Jet Propulsion Laboratory
California Institute of Technology

AN: A42D-06: A Database of upper air Temperatures from GPS Radio-occultations

by

M. de la Torre Juárez, G.A. Hajj, B.A. Ijima, C.O. Ao, A.J. Mannucci,

Jet Propulsion Laboratory/Caltech, Pasadena 91109.

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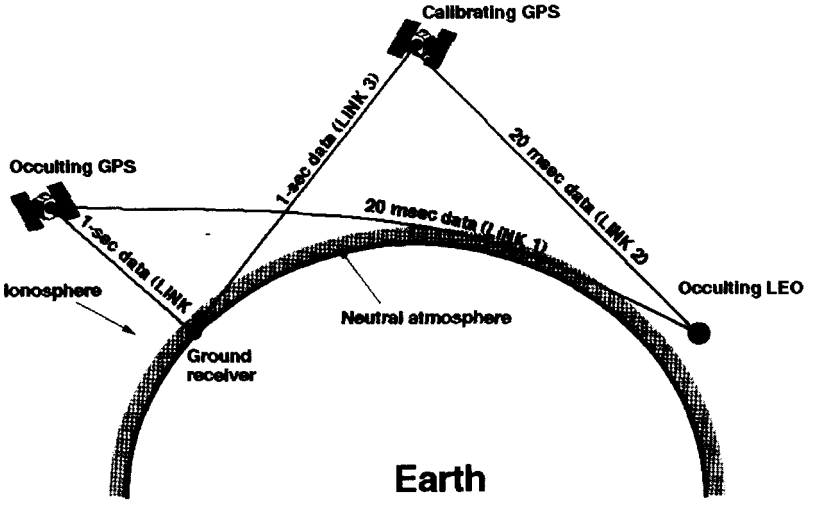
Abstract: The launches of the CHAMP, SAC-C, and GRACE spacecraft have started a campaign of dense remote sensing of atmospheric refractivity profiles using GPS radio-occultations of the Earth's atmosphere. These data provide high resolution profiles of pressure, and temperature as functions of geometric heights up to 30km above the surface. The quality, coverage, and features of the data will be discussed. Their use and availability is also described.

Overview of the measuring concept



The occultation geometry involving two GPS transmitters, one ground receiver and one space receiver

After removing clock errors, noise and bias terms, the delays in the measured signal are:

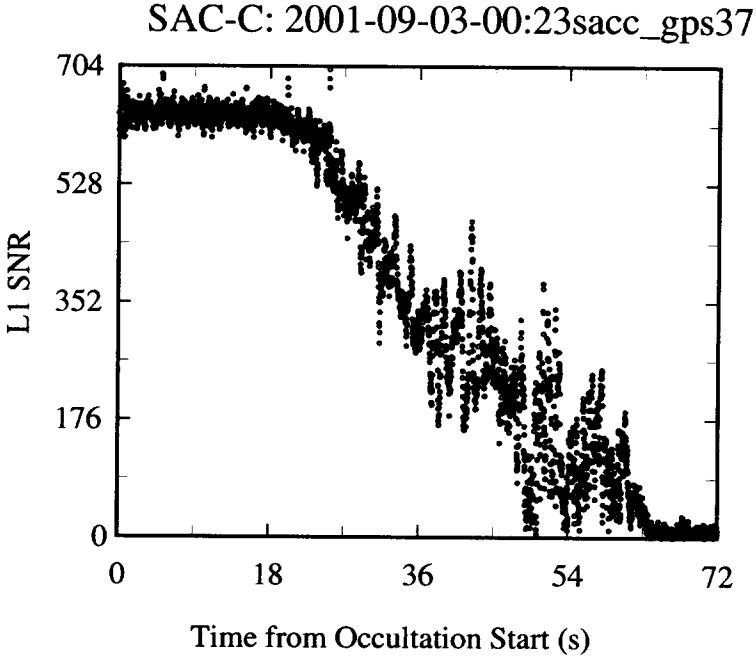
$$P_k = \rho + \eta_k + \frac{I}{f_k^2} \qquad L_k = \rho + \eta_k - \frac{I}{f_k^2}$$

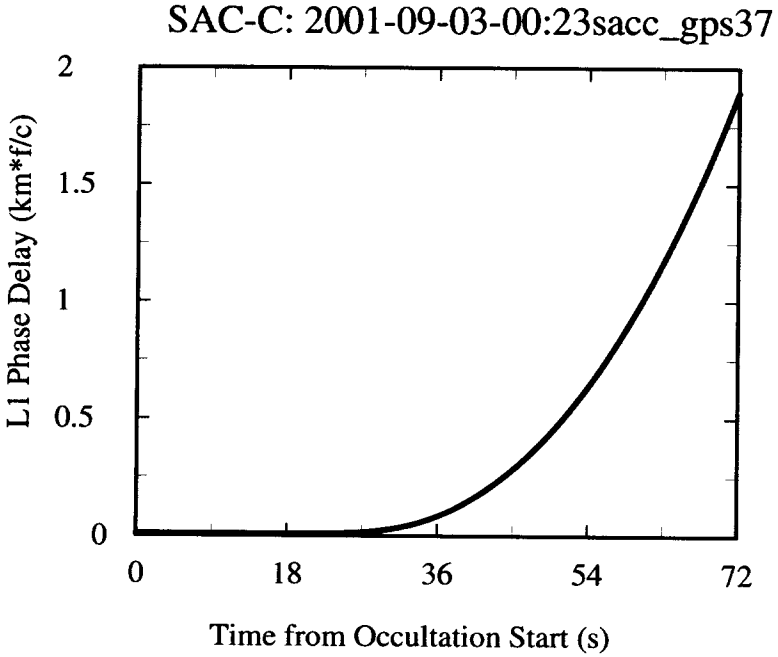
Where P_k, and L_k are delays of group and phase velocity, ρ is distance, η_k is atmospheric delay, I is ionospheric delay; $f_1 = 154 \times 10.23MHz$, $f_2 = 120 \times 10.23MHz$;

Three steps:

Orbit determination → Clock calibration → Retrieval.

Signals tracked: Amplitude and Phase delay.





Retreiving temperature and water vapor:

The typical retrieval uses:

1.
$$N = a_1 \frac{p}{T} + a_2 \frac{e}{T^2} = R\left(\frac{a_1}{M_a}\rho + \frac{a_2}{M_v}\frac{\rho_v}{T}\right) \quad (1)$$

Where N is refractivity, T is temperature in Kelvins, p is pressure in millibars, e is water vapor pressure in millibars, $a_1 = 77.6$ K/mbar, and $a_2 = 3.73 \times 10^5$ K^2/mbar.

2. Hydrostatic balance: $\partial_z p = -\rho g$

At altitudes above 250 K, the atmosphere is assumed dry.

$N = \frac{a_1 R}{M_a}\rho \quad \rightarrow \quad \rho = \frac{M_a}{a_1 R}N \quad ; \qquad p(z) - p(z_o) = -\frac{gM_a}{a_1 R}\int_{z_o}^{z} N dz.$

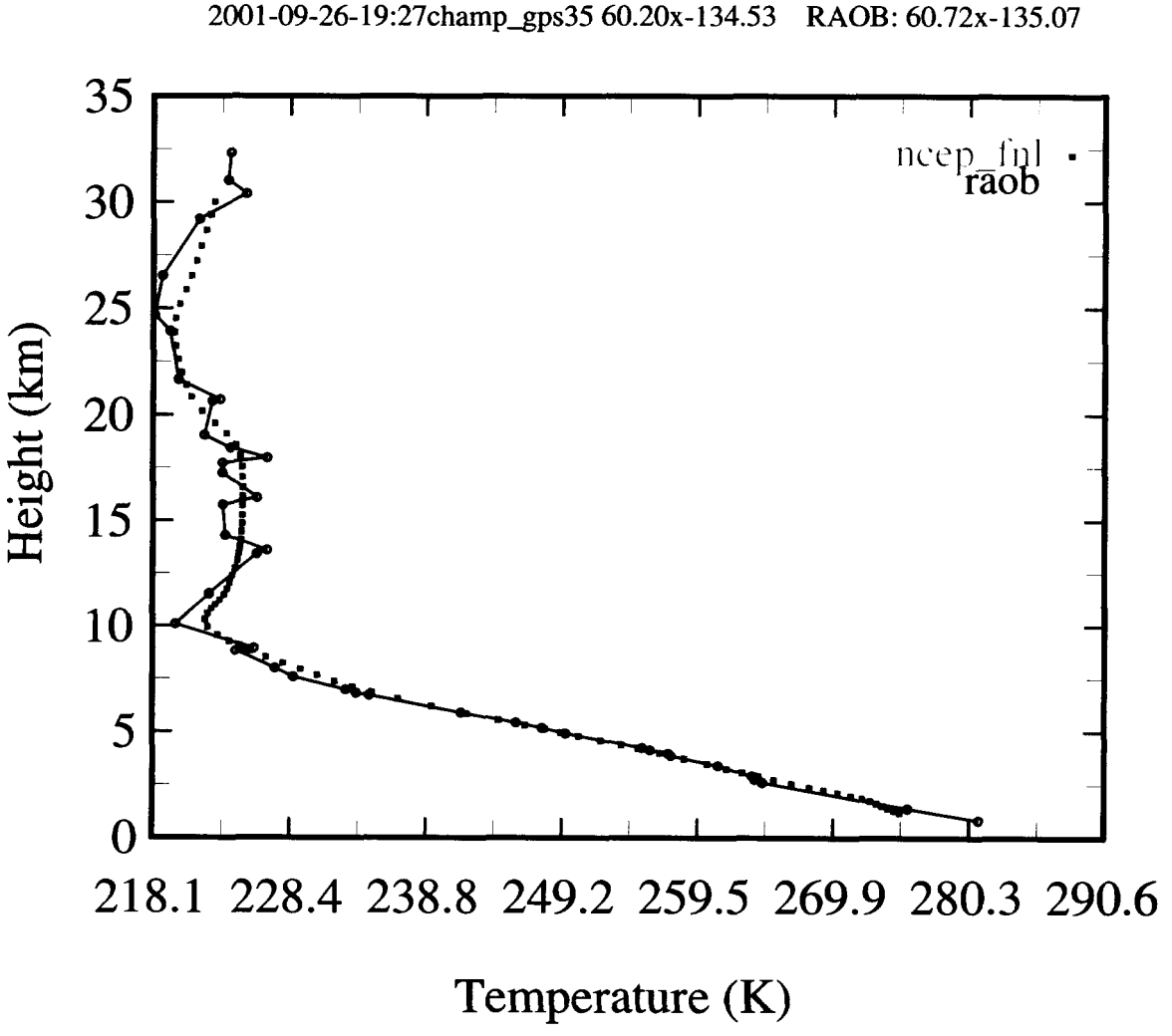
$T(z) = T(z_o)|_{model} - \frac{gM_a \int_{z_o}^{z} N dz}{RN}.$

With $T(z_o)$ from a model.

"Below" 250 K, the atmosphere is assumed wet and the temperature from the model is assumed correct.

MOTIVATIONS FOR RADIO-OCCULTATION PROFILING Provides profiles of refractivity, pressure, temperature, and water vapor in the neutral atmosphere with.

- High vertical resolution ($\lesssim$ 1 km).
- Accurate determination of tropopause height.
- Sub-Kelvin temperature precission between 5-30 km altitude.
- Global coverage.
- Self-calibrating quality.
- Long term stability.
- All weather conditions (clouds, rain or aerosols).



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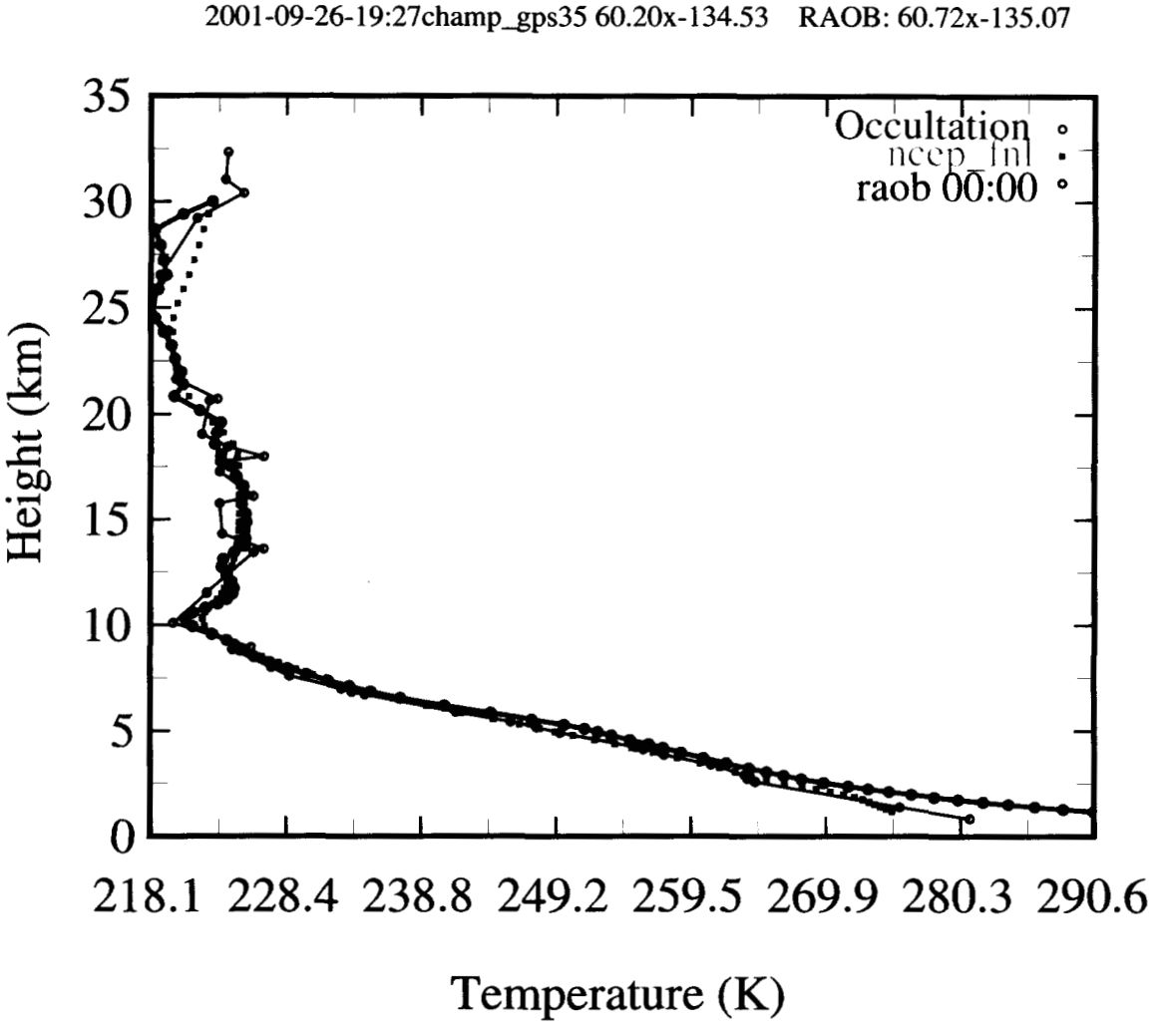

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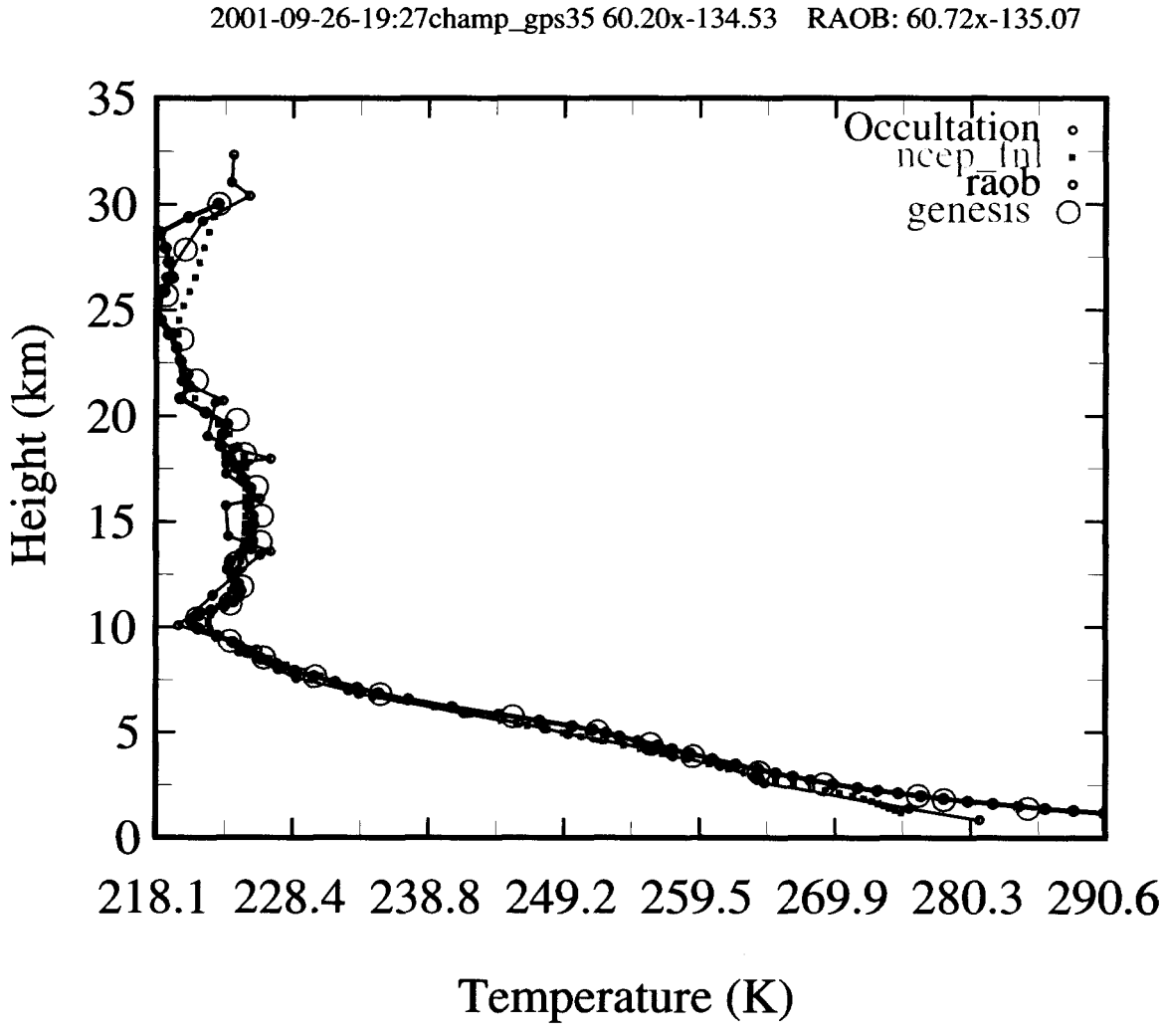
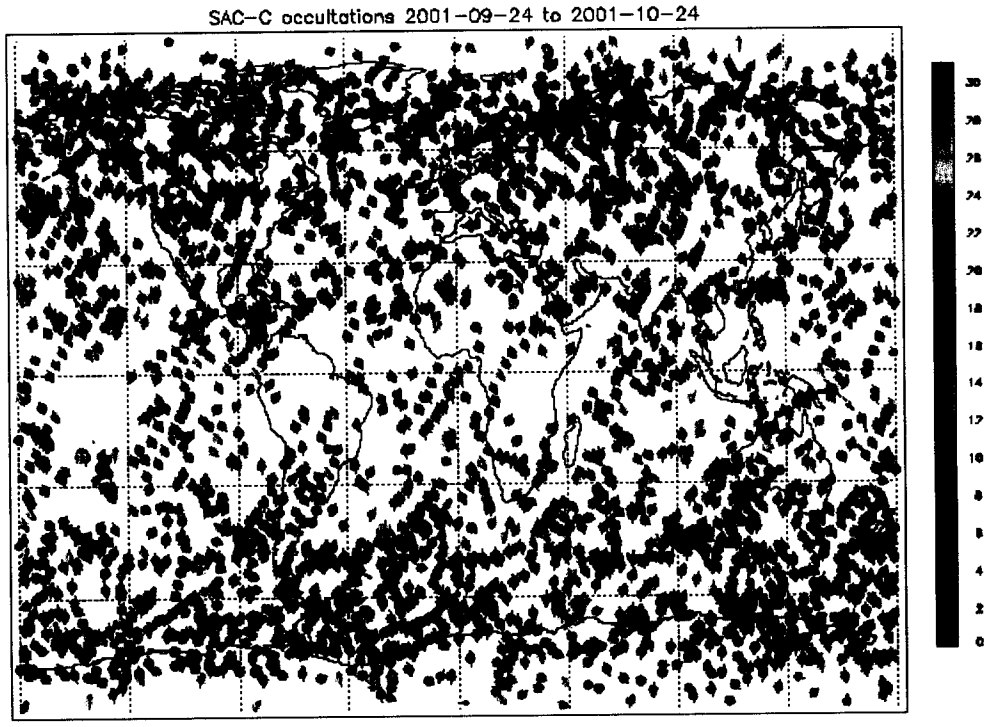
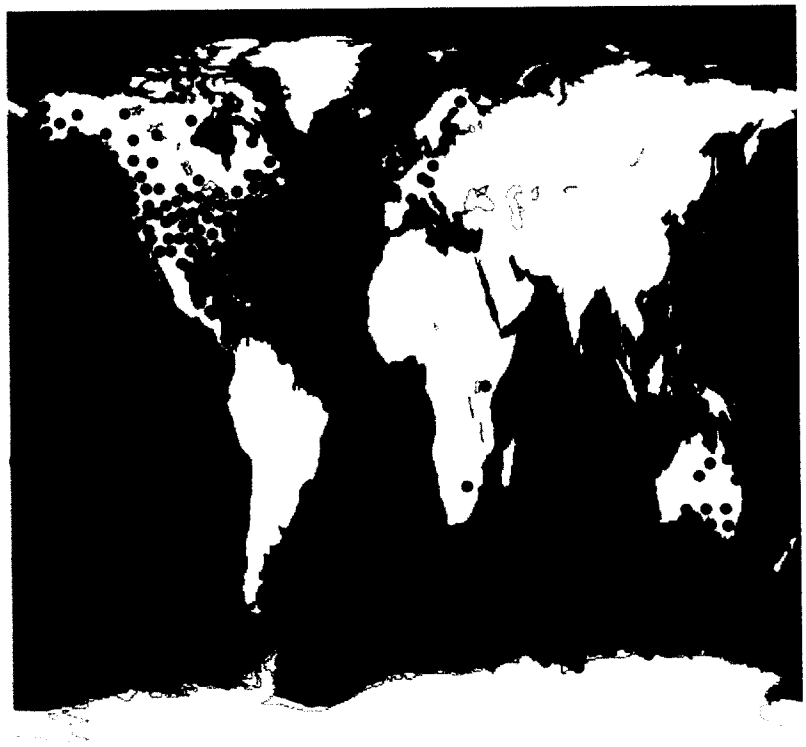


Spatial coverage 1 satellite in 1 month:

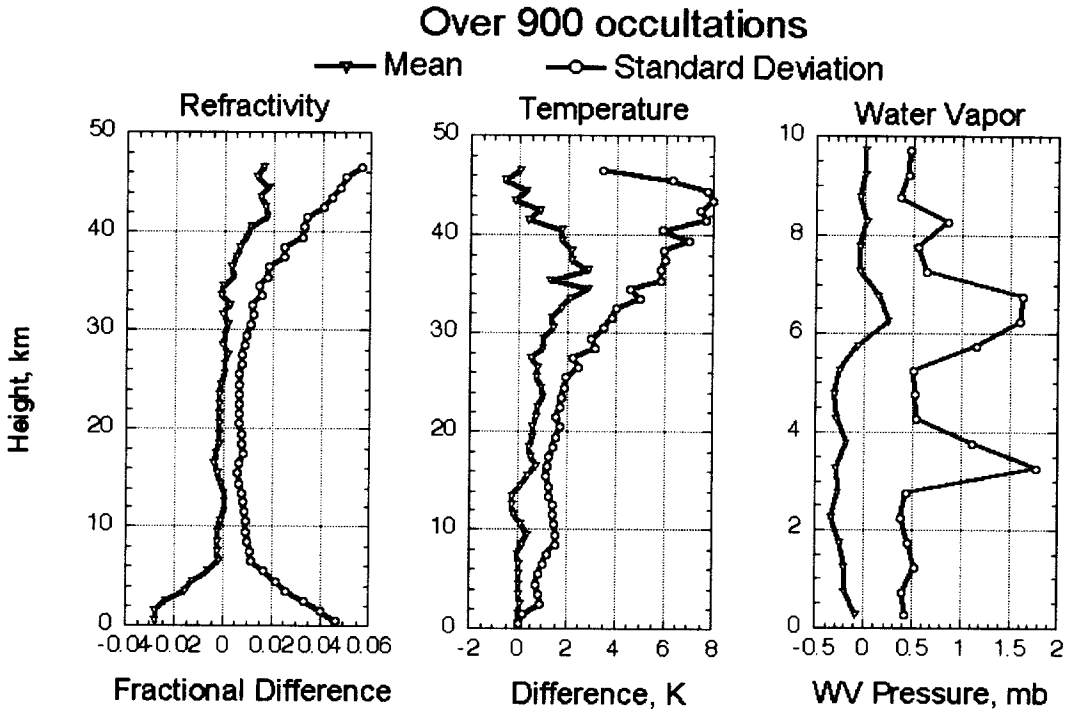


Global coverage vs. high vertical resolution radiosonde data:

SPARC Initiative, 2001

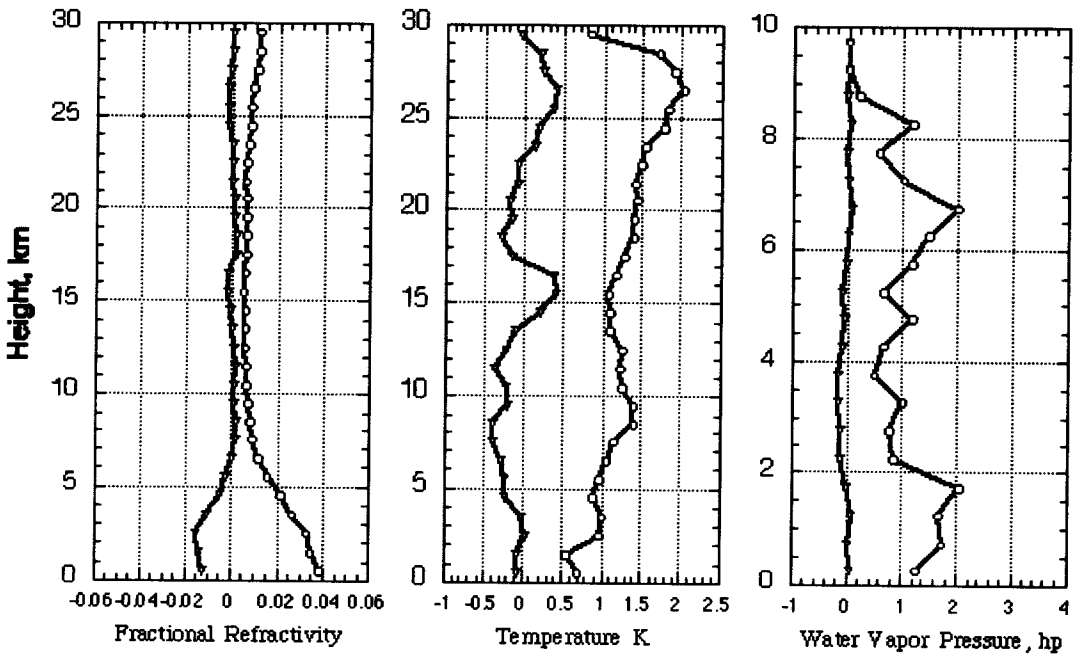


Connection with other climate efforts



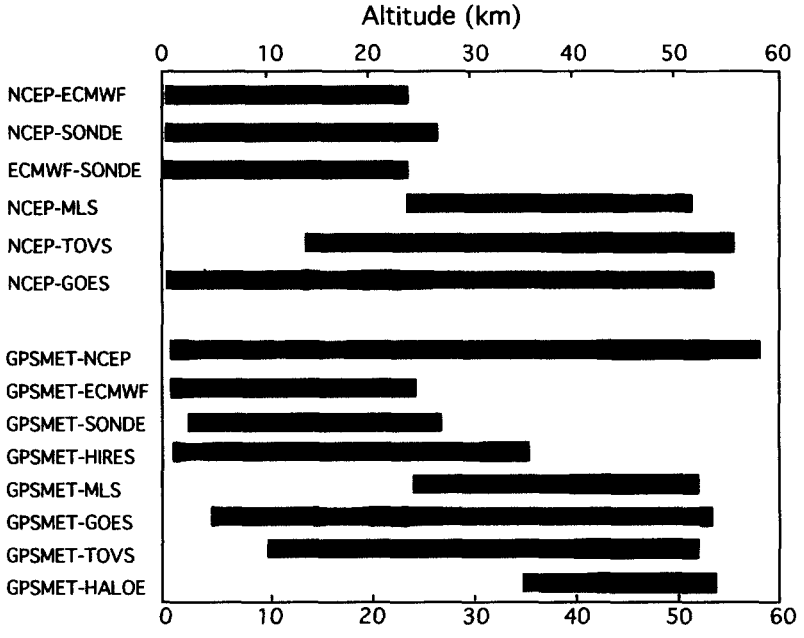
Comparisons of CHAMP with ECMWF ←

Comparisons of CHAMP with NCEP:



Possible use as validation or backup of other instruments:

Rocken et al. **1997**: JGR **102**, 29849–29866



Missions:

Temporal coverage:

Name	First processed data	Last processed data	Occs/day
GPS/MET	April 04 1995	March 1997	$\sim$ 50-160
OERSTED	January 24, 2000	April 28, 2000	$\sim$ 10-20
CHAMP	February 11, 2001	Present	200-250
SAC-C	July 6, 2001	Present	200-250
GRACE	Launched, March 2002		2$\times$(200-250) ?
TOTALS			(800 – 1000) ?

Summary:

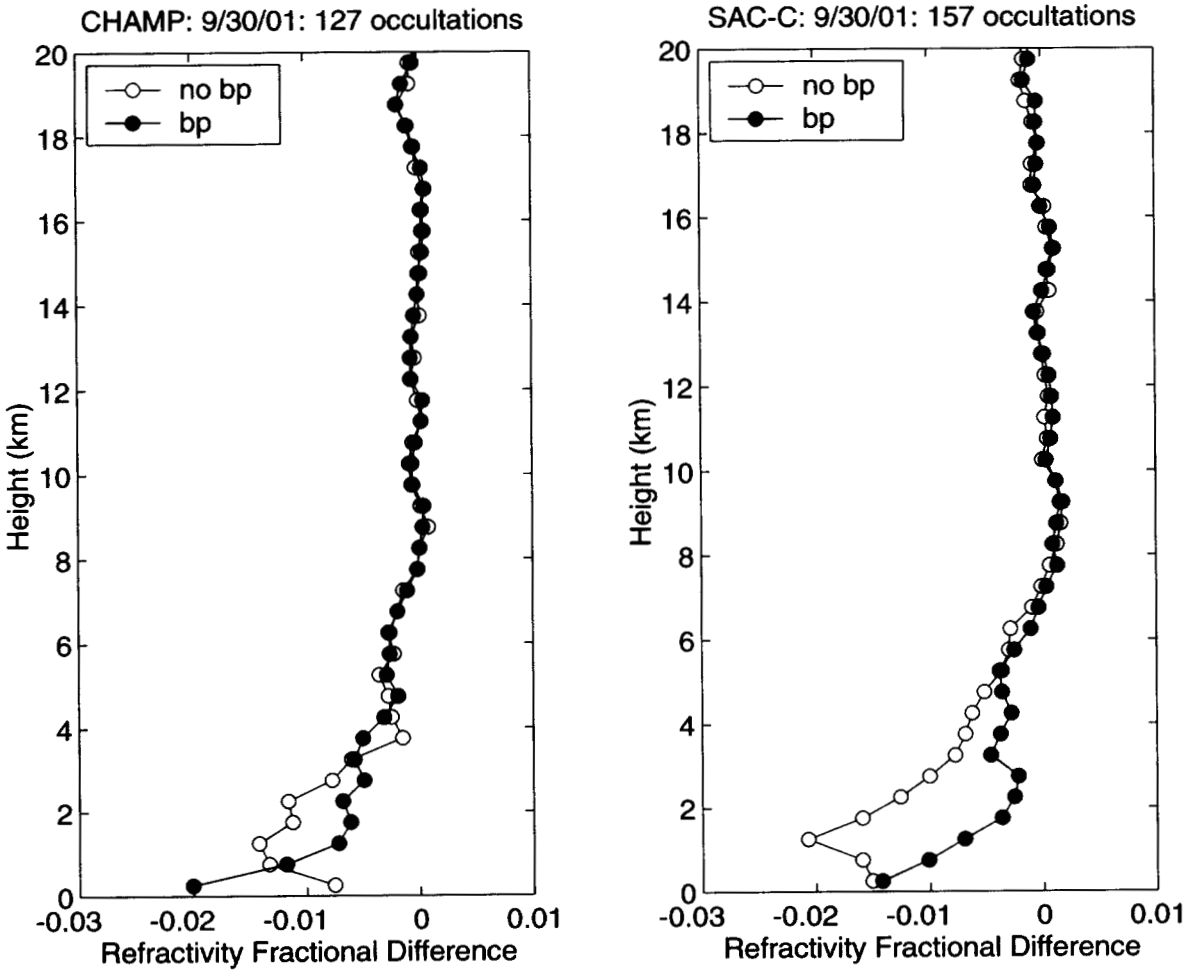
Our database of GPS occultations can provide:

- **Independent data set with high vertical resolution and self-calibrating:** It is generally felt that confidence in trends requires 2 independent measurement systems. GPS radio-occultations provides measurements of processes that other instruments cannot capture well.
- **Indirect detection of ultrathin cirrus clouds:** Occultations have a very high vertical resolution. Thin subvisible cirrus clouds might be detected through their signature in upper tropospheric temperatures. They are important for chemistry via heterogeneous reactions and possibly for scavenging (e.g. of HNO_3).
- **Detection of Gravity waves in the upper troposphere/lower stratosphere:** Gravity waves affect thermodynamical equilibrium and thus the reaction dynamics near the tropopause (Voigt et al. 2000: GRL **27**, 3873-3876). The quality of gravity waves detection by GPS radio-occultations has been cross-validated (Preusse et al. 2000: GRL **27**, 3877-3880).
- **Measurements of the Thermal Tropopause structure and dynamics:** GPS can capture temperature profiles with a sub-kilomieter resolution. High tropopause regimes correspond to low stratospheric temperatures, and they also correlate with a lower abundance of total ozone above it.

Where? at http://genesis.jpl.nasa.gov

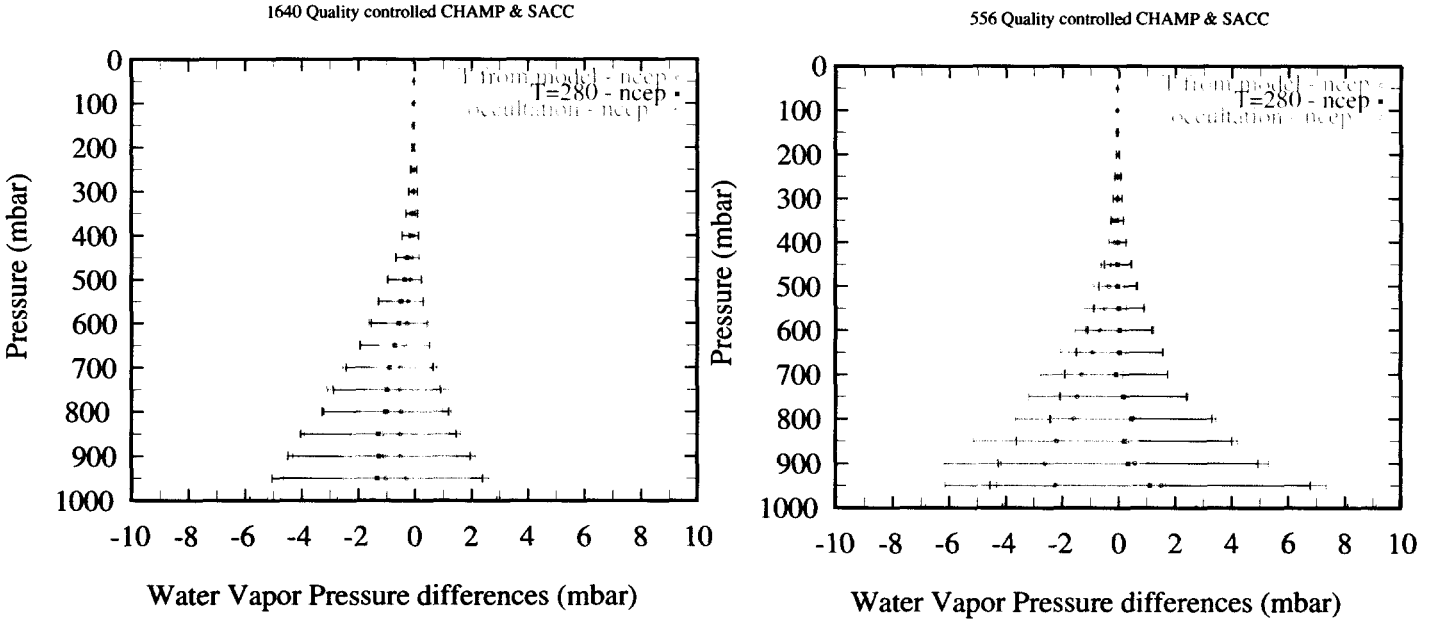
Open issues:

Negative refractivity bias in the lower troposphere:



Separating the water vapor contribution in the lower

troposphere:



Figures: 4000 occultations from SAC-C and CHAMP were chosen. Out of those, the ones where the refractivity differed from NCEP by less than 10% were kept to make a comparison of water vapor retrievals. Of these about 30% resulted in negative water vapor pressure values at some heights with the standard processing. The mean and standard deviation of the differences with NCEP are shown in both figures as a function of height.

Left figure shows the cases where water vapor pressure remained positive. Right figure corresponds to the cases where some values became negative.