Early Results from the COSMIC/ FORMOSAT-3 Mission

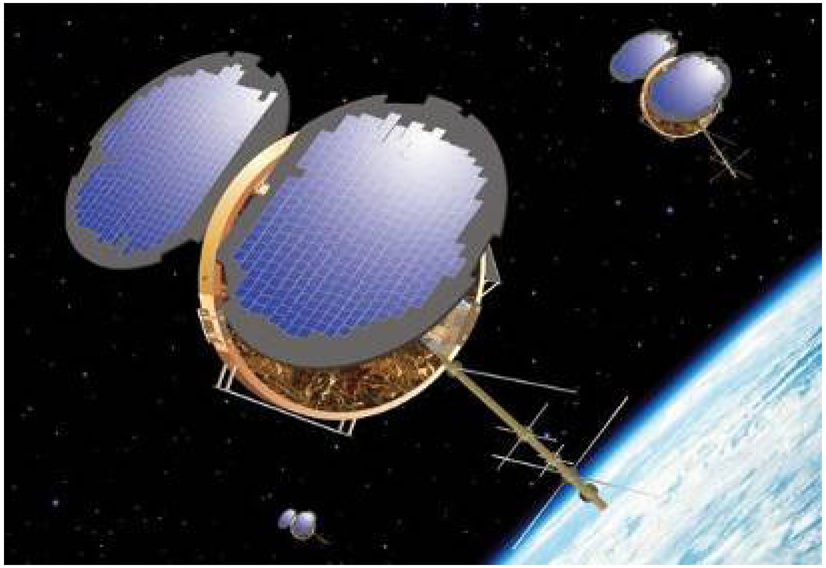
Bill Kuo

UCAR COSMIC Project

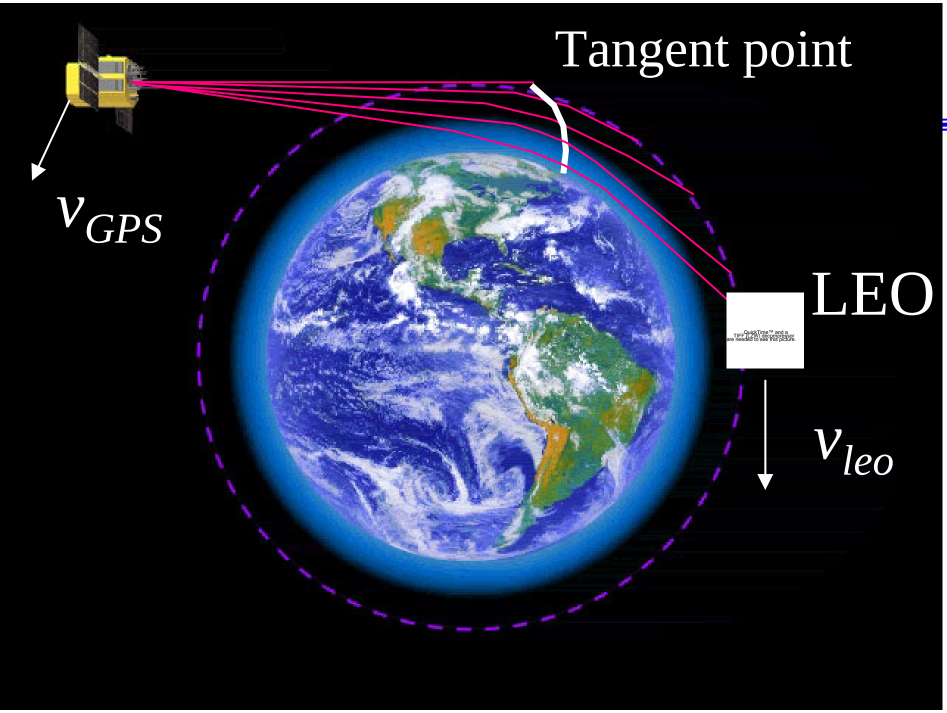
FORMOSAT-3

COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate)

- 6 Satellites was launched:
  01:40 UTC 15 April 2006
- Three instruments:
  GPS receiver, TIP, Tri-band beacon
- Weather + Space Weather data
- Global observations of:
  Pressure, Temperature, Humidity
  Refractivity
  Ionospheric Electron Density
  Ionospheric Scintillation

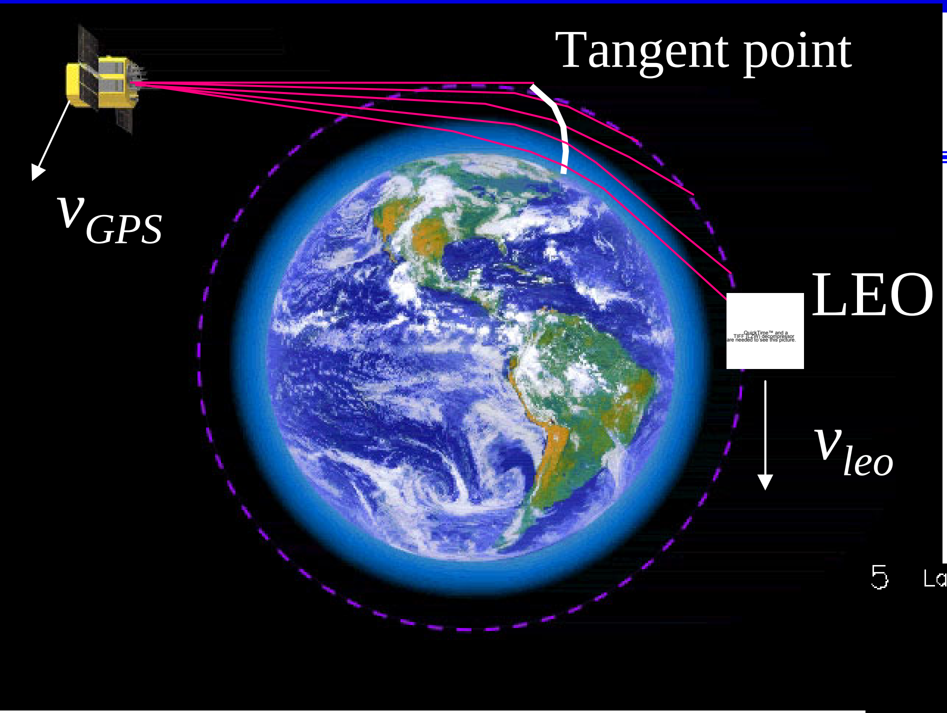


- Demonstrate quasi-operational GPS limb sounding with global coverage in near-real time
- Climate Monitoring



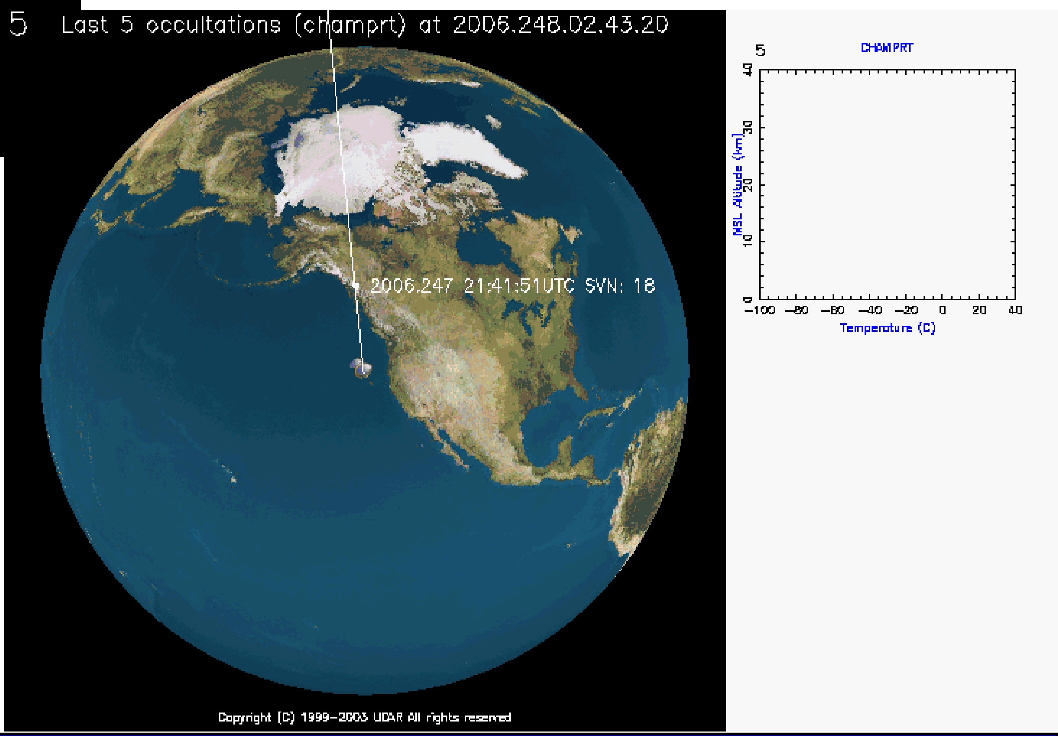
The LEO tracks the GPS phase while the signal is occulted to determine the Doppler

The velocity of GPS relative to LEO must be estimated to **~0.2 mm/sec** (velocity of GPS is ~3 km/sec and velocity of LEO is ~7 km/sec) to determine precise temperature profiles



The LEO tracks the GPS phase while the signal is occulted to determine the Doppler

The velocity of GPS relative to LEO must be estimated to **~0.2 mm/sec** (20 ppb) to determine precise temperature profiles

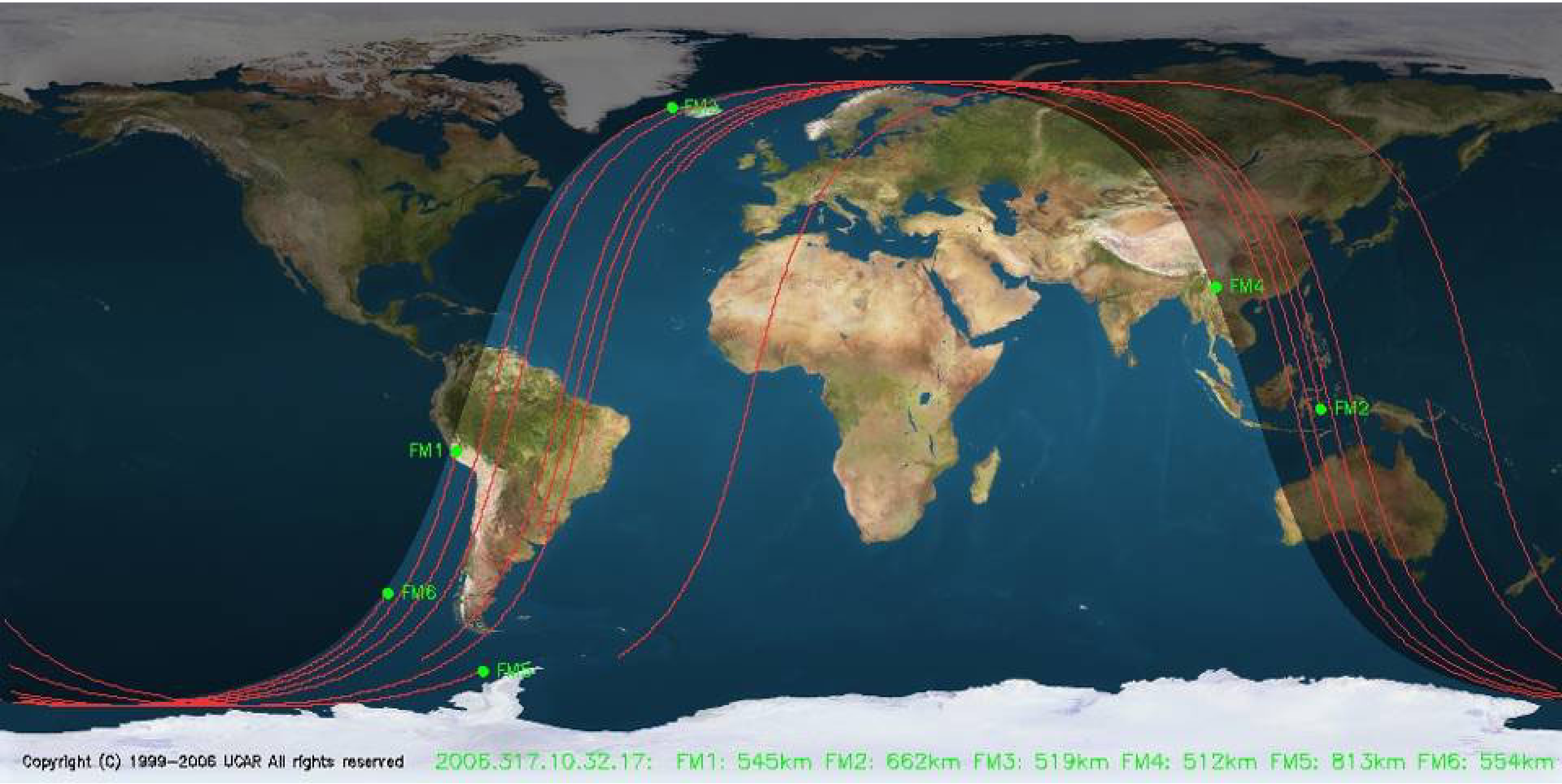


Launch on April 14, 2006, Vandenberg AFB, CA

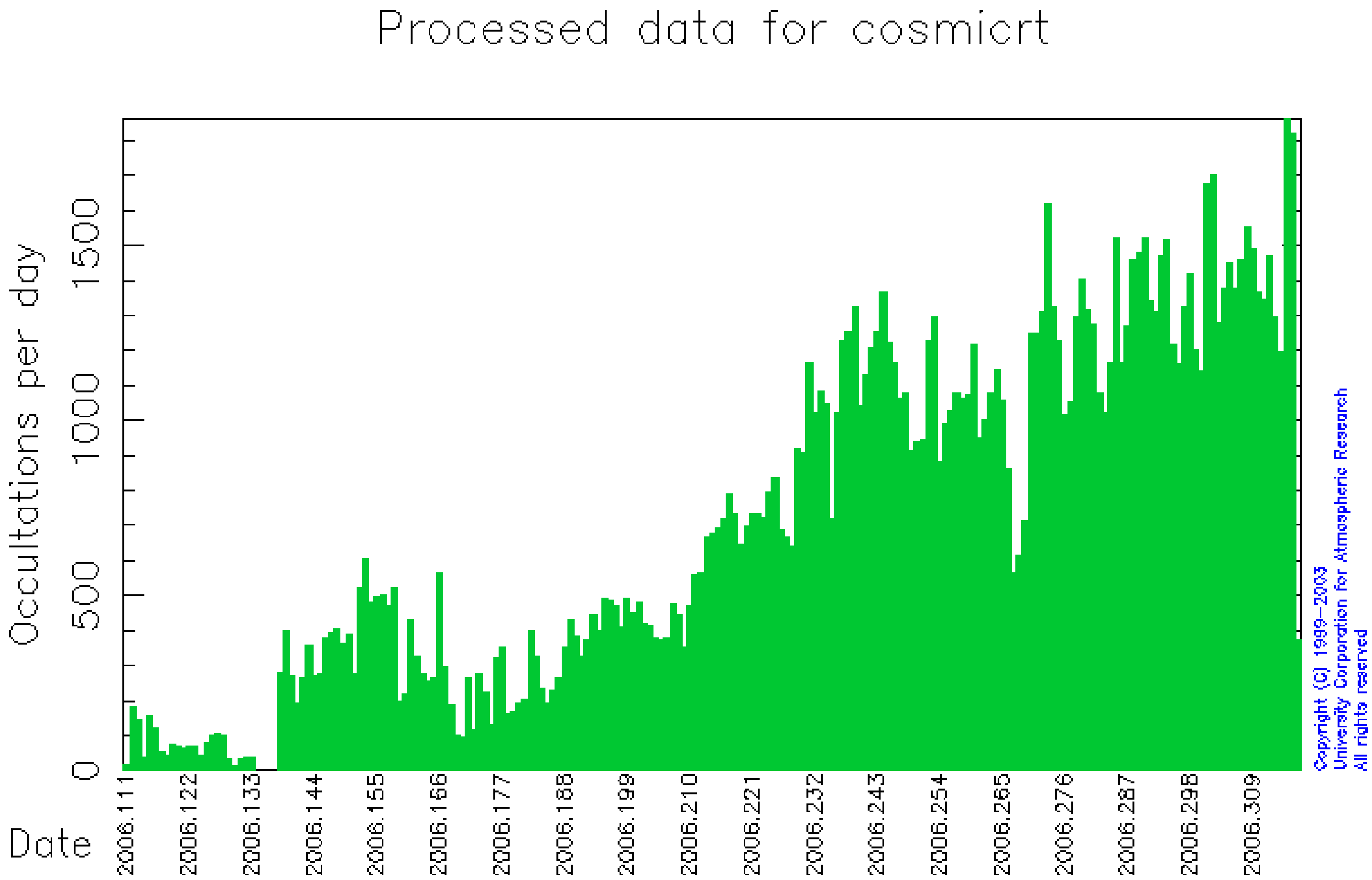
COSMIC launch picture provided by Orbital Sciences Corporation

- All six satellites stacked and launched on a Minotaur rocket
- Initial orbit altitude ~500 km; inclination ~72°
- Will be maneuvered into six different orbital planes for optimal global coverage (at ~800 km altitude)
- All satellites are in good health and providing initial data

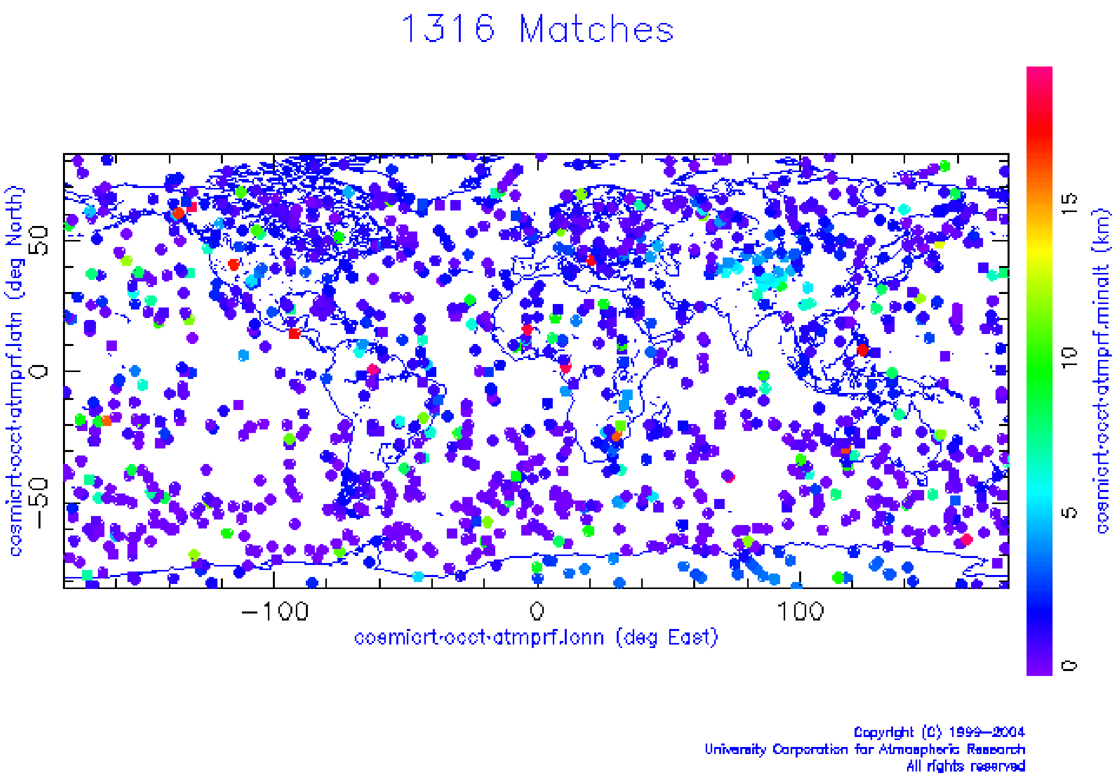
COSMIC satellite status

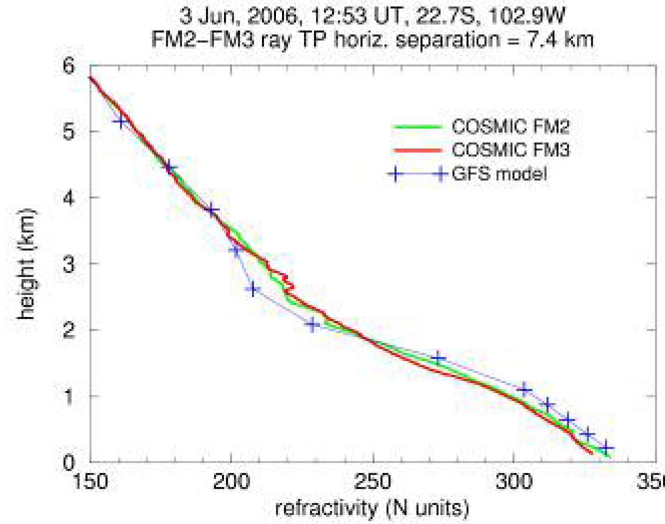


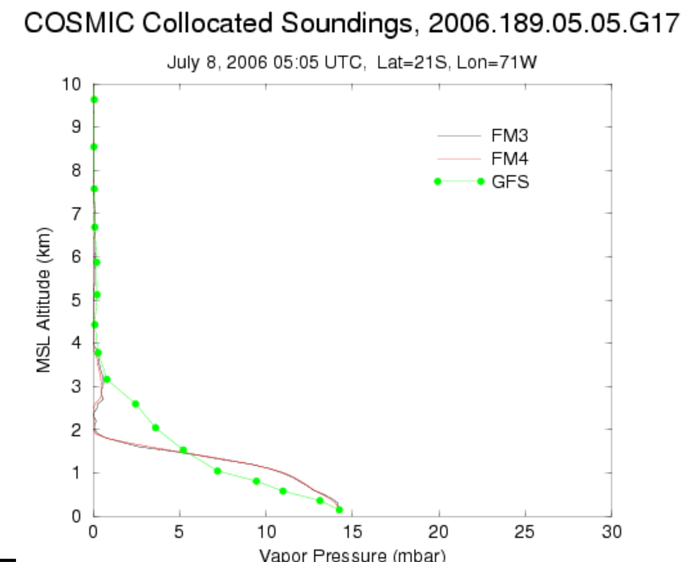
Processed COSMIC data since launch



COSMIC Sounding Penetration (Day 239, 2006)



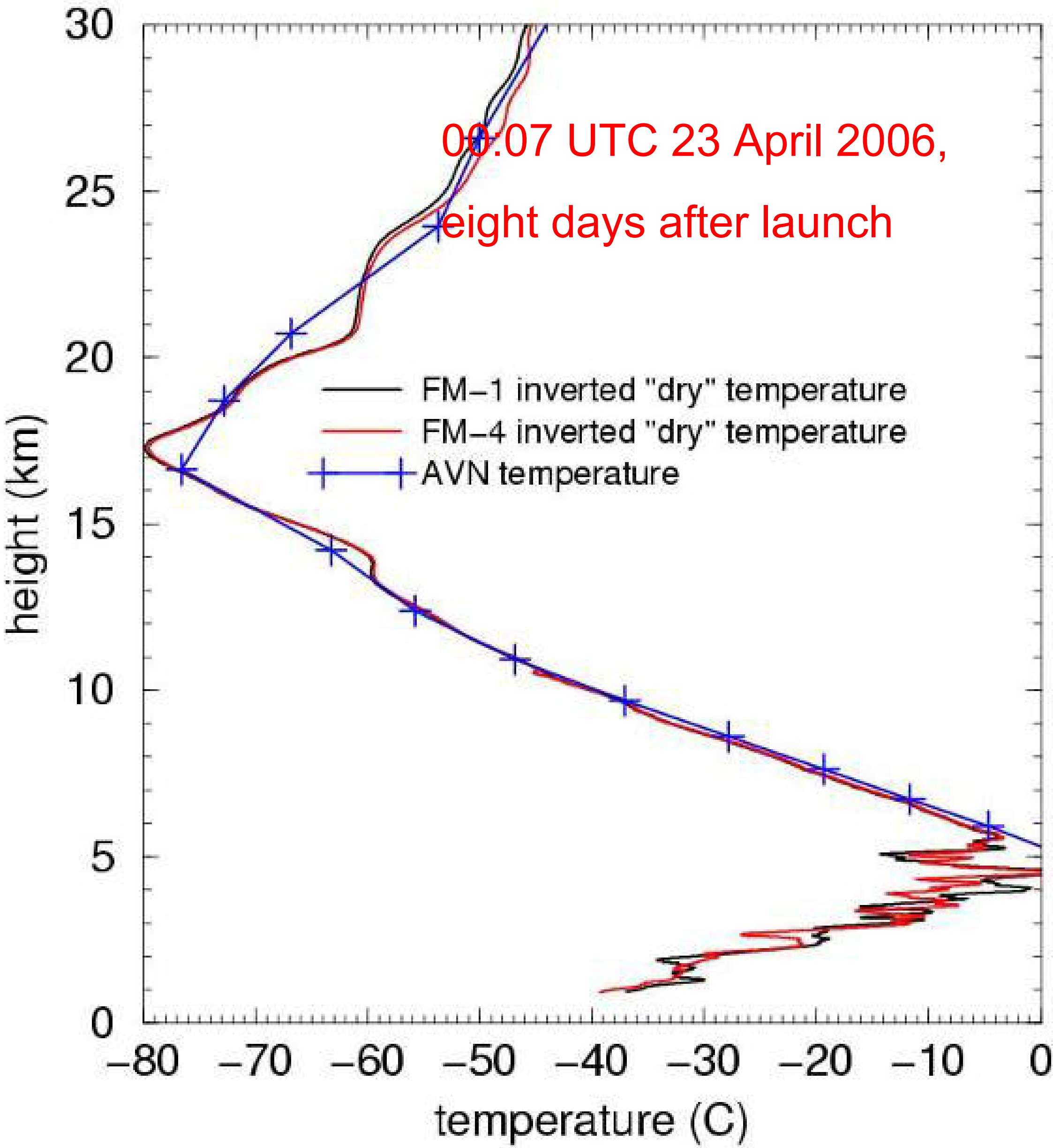




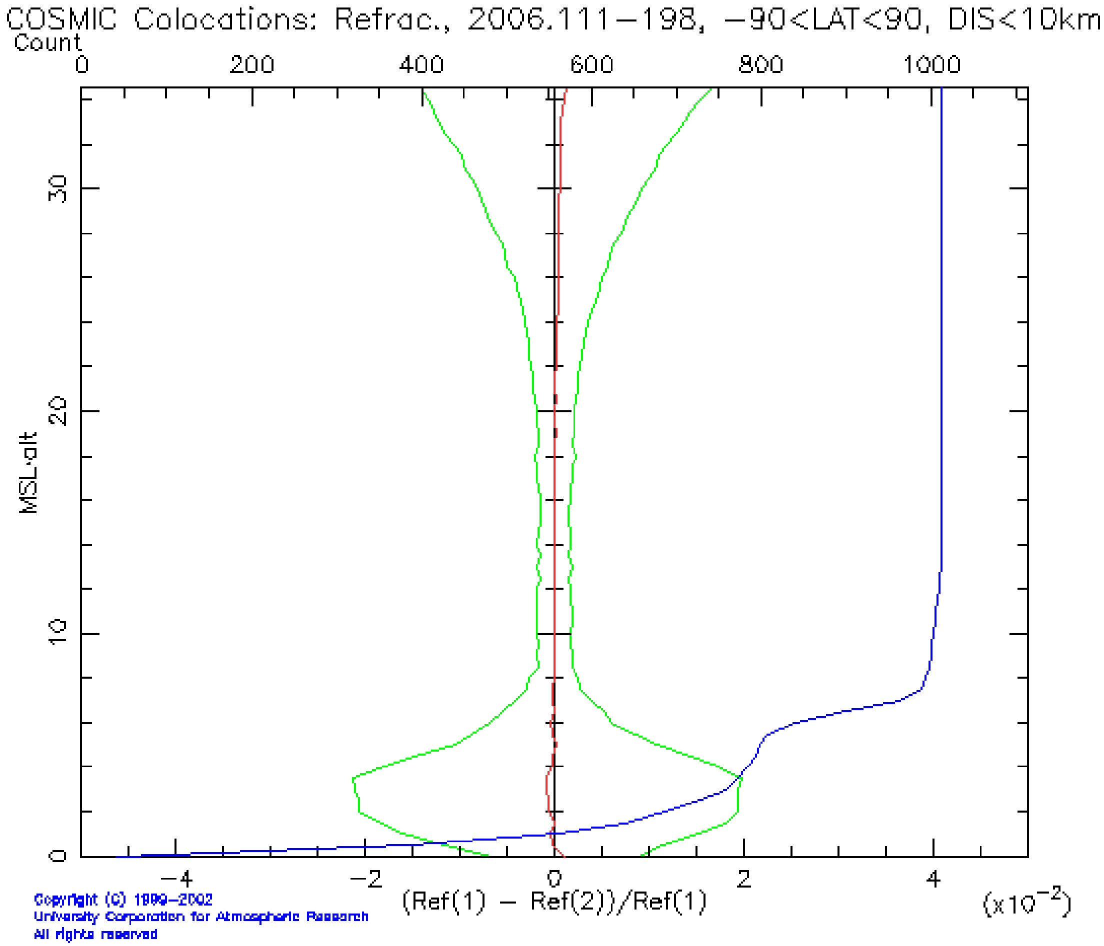
90% of COSMIC soundings can penetrate to below 1 km, and can be used to measure boundary layer height and moisture.

Precision of COSMIC GPS RO Measurements

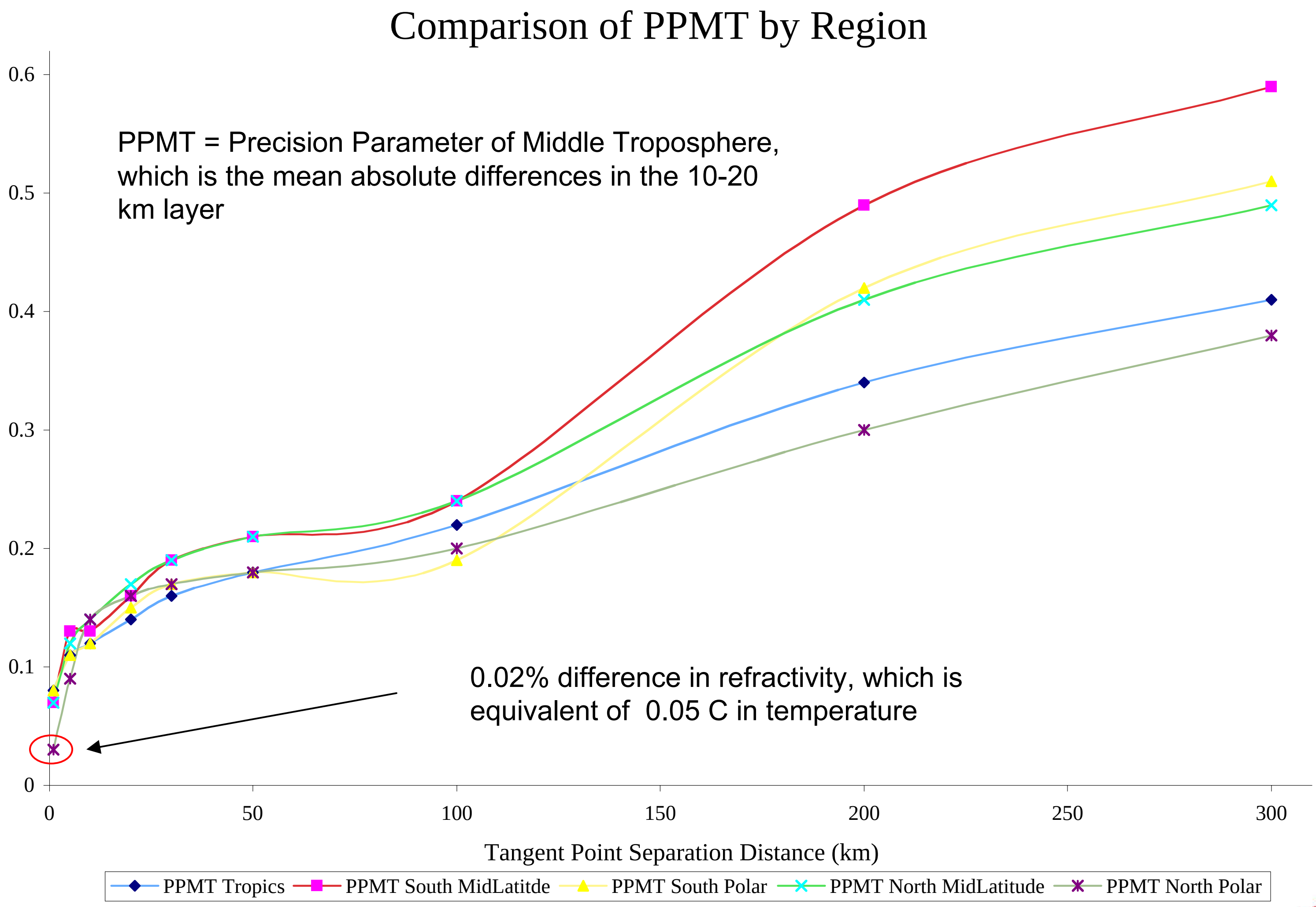
Vertical profiles of “dry” temperature (black and red lines) from two independent receivers on separate COSMIC satellites (FM-1 and FM-4) at 00:07 UTC April 23, 2006, eight days after launch. The satellites were about 5 seconds apart, which corresponds to a distance separation at the tangent point of about 1.5 km. The latitude and longitude of the soundings are 20.4°S and 95.4°W.



Deviation of the two GPS RO soundings separated by less than 10 km



Precision of GPS RO soundings



Detection of Tropical Boundary Layer

Monitoring PBL depth by GPS Radio Occultations

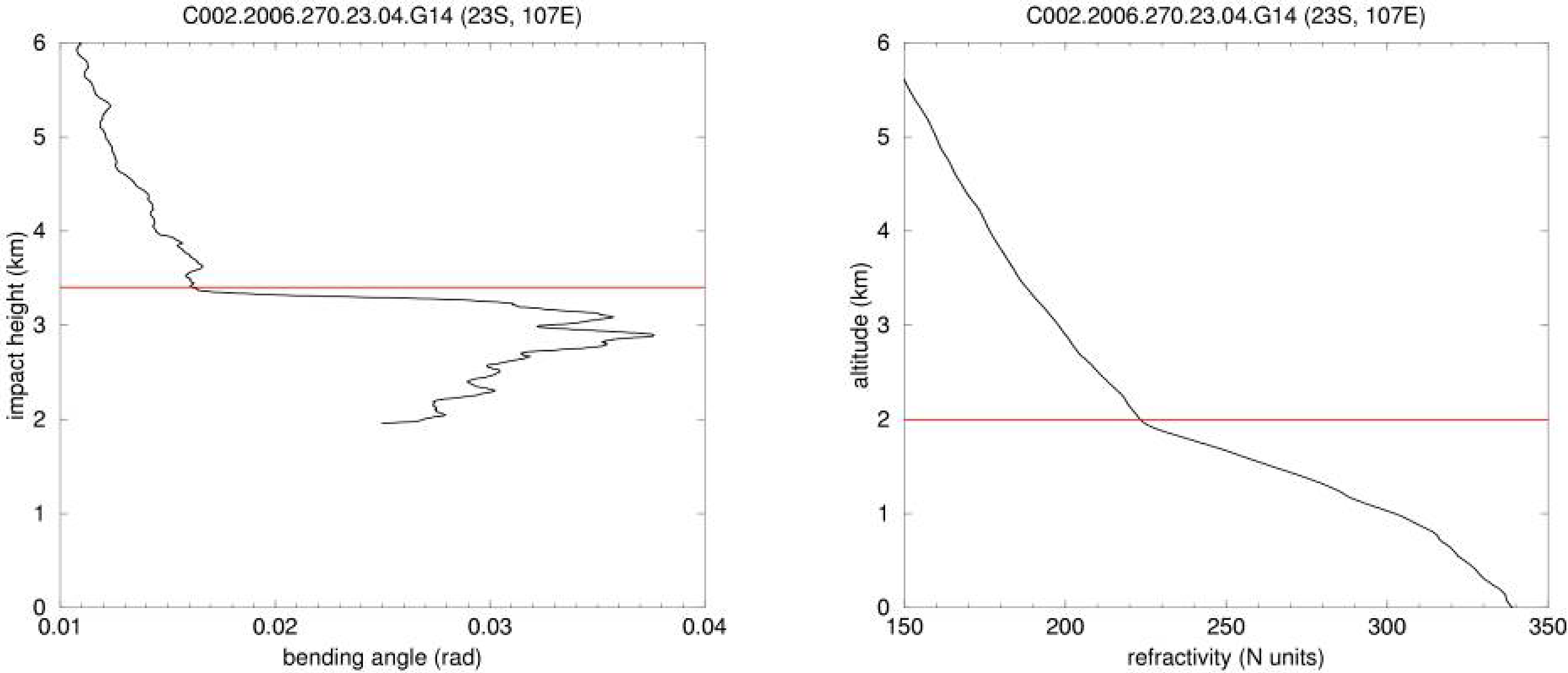
Two techniques are being tested to estimate PBL top or top of convective cloud layer:

1) Using sharp gradients of mean humidity via gradients of retrieved bending angle and refractivity profiles

2) Using signal fluctuations (scintillation) of recorded signal as measures of clear-air turbulence and cloud-forced convective mixing.

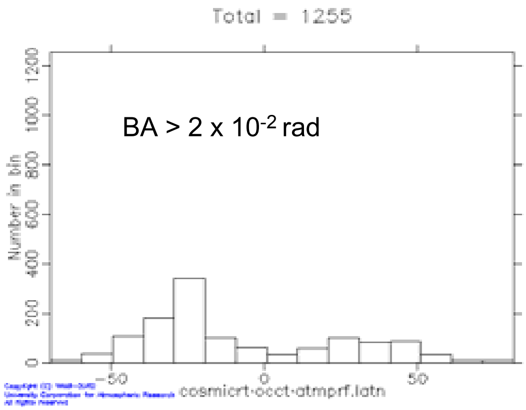
World-wide distribution of this interface contains information on the state of the lower troposphere and is predicted by regional and global models.

Examples of retrieved bending angle and refractivity profiles in the presence of a sharp boundary (ABL top) at ~ 2 km altitude

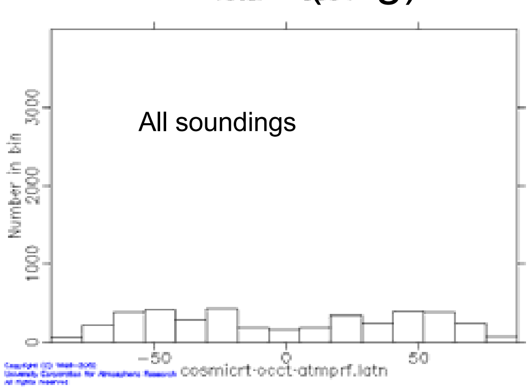


Bending angle profiles are scanned with 0.5 km window and the height of the maximum change (for bending angle) and the change in slope (for refractivity) is estimated for each profile.

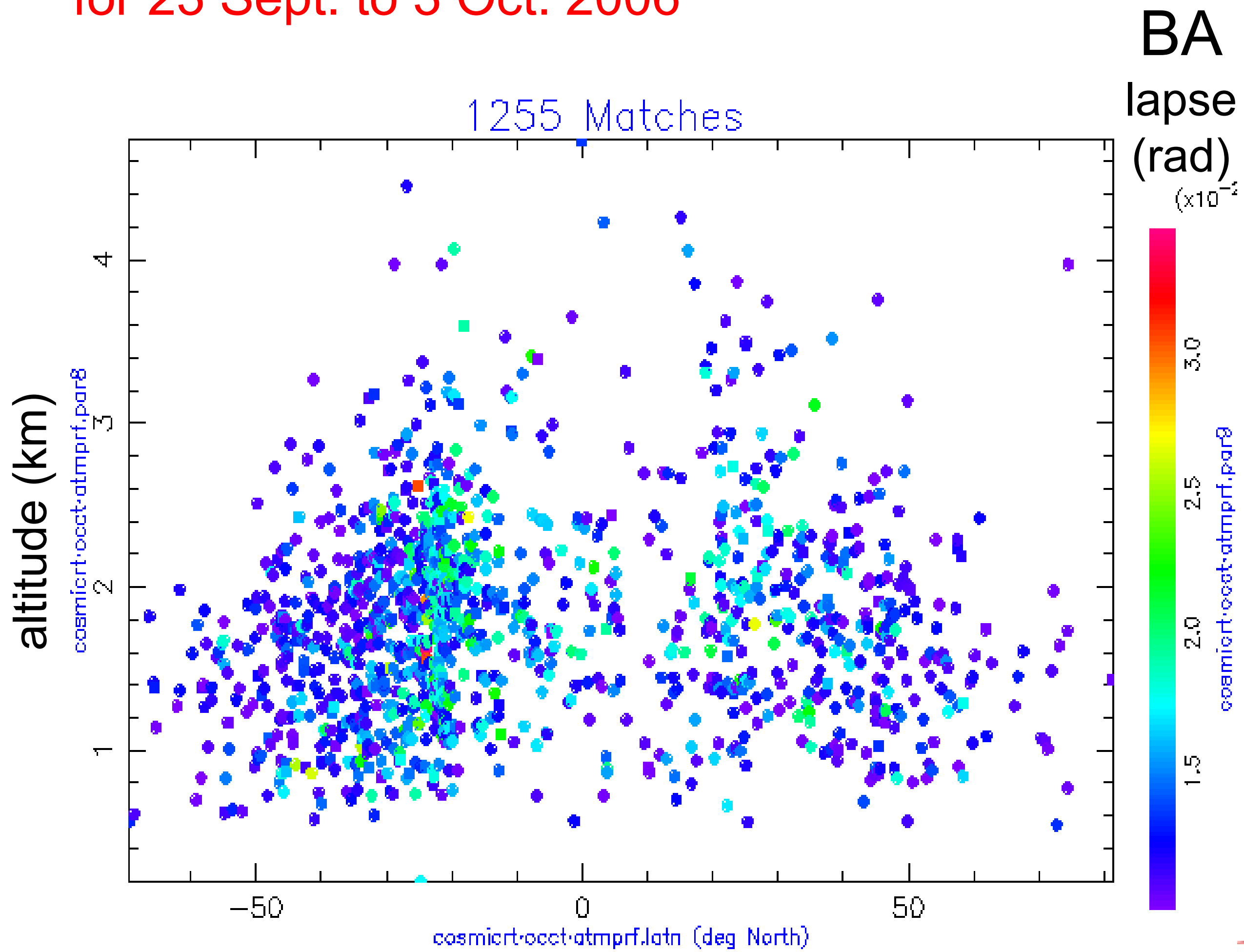
Zonal distribution of the heights of maximum bending angle lapse (>10^{-2} rad) within 0.5 km height (color scale shows the bending angle lapse rate) for 23 Sept. to 3 Oct. 2006



latitude (deg)

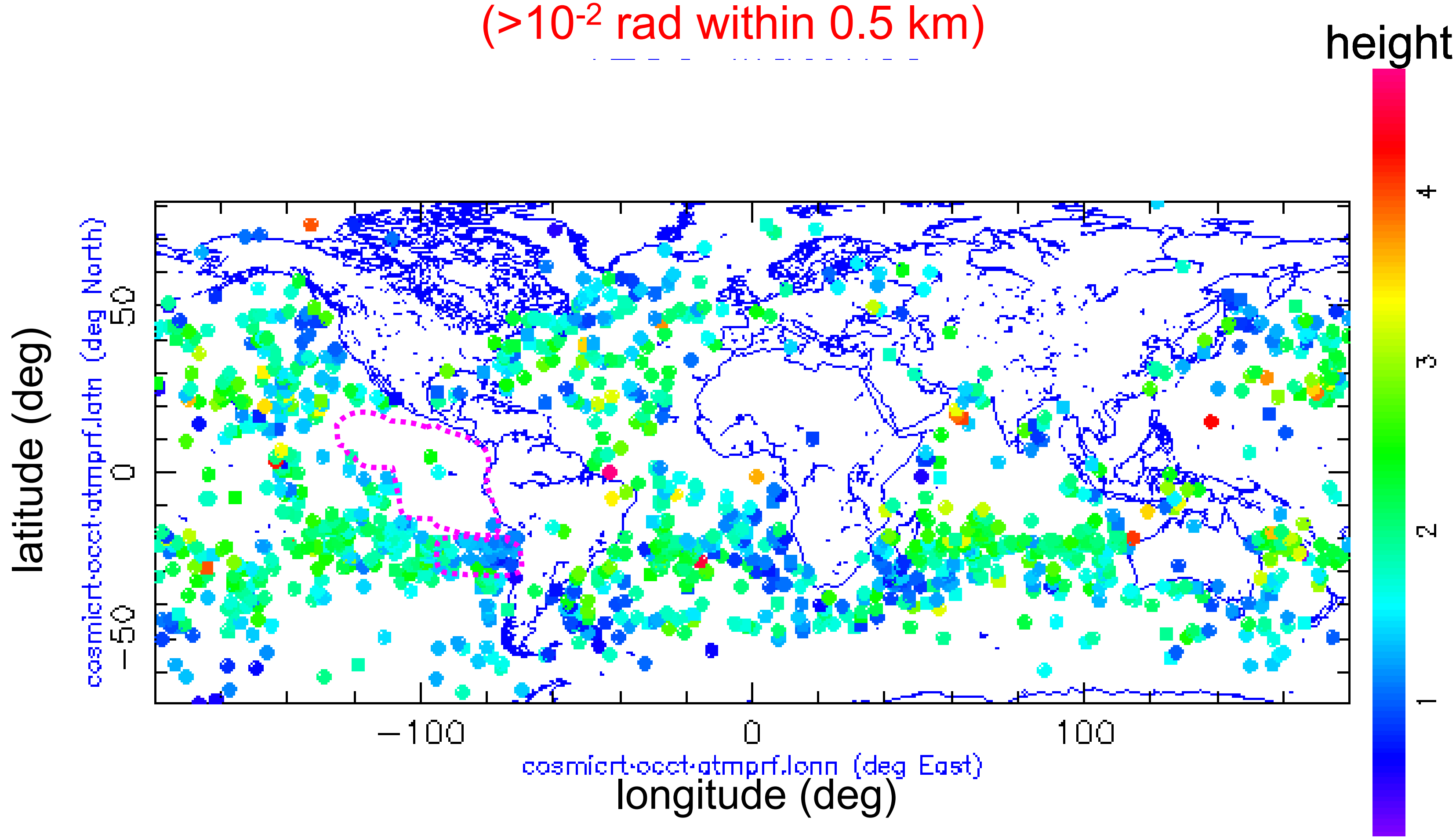


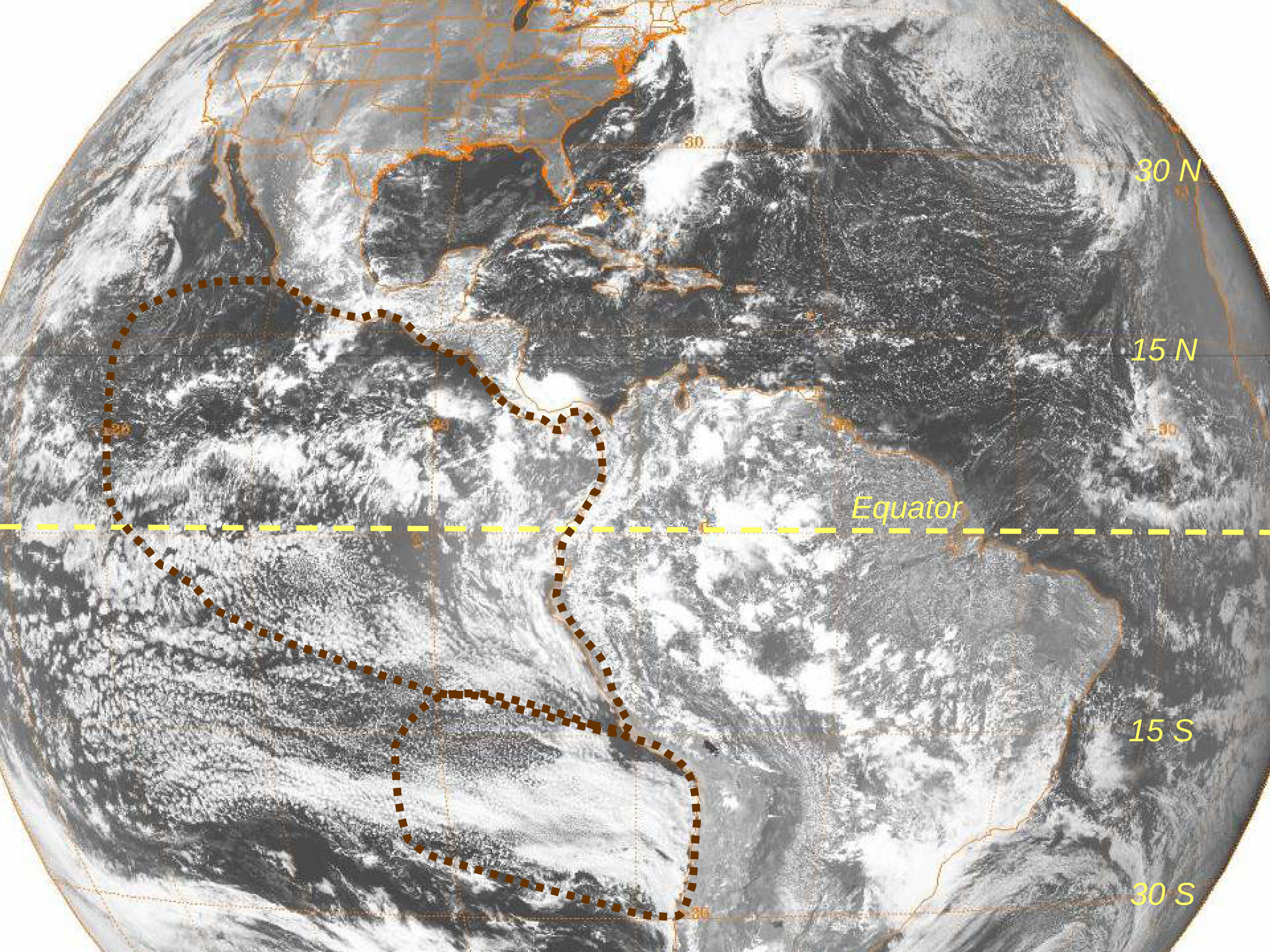
latitude (deg)



latitude (deg)

PBL height from COSMIC bending angle profiles for 23 Sept. – 3 Oct. 2006 (color scale shows height of max bending angle lapse rate ($>10^{-2}$ rad within 0.5 km)





30 N
15 N
Equator
15 S
30 S

Assimilation of COSMIC at ECMWF: Preliminary results

Sean Healy

COSMIC ASSIMILATION

We have started assimilation experiments with COSMIC using the 1D (local) bending angle observation operator that evaluates

$$\alpha(a) = -2a \int_a^\infty \frac{d\ln n / dx}{\sqrt{x^2 - a^2}}\, dx$$

A number of experiments are currently running. We are looking at the sensitivity to observation errors, quality of the rising occultations and how close to the surface should we assimilate the data.

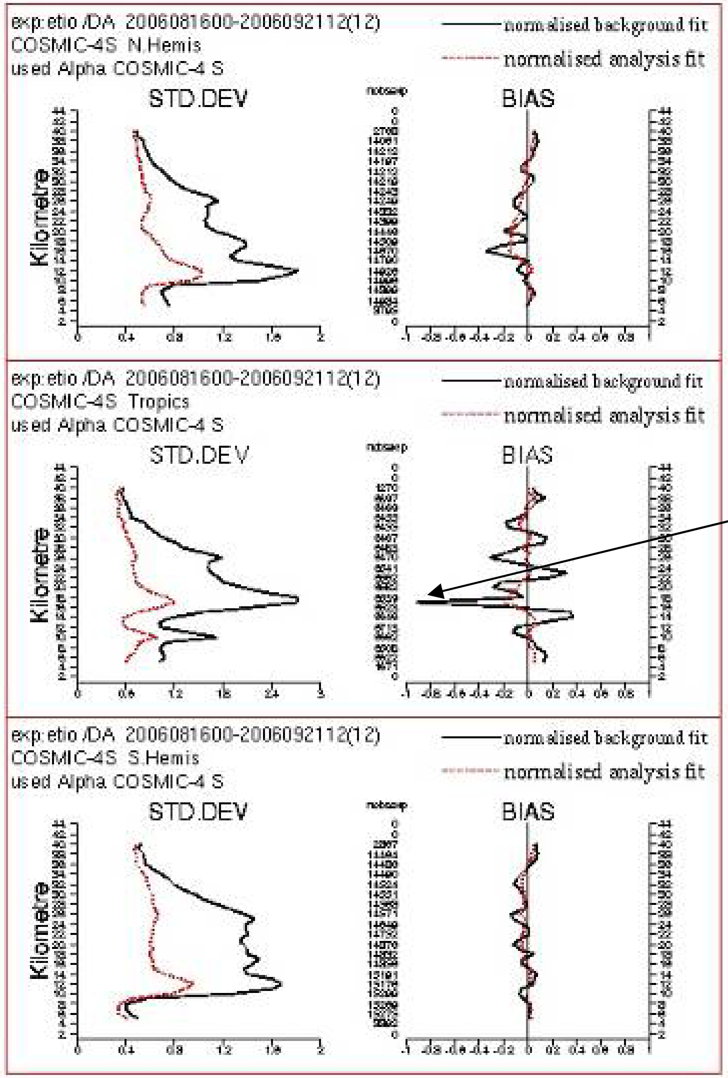
Results presented here: bending angles with impact heights less than 5km are blacklisted, rising occultations blacklisted. 32 days of forecast scores.

Vertical profile of the COSMIC "O-B" and "O-A" bending angle mean and standard deviation departure statistics, **normalized by the assumed observation errors** (*so that departures should be of order unity*)

NH

TR

SH



O-B = Black

O-A = Red

The departures shown here are for COSMIC-4, but similar results are obtained for the 5 other satellites.

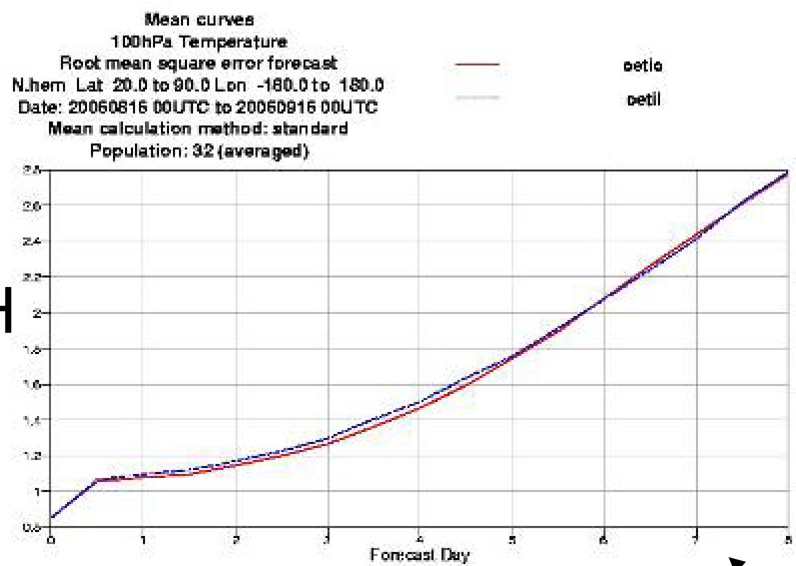
The bias in the tropics near 18 km is related to a model bias.

The standard deviation of the O-B departures near 40 km are typically 3 microradians. **Overall, the quality of the bending angles looks very good!**

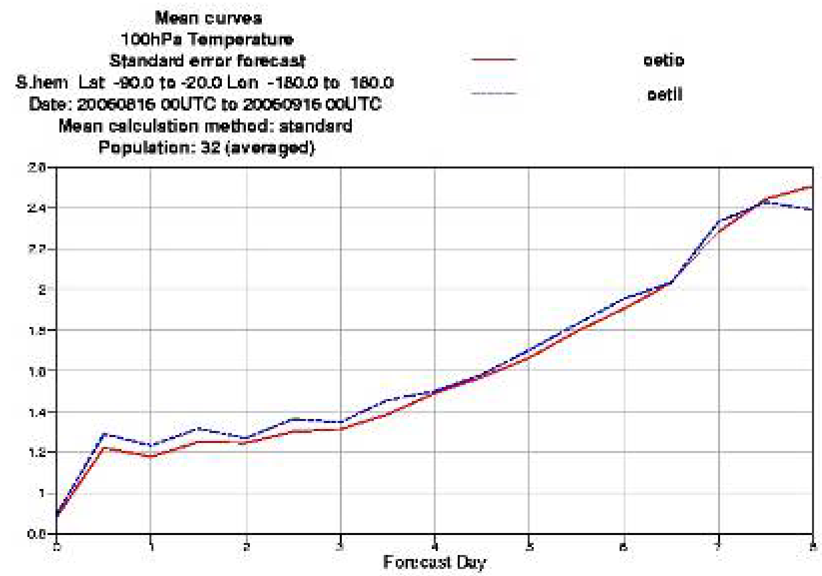
UCAR

Some promising forecast scores in the stratosphere. EG, verification against radiosonde at 100 hPa. Red = COSMIC experiment.

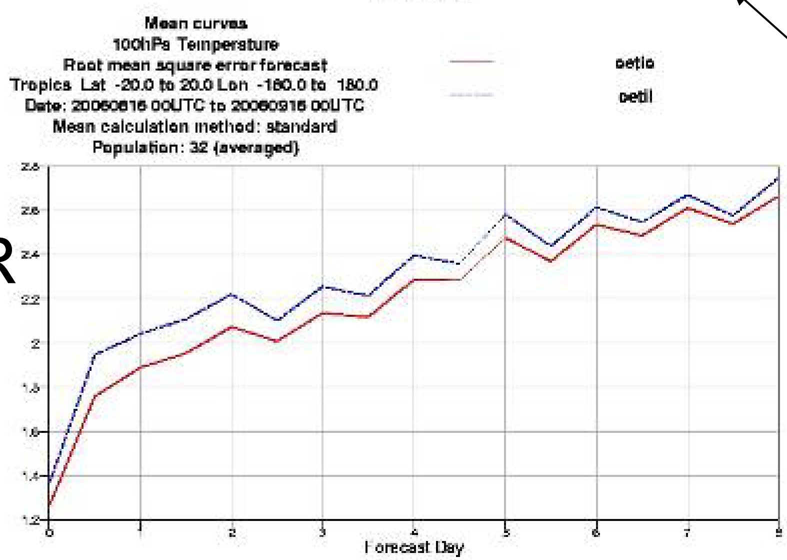
NH



SH



TR



The results in the NH are new. We had not seen improvements in NH with CHAMP. Note that the improvements are generally statistically significant at the 5% level.

COSMIC

Summary

- We have started assimilation experiments with COSMIC.
- The bending angle departure statistics suggest that the data is very good quality. All satellites have comparable statistics.
- Assimilating the data cleans up some known model problems in Antarctica and near the tropical tropopause.
- Forecast scores in the stratosphere encouraging. First positive impact in the NH (100hPa).
- Still some work required in the troposphere.

Using COSMIC refractivity profiles in an evaluation of Antarctic forecast models

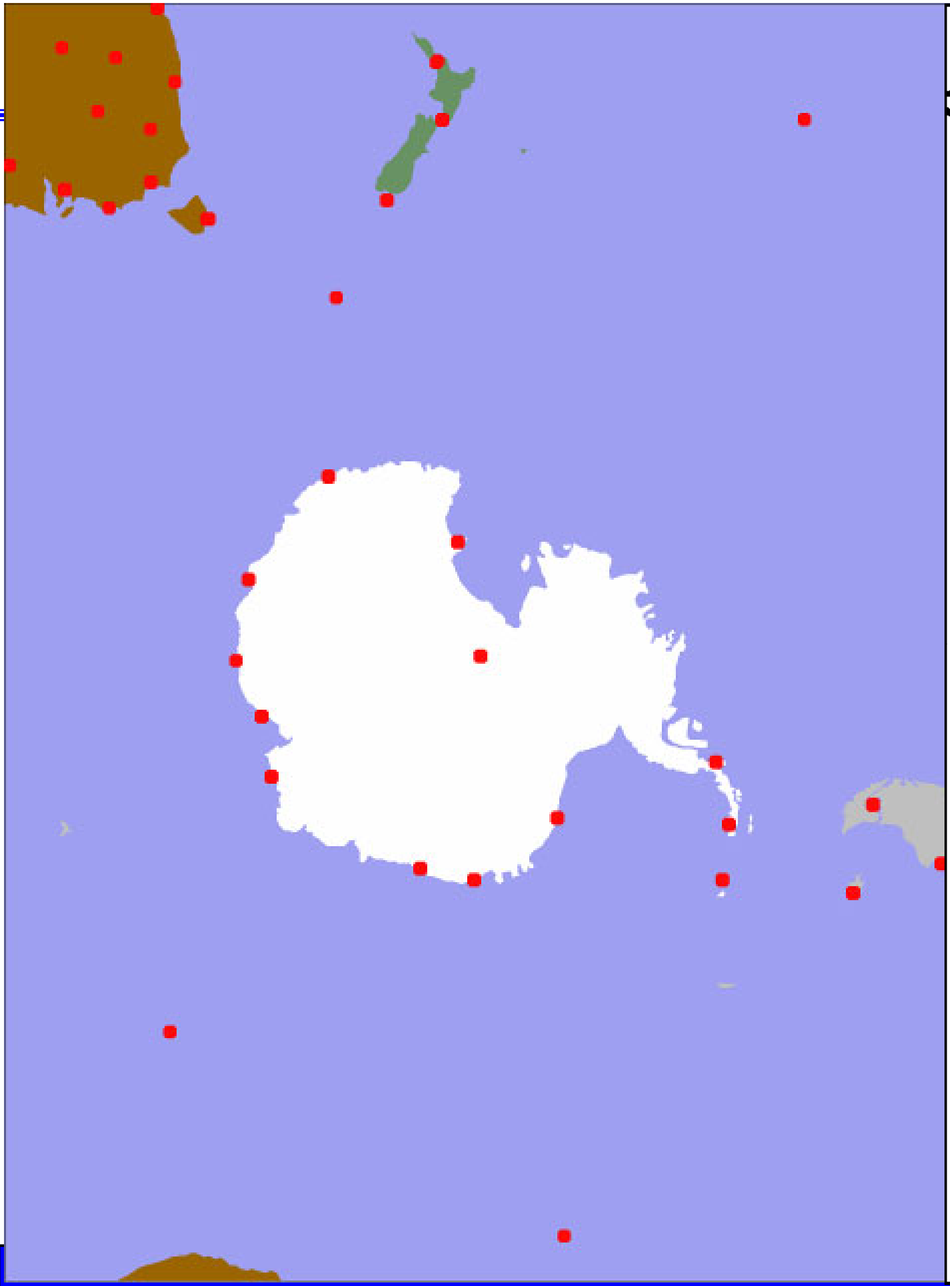
Kevin W. Manning

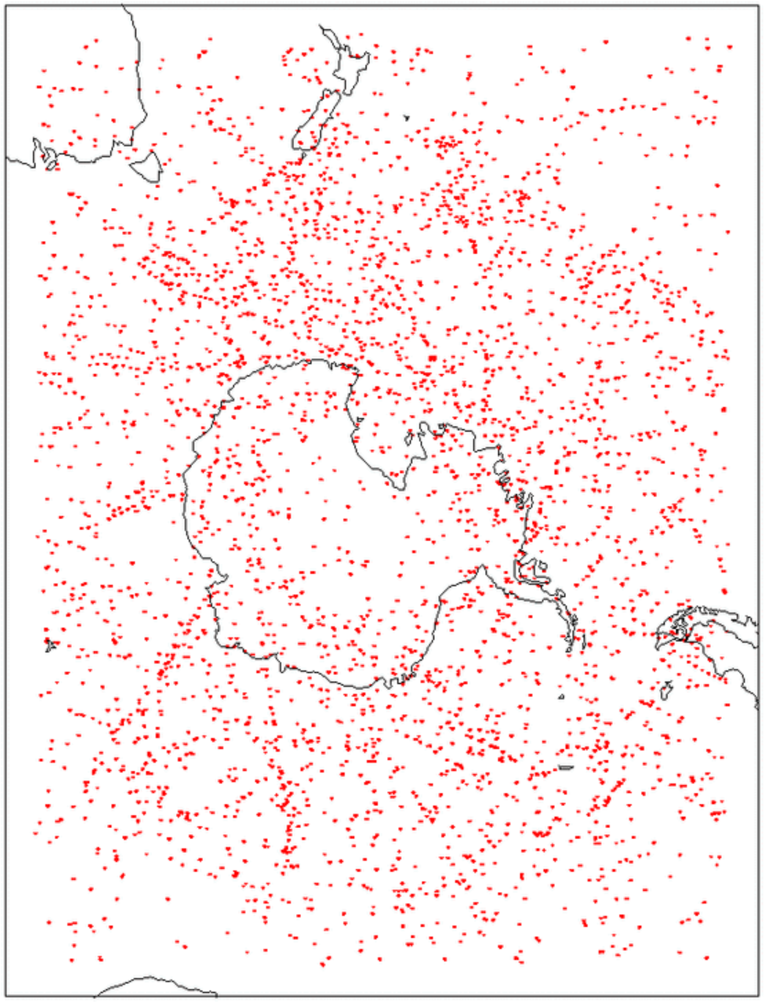
NCAR / ESSL / MMM

Ying-Hua Kuo

UCAR / UOP / COSMIC
NCAR / ESSL / MMM

– AMPS is funded by the National Science Foundation





V erification of AMPS (Antarctic Mesoscale Prediction System)

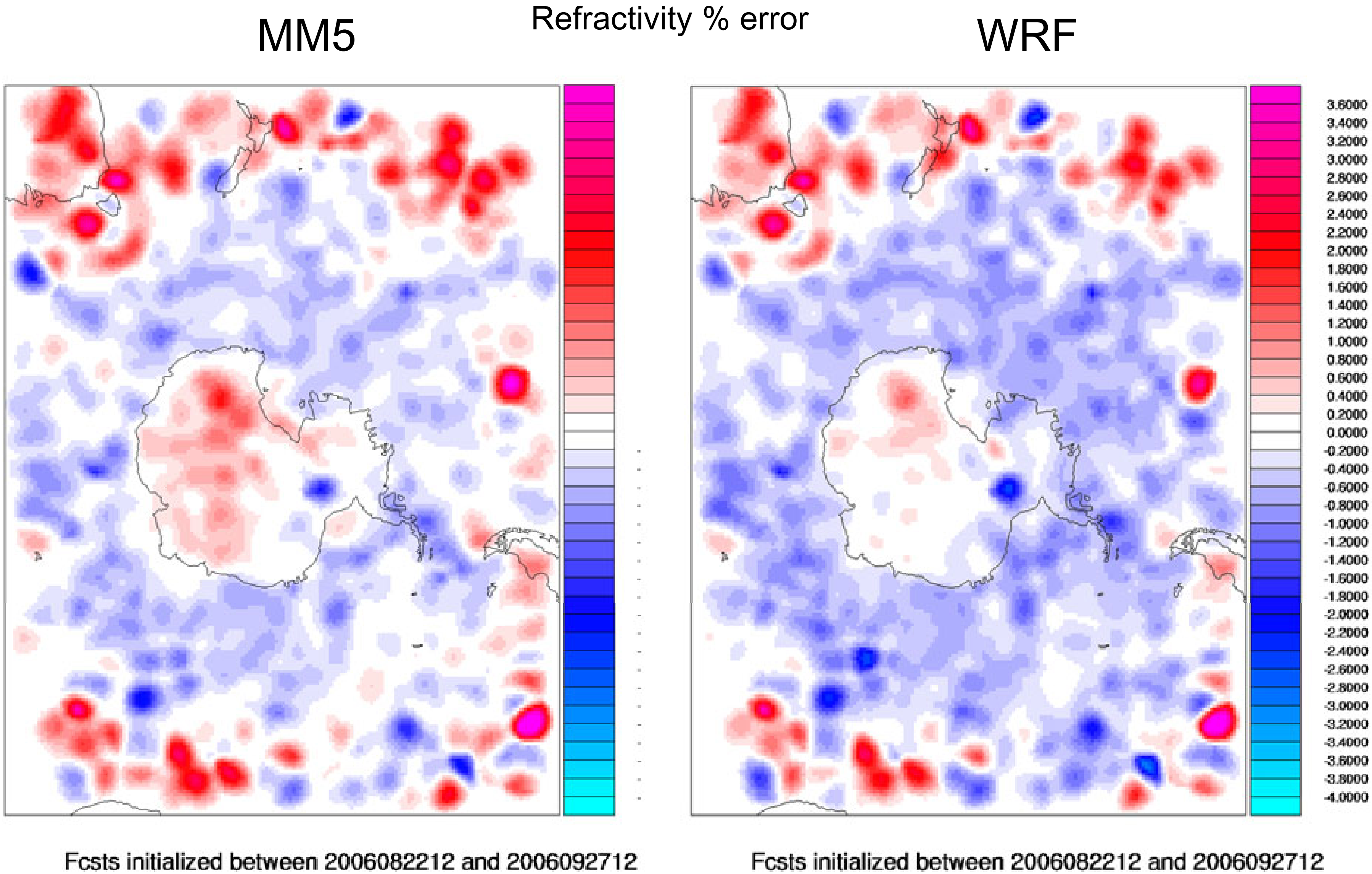
Antarctic is a data poor region of the world.

With 11 days of COSMIC operation, we collect several thousands GPS RO soundings. This provides a great opportunity for model verification.

Results are provided by

Kevin Manning (NCAR/MMM)

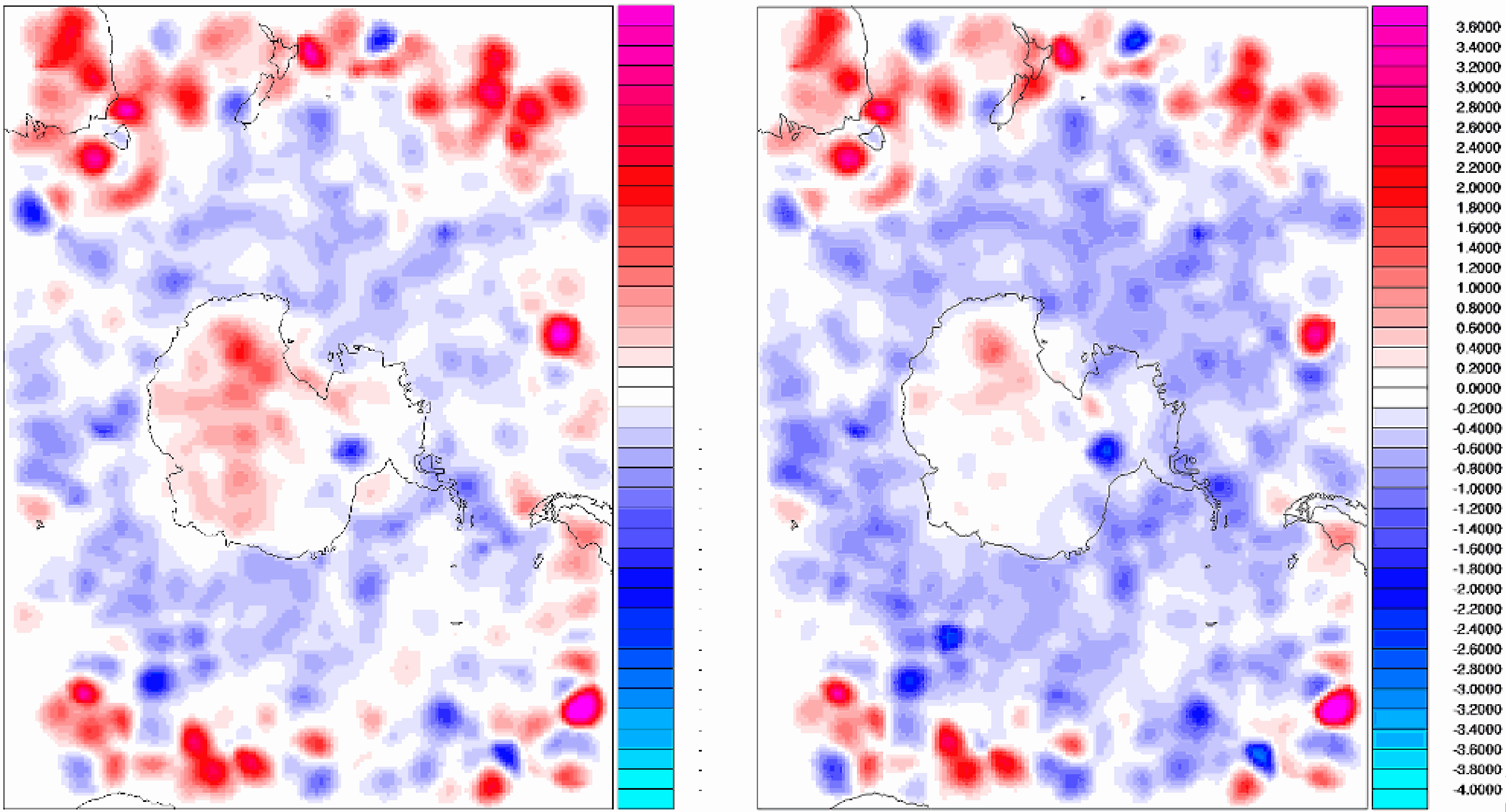
0.5 km – Initialization



0.5 km – Animation through 120 hrs

Refractivity % error

MM5 WRF

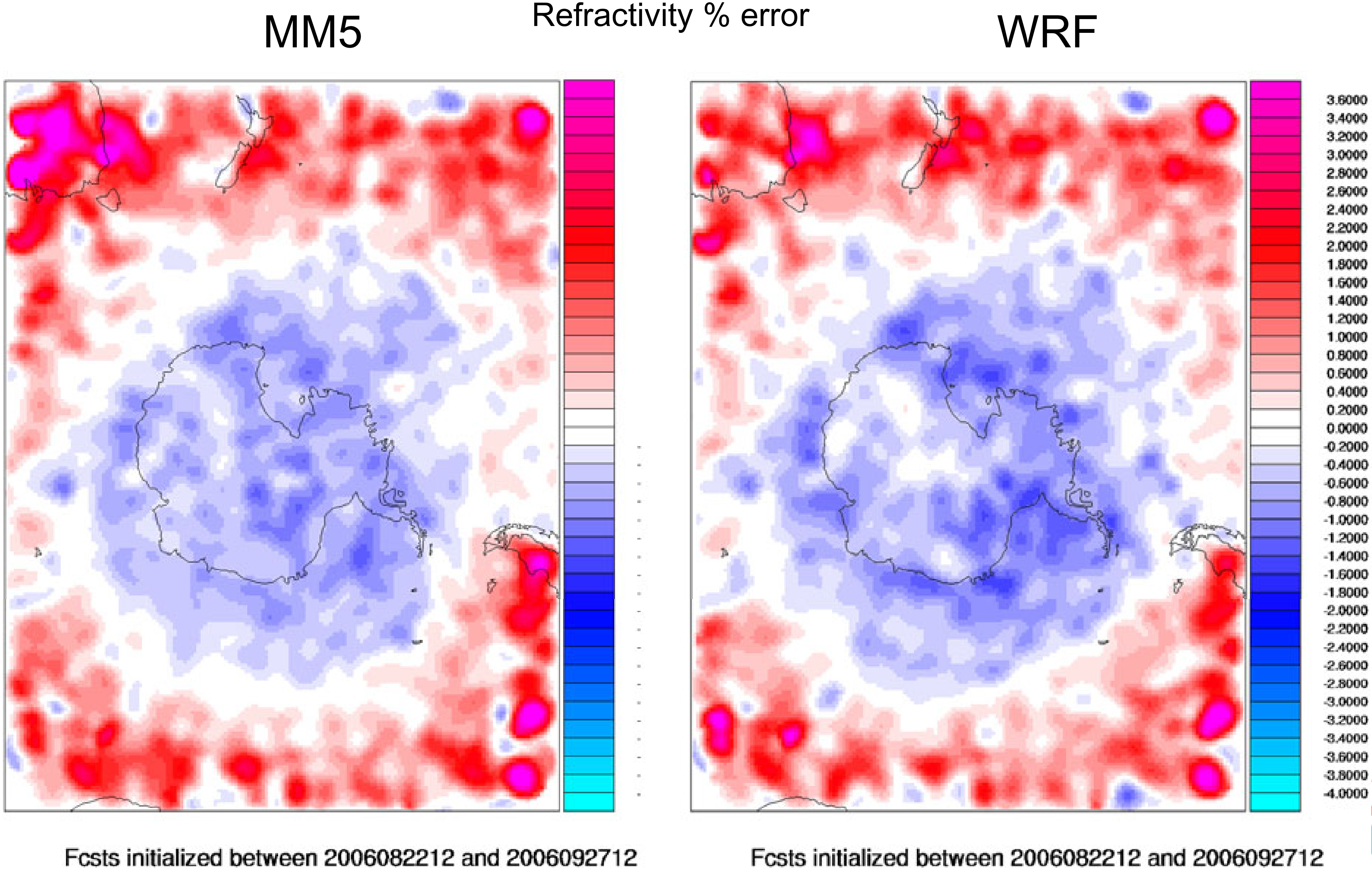


Fcsts initialized between 2006082212 and 2006092712

Fcsts initialized between 2006082212 and 2006092712

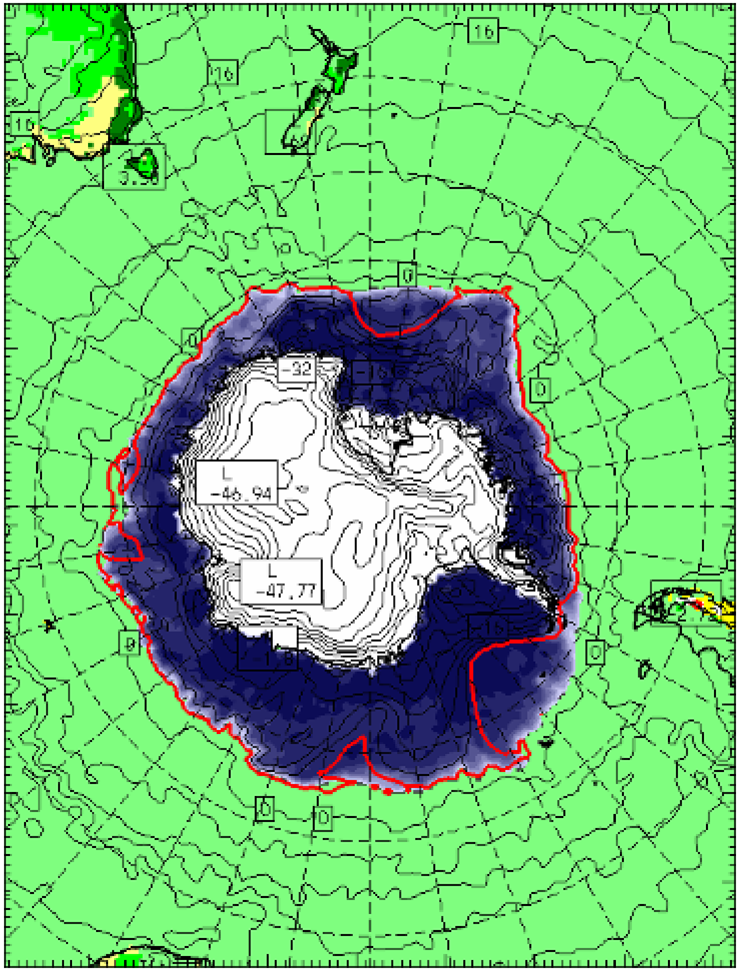
0.5 km – Fcst hour 120

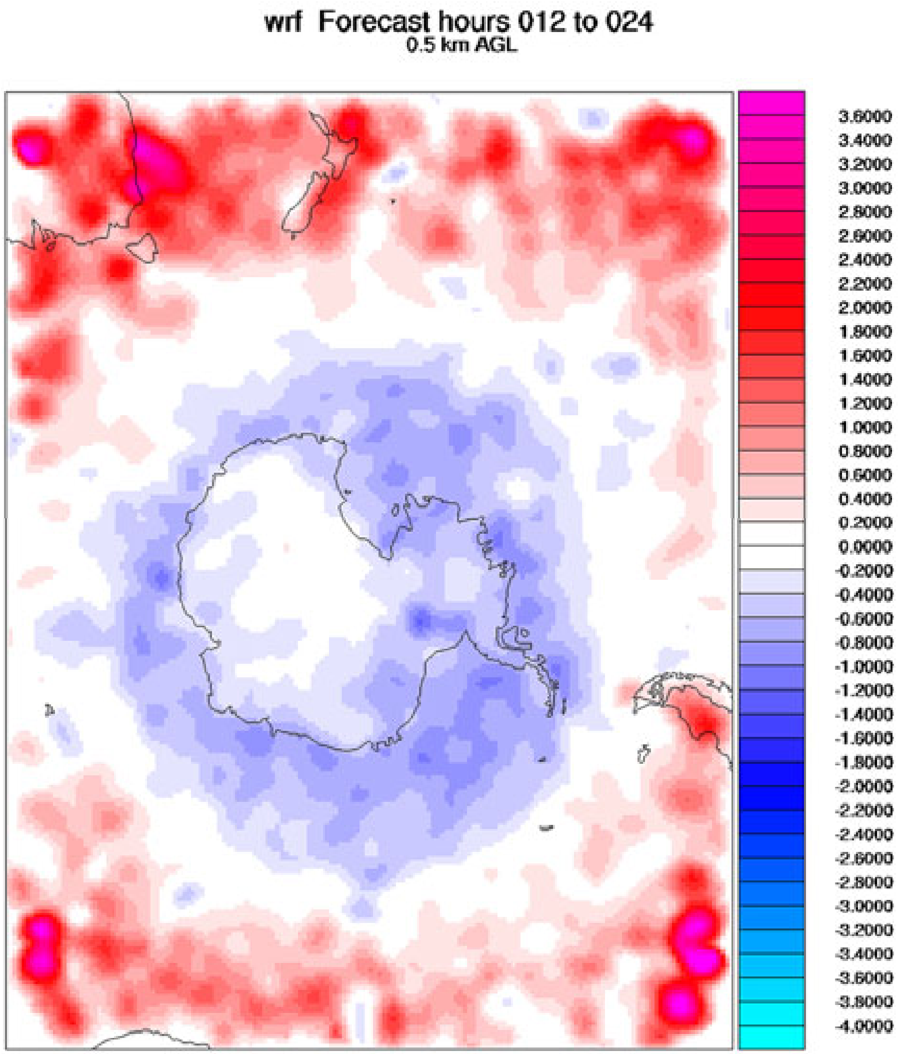
Refractivity % error



Low-level error statistics show influence of sea-ice representation:

Blue = sea ice; Green = open water



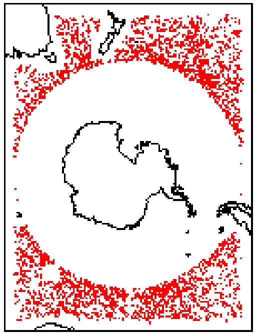


Refractivity RMSE

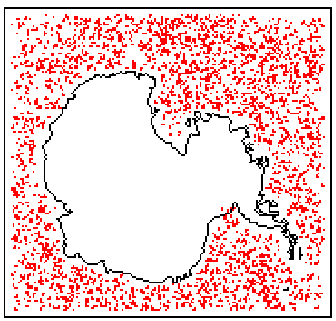
Animation through Forecast hour 120

(MM5 – Green WRF – Red)

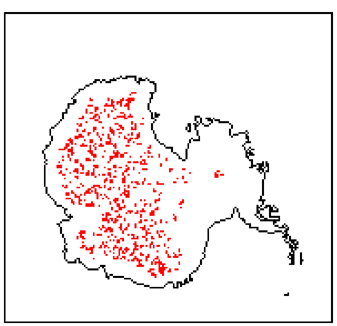
Lower Latitudes (> -50°)

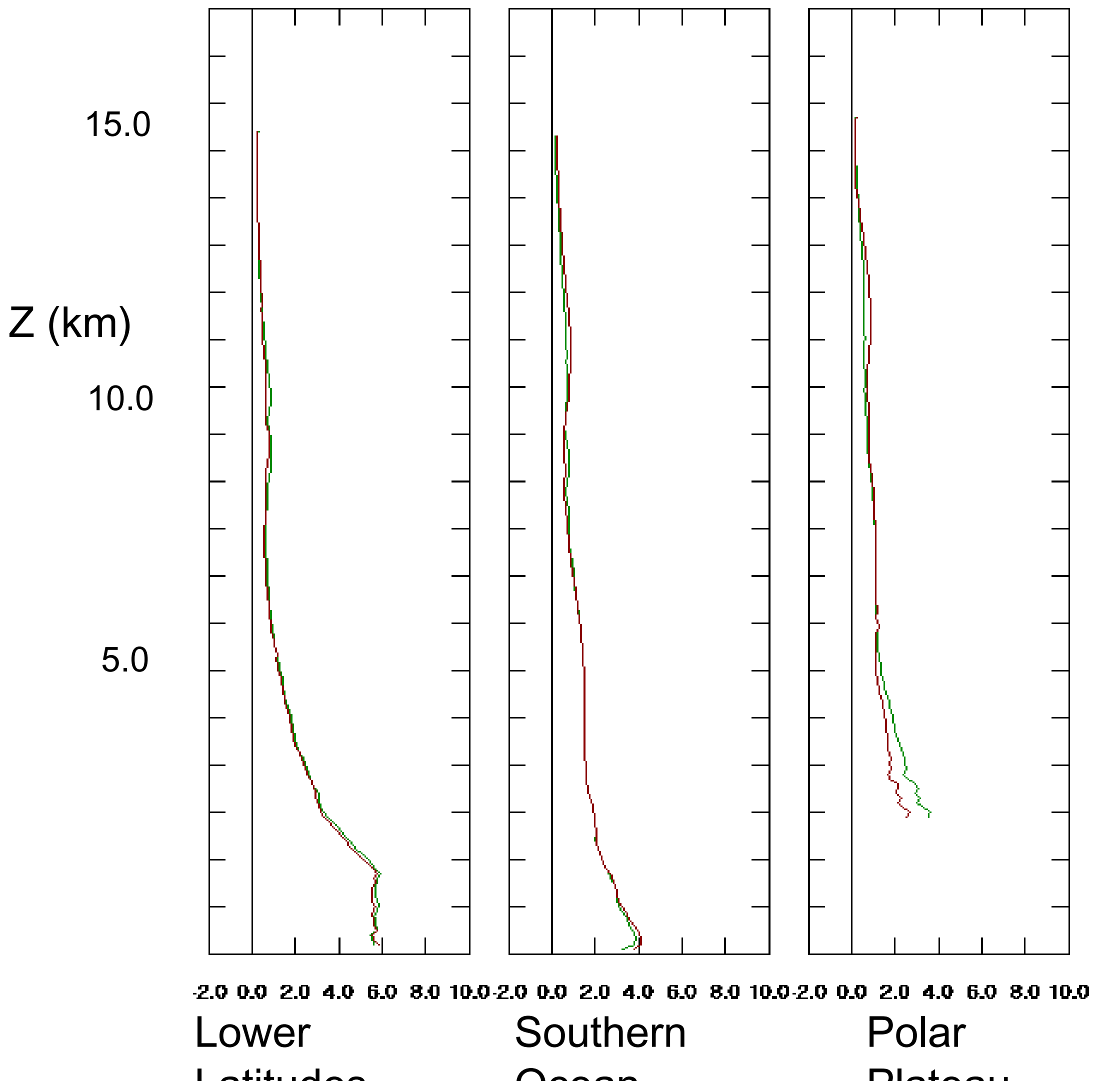


Southern Ocean



Polar Plateau





Conclusions – what COSMIC has revealed about AMPS NWP

- MM5 Polar modifications are important, and should be adapted into WRF
- WRF "free-troposphere" forecasts are superior to MM5
- Sea-ice treatment is deficient in the models
  - MM5 polar modifications show some improvement, but both models have a clear "warm" bias.
- Initial conditions need attention
  - Background Error Covariance?
- The model shows excessive moisture in the subtropical region (as refractivity forecasts are showing positive bias with time).

Conclusions – utility of COSMIC for Antarctic analysis

- COSMIC dataset is extremely valuable for examining model behaviours
  - With only a month or so of data, we see clear signals of model strengths and weaknesses that we really have had no way of seeing before
- COSMIC will be extremely useful in evaluating changes and improvements to the WRF AMPS system

Impact of COSMIC on Hurricane Ernesto (2006)

Hurrican Ernesto:

Formed: 24 August 2006

Reached Hurricane strength: 27 August

Dissipated: 1 September 2006

15:50 UTC 27 August 2006

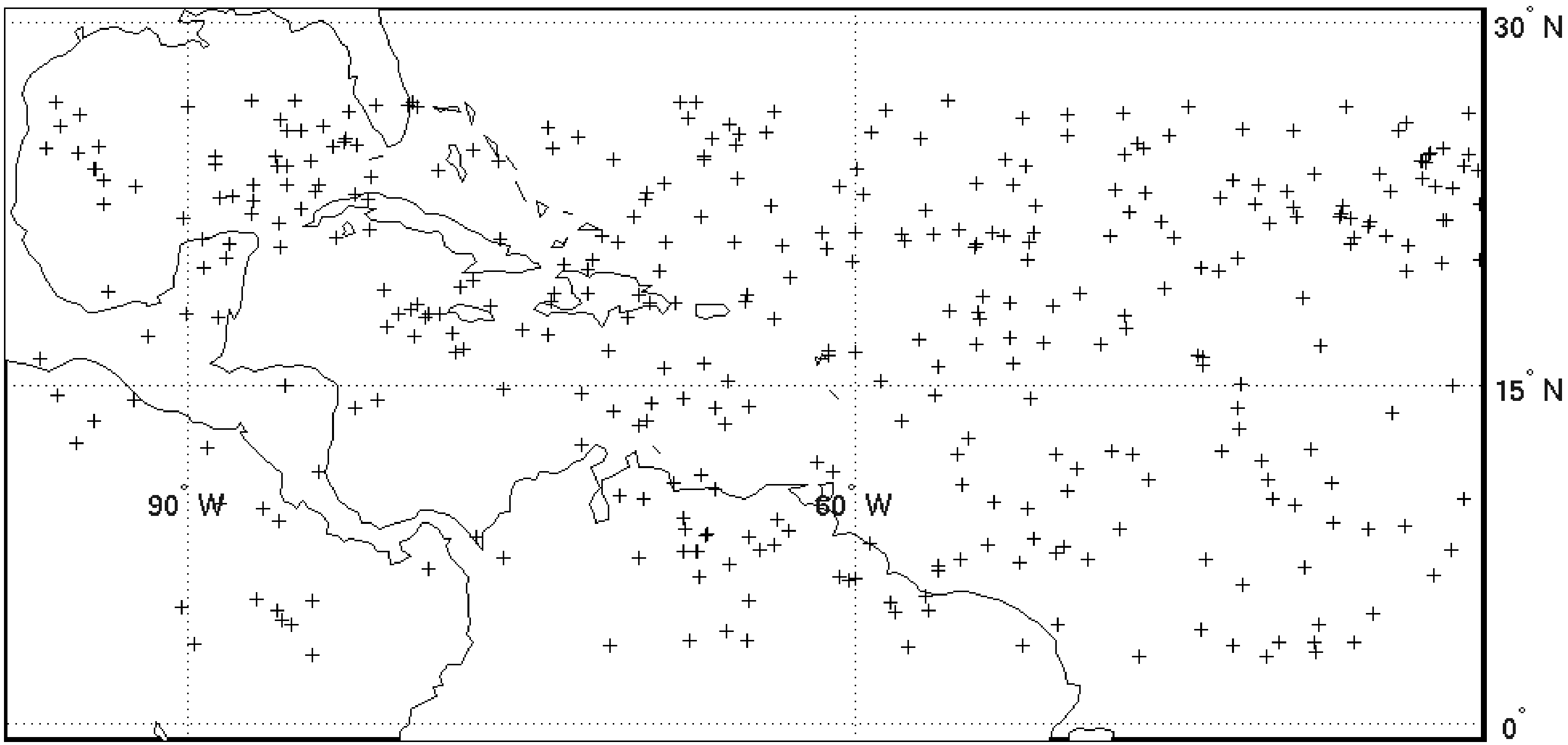
Picture taken by MODIS, 250 m resolution

Status of current tropical analyses

- The analyses rely on satellite radiances and cloud-drift winds.
- Significant areas of cloud-cover may exist, e.g., in case of hurricanes. Radiances are not routinely used in these areas.
- In such areas, satellite winds are the major data. Analyses of T and Q may have larger uncertainty.
- Hurricane forecasts initialized from such analyses may have larger uncertainty.
- Study of weather and climate over oceans (e.g., ITCZ, MJO, ENSO) also needs more reliable analyses of T, Q, and winds.
- RO data is not affected by clouds and may significantly improve tropical analyses in cloudy situations.

Location of the RO refractivity profiles

(Aug 16-31, 2006)



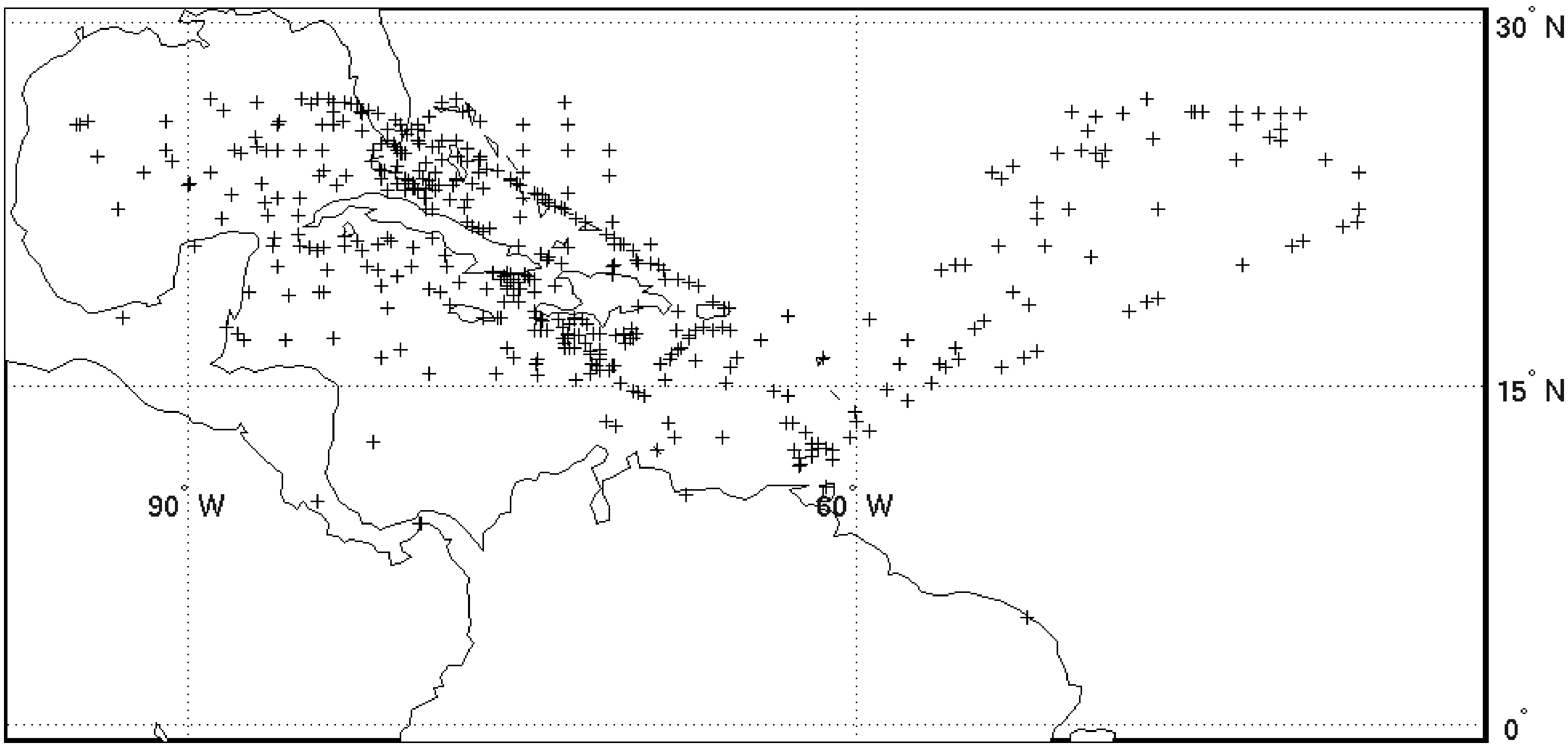
QC: RO data with differences from the forecasts more than 8 times the observation error are rejected. Almost all (425) of the RO data are assimilated.

The experiments

- *CTRL run*: Assimilate satellite cloud drift winds only.
- *GPS run*: Assimilate satellite cloud winds + RO refractivity assimilated using the non-local operator.
- *GPS2km run*: Same as *GPS run* but assimilate only RO data above 2km.
- WRF ensemble data assimilation system at 36 km resolution with 36 ensemble members is used.
- Continuously 6 hour cycle assimilation.
- Analyses and 6-h forecasts are verified to the dropsondes and radiosondes, which are withheld from the assimilations.

Sounds used for Verification

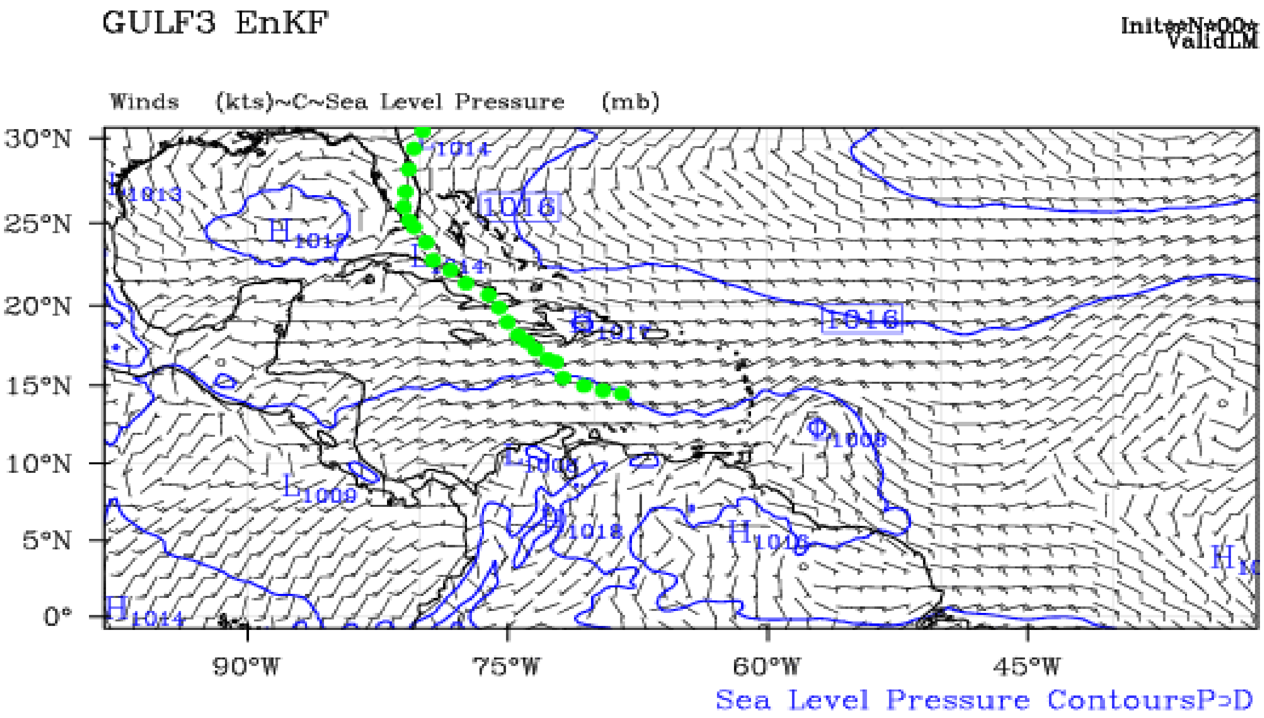
(Aug 16-31, 2006)



The sounds include most dropsondes and a few radiosondes

Impact on analyses of Hurricane Ernesto (2006)

(GPS run)



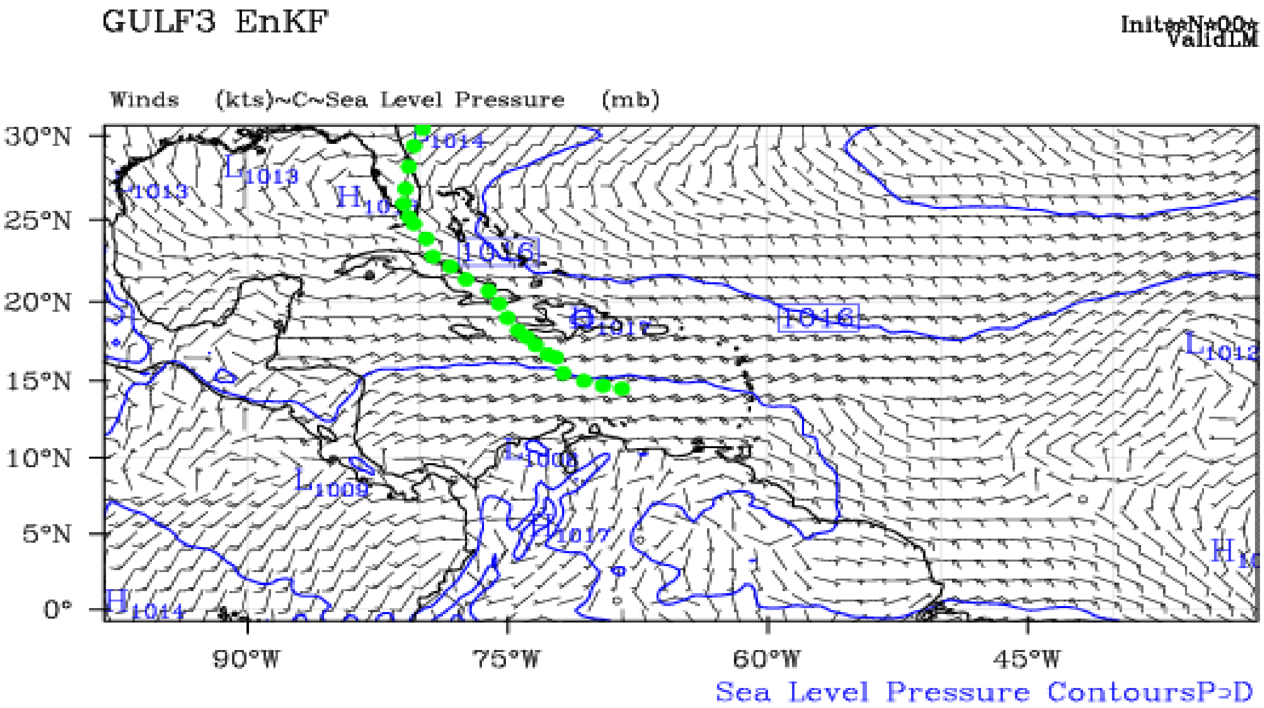
Green dots:

Best Track

Analyses of surface pressure and wind

Impact on analyses of Hurricane Ernesto (2006)

(CTRL run)



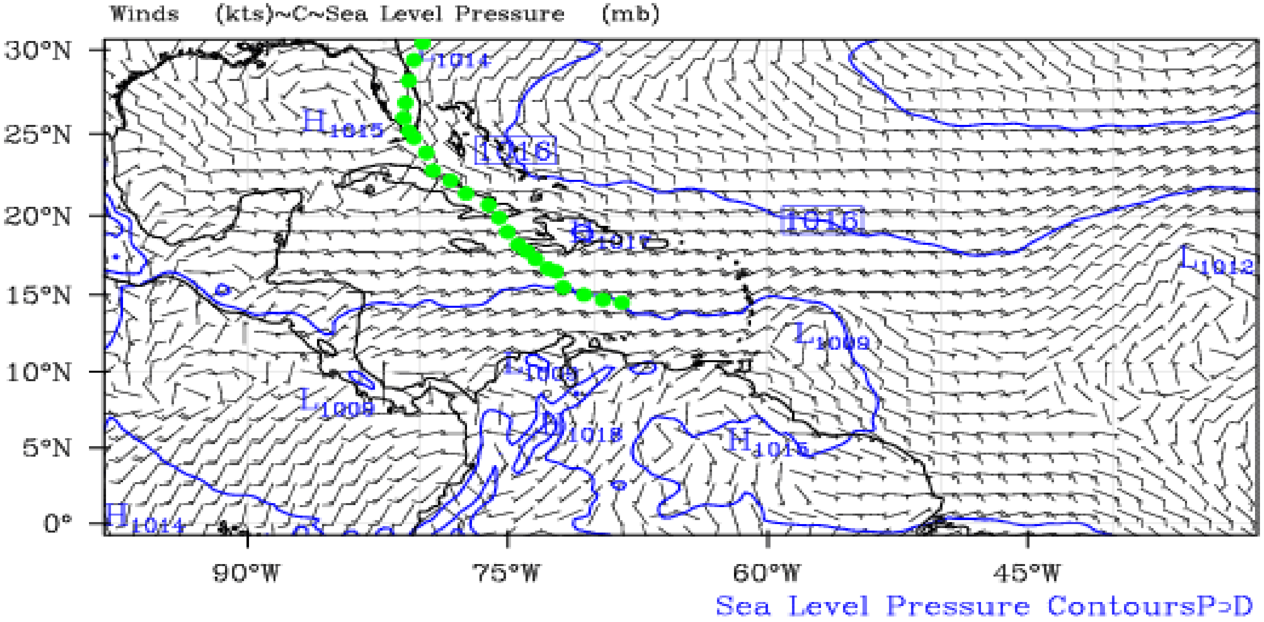
Green dots:

Best Track

Analyses of surface pressure and wind

Impact on analyses of Hurricane Ernesto (2006)

(GPS2km run)



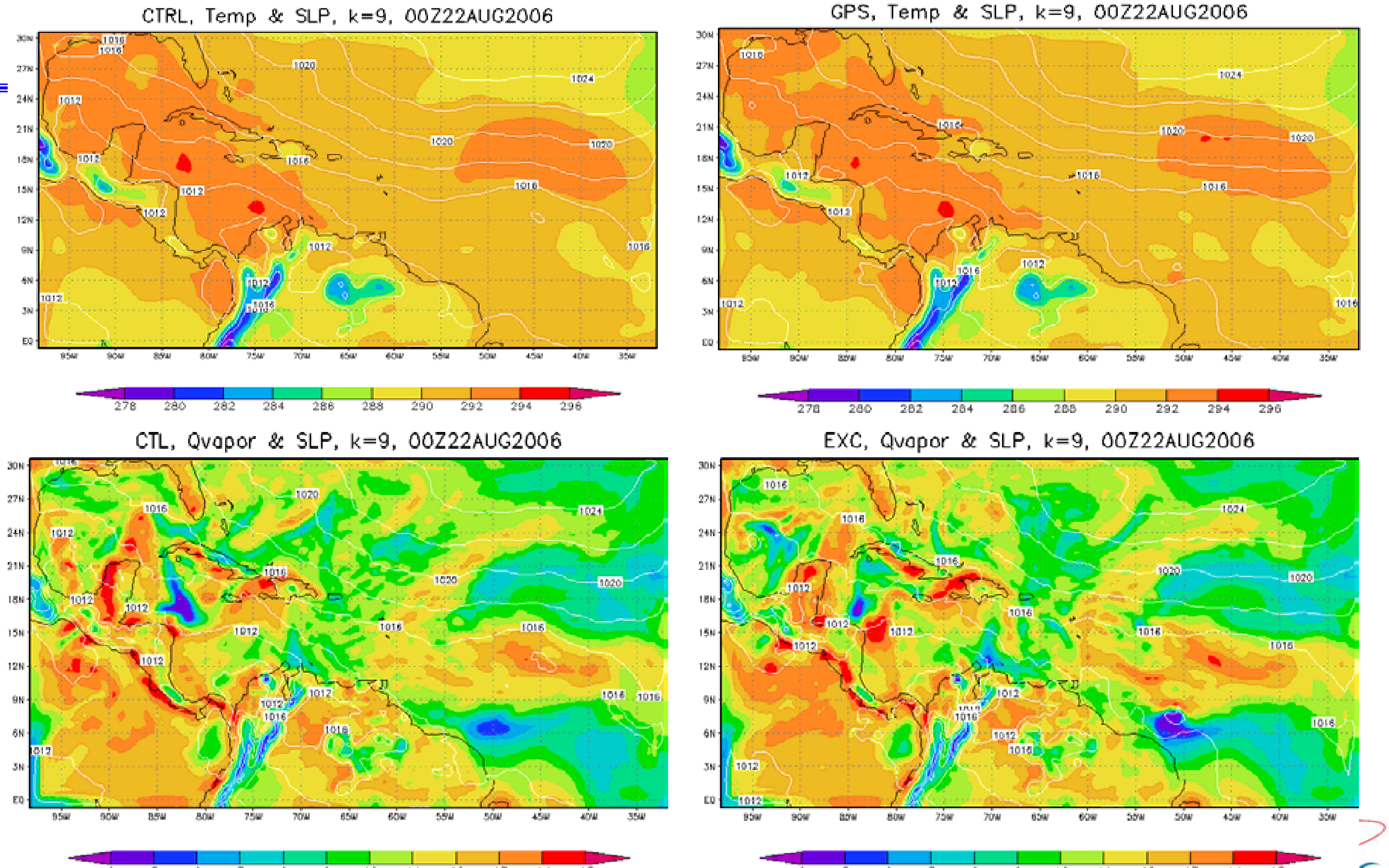
Green dots:

Best Track

Analyses of surface pressure and wind

Control

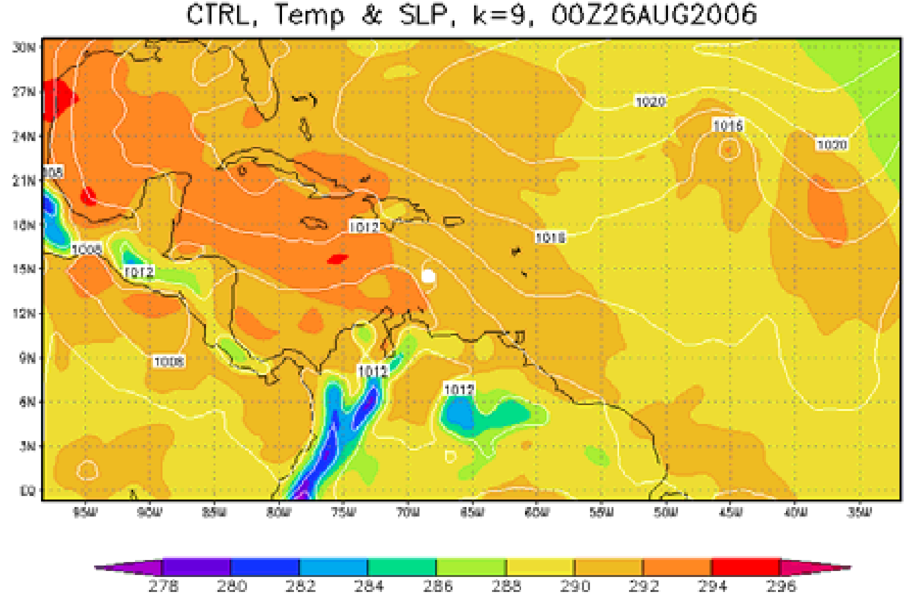
GPS

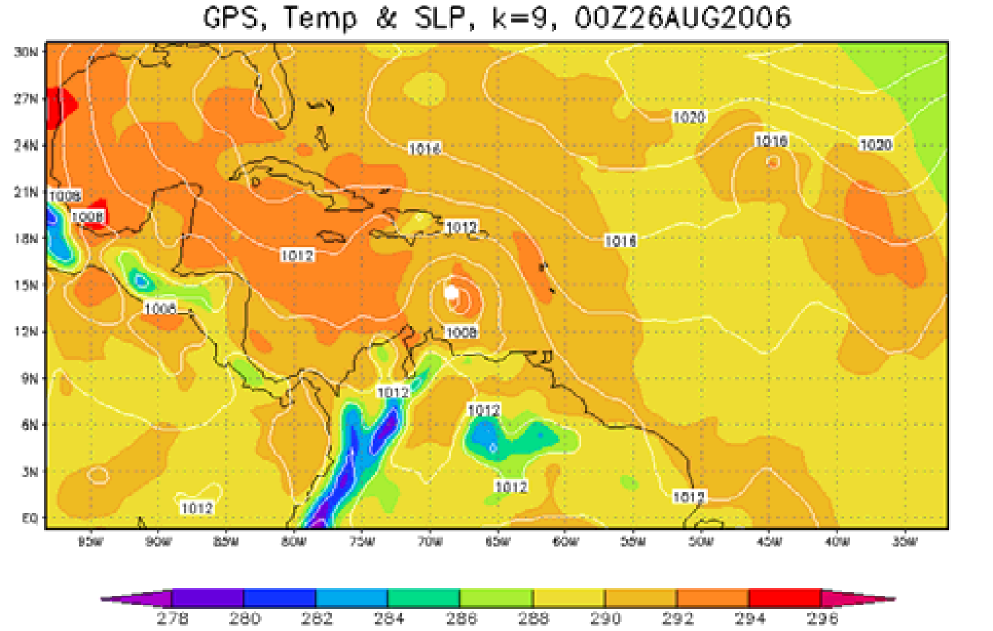


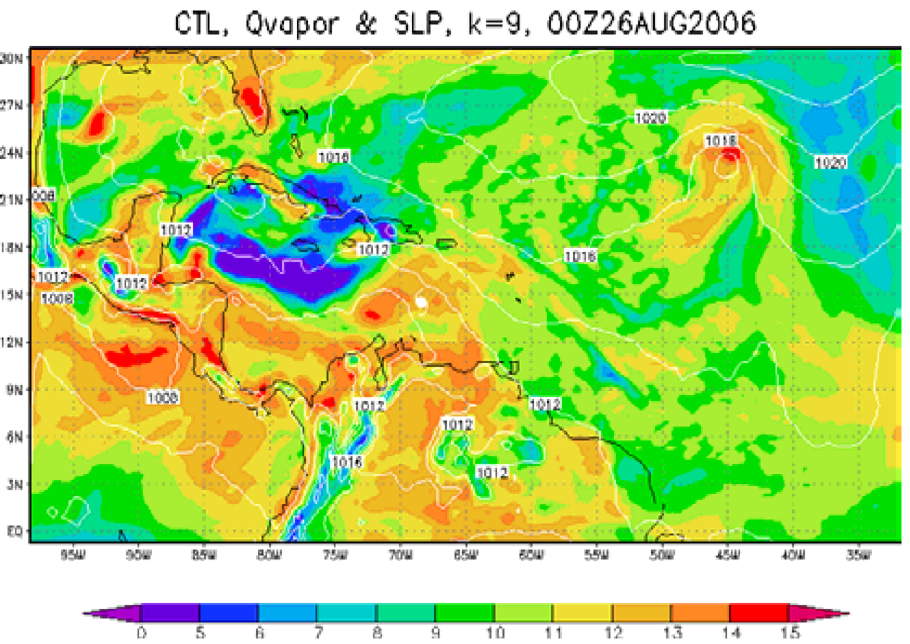
One week into assimilation - 00 UTC 22 August

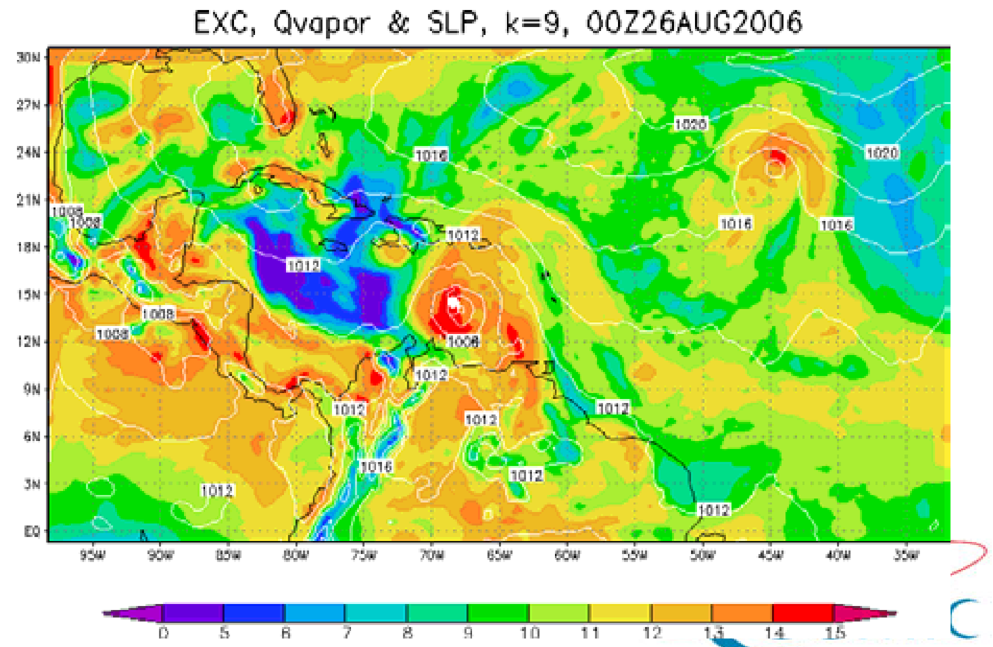
Control

GPS

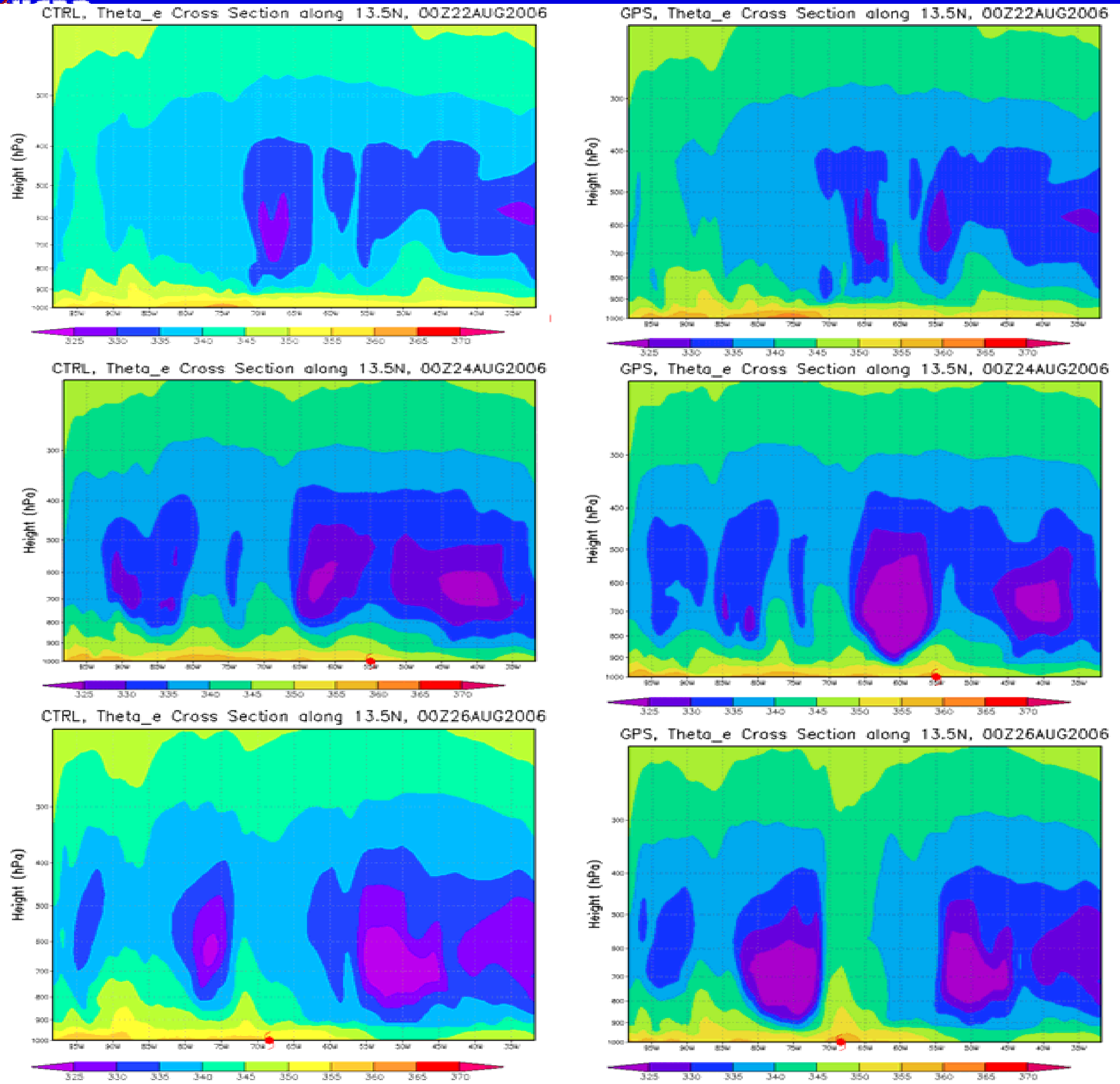








Ten days into assimilation - 00 UTC 26 August



Theta_e cross section

For 22, 24, 26 Aug 2006

Conclusion

- The RO data has improved analyses of moisture in the lower troposphere over tropical oceans.
- The RO improved analyses of the hurricane Ernesto's genesis through providing more favorable environment for the easterly wave to develop into a tropical cyclone.
- The RO data below 2km has useful information and positive impact on the analyses of the hurricane's genesis.

The ensemble data assimilation system is available on www.image.ucar.edu/DAReS

Impact of a few key COSMIC soundings at the right place

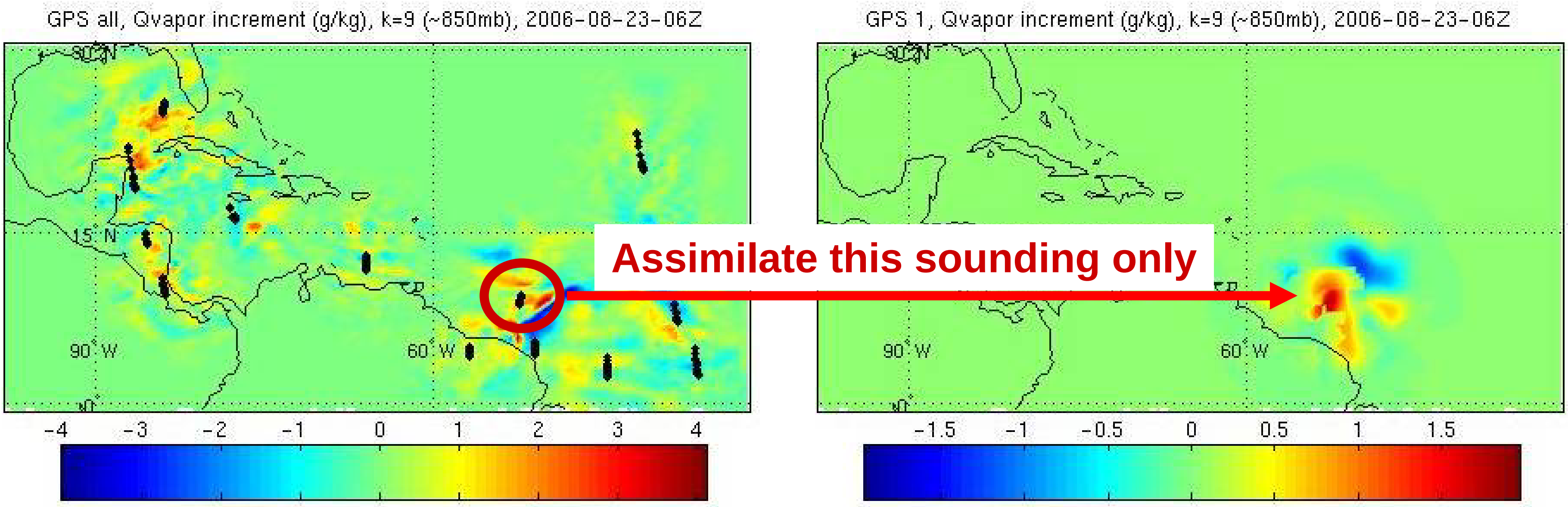
Forecast experiments

- No GPS: initialized from AVN/GFS analysis at 2006-08-23-06Z
- GPS all: assimilate all 15 GPS profiles at 2006-08-23-06Z, followed by a 5-day forecast
- GPS 1 : only assimilate 1 GPS profile at 2006-08-23-06Z, followed by a 5-day forecast

Low-level moisture change by assimilating GPS

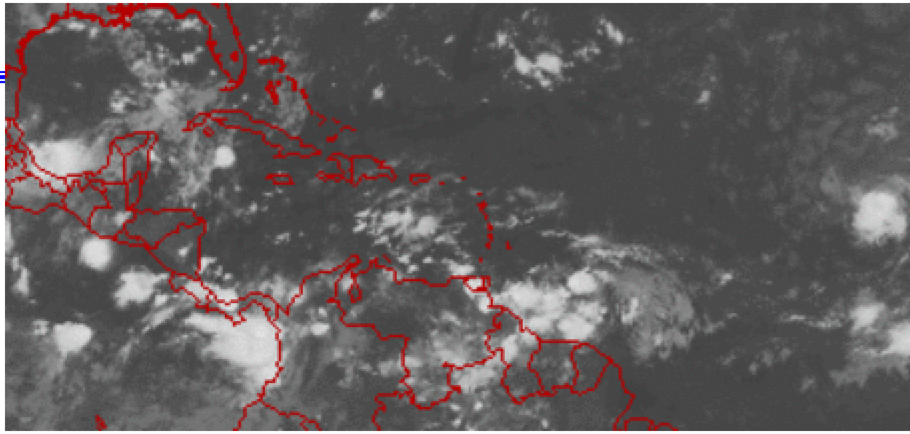
GPS all

GPS 1

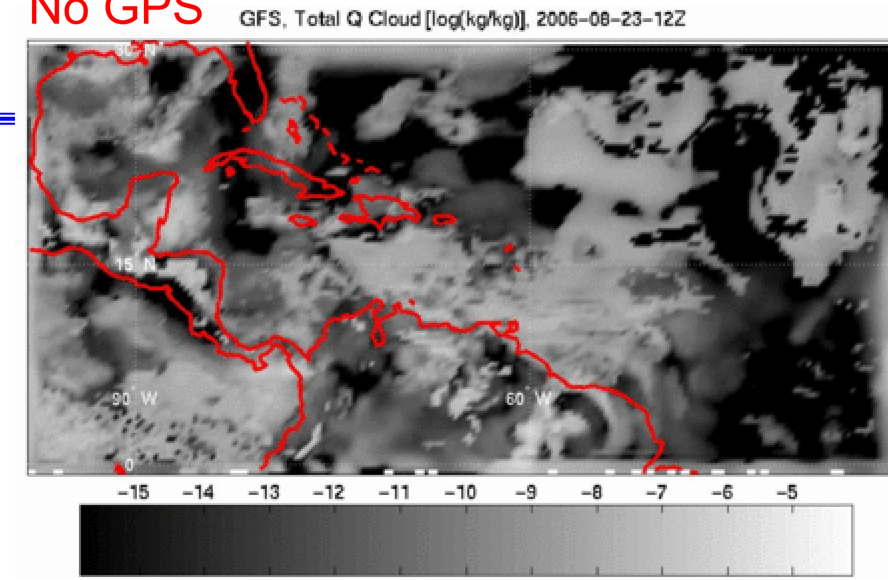


2006-08-23-12Z (06h forecast)

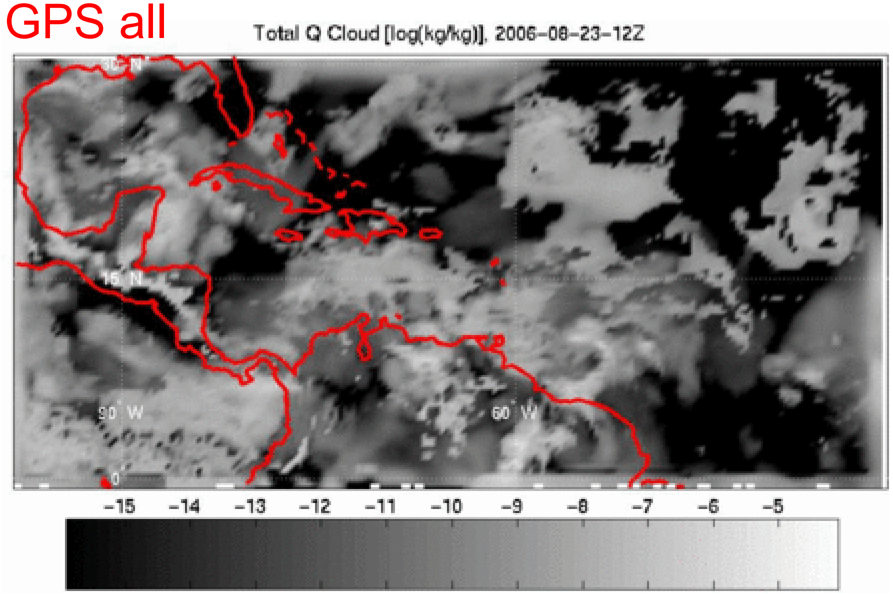
Sat. IR



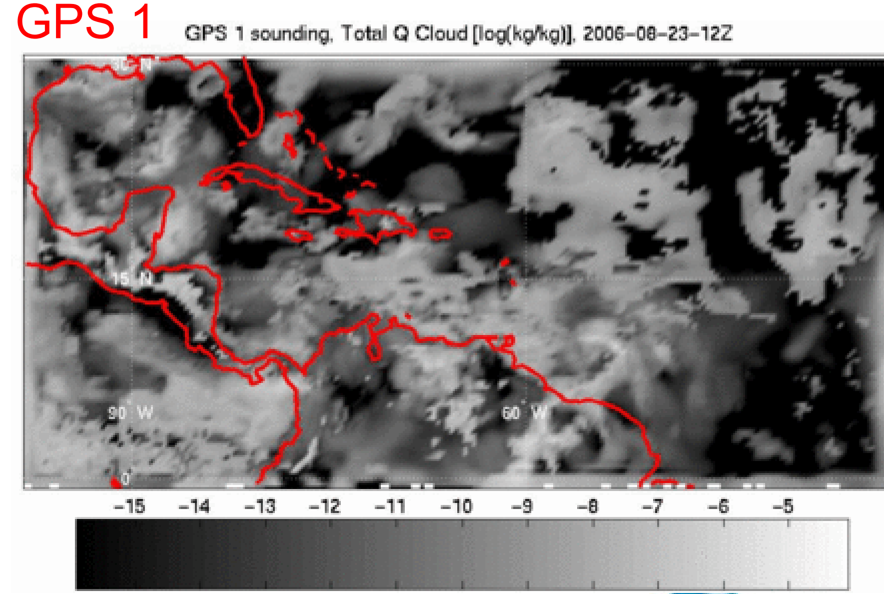
No GPS



GPS all

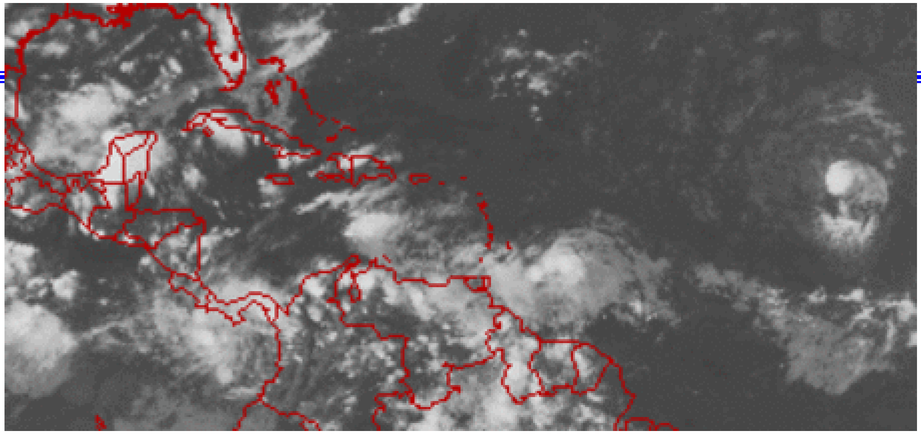


GPS 1



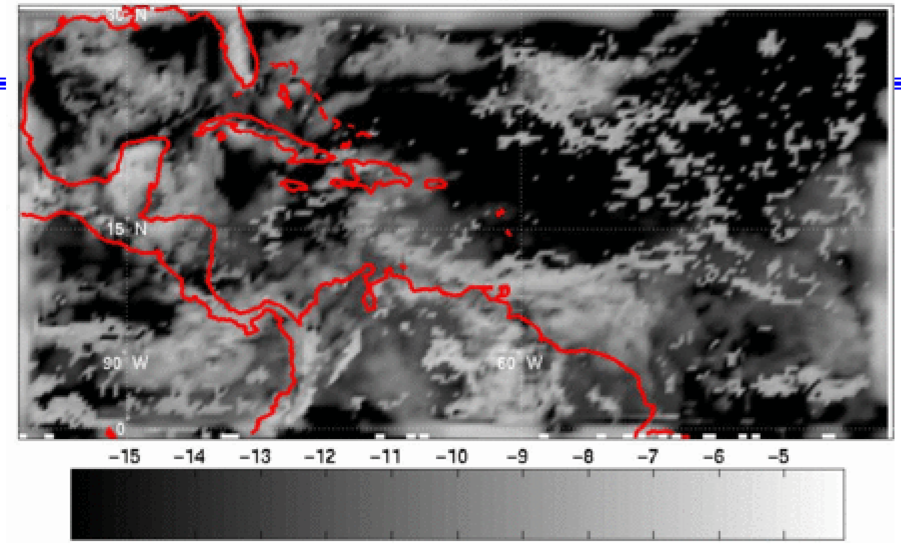
2006-08-24-00Z (18h forecast)

Sat. IR



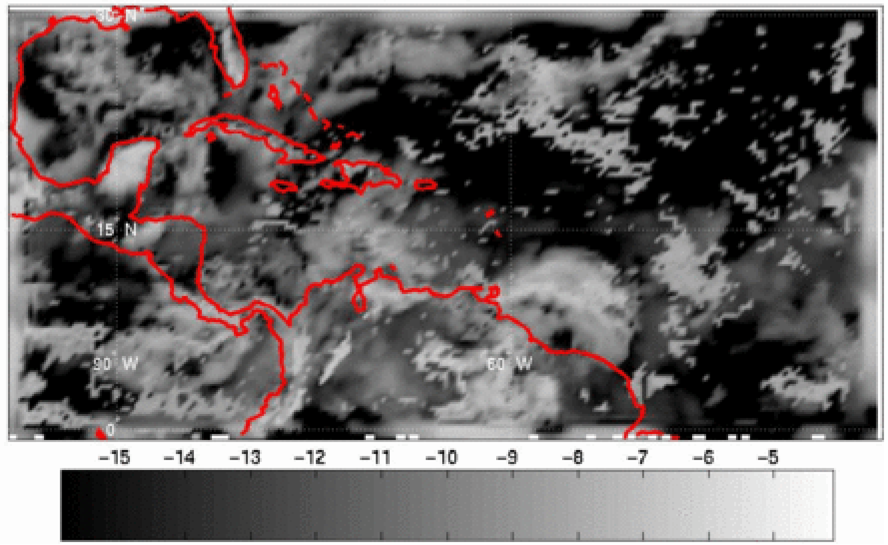
No GPS

GFS, Total Q Cloud [log(kg/kg)], 2006-08-24-00Z



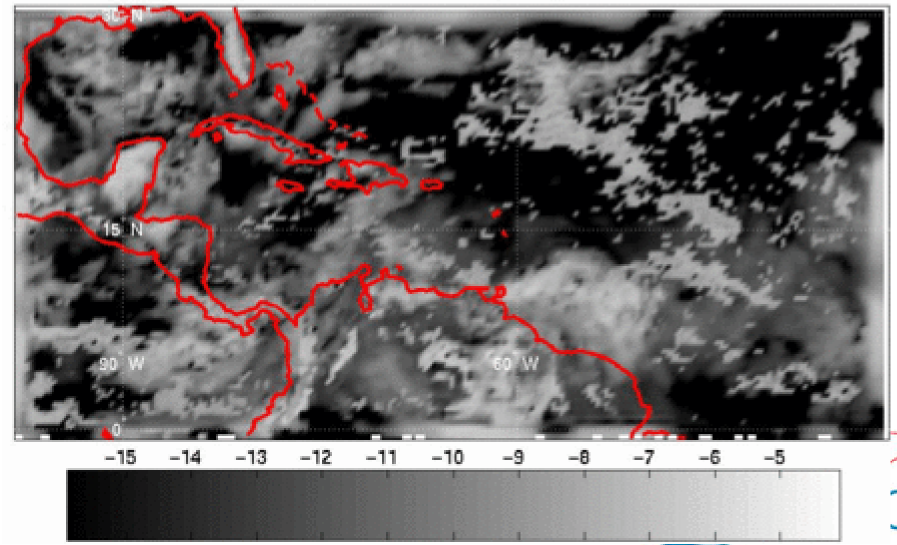
GPS all

Total Q Cloud [log(kg/kg)], 2006-08-24-00Z



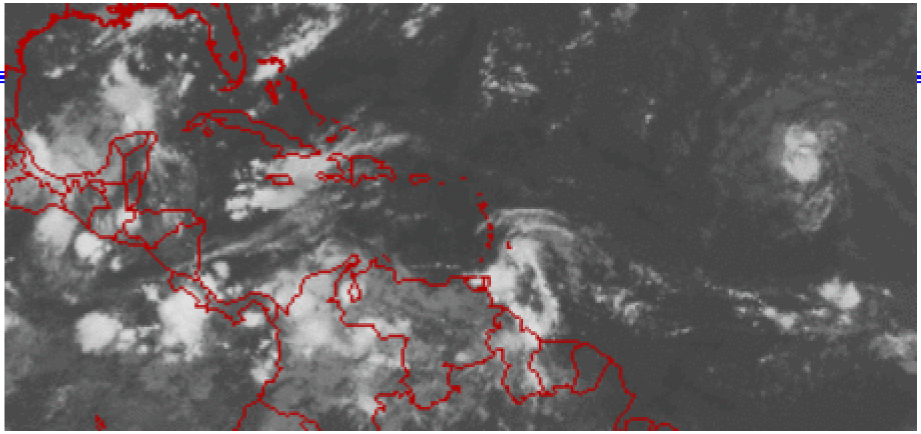
GPS 1

GPS 1 sounding, Total Q Cloud [log(kg/kg)], 2006-08-24-00Z



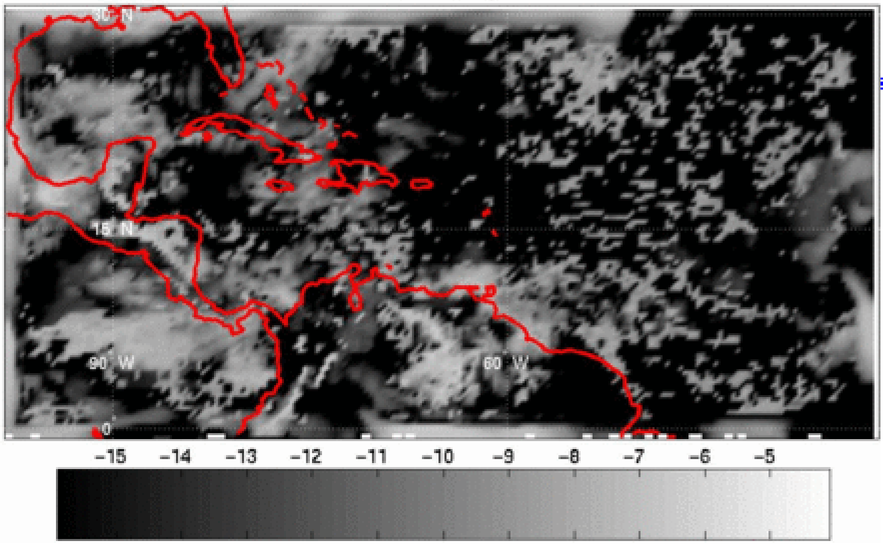
2006-08-24-12Z (30h forecast)

Sat. IR



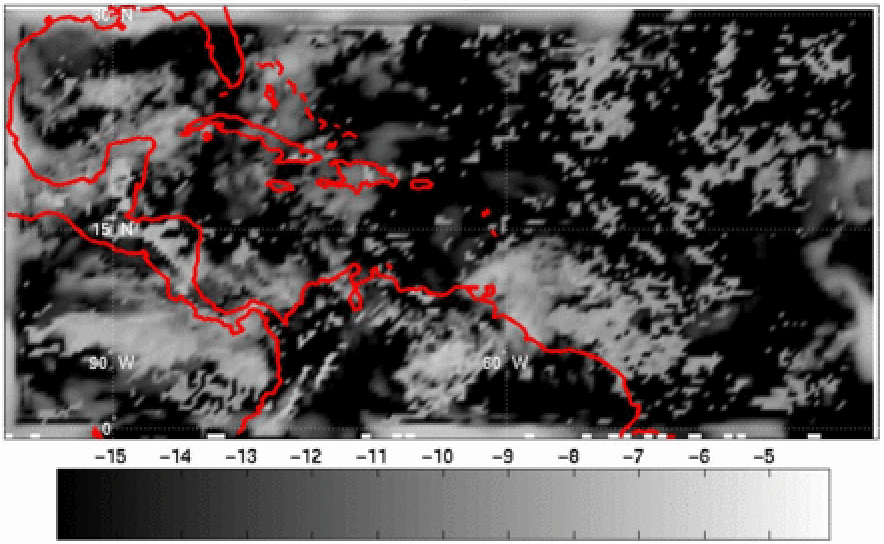
No GPS

GFS, Total Q Cloud [log(kg/kg)], 2006-08-24-12Z



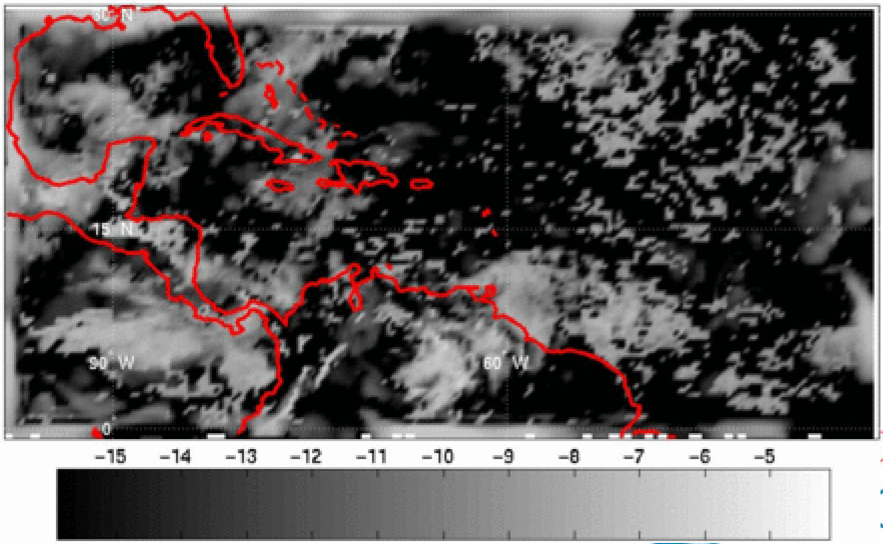
GPS all

Total Q Cloud [log(kg/kg)], 2006-08-24-12Z



GPS 1

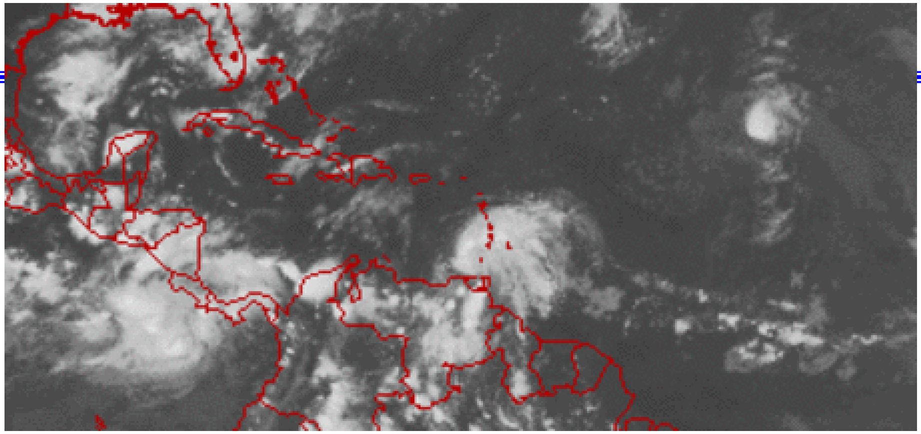
GPS 1 sounding, Total Q Cloud [log(kg/kg)], 2006-08-24-12Z



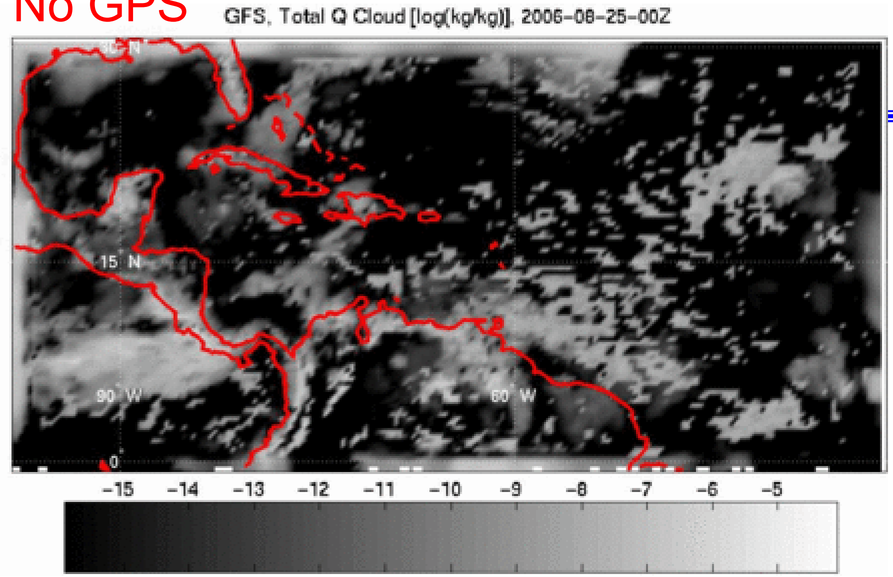
UCAR

2006-08-25-00Z (42h forecast)

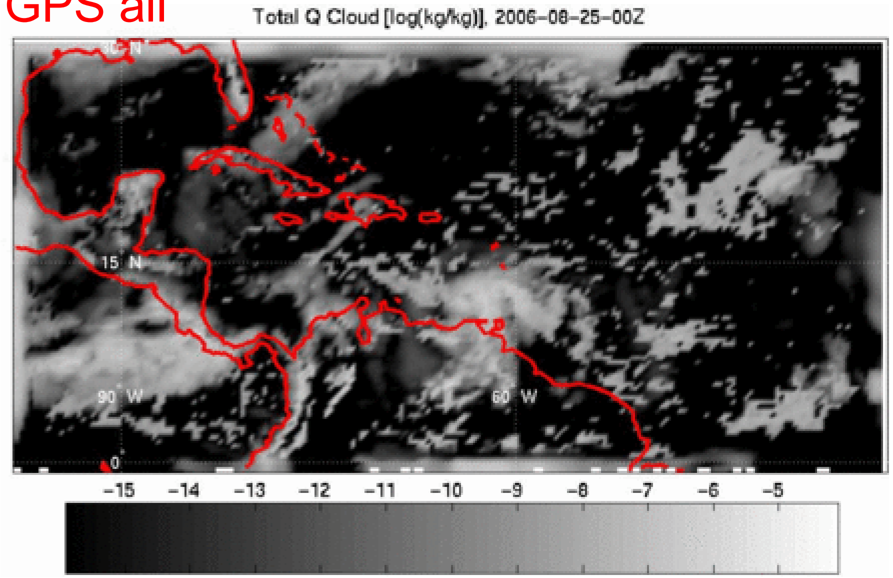
Sat. IR



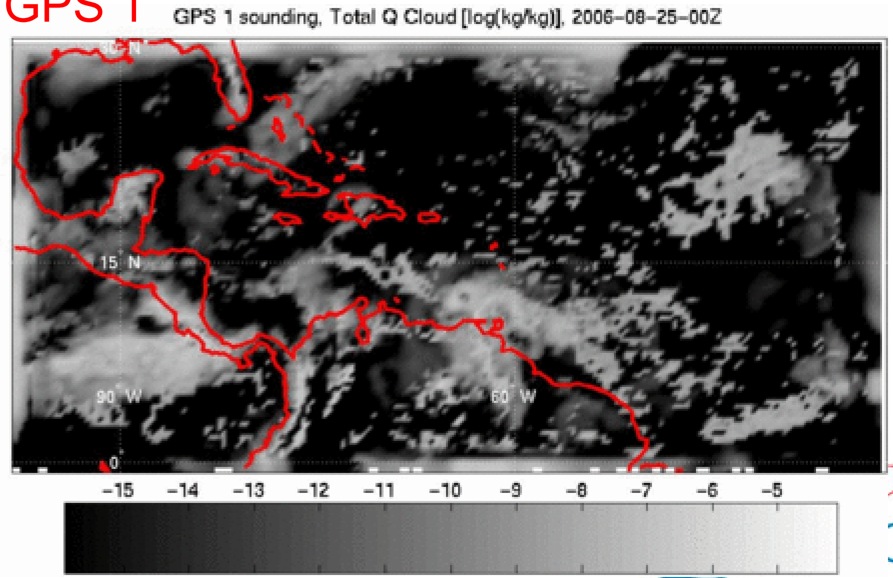
No GPS



GPS all

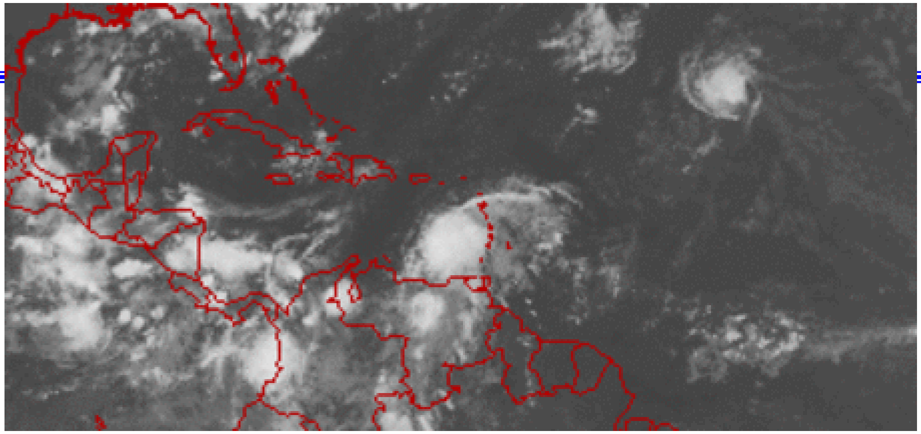


GPS 1

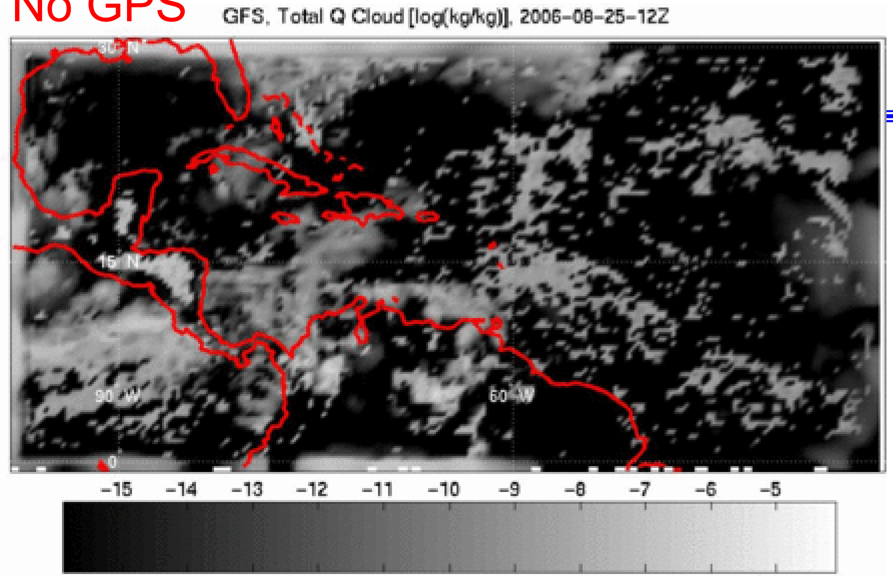


2006-08-25-12Z (54h forecast)

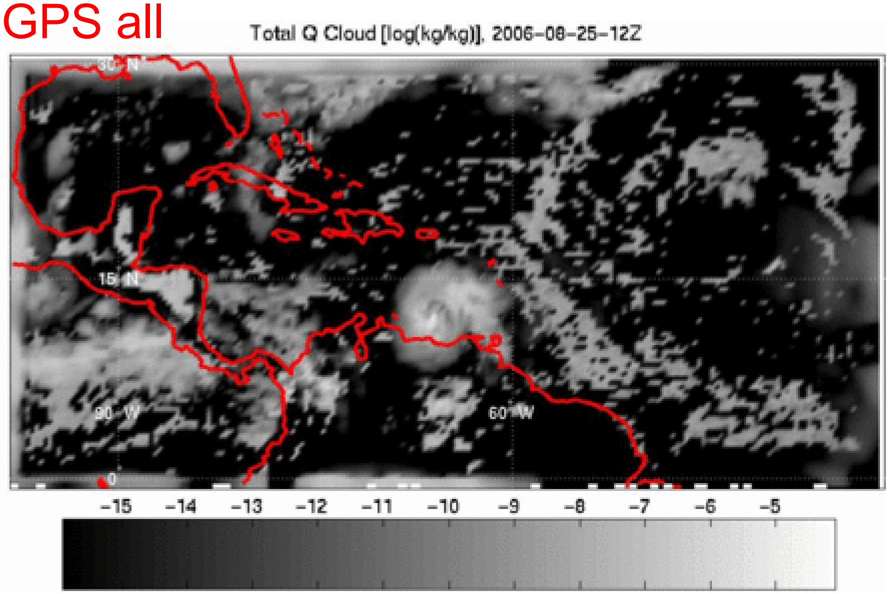
Sat. IR



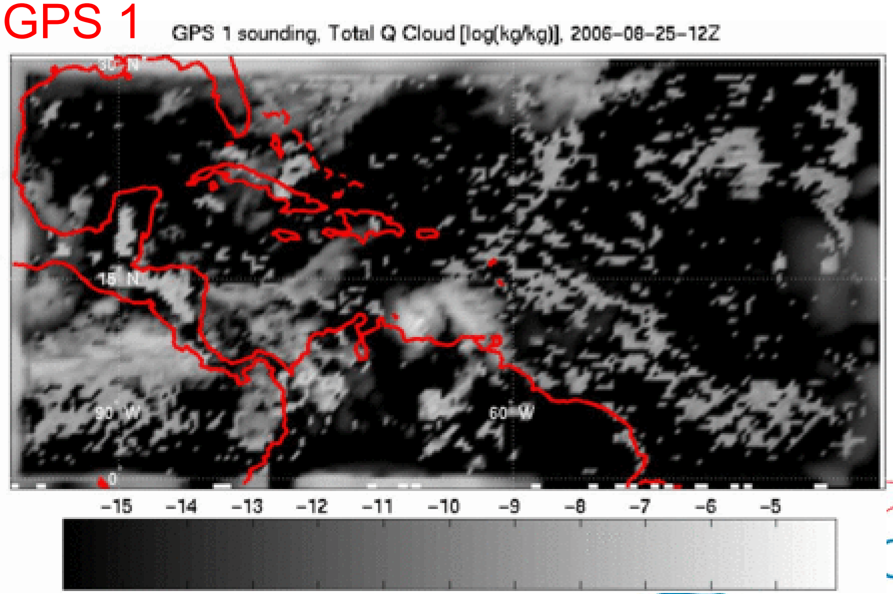
No GPS



GPS all

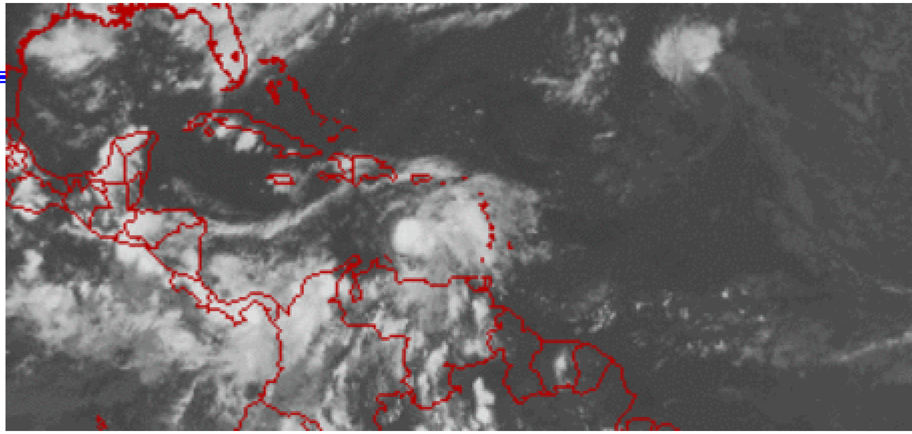


GPS 1

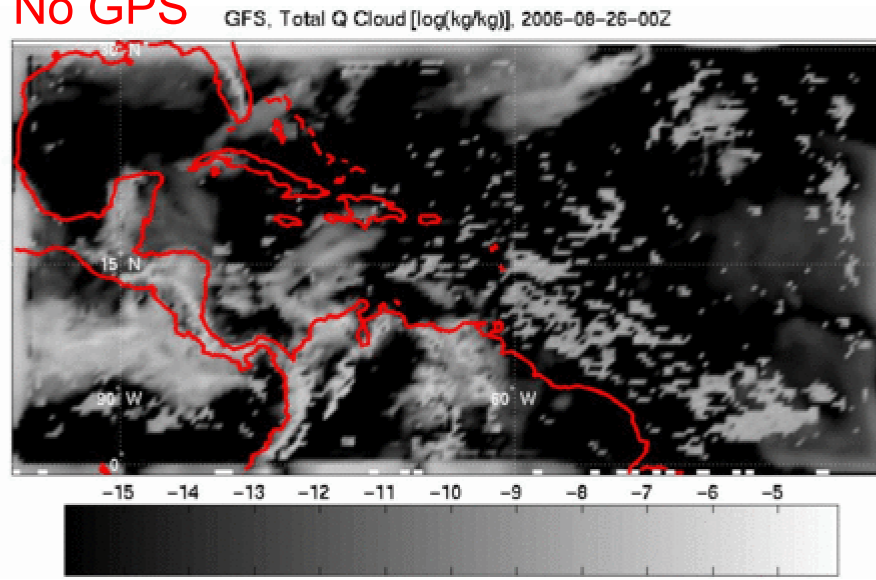


2006-08-26-00Z (66h forecast)

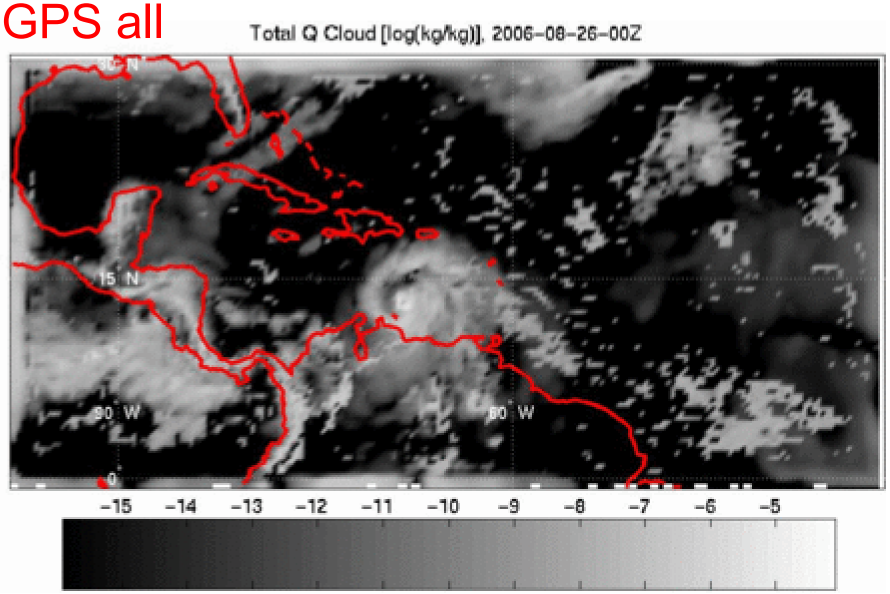
Sat. IR



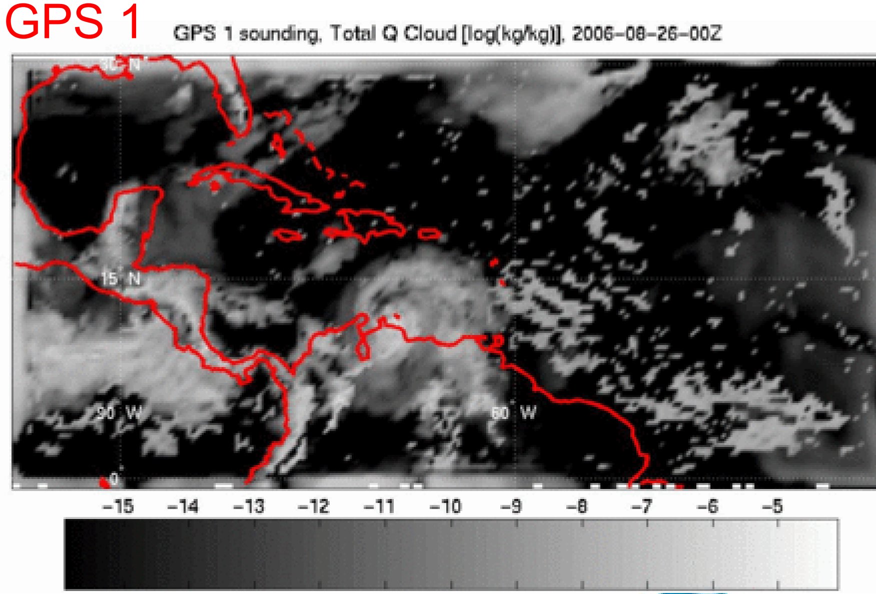
No GPS



GPS all

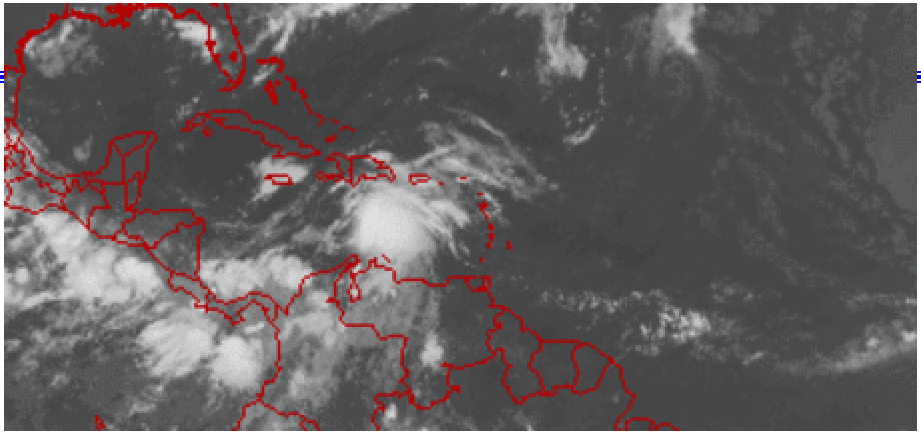


GPS 1

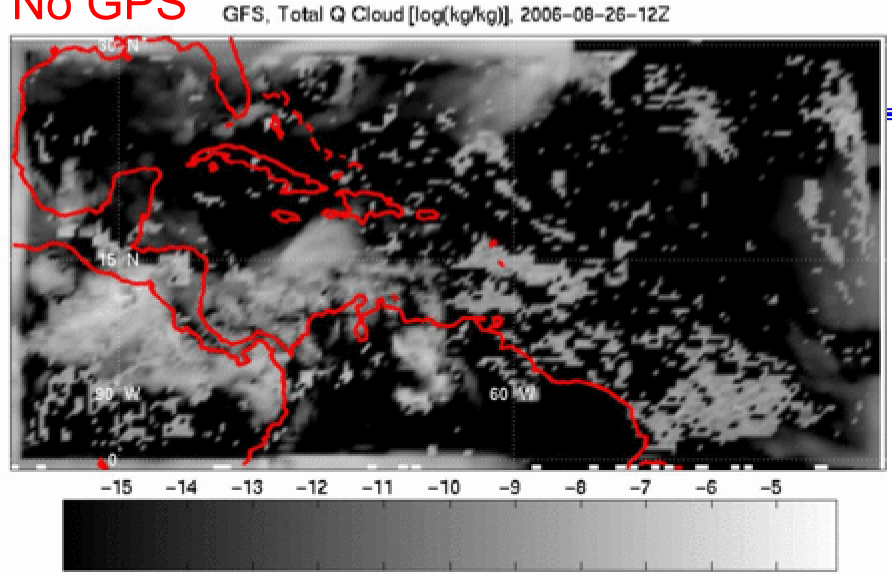


2006-08-26-12Z (78h forecast)

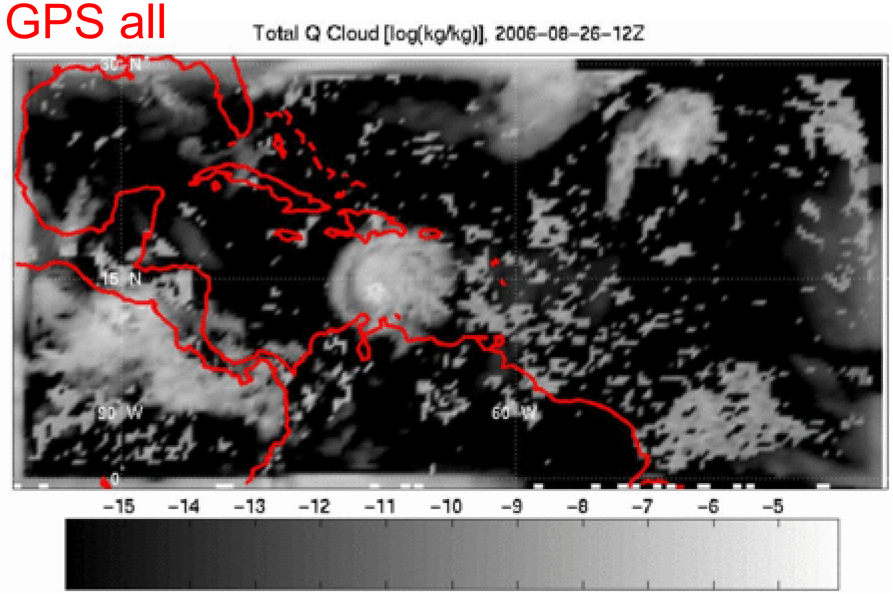
Sat. IR



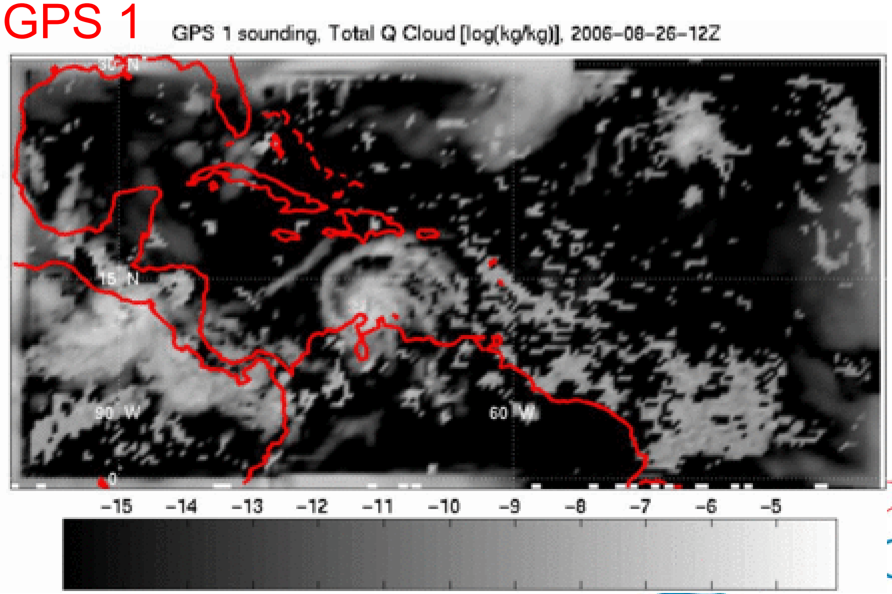
No GPS



GPS all

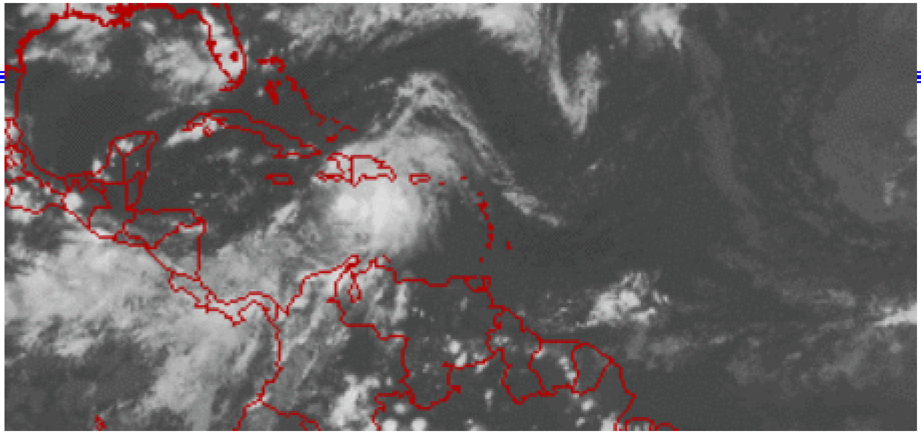


GPS 1

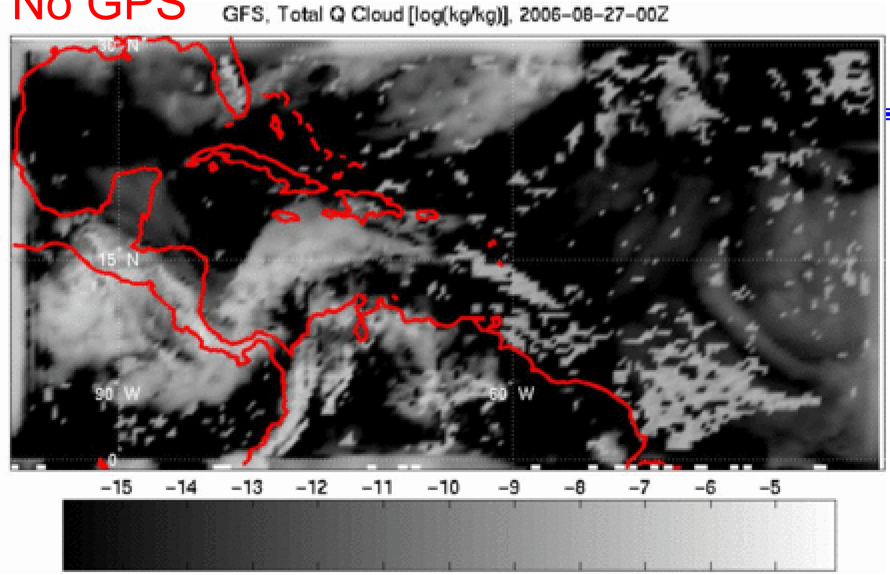


2006-08-27-00Z (90h forecast)

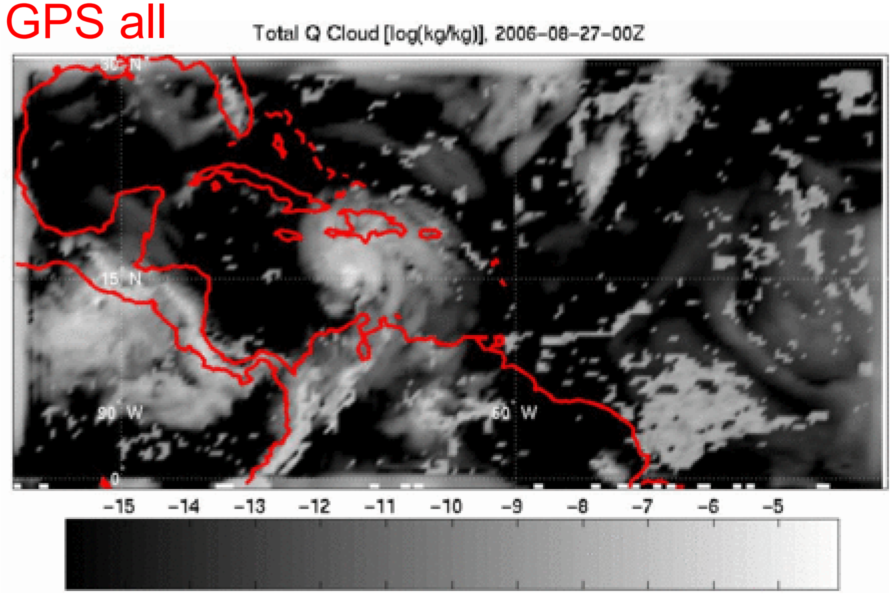
Sat. IR



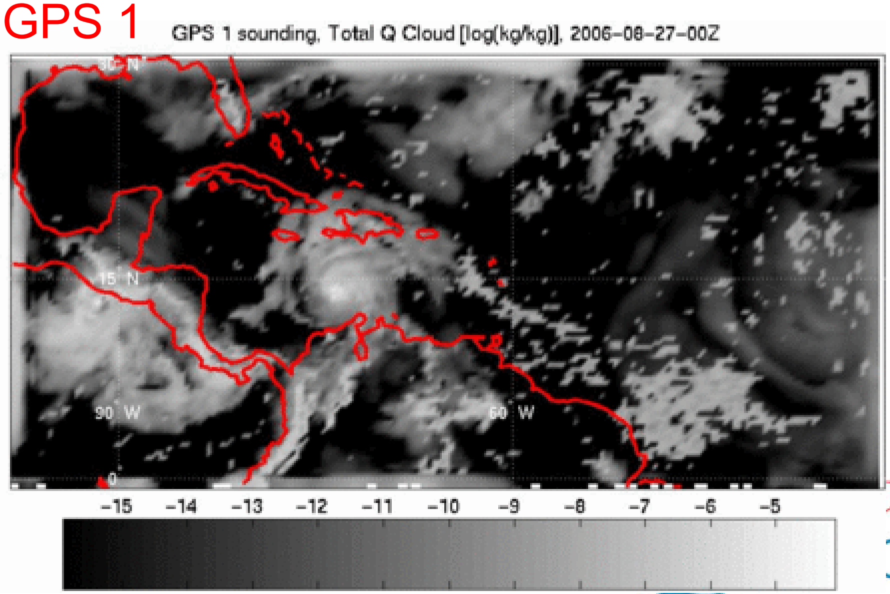
No GPS



GPS all

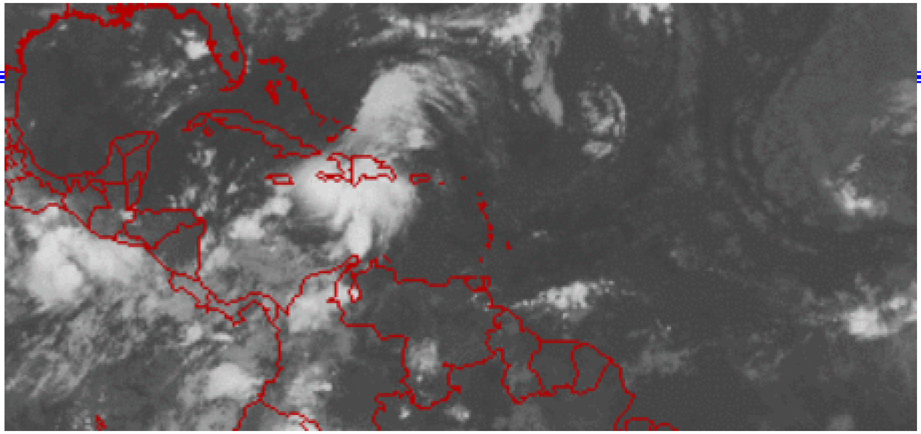


GPS 1

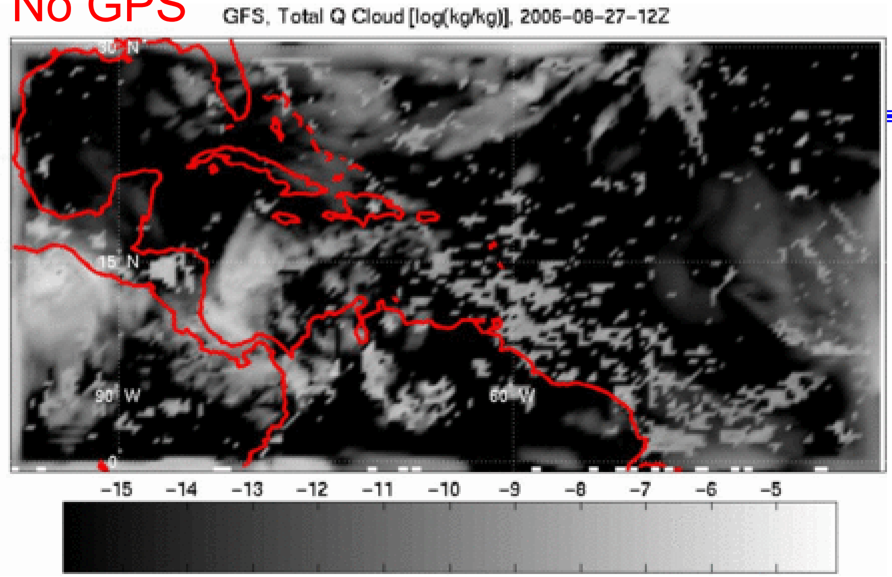


2006-08-27-12Z (102h forecast)

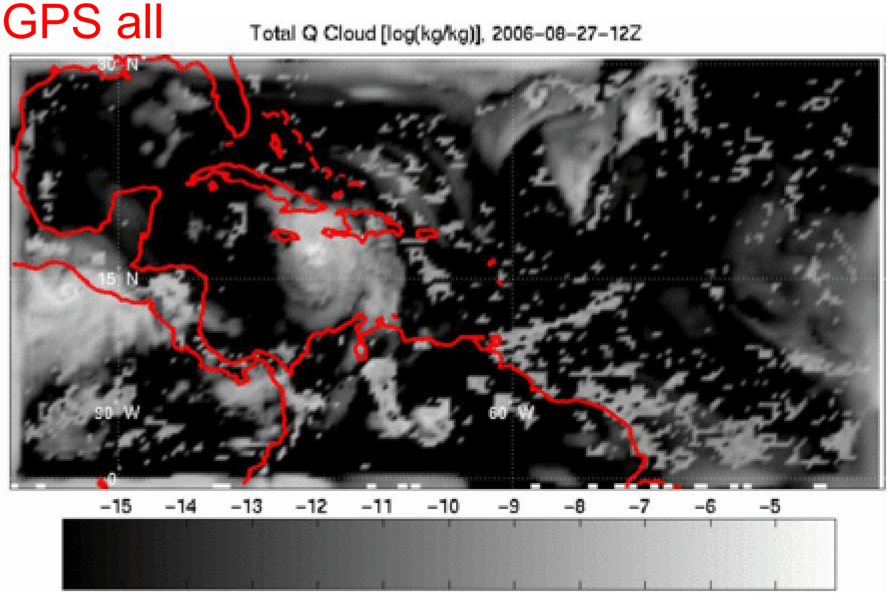
Sat. IR



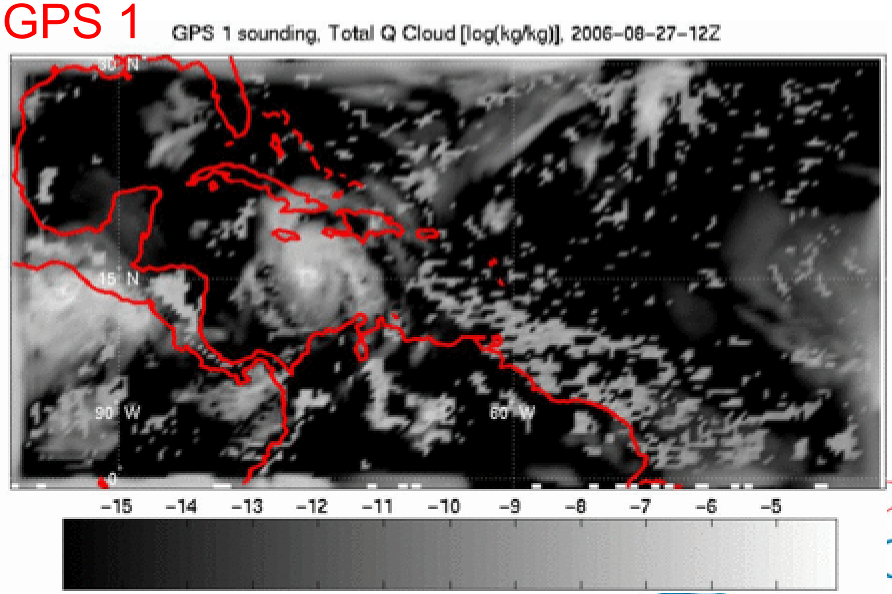
No GPS



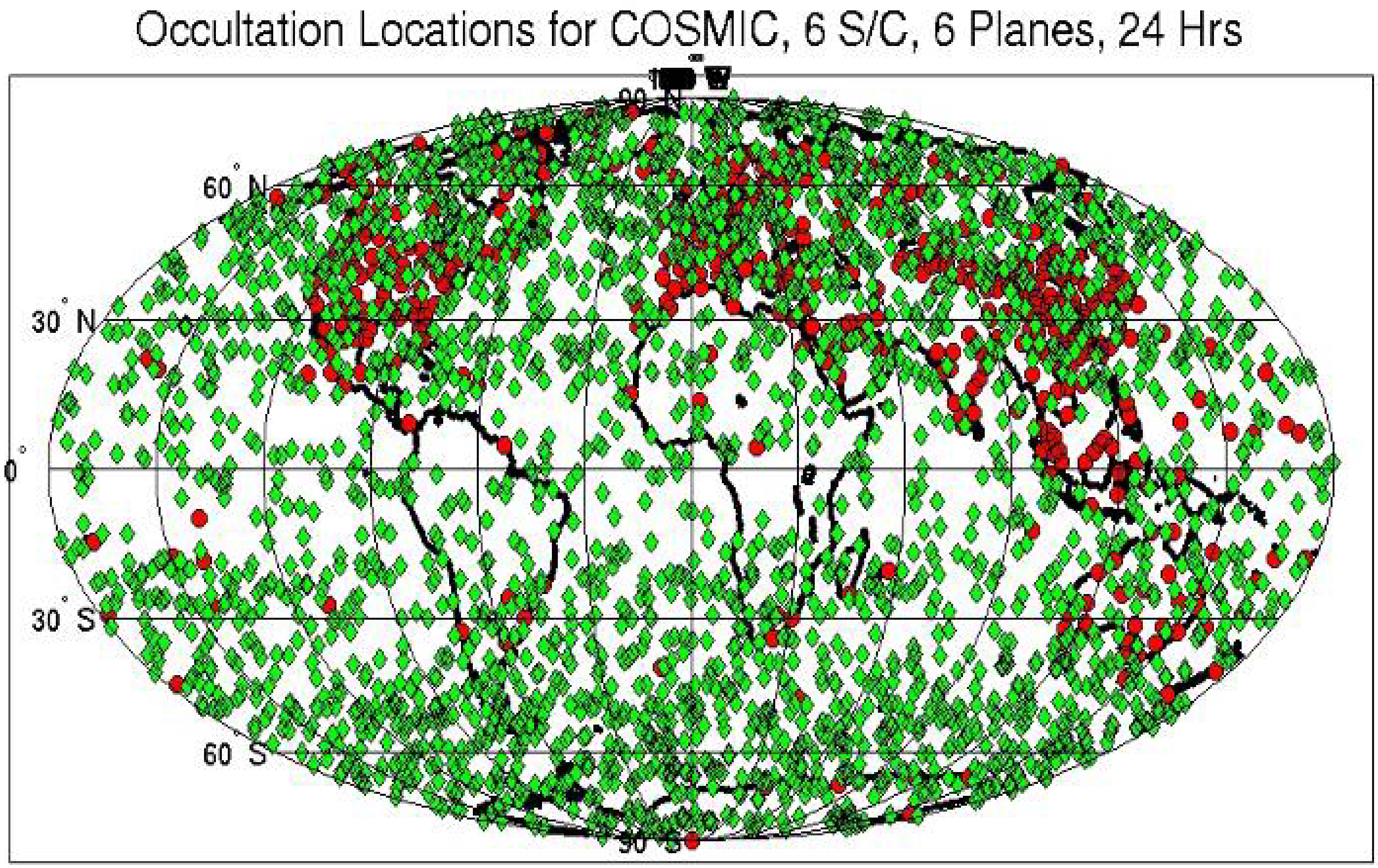
GPS all



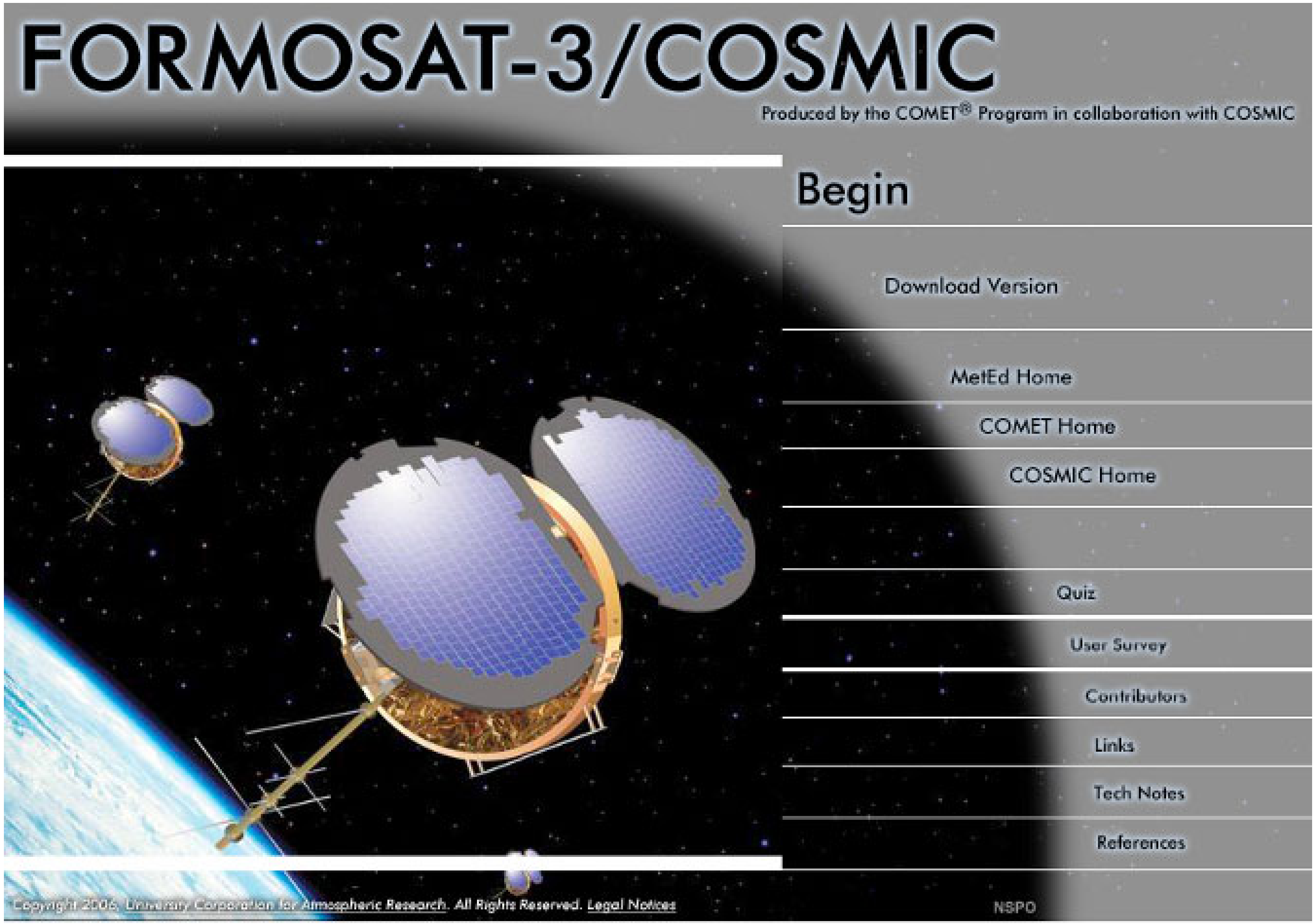
GPS 1



COSMIC sounding distribution in a day



A COSMIC Education Module



A joint effort by COMET and COSMIC.

It covers:

- Basics of GPS radio occultation science

- Applications to weather, climate, and ionosphere

- COSMIC Mission description

http://www.meted.ucar.edu/COSMIC/

COSMIC Data Access

http://www.cosmic.ucar.edu

* Select the 'Sign Up ' link under COSMIC

•Accept data use agreement

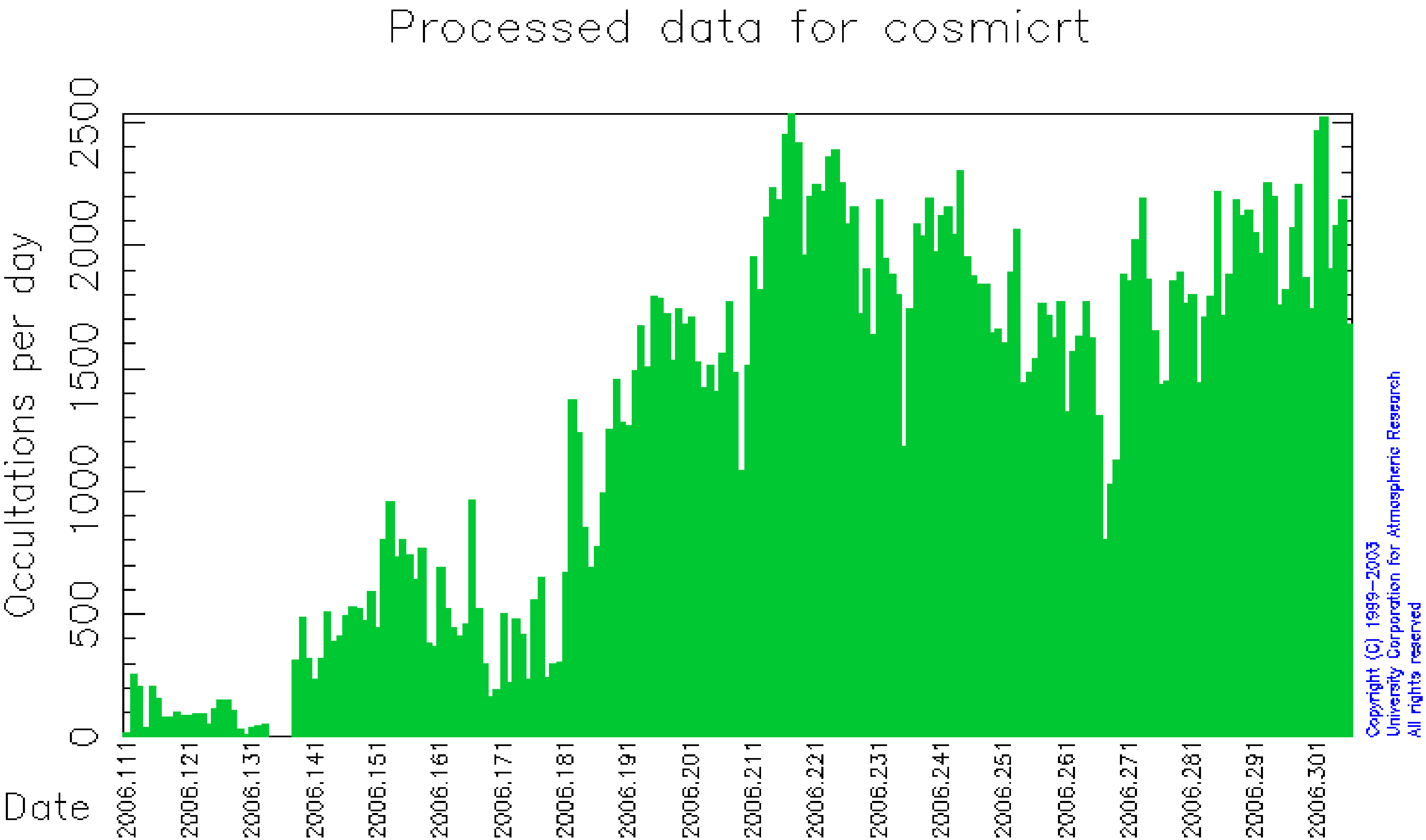
* Enter information:
Name, Address, email, user_id, Password, planned use of data

• An email will be sent within 2-3 business days to indicate access has been granted.

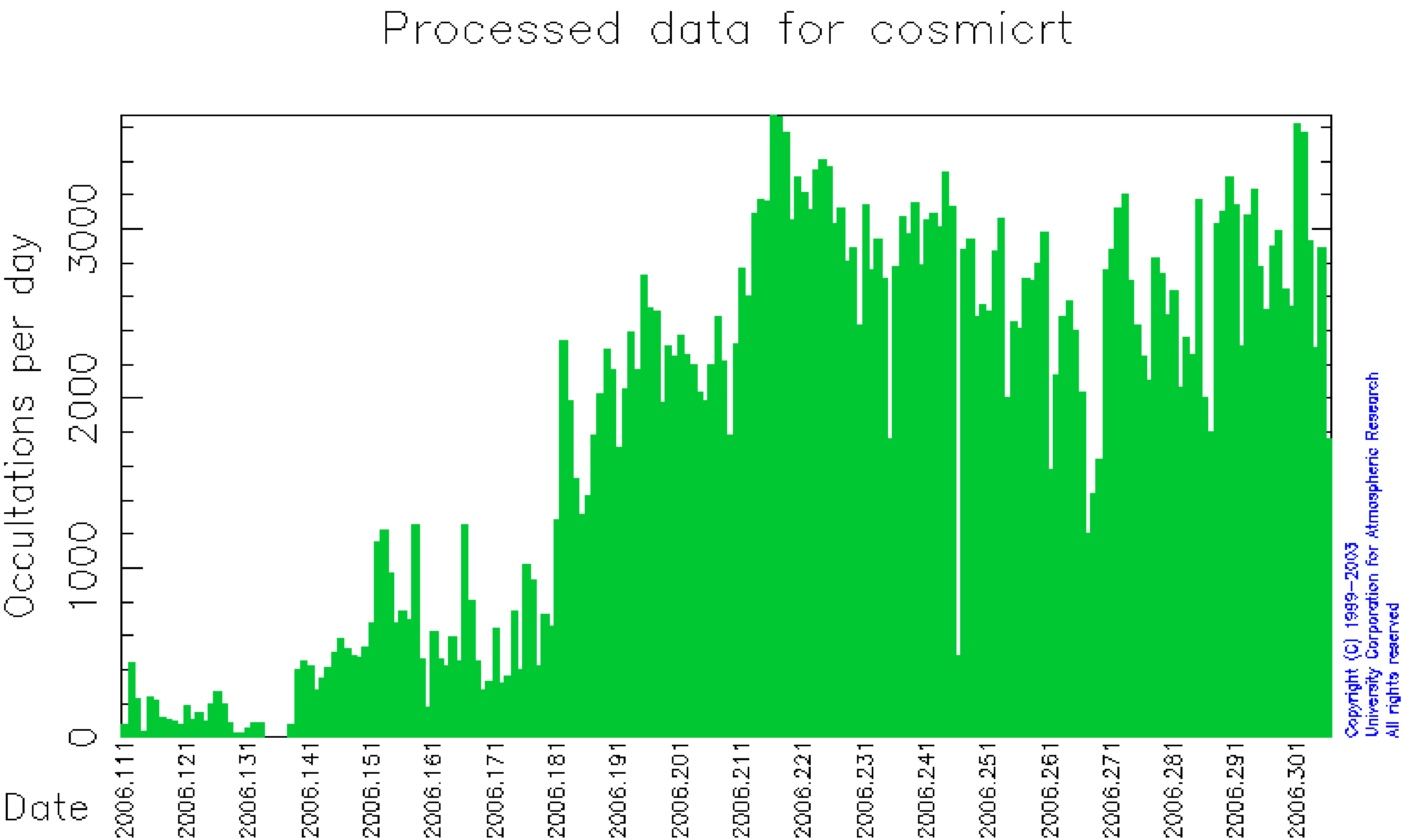
More than 270 users have already registered

Space Weather

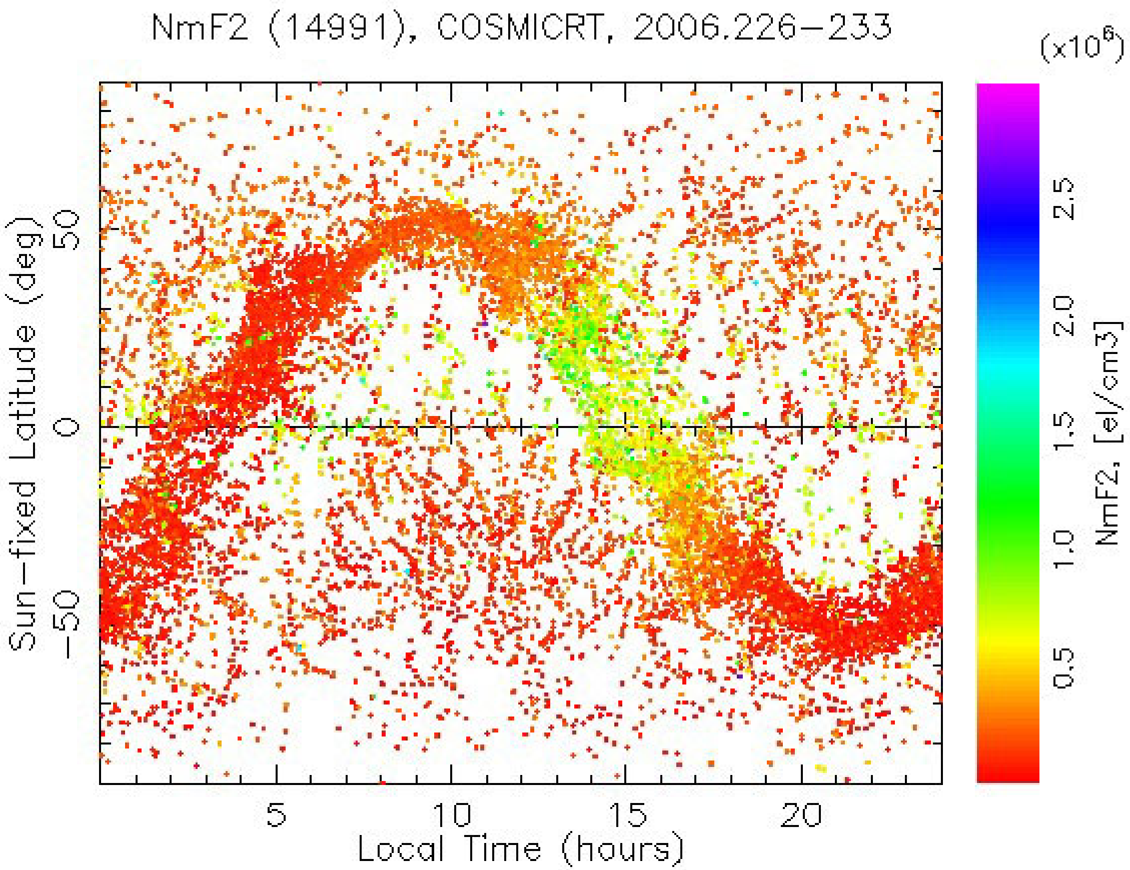
Ionospheric profiles availability



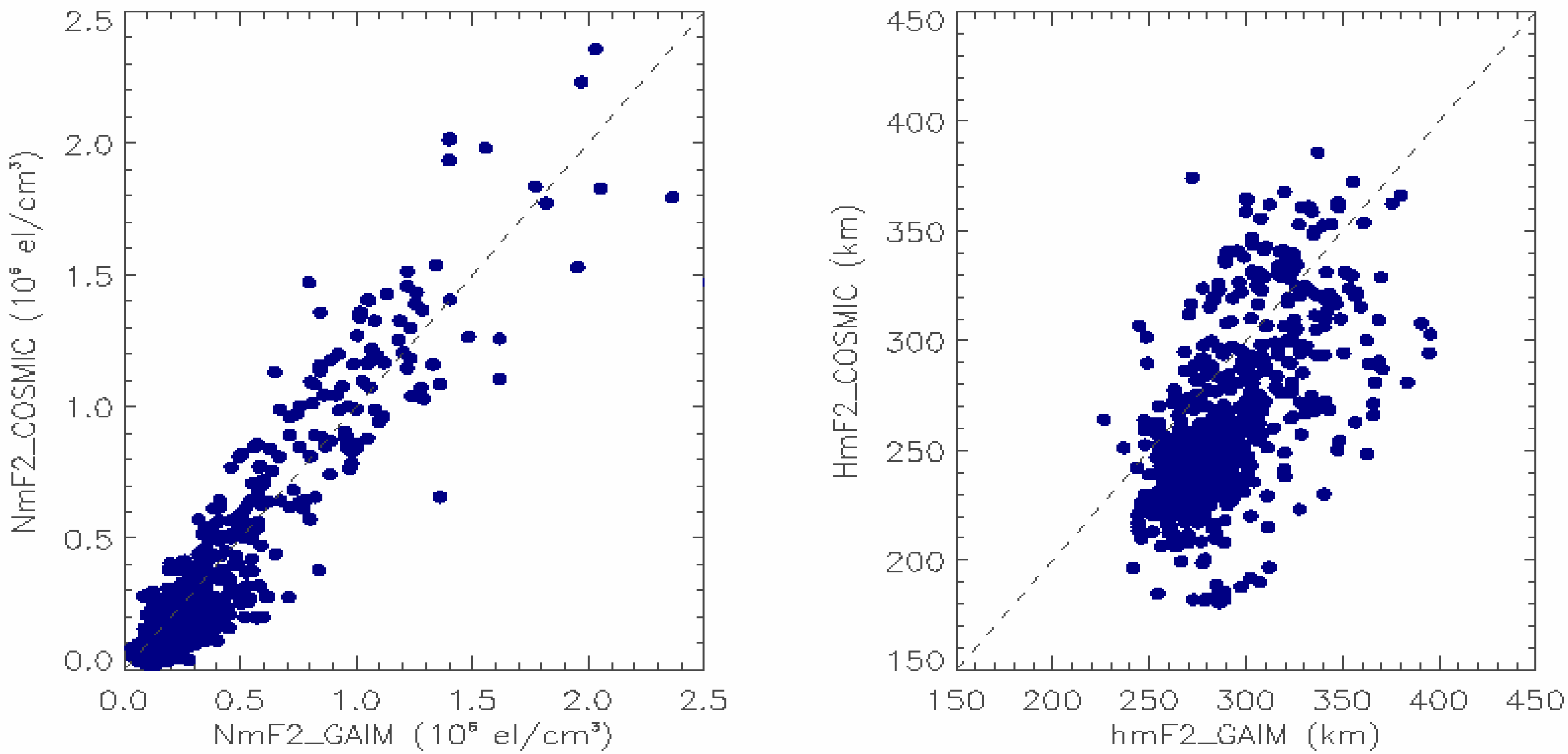
Total Electron Content availability



COSMIC NmF2 - 1 week



Comparison of NmF2 and HmF2 between COSMIC and GAIM during Apr. 21-28, 2006



From presentation by Zhen Zeng, NCAR/HAO

Good agreement of NmF2 between COSMIC and GAIM;

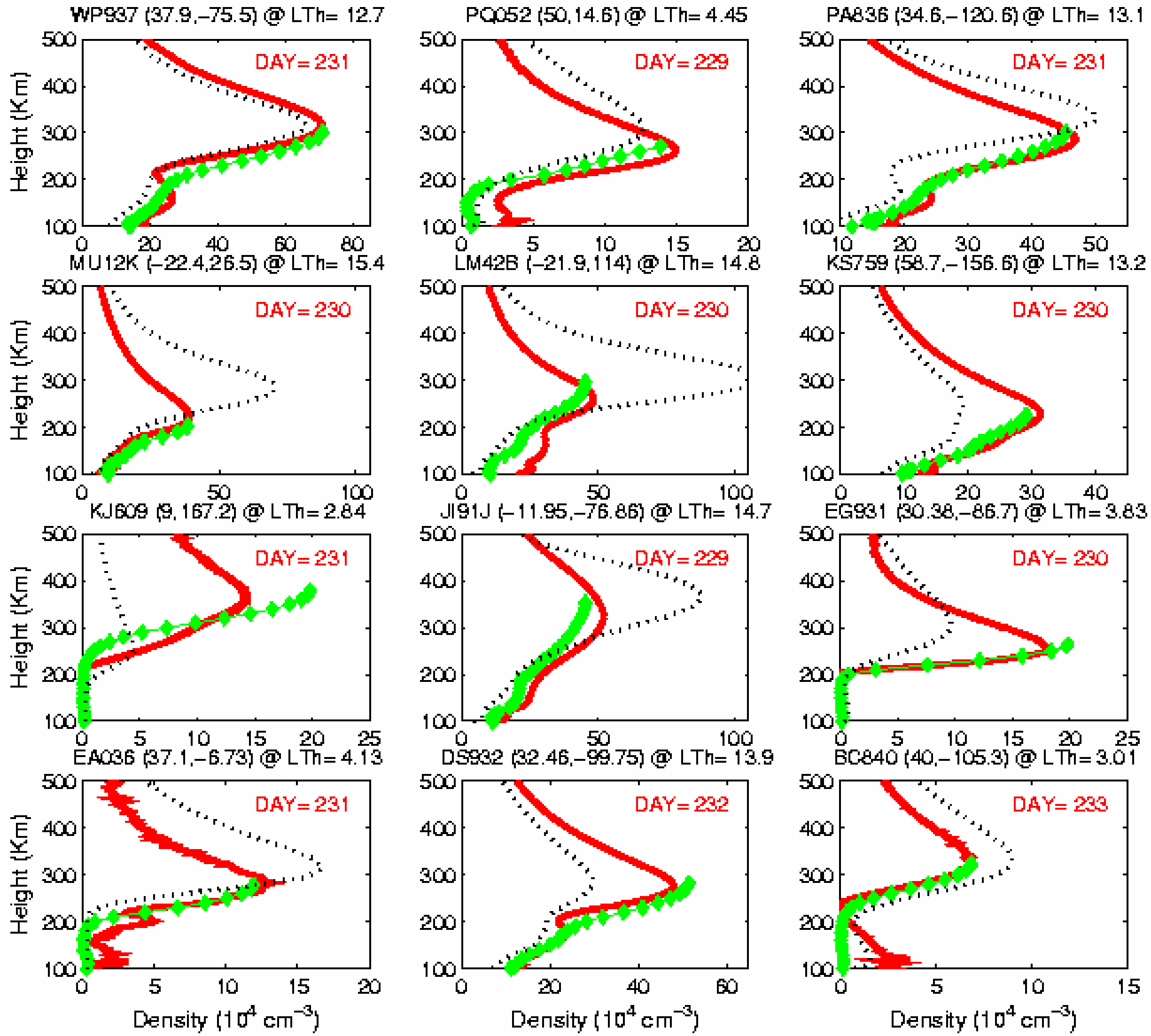
Higher peak heights from GAIM than those from COSMIC

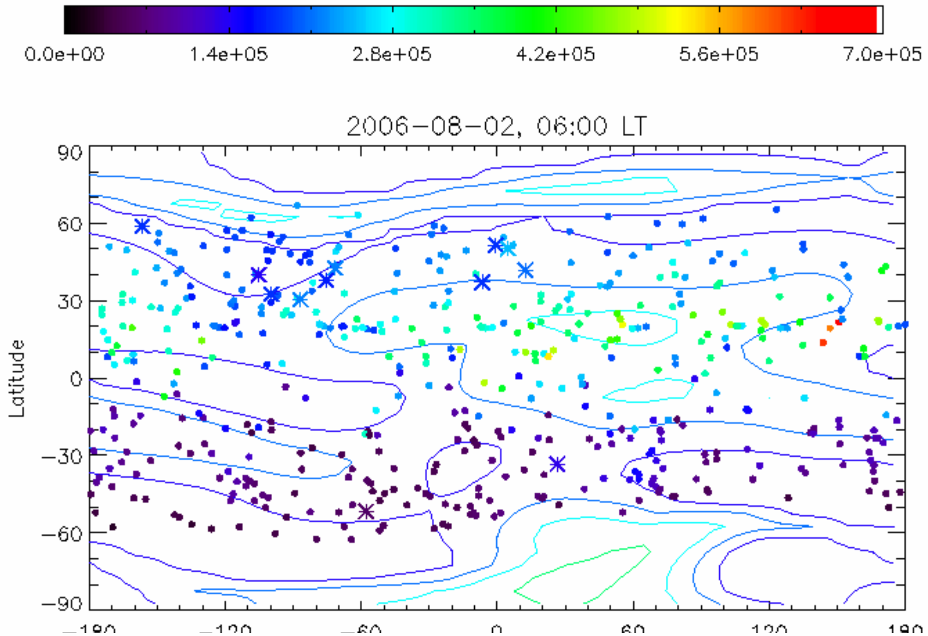
Comparison of Ne(h) between COSMIC (red), Ionosondes (green)and TIEGCM (black) on Aug. 17 - 21nd

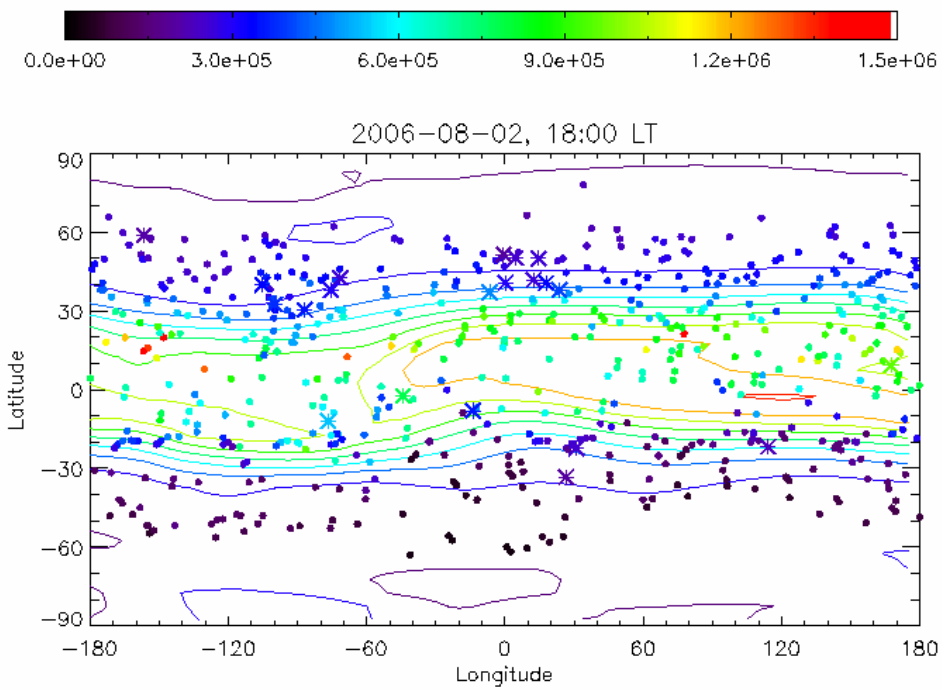
COSMIC agree well with ionosonde obs, especially the HmF2;

Vertical structures from COSMIC coincide well with TIEGCM in the mid-lat, but not in the tropics.

TIEGCM shows a bit higher HmF2 compared with obs.







Maps of NmF2 for:

COSMIC (dots),
Ionosondes (stars),
TIEGCM (contour)

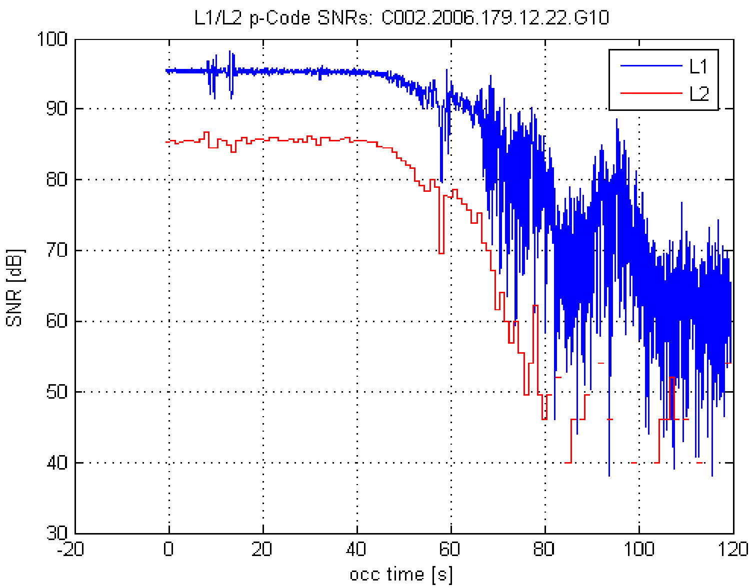
COSMIC agree well with ionosonde observations;

Global map of NmF2 revealed from COSMIC is well represented by TIEGCM model, though TIEGCM shows higher peak density in the low latitude.

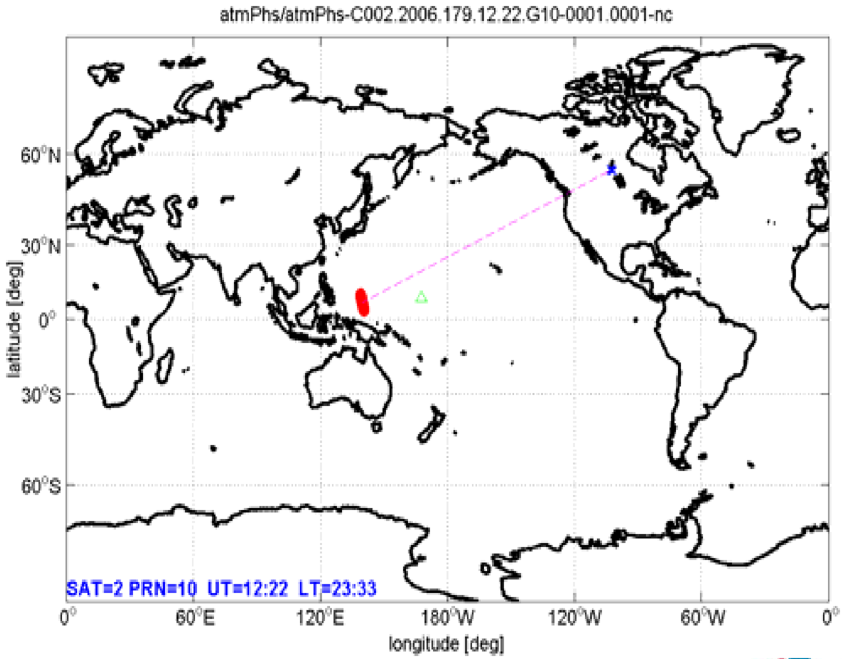
Formosat-3/COSMIC

Observations of Scintillations

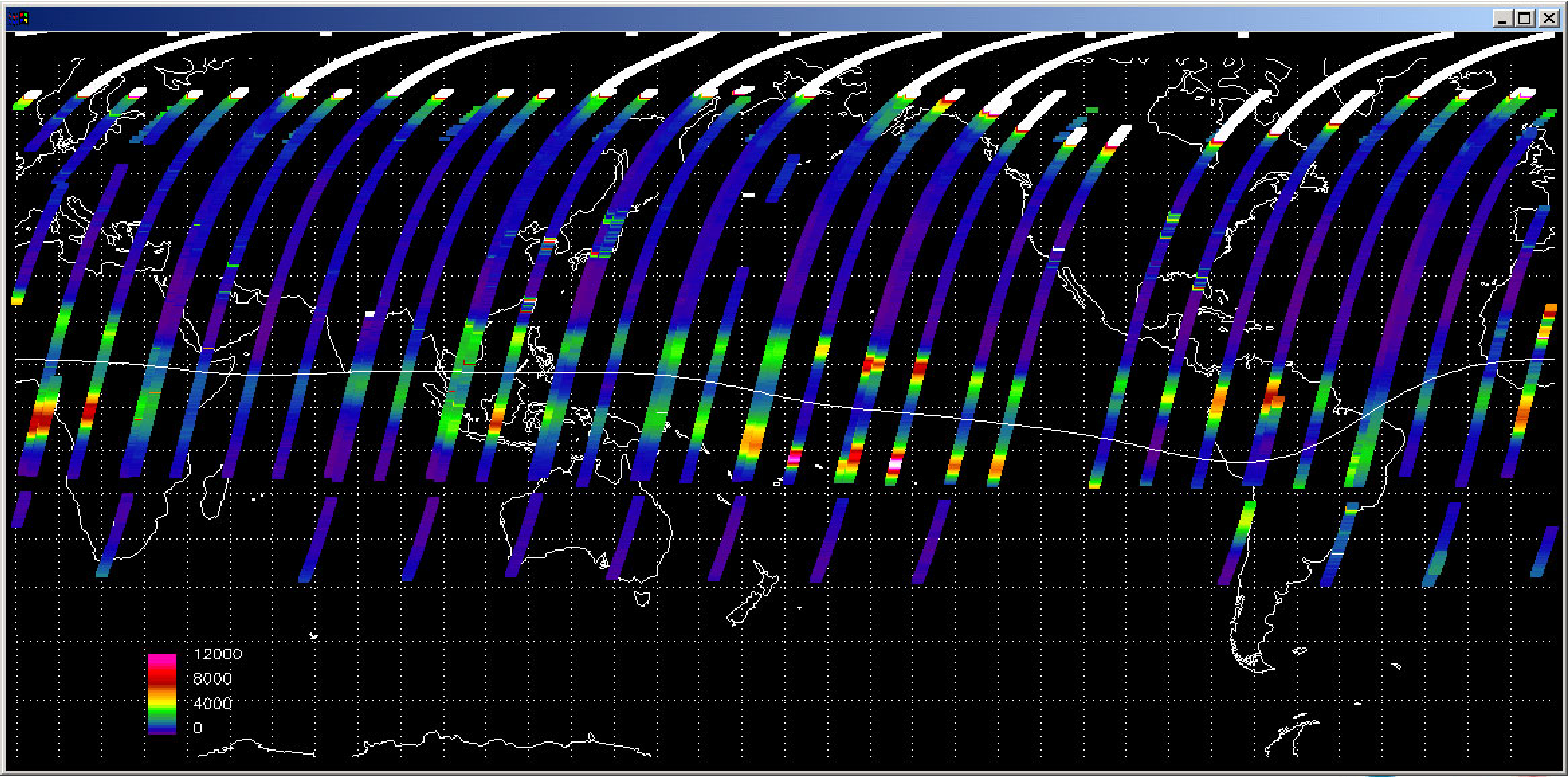
From presentation by Chin S. Lin, AFRL



RED = COSMIC sat
BLUE = GPS sat



TIP 135.6-nm passes 14 Sep 2006 FM1 FM3 FM6 0-24 UT (2100 LT)



From presentation by Clayton Coker, NRL