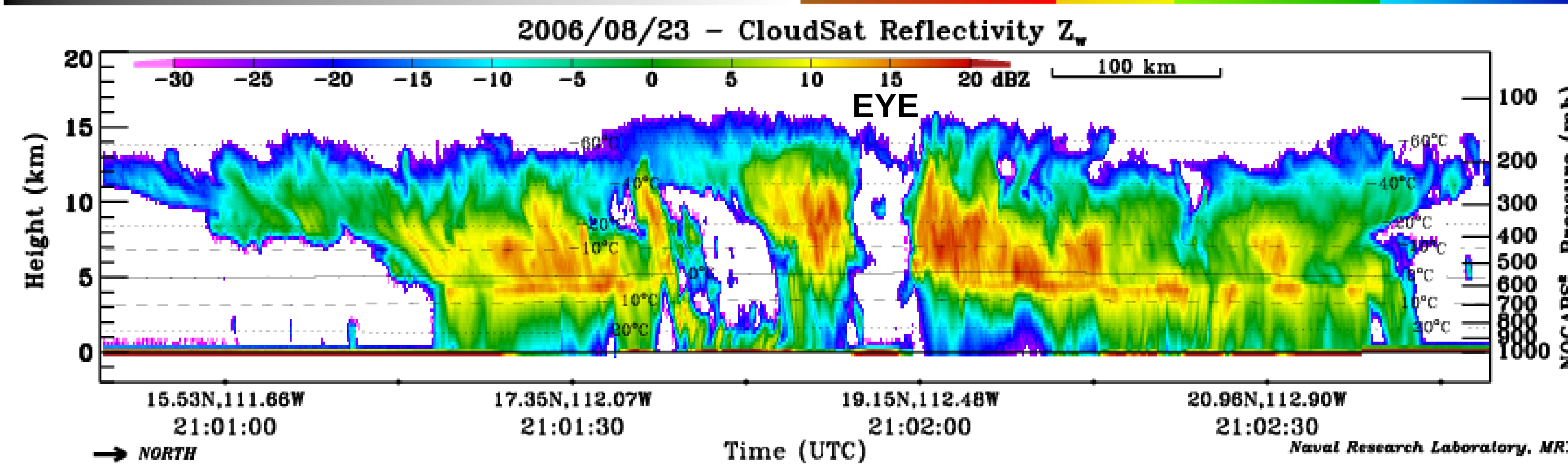
Vertical Extent of Convective Burst | **Vertical Extent of Central Dense Overcast Eye**



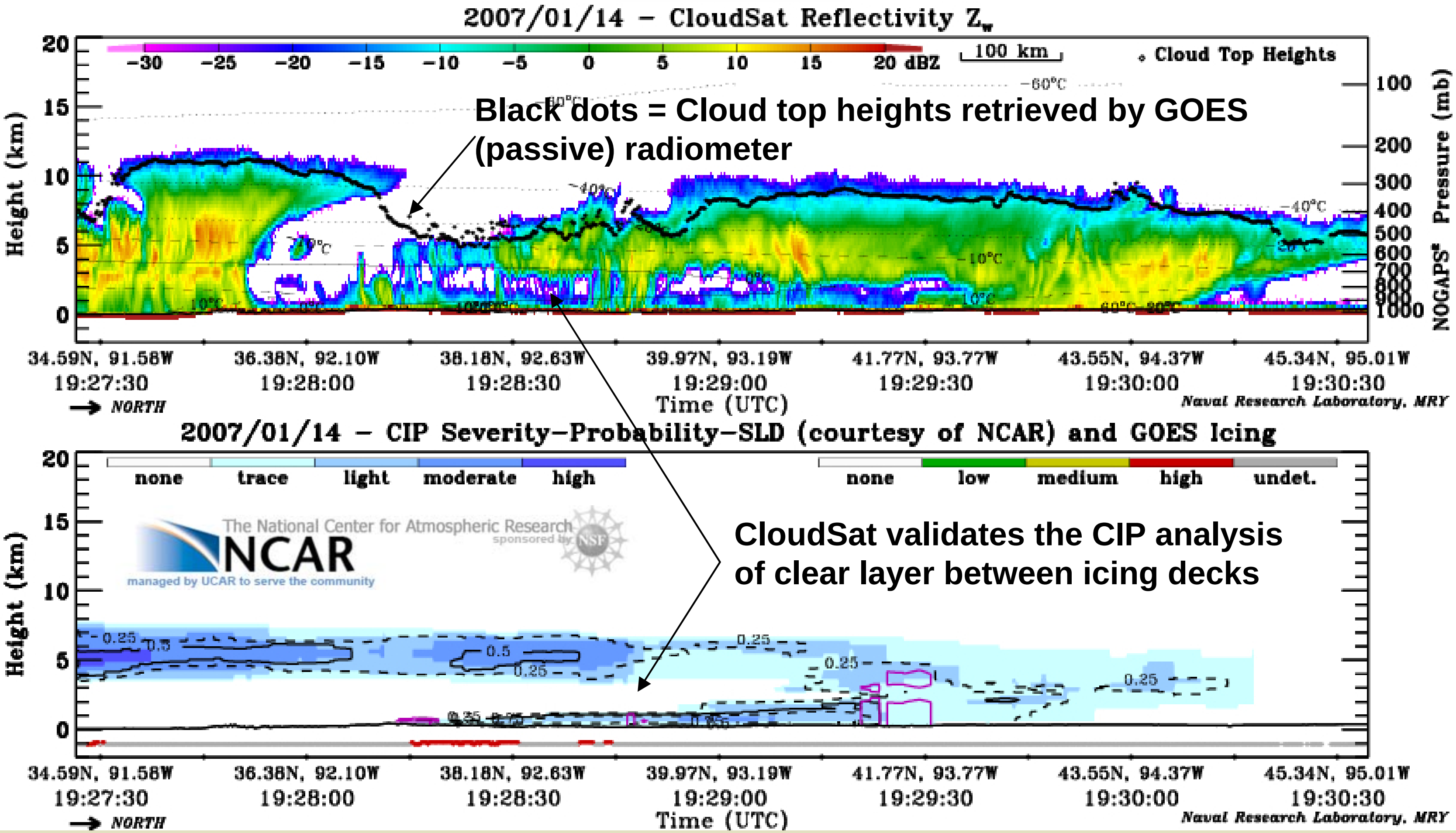
→ NRL/CSU are compiling a Tropical Cyclone CloudSat-intercept database to provide researchers the first global statistics on storm vertical structure.



→CloudSat has provided numerous crossings (> 1000) of tropical cyclones worldwide, including several across the eye of the storm, revealing detailed internal structure.



Aircraft Icing Support



→ CloudSat-derived vertical structure provides a valuable new tool for analysis and validation of the NCAR/FAA Current Icing Potential (CIP) product.

NexSat Near Real-Time Demonstrations

- CloudSat is now showcased on the NPOESS demonstration and educational website

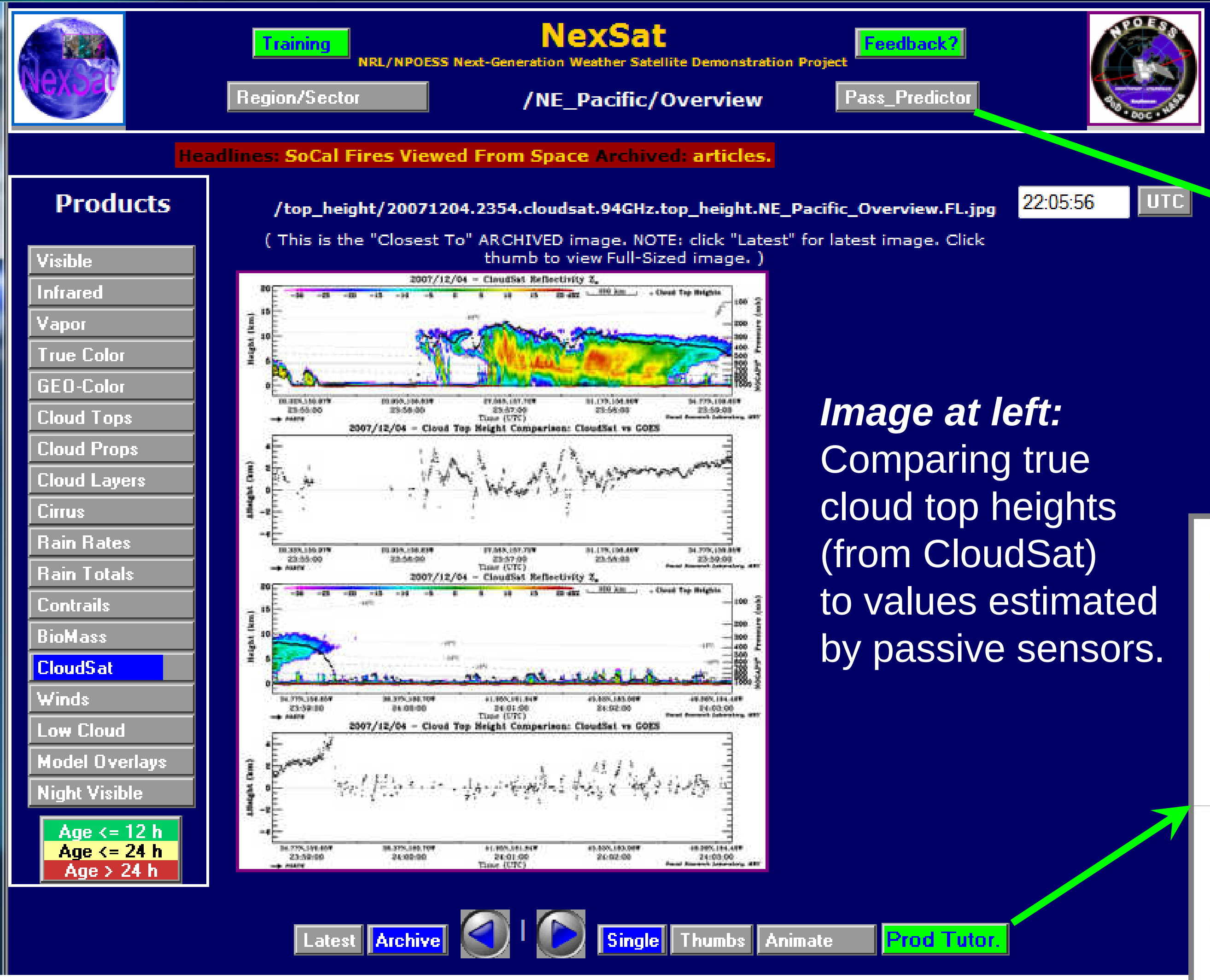
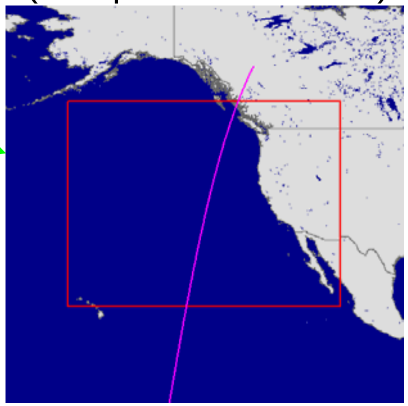
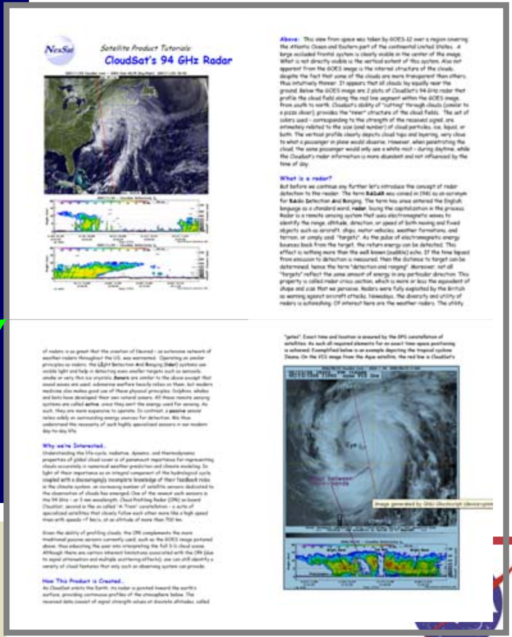


Image at left:
Comparing true cloud top heights (from CloudSat) to values estimated by passive sensors.

Satellite Pass Predictors
(for operational users)



New User Training Modules



→ CloudSat provides an important source of validation for new algorithms being developed for the future NPOESS constellation

CloudSat makes the measurements that delivers rudimentary knowledge on

How much water resides in clouds and how much rain and snow is produced

How much heat is generated to fuel storms

How much sunlight is reflected to space, or how the planets greenhouse effect is changed by clouds

Summary

The new observations collected from CloudSat combined with other A-Train observations are beginning to shed new understanding on important climate processes.

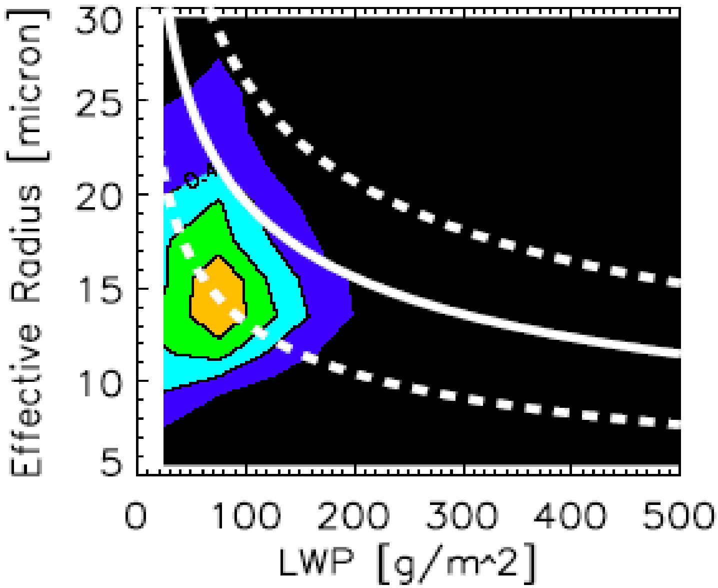
These new observations tell us about:

1. Cloud changes in the polar regions, and the effects of these changes on the energy balance of the Arctic, their relation to weather changes and their role in sea ice change.
2. How frequently clouds rain and how much rain falls over the global oceans - thus offering insight into processes critical to the cycling of fresh water.
3. How properties of clouds AND precipitation together change with increasing aerosol, thus offering new insights into how aerosol might indirectly affect climate.

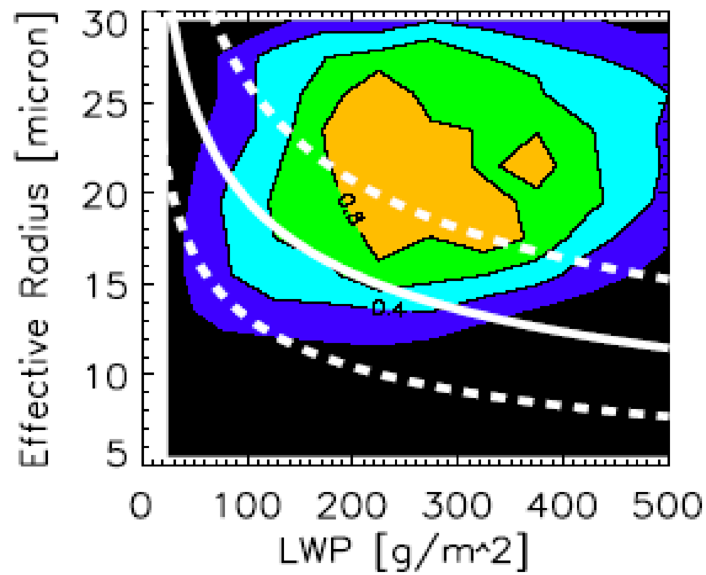
Backups

Water and Particle Size Properties of Warm Clouds From A-Train Data

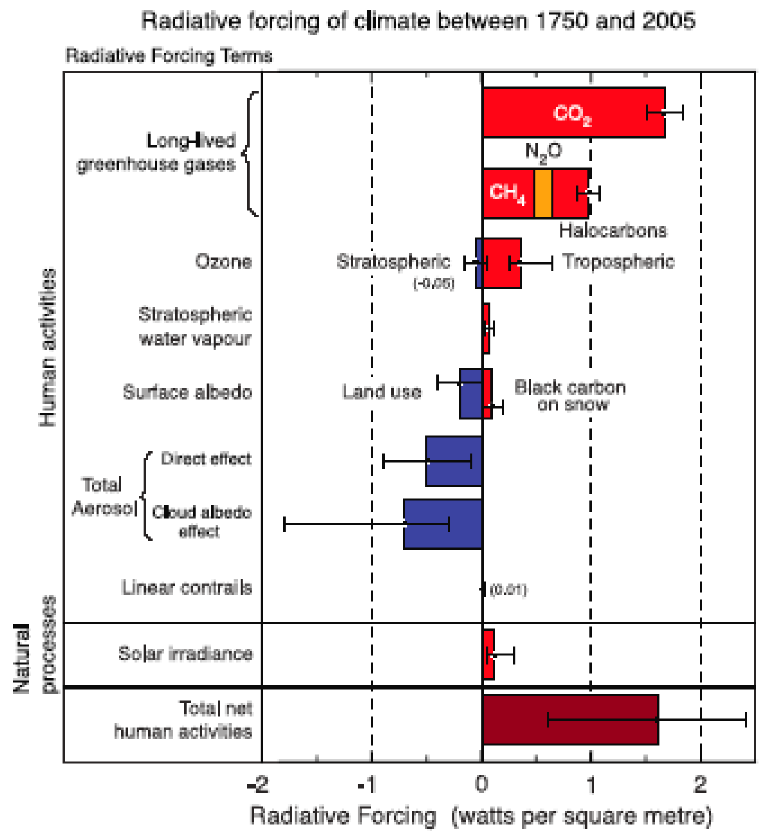
No Precipitation



Certain Precipitation

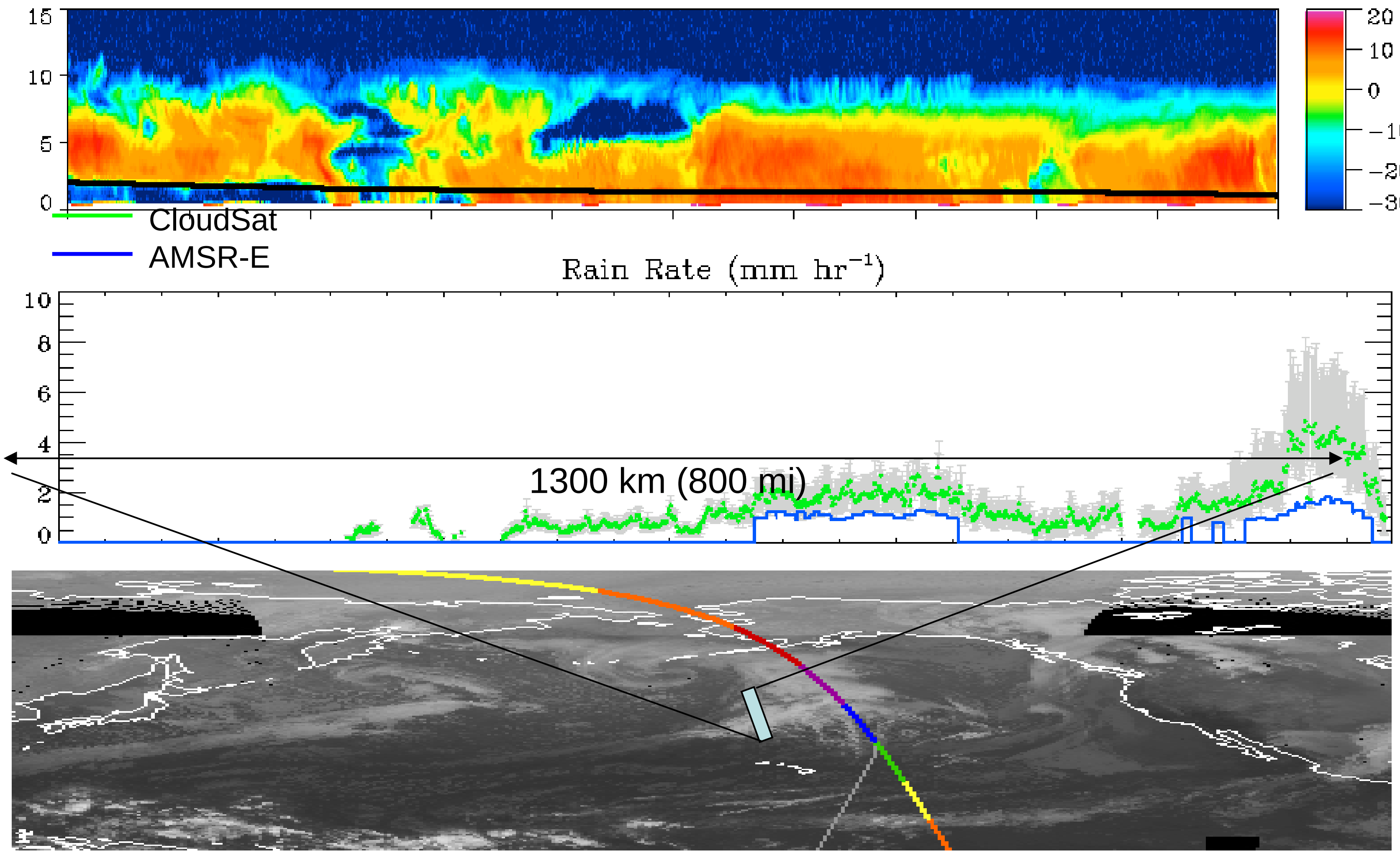


The aerosol forcing factors of climate are highly uncertain and aerosol indirect effects are most uncertain of all.

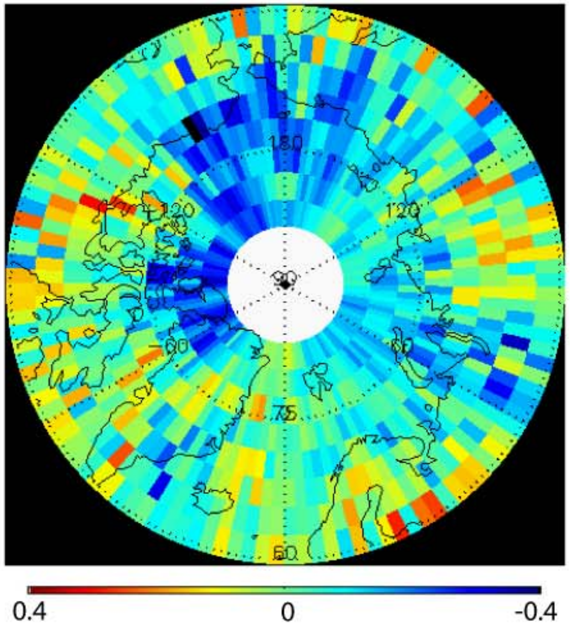


FAQ 2.1, Figure 2. *Summary of the principal components of the radiative forcing of climate change. All these radiative forcings result from one or more factors that affect climate and are associated with human activities or natural processes as discussed in the text. The values represent the forcings in 2005 relative to the start of the industrial era (about 1750). Human activities cause significant changes in long-lived gases, ozone, water vapour, surface albedo, aerosols and contrails. The only increase in natural forcing of any significance between 1750 and 2005 occurred in solar irradiance. Positive forcings lead to warming of climate and negative forcings lead to a cooling. The thin black line attached to each coloured bar represents the range of uncertainty for the respective value. (Figure adapted from Figure 2.20 of this report.)*

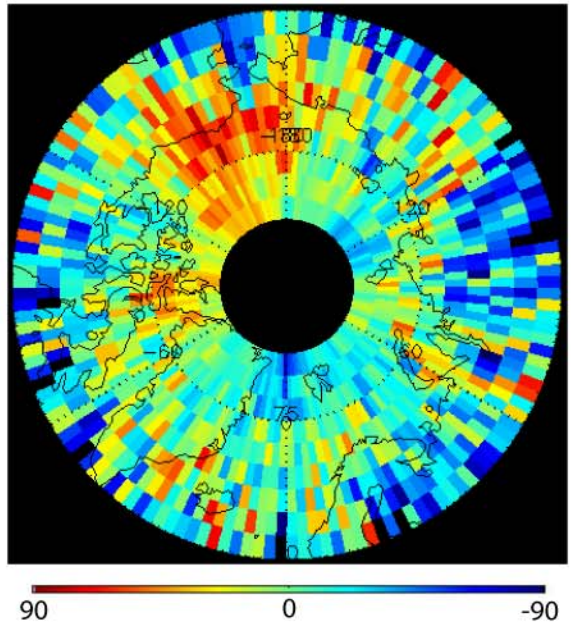
IPCC, 2007


15
10
5
0
20
10
0
−10
−20
−30
CloudSat
AMSR-E
Rain Rate (mm hr⁻¹)
10
8
6
4
2
0
1300 km (800 mi)

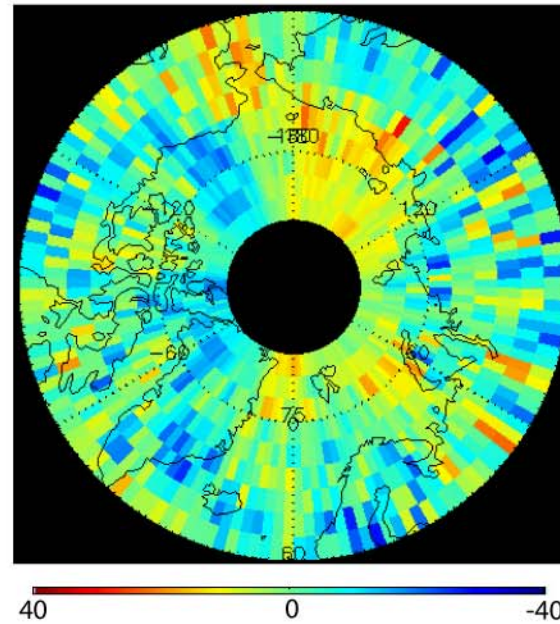
2007-2006 Cloud and Surface Radiation Differences



Cloud Fraction



Downwelling Solar Radiation (W m^{-2})

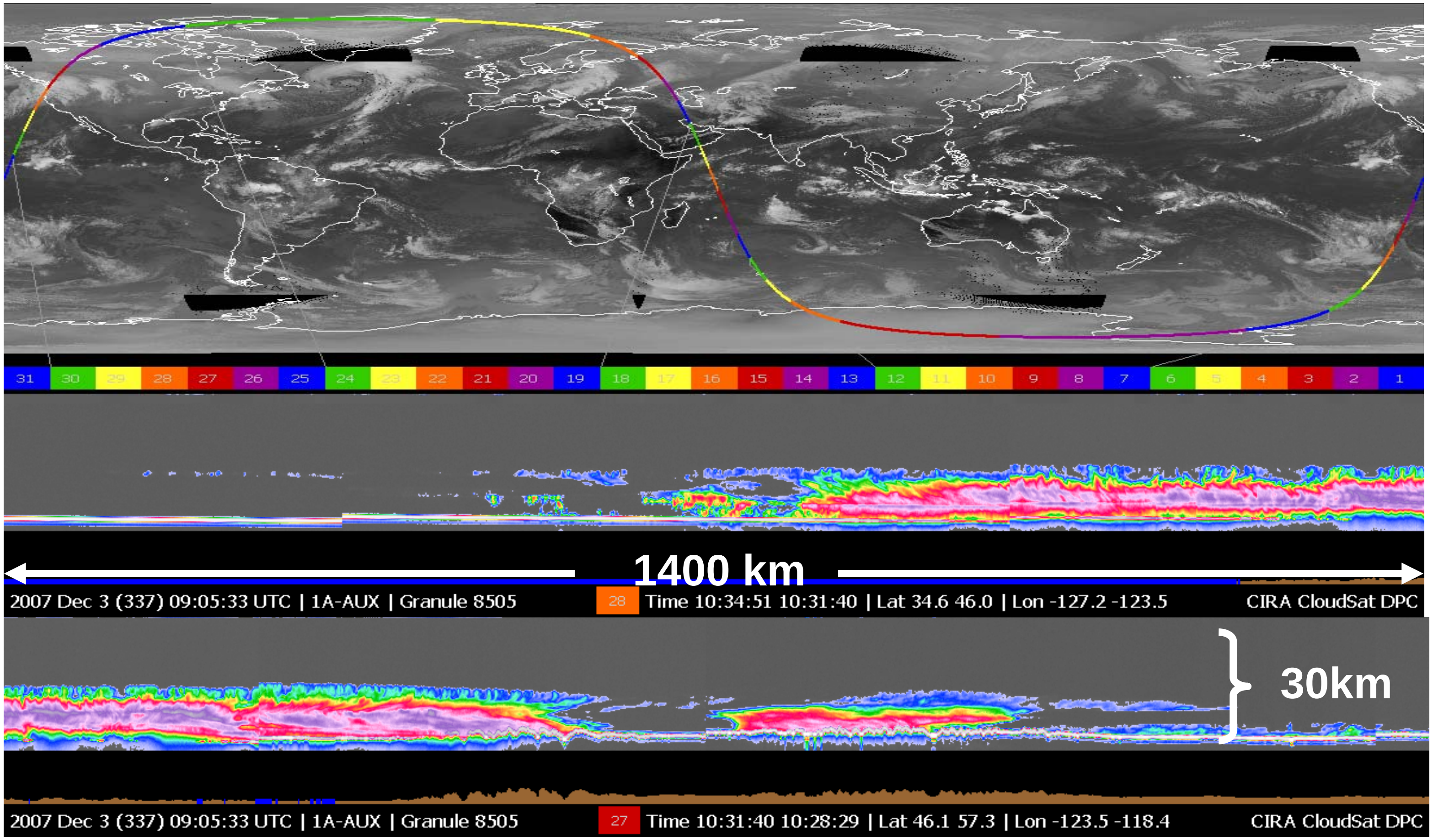


Downwelling Longwave Radiation (W m^{-2})

Radiation Calculations by T. L'Ecuyer (CSU).

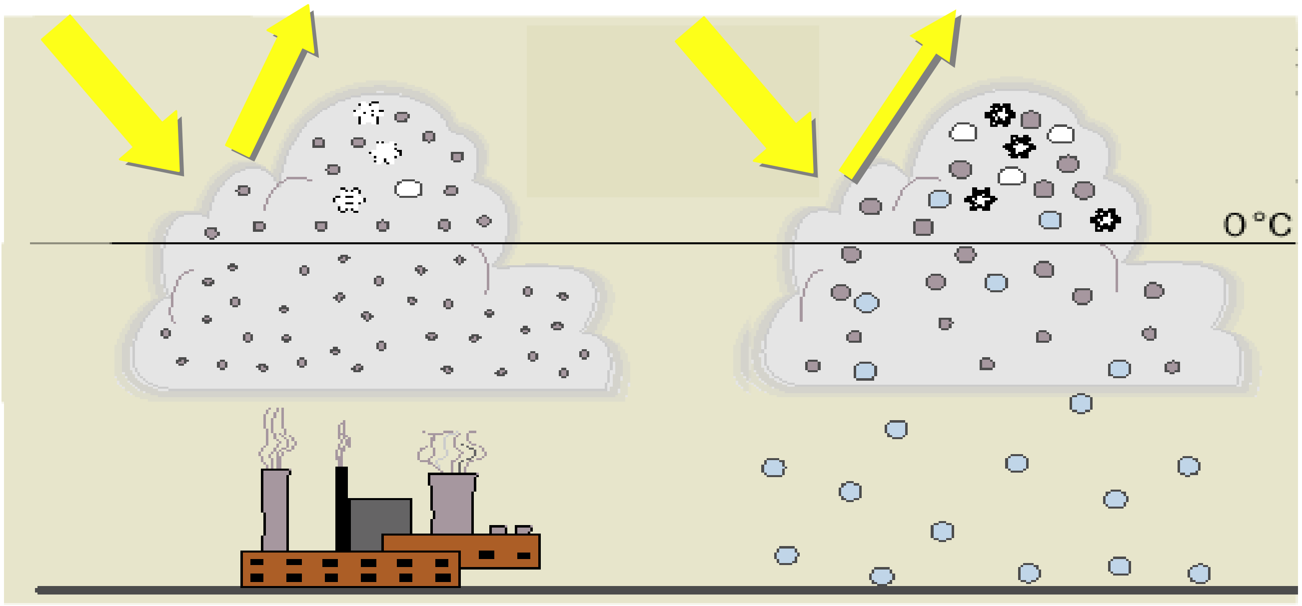
These radiation differences alone could melt ~0.3 meters of sea ice and increase ocean mixed layer temperatures by ~1.6 degrees Kelvin.

Views of Weather on Scales Not Seen Before



Example of CloudSat 'quicklook' data taken directly from the CloudSat data processing center (http://cloudsat.cira.colostate.edu)

Aerosol Pollution is Making Clouds Brighter



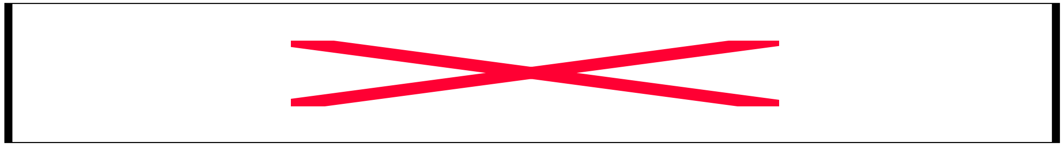
Polluted clouds = more drops, smaller drops, less precipitation, more reflected sunlight

Clean clouds = fewer drops, larger drops, more precipitation, less reflected sunlight

Lebsock and Stephens, 2007

Two Principle Influences in ‘Warm’ (Liquid Water) Clouds:

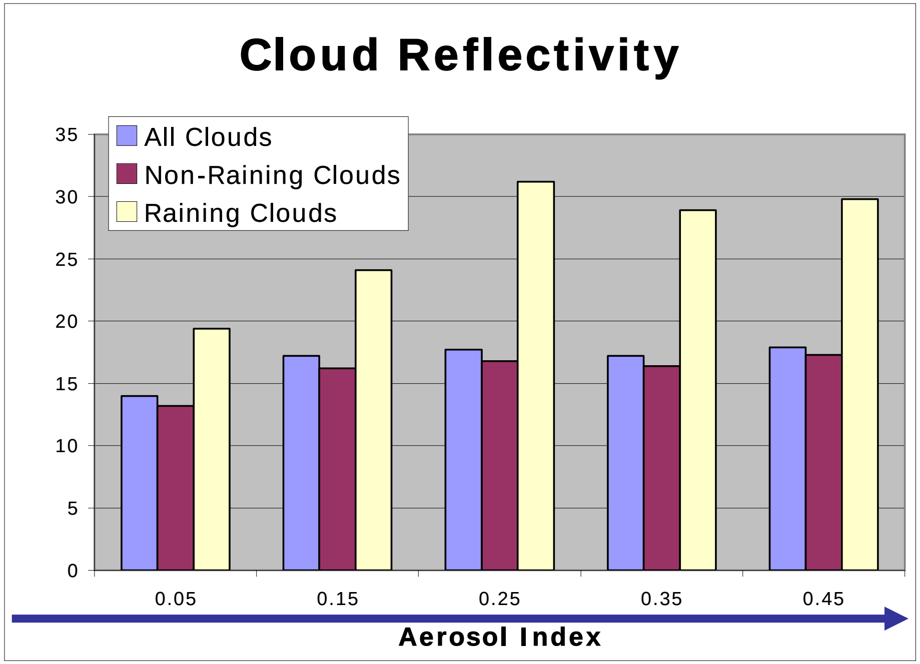
1) Changes to Cloud Reflection (Twomey Effect)



2) Changes to Precipitation

A simple example of the Twomey effect - the tracks of ships below the clouds appear in clouds through the ship effluents that act as an enhanced source of cloud condensation nuclei.

Raining clouds are also brighter

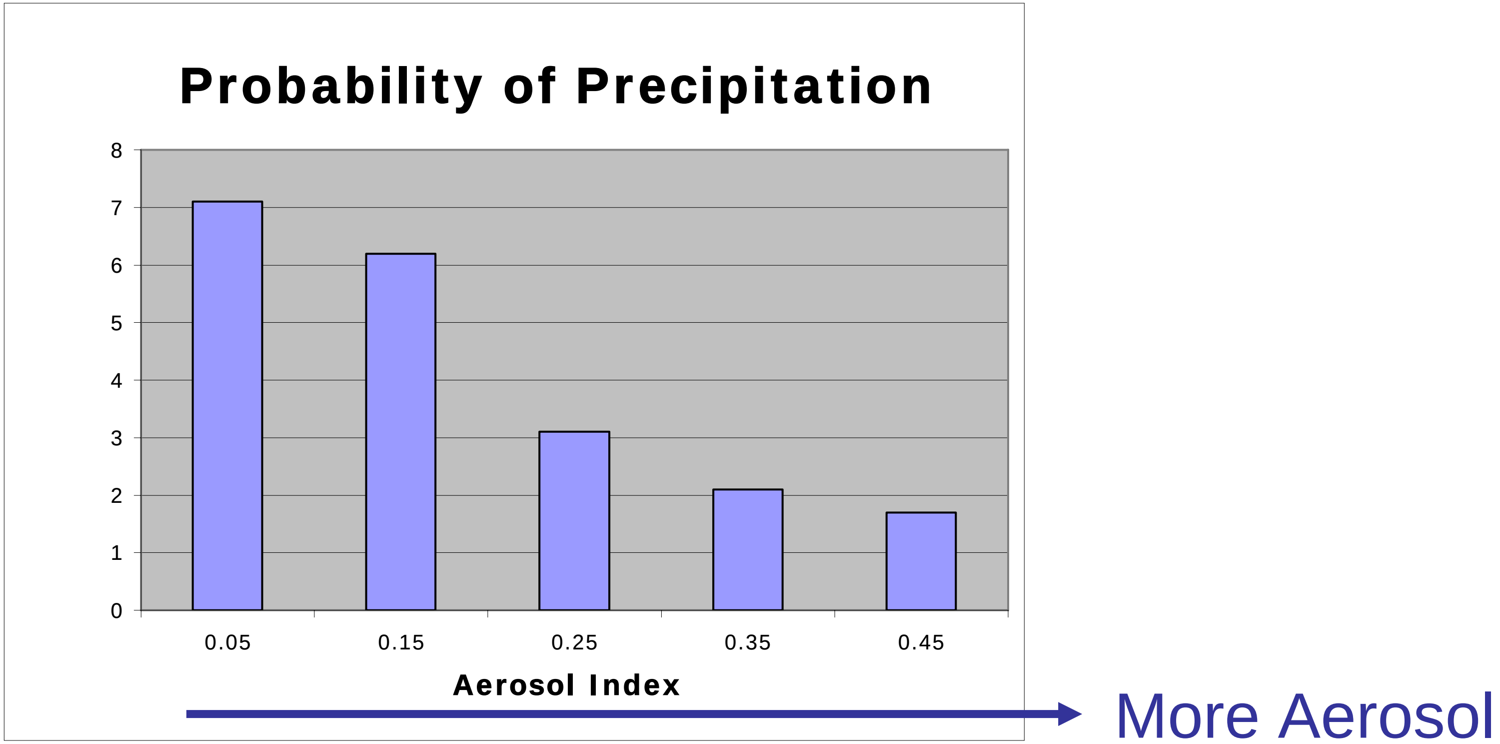


More Aerosol

It's not just the smaller particle sizes of polluted clouds that determine increases in reflected solar radiation.

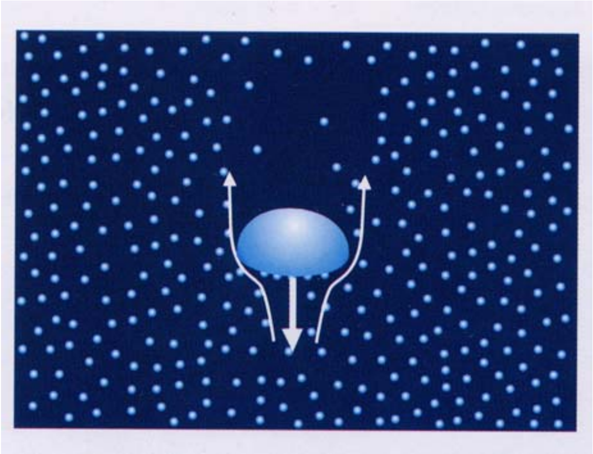
Raining clouds in high aerosol air are thicker, wetter and more reflective.

It Also Rains Less in High Aerosol Air



The probability of precipitation decreases dramatically as aerosols increase - this has been hypothesized for a long time but now it is confirmed with observations.

The coalescence in warm cloud

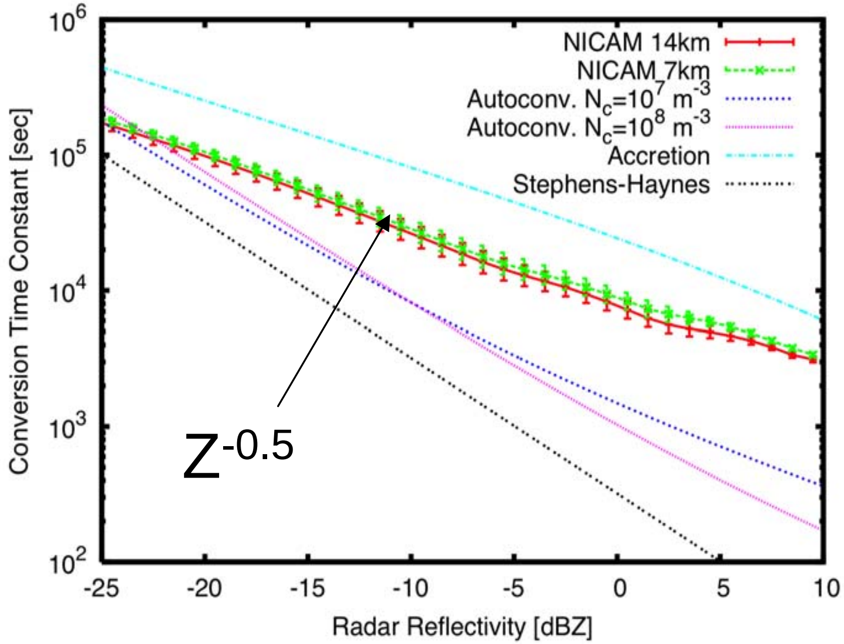


Stephens and Haynes (SH), 2007 indicated that the rate of conversion of cloud water to rain water is determined by the measured CloudSat CPR reflectivity

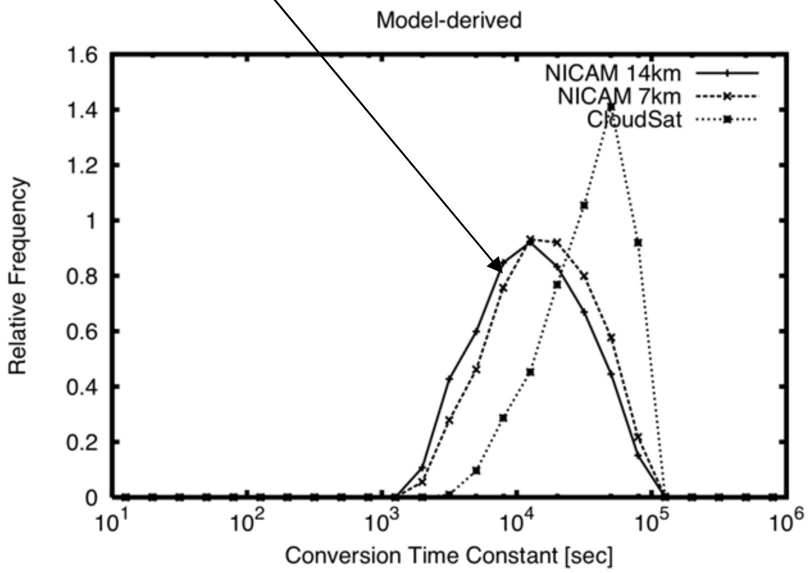
For auto-conversion processes (SH), $\tau \propto Z^{-1}$

For combined auto-conversion/accretion, $\tau \propto Z^{-0.5}$ derived from the NICAM global CRM

Suzuki and Stephens, 2007



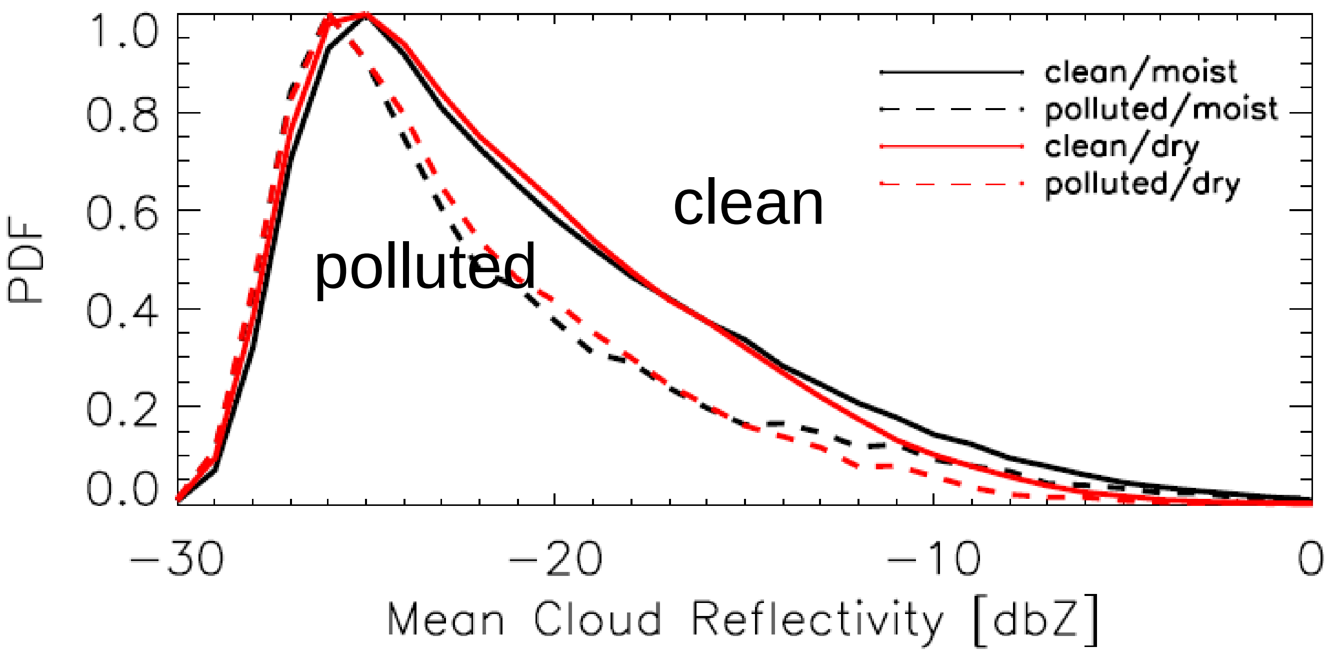
Global cloud model with CloudSat simulator



The real message is that models invoking even different assumptions about coalescence also suggest Z is related to the time scale of the conversion process

The reflectivity difference implies time scale differences which have therer root cause in lack of rain out in the CRM

Provides a new interpretation of reflection data



This maybe the first real evidence that aerosol may be slowing the coalescence process