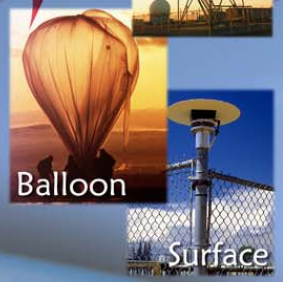
Forecast Systems Laboratory

Observing Systems



Aircraft

Modeling, Assimilation, & Computing

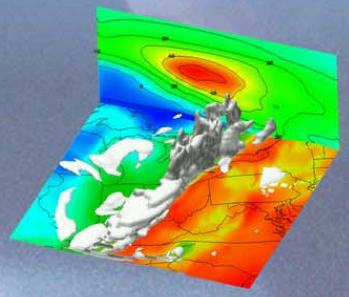
Assimilate

Model

Operational Forecast

Human Interaction and Value-Added

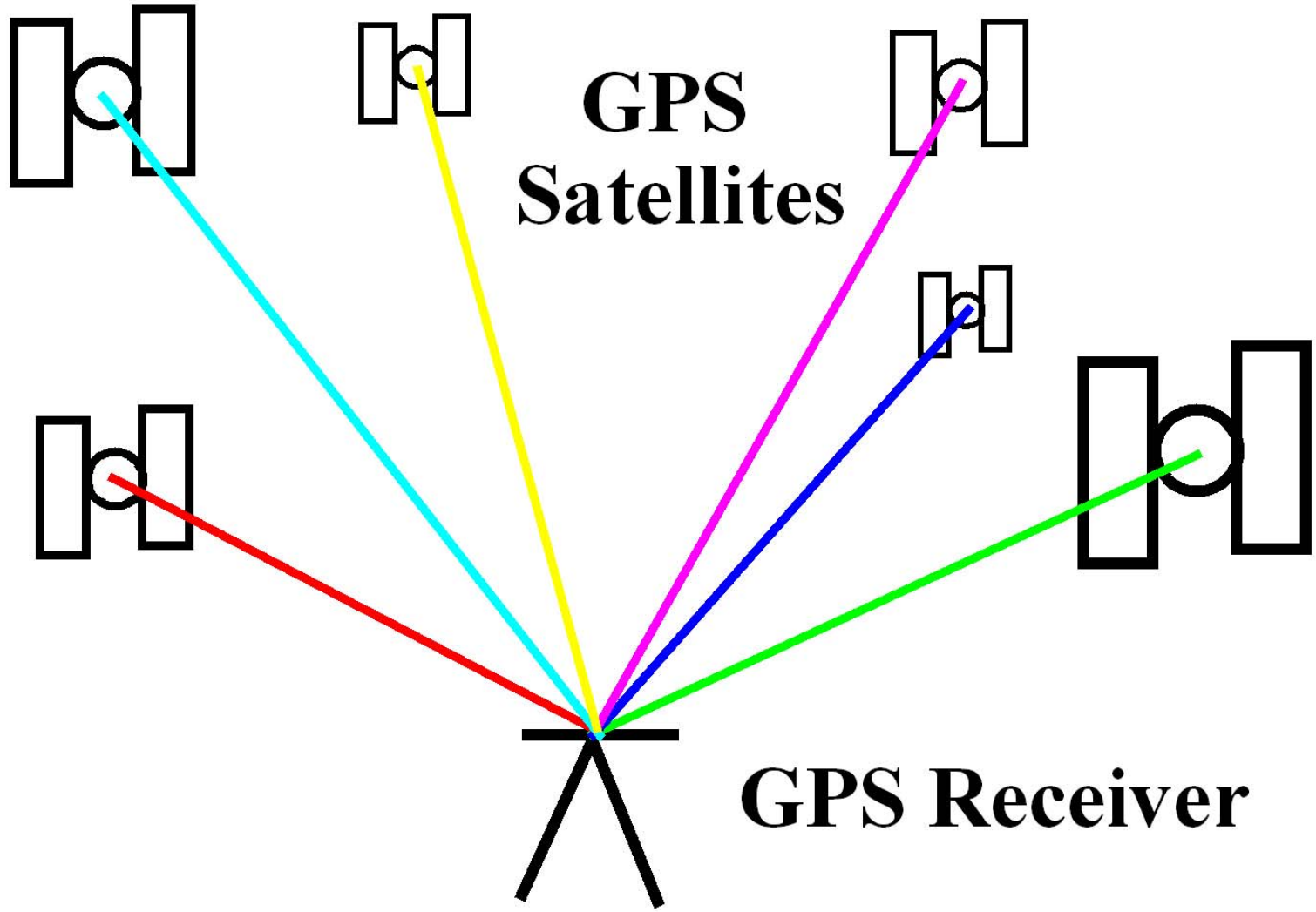
Visualization



Public

Transferring science and technology to operational weather services

Ground Based Measurements



Precipitable water (PW) is obtained from slant delay and surface pressure measurements.

Atmospheric Refractivity N

$$N = 77.6\frac{P}{T} + 3.73\times10^{-5}\frac{P_w}{T^2} - 4.03\times10^{7}\frac{n_e}{f^2}$$

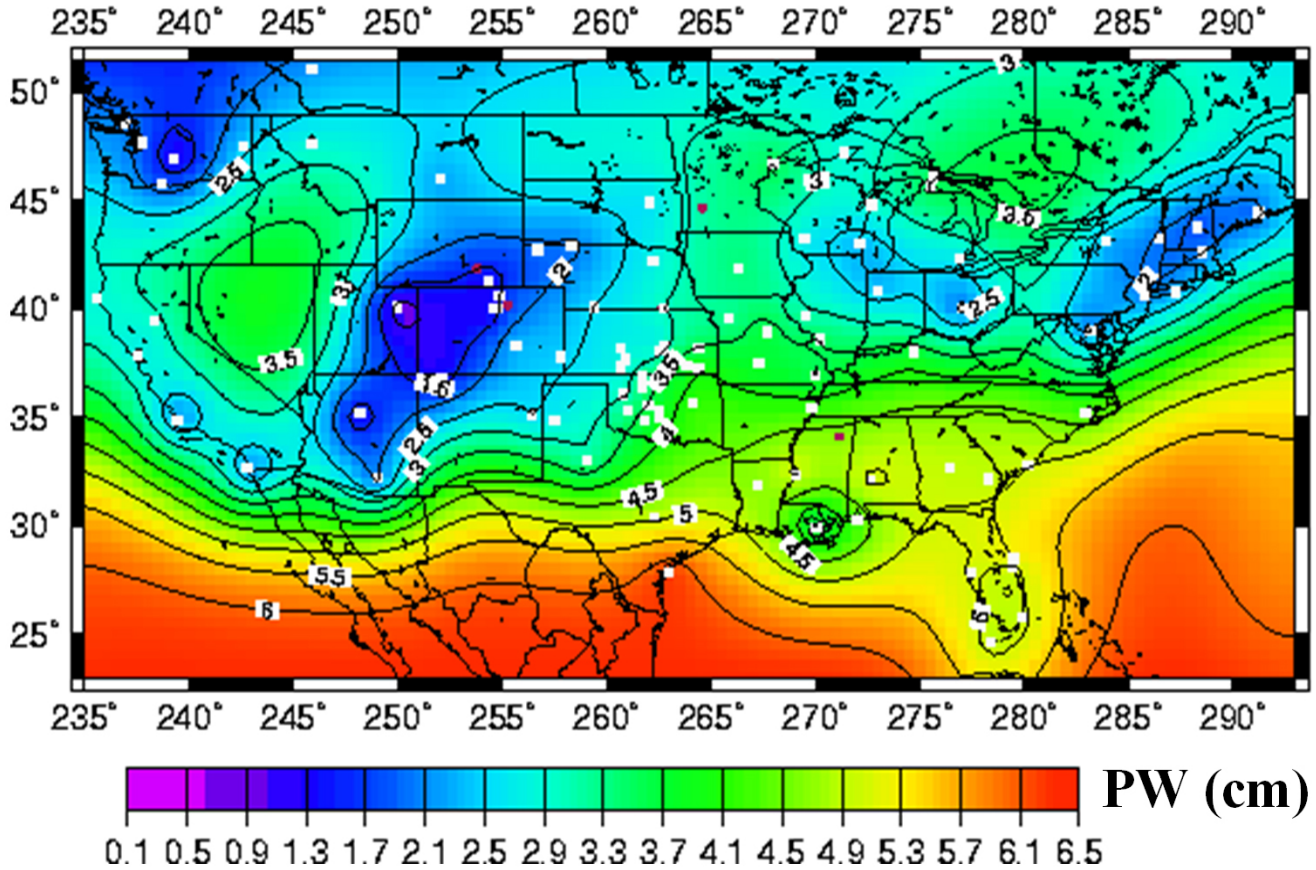
Above 90 km, pressure and water vapor terms are negligible. *N* is directly proportional to the electron density.

In the stratosphere and upper troposphere, water vapor is negligible, *N* can be used to deduce accurate temperatures (with the use of hydrostatic equation.).

In the lower troposphere, water vapor can contribute to as much as 30% of *N*. *N* can be used to deduce accurate vertical profiles of water vapor given independent estimates of temperature (e.g. from global analysis or short-term forecast).

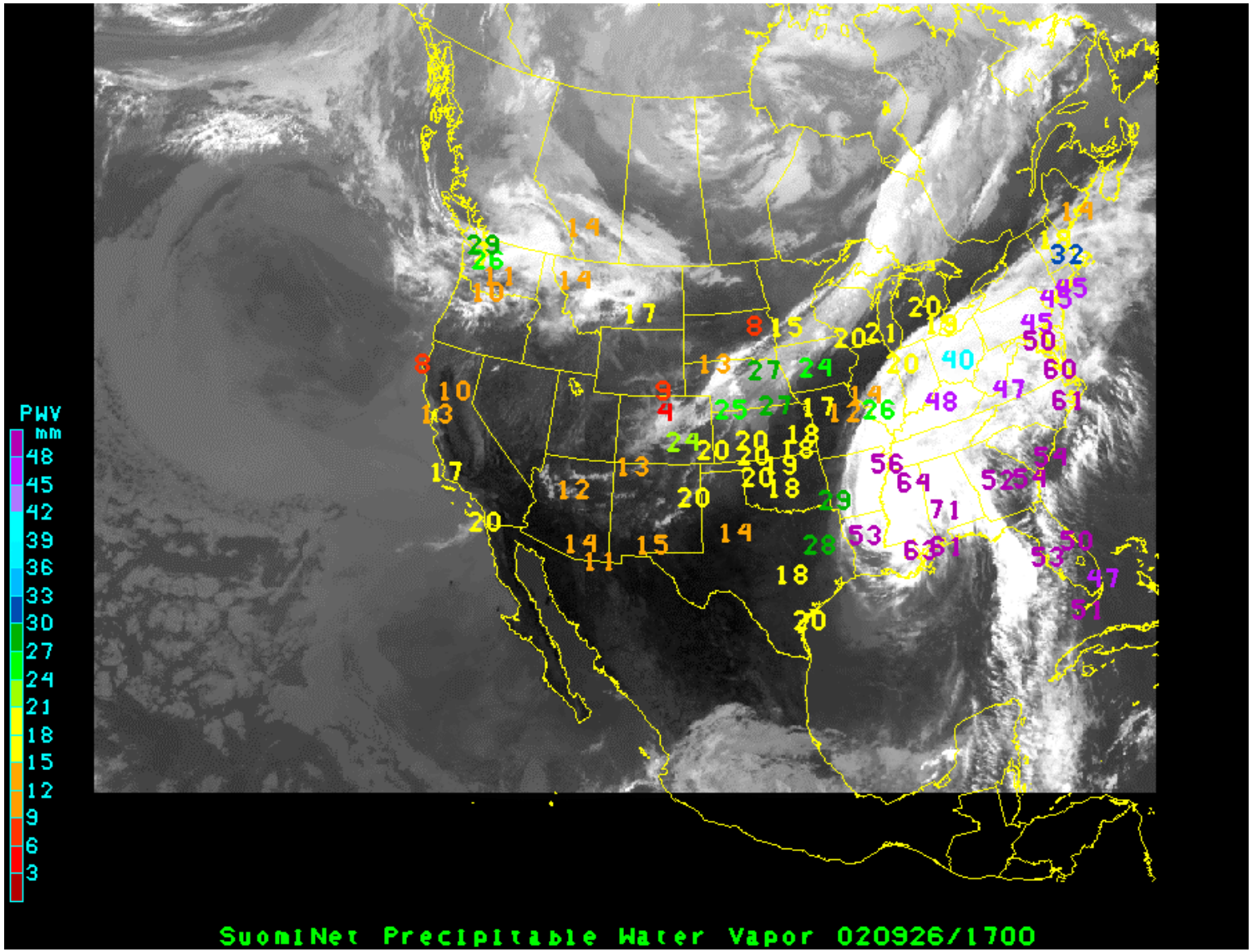
PWV 14 hr 06/29/02

http://www.suominet.ucar.edu

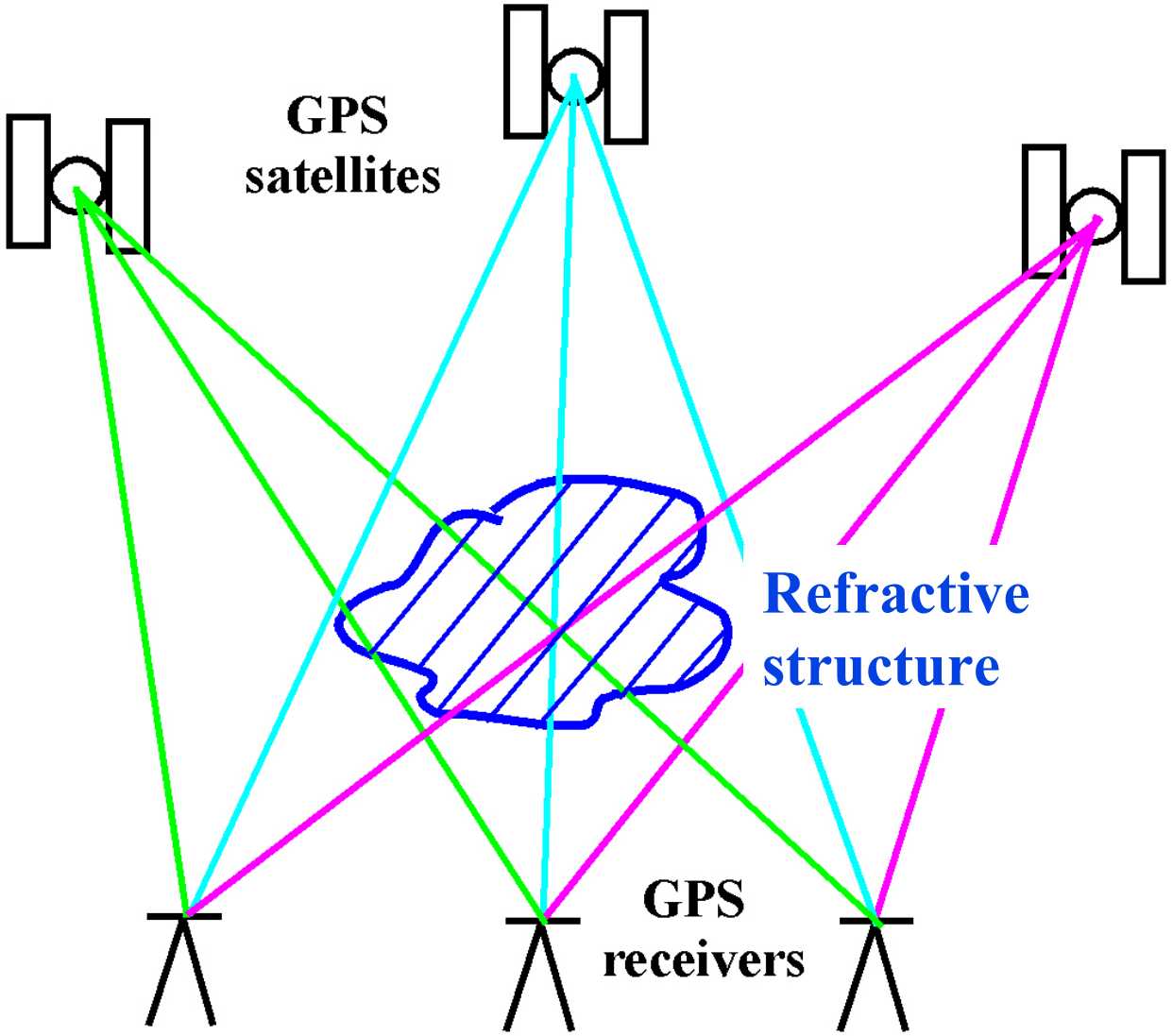


Example hourly precipitable water contour map provided in real-time by SuomiNet. White squares indicate SoumiNet site locations.

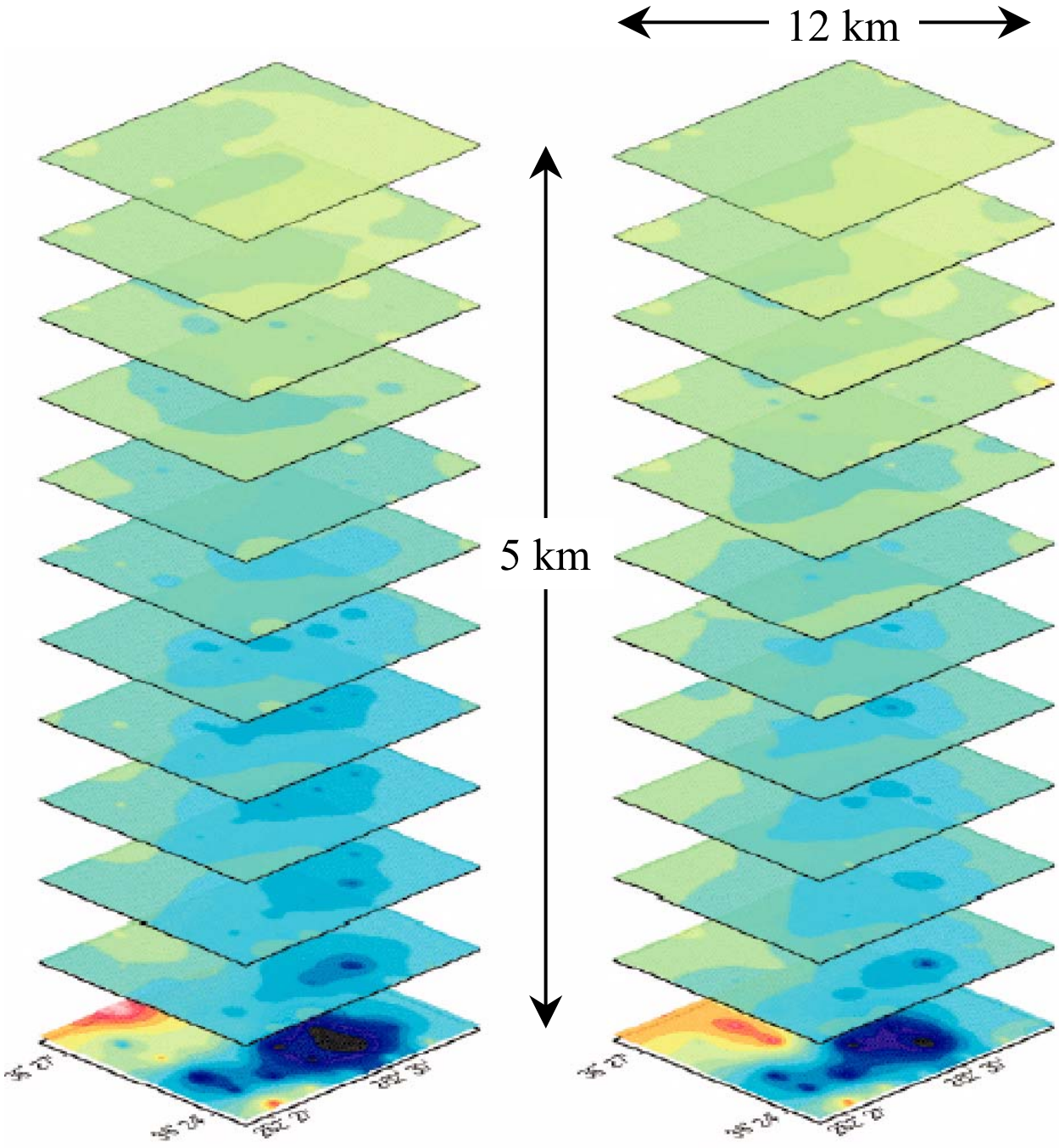
isidore



Hurricane Isidore in GOES plus SuomiNet from www.unidata.ucar.edu/suominet/loop.



Slant delay measurements are sensitive to atmospheric refractive structure

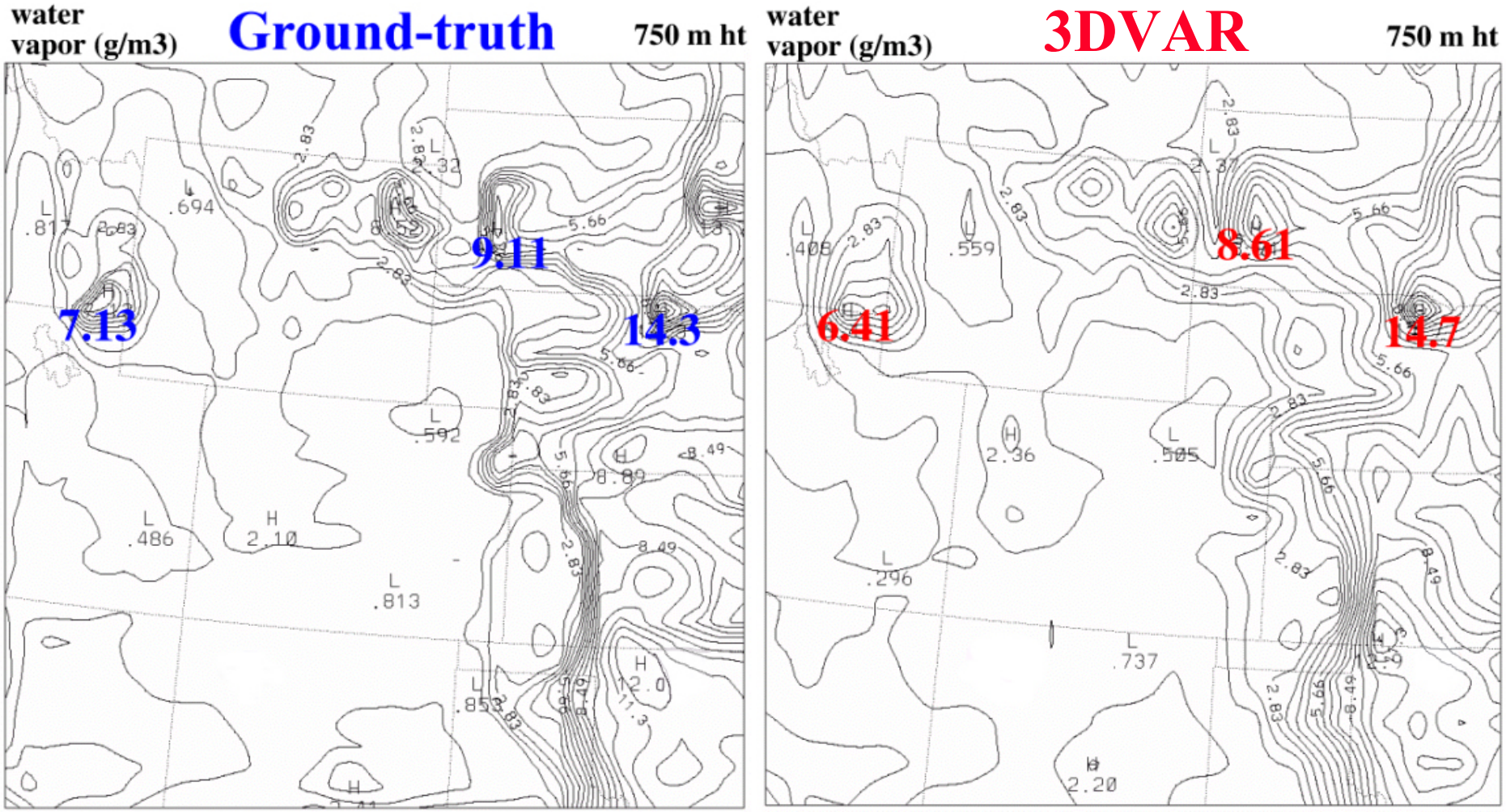


Refractive tomography using slant delays from 24 GPS sites. Plots are 10 min apart.

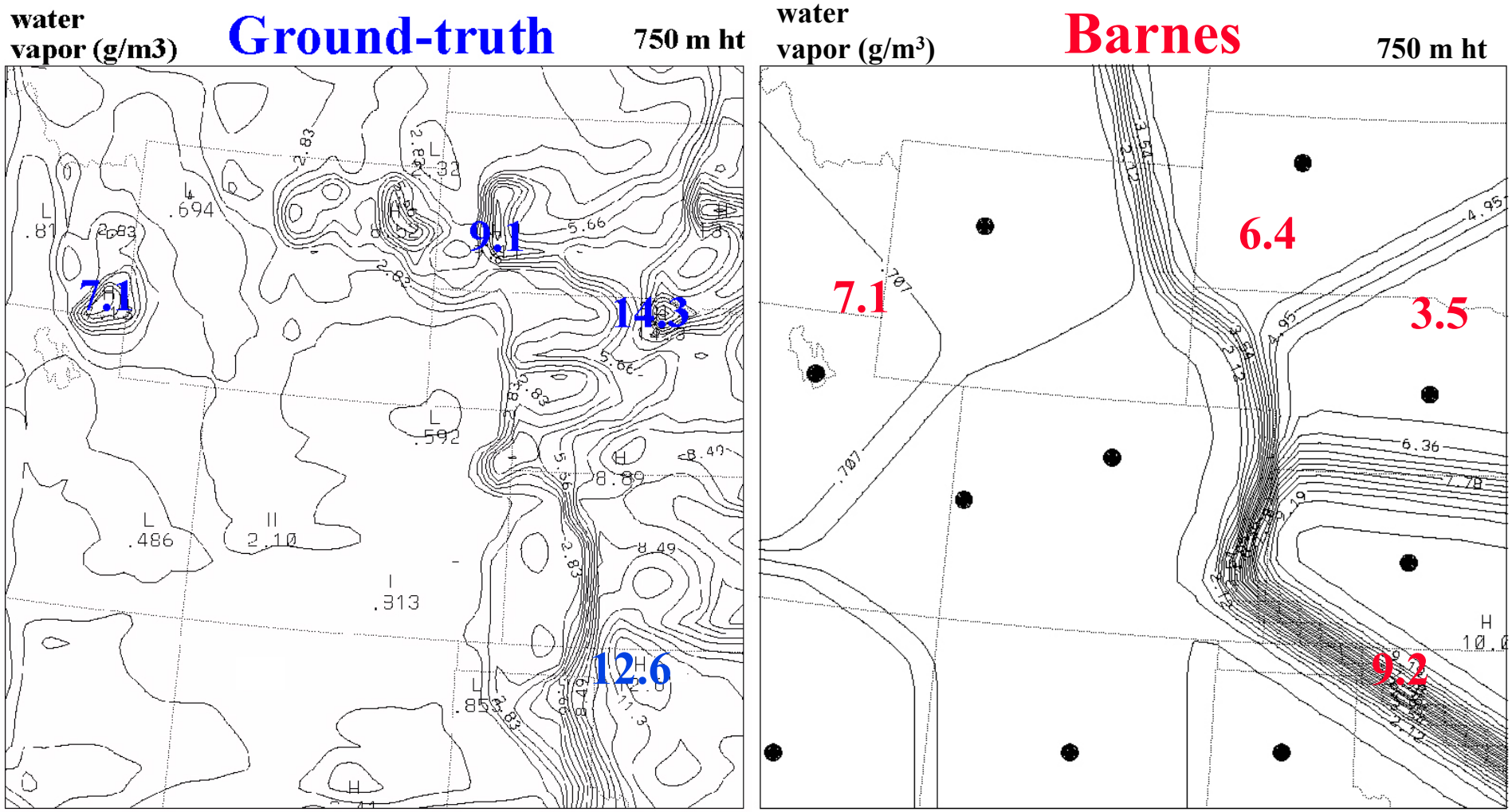
3DVAR water vapor analysis

- GPS network with 100-km grid spacing
- Continuous thermodynamic soundings with 360-km spacing
- Accurate 3D water vapor analysis using slant GPS and radiometric profiler data
- Substantial Improvement in Storm Forecasts

[MacDonald, Xie and Ware, **Monthly Weather Review 130**, 386-397, 2002]



Magnitude and location of major convection is recovered in **3DVAR analysis**

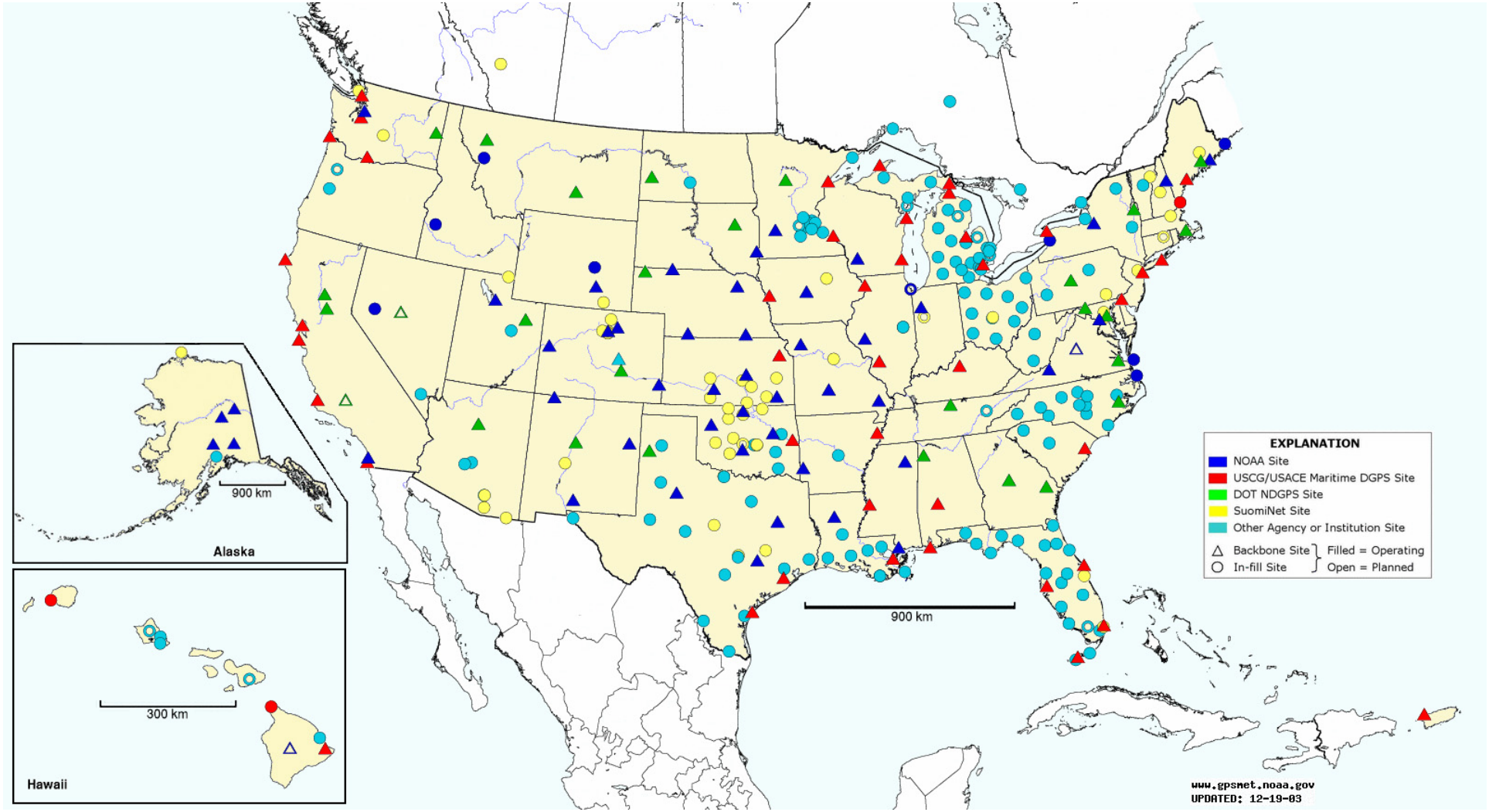


Assumed and **Barnes** (raob analysis) humidity fields at 750 m height. Convective features are not resolved in the Barnes analysis.

National MesoNet

- National Weather Service Forecast Offices will operate thermodynamic profilers (winds, temperature, moisture) at 120 sites.
- Profilers and a high density network of GPS observations will be used jointly for high resolution three dimensional water vapor and wind analysis.
- Significant improvements are expected in analyzing and forecasting severe storms, precipitation, and toxic substance dispersion.

Current Configuration of the NOAA GPS Water Vapor Network



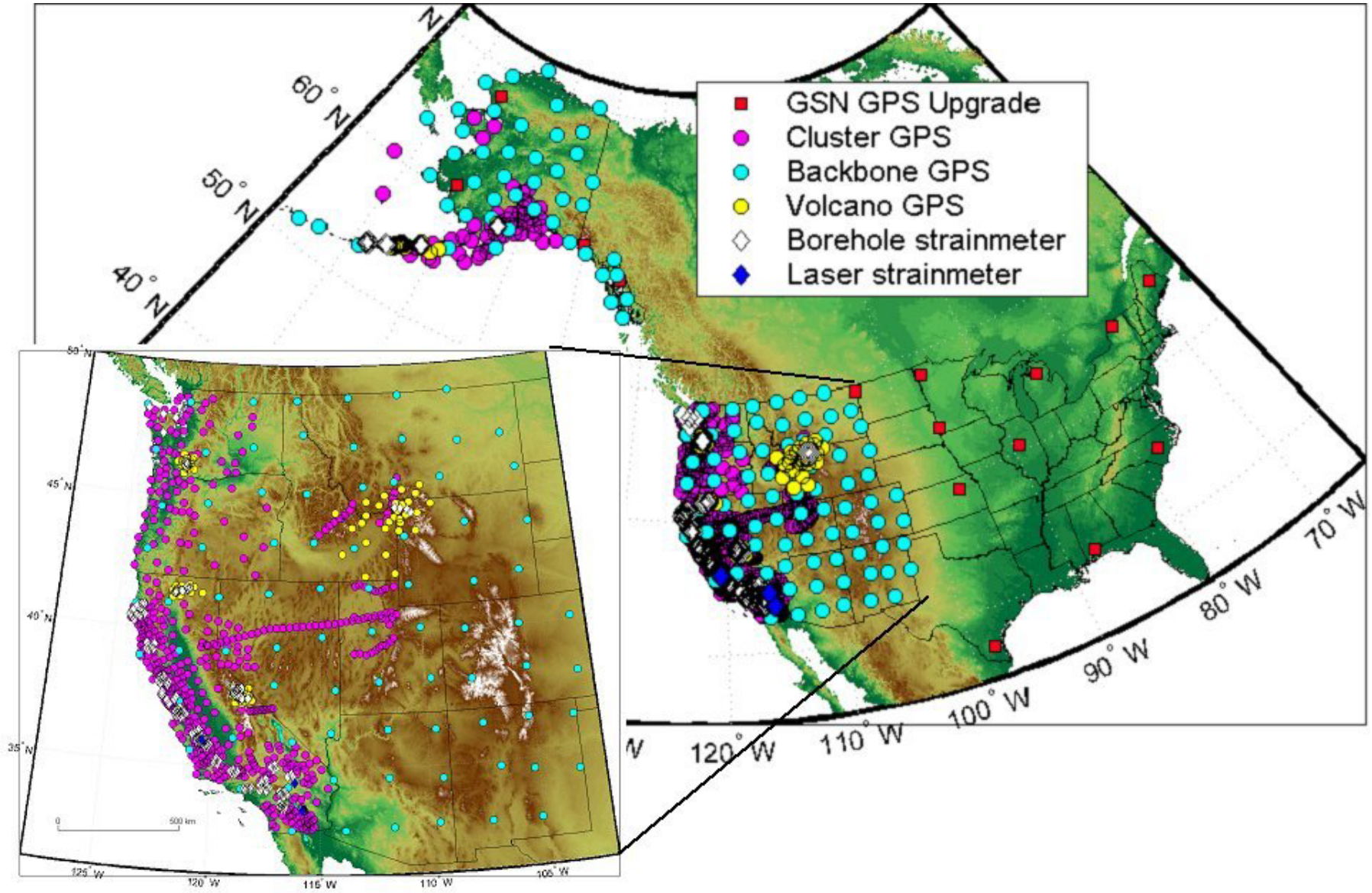


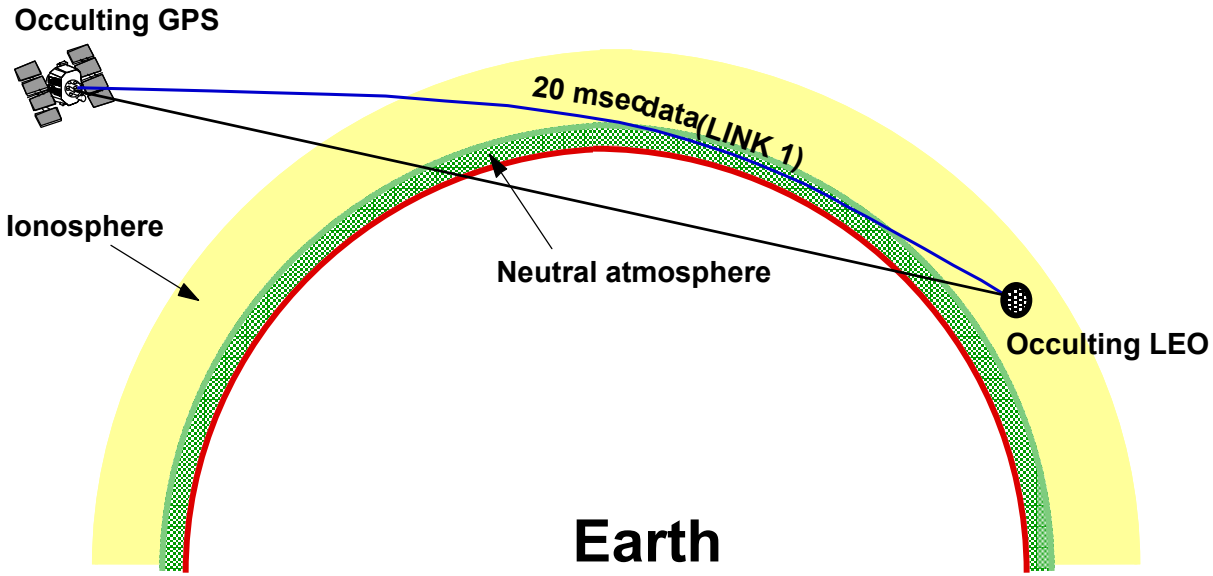
Plate Boundary Observatory including 200 backbone GPS stations.

LEO Occultation Measurements

GPS Occultation

Basic measurement principle:

Deduce atmospheric properties based on
precise measurement of phase delay and amplitude.



Characteristics of GPS RO Data

- Limb sounding geometry complementary to ground and space nadir viewing instruments
- High accuracy (equivalent to < 1 deg K from 5-25 km)
- High vertical resolution (0.1 km surface - 1km tropopause)
- All weather-minimally affected by aerosols, clouds or precipitation
- Independent height and pressure
- Requires no first guess sounding
- Independent of radiosonde calibration
- No instrument drift
- No satellite-to-satellite bias

GPS/MET Experiment

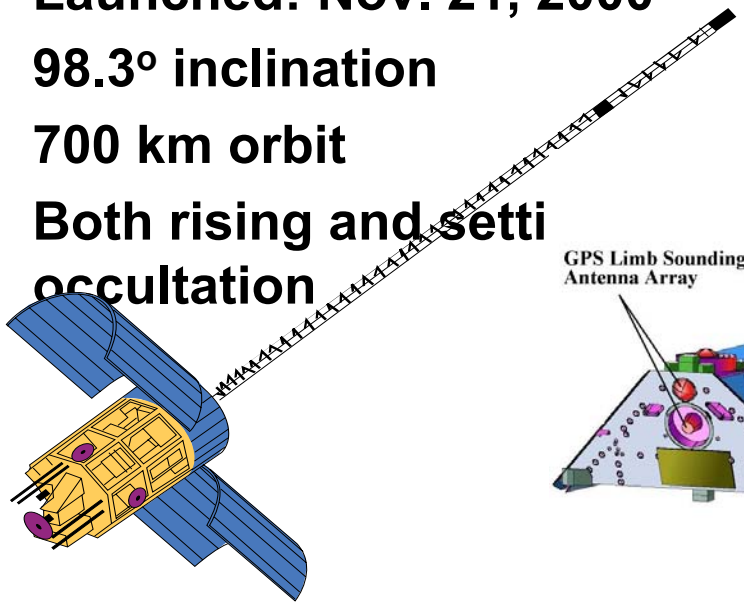
- UCAR, JPL, U. of Arizona, and OSC collaborated on the GPS/MET program in 1993, with a goal to demonstrate the radio occultation sounding technique for Earth's atmosphere.
- The satellite was launched on April 13, 1995, and data were collected for two years.

The GPS/MET Team

Two Recent GPS Occultation Missions

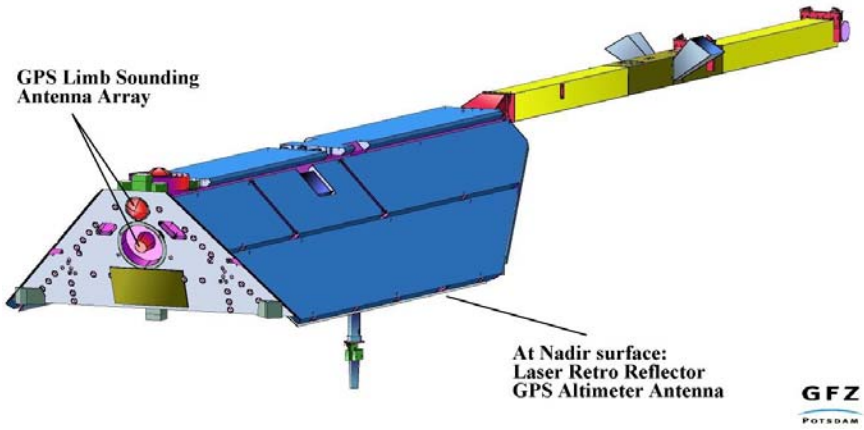
SAC-C

- Argentine spacecraft carrying a multispectral imager and magnetometer
- Launched: Nov. 21, 2000
- 98.3° inclination
- 700 km orbit
- Both rising and setti occultation



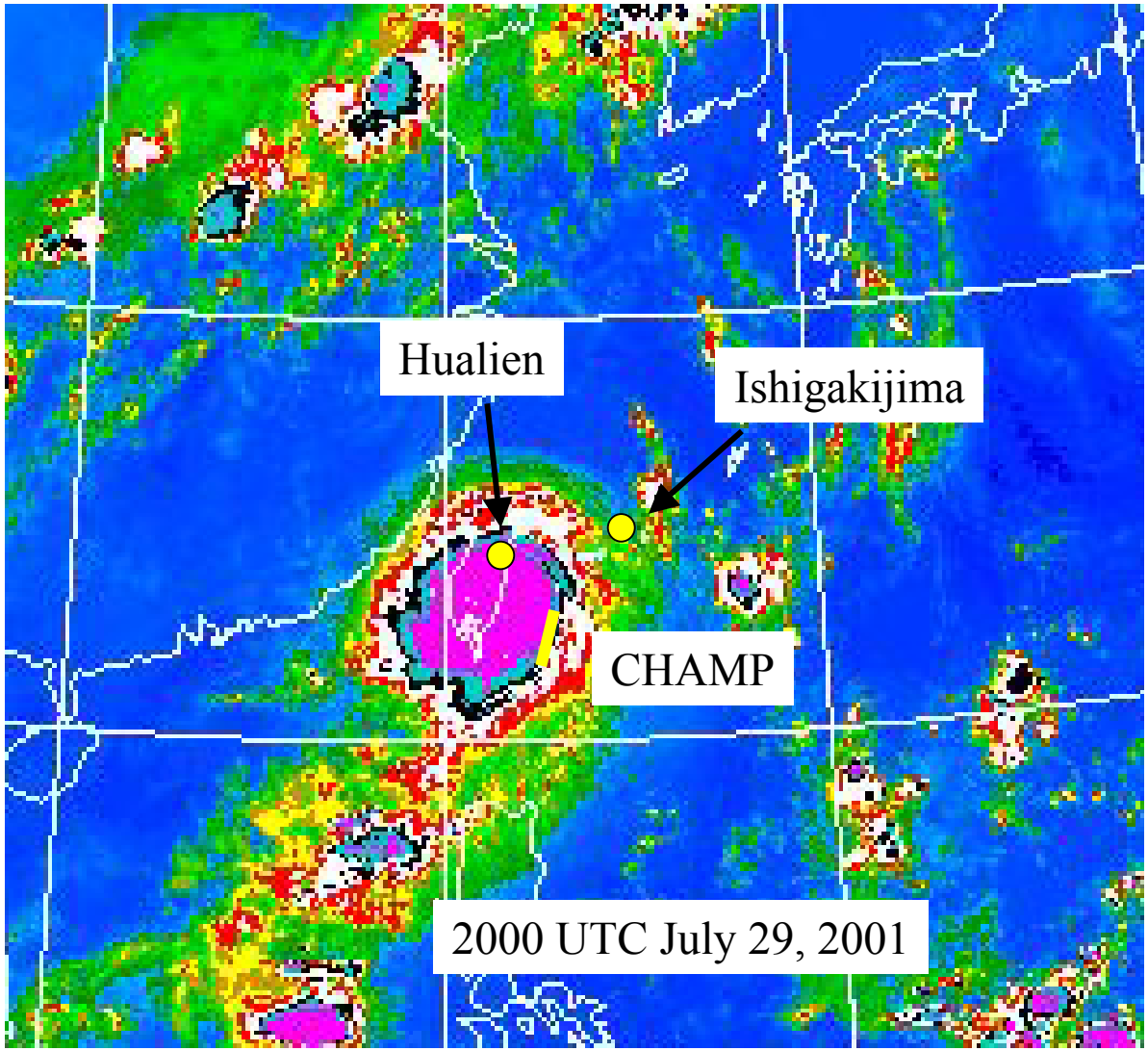
CHAMP

- a German mission for magnetometry and gravity mapping
- Launched: July 15, 2000
- 87° inclination
- 435 km orbit



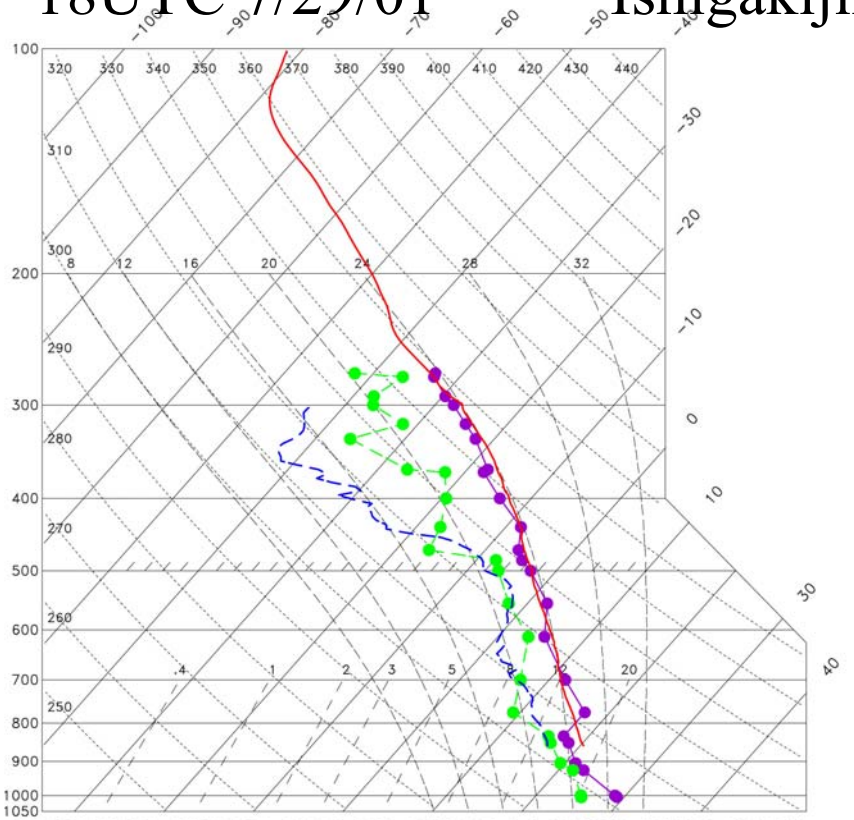
Examples of GPS RO soundings

Location of a CHAMP sounding

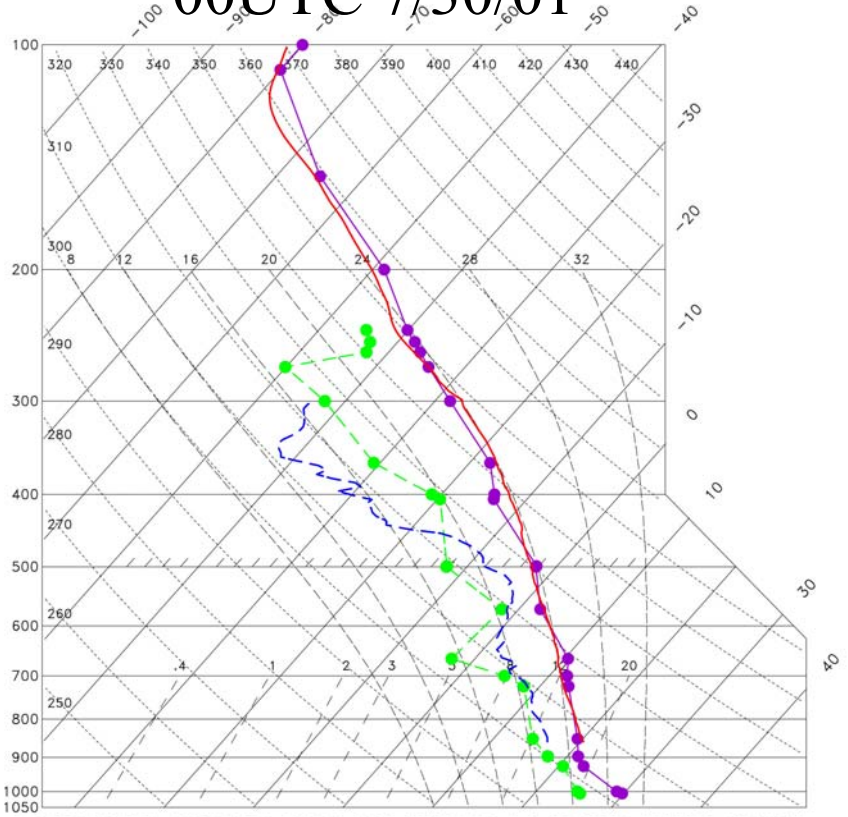


CHAMP compared to two radiosondes in Typhoon

18UTC 7/29/01 Ishigakijima 00UTC 7/30/01



ISHIGAKIJIMA (47918) RAOBS (DOTS) 1800 UTC, July 29, 2001 (24.33N, 124.17E)
CHAMP (LINES) 2008 UTC, July 29, 2001 (21.74N, 122.90E)
Distance 317.39 km

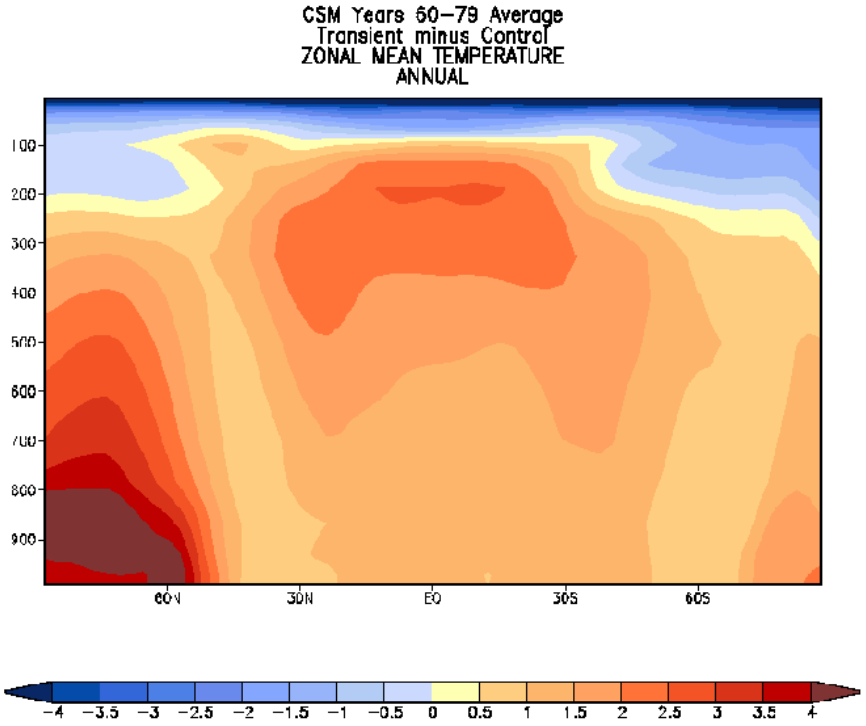


ISHIGAKIJIMA (47918) RAOBS (DOTS) 0000 UTC, July 30, 2001 (24.33N, 124.17E)
CHAMP (LINES) 2008 UTC, July 29, 2001 (21.74N, 122.90E)
Distance 317.39 km

CHAMP (red/blue lines): 2008 UTC 29 July 2001

Climate

- Perhaps the most accurate and stable global thermometer for estimating climate change
- Most accurate where model-predicted temperature changes are large in upper troposphere and lower stratosphere



Meehl et al. 2000, J. Climate.

Note sharper tropopause in GPS/MET and warm bulge between 23 and 30 km (caused by QBO) which is underestimated in operational analyses.

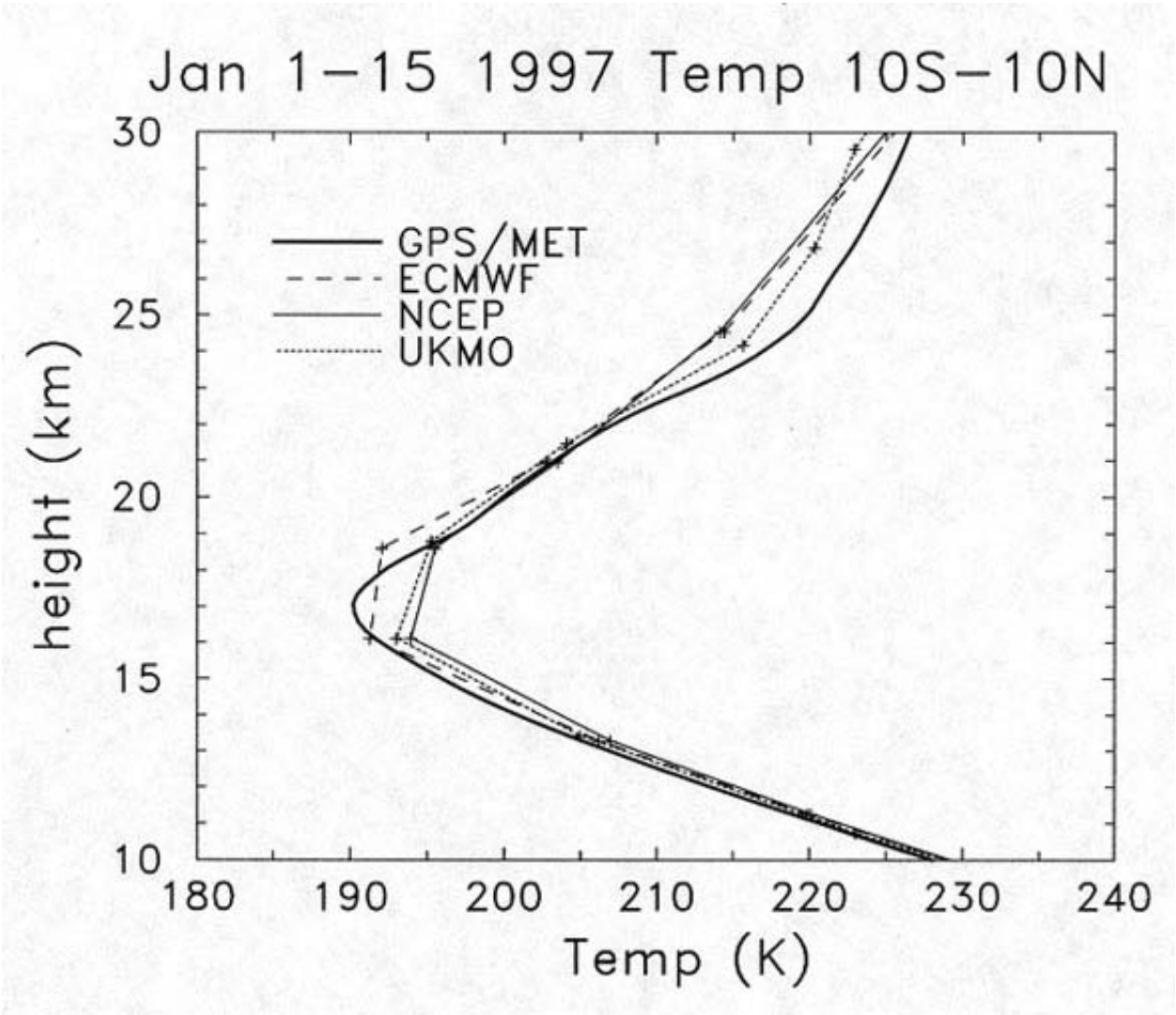
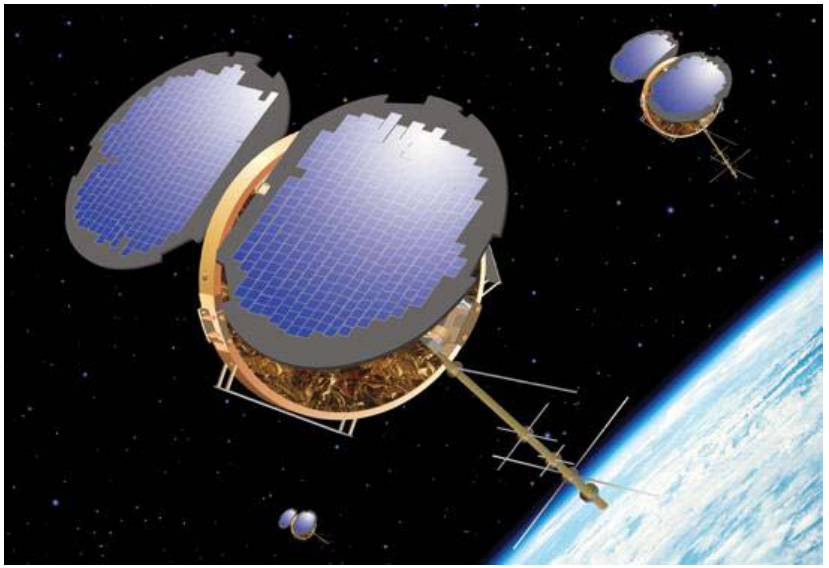


Fig. 3, Randel et al.,2003

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

- 6 Satellites launched in late 2005
- 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

COSMIC PARTICIPANTS

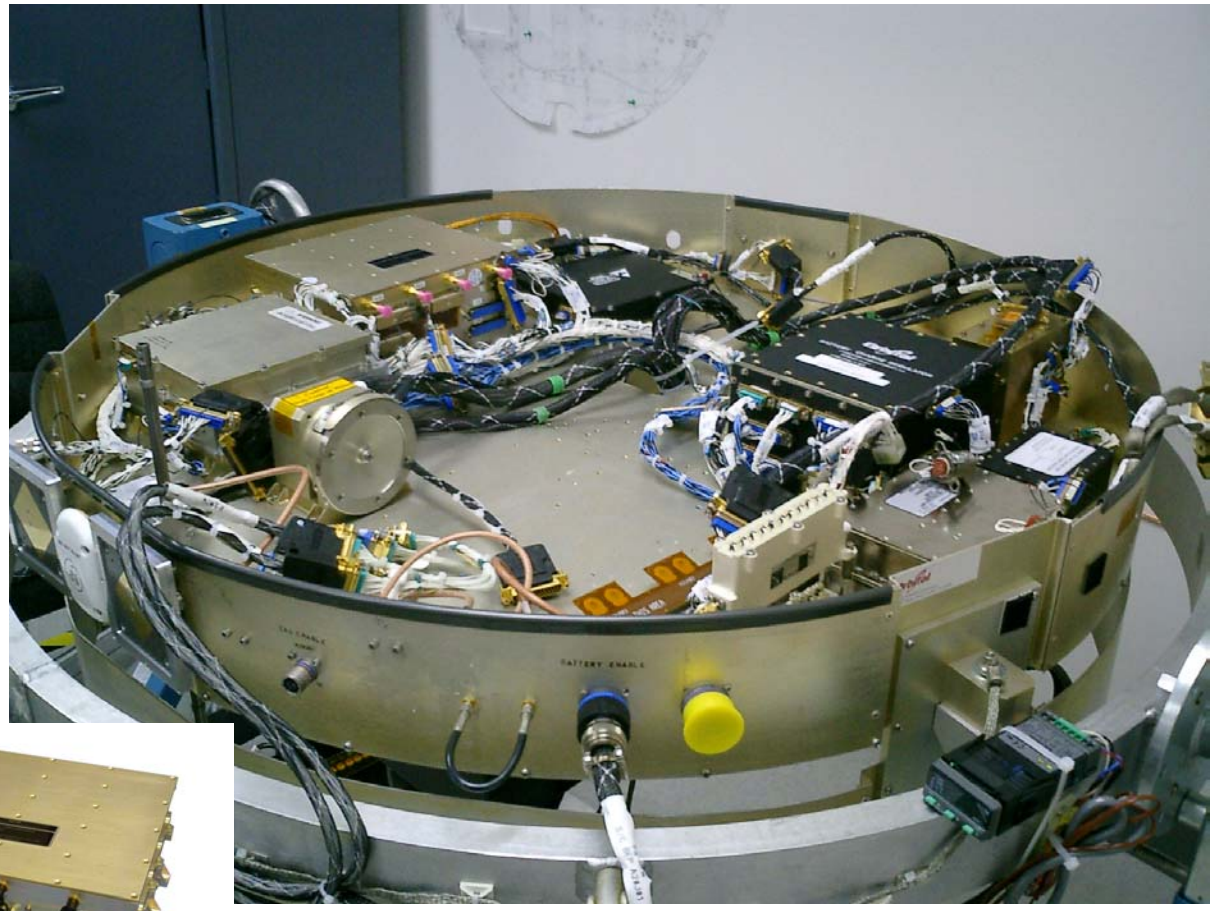
- NSPO
- NASA
- NOAA
- NSF
- DOD
- UCAR
- NCAR
- UNIVERSITIES
- JPL
- OSC

GPS Radio Occultation (RO) Data

- Climate:
  - **Characterize climate, its variability and change**
  - **Evaluate global climate models and analyses**
  - **Monitor climate change and variability with unprecedented accuracy-**world's most accurate thermometer!
- Meteorology:
  - **Improve global weather analyses, particularly over data void regions such as the oceans and polar regions**
  - **Improve skill of global and regional weather prediction models**
  - **Improve understanding of tropical, midlatitude and polar weather systems and their interactions**
- Ionosphere:
  - **Characterize global electronic density distribution**
  - **Observe the interactions among the upper stratosphere, mesosphere and ionosphere**
  - **Improve the analysis and prediction of space weather.**

Minotaur
launch vehicle

GPS receiver

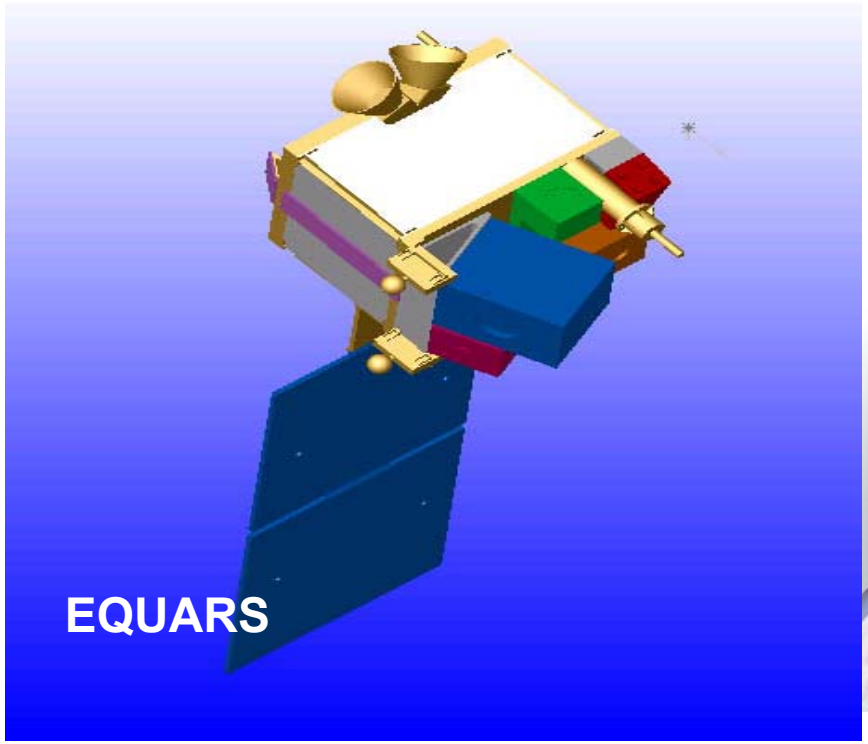


COSMIC
spacecraft

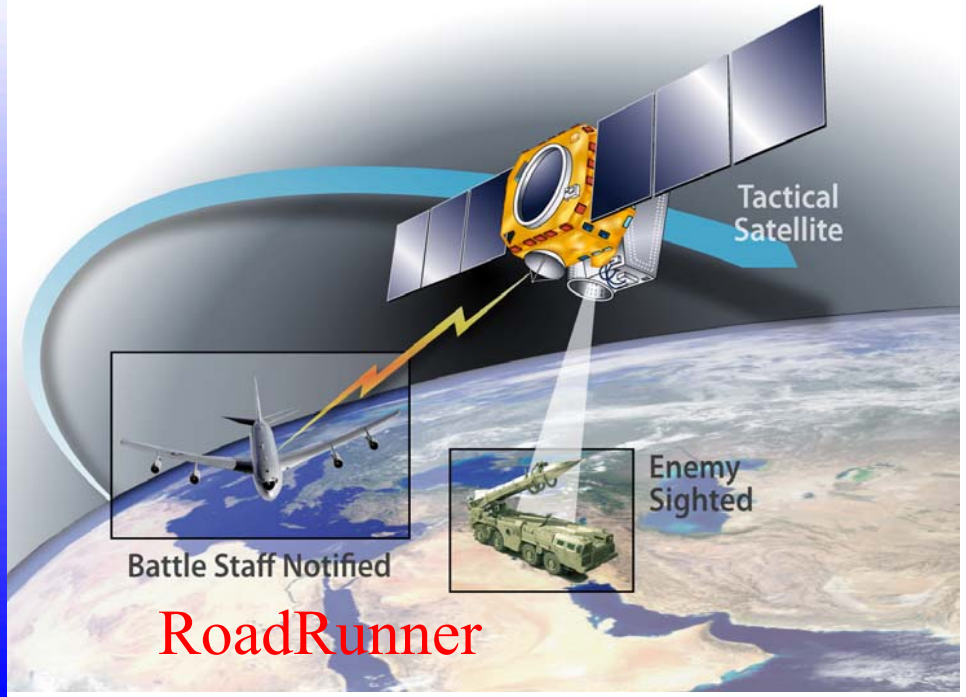
Mission	Launch-Duration	# Soundings/day	Remarks
GPS-MET	**4/1995 2+**	**~125**	**Proof of Concept**
CHAMP	**11/2000 ~5**	**~250**	**Improved receiver, tracking**
SAC-C	**11/2000 ~3**	**~500**	**Improved receiver, open loop tracking test**
GRACE	**5/2002 ~5**	**~500**	**RO data not yet available**
COSMIC	**9/2005 ~5**	**2500-3000**	**Real time-ops**
TerraSAR-X	**7/2005 ~5**	**~400**	**COSMIC RX & Antennas**
EQUARS	**7/2006 ~3**	**~400**	**COSMIC RX & CHAMP antennas**
METOP	**5/2007 ~5**	**~500**	**Real time - ops**
NPOESS	**3/2011 ~10**	**~500**	**Real time-ops. Ionosphere**

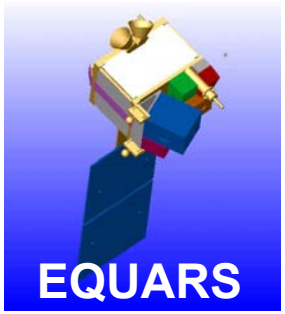
EQUARS - real-time RO data from low-latitudes analyzed as CDAAC
RoadRunner - Late 2004 launch with IGOR receiver - Risk Reduction

INPE / Brazil

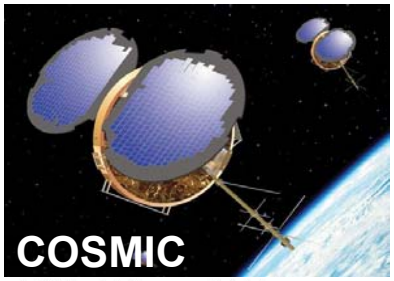


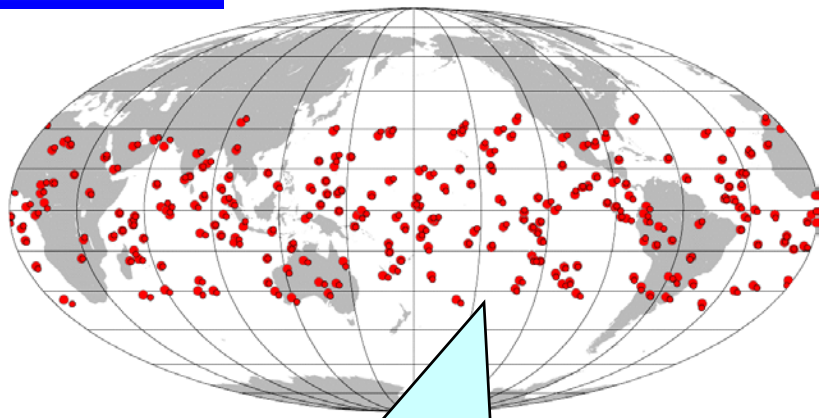
USAF / US





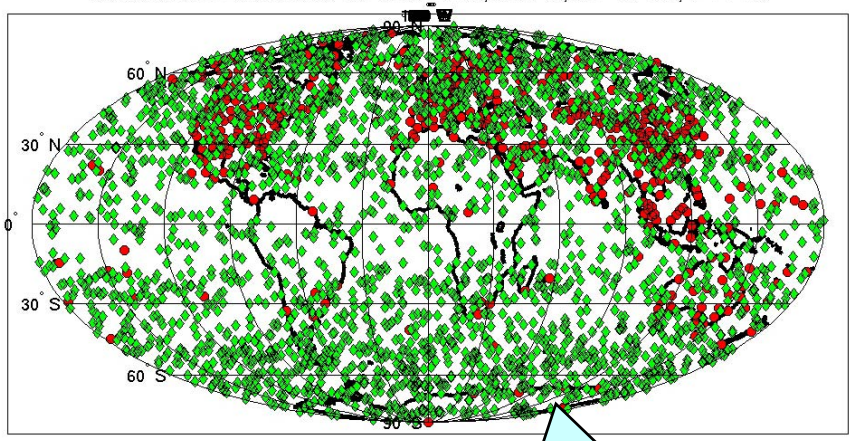
Distribution of GPS Occultation events in 24 hrs with EQUARS (2006, inclination angle<20°) and COSMIC (2005, 6 LEO satellites at 72°)



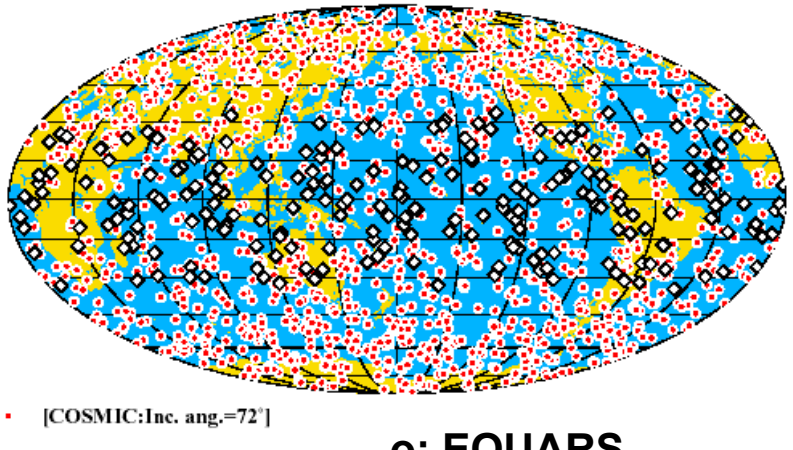


Dense data rate in equatorial region

Occultation Locations for COSMIC, 6 S/C, 6 Planes, 24 Hrs



Global coverage, but less data at low latitudes



▪ [COSMIC:Inc. ang.=72°]

◇ [EQUARS:Inc. ang.=20°]

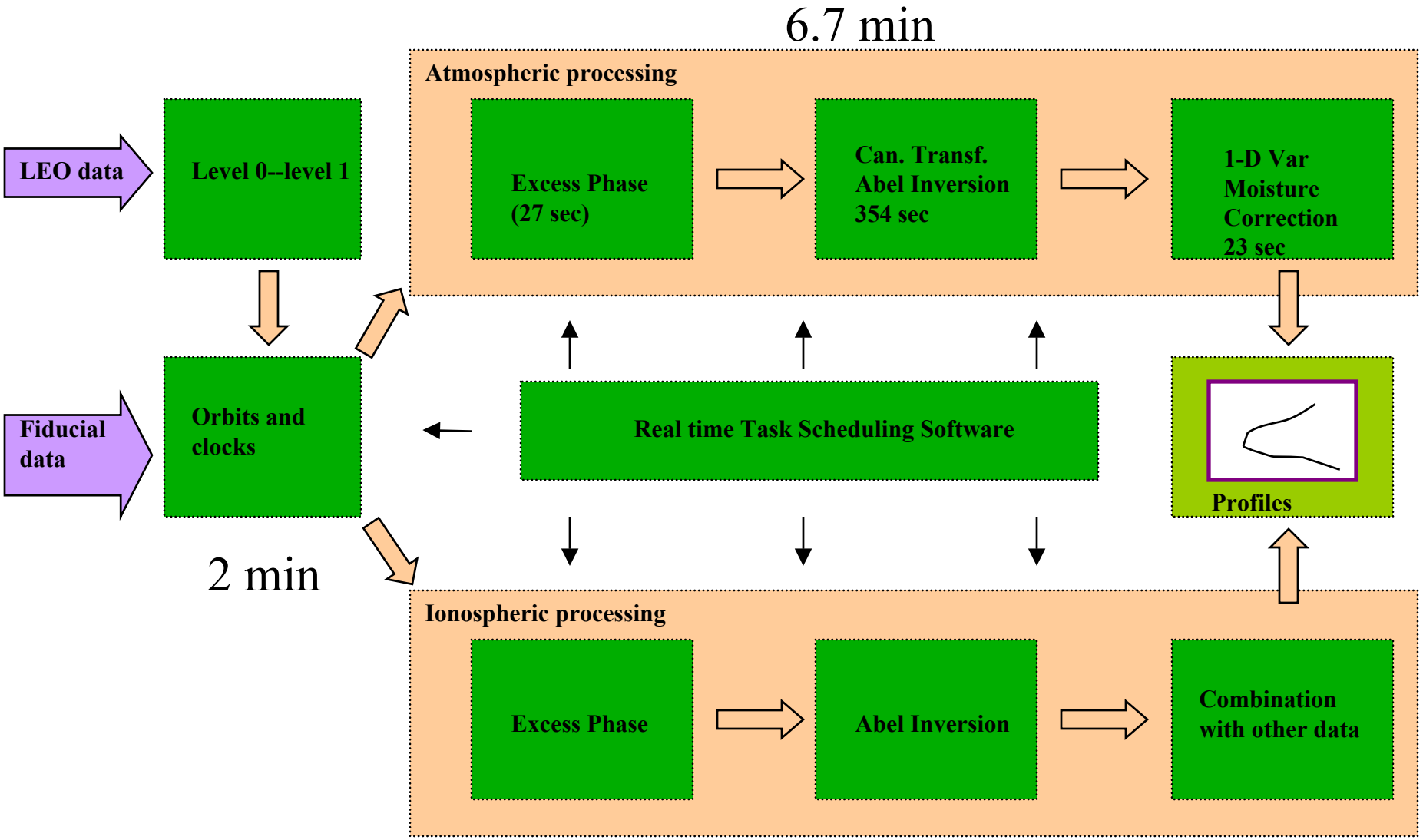
o: EQUARS

o: COSMIC

Status of COSMIC Data Analysis and Archive Center (CDAAC)

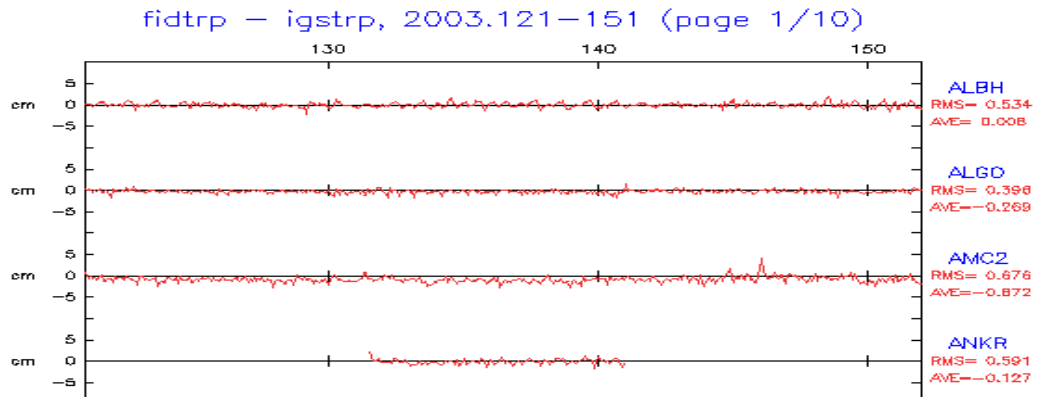
COSMIC CDAAC RESPONSIBILITIES

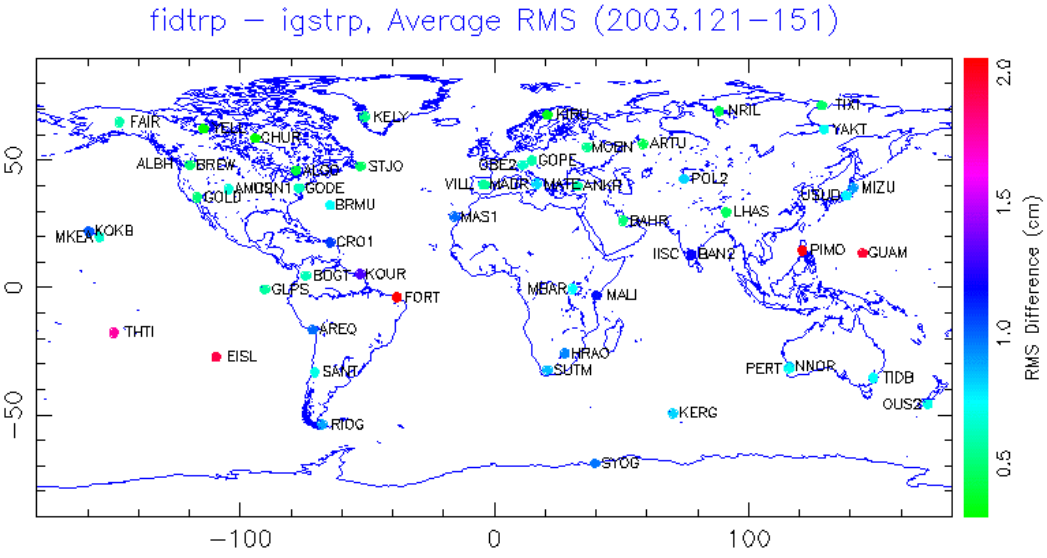
- **Process all COSMIC observations**
  - **LEO/GPS orbit determination**
  - **Atmospheric & Ionospheric profiles**
  - **Rapid analysis for operational demonstration**
  - **Post-processed analysis for climate and other research**
- **Provide data to universities and research laboratories**
- **Provide data feeds (< 3hr) to operational centers**
- **Archive data & provide web interface**

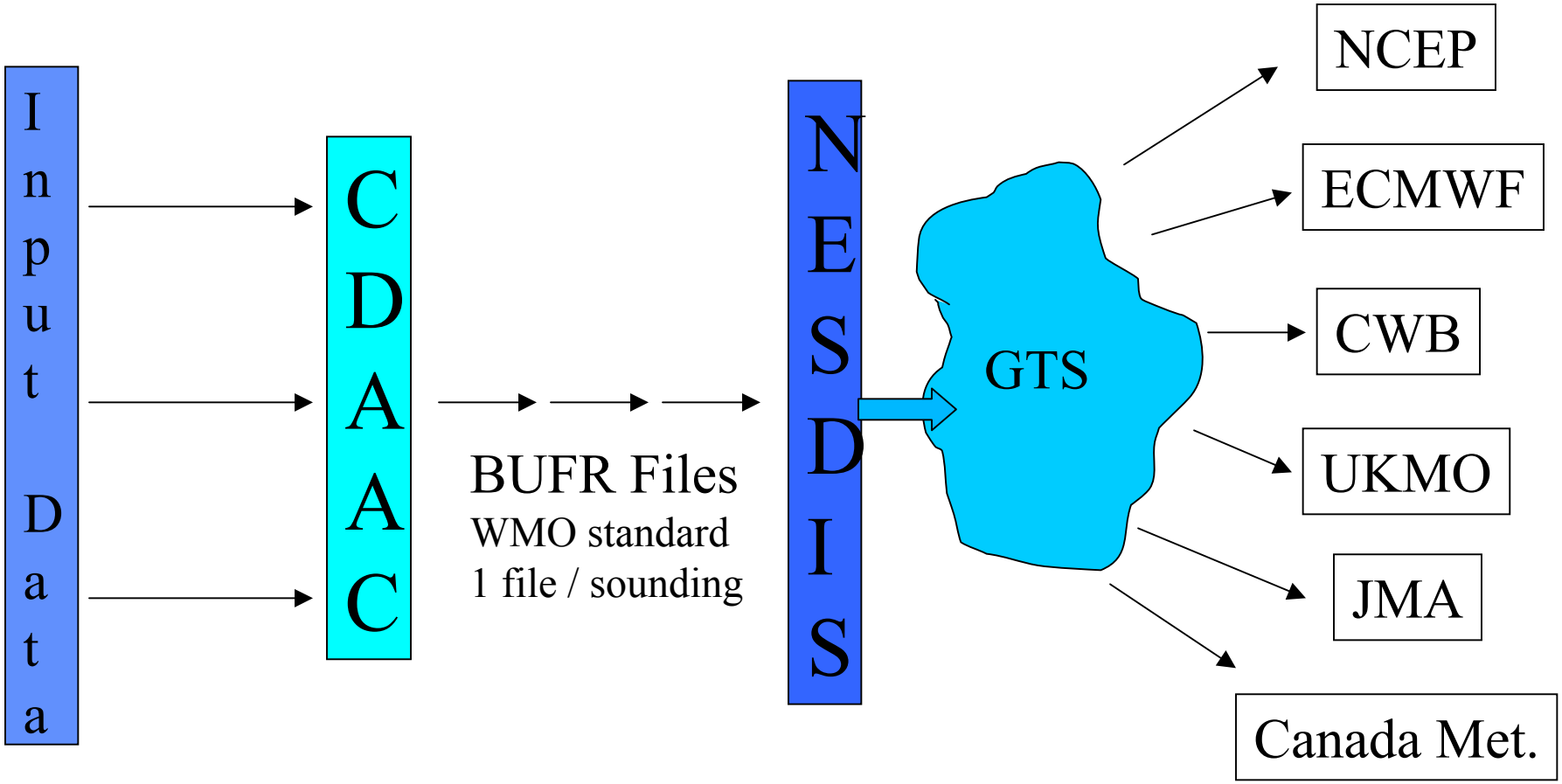


Current processing time for 35 occultations + 100 minutes of fid data: 9min

- Comparisons of CDAAC post-processed zenith delays with IGS final values
- CDAAC software in place to automatically fetch files, populate database with comparison values and display reports, including global summary maps.
- Most sites show monthly average RMS differences with IGS of < 1cm with little bias



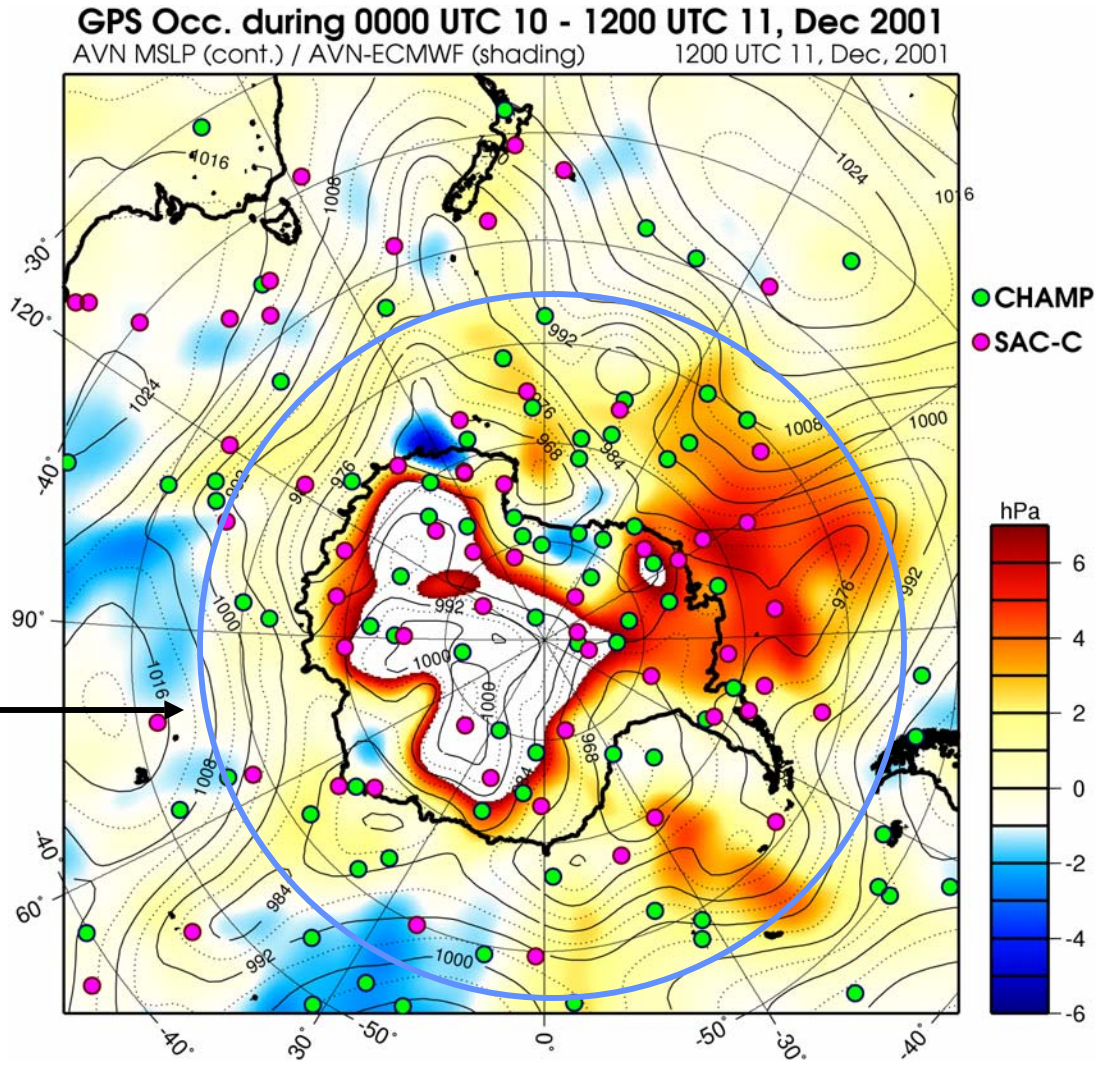




This system is currently under development by UCAR, NESDIS, + UKMO

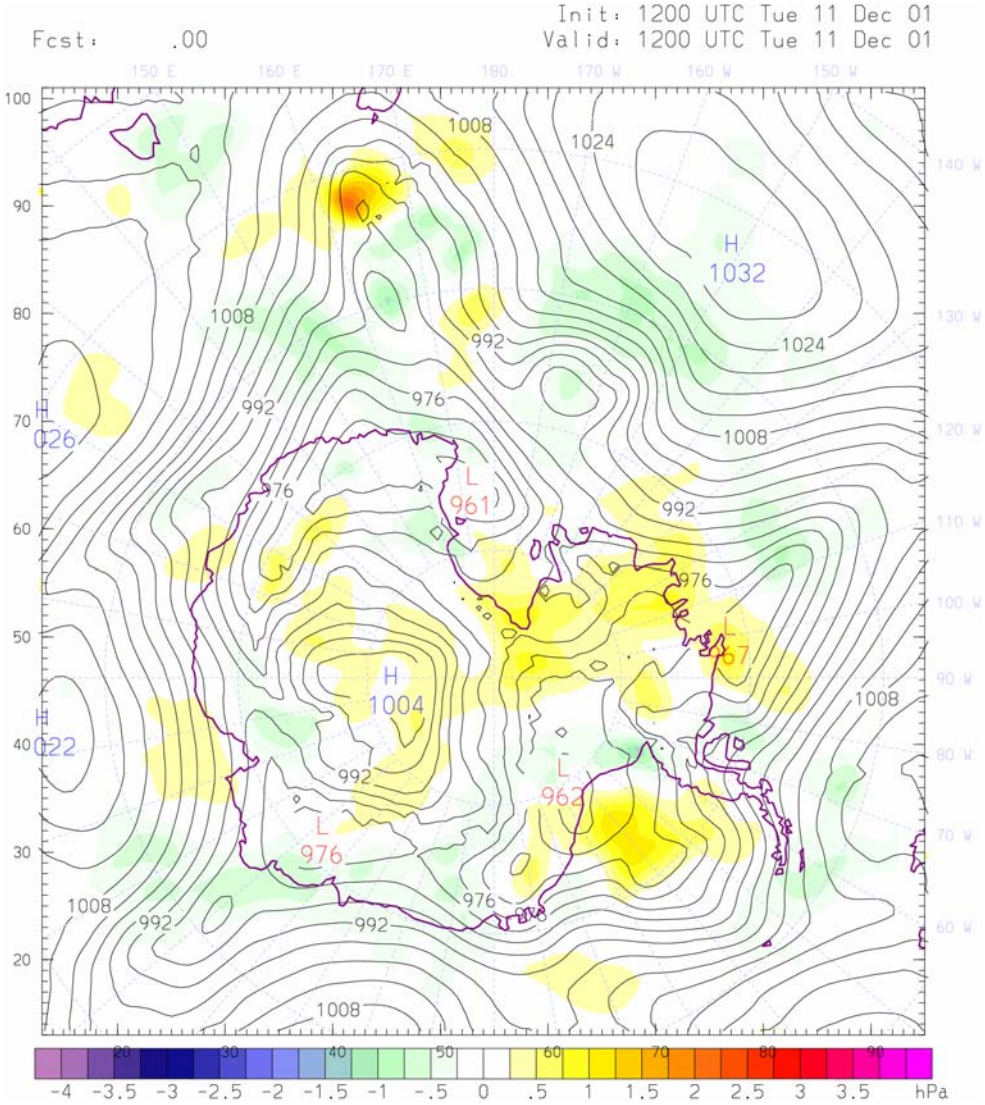
Assimilation of GPS RO data over the Antarctic

Domain of 4DVAR Experiment



Area used for comparison with global analysis

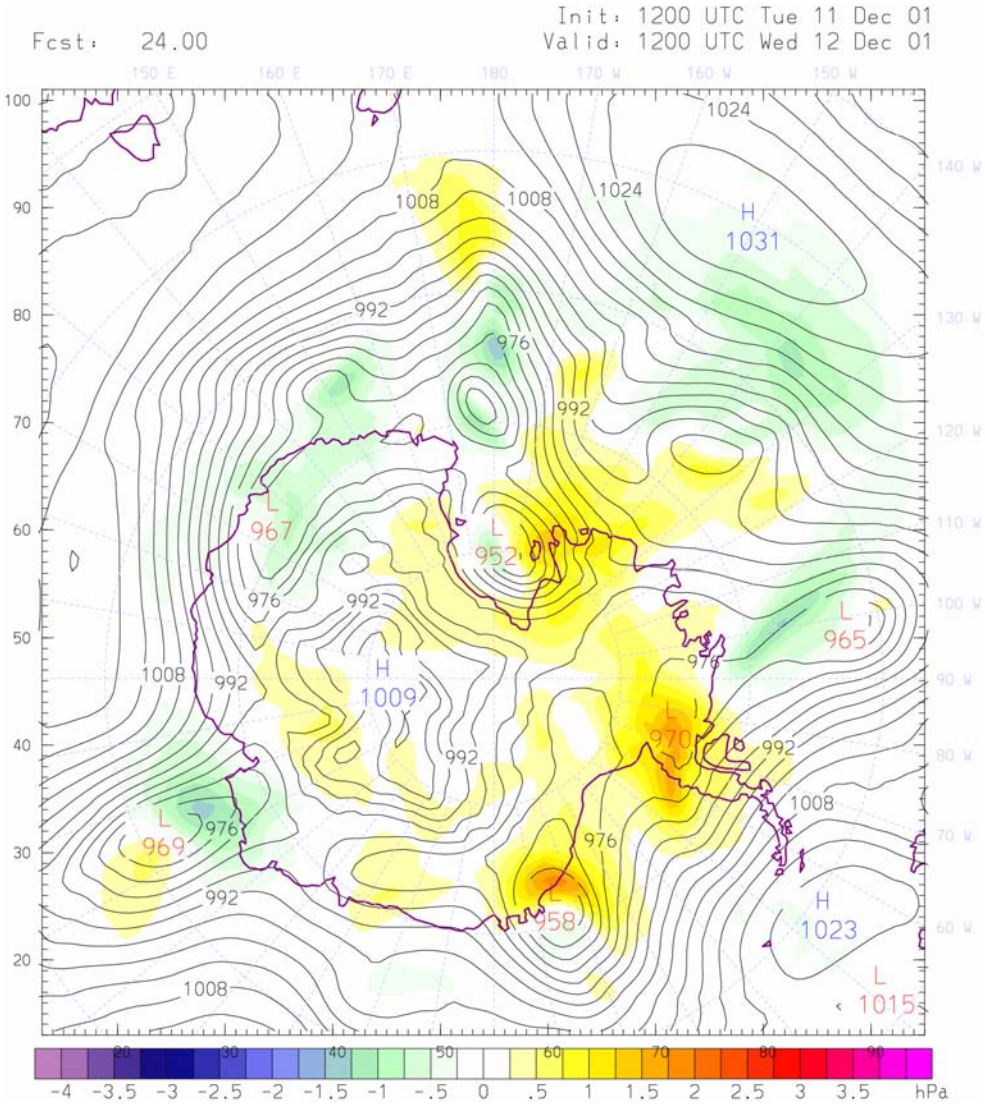
Differences in SLP between GPS and no-GPS experiments



0 h

FCST

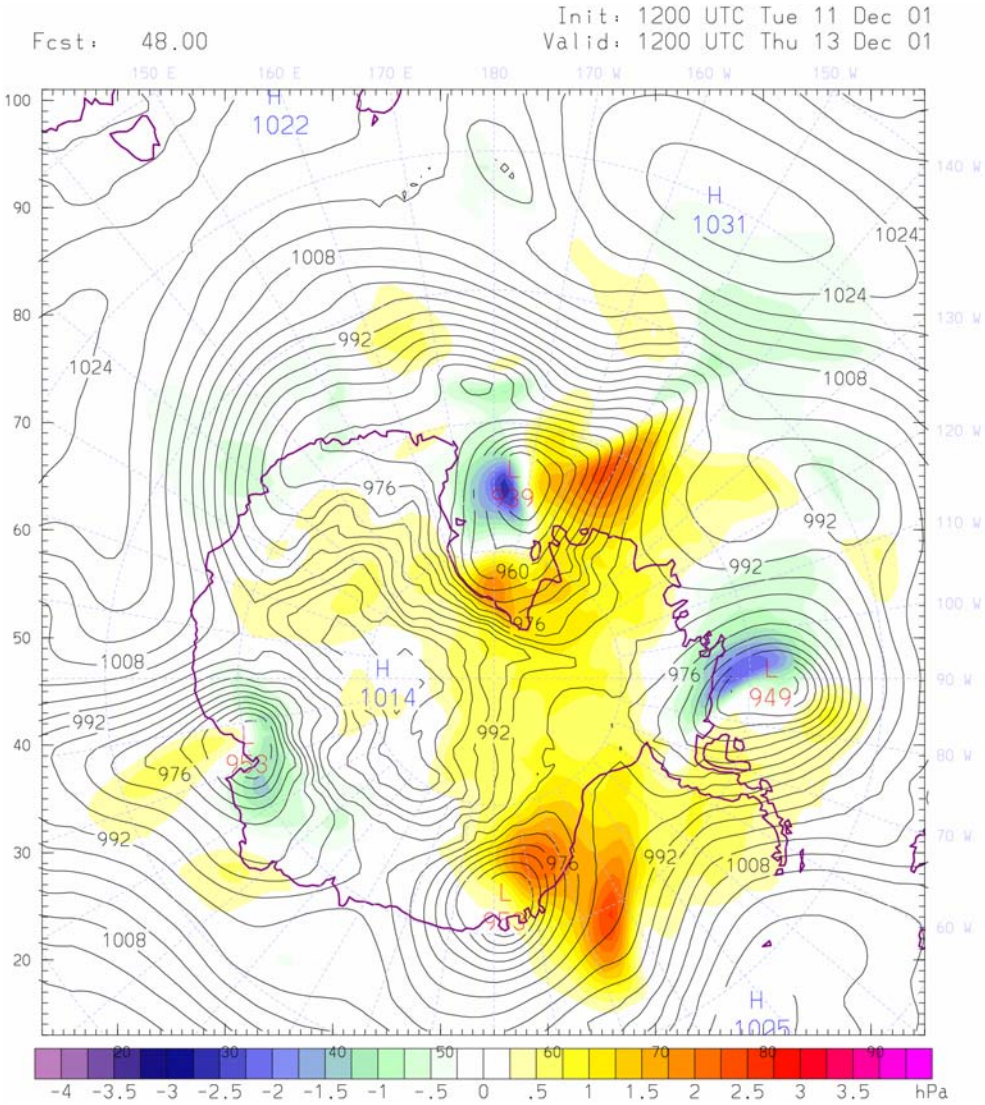
Differences in SLP between GPS and no-GPS experiments



24 h

FCST

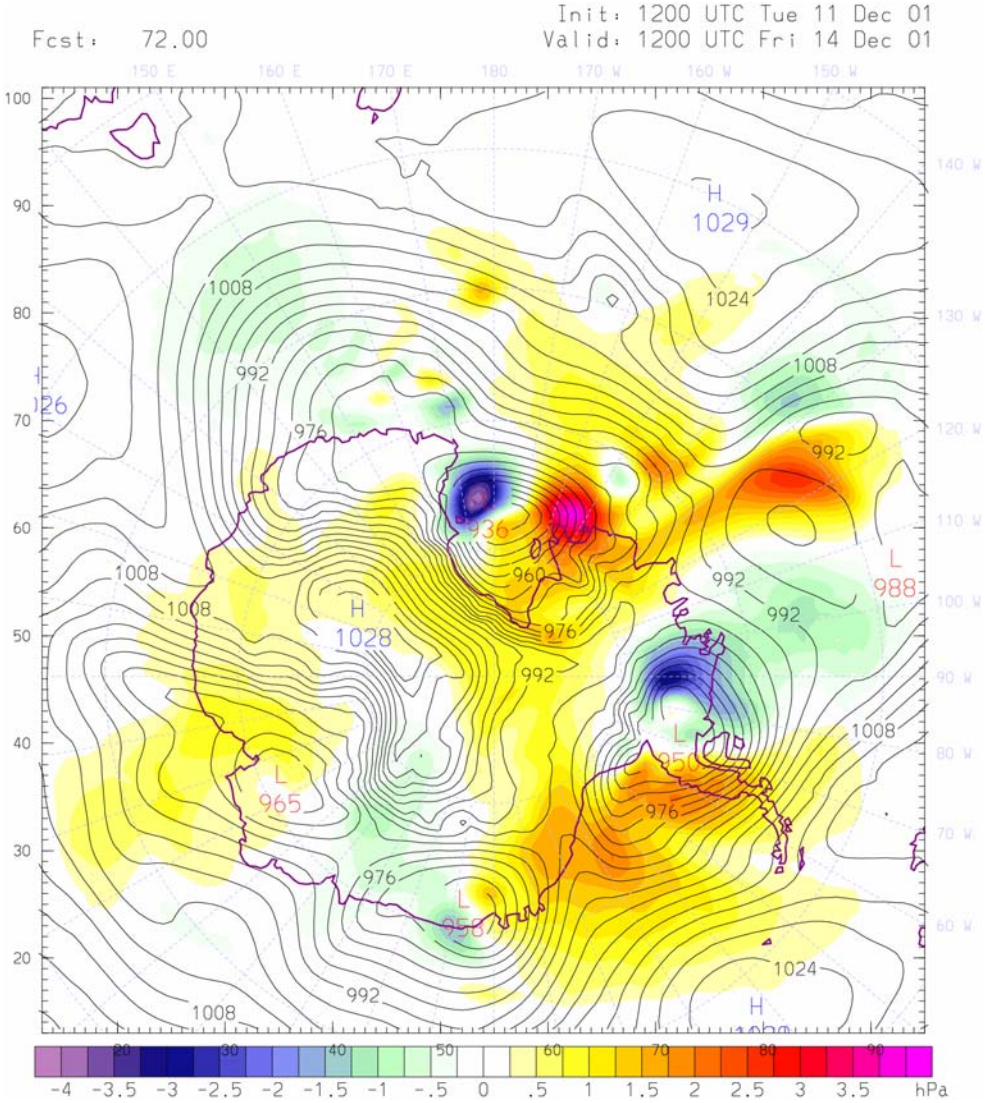
Differences in SLP between GPS and no-GPS experiments



48 h

FCST

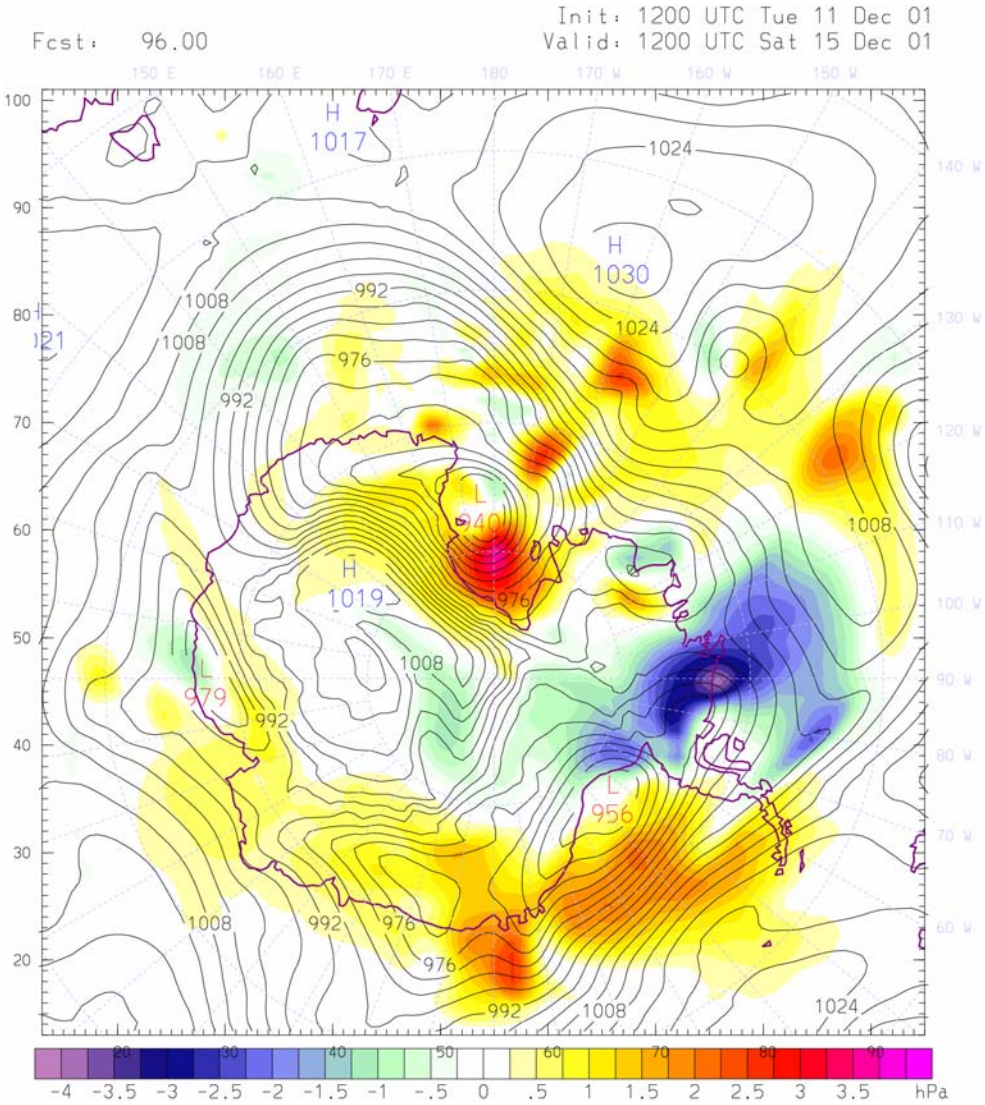
Differences in SLP between GPS and no-GPS experiments



72 h

FCST

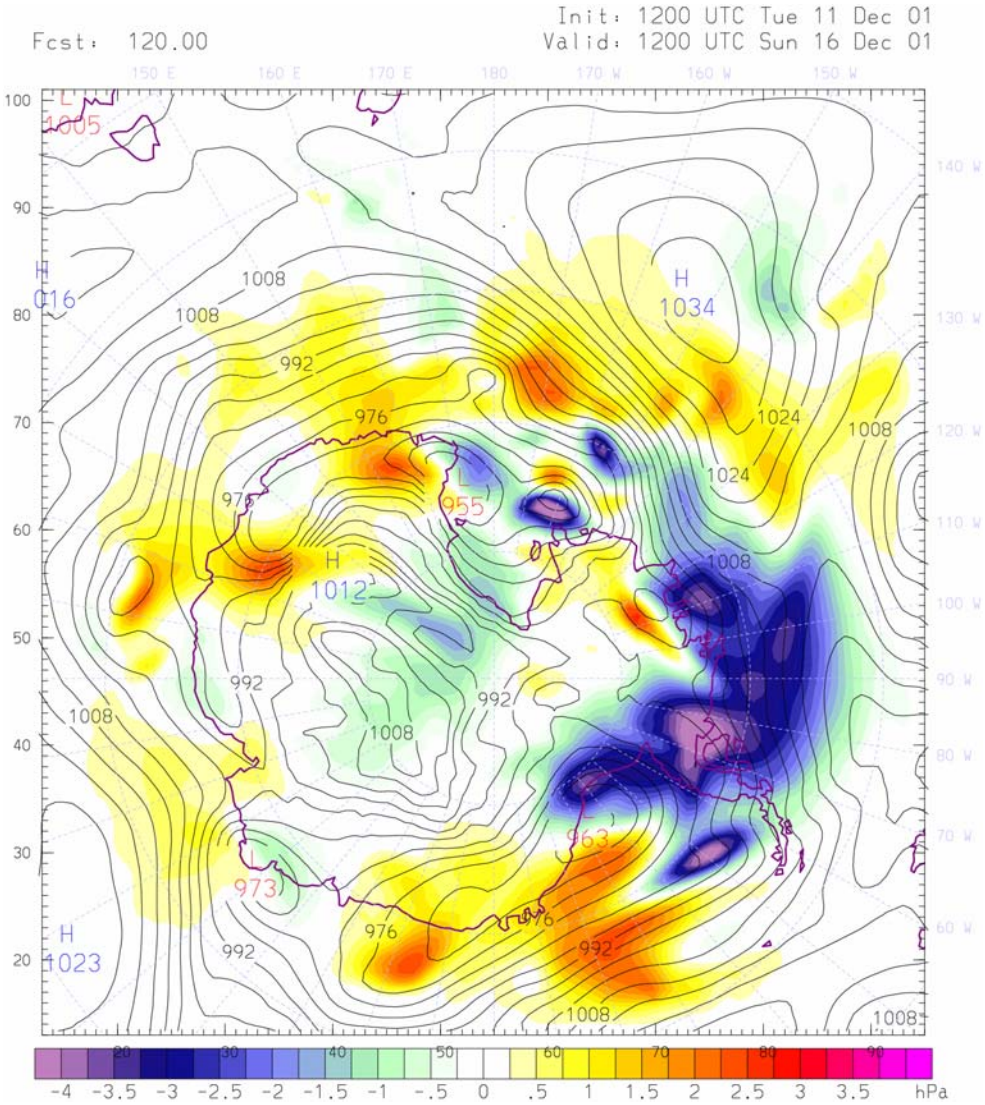
Differences in SLP between GPS and no-GPS experiments



96 h

FCST

Differences in SLP between GPS and no-GPS experiments

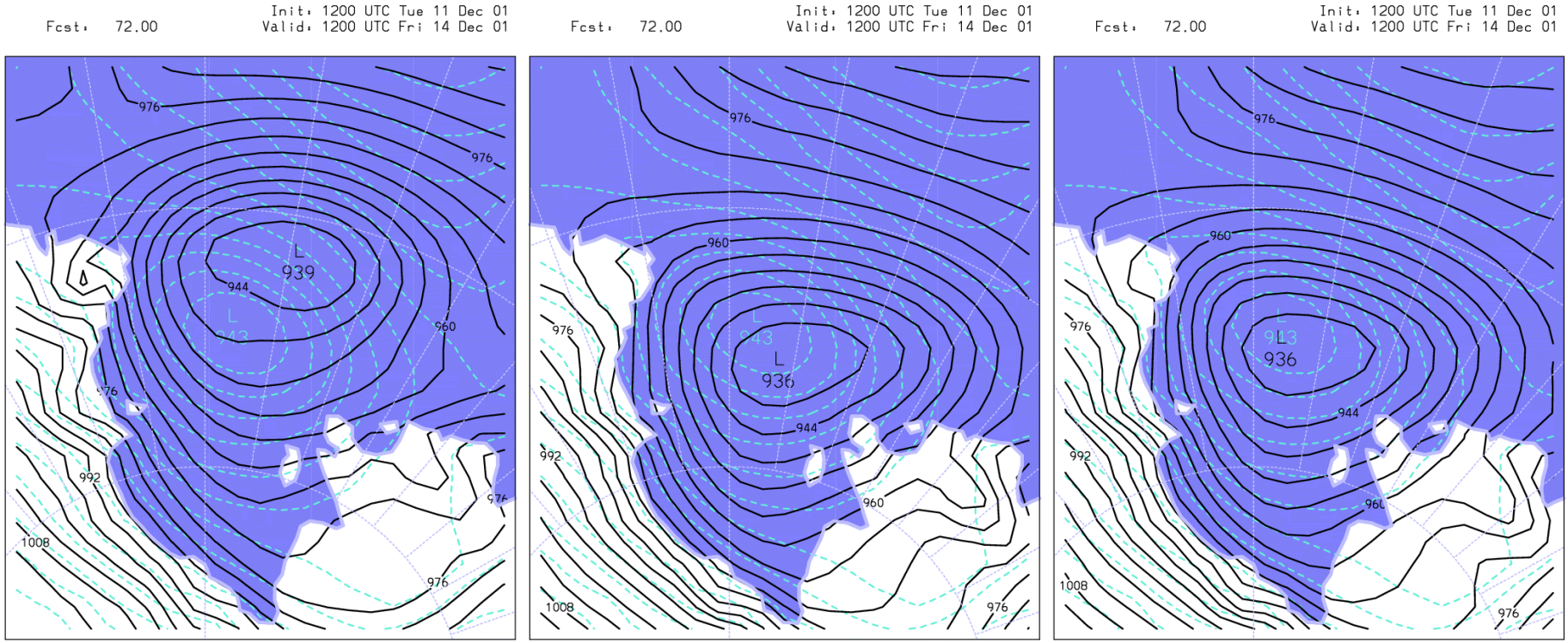


120 h

FCST

Comparison with ECMWF Analysis

AVN/MM5 FCST **No GPS** **+ GPS**



72 h forecast

A forecast impact trial with CHAMP radio occultation measurements

Sean Healy, Adrian Jupp and
Christian Marquardt

Summary of UK Met Office Study (Healy et al. 2003)

We have performed the 1st impact study with RO data at the Met Office. Given the small number of observations, results are very encouraging.

PMSL in tropics improved, but largest impact seen in the southern hemisphere.

Upper-troposphere and lower stratosphere show improvements in the 250hPa Temp (SH) and 50hPa(all) .

The results would support the case for assimilating RO measurements operationally.

Prospects of obtaining measurements from a constellation (e.g., COSMIC, ACE+) are very exciting in the light of these results.

Concluding Remarks

- **GPS radio occultation technique is a very promising atmospheric observing system for both weather and climate:**
  - **High vertical resolution**
  - **High density (depending on the number of missions)**
  - **High accuracy**
  - **No instrument drift (important for climate detection)**
- **GPS RO technique is here to stay (COSMIC is coming, and more missions are being planned)**
- **GPS RO data will be valuable to:**
  - **climate change analysis, validating of climate simulations**
  - **operational weather prediction**
  - **ionospheric research and space weather forecasting**

The END