



**CLOUDSAT**

NASA EARTH SYSTEM SCIENCE PATHFINDER MISSION



# 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.



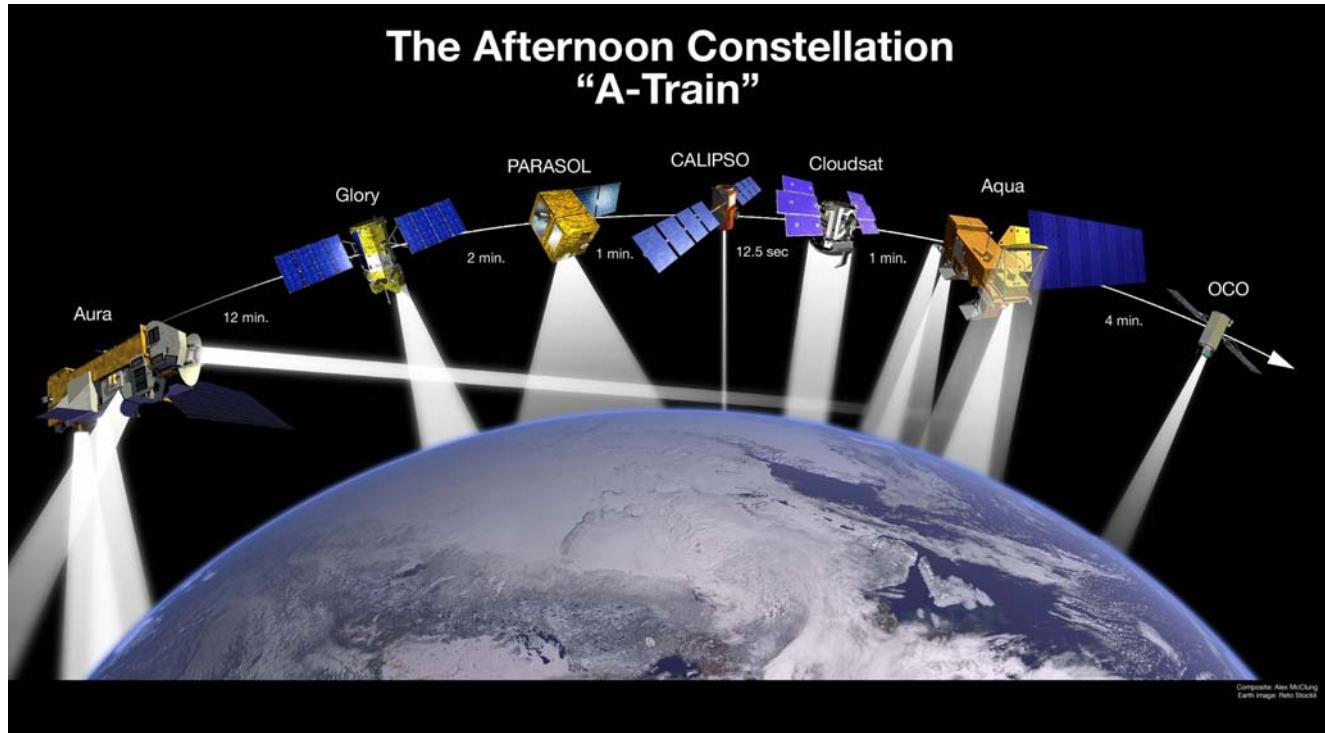
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Launch, April  
28, 2006

# 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.

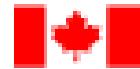


Science leadership & data processing CIRA



Mission management & payload development

Spacecraft



Canadian Space Agency Subsystem development, validation, (CONTRIBUTION)



USAF Ground operations system (CONTRIBUTION)

Calipso

Formation flying (CONTRIBUTION)



DOE

Science, validation and analyses (CONTRIBUTION)

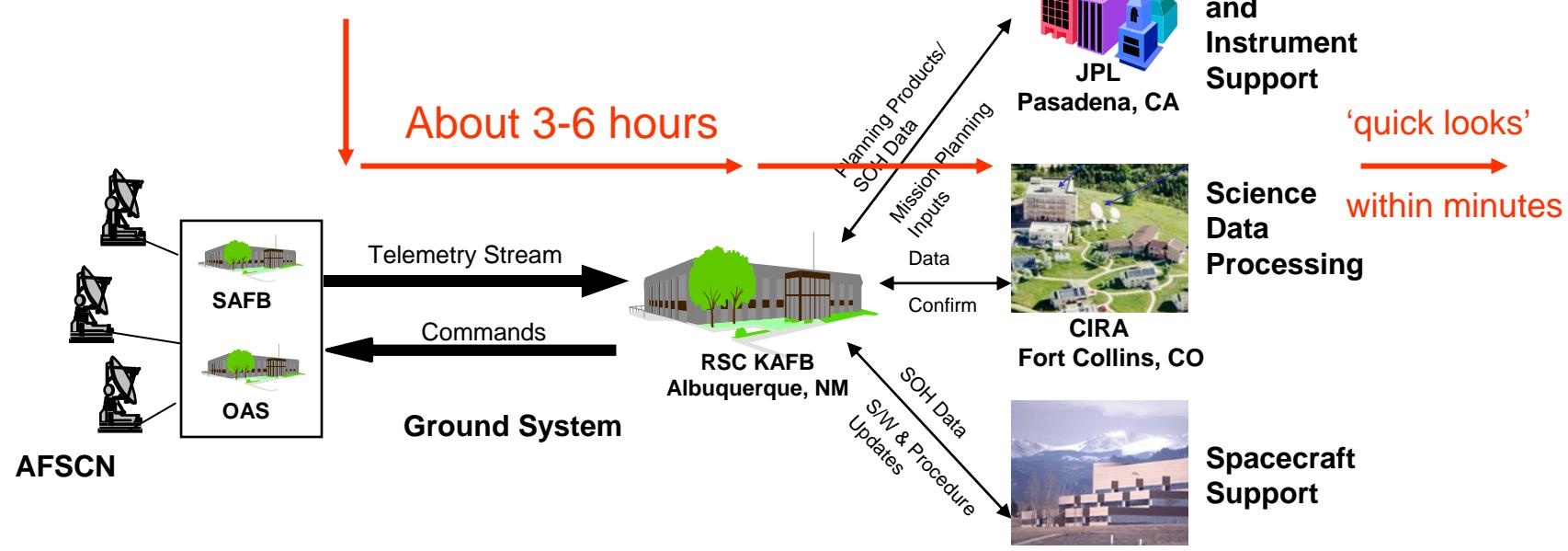
Universities world-wide,

Weather centers

Major climate groups - part of the next IPCC process

NASA funded investigators ~O(70)

# Mission elements



# Data acquisition performance



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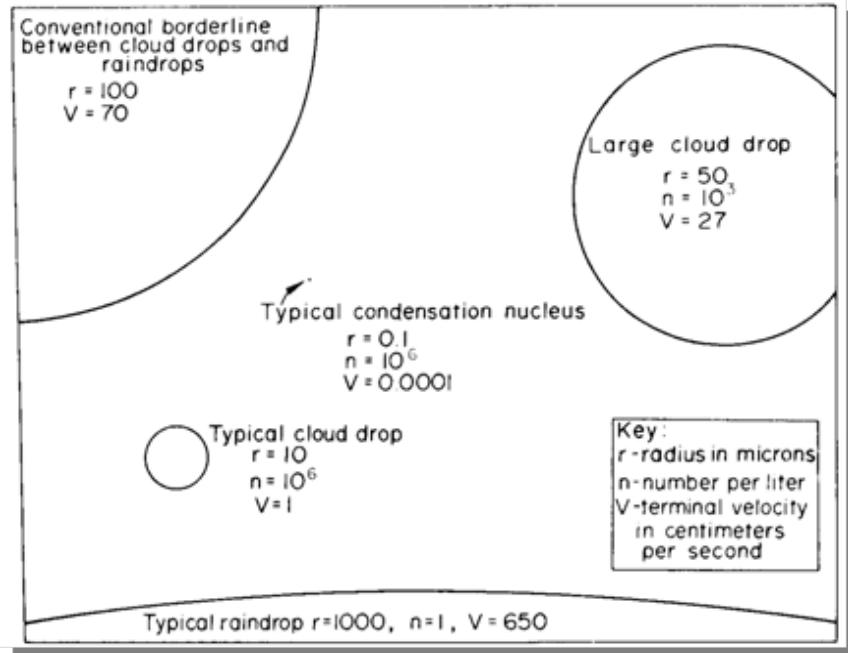
	Requirement	Performance
CloudSat Project	85%	96.93%
CPR	96%	99.17%
Spacecraft	96%	98.52%
RSC	94%	99.21%
CIRA	98%	100%

From June 06-Oct 07

# Why W-band?



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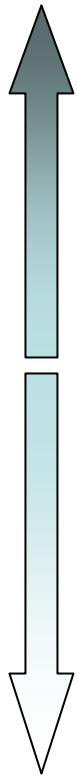


# Why W-band?



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Visible  $\lambda$ 's:  
too much attenuation



S-band  $\lambda$ 's :  
too little sensitivity

Transmitter	Advantage	Disadvantage
Laser (visible, infrared wavelengths; 0.5-10 $\times 10^{-6}$ m)	Sees* all particles of a few $0.1 \times 10^{-6}$ 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) cm wavelength (1-10 cm)	Sees* all particles of a few $\sim 5 \times 10^{-6}$ m (most cloud particles) and greater. <del>No</del> multiple scattering effects Less attenuated under heavy rain	Attenuation in moderate to heavy rainfall <b>Some multiple scattering in heavy rain</b> Unable to see majority of cloud

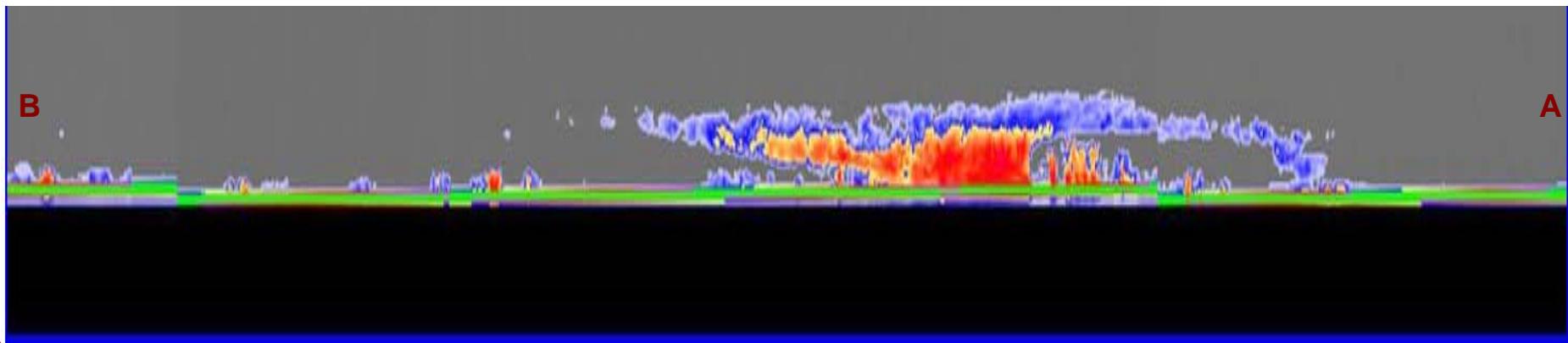
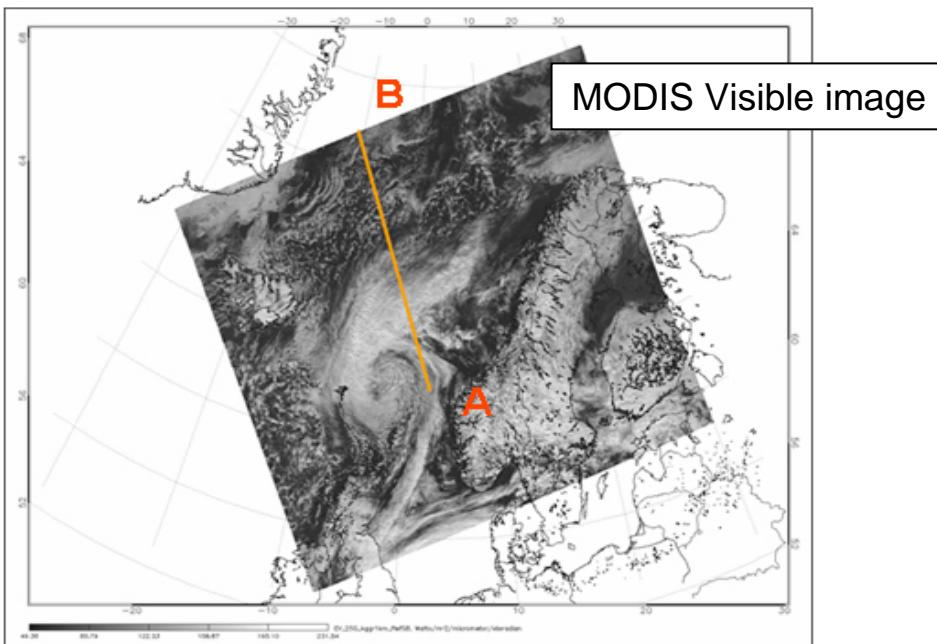
\* Depends also on volume concentration of particles sees ice and water particles with almost equal sensitivity

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**

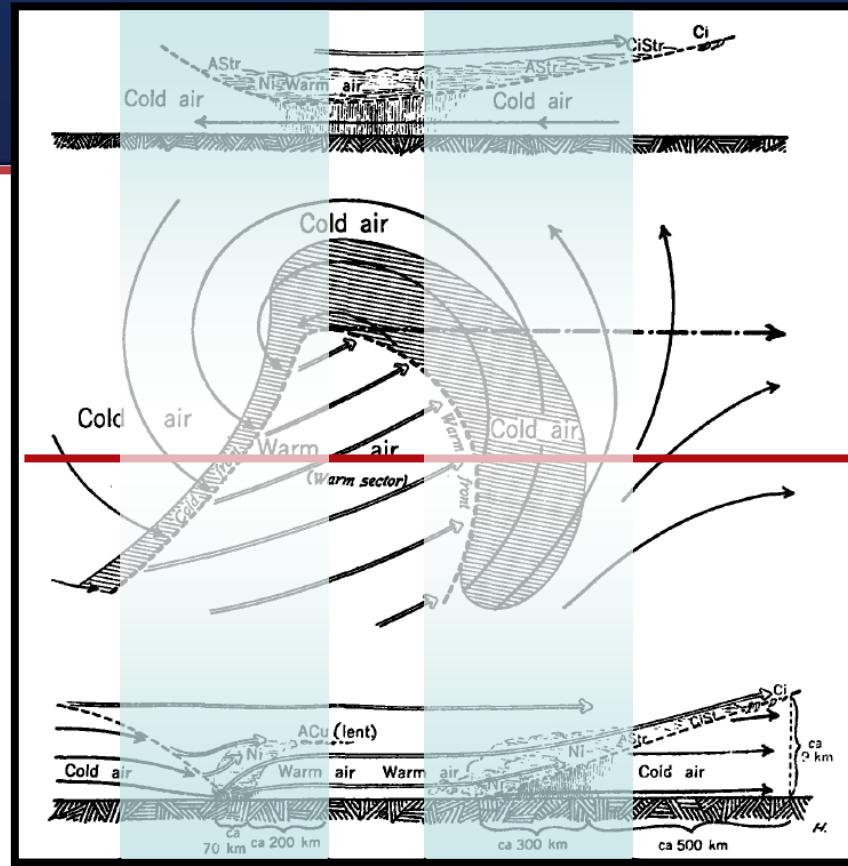


2006 May 20 (140) 11:19 | 1A-AUX | Orb 322 | Seg 22 | Time 12:29 12:26 | Lat 73.3 62.6 | Lon -10.5 2.8 CIRA CloudSat DPC



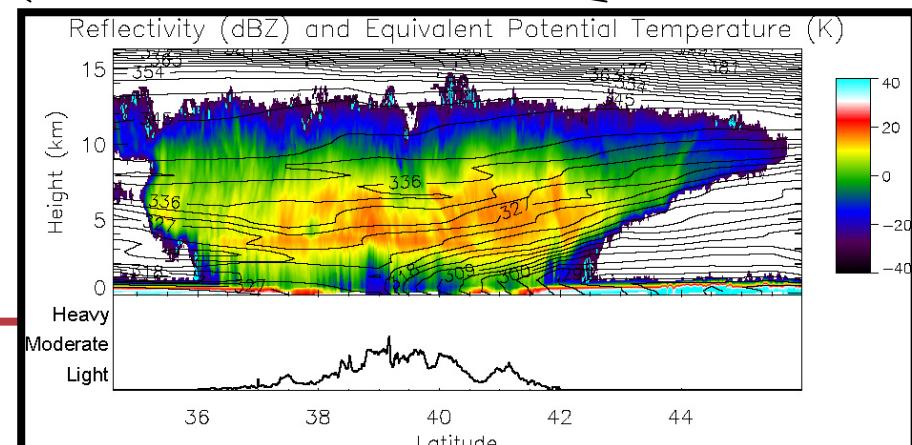
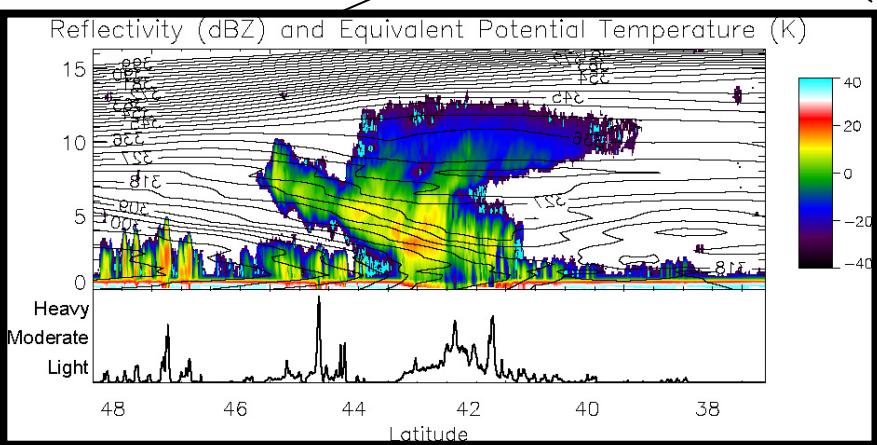
Revisiting history  
The Norwegian  
Cyclone Model  
Circa, 1923

Cold front



Posselt et al., 2007

Warm front +



# Fundamental tests of a theory of hurricane



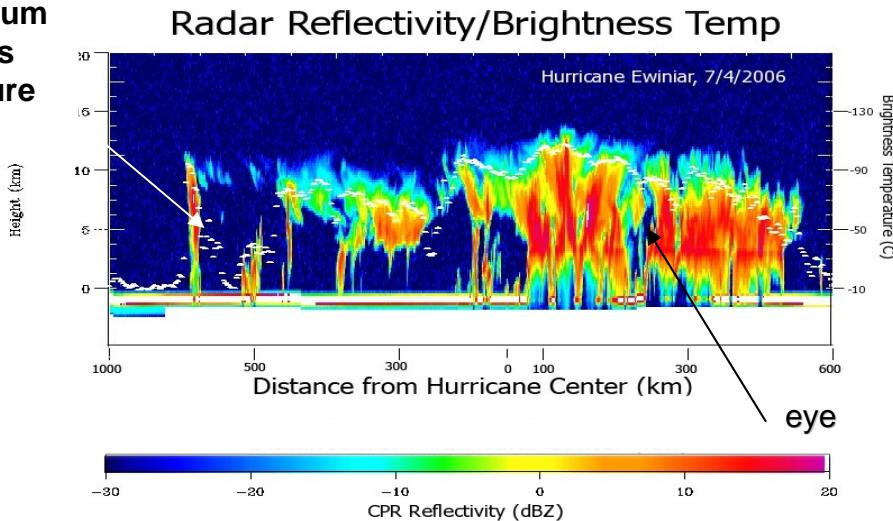
Three unique pieces of information

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

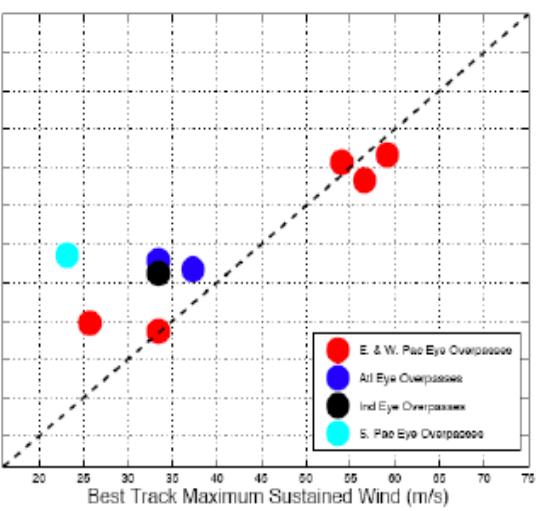
These three pieces of information combine to test the Emanuel theory predicts:

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

MODIS 11um  
brightness  
temperature

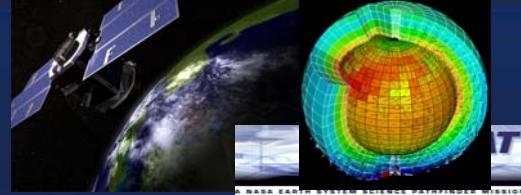


Cloudsat+MODIS data -  
the Emanuel theory



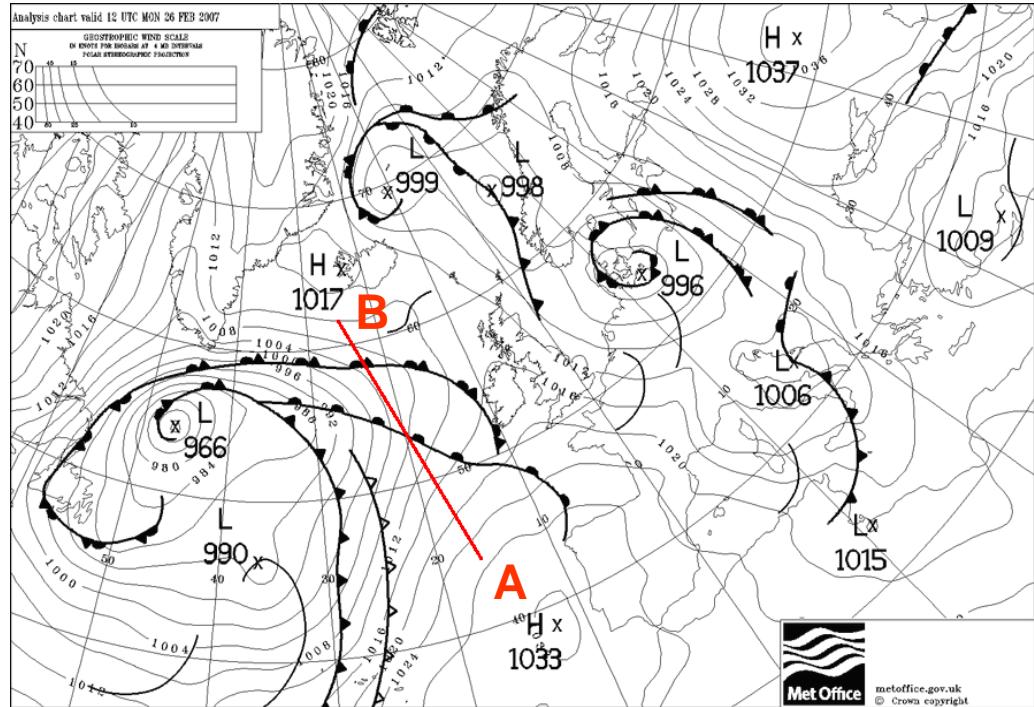
Luo et al., 2007





## Case study example : 26 February 2007

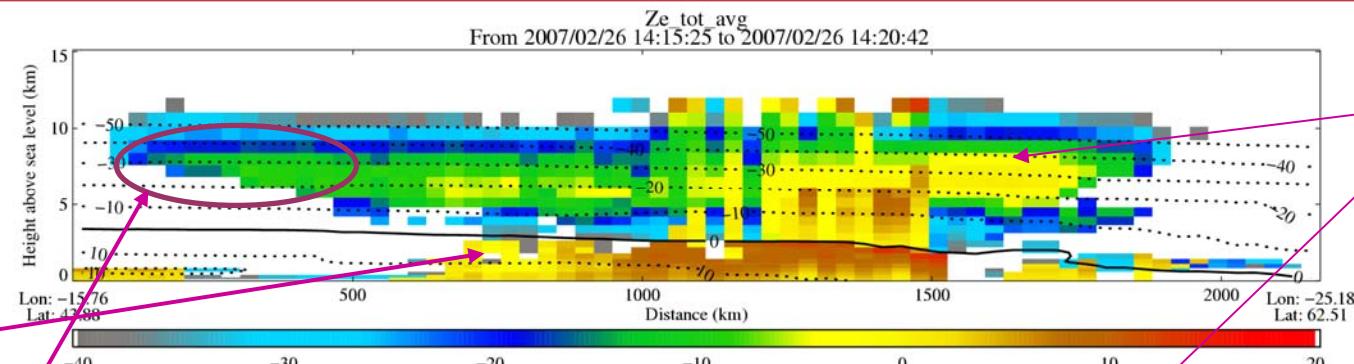
- Analysis chart valid at 12 UTC
- CloudSat overpass at ~14:15 UTC



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

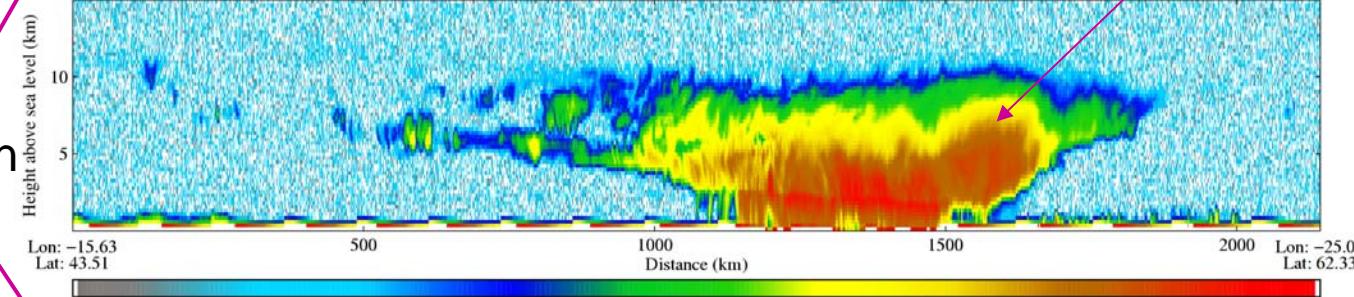


Spurious  
drizzle

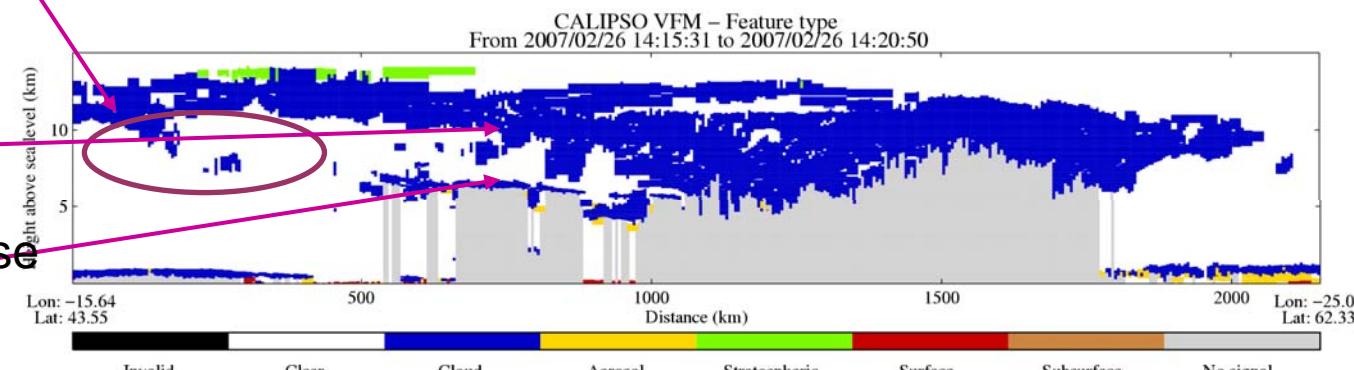


Less IWC

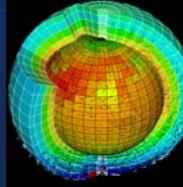
Deep  
evaporation  
zone



Multilayer



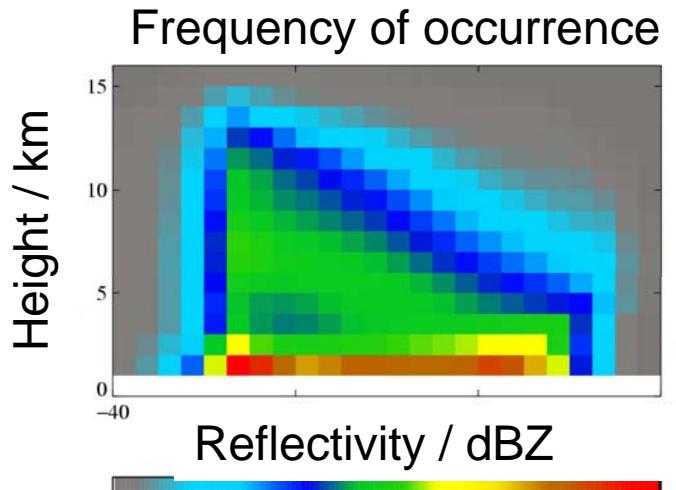
# Quantifying model error



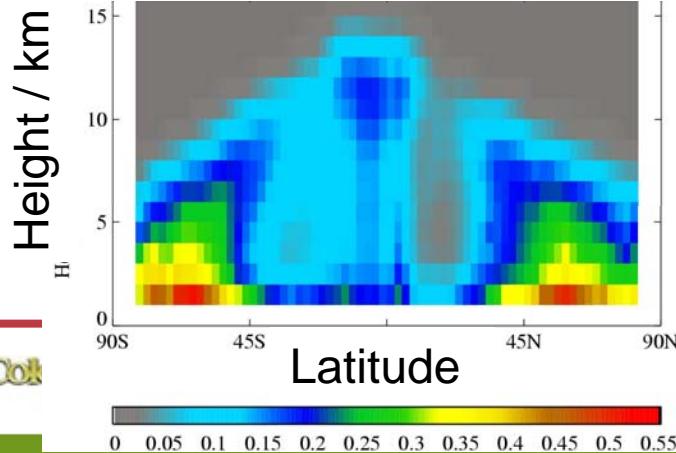
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## Global histograms: 2006/12 – 2007/02

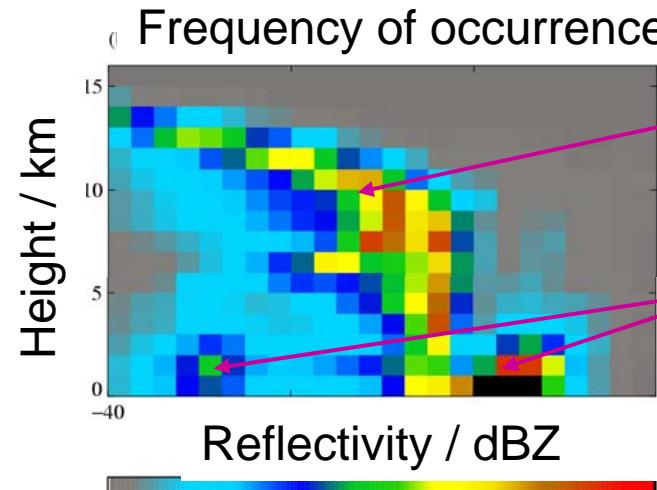
### CloudSat



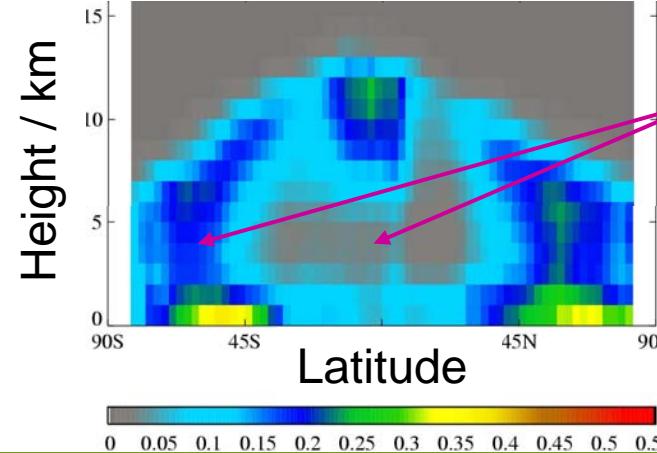
Occurrence of  $Z > -27.5$  dBZ



### MetUM N320L50



Occurrence of  $Z > -27.5$  dBZ



Strong dependence of  $N_0$  with  $T$

Two regimes. Drizzling or not drizzling cloud?

Lack of mid-level cloud

Col

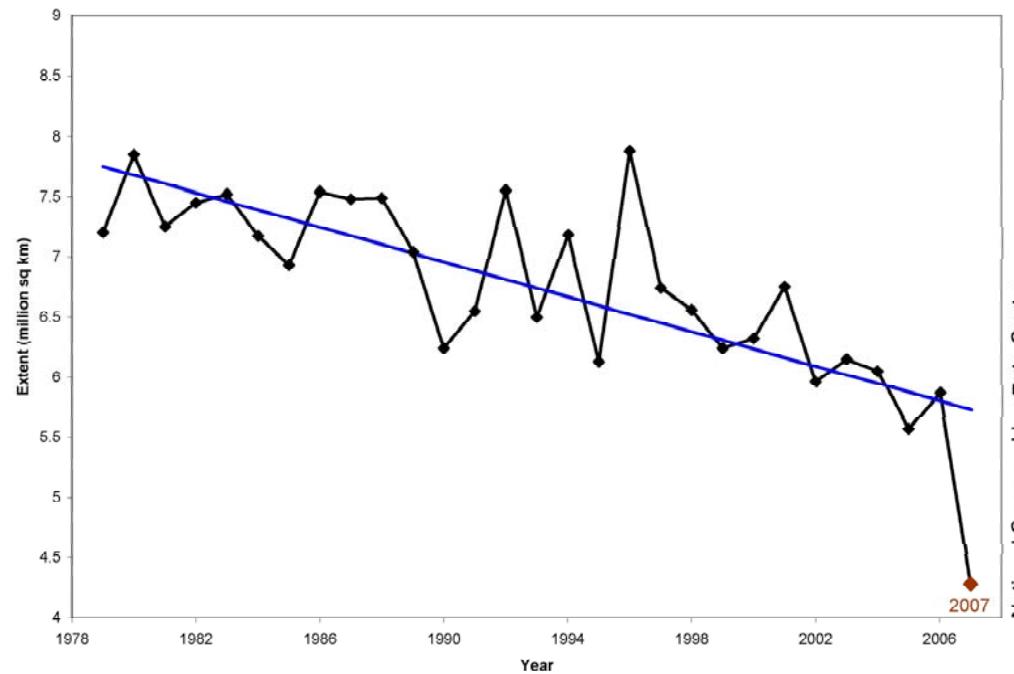


# The Disappearance Act of 2007



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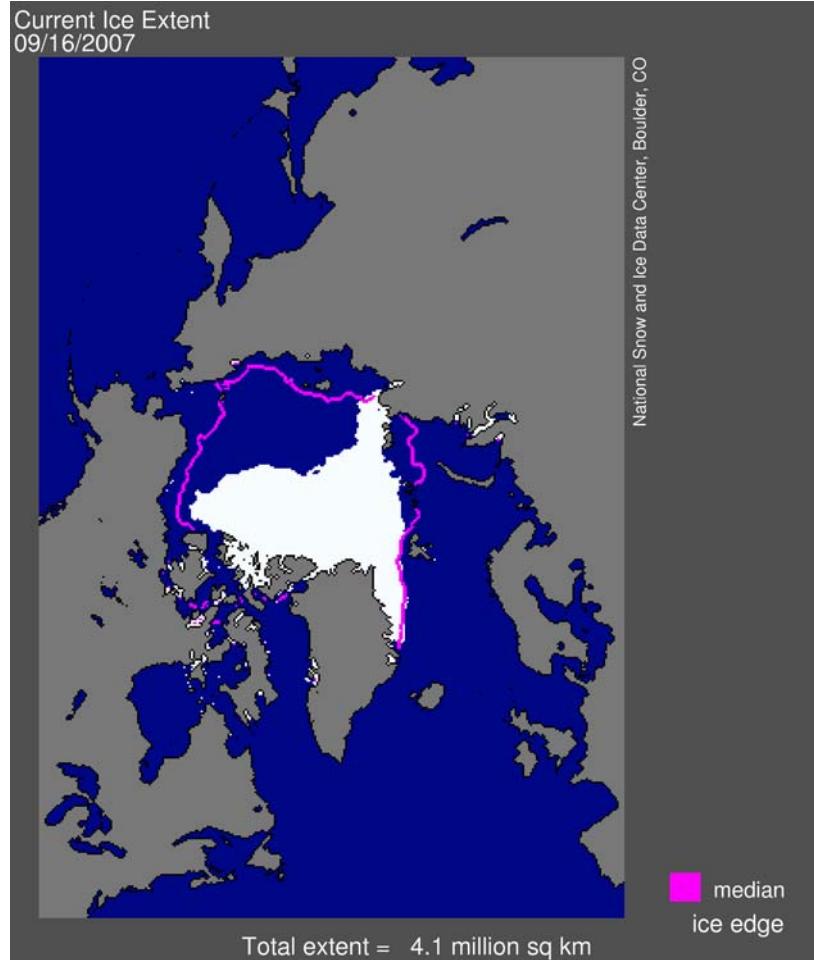
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## Sea Ice Minimum Extent Time Series

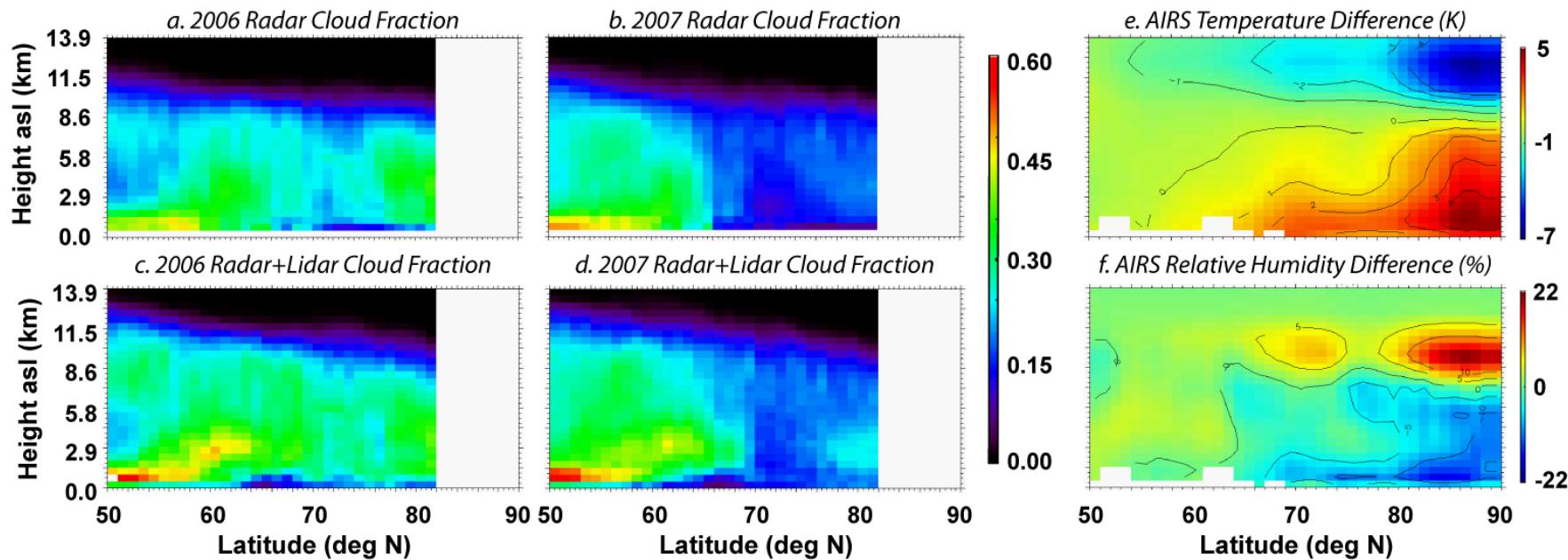
Kay et al., 2007

Source: National Snow and Ice Data Center



New Record Minimum - Sept. 2007

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

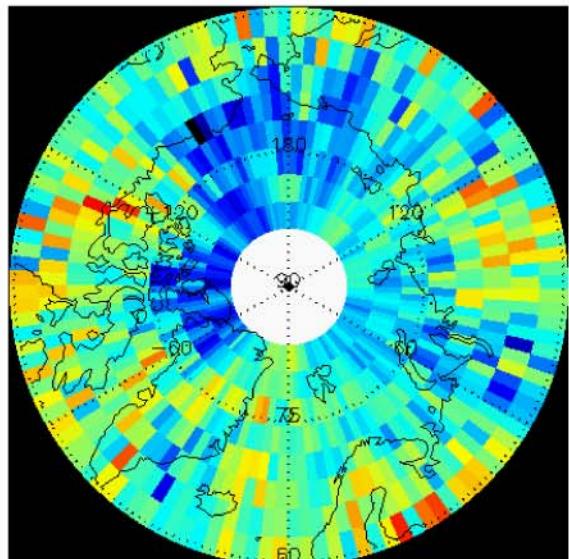


These Arctic cloud reductions are associated with  
anomalous weather patterns.

We see drying, warming and large cloud reductions  
Kay et al. (2007)

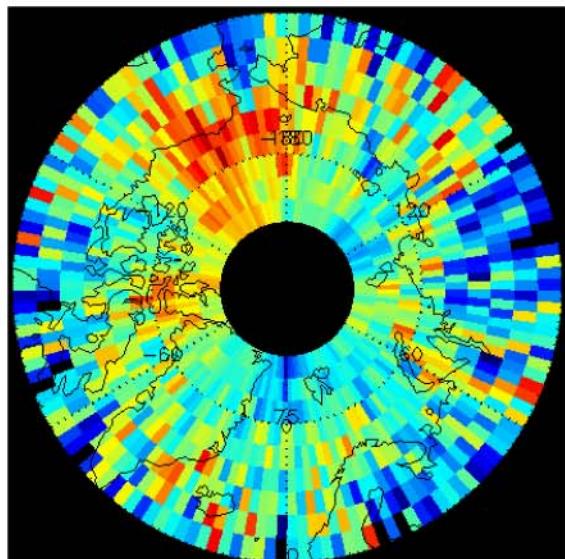


## 2007-2006 Cloud and Surface Radiation Differences



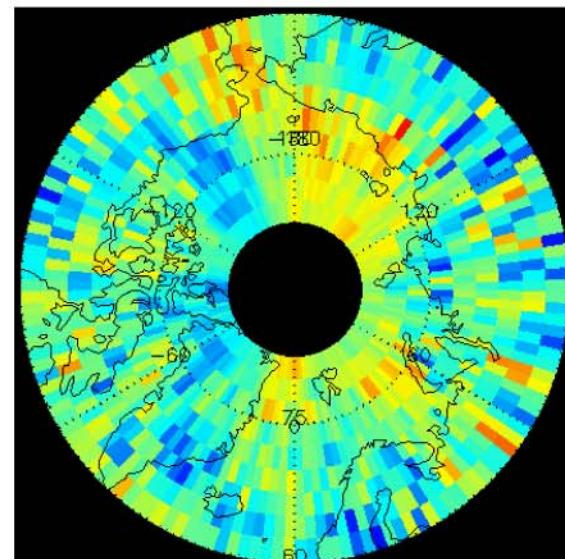
0.4 0 -0.4

Cloud Fraction



90 0 -90

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



40 0 -40

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

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

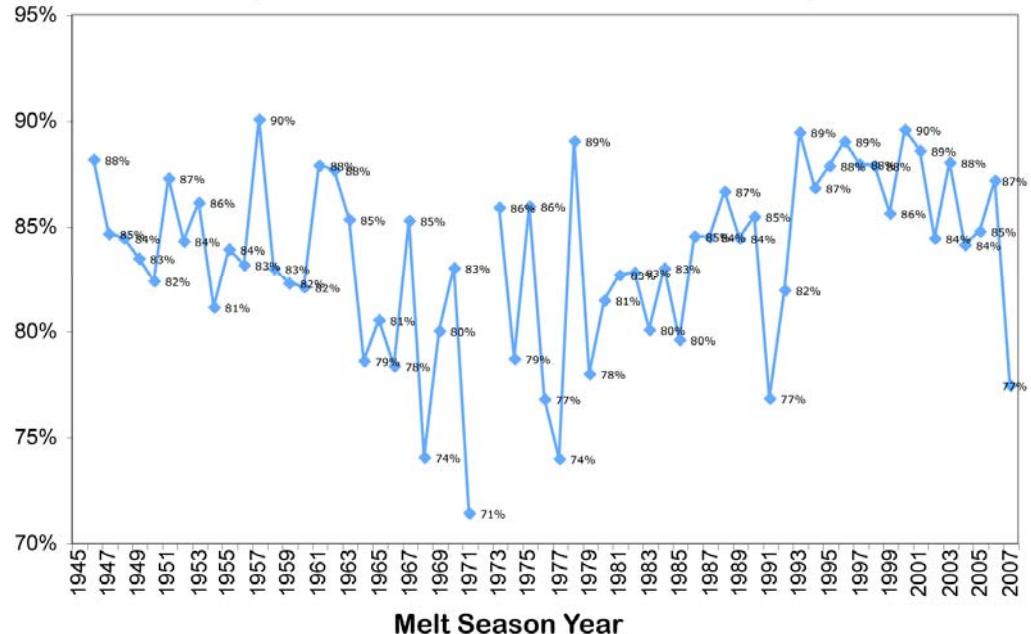


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The summer 2007 observed cloud decreases are anomalous but not unprecedented.

Barrow, Alaska (71 N, 157 W) JJA Cloudiness  
(based on surface observations)



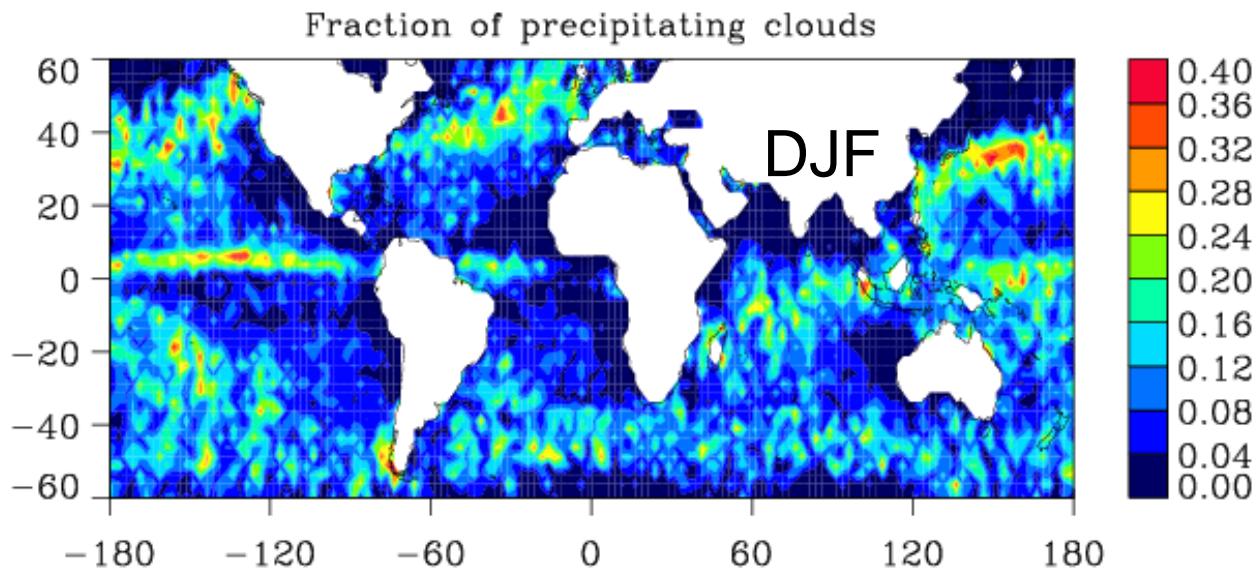
Barrow

MODIS - June 2, 2007

Atqasuk



## The Fraction of Oceanic Clouds That Precipitate

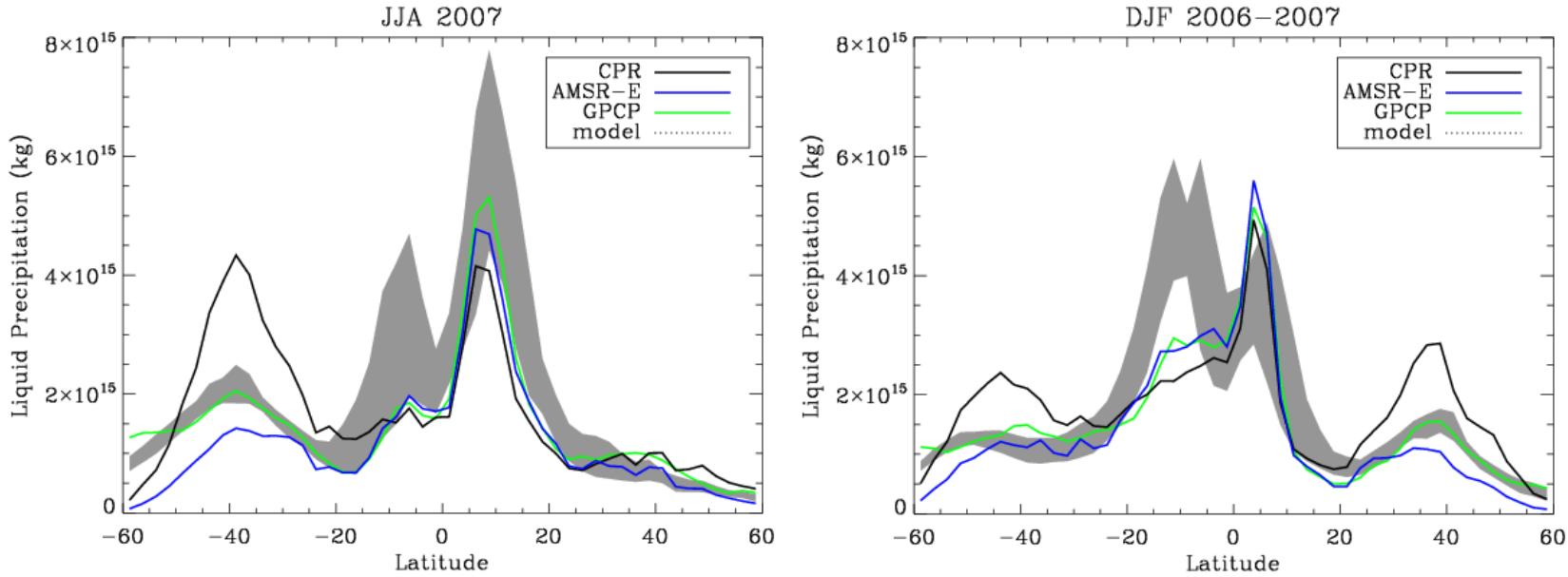


The global mean value is ~0.12, i.e., on average, about 12 percent of the clouds observed over our oceans at any time are producing rain. This fraction is much higher than previously speculated (0.08).

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



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

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 require 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 HQ  
Graeme Stephens, CSU  
Deborah Vane, JPL  
Diane Evans, JPL  
Randy Friedl, JPL

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



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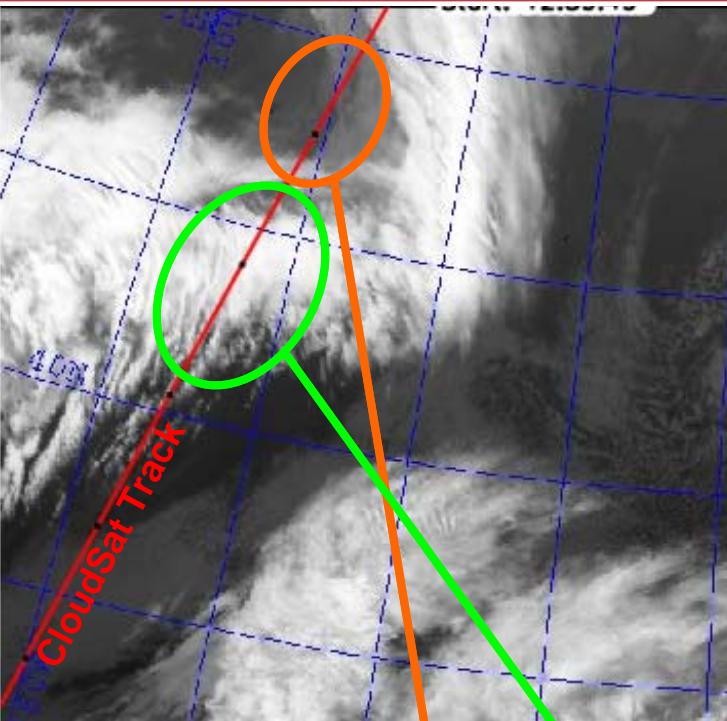
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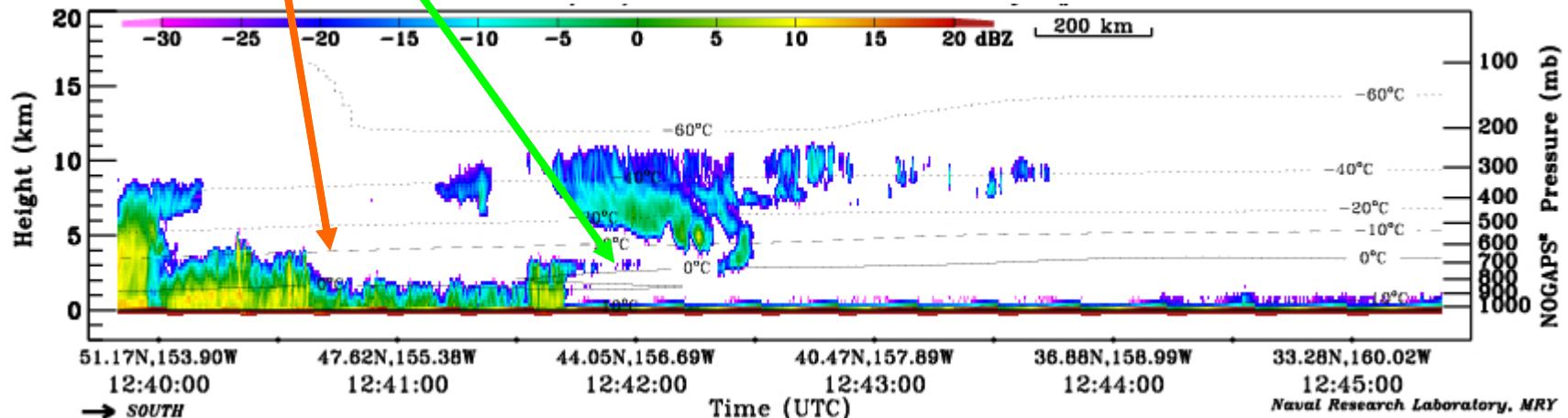
...these measurements provide operationally relevant information (particularly in the data-sparse/void areas where many DoD flight operations often occur).





## 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.

2007 Storms      Latest Previous      Pass Mosaic Mosaic FASTAnim.      Text Track ATCF      Track&Image      Scatt      CloudSat

Atlantic

16L NOEL  
16L NONAME  
15L NONAME  
14L MELISSA  
13L LORENZO  
12L DENNEN  
11L JERRY  
10L NONAME  
09L HUMBERTO  
08L INGRID  
07L GABRIELLE  
06L FELIX  
05L ERIN  
04L DEAN  
03L CHANTAL  
02L BARRY  
01L ANDREA

East Pacific

15E KIKO  
14E JULIETTE  
13E NONAME  
12E IVO  
11E HENRIETTE  
10E KATIA  
09E FLOSSIE  
08E BRICK  
07E DALILA  
06E COSME  
05E NONAME  
04E NONAME  
03E NONAME  
02E BARBARA  
01E ALVIN

Central Pacific

West Pacific

96W INVEST  
91W INVEST  
26W NONAME  
25W NONAME  
24W MITAG  
23W HAGIBIS  
22W TAPAH  
21W KALMAE  
21W PEPAN  
20W PAXAI  
19W KAIAKI  
18W LINGLING  
17W KROSA  
16W LEKIMA  
15W FRANCISCO  
14W NONAME  
13W WIPHA  
12W NARMI  
11W KALMAS  
10W PITOW  
09W SEPAT  
08W WUTIP  
07W PABUK  
06W NONAME  
05W USAGI  
04W MAN-YI  
03W TORAJI  
02W YUTU  
01W KHMIS-REV

**Environment**      Total\_Precip\_Water\_Vapor(TPW)      TPW&NOGAPS\_TPW      TPW&NOGAPS\_850\_Winds      Wind\_Shear

Sensor	% Cov	VIS	IR	IR-BD	Multi Seas.	85GHz H	85GHz weak	85GHz PCT	Color	Rain	Wind	37GHz Color	37GHz V	37GHz H	SSM/I Vapor
SSMI	44%	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
SSMIS	47%	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
TMI	38%	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
AMSR2	68%	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
WINDSAT	74%	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
AMSUB	36%	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■

VIS      IR      Vapor

GAC:      GEO:      MODIS:      OLS:

■ = <= 6 hrs. old, ■ = 12 hrs. old, ■ = > 12 hrs. old

88/17/07 1900Z 04L DEAN GOES 12 VIS

20070817.1747.cloudsat.94GHz.radar, 0kts-961mb-148N-636W.x.jpg thumb

Naval Research Lab http://www.navy.navy.mil/radars\_products.html  
<< Visible >> sum deviation at dante is 87 degrees

2007/08/17 - CloudSat Reflectivity Z<sub>r</sub>

Height (km)      Pressure (mb)

0.000 0.500 1.000 1.500 2.000 2.500 3.000 3.500 4.000 4.500 5.000 5.500 6.000 6.500 7.000 7.500 8.000 8.500 9.000 9.500 10.000 10.500 11.000 11.500 12.000 12.500 13.000 13.500 14.000 14.500 15.000 15.500 16.000 16.500 17.000 17.500 18.000 18.500 19.000 19.500 20.000

0.000 1000 900 800 700 600 500 400 300 200 100 0

9.000 02:40Z 11.400 02:50Z 13.200 03:20Z 15.000 03:50Z 16.800 04:20Z 18.600 05:10Z 20.400 06:00Z 22.200 06:50Z 24.000 07:40Z 25.800 08:30Z 27.600 09:20Z 29.400 10:10Z 31.200 11:00Z 33.000 11:40Z 34.800 12:30Z 36.600 13:20Z 38.400 14:10Z 40.200 15:00Z 42.000 15:50Z 43.800 16:40Z 45.600 17:30Z 47.400 18:20Z 49.200 19:10Z 51.000 20:00Z 52.800 20:50Z 54.600 21:40Z 56.400 22:30Z 58.200 23:20Z 60.000 24:10Z 61.800 25:00Z 63.600 25:50Z 65.400 26:40Z 67.200 27:30Z 69.000 28:20Z 70.800 29:10Z 72.600 29:50Z 74.400 30:40Z 76.200 31:30Z 78.000 32:20Z 79.800 33:10Z 81.600 34:00Z 83.400 34:50Z 85.200 35:40Z 87.000 36:30Z 88.800 37:20Z 90.600 38:10Z 92.400 39:00Z 94.200 39:50Z 96.000 40:40Z 97.800 41:30Z 99.600 42:20Z 101.400 43:10Z 103.200 44:00Z 105.000 44:50Z 106.800 45:40Z 108.600 46:30Z 110.400 47:20Z 112.200 48:10Z 114.000 49:00Z 115.800 49:50Z 117.600 50:40Z 119.400 51:30Z 121.200 52:20Z 123.000 53:10Z 124.800 54:00Z 125.600 54:50Z 126.400 55:40Z 127.200 56:30Z 128.000 57:20Z 128.800 58:10Z 129.600 59:00Z 130.400 59:50Z 131.200 60:40Z 132.000 61:30Z 132.800 62:20Z 133.600 63:10Z 134.400 64:00Z 135.200 64:50Z 136.000 65:40Z 136.800 66:30Z 137.600 67:20Z 138.400 68:10Z 139.200 69:00Z 140.000 69:50Z 140.800 70:40Z 141.600 71:30Z 142.400 72:20Z 143.200 73:10Z 144.000 74:00Z 144.800 74:50Z 145.600 75:40Z 146.400 76:30Z 147.200 77:20Z 148.000 78:10Z 148.800 79:00Z 149.600 79:50Z 150.400 80:40Z 151.200 81:30Z 152.000 82:20Z 152.800 83:10Z 153.600 84:00Z 154.400 84:50Z 155.200 85:40Z 156.000 86:30Z 156.800 87:20Z 157.600 88:10Z 158.400 89:00Z 159.200 89:50Z 160.000 90:40Z 160.800 91:30Z 161.600 92:20Z 162.400 93:10Z 163.200 94:00Z 164.000 94:50Z 164.800 95:40Z 165.600 96:30Z 166.400 97:20Z 167.200 98:10Z 168.000 99:00Z 168.800 99:50Z 169.600 100:40Z 170.400 101:30Z 171.200 102:20Z 172.000 103:10Z 172.800 104:00Z 173.600 104:50Z 174.400 105:40Z 175.200 106:30Z 176.000 107:20Z 176.800 108:10Z 177.600 109:00Z 178.400 109:50Z 179.200 110:40Z 180.000 111:30Z 180.800 112:20Z 181.600 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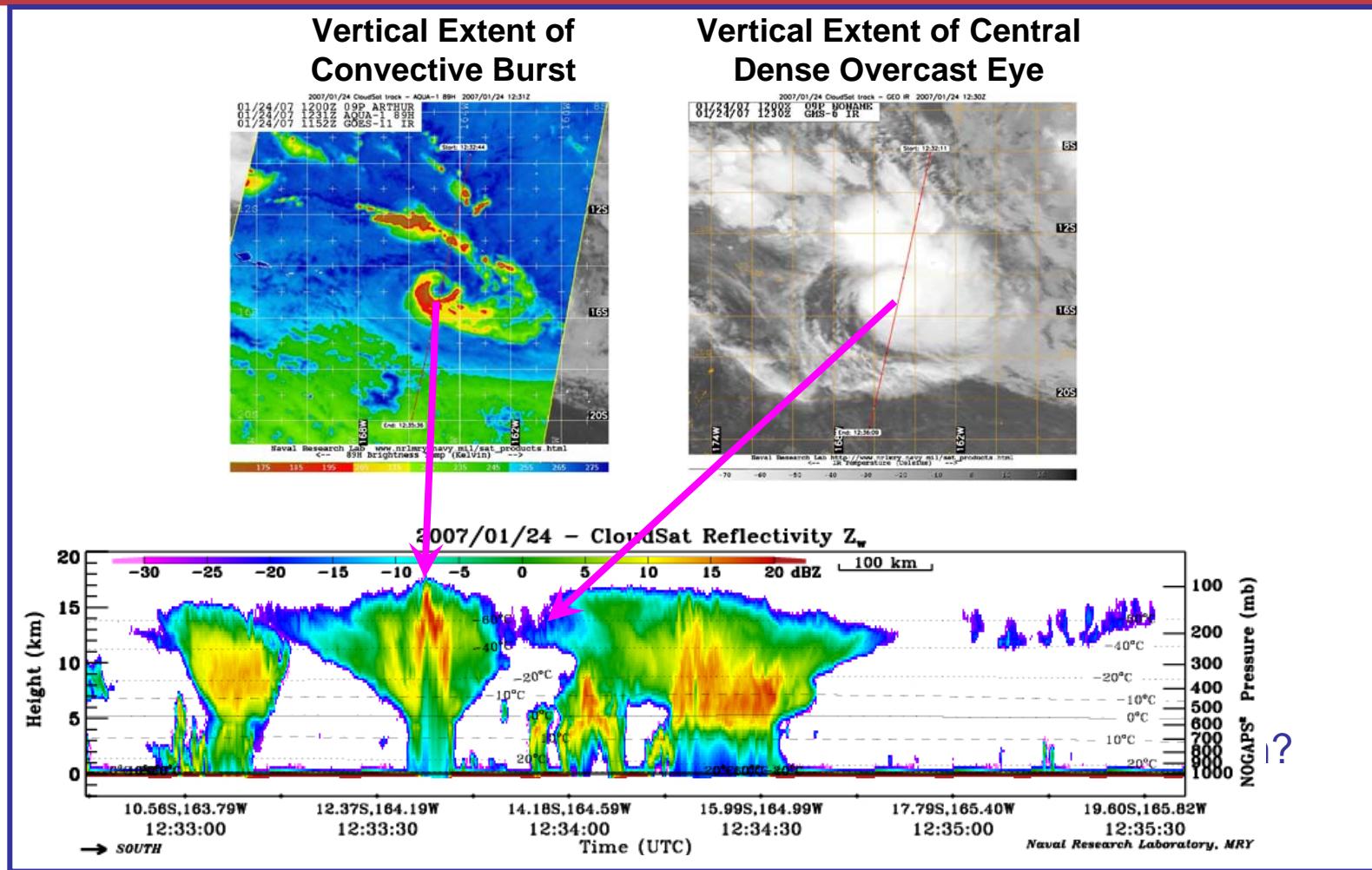




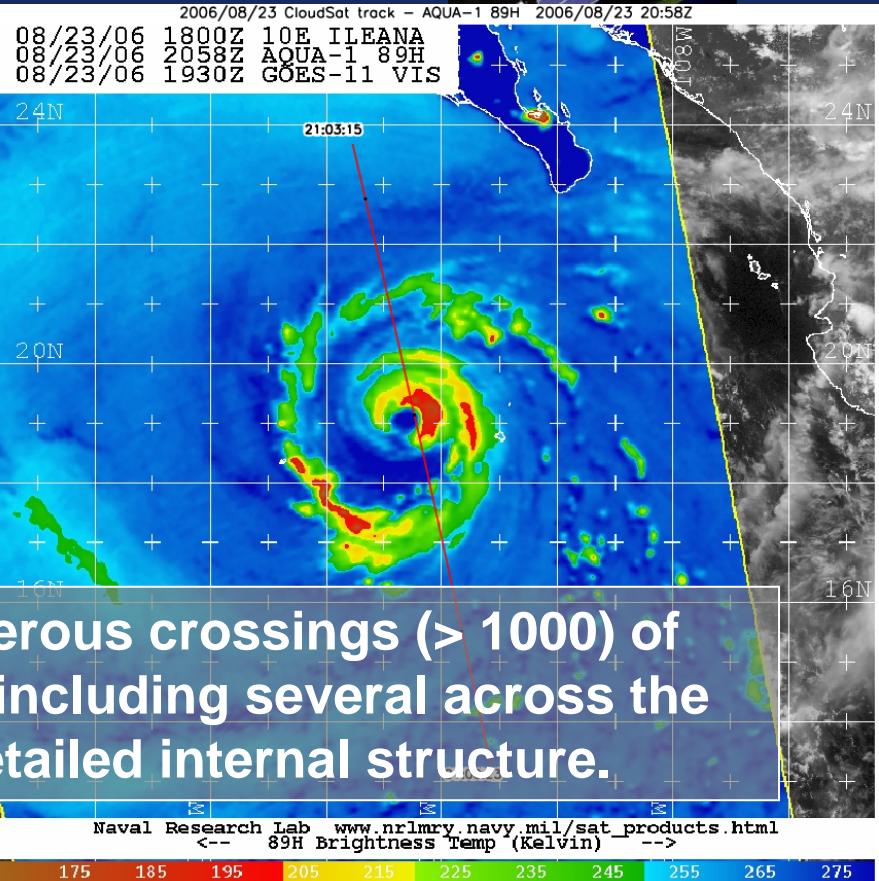
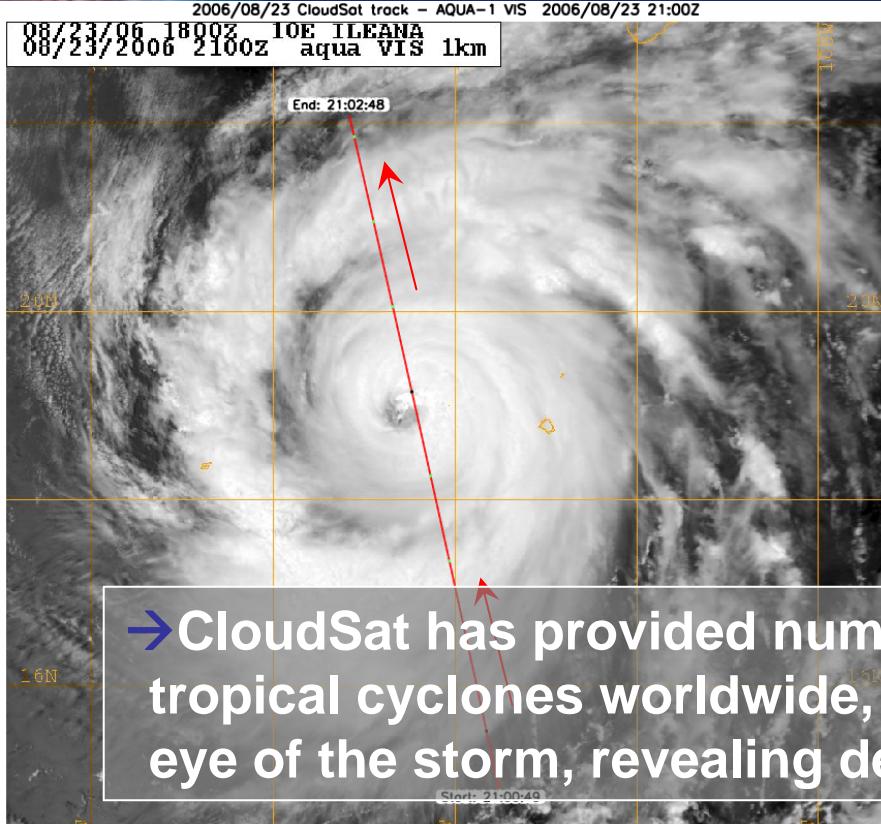
# TC Web Example: Typhoon Arthur



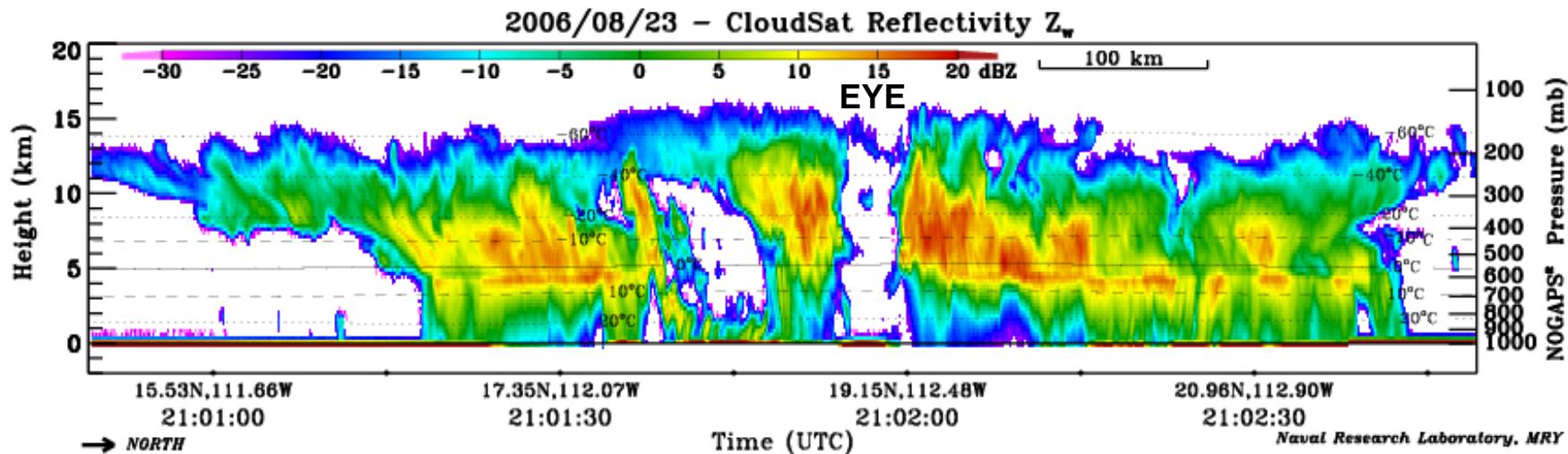
CLOUDSAT



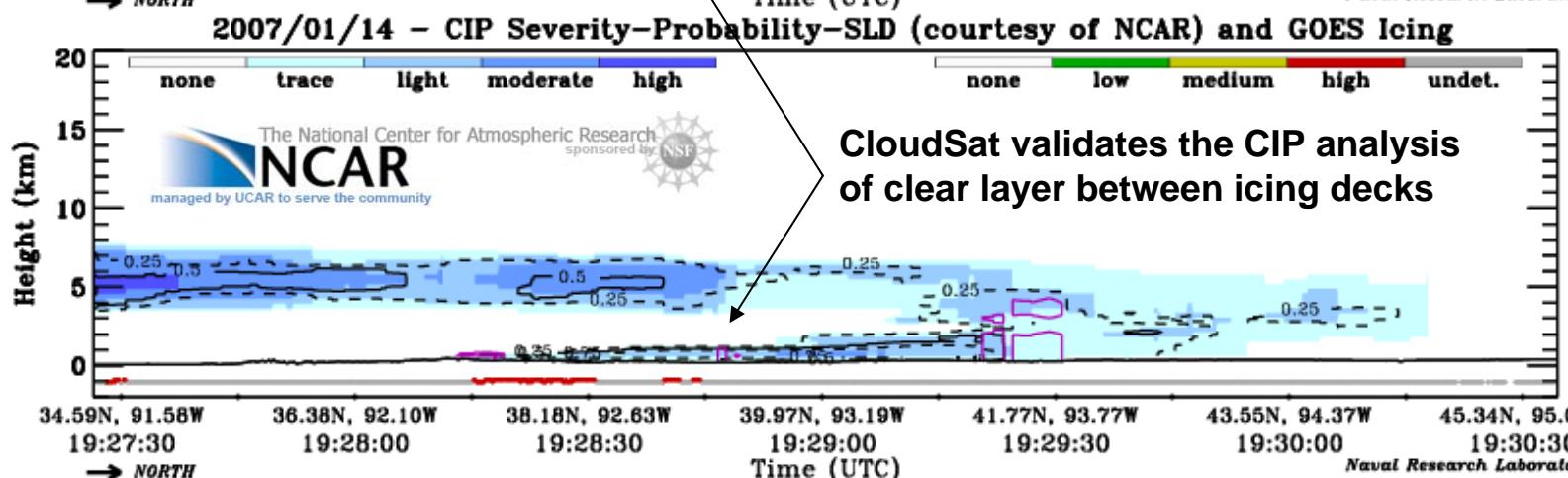
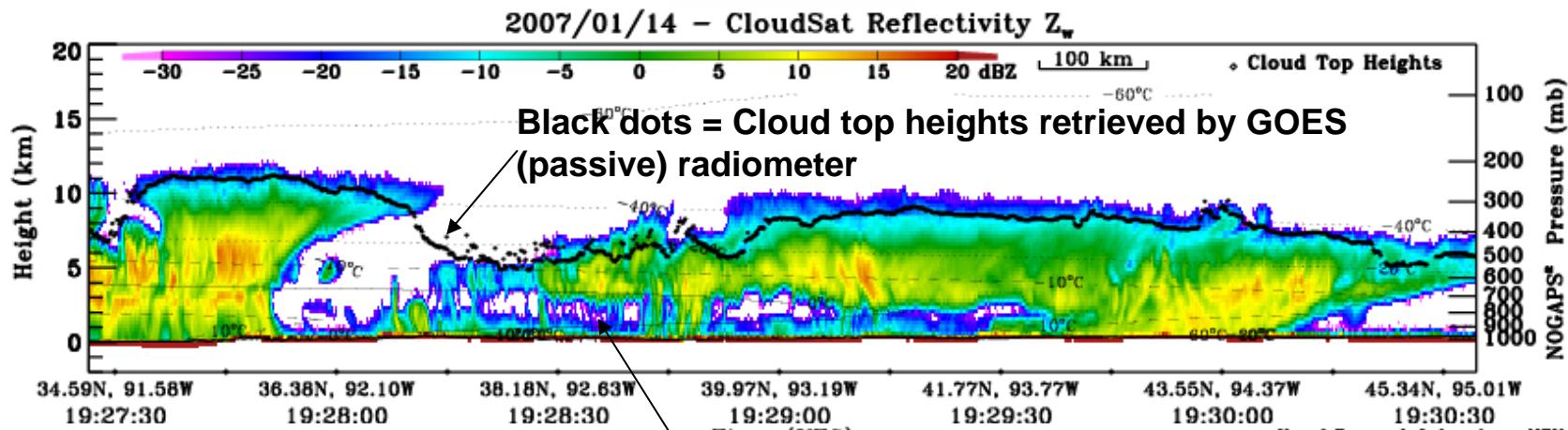
→ NRL/CSU are compiling a Tropical Cyclone CloudSat-intercept database to provide researchers the first global statistics on storm vertical structure.



→ 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.

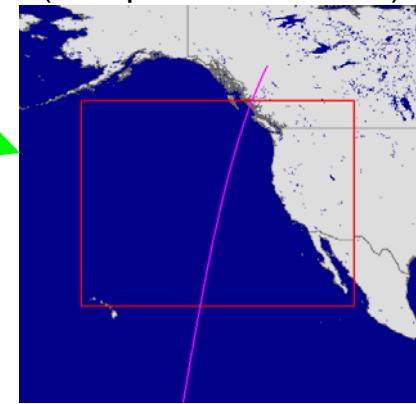
# NexSat Near Real-Time Demonstrations

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

The screenshot shows the NexSat website interface. At the top, there are buttons for 'Training', 'Feedback?', and a 'Pass\_Predictor' logo. Below that, a 'Region/Sector' dropdown is set to '/NE\_Pacific/Overview'. The main content area features a headline 'Headlines: SoCal Fires Viewed From Space Archived: articles.' and a timestamp '22:05:56 UTC'. A green arrow points from this timestamp to the 'Cloud Top Height Comparison' section below. The 'Products' sidebar on the left lists various data types, with 'CloudSat' highlighted in blue. Below the sidebar are buttons for 'Age <= 12 h', 'Age <= 24 h', and 'Age > 24 h'. The central part of the page displays two sets of plots for CloudSat Reflectivity (%) and Cloud Top Height (km) over time (UTC) for December 4, 2007. The bottom navigation bar includes 'Latest', 'Archive', 'Single', 'Thumbs', 'Animate', and 'Prod Tutor' buttons.



## Satellite Pass Predictors (for operational users)



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

## New User Training Modules

The screenshot shows a 'Satellite Product Tutorial' for 'CloudSat's 94 GHz Radar'. It includes a title, a 'CloudSat' logo, and a detailed description of the radar's capabilities. The text explains the radar's role in measuring cloud top heights and reflectivity, and how it compares to passive sensors. It also discusses the radar's ability to penetrate clouds and its use in monitoring ice clouds. The bottom of the page features a 'Why we are important?' section and a 'How This Product is Created' section, both with detailed sub-sections and images.

→ 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.

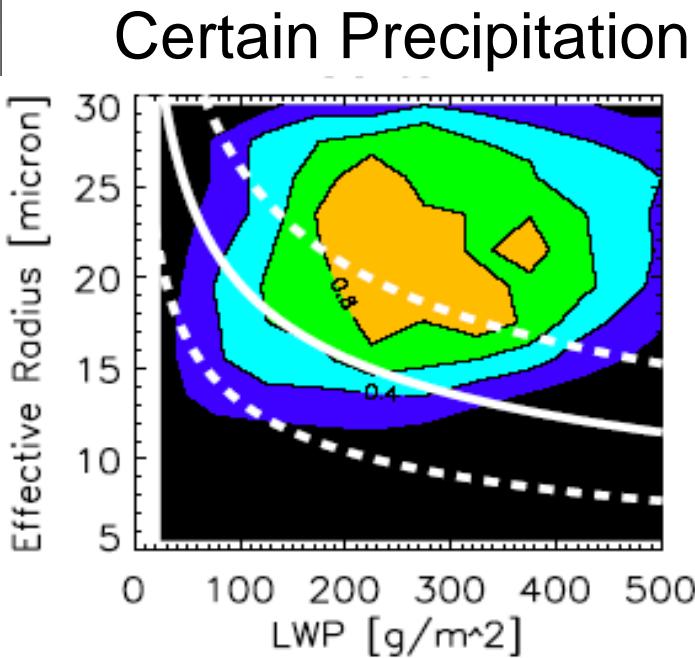
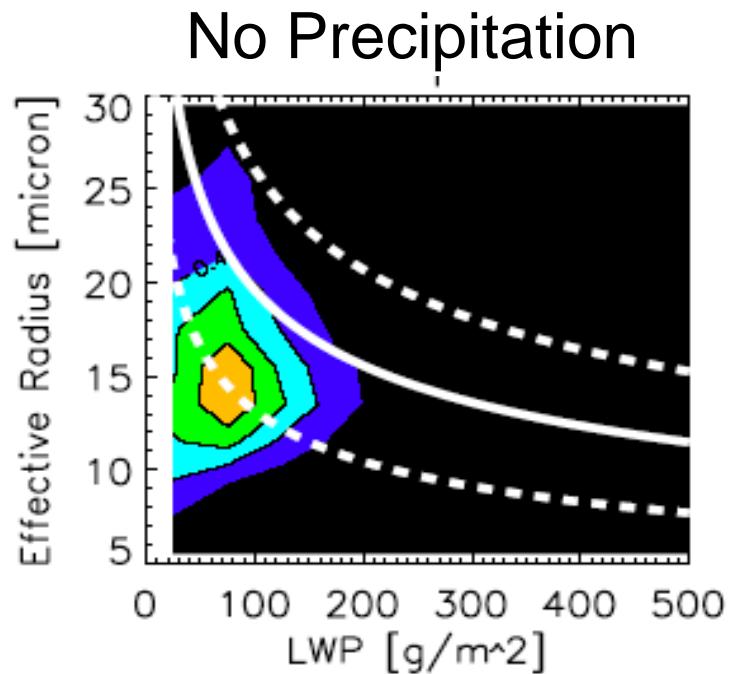


**CLOUDSAT**  
NASA EARTH SYSTEM SCIENCE PATHFINDER MISSION

# Backups

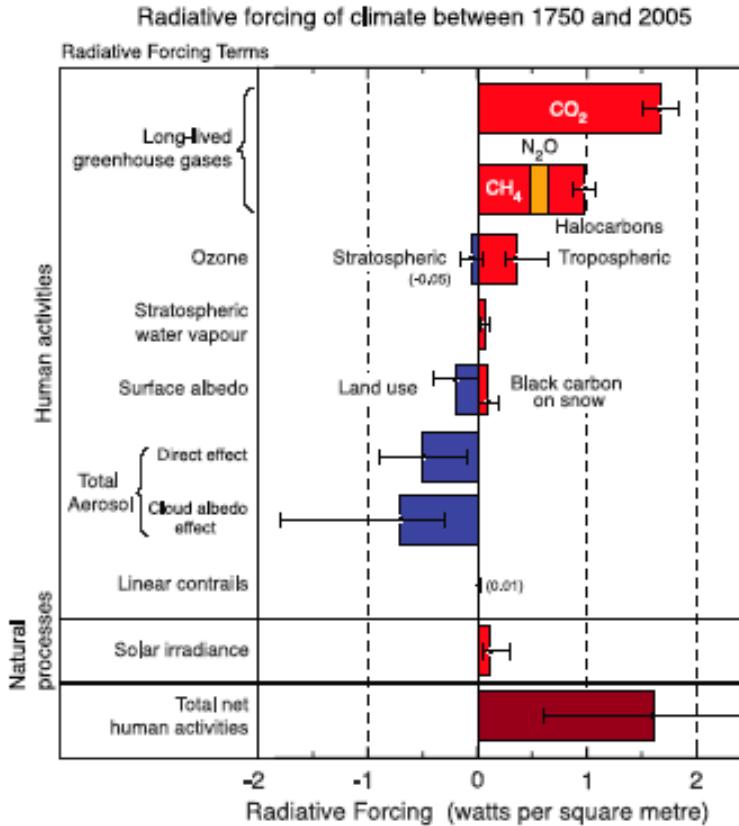


# Water and Particle Size Properties of Warm Clouds From A-Train Data



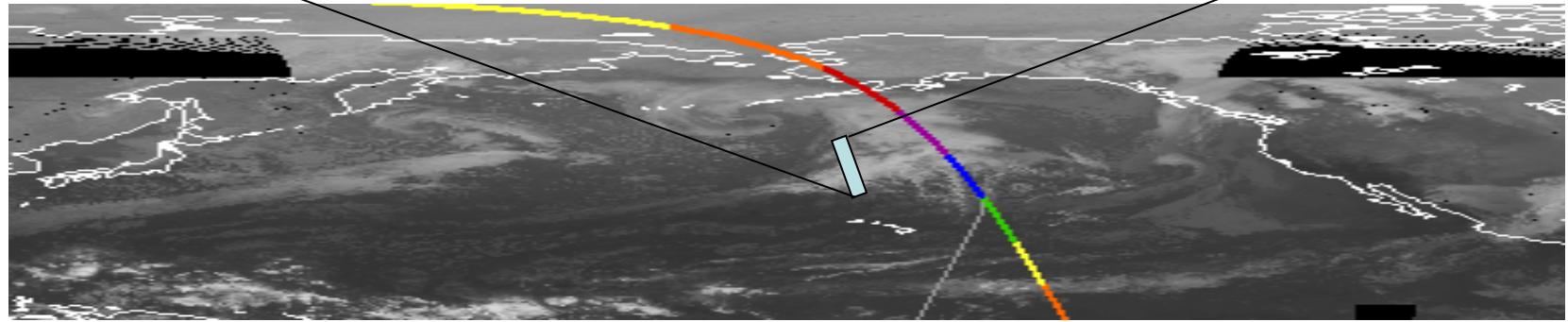
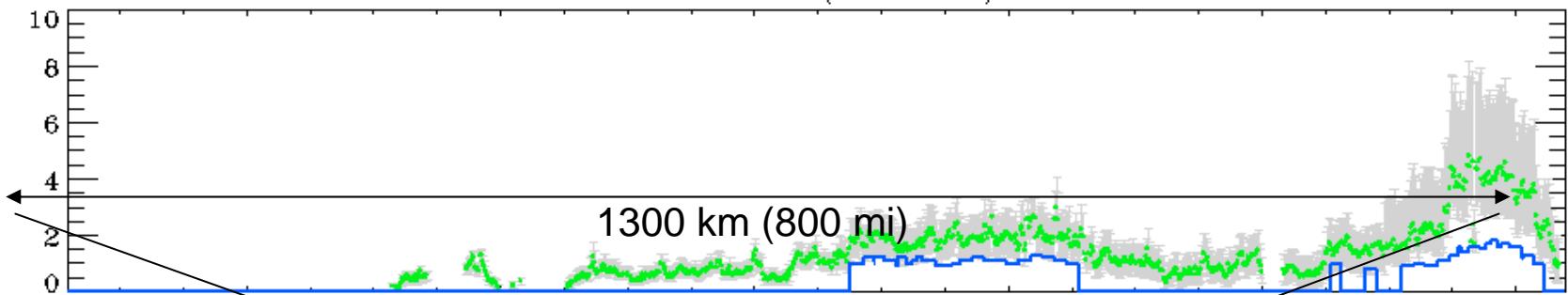
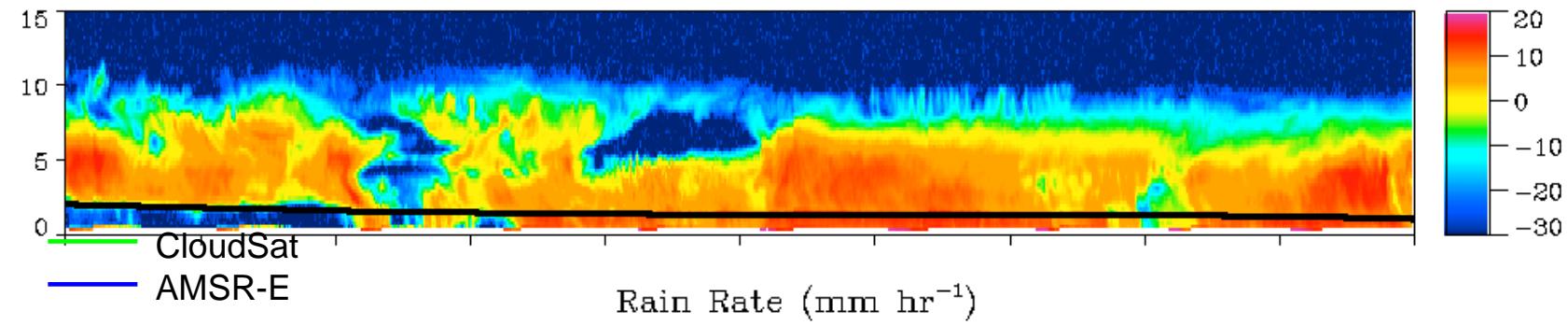


The aerosol forcing factors of climate are highly uncertain and aerosol indirect effects are most uncertain of all.



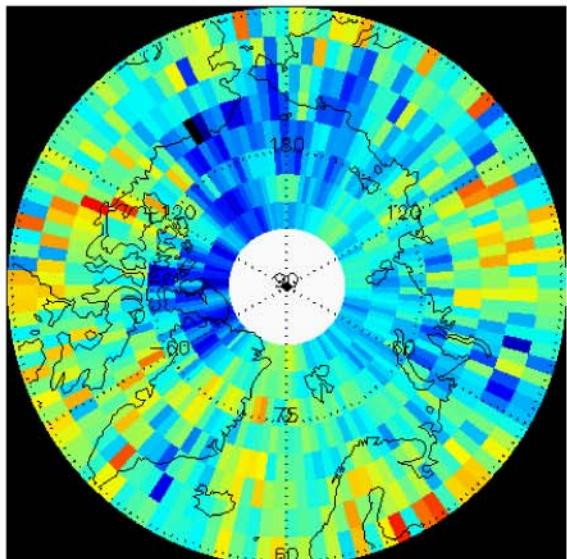
FAQ 2.1, Figure 2. Summary of the principal components of the radiative forcing of climate change. All these radiative forcings result from one or more factors that affect climate and are associated with human activities or natural processes as discussed in the text. The values represent the forcings 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



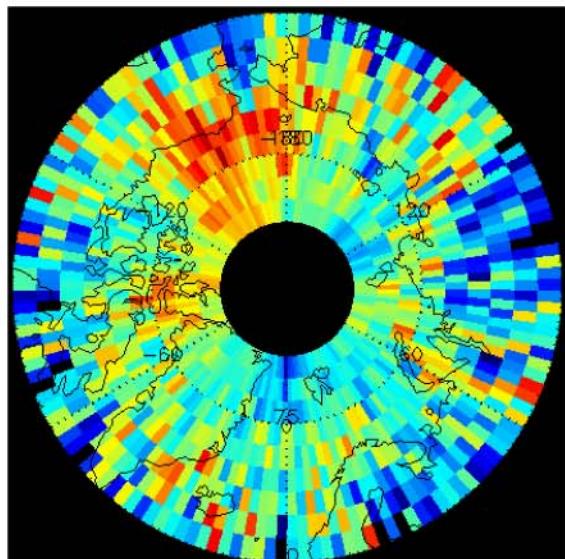


## 2007-2006 Cloud and Surface Radiation Differences



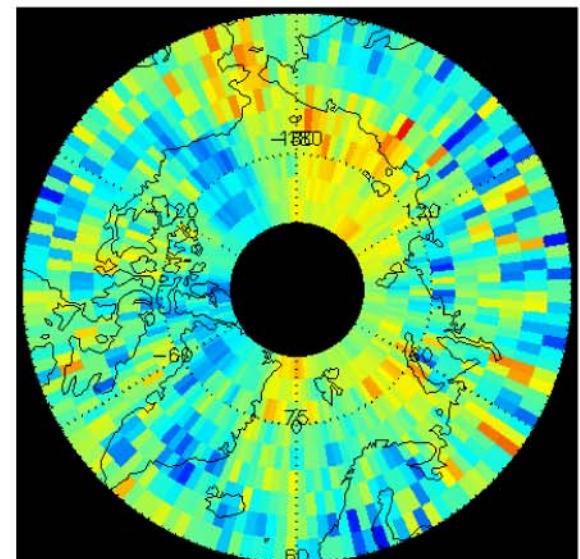
0.4 0 -0.4

Cloud Fraction



90 0 -90

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



40 0 -40

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

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

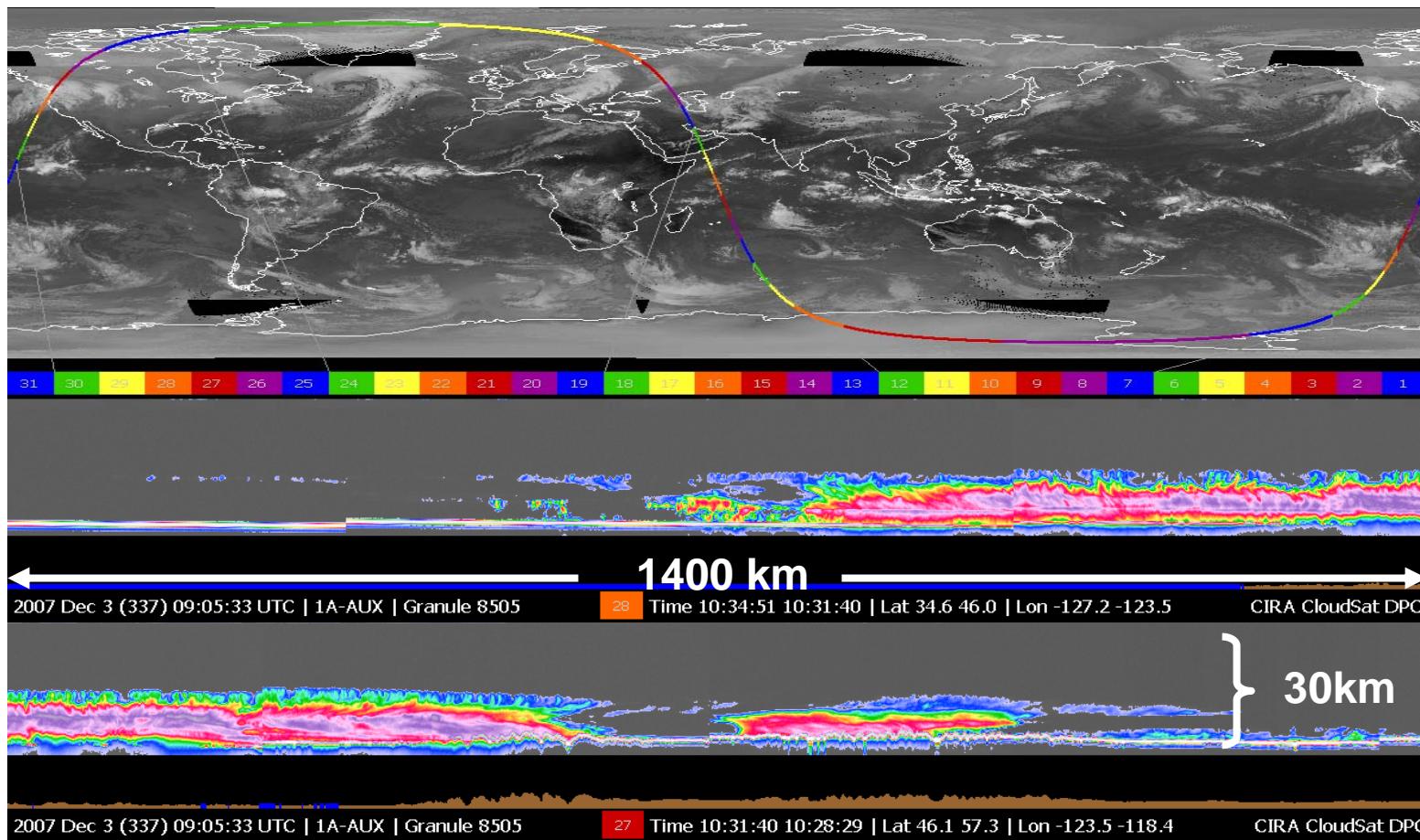
These radiation differences alone could melt ~0.3 meters of sea ice and increase ocean mixed layer temperatures by ~1.6 degrees Kelvin.

# Views of Weather on Scales Not Seen Before



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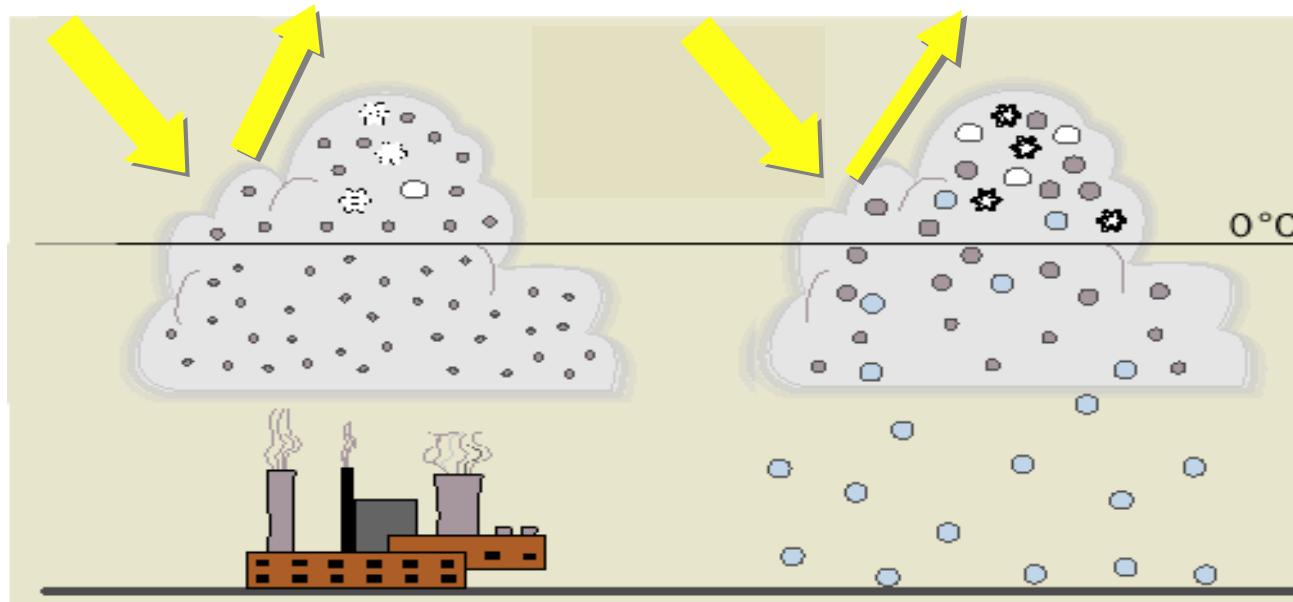


Example of CloudSat 'quicklook' data taken directly from the CloudSat data processing center (<http://cloudsat.cira.colostate.edu>)

# Aerosol Pollution is Making Clouds Brighter



CLOUDSAT



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

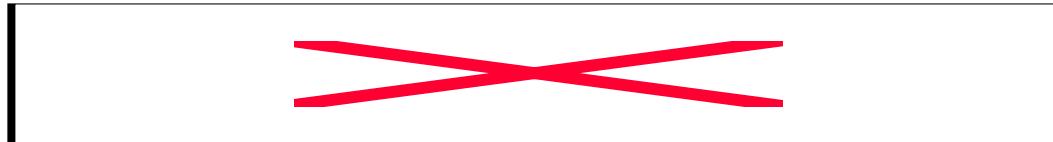
Clean clouds = fewer drops,  
larger drops, more precipitation,  
less reflected sunlight

Lebsack and Stephens, 2007



## Two Principle Influences in 'Warm' (Liquid Water) Clouds:

- 1) Changes to Cloud Reflection (Twomey Effect)

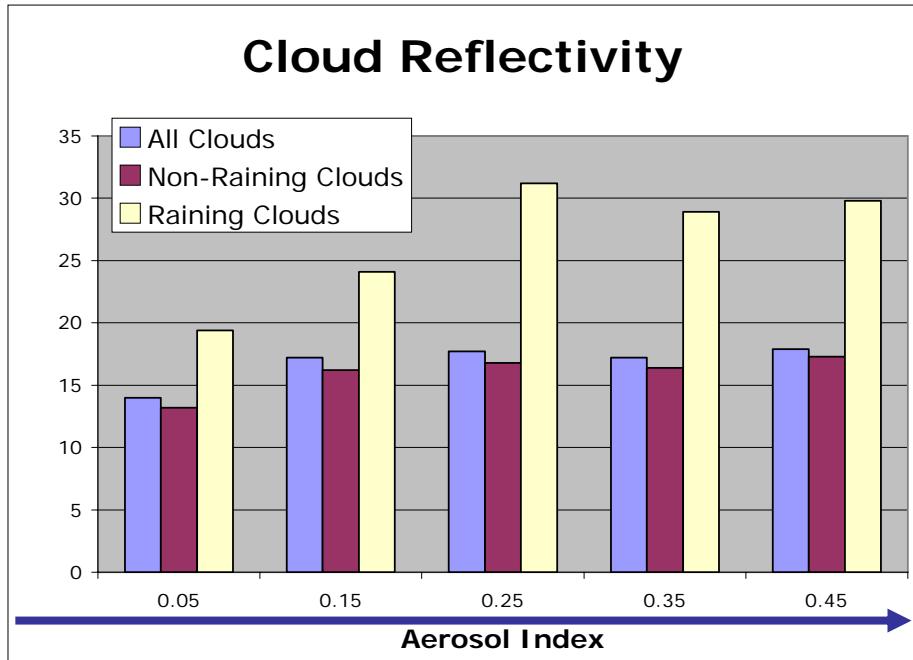


- 2) Changes to Precipitation



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.

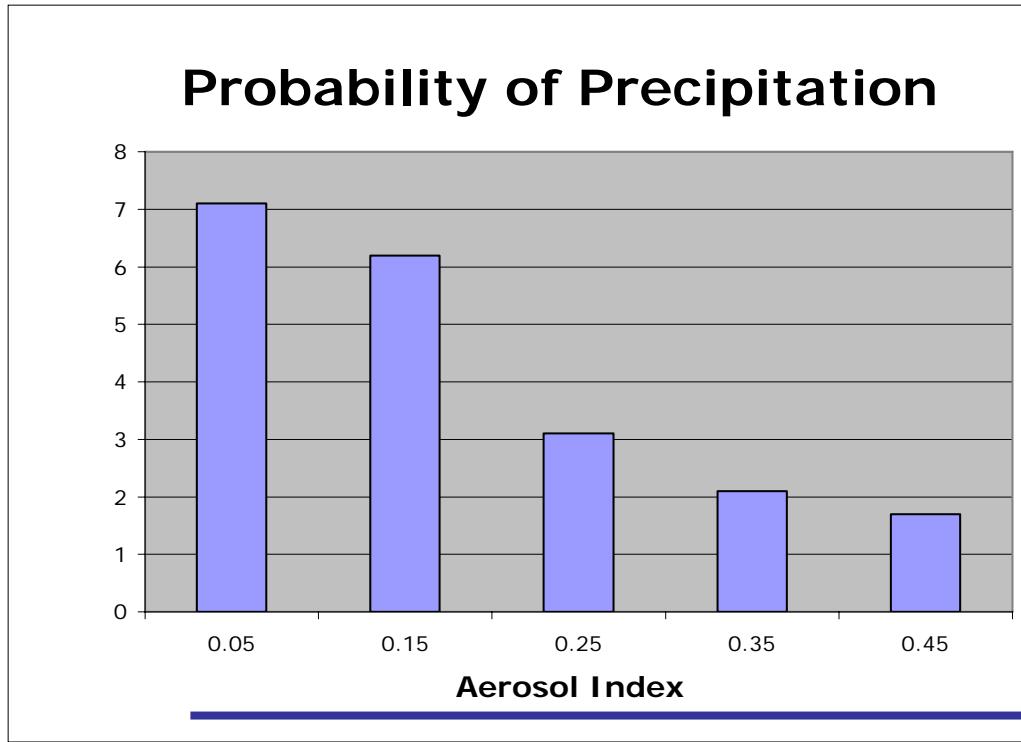
# Raining clouds are also brighter



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

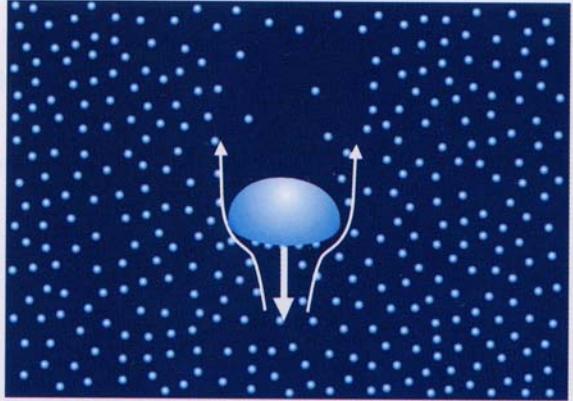
Raining clouds in high aerosol air are thicker, wetter and more reflective.

More Aerosol



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



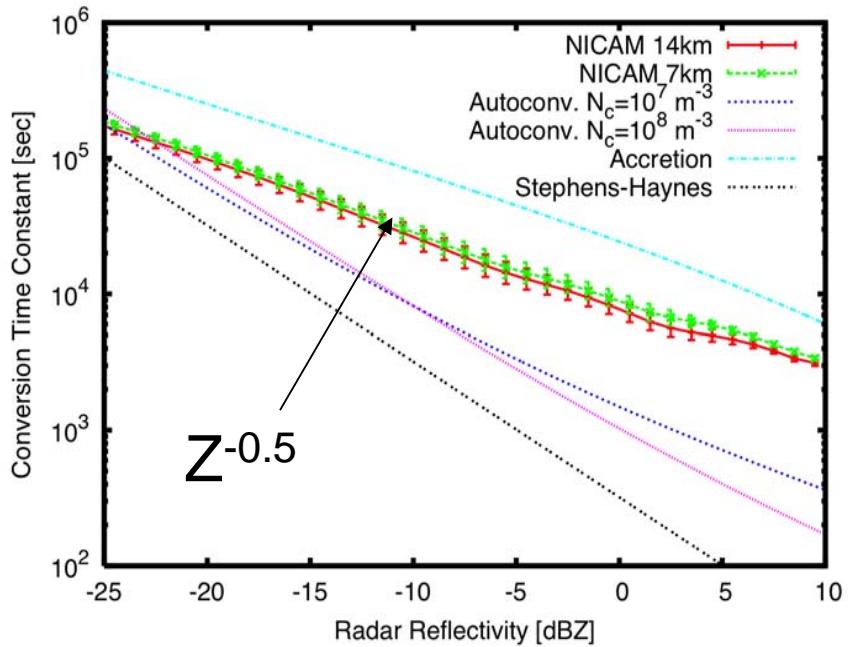
Stephens and Haynes (SH), 2007 indicated that the rate of conversion of cloud water to rain water is determined by the measured CloudSat CPR reflectivity

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

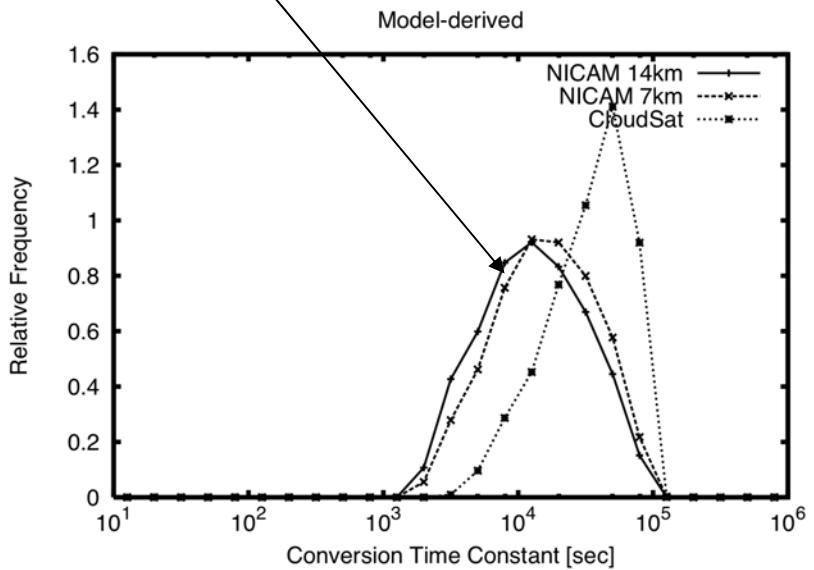
For combined auto-conversion/accretion,  $\tau \propto Z^{-0.5}$   
derived from the NICAM global CRM



## Suzuki and Stephens, 2007



Global cloud  
model with  
CloudSat  
simulator

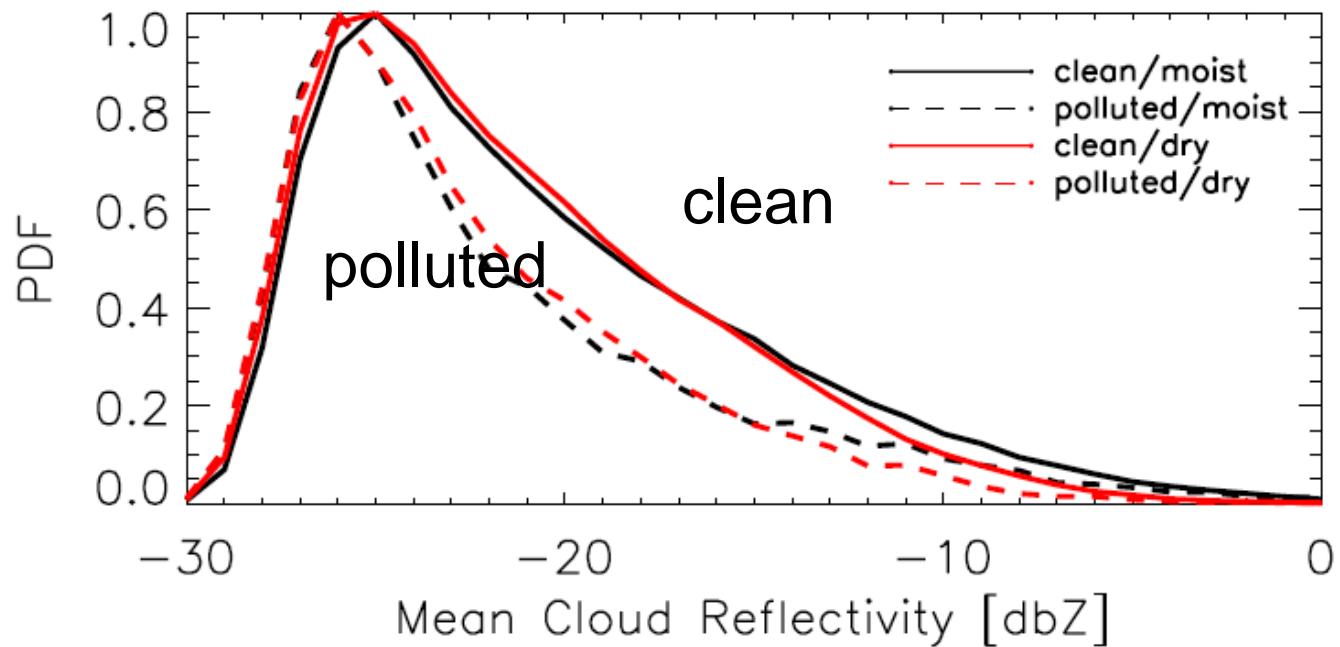


The real message is that models invoking even different assumptions about coalescence also suggest  $Z$  is related to the time scale of the conversion process

The reflectivity difference implies time scale differences which have their 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