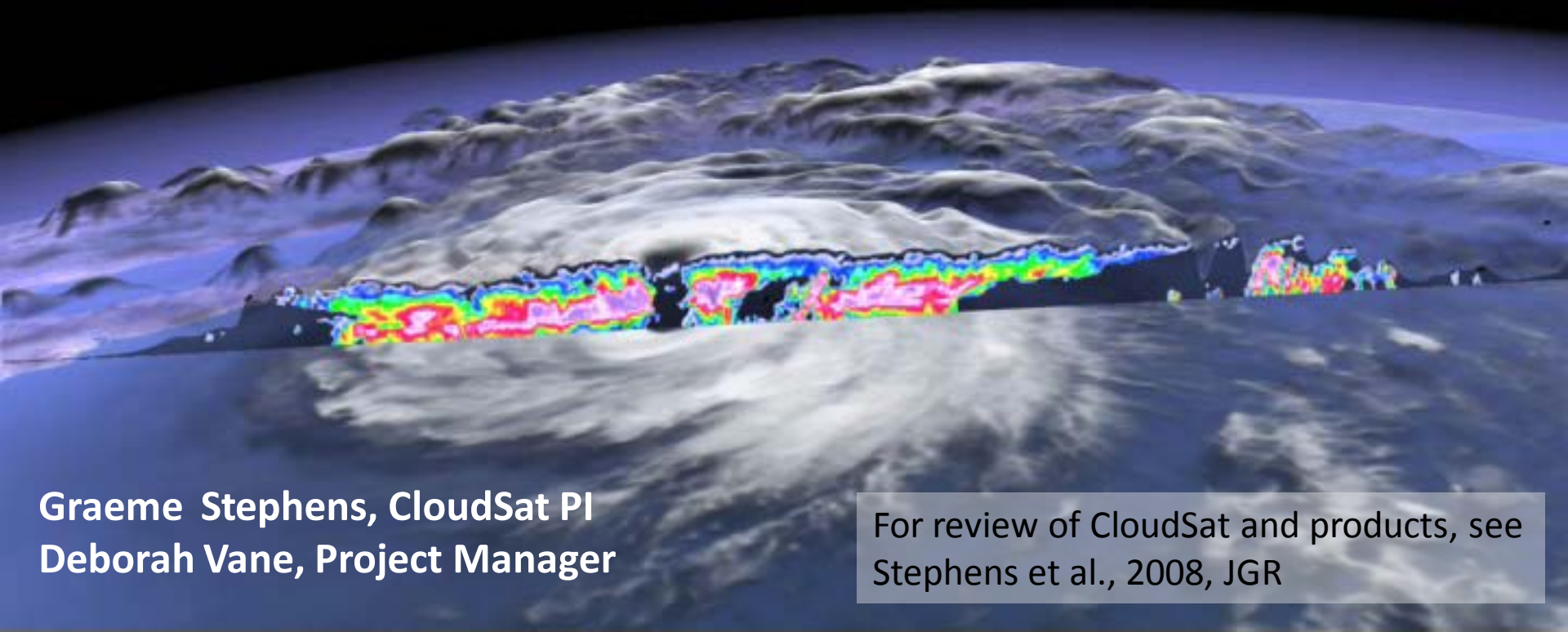
CloudSat & A-Train

Penetrating and Revealing Deep Convection, Severe Weather & properties of clouds and precipitation

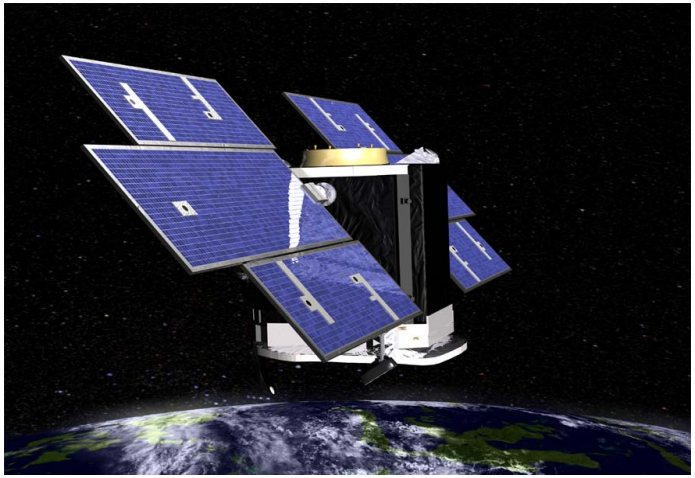


Graeme Stephens, CloudSat PI
Deborah Vane, Project Manager

For review of CloudSat and products, see Stephens et al., 2008, JGR

CloudSat Mission Overview

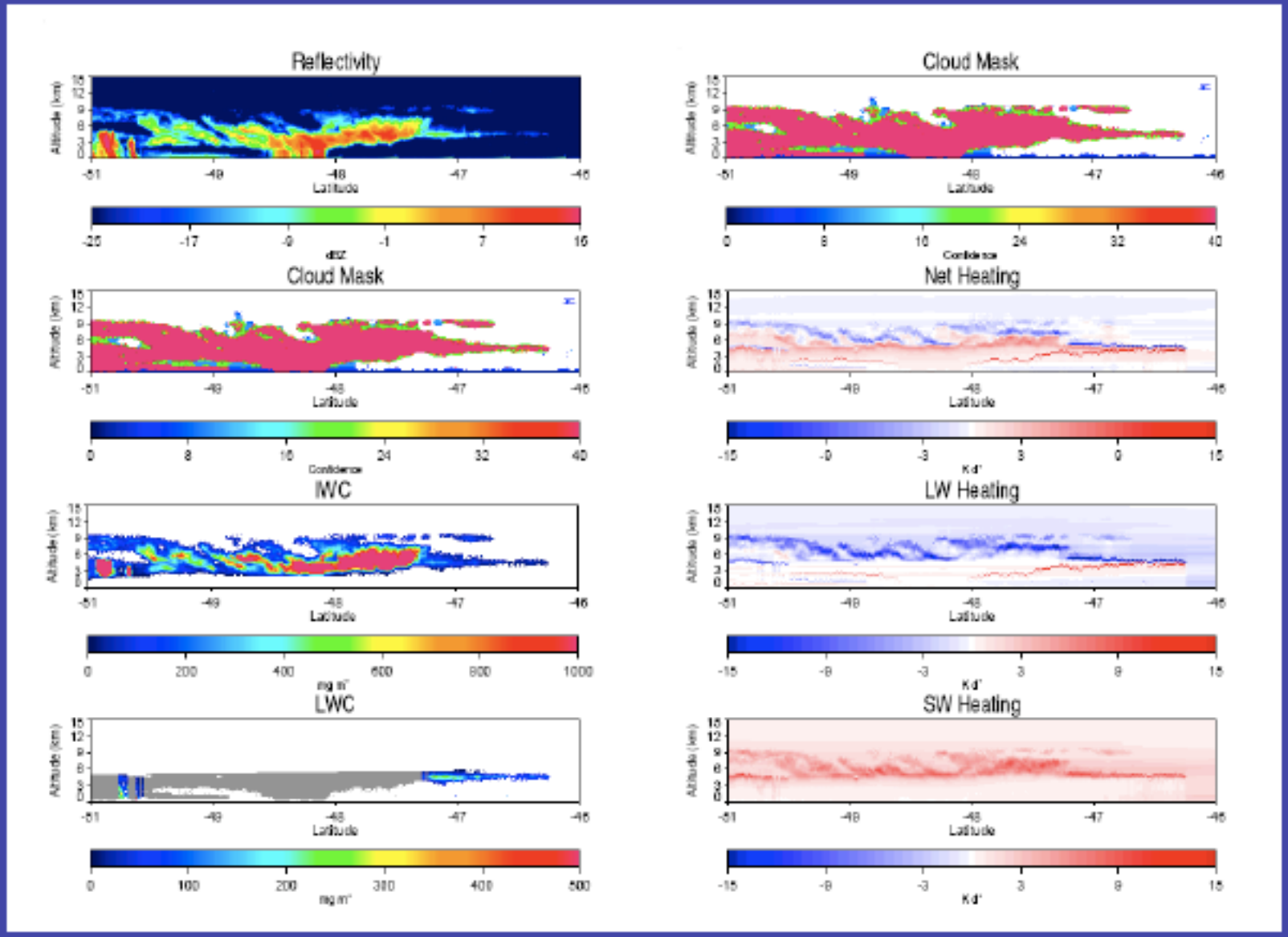
First 94 GHz radar space borne system
Co-manifested with CALIPSO on Delta II launch vehicle
Flies in formation with the EOS Constellation
Launch date: 28 April 2006
Partnership with DoD (on-orbit ops), DoE (validation) and CSA (radar development)
PI: Prof. Graeme Stephens, Colorado State University
Project Management: Deborah Vane, JPL



<u>Science</u>

Measure the vertical structure of clouds and quantify their ice and water content
Improve weather prediction and clarify climatic processes.
Improve cloud information from other satellite systems, in particular those of Aqua
Investigate the way aerosols affect clouds and precipitation
Investigate the utility of 94 GHz radar to observe and quantify precipitation, in the context of cloud properties, from space

CloudSat DPC: Standard Data Product Examples: Fluxes and Heating Rates



CloudSat "Standard" Product Release Status/Sched.

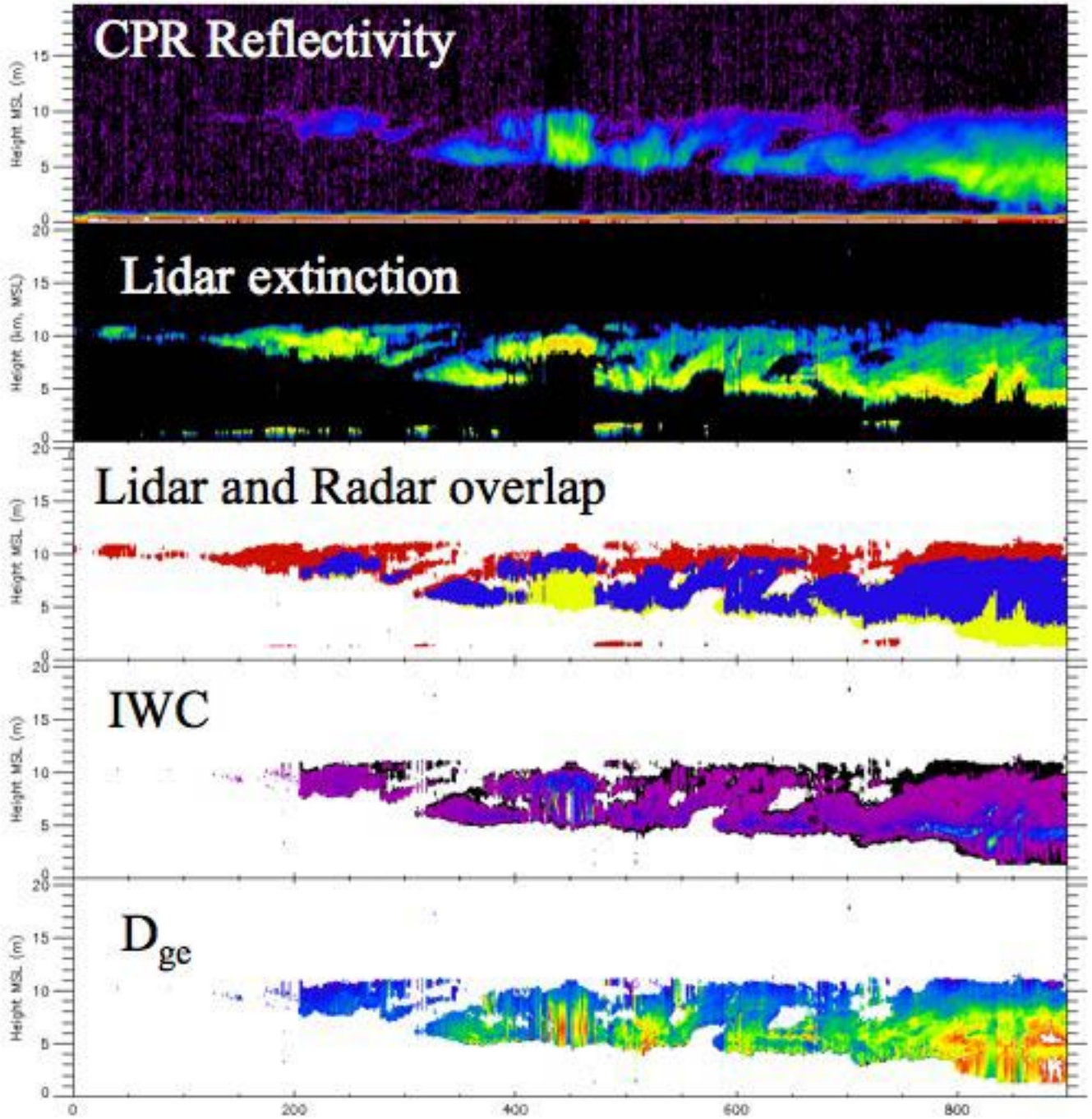
	Description	Algorithm Developer(s)	Current Version	Next Release Date (NET)
1B-CPR	Radar Backscatter Profiles	Steve Durden (JPL), Simone Tanelli (JPL)	R04	Jan-10 (R05 to ST)
2B-GEOPROF	Cloud Geometrical Profile	Jay Mace, Qiuqing Zhang (U of Utah) , Roj Marchand (U. Wash)	R04	Mar-10 (R05 to ST)
2B-CLDCLASS	Cloud Classification	Ken Sassen (U of Alaska), Zhien Wang (U. Wyo)	R04	Apr-10 (R05 to ST)
2B-CWC-RO	Combined Water Content - Radar Only	Norm Wood (CSU)	R04	Apr-10 (R05 to ST)
2B-TAU	Cloud Optical Depth - Off Nadir	Igor Polonsky (CSU)	R04	May-10 (R05 to ST)
2B-CWC-RVOD	Combined Water Content - Radar + Vis. Optical Depth	Norm Wood (CSU)	R04	Jun-10 (R05 to ST)
2B-FLXHR	Fluxes and Heating Rates	Tristan L'Ecuyer (CSU)	R04	Jun-10 (R05 to ST)
2B-GEOPROF-LIDAR	Cloud Geometrical Profile from CPR and CALIPSO Lidar	Jay Mace, Qiuqing Zhang (U. UT), Roj Marchand (U. WA)	R04	May-10 (R05 to ST)
2B-CLDCLASS-LIDAR	Cloud Classification from CPR and CALIPSO Lidar	Zhien Wang (U. Wyo)	n/a	May-10 (R05 to ST)

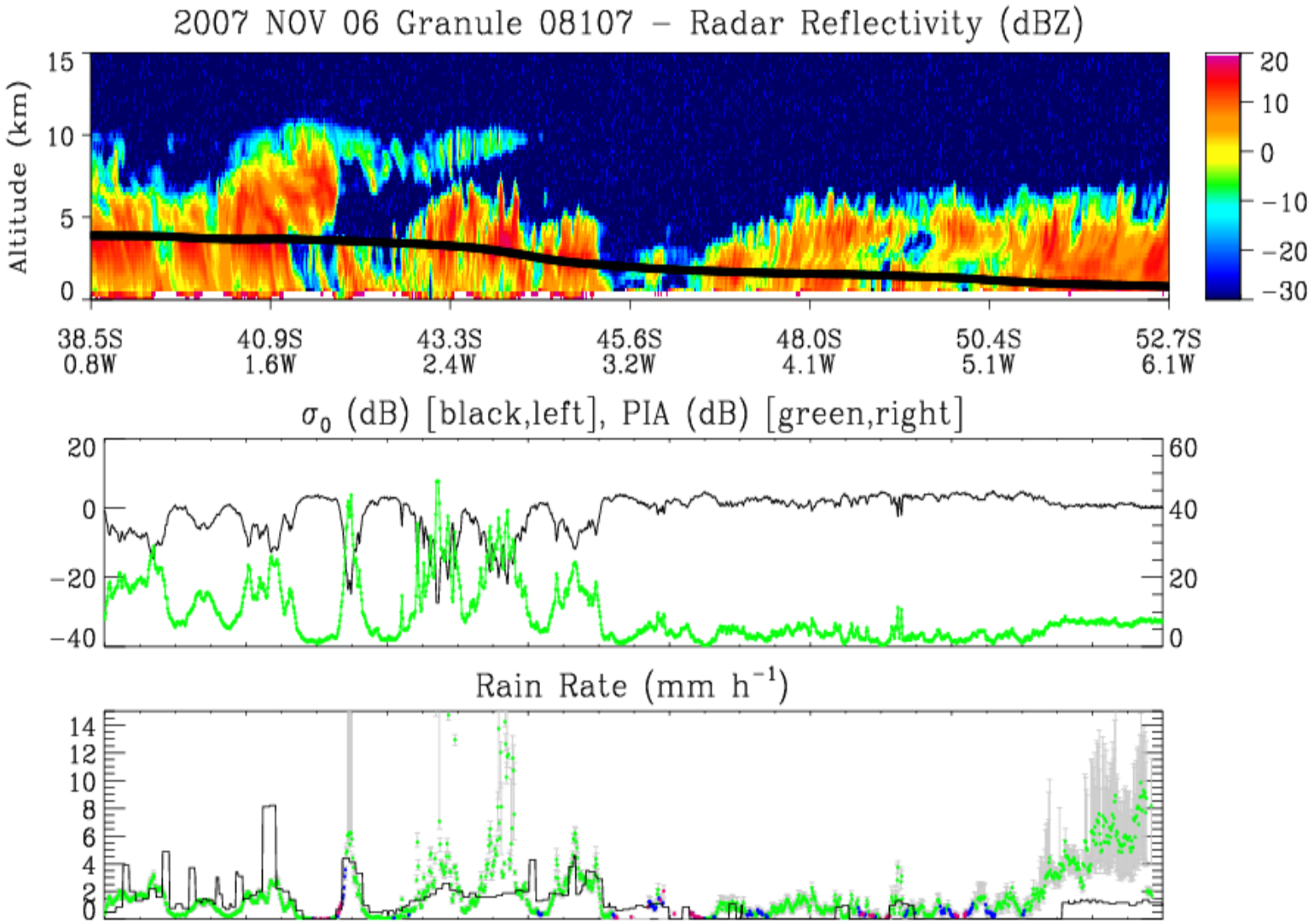
We will wait until the release of CALIPSO V3.0 Level 2 products before we press on with the advanced precip products and/or the R05 GEOPROF-Lidar.

CloudSat "Enhanced" Product Release Status/Sched.

	Description	Algorithm Developers	Current Version	Next Release Date (NET)
2C-PRECIP-COLUMN	Column Integrated Precipitation	John Haynes (CSU), Tristan L'Ecuyer (CSU) Dave Henderson (CSU)	n/a	(Released R04 to GSC)
2C-RAIN-PROFILE	Vertical Distribution of Rain	Tristan L'Ecuyer (CSU), Cristian Mitrescu (NRL) Matt Lebsock (CSU)	n/a	Jan-10 (R04 to ST)
2C-SNOW	Vertical Distribution of Snowfall	Norm Wood (CSU), Tristan L'Ecuyer (CSU), Sergey Matrosov (U. CO)	n/a	Feb-10 (R04 to ST)
2C-ICE	Radar / Lidar Microphysics	Jay Mace (U. UT), Min Deng (U. WY), Zhien Wang (U. WY), Hajime Okamoto (Japan)	n/a	May-10 (R04 to ST)

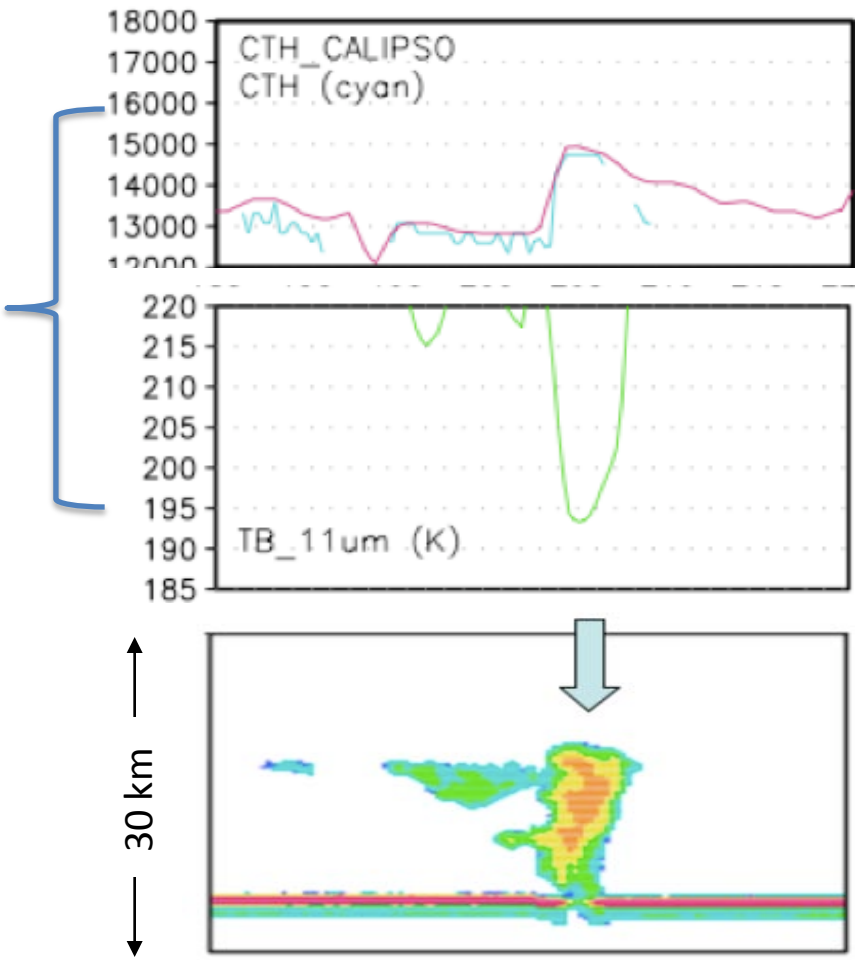
Ice microphysics




2007 NOV 06 Granule 08107 – Radar Reflectivity (dBZ)
Altitude (km)
15
10
5
0
20
10
0
−10
−20
−30
38.5S 0.8W
40.9S 1.6W
43.3S 2.4W
45.6S 3.2W
48.0S 4.1W
50.4S 5.1W
52.7S 6.1W
σ0 (dB) [black,left], PIA (dB) [green,right]
20
0
−20
−40
60
40
20
0
Rain Rate (mm h−1)
14
12
10
8
6
4
2
0

CloudSat provides measurements of severe convection and storm intensity. Luo et al., 2007,; 2008 GRL

We use three pieces of information



Cloud top height

Cloud top temperature (MODIS 11 μm TB)

CPR profile

These two define the moist static energy at cloud top

We can infer the 'intensity' of convective updrafts from th CPR profiles and whether the ascent is undilute

Moist static energy at cloud top and undilute ascent means we know the moist static energy of the boundary layer

The latter relates to the hurricane intensity according to the Emanuel theory

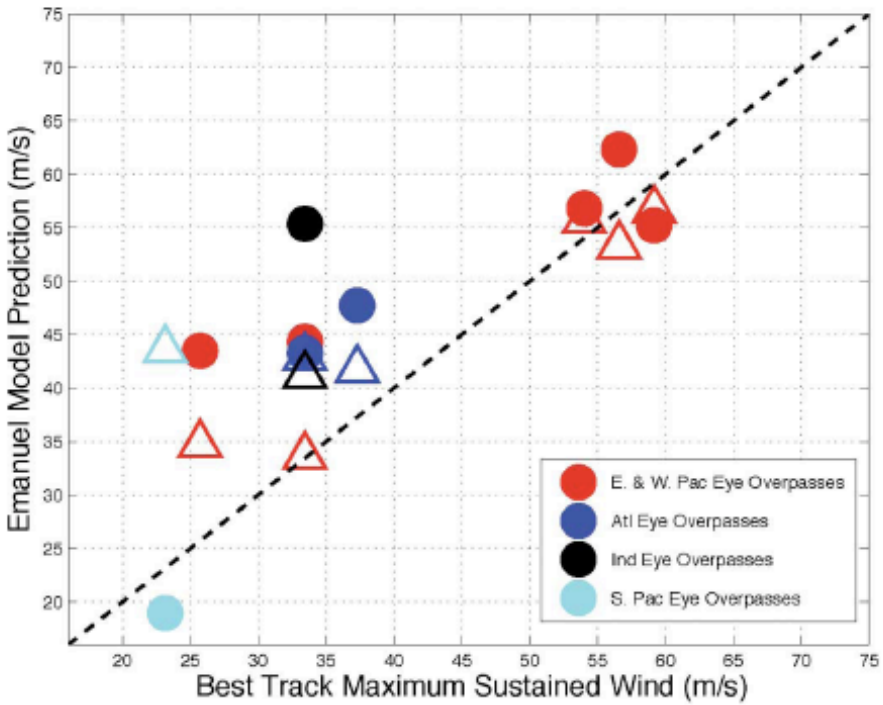


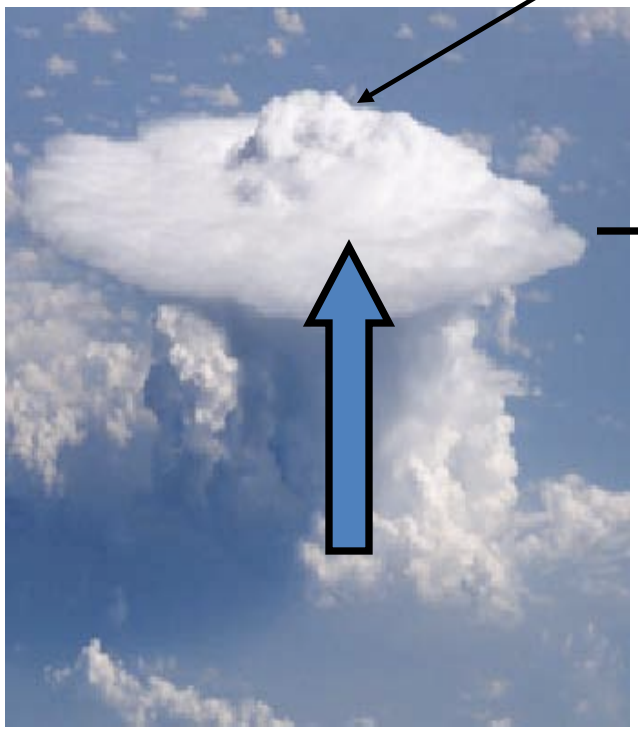
Fig. 2. Estimated versus best track "observed" tropical storm intensity. The dots are for the method that uses SST and 80% RH for estimating the environmental h_0^*, whereas the triangles are for the methods that use satellite data alone to estimate Δh^* (see text for details).

Luo et al. 2007

Classification of deep convection

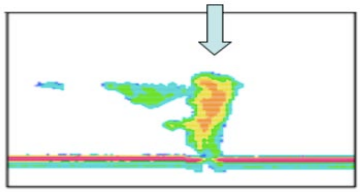
Concept

These overshooting areas continue to follow an adiabatic path (~ 10 K/km) and could be colder than the *cold point tropopause* (CPT) before reaching this height.



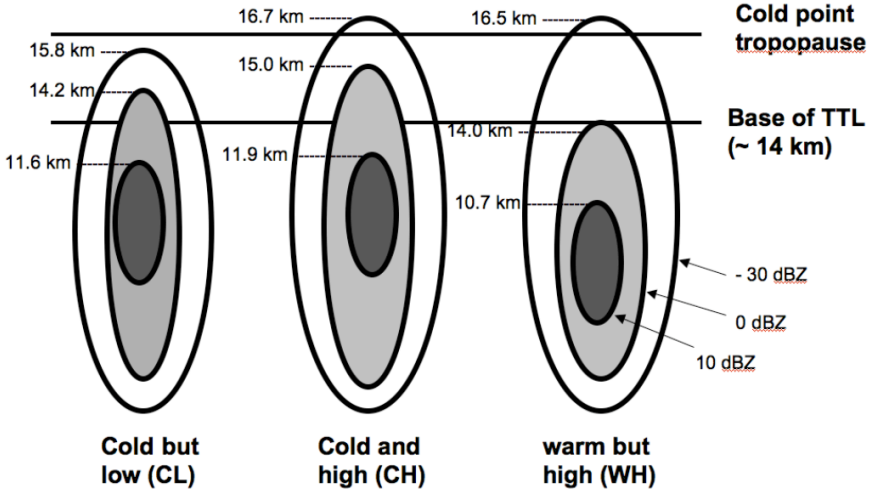
LNB (~ 14 km)

Assuming "undiluted" ascent



1. Collocated ECMWF temperature profiles are used to identify the cold point tropopause.
2. We only focus on the deep convection cloud type (radar signal extending from the surface to UT and having high precip intensity)

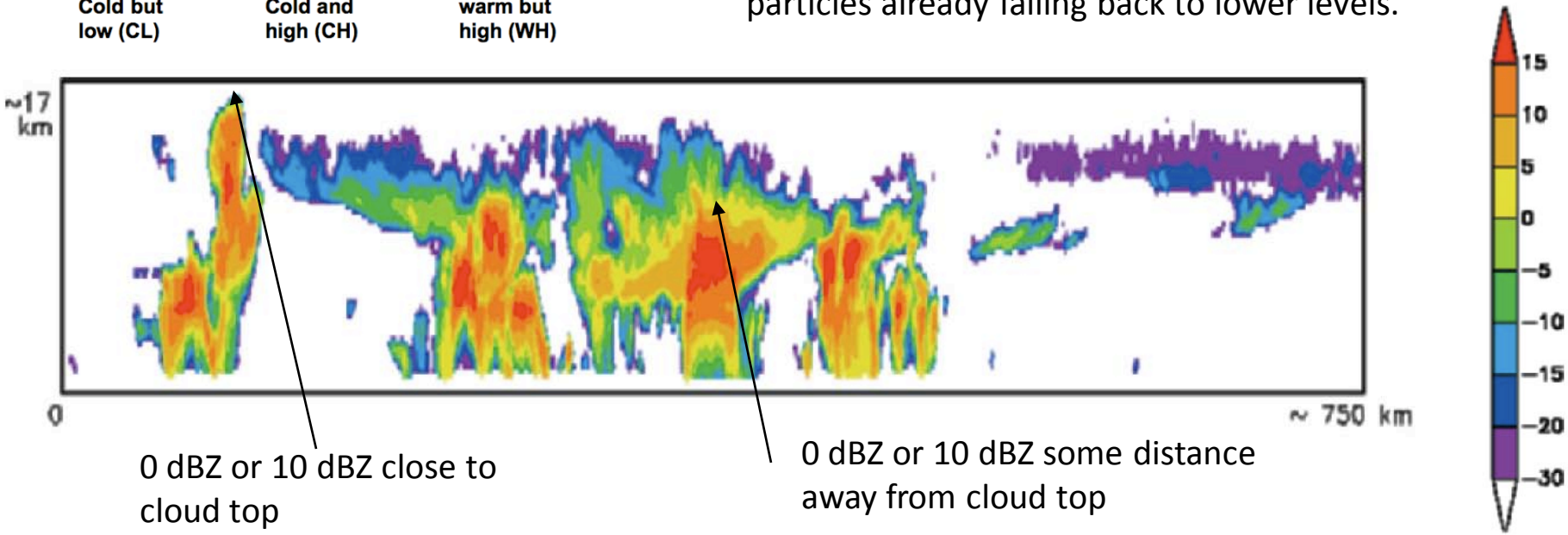
We find 3 types of deep convection



1) CL is newly developed, “undiluted” convection most likely in the early stage of the penetrative convective lifecycle.

2) CH is associated with the mature stage of the penetrative convection.

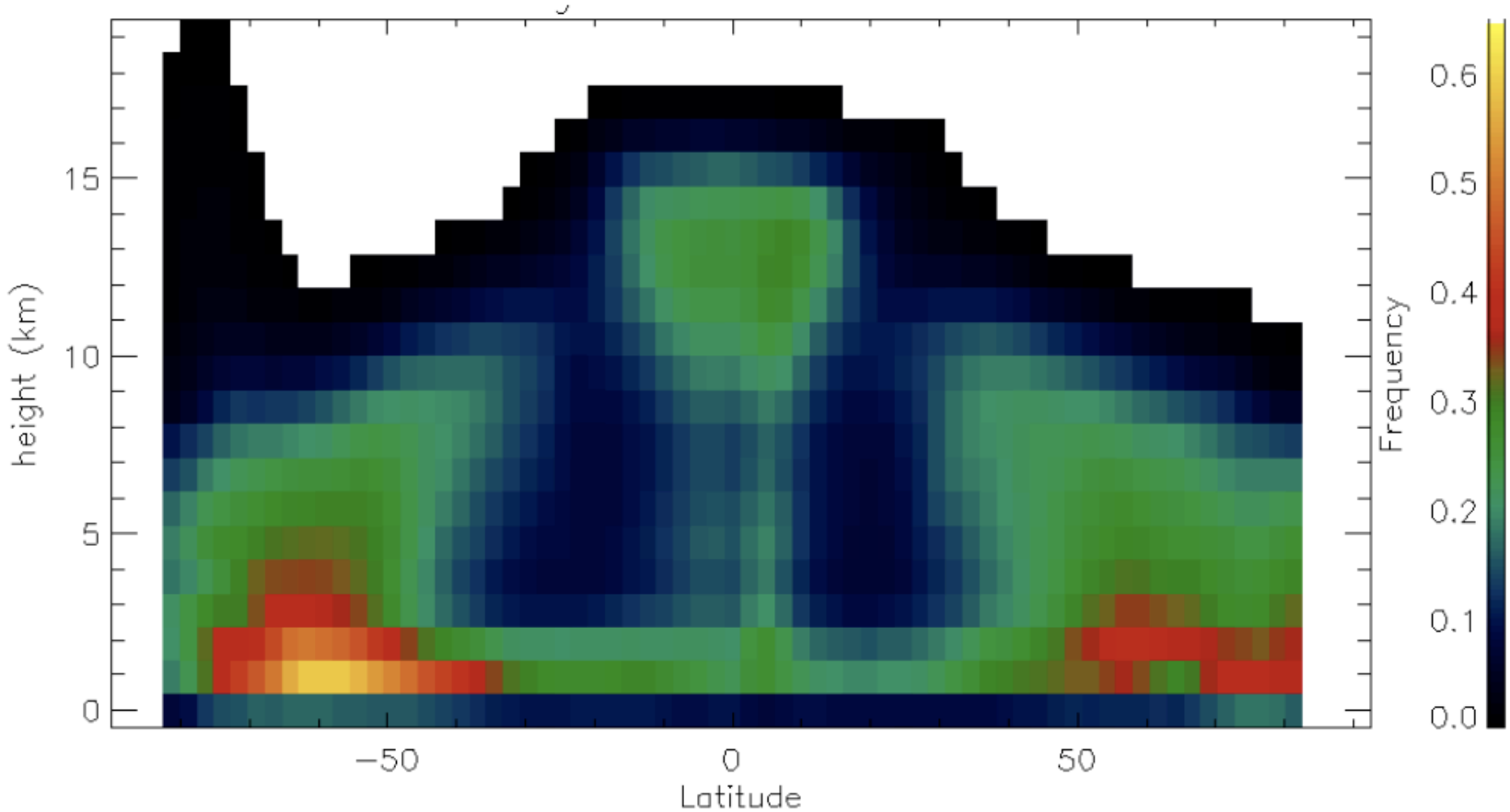
3) WH is associated with the dissipating stage with large particles already falling back to lower levels.



0 dBZ or 10 dBZ close to cloud top

0 dBZ or 10 dBZ some distance away from cloud top

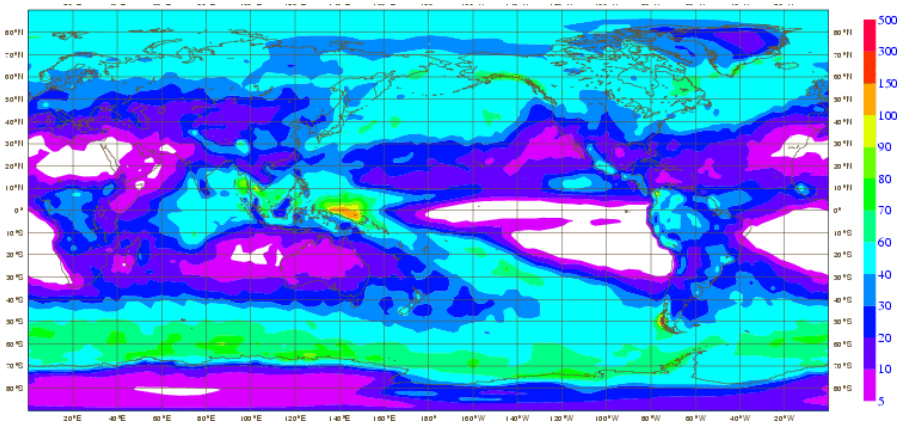
The vertical structure of cloud systems and the microphysical properties



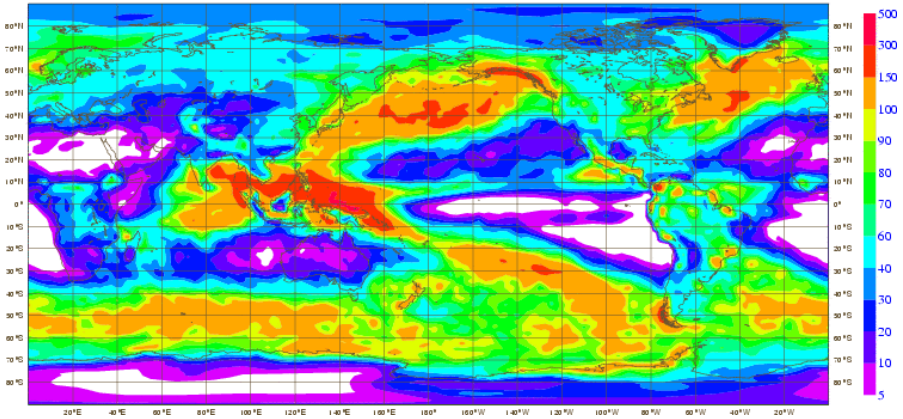
Testing and Improving weather prediction models

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

Current cloud scheme with diagnostic snow



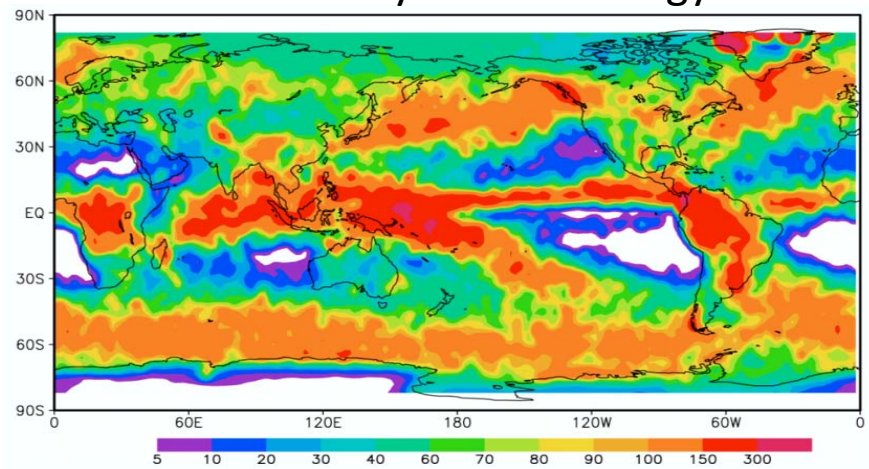
New cloud scheme with prognostic snow



g m^{-2}

Observed Ice Water Path (IWP)

CloudSat 1 year climatology

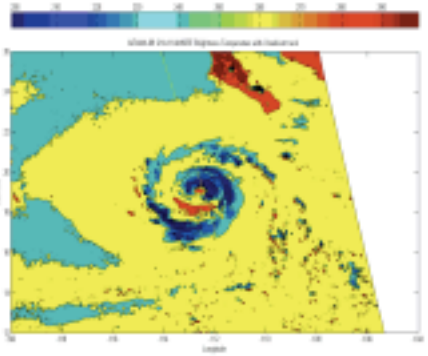


Waliser et al. (2009), JGR

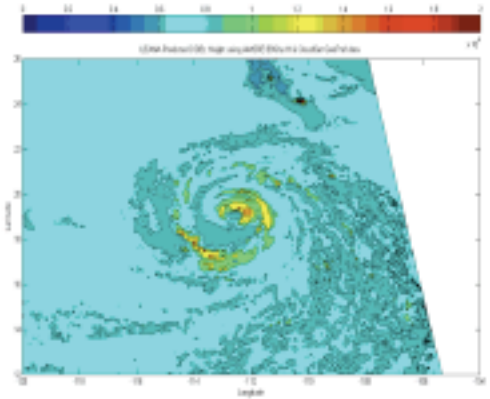
The new scheme (with separate prognostic liquid and ice variables and prognostic snow included in the definition of "Ice Water Path") is closer to the CloudSat estimate. Tuning to obs has has constrained model sedimentation

(Richard Forbes, ECMWF)

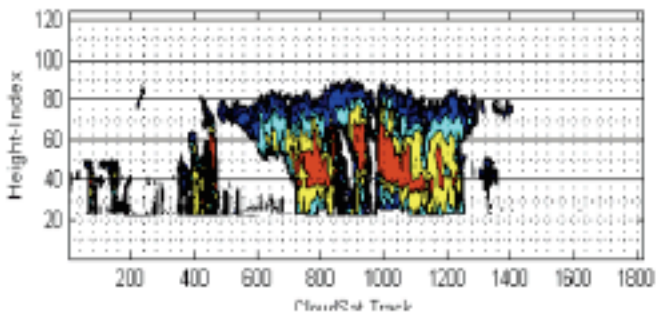
Hurricane Ileana, AMSR-E 89 GHz



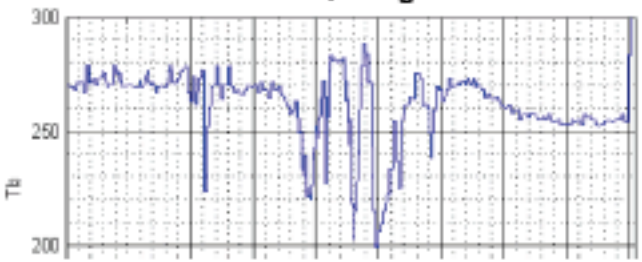
"Predicted" echo-top height



Reflectivity Profile - CloudSat GeoProf data

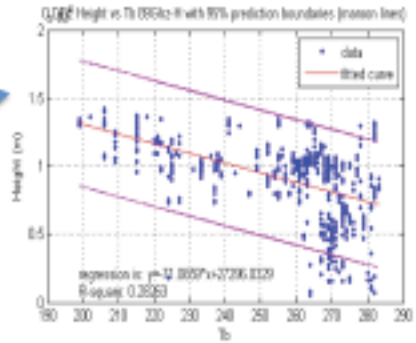


AMSR-E 89 GHz TB, along CloudSat track



Use this relationship to make maps of CloudSat-type ETH based on AMSR-E, practically extending CloudSat beyond its narrow swath

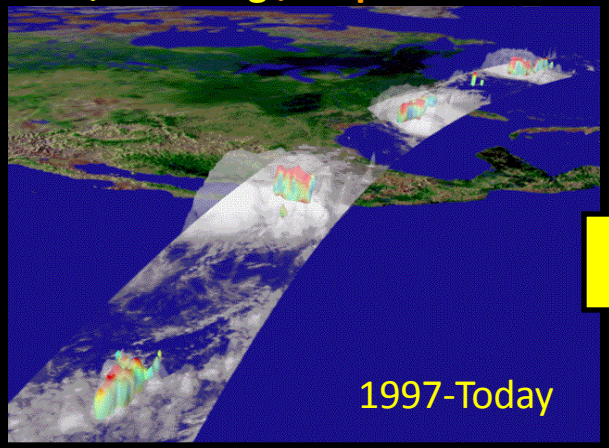
Tune up a relationship b/t AMSR-E TB (89 GHz, but we also tested other channels) and CloudSat echo top height (ETH)



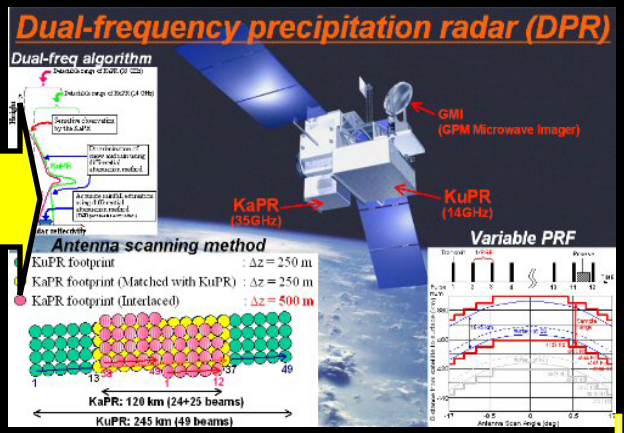
Luo, 2010 in press

Spaceborne Atmospheric Radars

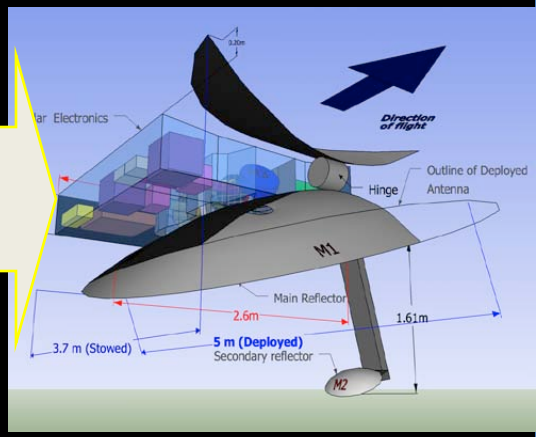
TRMM/PR – NICT/JAXA
Ku, Scanning , Tropical Rain



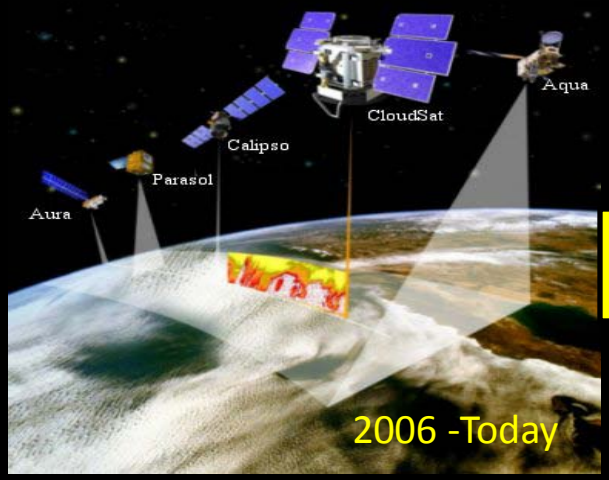
GPM/DPR – NICT/JAXA
Ku/Ka, Scanning, Precipitation



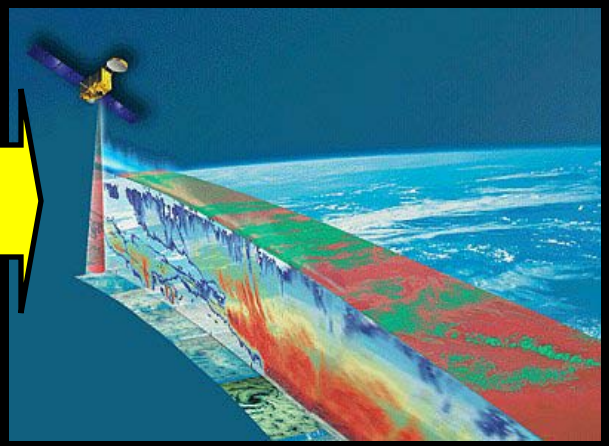
ACE Radar (one concept)
W/Ka, Scanning, Doppler



CloudSat/CPR – JPL/NASA
W, -30dBZ , Clouds



EarthCARE/CPR – NICT/JAXA
W, Doppler, Clouds



Backups

ES-02

ISS Cloud Profiling Radar (ISS-CPR) for Climate / Weather / Aviation Safety
Jet Propulsion Laboratory, Priority

DESCRIPTION AND OBJECTIVES

Mission Themes: Climate Change Science/ Weather Prediction/Aviation Safety

Technical Description: A 94GHz Cloud Profiling Radar (CPR)

- **Built-in design to allow future incorporation of advanced technology and capability enhancements over time**
  - Dual frequency (35/94 GHz), Doppler velocity, wide-swath

Physical Description: Mass: 200kg; Power: 275W;
Dimension: 0.8m x 1m x 1m; Data rate: 25 kbps.

Climate Change Objectives

- **Reduce a major uncertainty in climate models** by extending the detection of low clouds down from 750m to 350m above the surface.
- **Characterize the diurnal cycle of clouds coupled to precipitation**, previously impossible from CloudSat's sun-synchronous orbit, and unmeasured by TRMM.
- **Fill the data-record gap on a key climate variable** by providing data continuity between CloudSat and EarthCARE missions .

Weather and Aviation Safety Objectives

- **Improve aviation safety** by enhancing the detection of icing and active turbulent updrafts in tropical convection, even at night.
- **Improve operational weather prediction** by providing cloud observation data in near real-time (< 3 hours).
- **Increase frequency of hazardous-weather observations** in North American population corridor by utilizing the unique mid-latitude sampling of the ISS orbit.

Low-Risk Implementation Approach

- A high-heritage design based on the very successful CloudSat CPR.
- Same technical team at JPL; All primary components and design are **TRL 8+.**
- Extend CloudSat partnership with Canadian Space Agency (CSA).
- Mature algorithms & data processing in place at Colorado State University (CSU).

Schedule: Flight-ready 30-36 month from ATP

Cost: $34 - 60M cost to NASA (accounted for CSA contribution)

APPROACH

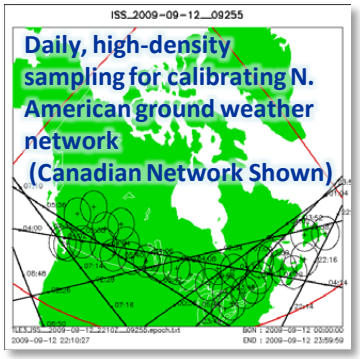
Critical Observations for Climate Change

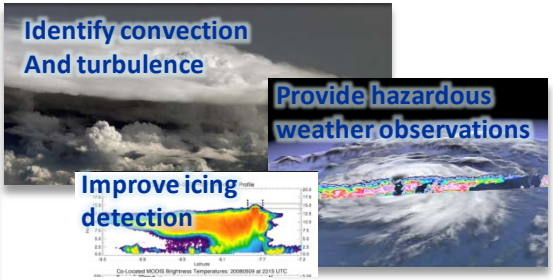
- Day/night cloud type/location/height/depth/ice & water content and particle size
- Reveals inner structure of clouds, indicates severe convection and turbulence and the presence of super-cooled water and ice, detects near-surface precipitation.
- 2X higher vertical resolution over Cloudsat CPR.

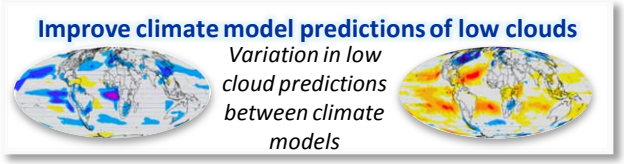
ISS Accommodations: Fits within physical/mass/power/data envelopes of any of the external payload sites.

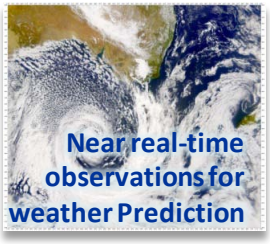
Minimal ISS Resource Demand: Requires SSRMS or equivalent for LV to payload site transfer; Ground originating command and control; No ISS pointing/articulation is required.

PRACTICAL APPLICATIONS: Clouds, Convection, Climate, Weather, Aviation









JUSTIFICATION

Value to NASA and Nation:

- Reduce prediction uncertainty in climate change – major issue facing human kind
- Improve weather prediction and aviation safety – saving lives and enhance socio-economic well being
- Bring out public awareness of ISS value on science and practical applications

ISS Provides Unique Capabilities:

Low altitude	⇨	2x better vertical res. and improved low-cloud detection
Orbit precession	⇨	diurnal sampling of clouds
Orbit inclination	⇨	increased sampling in key weather-sensitive areas
Near real-time data	⇨	enables climate and weather operational applications
Freq. transportation	⇨	allows future technology & capability expansion/demo

COLLABORATORS/ROLES

JPL	**Project Mgmt.; Payload Dev. & Integration**
CSA	**Radar Hardware Contribution**
Environment Canada / CSU / McGill University / JPL	**Science**
Environment Canada / FAA / NOAA / USAF / NRL	**Operational Data Users**

CSA Partnership Status: CSA providing Letter of Interest on partnership; NASA/CSA Partnership agreement will be developed during proposal development.

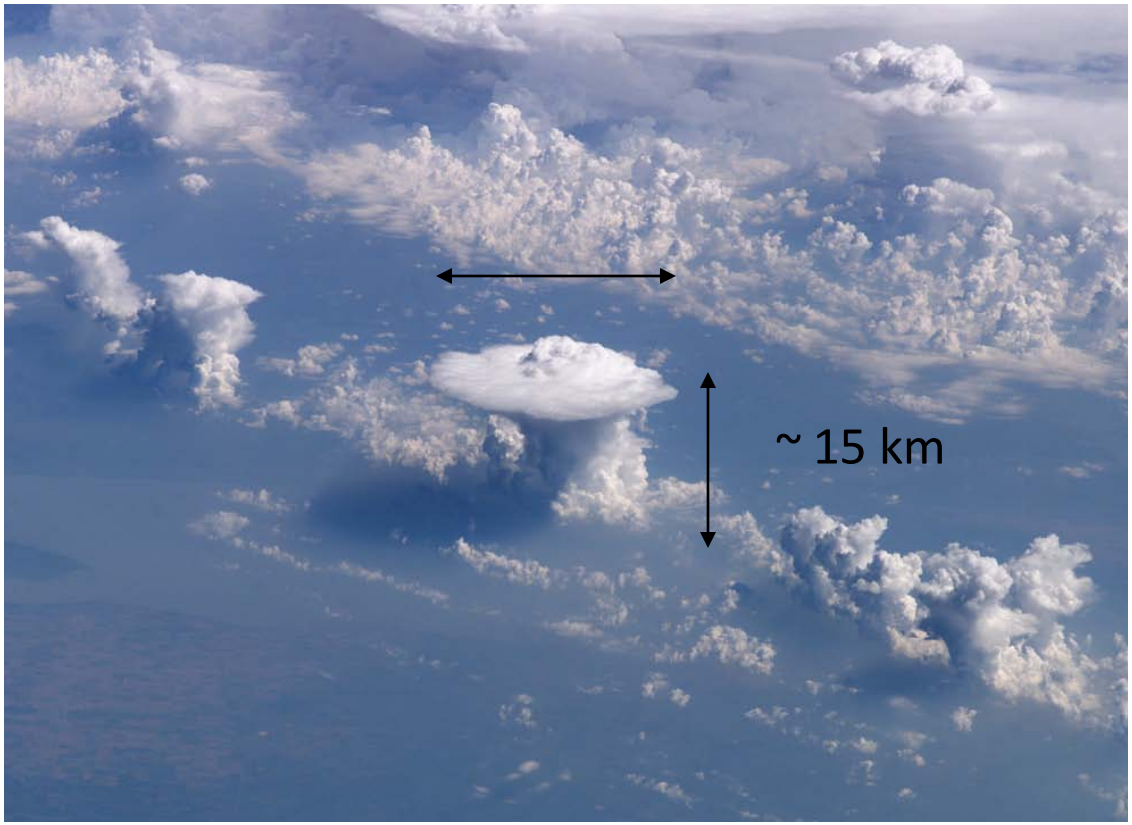
Point of Contact

Adam Loverro (JPL), Adam.L.Loverro@jpl.nasa.gov (P) 818-393-5056

Occurrence frequency (30S-30N) out of all deep convection (DC) type (which covers ~ 4% of the tropics)

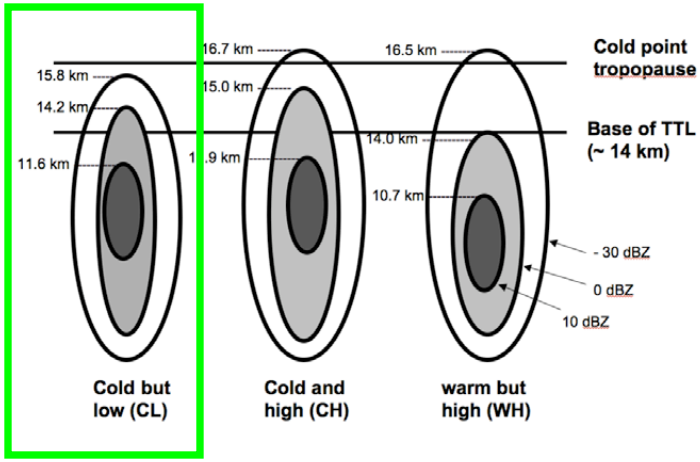
	All	Land	Ocean
CL fraction (out of DC)	0.60%	0.98%	0.41%
CH fraction (out of DC)	0.40%	0.71%	0.31%
WH fraction (out of DC)	0.89%	0.71%	0.93%

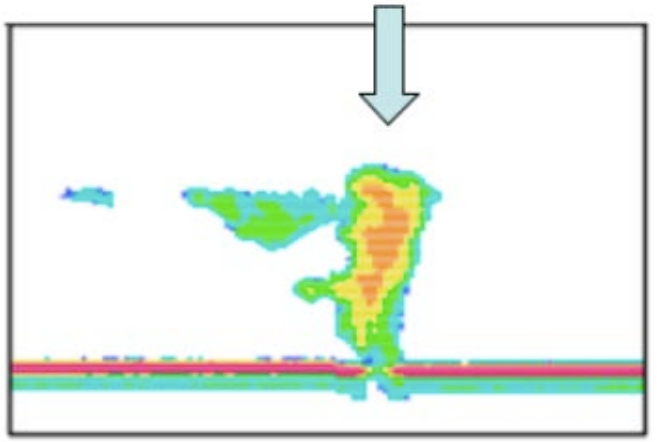
Caveats: the 1:30 am/pm equator crossing time means that important phases of deep convection are not sampled, especially over land. So these occurrence frequencies should be considered as tentative.



Cold & Low (CL)

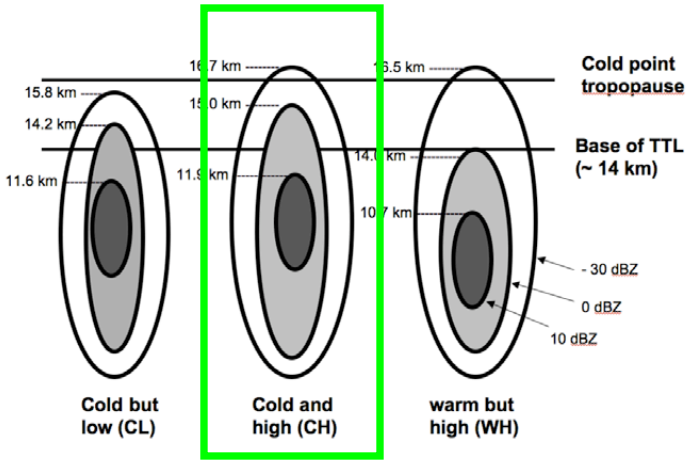
Scale: tens of km

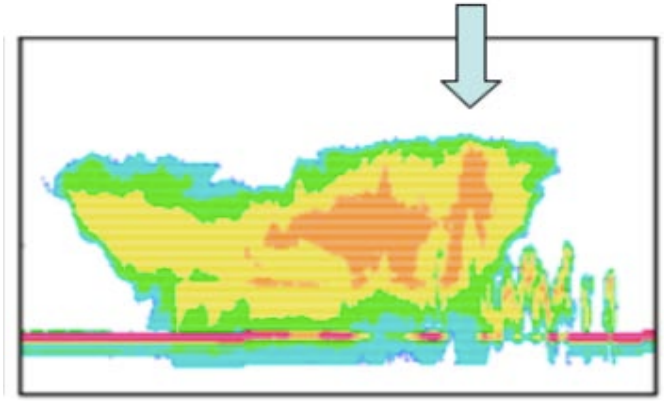




~ 130 km

Scale: ~ 100 km

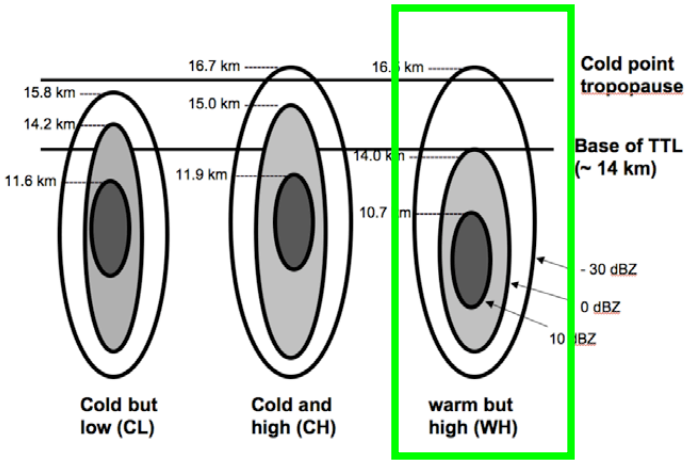


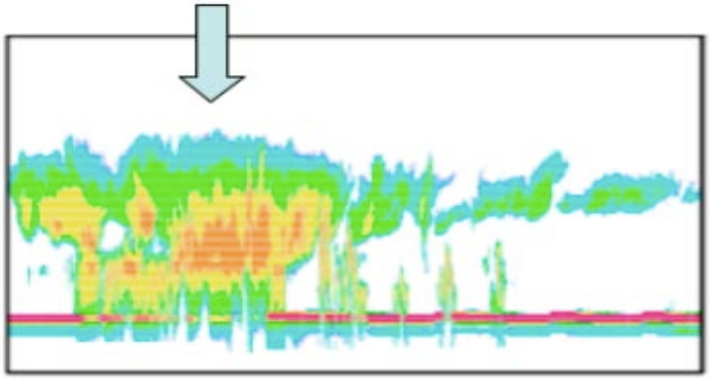


~ 330 km

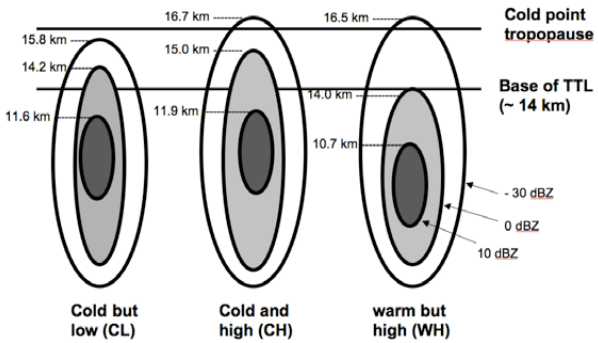
Scale: ~ hundreds of km
to 1,000 km

warm & high (CH)

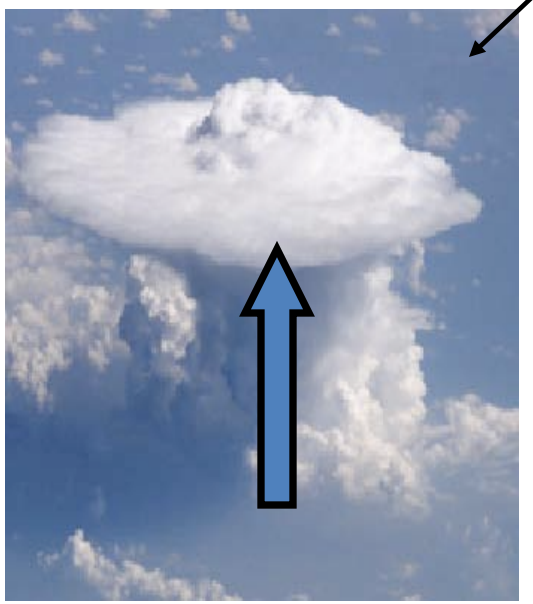




~ 1700 km



Calculate, for each occurrence of penetrating convection, the cloud top temperature assuming undiluted, adiabatic ascent from the PBL (1000 or 925 hPa whichever has greater θ_e) - "T(adibatic)".



	$\delta T = TB - T(adiabatic)$
CL:	1.0 K
CH:	7.7 K
WH:	14 K

Could be partly due to fuzzy cloud tops, but consistent with the "aged" convection hypothesis.

CL: Most undiluted.
CH: Moderate dilution.
WH: Most diluted.