CloudSat's Cloud Profiling Radar (CPR): status, performance and new products

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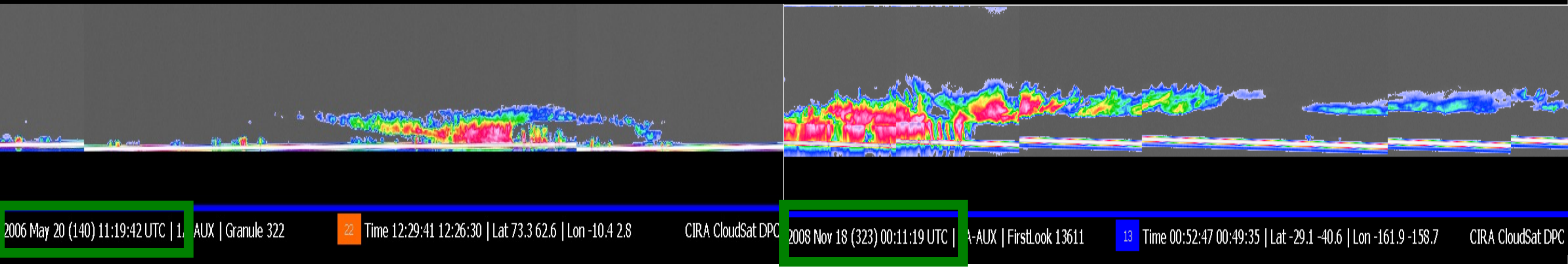
CloudSat/CALIPSO STM, Madison, WI, July 28 2009

CPR Status

- **CPR is currently operating at better than required performance**
- Minor aging of hardware components to date (June 2009) has minor impact on radar performance and data quality. Still on primary side Tx.
- End-to-end radar stability is estimated to be better than 0.6 dB in the first 3 years s of operation, 0.7 dB to date. Prime Mission successfully completed in Feb 2008.
- CPR has been collecting data continuously with few exceptions:
  - CPR has stopped transmitting several times for brief periods (few minutes) to allow planned spacecraft maneuvers
  - CPR has stopped transmitting for a few days in 5 occasions (Sept. ’06, Mar. ’07, Apr. ’07, Jan ‘08 and May ‘08): all were triggered by the spacecraft autonomous fault response, in all instances the radar was brought back online and did not suffer damage.
  - CPR has stopped transmitting for 7 minutes on 5 occasions (June and July ‘06, August ‘07, Sept ‘08 and May ‘09): all were triggered by CPR/HPA autonomous fault response, in all instances the radar came back online automatically and did not suffer damage.

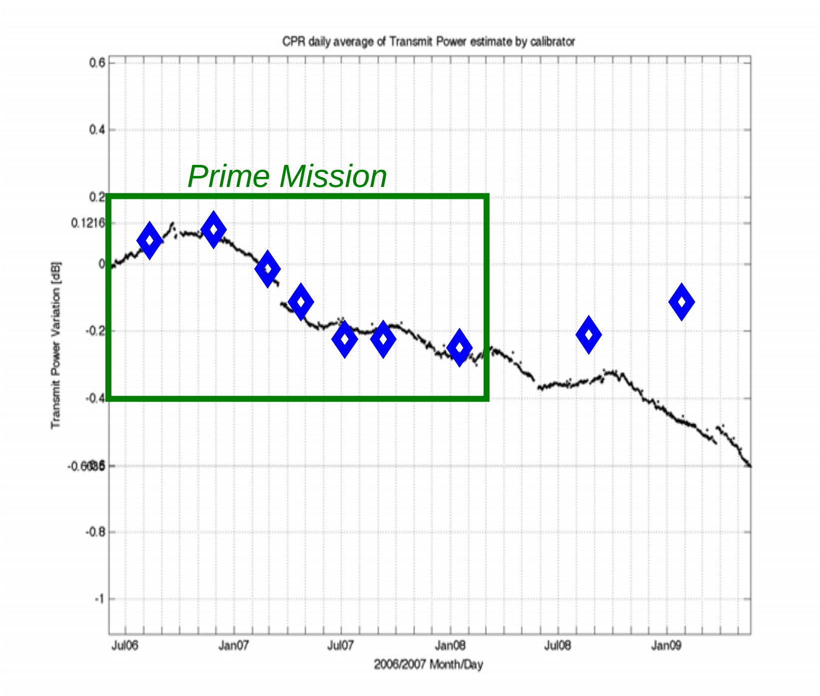


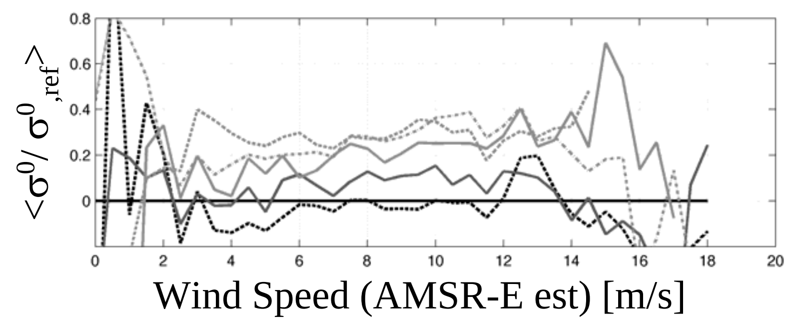
CPR End-to-End Stability

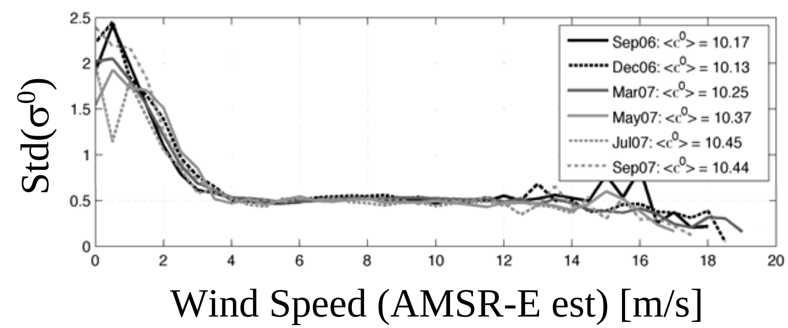
- Avg Orbital Transmit power as measured by calibrator has fluctuated ~ 0.7 dB (as of May 2009)
- During the first two years, apparent drop in P_t corresponds to an apparent increase in surface back scatter (>0.95 correlation) - Best estimate is that actual transmit power, and receiver gain have been stable to better than 0.4 dB during Prime Mission. See *IEEE TGRS Tanelli et al. 2008.*

$$\sigma^0 = \frac{P_r}{P_t} C r^2 \Delta$$

$$\diamond = \sigma^0_{ref} / \sigma^0 = P_t / P_{t,ref}$$







CPR Calibration/Validation

A NASA EARTH SYSTEM SCIENCE PATHFINDER MISSION

High quality external calibration and validation assessment made possible by

• A-TRAIN (CALIPSO & AMSR-E)

•Philippa A.M. Berry and Susan M.S. Bramer, DeMontfort U. Leicester U.K. - Independent Assessment

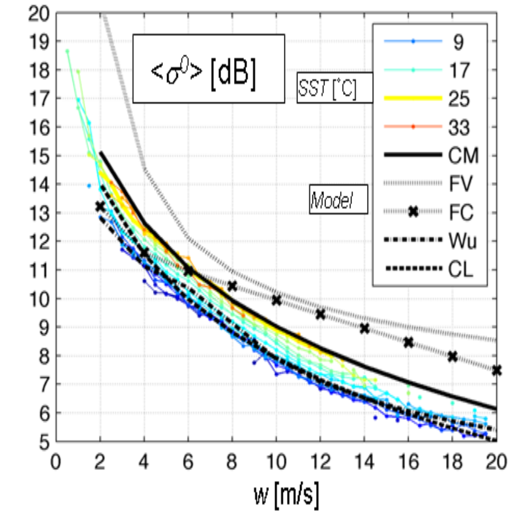
• Alain Protat, Gerald Heymsfield, Mengistu Wolde, Dave Leon, Richard Austin, and many others - (Validations from multiple instruments, mainly W-band radars)

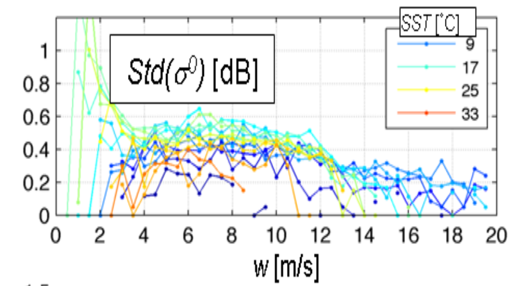
•Joel Johnson and Nino Majurec, Ohio State U. – Advanced scattering models – Multi frequecny comparison.

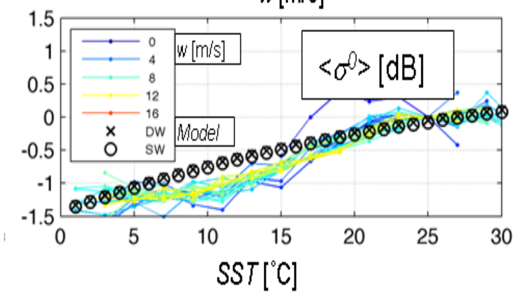
• Hiroaki Horie et al. NICT/JAXA team – Experimental active calibration experiment, best pulse shape observation to date.

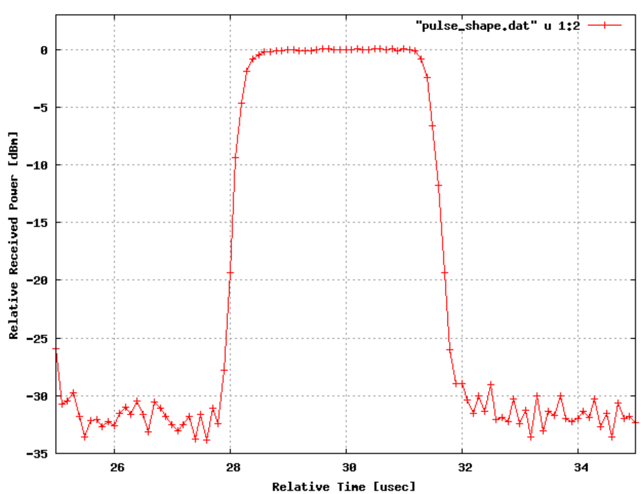
• Jacques Pelon, Damien Josset and Hu Yongxiang – CPR/CALIOP cross-calibration

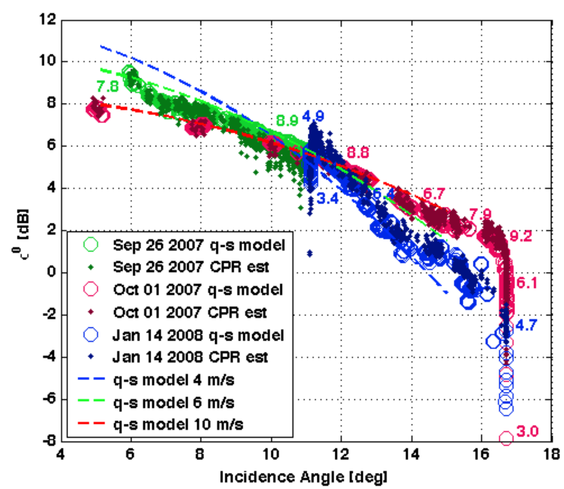
• ECMWF, ARM, NCEP





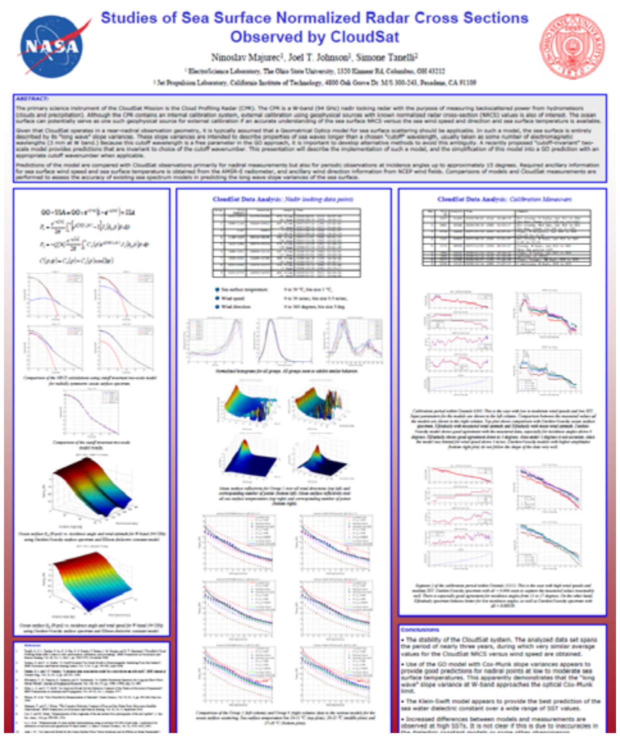


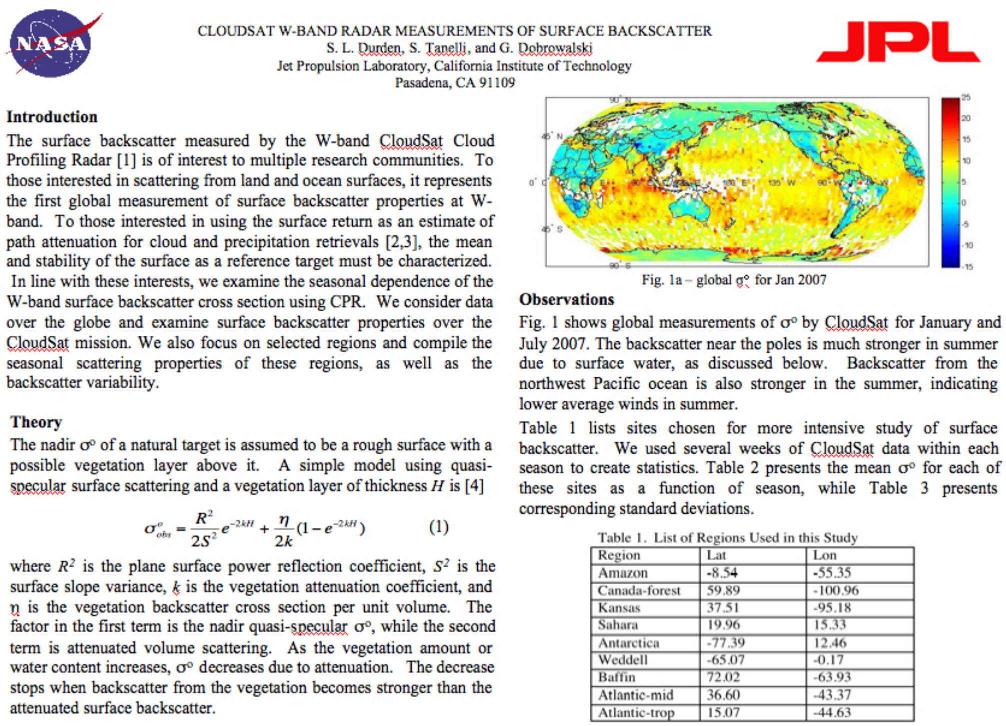




Surface Backscattering modeling advancement

- Cloud Sat data are being used to analyze and improve modeling of surface backscatter. Should coordinate with CALIPSO team. Two posters in this worshop:
  - Durden et al.
  - Majurec et al.





CLOUDSAT W-BAND RADAR MEASUREMENTS OF SURFACE BACKSCATTER

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Introduction

The surface backscatter measured by the W-band CloudSat Cloud Profiling Radar [1] is of interest to multiple research communities. To those interested in scattering from land and ocean surfaces, it represents the first global measurement of surface backscatter properties at W-band. To those interested in using the surface return as an estimate of path attenuation for cloud and precipitation retrievals [2,3], the mean and stability of the surface as a reference target must be characterized. In line with these interests, we examine the seasonal dependence of the W-band surface backscatter cross section using CPR. We consider data over the globe and examine surface backscatter properties over the CloudSat mission. We also focus on selected regions and compile the seasonal scattering properties of these regions, as well as the backscatter variability.

Theory

The nadir σ^o of a natural target is assumed to be a rough surface with a possible vegetation layer above it. A simple model using quasi-specular surface scattering and a vegetation layer of thickness H is [4]

$$\sigma^o_{obs} = \frac{R^2}{2S^2} e^{-2kH} + \frac{\eta}{2k}(1-e^{-2kH}) \qquad (1)$$

where R^2 is the plane surface power reflection coefficient, S^2 is the surface slope variance, k is the vegetation attenuation coefficient, and η is the vegetation backscatter cross section per unit volume. The factor in the first term is the nadir quasi-specular σ^o, while the second term is attenuated volume scattering. As the vegetation amount or water content increases, σ^o decreases due to attenuation. The decrease stops when backscatter from the vegetation becomes stronger than the attenuated surface backscatter.

Fig. 1a – global σ^o for Jan 2007

Observations

Fig. 1 shows global measurements of σ^o by CloudSat for January and July 2007. The backscatter near the poles is much stronger in summer due to surface water, as discussed below. Backscatter from the northwest Pacific ocean is also stronger in the summer, indicating lower average winds in summer.

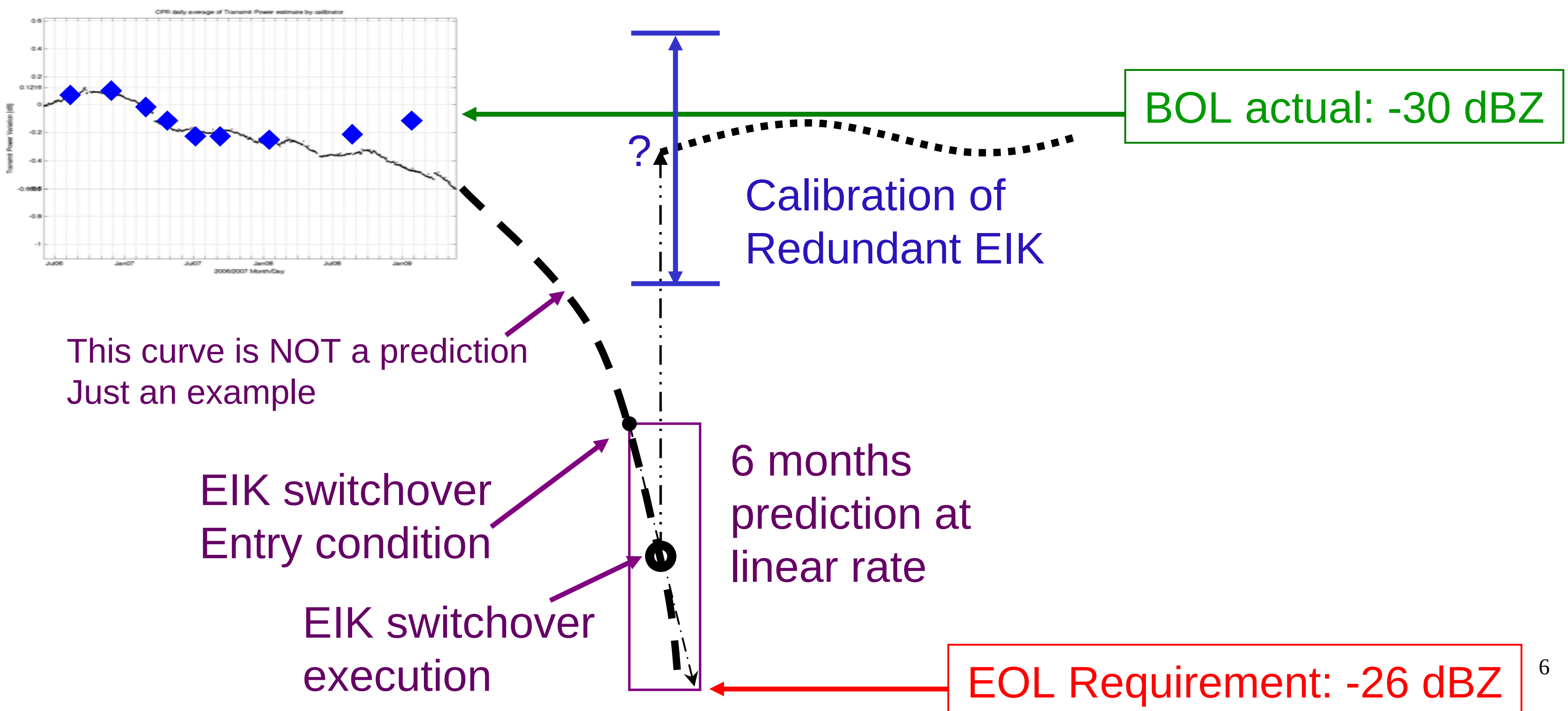
Table 1 lists sites chosen for more intensive study of surface backscatter. We used several weeks of CloudSat data within each season to create statistics. Table 2 presents the mean σ^o for each of these sites as a function of season, while Table 3 presents corresponding standard deviations.

Table 1. List of Regions Used in this Study

Region	Lat	Lon
Amazon	-8.54	-55.35
Canada-forest	59.89	-100.96
Kansas	37.51	-95.18
Sahara	19.96	15.33
Antarctica	-77.39	12.46
Weddell	-65.07	-0.17
Baffin	72.02	-63.93
Atlantic-mid	36.60	-43.37
Atlantic-trop	15.07	-44.63

Transmitter Switchover Plan

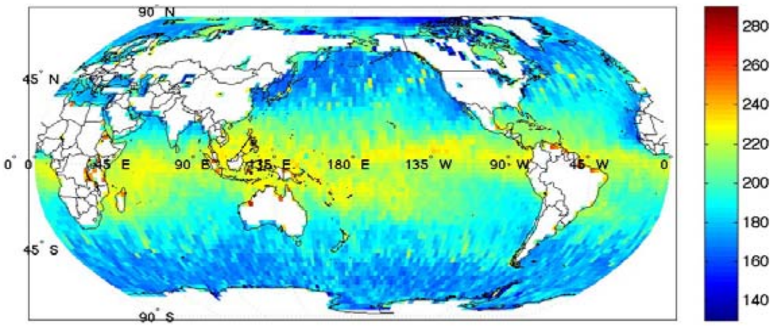
- Entry condition: minimum detectable sensitivity projected 6 months into the future at the current trend violates EOL requirement of -26 dBZ.
  - Mission Operations Team will issue warning to PI, ADWG and STM
  - PI, ADWG and STM will provide input on upcoming periods of high interest (i.e., to avoid execution of switchover in the middle of a field experiment).
- Execution: within the 6 months window.
- Expected “blind” period: in absence of anomalies 2-4 days.
- Calibration period (i.e., delay in release of L1B data from redundant side): 1-2 months, initially limited to Science Team.



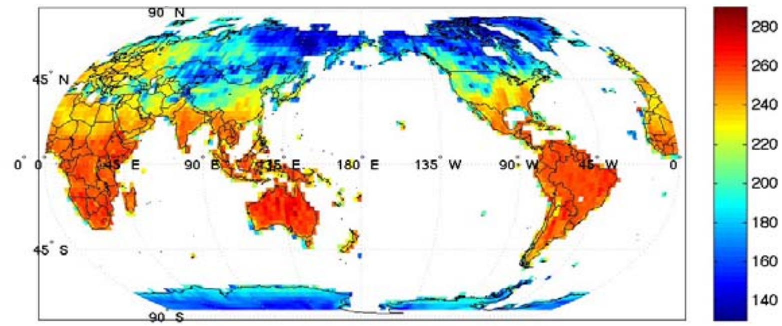
CPR as Radiometer

- CPR noise power converted into brightness temperature using relationship obtained by comparing with AMSR-E 89-GHz TB
- Preliminary estimation of NEΔT ≅ 5K

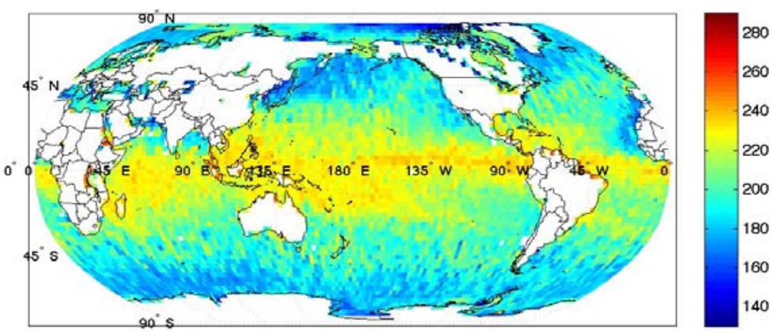
Ocean, clear sky (Jan 1-17, 2007)



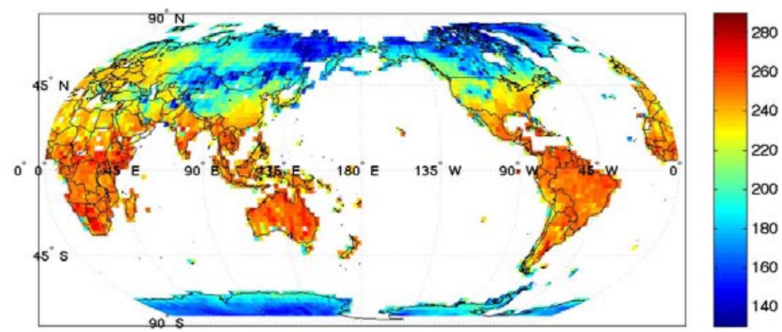
Land, clear sky (Jan 1-17, 2007)



Ocean, cloudy sky (Jan 1-17, 2007)

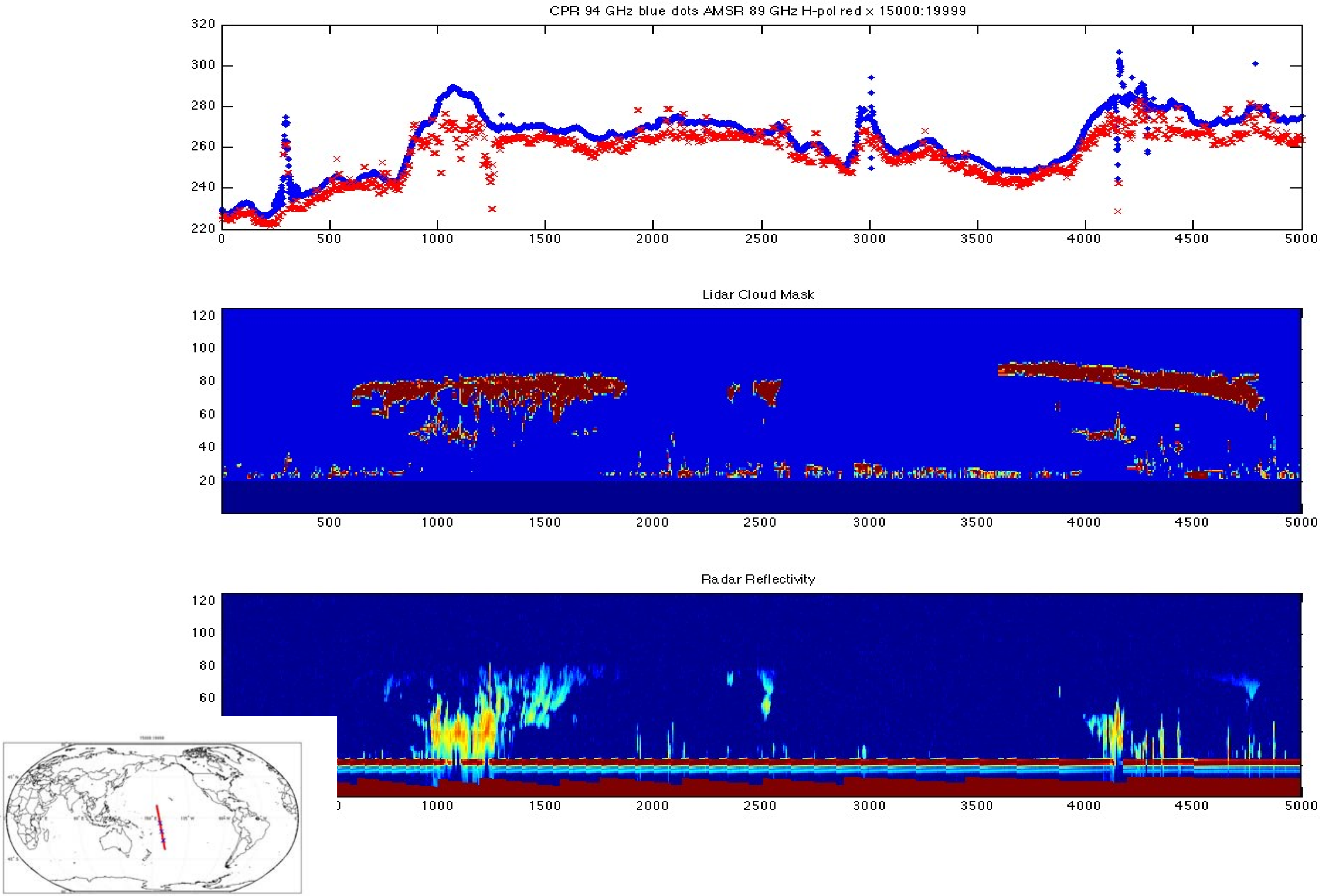


Land, cloudy sky (Jan 1-17, 2007)



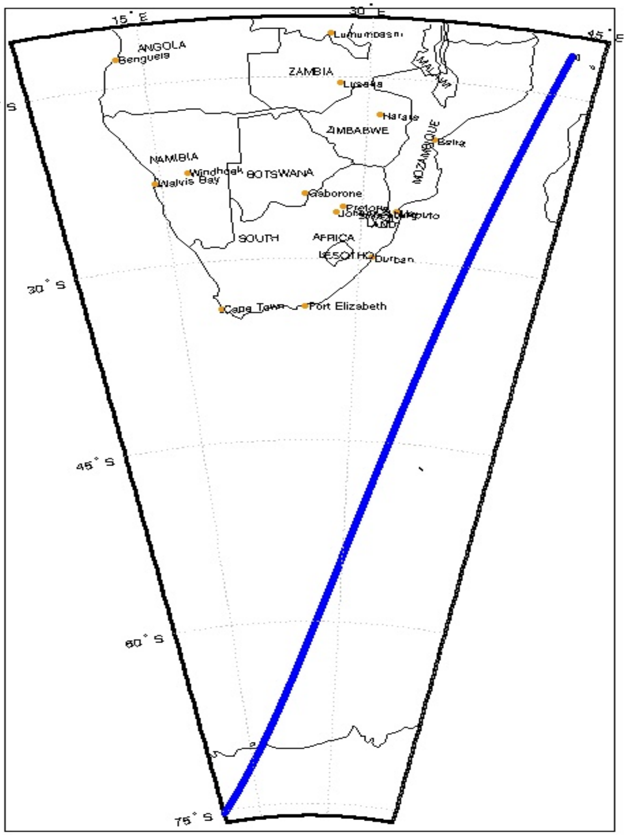
- Cold background (ocean) appears warmer in the presence of water cloud

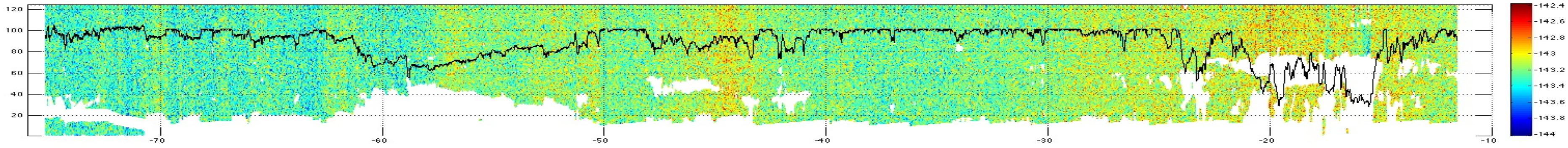
CPR as Radiometer

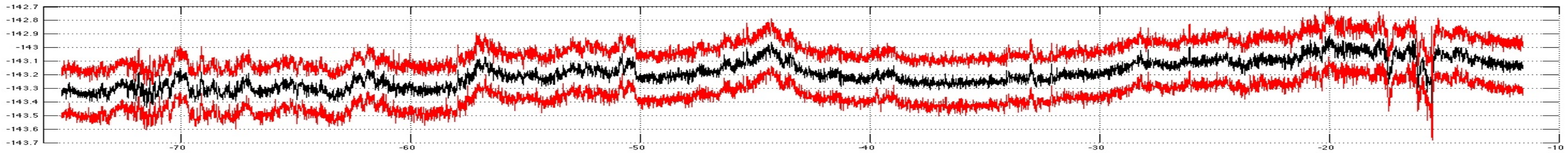


Tb product: step 1

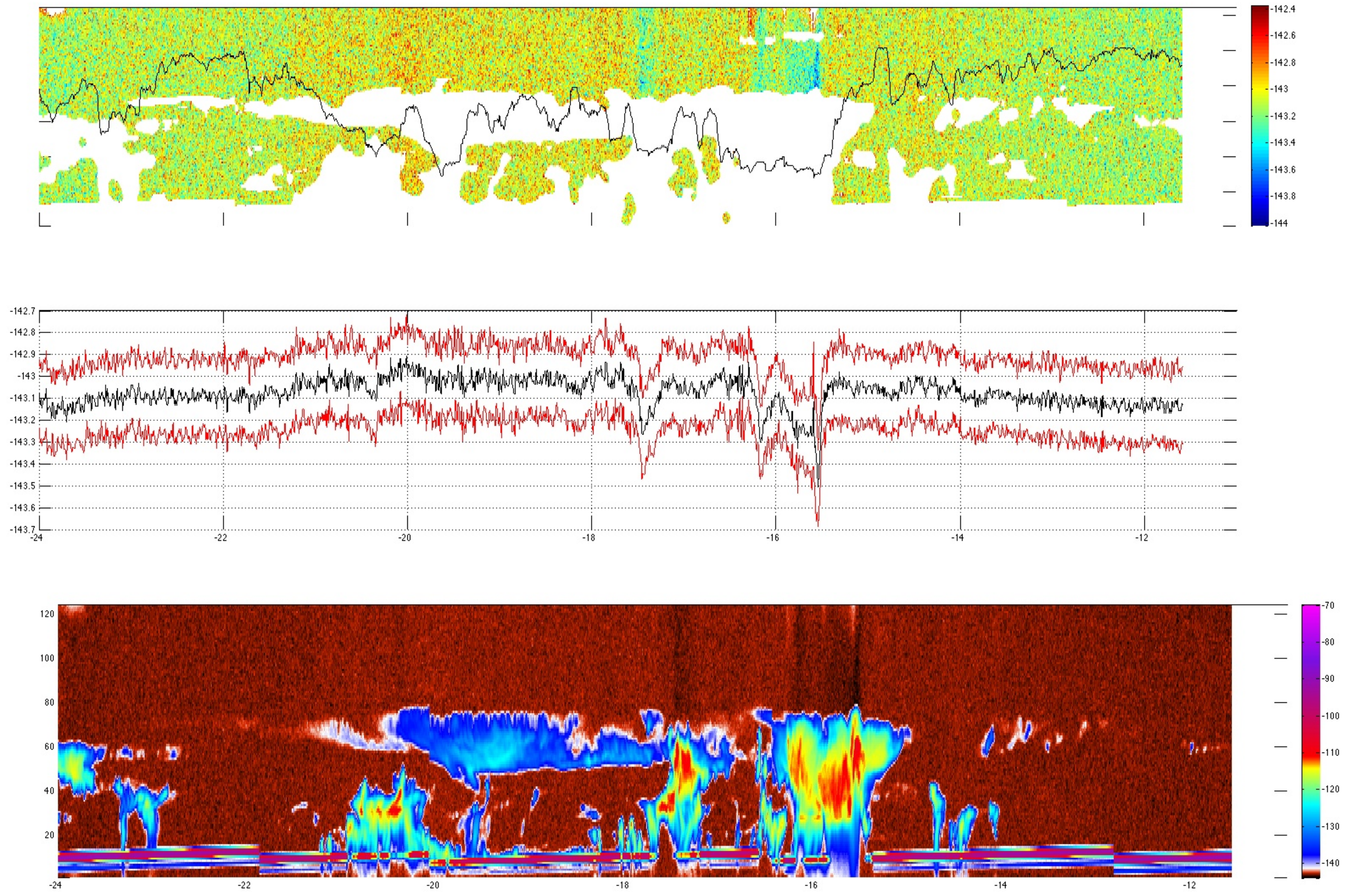
- **Calculate CPR noise from L1B-CPR ReceivedEchoPowers**
  - **Use L2B Cloud Mask and sem_noise_floor to flag 'cloudy bins' in the 'noise region'.**
    - **Iter #1: 4-sigma above mean**
    - **Iter #2: 3-sigma away from mean**
  - **Option (Flag all bins beyond #85 in GEOPROF (i.e., lowest 5 km))**
  - **Option (Flag all bins with Lidar echo)**
  - **Use all unflagged bins to calculate mean noise of each ray**
- **Filter CPR 1-ray noise along track**
  - **Apply moving average filter with 6 window sizes, (1, 5, 11, 31, 61, 101)**
  - **Adopt largest window in which noise population is distributed according to expectation.**
- **Convert noise to Brightness Temperature:**
  - **TB94 = filtered_noise * C1 + C2**
  - **C1 = 189 10^{15}**
  - **C2 = -670**
  - **Coefficients calculated from AMSR-E 89H Tb, Ws, SST, and WVmm using lookup table**
    - **Tb 89H 55˚ --> Tb 94 0.16˚ with 1-D Radiative Transfer over ocean and clear air (Eddington Approximation)**







Step 1: zoom in



Tb product: step 2

- Calculate CPR noise from L1B-CPR ReceivedEchoPowers
  - Use L2B Cloud Mask and sem_noise_floor to flag ‘cloudy bins’ in the ‘noise region’.
    - Iter #1: 4-sigma above mean
    - Iter #2: 3-sigma away from mean
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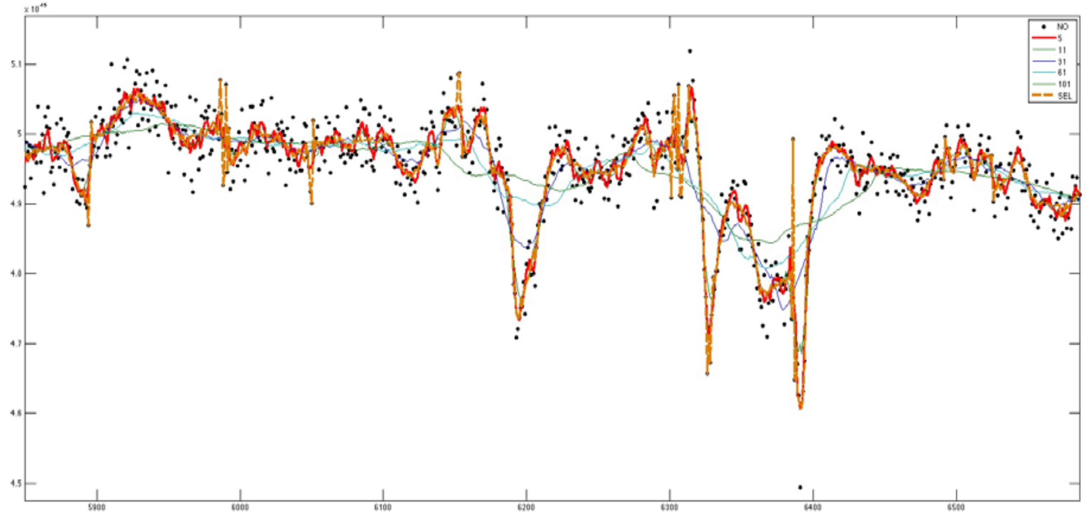

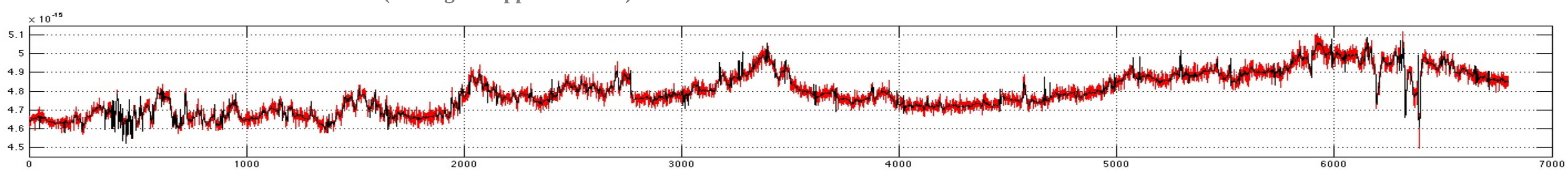

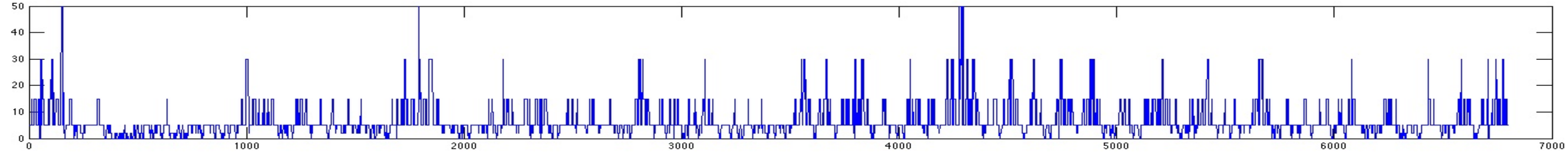

Tb product: step 3

- Calculate CPR noise from L1B-CPR ReceivedEchoPowers
  - Use L2B Cloud Mask and sem_noise_floor to flag ‘cloudy bins’ in the ‘noise region’.
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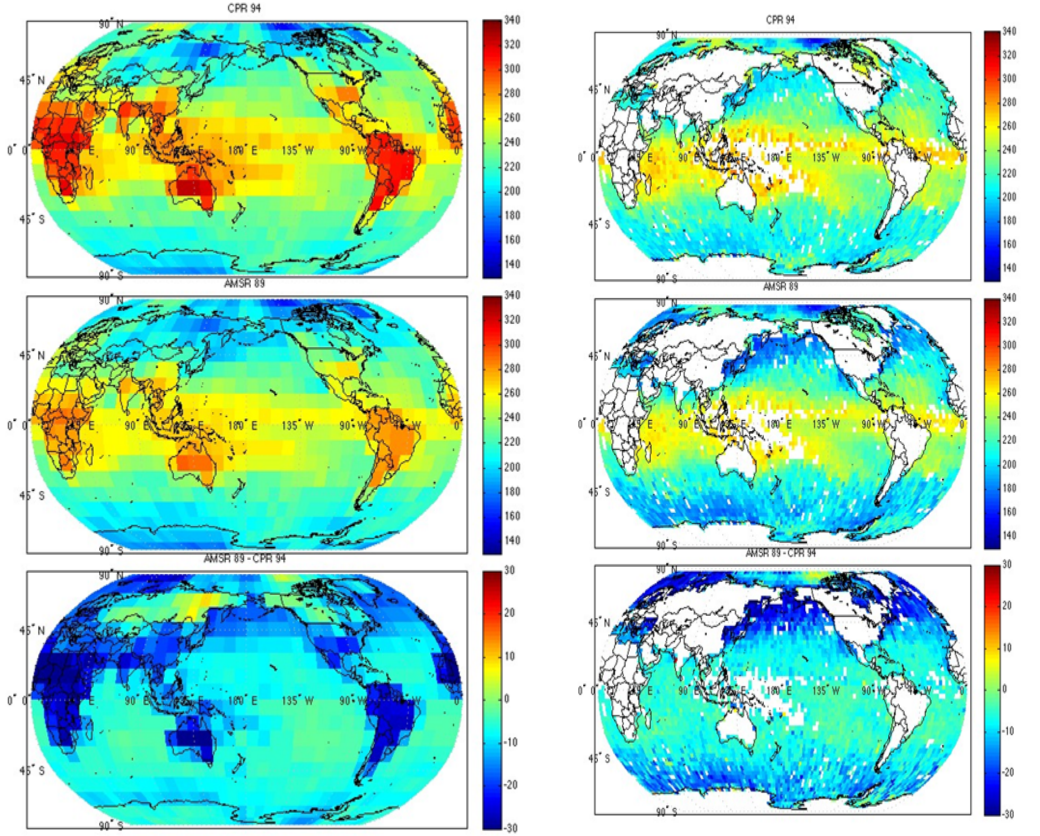
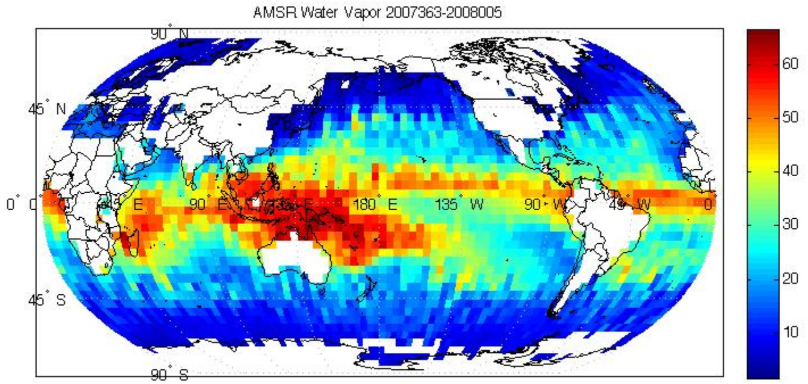
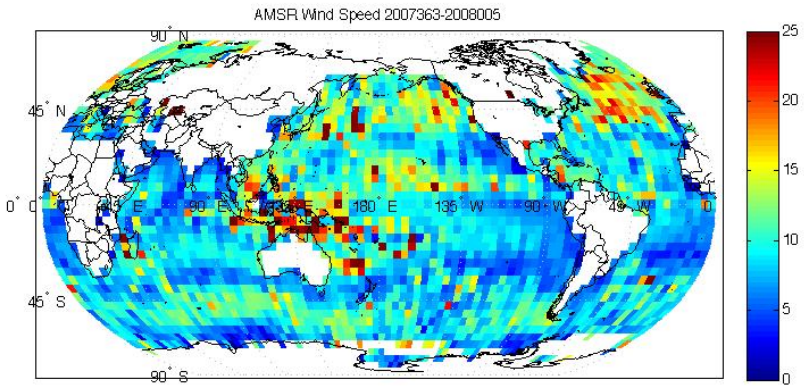


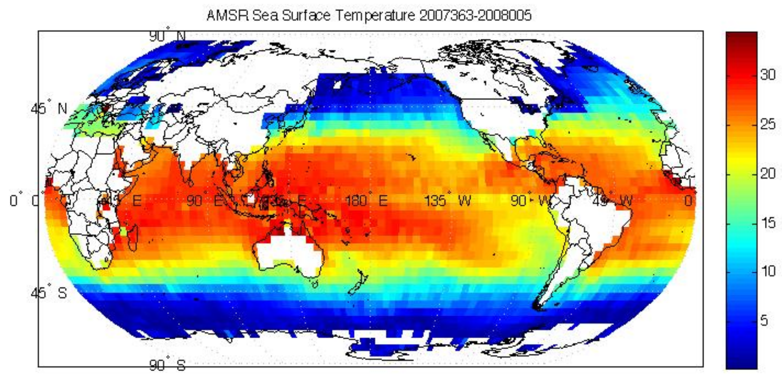
Parameters used
to find constants via lookup table

From AMSR-E

- TB89H
- Water vapor
- Wind Speed
- Sea Surface Temperature

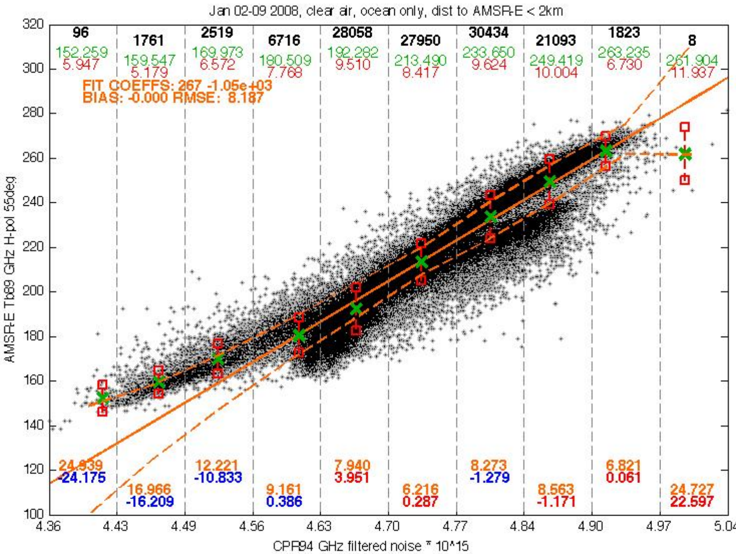






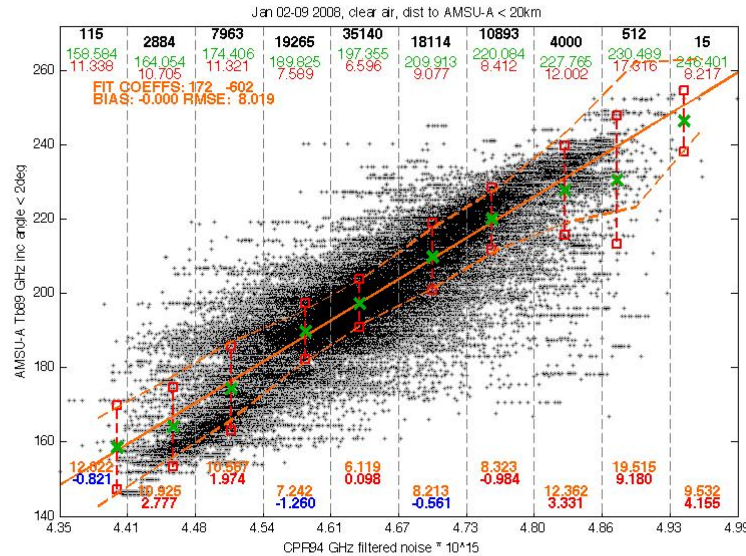
Tb product: step 3

AMSR-E @ 55deg



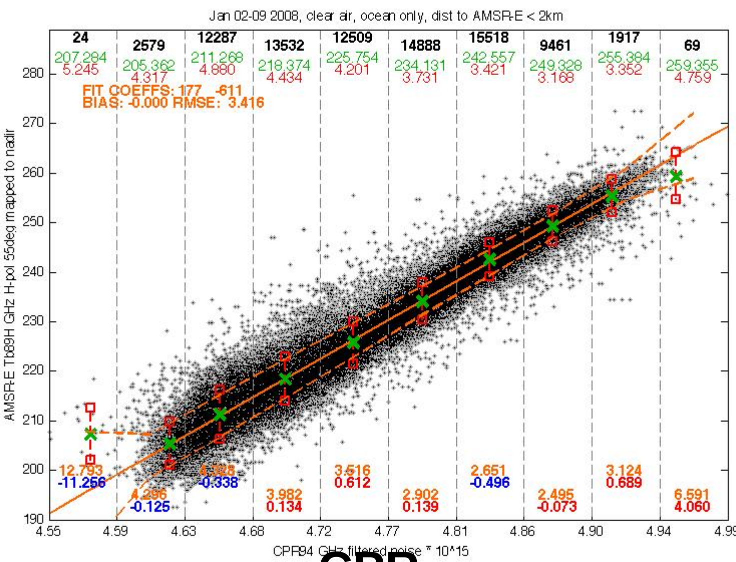
CPR

AMSU-A → nadir



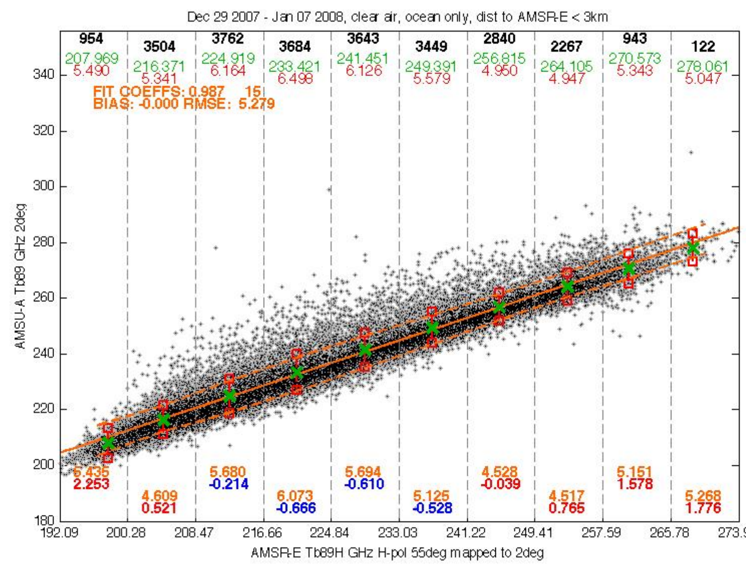
CPR

AMSR-E → nadir



CPR

AMSU-A @ nadir

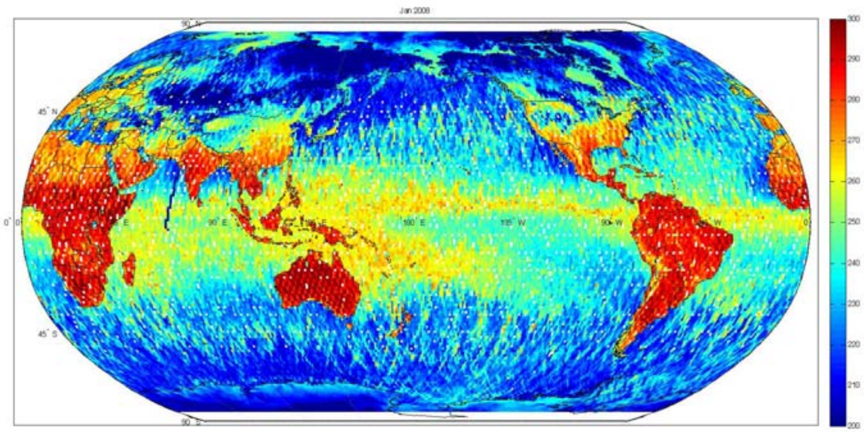


AMSR-E → nadir

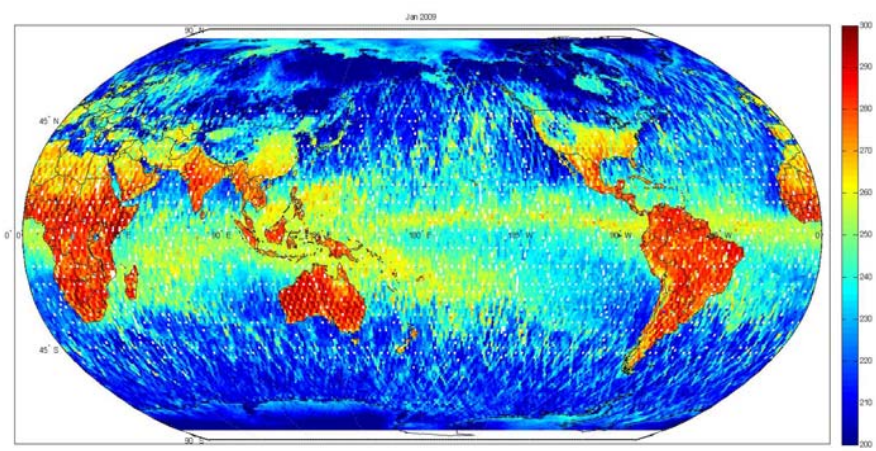
Tb Product Status

- Code has been test run over several periods by the DPC
- Will be distributed for more testing
- Data will be added to 2B-GEOPROF output and stored in separate product file (name TBD) with R05
  - Single ray noise avg
  - Single ray number of noise bins
  - Single ray noise std dev
  - Filter window size

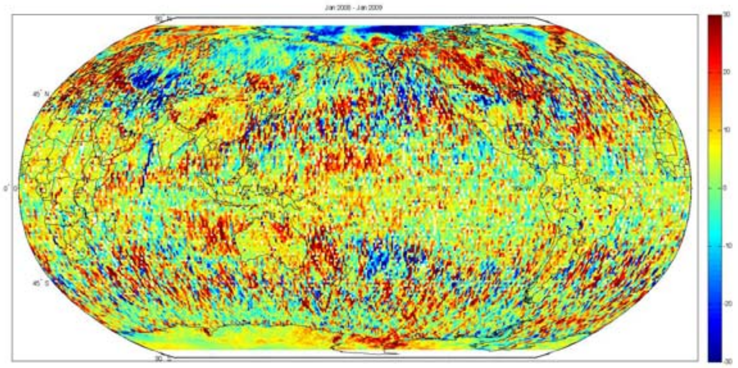
Temporal drift due to Receiver Gain drift



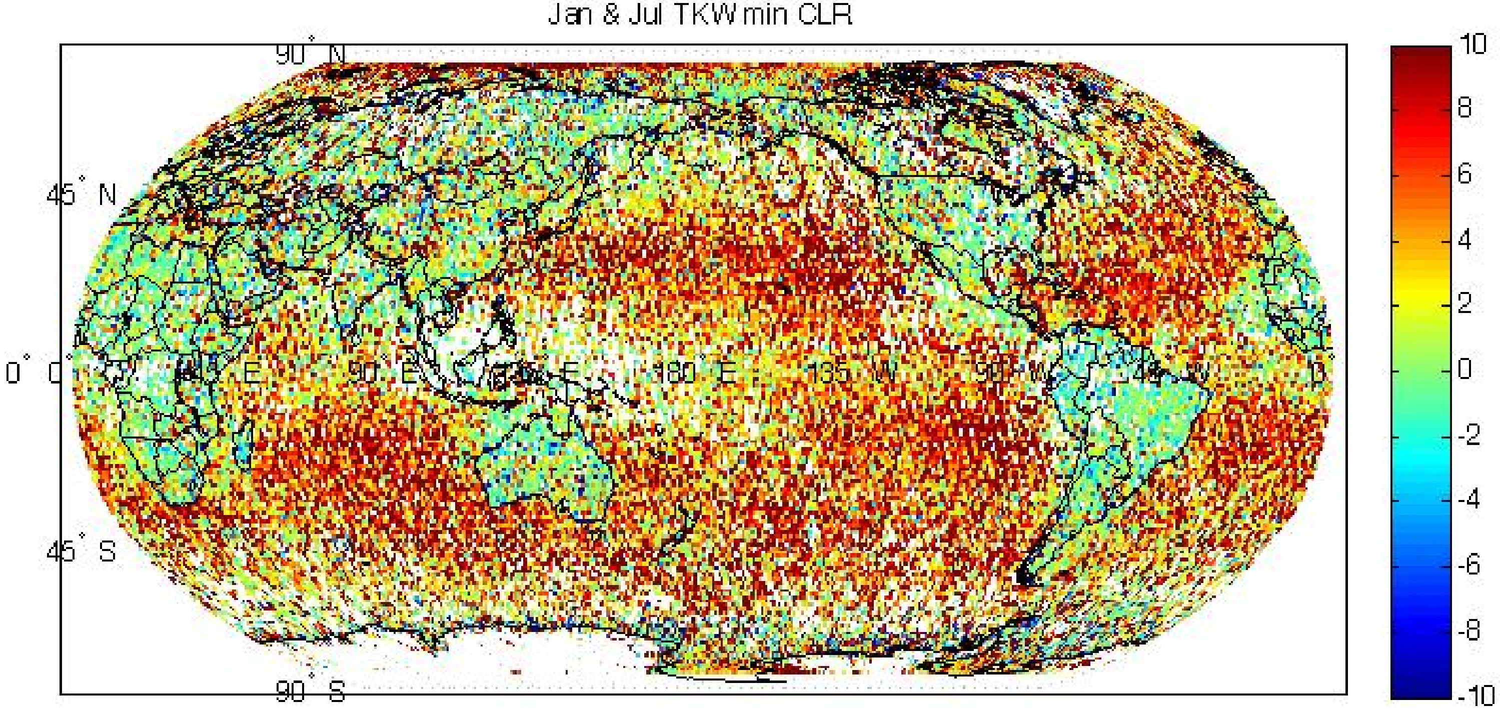
Jan 2008 <Tb> = 242.741



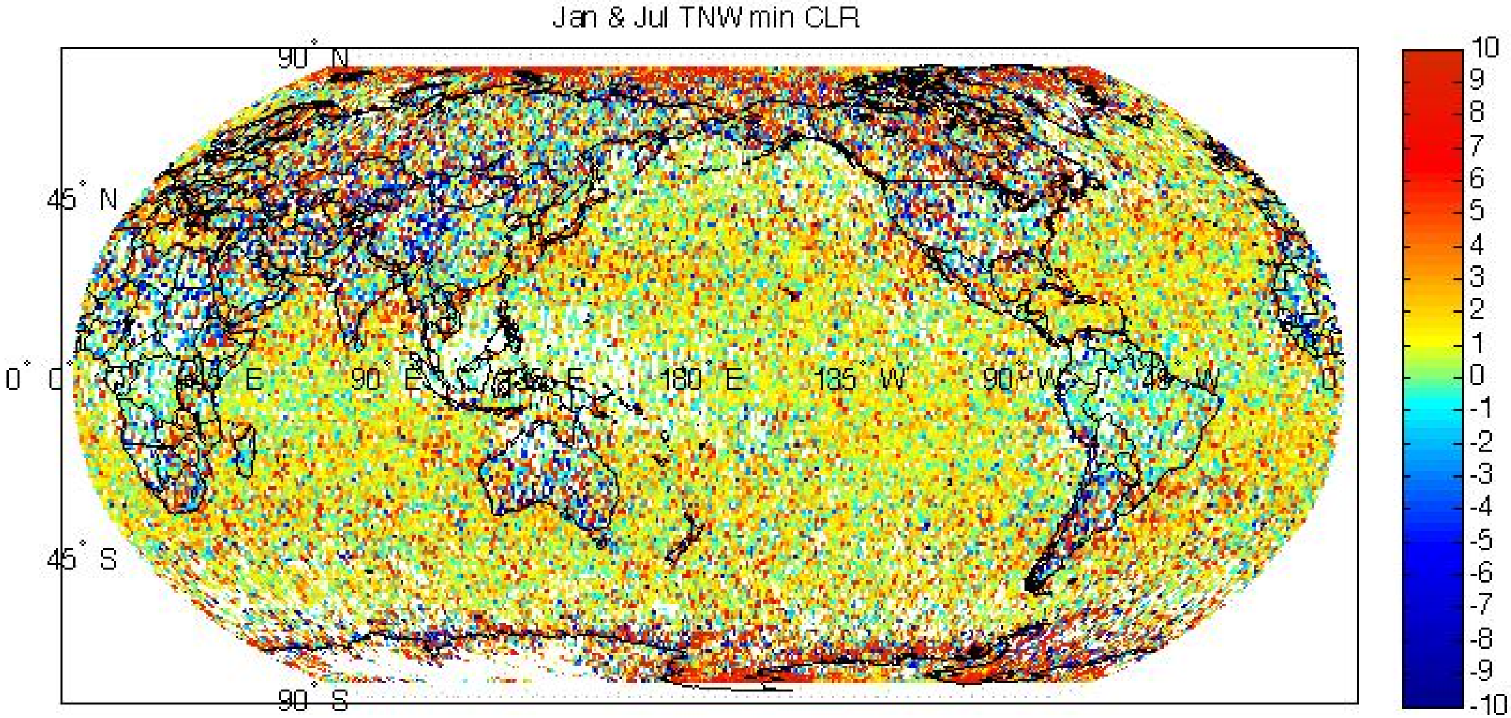
Jan 2009 <Tb> = 239.401

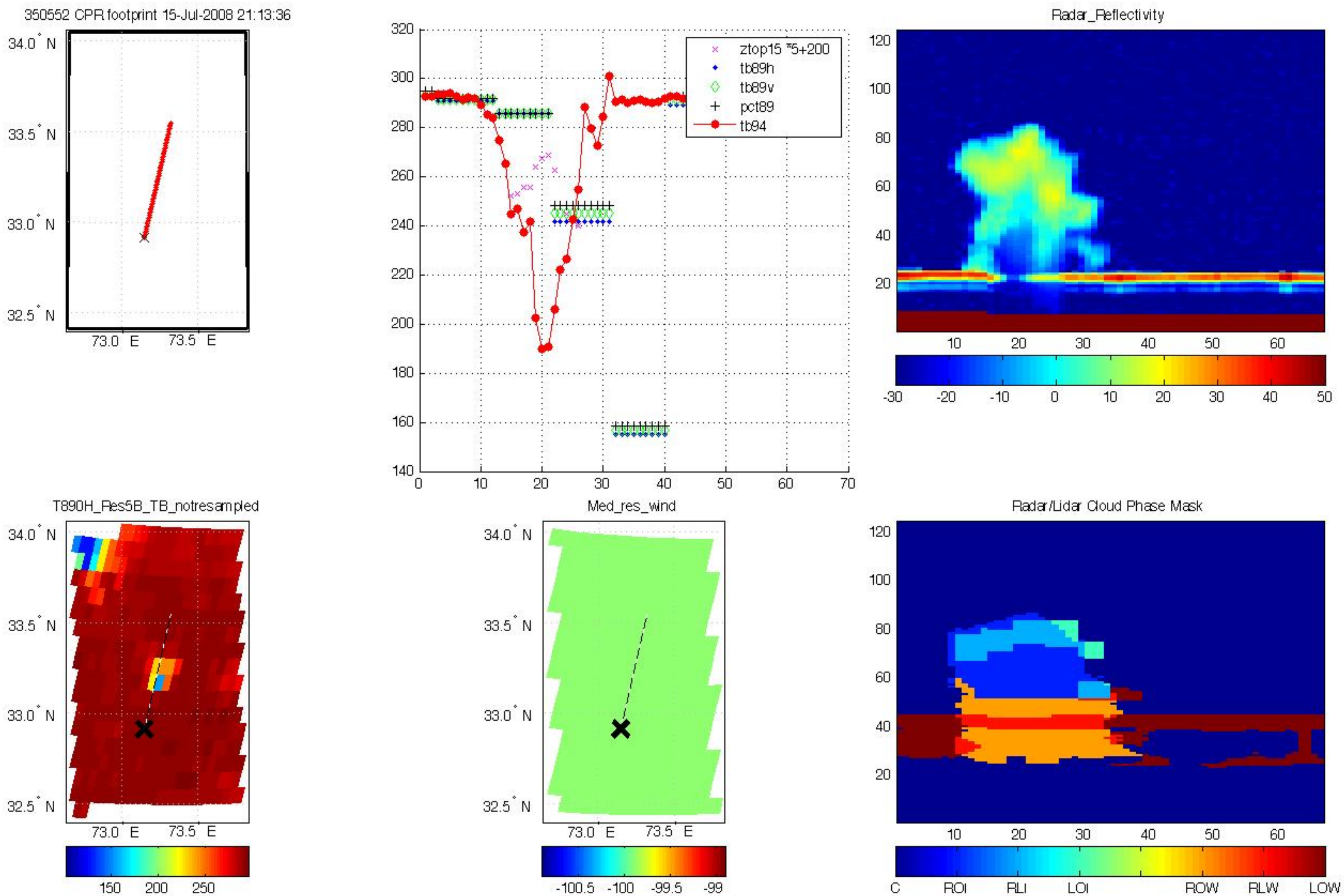


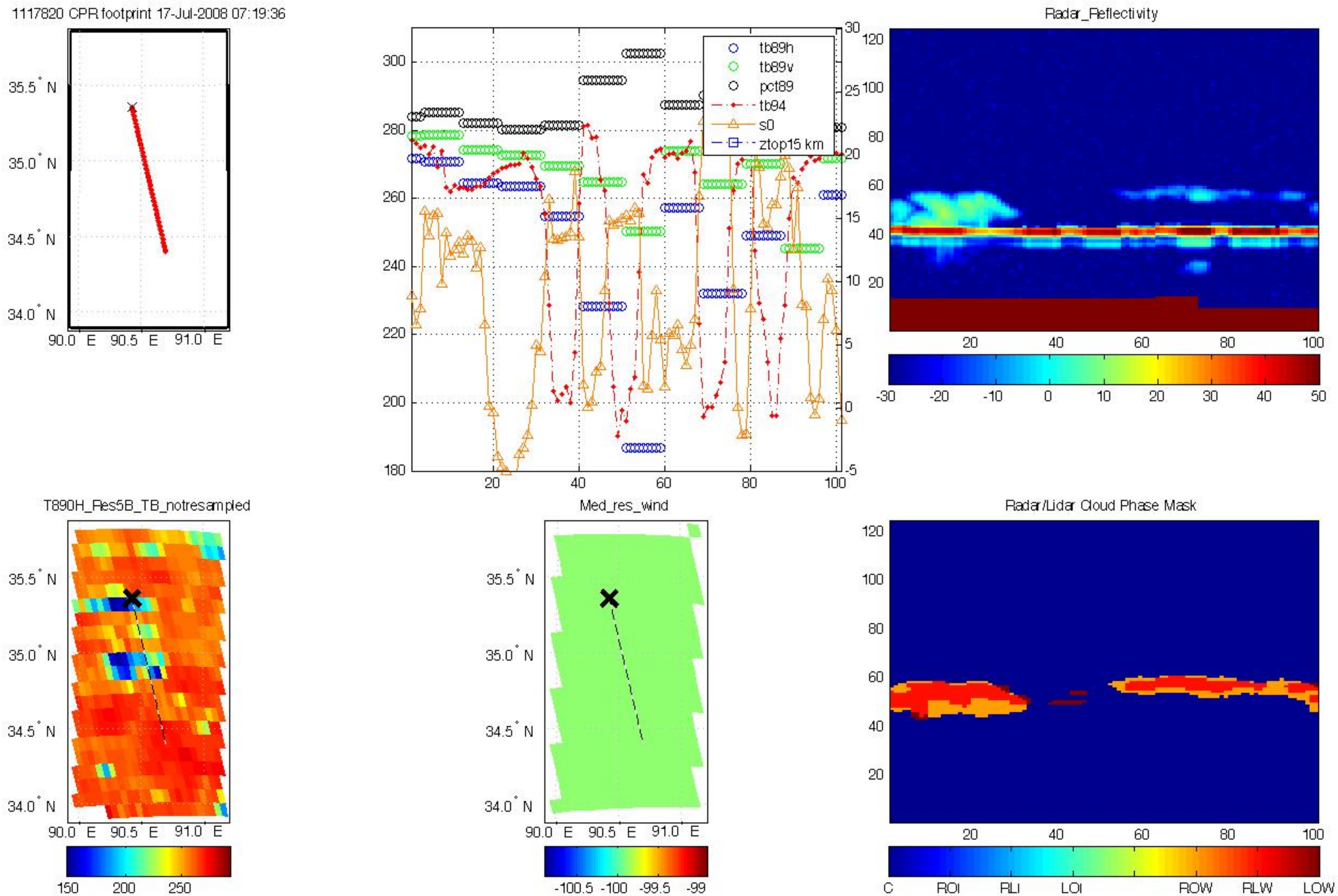
Jan & Jul TKW -CLR ocean avg =5.6477



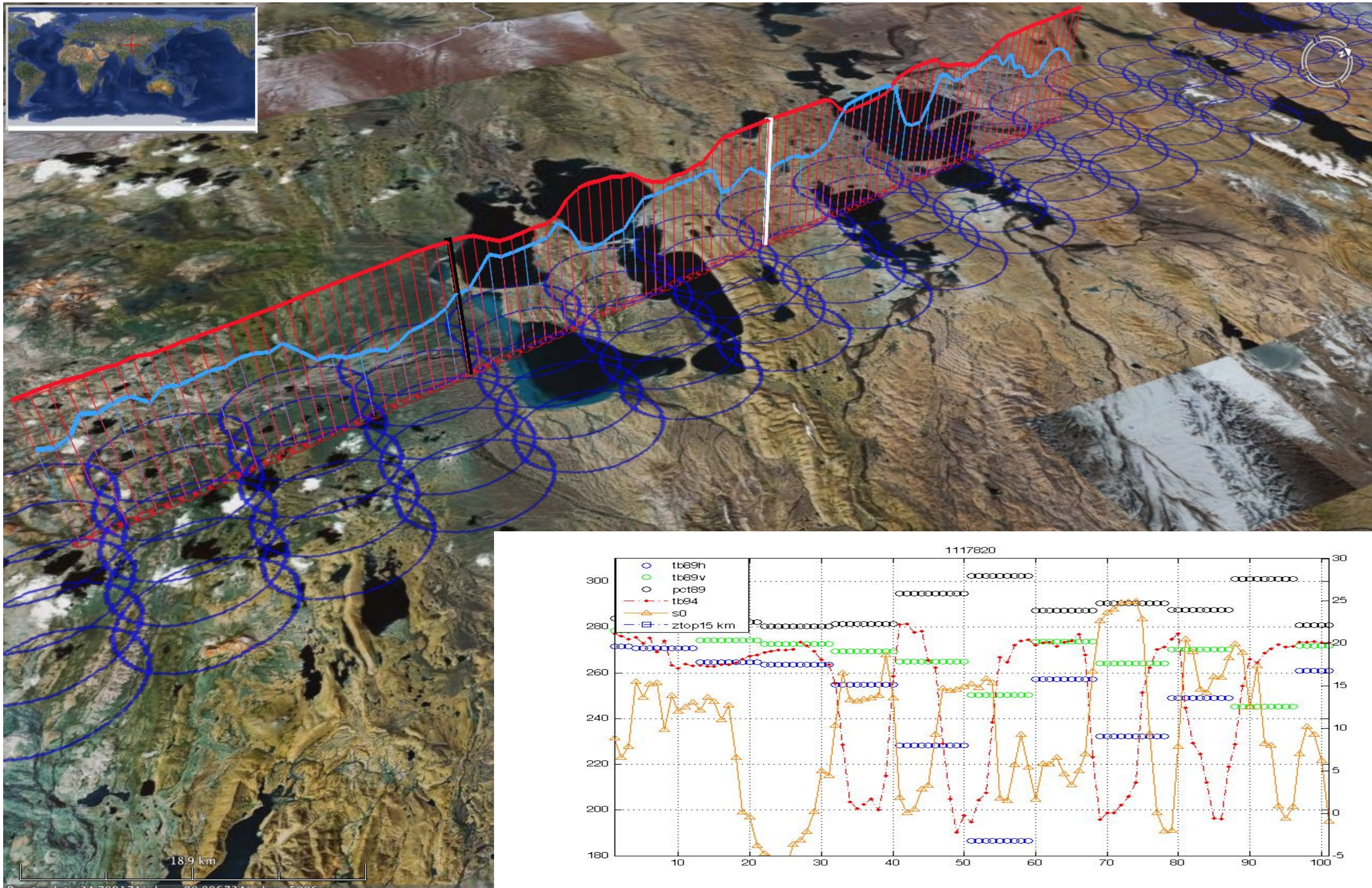
Jan & Jul TNW -CLR



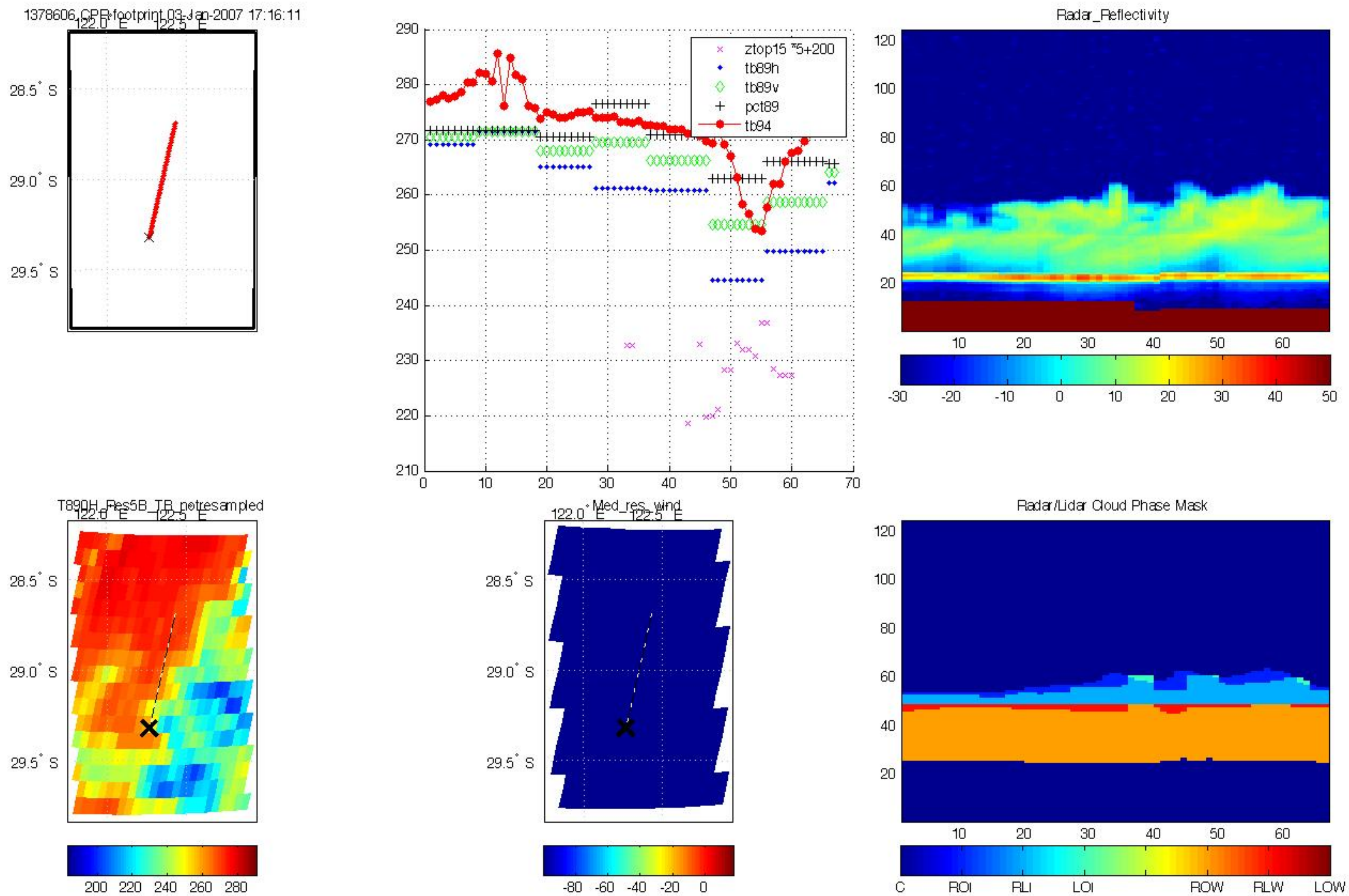

350552 CPR footprint 15-Jul-2008 21:13:36
34.0° N
33.5° N
33.0° N
32.5° N
73.0 E
73.5 E
ztop15 *5+200
tb89h
tb89v
pct89
tb94
320
300
280
260
240
220
200
180
160
140
0
10
20
30
40
50
60
70
Radar_Reflectivity
120
100
80
60
40
20
10
20
30
40
50
60
-30
-20
-10
0
10
20
30
40
50
T890H_Res5B_TB_notresampled
150
200
250
Med_res_wind
-100.5
-100
-99.5
-99
Radar/Lidar Cloud Phase Mask
C
ROI
RLI
LOI
ROW
RLW
LOW

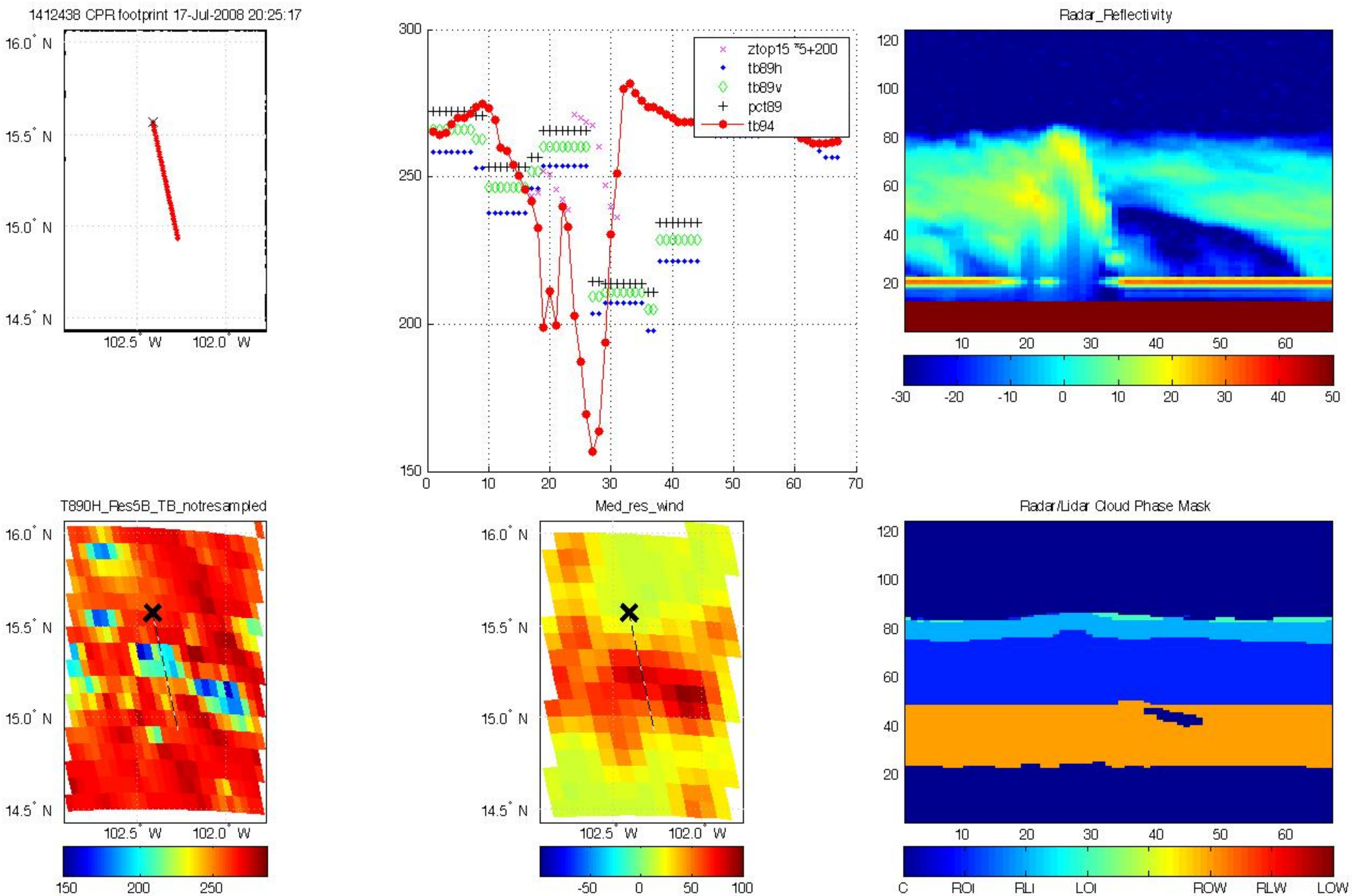

1117820 CPR footprint 17-Jul-2008 07:19:36
tb89h
tb89v
pct89
tb94
s0
ztop15 km
Radar_Reflectivity
T890H_Res5B_TB_notresampled
Med_res_wind
Radar/Lidar Cloud Phase Mask
C
ROI
RLI
LOI
ROW
RLW
LOW

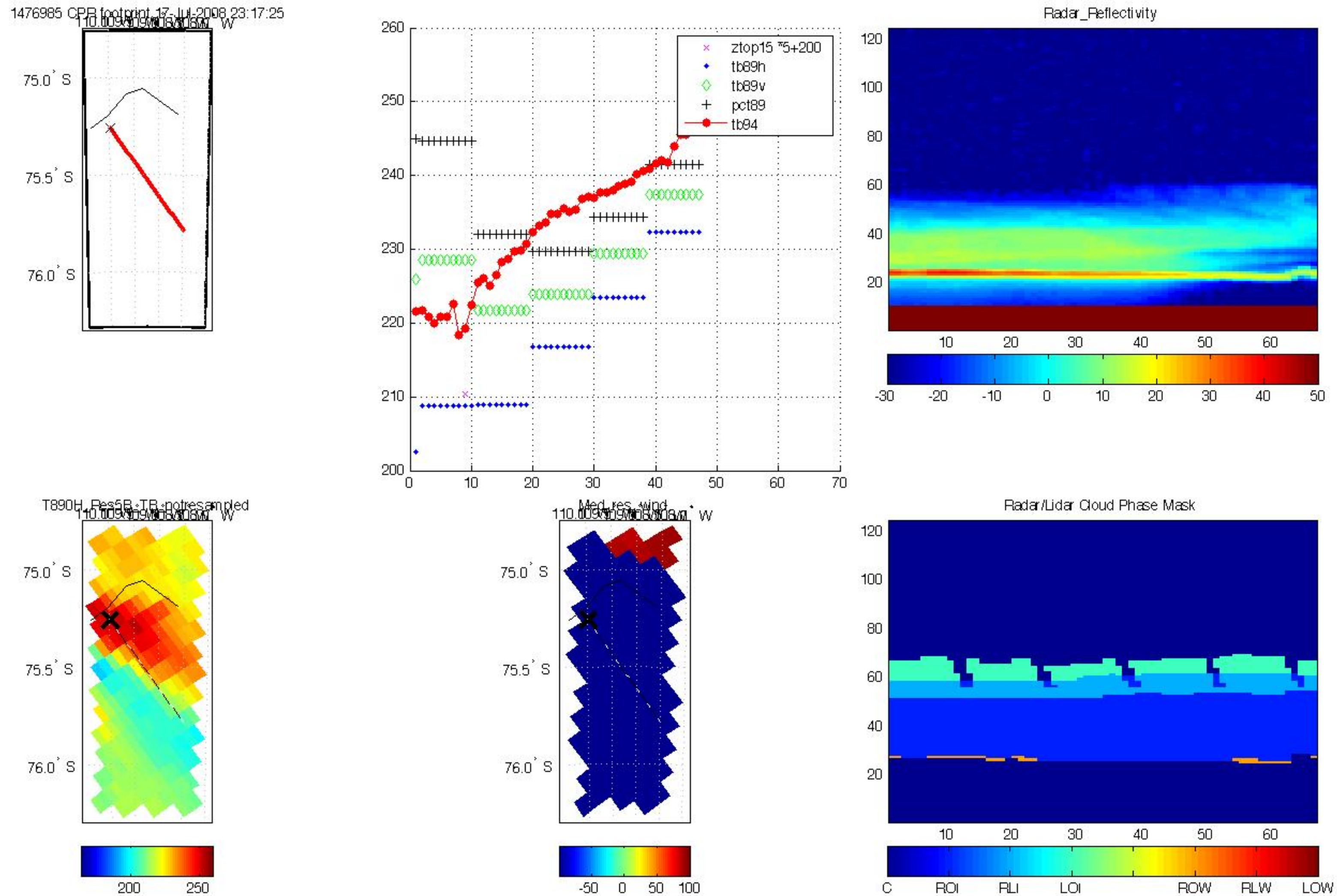
17 July 2008



black marker at ray 30, white at ray 60

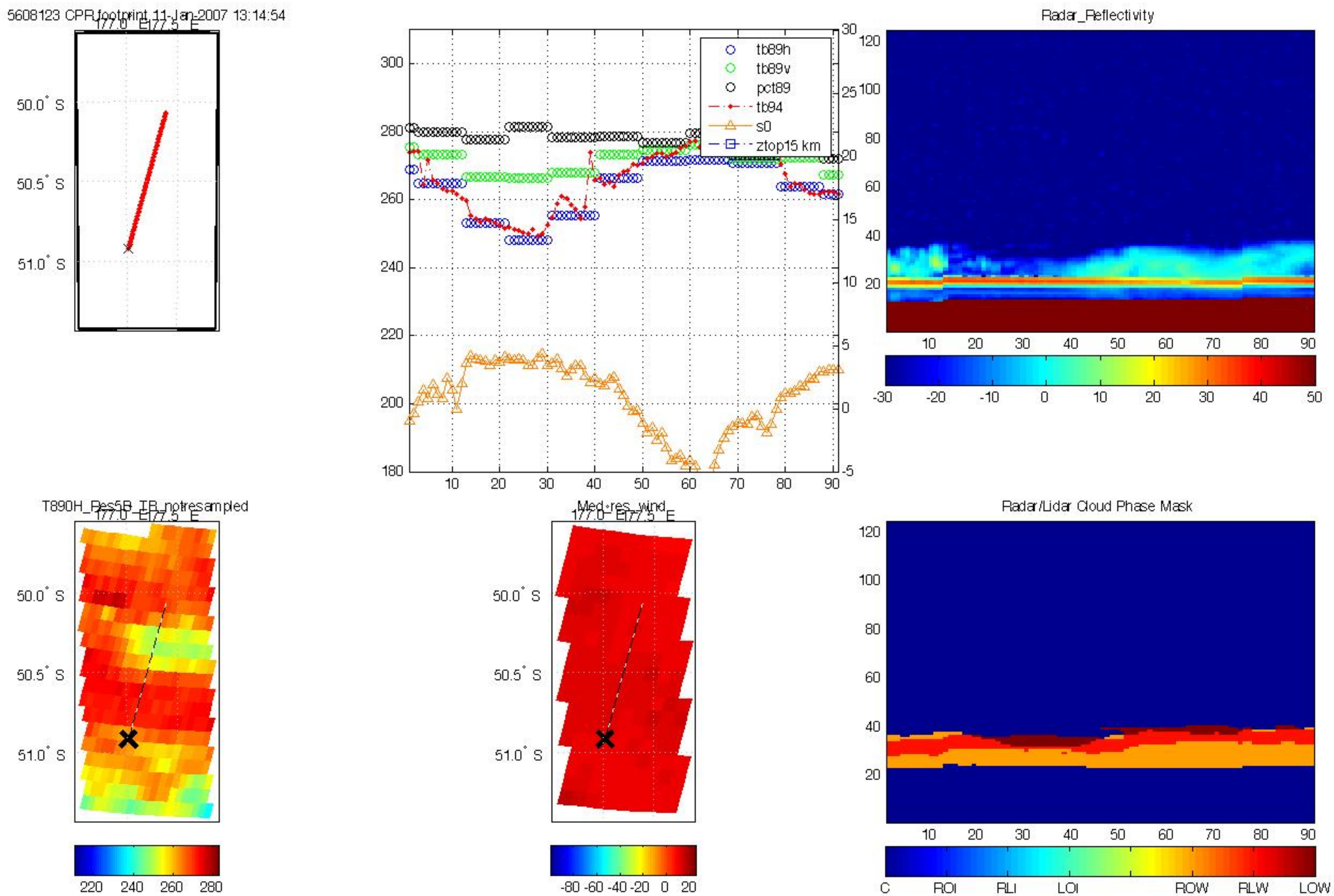

1378606 CPR footprint 03-Jan-2007 17:16:11
122.0° E
122.5° E
28.5° S
29.0° S
29.5° S
ztop15 *5+200
tb89h
tb89v
pct89
tb94
Radar_Reflectivity
T89OH_Res5B_TB_notresampled
200 220 240 260 280
Med_res_wind
-80 -60 -40 -20 0
Radar/Lidar Cloud Phase Mask
C
ROI
RLI
LOI
ROW
RLW
LOW


1412438 CPR footprint 17-Jul-2008 20:25:17
16.0° N
15.5° N
15.0° N
14.5° N
102.5° W
102.0° W
ztop15 *5+200
tb89h
tb89v
pct89
tb94
300
250
200
150
0
10
20
30
40
50
60
70
Radar_Reflectivity
120
100
80
60
40
20
-30
-20
-10
0
10
20
30
40
50
T890H_Res5B_TB_notresampled
150
200
250
Med_res_wind
-50
0
50
100
Radar/Lidar Cloud Phase Mask
C
ROI
RLI
LOI
ROW
RLW
LOW


1476985 CPR footprint 17-Jul-2008 23:17:25
75.0° S
75.5° S
76.0° S
ztop15 *5+200
tb89h
tb89v
pct89
tb94
Radar_Reflectivity
T890H_Res5B:TB:notresampled
Med_res_wind
Radar/Lidar Cloud Phase Mask
C
ROI
RLI
LOI
ROW
RLW
LOW

CLOUDSAT

A NASA EARTH SYSTEM SCIENCE PATHFINDER MISSION



Summary

- CPR is not a youngster anymore but still running strong
- Tb will be added to R05. This is an experimental product, feedback from STM is NECESSARY.