

**GPS Radio-occultations coming of age: TWO SPACECRAFT LAUNCHES ADD TWO
NEW INSTRUMENTS FOR CLIMATE MONITORING.**

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GPS Radio occultations are active limb soundings which measure the time delay of the GPS signal propagating through the atmosphere. This time delay can be related to vertical profiles of atmospheric refractivity from which highly accurate profiles of geopotential height, temperature, pressure, and specific humidity are derived. With their global coverage, self-calibrating nature, insensitivity to clouds, and high vertical resolution, atmospheric radio occultations hold great promise for weather prediction and climate monitoring. The accuracy and use of GPS atmospheric profiling in weather, climate and ionospheric applications has been previously addressed (*Kursinski et al.*, 2000; *Anthes et al.*, 2000, *e.g.* and references therein for detailed reviews), but the potential of this technique in scientific investigations has not been fully realized due to the limited data available. Until this year only the GPS/MET instrument (*Ware et al.*, 1996) was able to produce significant results with data collected between 1995 and 1997. That instrument was launched in a collaboration among the University Corporation for Atmospheric Research (UCAR), the University of Arizona, and the Jet Propulsion Laboratory (JPL) to prove the feasibility of this sounding technique.

In the year 2000, two satellites, the German CHAMP and the Argentinian SAC-C, were launched carrying a new generation of GPS receivers, the “Blackjack”. Developed at JPL, two Blackjacks have been collecting up to 500 occultations daily since the middle of 2001. These receivers have enhanced capabilities over the older generation GPS/MET instrument which include “enhanced codeless” tracking (i.e., the ability to track the encrypted GPS

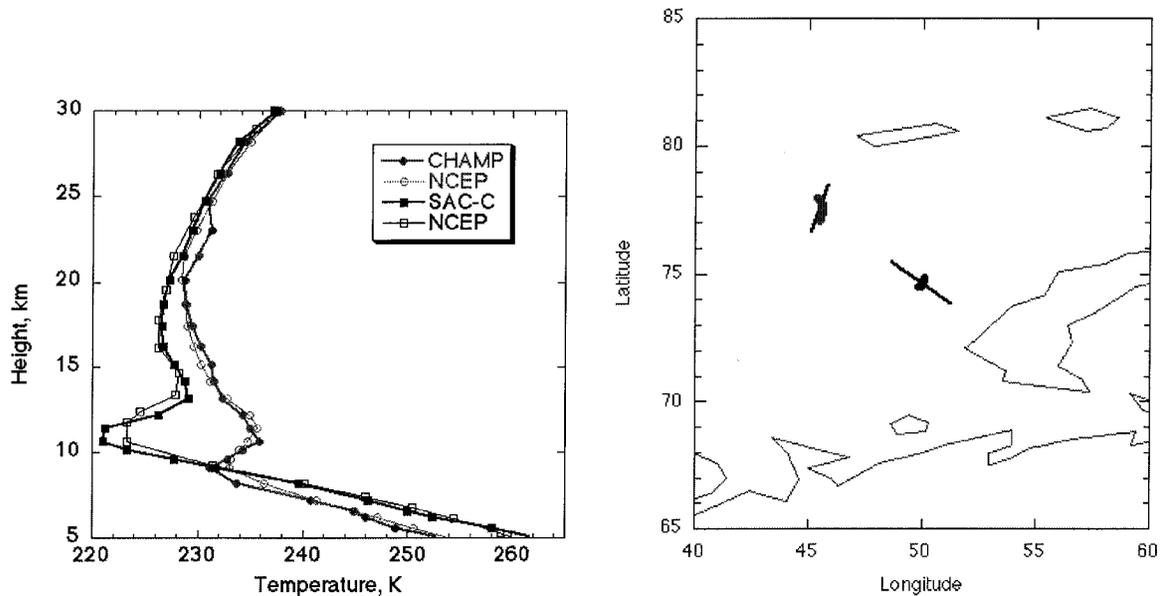


Figure 1: (a) Nearly coincident profiles from CHAMP and SAC-C and the corresponding profiles from semi-daily NCEP analyses interpolated to the locations and times of the GPS occultations. (Bottom). (b) Map of the geometry of the CHAMP (at 45E) and SACC (at 50E) occultation shown shown in 1.a. The spread of the points indicates the drift of the tangent point during the occultation. The lines indicate the direction of the occultation links extended over 200 km. The CHAMP and SAC-C occultations are separated by 300 km and occurring on July 11, 2001 at 1600 and 1800 UTC, respectively.

signals), higher signal-to-noise ratio, and tracking lower in the atmosphere. The two GPS receivers are capturing high vertical resolution profiles over land and oceans and are expected to provide data complementary to other sounding techniques. From this point on, the amount of data is expected to increase somewhat with ongoing enhancements of the receiver's software and with the launch of the GRACE mission carrying GPS occultation instruments aboard each of its two satellites. By the end of 2001, it is expected that up to 1250 occultations will be collected daily.

Some features of GPS radio occultations

To illustrate some of the features of radio occultations we show two occultations from CHAMP and SAC-C (Figure 1.a). The two occultations were chosen because of their (1) proximity and (2) quite distinct features. Shown also in Figure 1 are two profiles based

on semi-daily analysis from the National Centers for Environmental Prediction (NCEP) interpolated to the locations and times of the occultations. A notable strength of occultation measurements is the ability to resolve the structure of the thermal tropopause with high vertical resolution. We notice that the retrieved temperatures are colder and warmer than the analyses below and above the tropopause, respectively. This can be explained by the lower vertical resolution of the analysis which is effectively smoothing the structure around the tropopause. Such high resolution can be of great significance for addressing global change as a function of height, or the problem of water vapor transport across the tropopause which is important for the understanding of the chemistry and dynamics of the lower stratosphere. The proximity of the occultations (Figure 1.b) yet their distinct features and resemblance to the analyses is an indication that occultations are capable of resolving horizontal features that are significantly smaller than 300 km (the distance between the two occultations).

From a climate monitoring point of view, radio occultations can provide an excellent long-term record due to their high accuracy and self-calibrating features. Because they rely on time delay (rather than intensity) measurements, and because they either start or end at a zero atmospheric delay, their absolute calibration is relatively easy to achieve. This implies that measurements taken today by one mission and a decade later by a different mission can be compared directly without concern for instrumental biases. Temperature accuracies of radio occultations are estimated to be sub-Kelvin between 5-35 km for individual occultations. More importantly, averaged ensembles of occultations that would be used for climate monitoring are estimated to have an accuracy of < 0.1 K. Such accuracy implies that climate trends can be detected with relatively few years of continuous monitoring. Statistical comparisons of 962 CHAMP occultations to NCEP analysis (Figure 2) indicate that the two sets of temperatures are consistent to better than 1.5 K below 20 km, and to better than 0.5 in the mean everywhere between 0-30 km. The relatively large oscillation in the mean temperature difference between 7-17 km can be attributed to the inferior vertical resolution of the model as mentioned earlier.

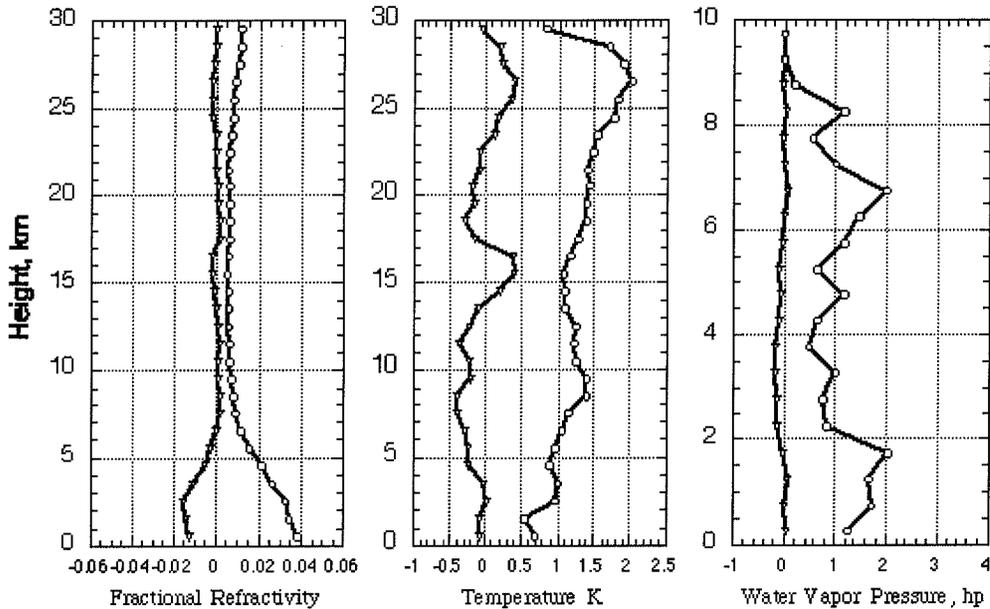


Figure 2: Statistics on 962 CHAMP occultations collected during 8 days in April, 2001. From left to right, the mean and standard deviation of fractional refractivity difference, temperature difference and water vapor pressure difference between CHAMP occultations and NCEP analysis interpolated to the location and time of the occultations are shown.

Another essential strength of radio occultations is the ability to penetrate through clouds. This allows sounding at altitudes lower than other techniques under cloudy regions. Because it offers global coverage, radio occultation is particularly important for better understanding of the Southern Hemispheric climate where data coverage is usually poor.

These characteristics of GPS radio occultations have made them attractive for data assimilation in climate and weather models. NASA's office for Data Assimilation, NOAA, NCAR, and the United Kingdom Meteorological Office are some of the institutes working on the assimilation of occultation soundings for weather prediction. GPS radio occultations can also be used for validating other remote sensing instruments, especially in areas where radiosonde measurements are not available. A JPL website and ftp server are being developed to help support these and other applications.

How to obtain GPS radio occultation data from JPL

Very soon the commissioning phases for CHAMP and SAC-C will be over, and JPL will release occultation data to be freely available to the general community. GPS data from CHAMP will be released by the 2 major processing centers associated with this mission, JPL and GFZ. SAC-C data will also be available through JPL and the other partner center at CONAE. The data can be reached through JPL's *Genesis* data system at (<http://genesis.jpl.nasa.gov/>). Raw data (Level 0) from the SAC-C mission have already been released by JPL. Besides raw data, occultations processed by JPL and documentation on how to read the files will be available from the *Genesis* web-site cited above. Occultations processed by JPL will include profiles of atmospheric excess delay, Doppler, bending, refractivity, geopotential heights, pressure, temperature, and specific density of water vapor. This will be offered for all available data from GPS/MET, OERSTED, CHAMP, SAC-C, and GRACE. The table below shows the experiment dates for each of these missions.

Mission	First processed data	Last processed data
GPS/MET	April 04 1995	March 1997
OERSTED	January 24, 2000	April 28, 2000
CHAMP	April 6, 2001	Present
SAC-C	July 7, 2000	Present
GRACE	Launch in November 2001	

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