A DATABASE OF ATMOSPHERIC REFRACTIVITIES FROM GPS RADIO OCCULTATIONS

by

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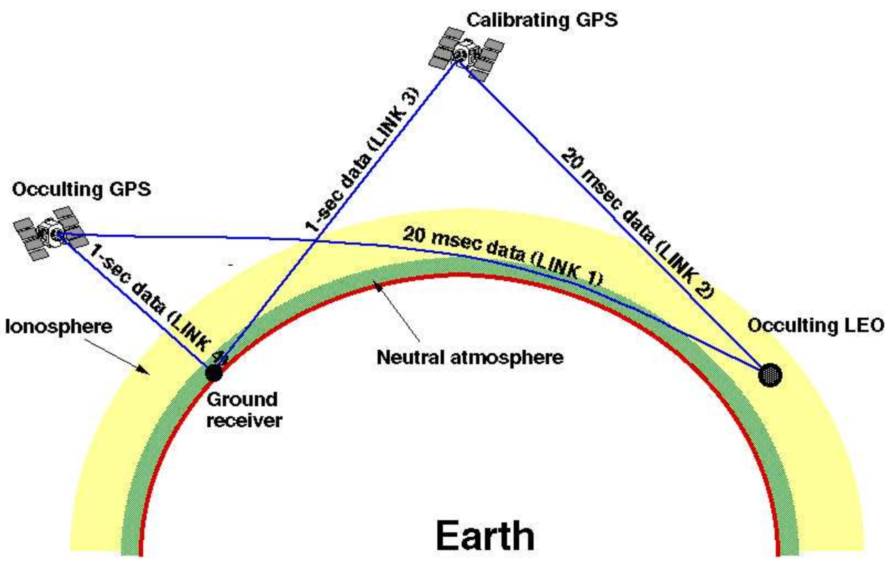
Abstract:

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 refractivities as a function of altitude up to the 60km above the surface which can be converted into geopotential heights, pressure, and temperature. These data are being made available to the community interested in operational applications. The characteristics and quality of the data will be described.

Acknowledgments: The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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:

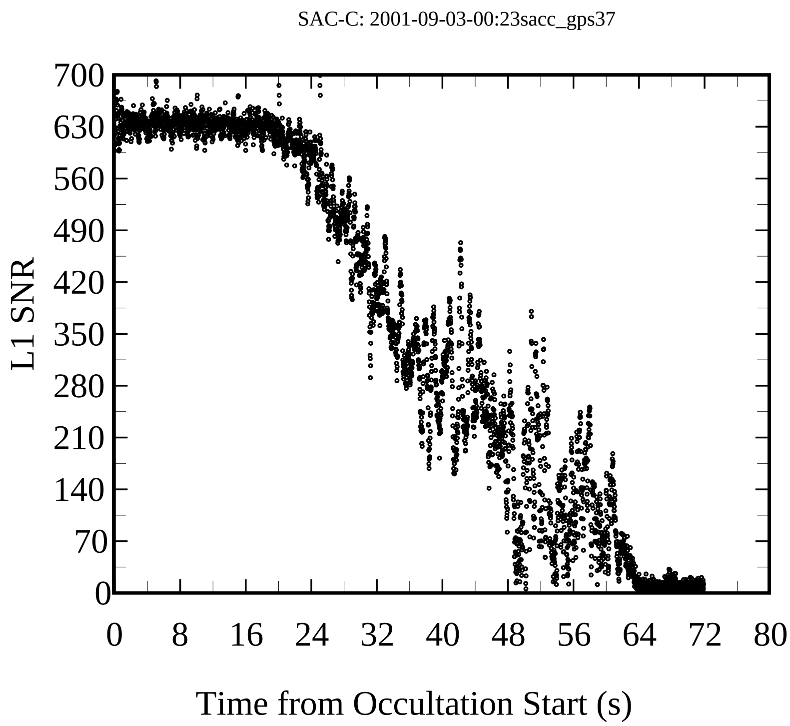
$$P_k = \rho + \eta_k + \frac{I}{f_k^2} \qquad L_k = \rho + \eta_k - \frac{I}{f_k^2}$$

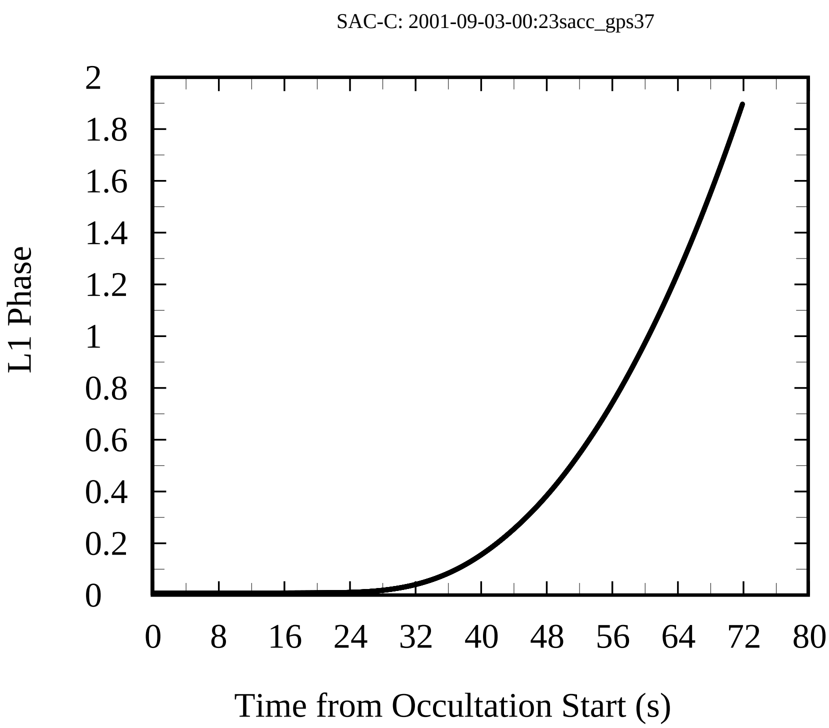
Where P_k, and L_k are delays of group and phase velocity, ρ is distance, η_k is atmospheric delay, I is ionospheric delay; $f_1 = 154 \times 10.23 MHz$, $f_2 = 120 \times 10.23 MHz$;

Three steps:

Orbit determination → Clock calibration → Retrieval.

Signals tracked: Amplitude and Phase delay.





Retrieving atmospheric variables

Geometric optics: (Current)

Using phase delay information only.

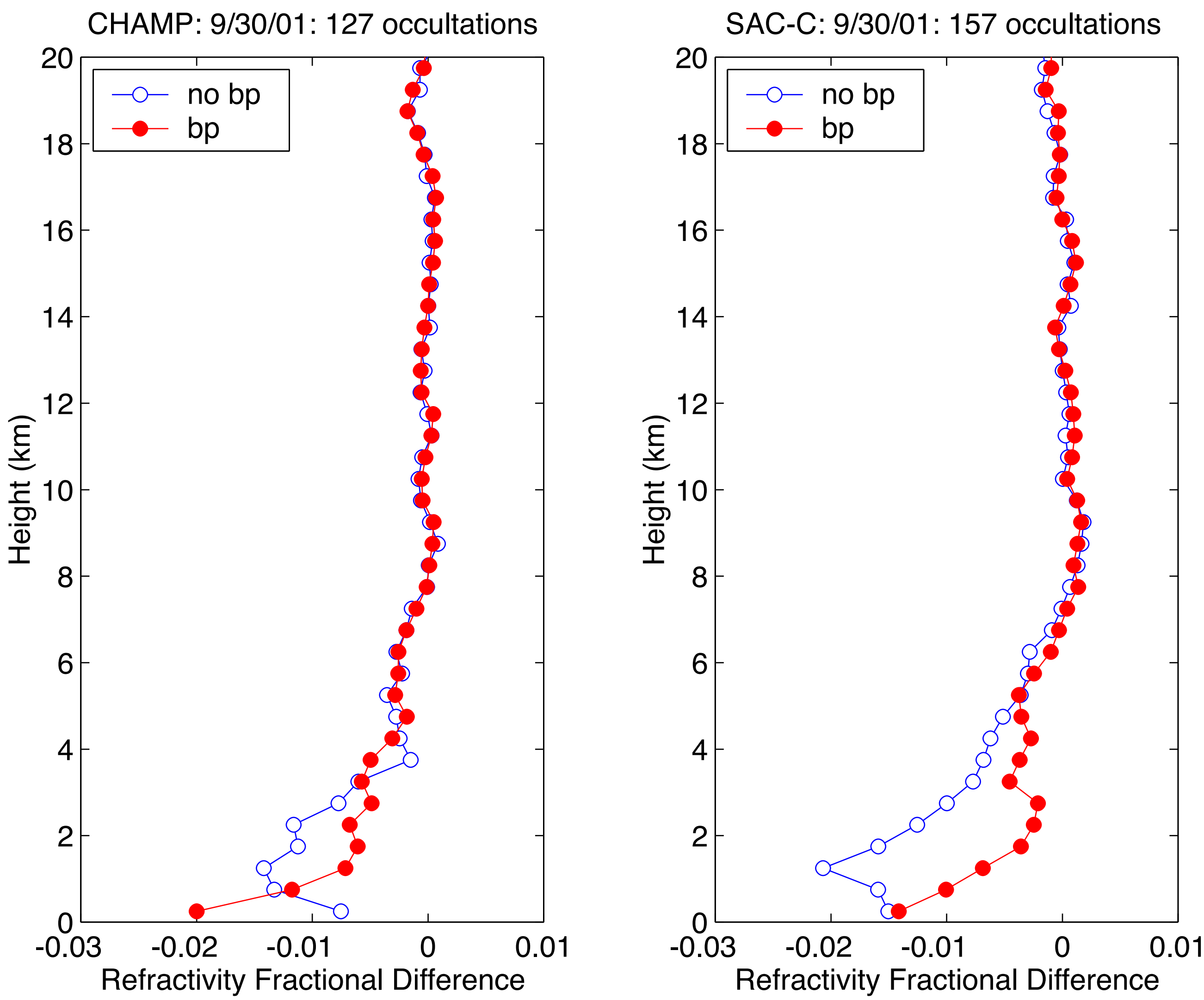
$$\frac{d}{ds}\left(n\frac{d\mathbf{r}}{ds}\right) = \nabla n \qquad \rightarrow \qquad \frac{d}{ds}(\mathbf{r} \times n\mathbf{s}) = \mathbf{r} \times \nabla n \tag{1}$$

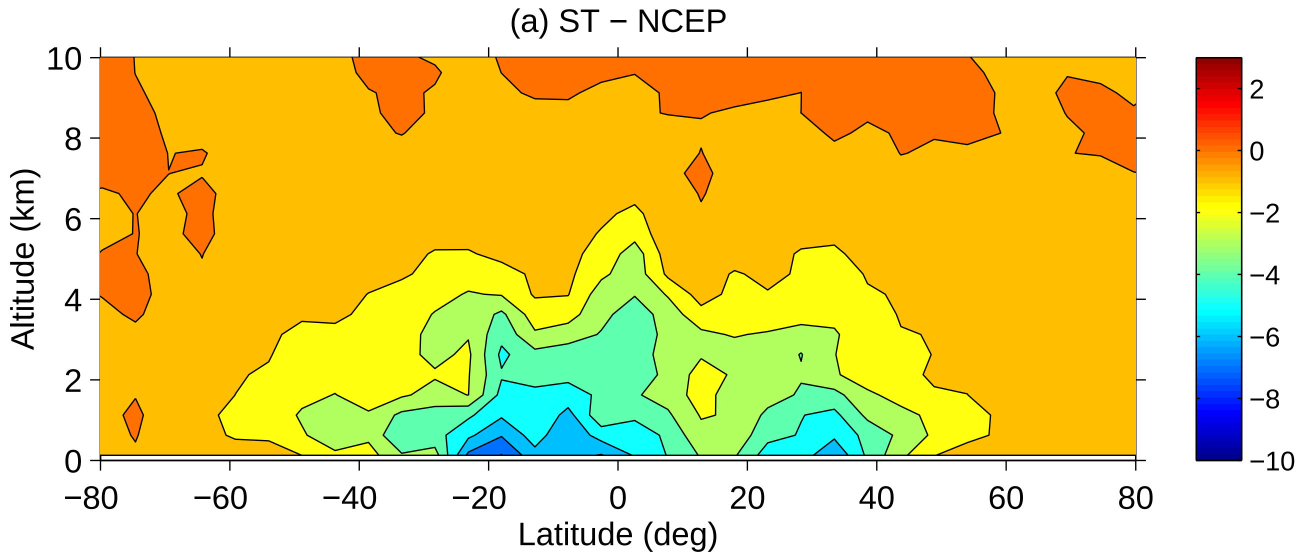
Under spherical symmetry:

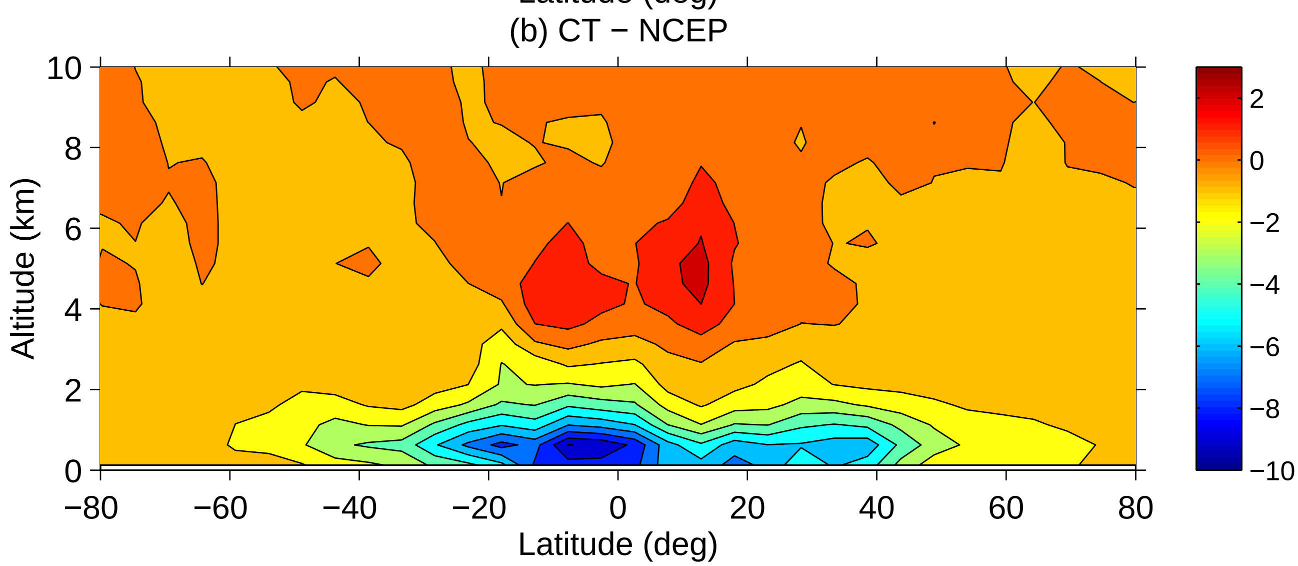
- $rn \sin\phi = a$, with a, the impact parameter.
- $\frac{d\alpha}{dr} = \left(\frac{d\ln n}{dr}\frac{a}{\sqrt{n^2r^2 - a^2}}\right) \qquad \rightarrow \qquad \pi \ln[n(a)] = \int_a^\infty \frac{\alpha(a')da'}{\sqrt{a'^2 - a^2}}$.
  with α the bending angle

Wave optics: (On implementation)

Using amplitude and phase delay information where the measured signal is $U(\mathbf{r}') = A(\mathbf{r}')e^{i\varphi(\mathbf{r}')}$. It is then backward "propagated" using diffraction integral.


CHAMP: 9/30/01: 127 occultations
no bp
bp
Height (km)
Refractivity Fractional Difference
SAC-C: 9/30/01: 157 occultations
no bp
bp
Height (km)
Refractivity Fractional Difference


(a) ST − NCEP
Altitude (km)
Latitude (deg)
10
8
6
4
2
0
−80
−60
−40
−20
0
20
40
60
80
2
0
−2
−4
−6
−8
−10


(b) CT − NCEP
Altitude (km)
Latitude (deg)
10
8
6
4
2
0
−80
−60
−40
−20
0
20
40
60
80
2
0
−2
−4
−6
−8
−10

Retrieving temperature and water vapor:

The typical retrieval uses:

1. $$N = k_1 \frac{p}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2} = R\left[\frac{k_1}{M_a}\rho + \frac{\rho_v}{M_v}\left(k_2 + \frac{k_3}{T}\right)\right] \qquad (2)$$

   Where N is refractivity, T is temperature in Kelvin, p is total pressure in millibar, e is water vapor pressure in millibar, $k_1 = 77.6$ K/mbar, $k_2 = -12.81$ K/mbar, and $k_3 = 3.776 \times 10^5$ K^2/mbar.

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

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

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

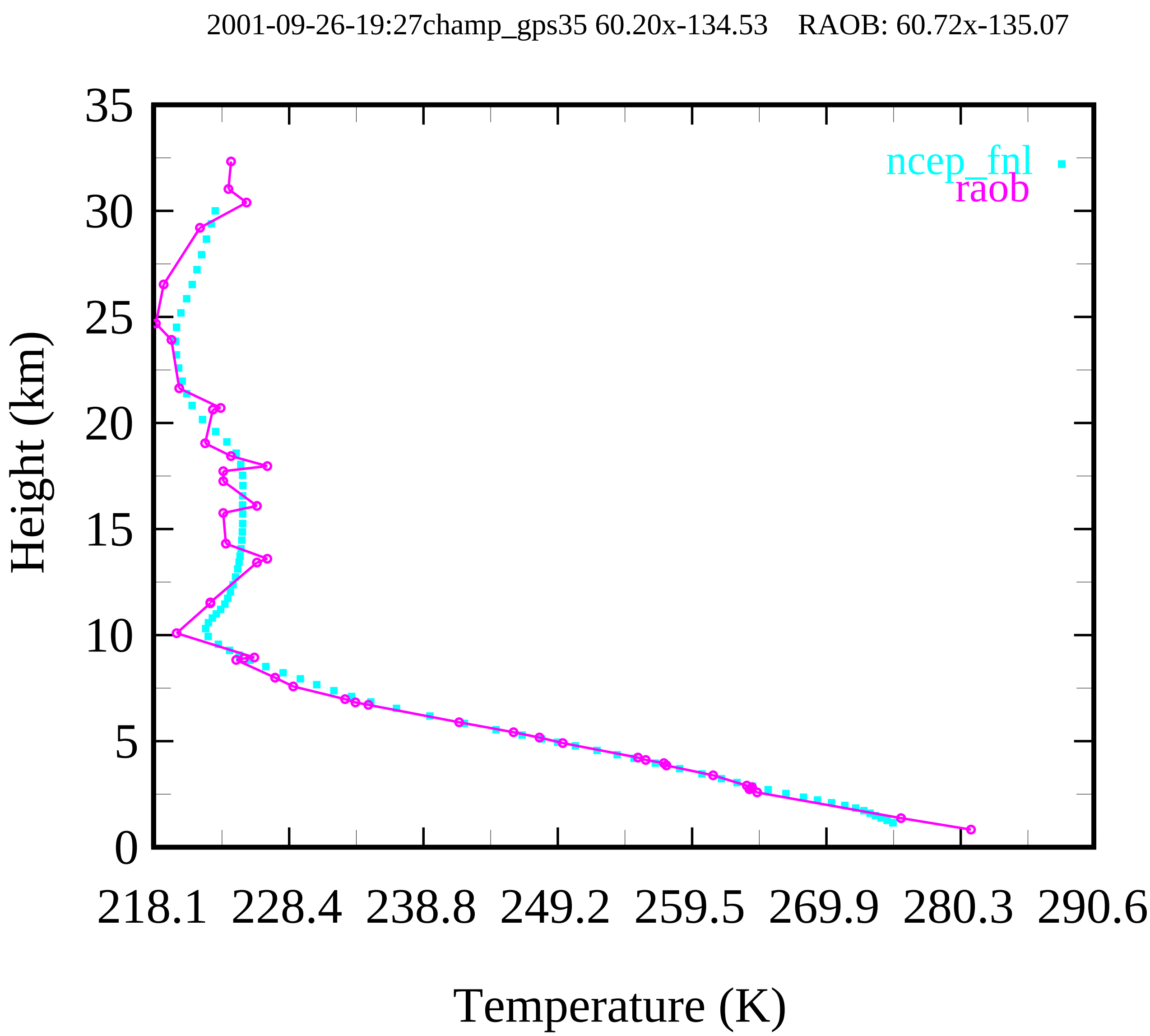
$$T(z) = T(z_o)|_{model} - \frac{g M_a \int_{z_o}^{z} N dz}{RN}.$$

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 precision between 5-30 km altitude.
- Global coverage.
- Self-calibrating.
- Long term stability.
- All weather conditions (clouds, rain or aerosols).
- Gives profiles of electron density in the ionosphere



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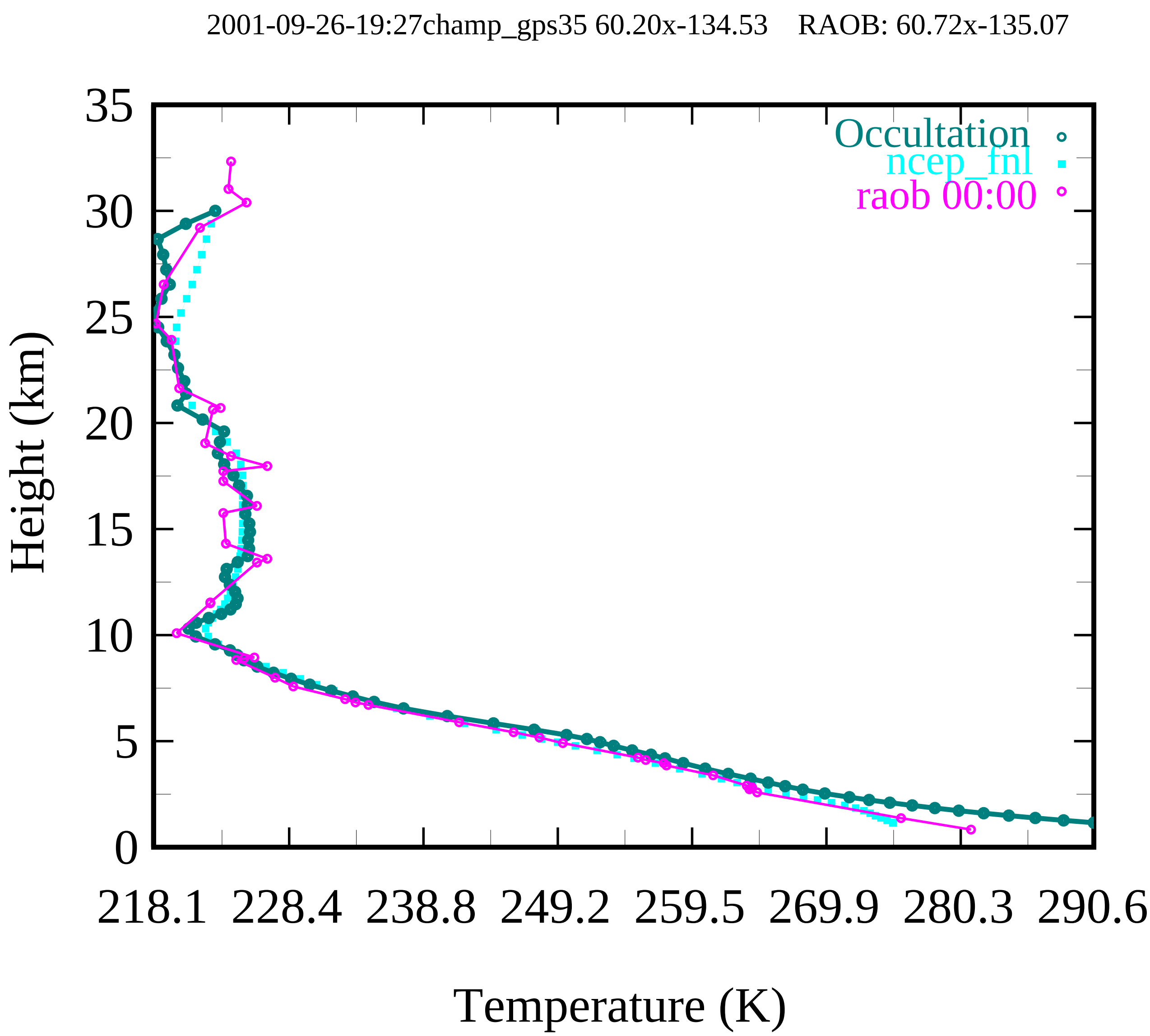


Coverage of the lower troposphere:

GPS/MET: First prime period 4/24-5/5 1995 (No Fly Wheeling)

Lat(N&S)	<0.5km	<1km	<2km	<3km	<4km	< 6km	< 8km
<30	4.76	9.52	21.43	35.71	52.38	78.57	95.24
30-60	6.78	10.17	28.81	47.46	54.24	86.44	89.83
< 60	7.69	15.38	23.08	46.15	69.23	92.31	96.15
Global	6.30	11.02	25.20	43.31	56.69	85.04	92.91

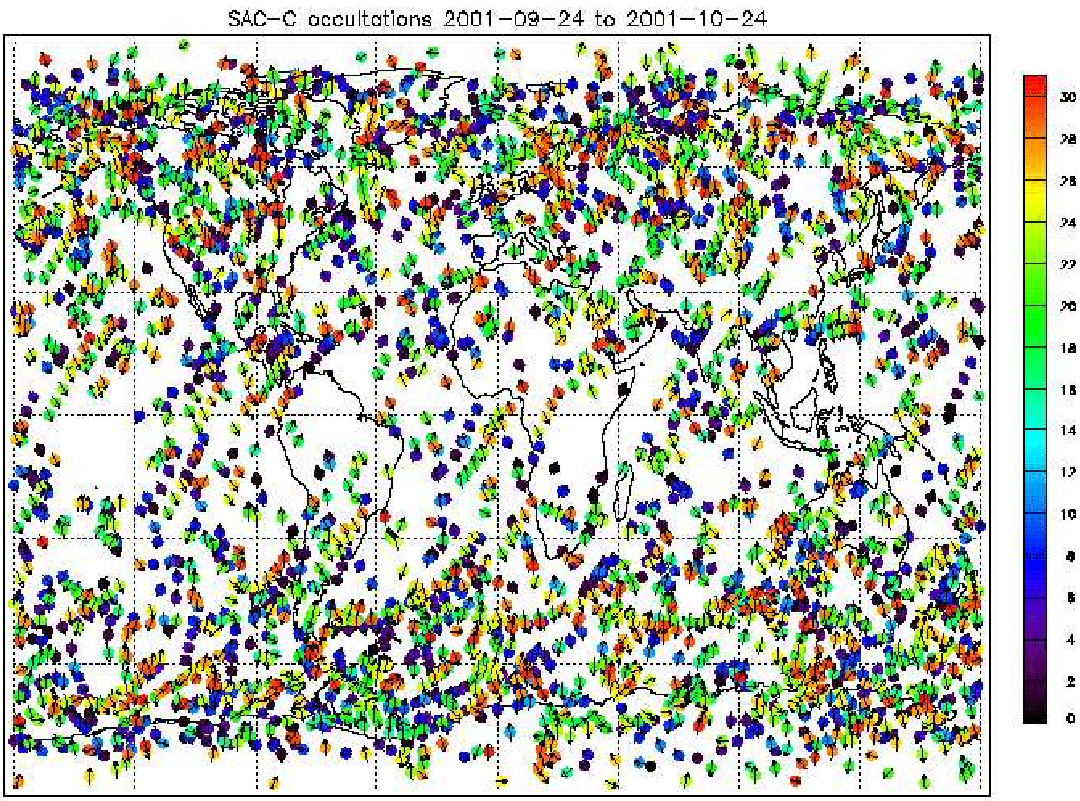
GPS/MET: Second prime period 6/12-7/4 1995 (5 sec Fly Wheeling)

Lat(N&S)	<0.5km	<1km	<2km	<3km	<4km
< 30	20.07	37.46	65.89	87.29	94.31
30-60	35.05	62.23	85.05	93.75	97.28
< 60	47.83	72.05	90.06	96.89	99.38
Global	32.13	55.19	79.11	92.03	96.62

CHAMP: Period 3/29-4/01 2001 (5 sec Fly Wheeling)

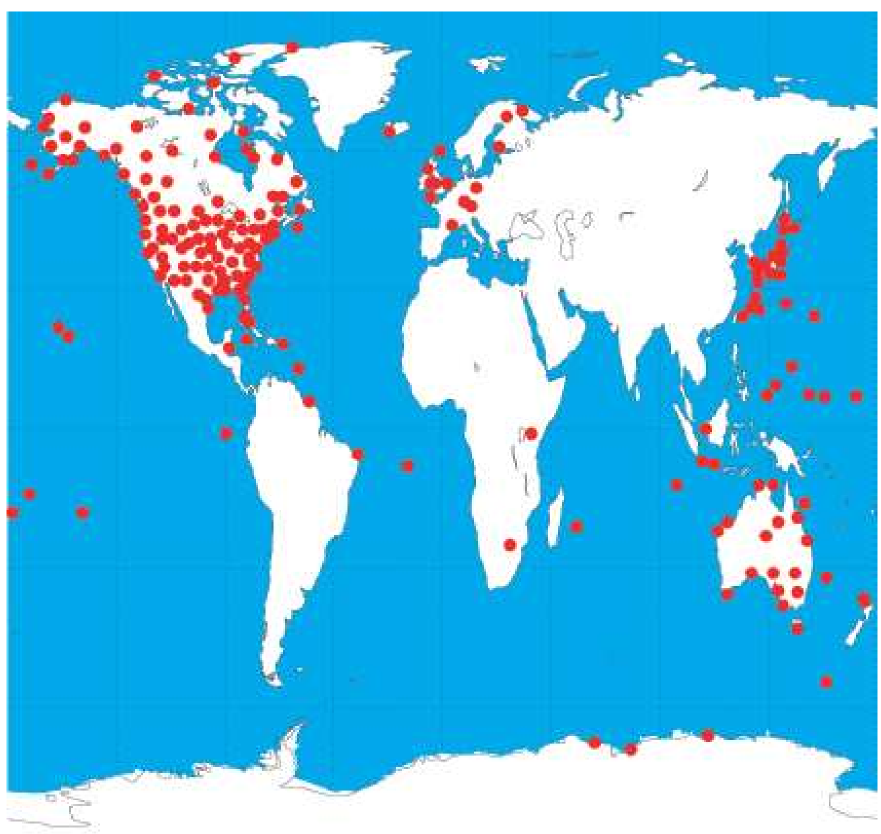
Lat(N&S)	<0.5km	<1km	<2km	<3km	<4km
< 30	64.20	79.01	92.59	96.30	98.77
30-60	73.55	87.60	96.69	99.17	100.00
< 60	72.37	73.68	85.53	92.11	100.00
Global	70.50	81.29	92.45	96.40	99.64

Spatial coverage 1 satellite in 1 month:

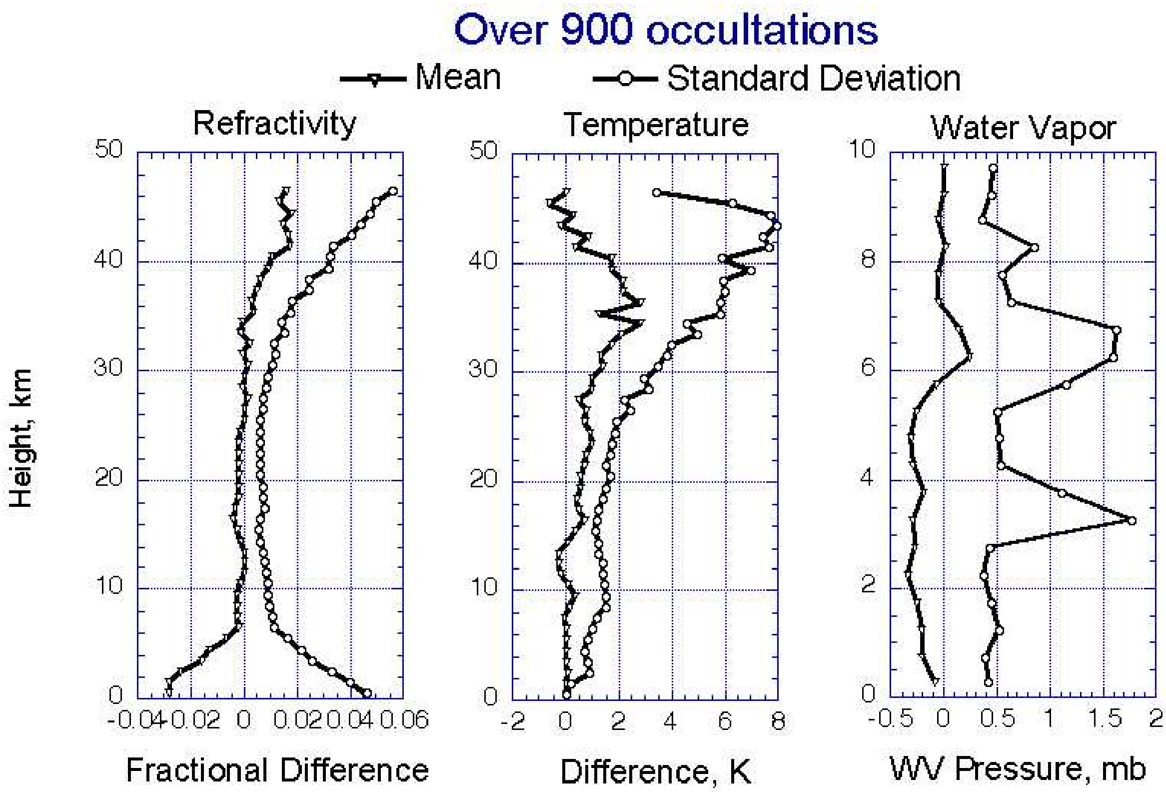


Global coverage vs. high vertical resolution radiosonde data:

SPARC Initiative, 2001

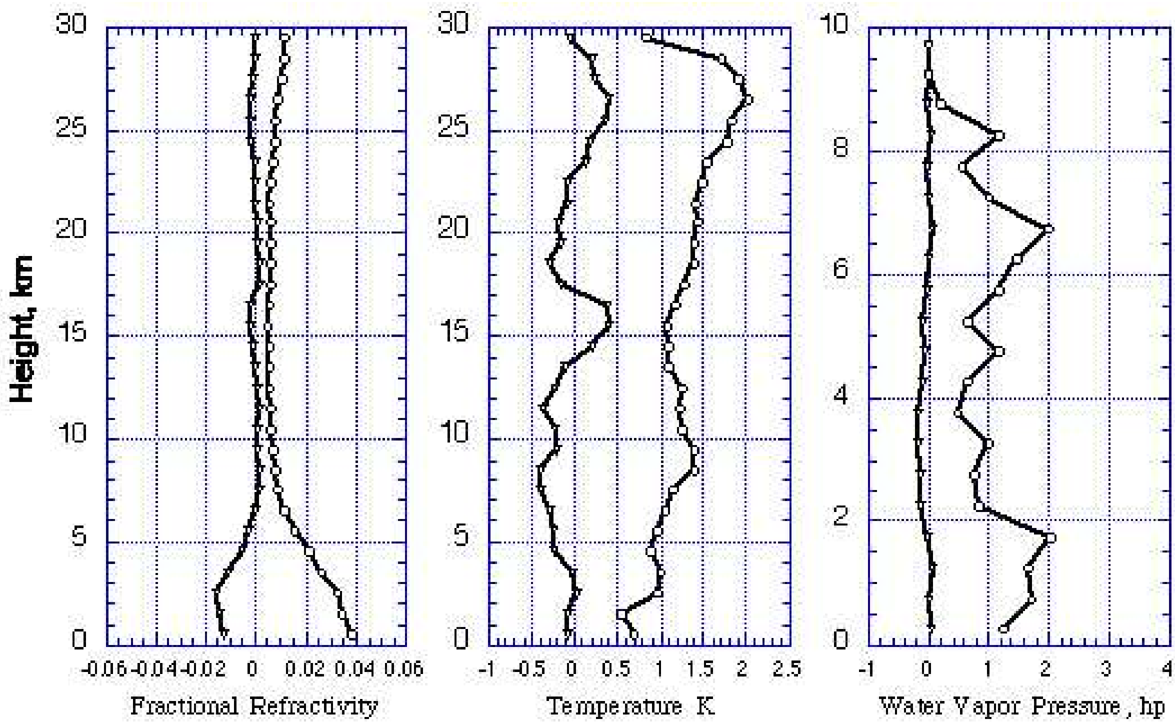


Connection with other climate efforts



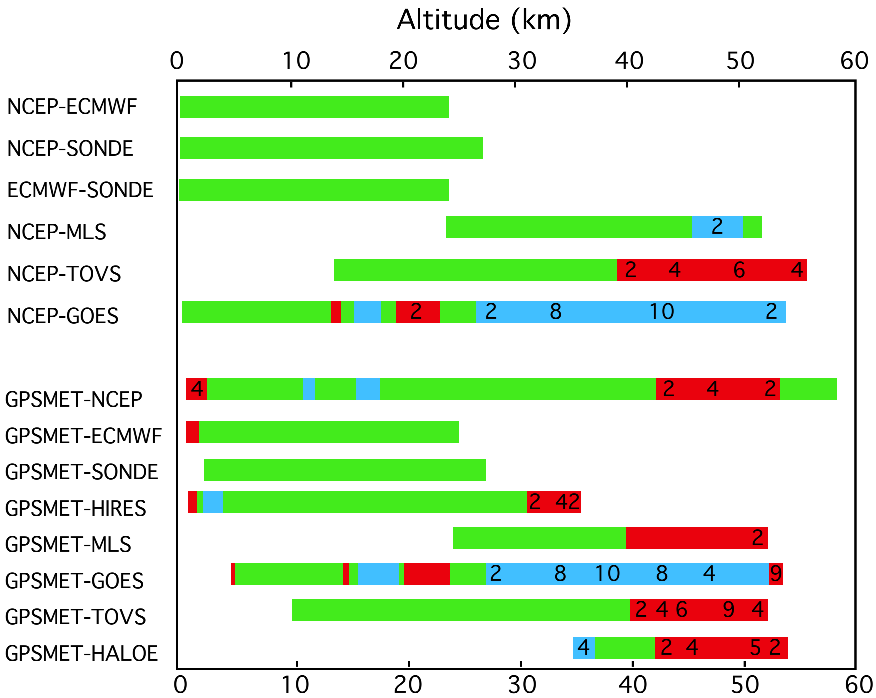
Comparisons of CHAMP with ECMWF ←

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×(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.
- **Refractivities up to 60 km:** Currently published as level 2 product up to 30 km, until 2002-09-29.
- **Link orientation.**

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