Journal of Global Positioning Systems (2002)
Vol. 1, No. 1: 58-60

Journal of Global Positioning Systems
2002
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An Overview of Atmospheric Radio Occultation

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Received: 30 April 2002 / Accepted: 30 April 2002

Biography

Thomas P. Yunck, holds a bachelor's degree in electrical engineering from Princeton University and a Ph.D. in systems and information science from Yale University. Since 1978 he has been with the Jet Propulsion Laboratory, California Institute of Technology, where he currently manages the GPS Observatories Office. At JPL, Dr. Yunck has been involved in the development of radio metric techniques for spacecraft navigation and for a variety of related science pursuits. For the past 15 years he has managed the development of technologies to employ the signals from GPS for high precision Earth science and remote sensing. His current work focuses on the development of spaceborne GPS systems for applications in geodesy, atmospheric sounding, and ionospheric imaging.

When a radio signal passes through the atmosphere its phase is perturbed in a manner related to the refractivity along the ray path. Measurements of the phase perturbations can reveal the refractivity, from which one can then derive such quantities as atmospheric density, pressure, temperature, moisture, geopotential heights, and winds. This general technique is known as atmospheric *radio occultation*.

The probing of planetary atmospheres by radio occultation dates to the early 1960s when Mariners 3 and 4, viewed from Earth, passed behind Mars. While radio occultation has probed planets and moons throughout the solar system, it has as not found operational application to Earth, for two reasons. First, the observation requires both a radio source and a suitable receiver off the planet, outside the atmosphere; seldom have we had such matched pairs in Earth orbit. Second, to be of use in studying Earth's atmosphere, the nature of which we know well, such measurements must be continuous, comprehensive, synoptic. We therefore need many transmitters and receivers aloft at once, densely sampling the global atmosphere every few hours.

In the late 1980s, a group at JPL proposed observing GPS signals from space to make atmospheric soundings, as shown in Fig. 1. Briefly, the observed Doppler shift in the GPS signal induced by atmospheric bending permits accurate estimation of the atmospheric refractive index. From that one can retrieve, in sequence, profiles of the atmospheric density, pressure, and temperature (or, in the lower troposphere, water vapor) with high accuracy (<1 Kelvin in temperature) and a vertical resolution of a few hundred meters. Figure 2 shows the predicted accuracy of atmospheric temperature profiles as a function of altitude. In the lower part of the troposphere, the uncertainty in water vapor content, particularly in the tropics, leads to a large error in the recovered temperature. In that region, since it is water vapor that is of greater consequence in weather modeling, it becomes advantageous to adopt nominal temperature lapse rates and instead recover water vapor profiles.

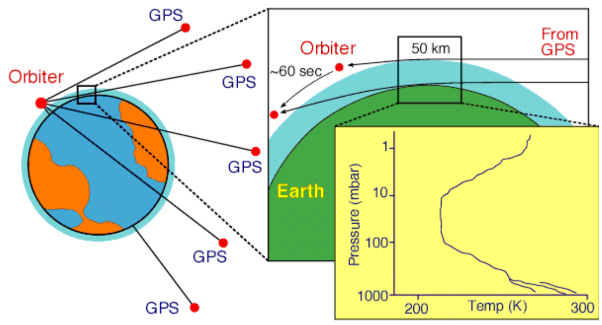

Fig. 1 Atmospheric temperature profiling by GPS occultation

A single satellite can recover more than 500 profiles each day, distributed almost uniformly around the globe; a large constellation would recover many thousands of profiles, which could one day have a profound impact on both long term climatological studies and short term weather modeling.

In the early 1990's, a group led by the University Corporation for Atmospheric Research (UCAR) succeeded in obtaining sponsorship from the U.S. National Science Foundation for a low-cost demonstration experiment called GPS/MET. UCAR and JPL converted a low cost geodetic ground receiver to fly in space and acquire the occultation data.

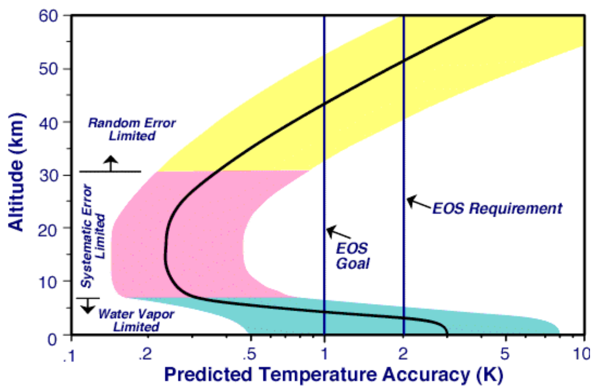

Fig. 2 Approximate occultation temperature accuracy vs altitude.

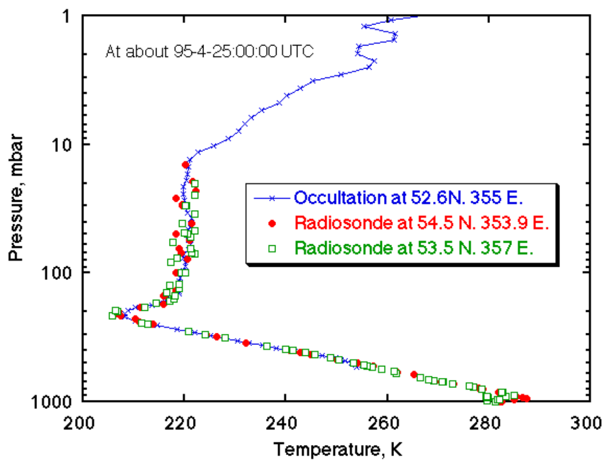

Fig. 3 GPS temperature profile compared with two radiosondes.

Figure 3 shows a typical GPS/MET temperature profile, along with nearby radiosonde measurements for comparison. Recently, five new spacecraft have been launched into low Earth orbit carrying NASA occultation receivers: CHAMP (Germany), SAC-C (Argentina), GRACE (2 spacecraft, US/Germany), and IOX (US). Still others are being planned by the US, Europe, Japan, Brazil, and Taiwan.

While these missions will do much to advance spaceborne GPS science, they will not in themselves establish an ongoing presence of large numbers of GPS sensors in earth orbit. It is the hope of the growing GPS Earth science community that a permanent constellation of a dozen or more occultation sensors may emerge in the near future.

There has been much speculation on how this might unfold. In one view, the model of a dedicated constellation will be taken to its logical extreme: flight systems will be further miniaturized and we will see dedicated constellations of dozens or more free-flyers, each with a mass of a few kilograms (Fig. 4). There is much to be said for this view. Consider that the next generation of miniature occultation receiver will also provide:

- Real time onboard position, velocity, attitude, and timing
- All onboard spacecraft computation and control
- Uplink extraction and command interpretation

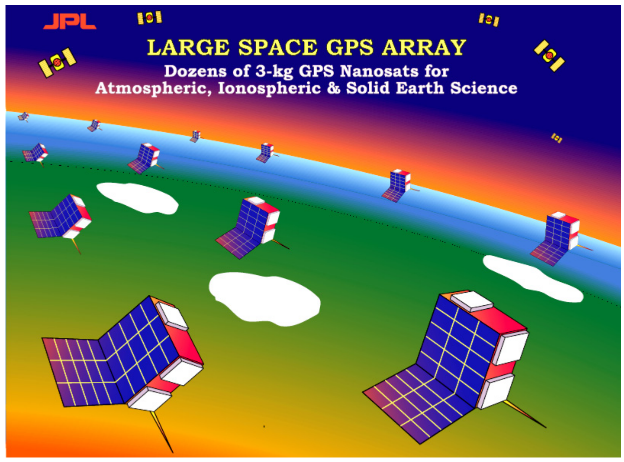

Fig. 4 Concept for a pilot constellation of spaceborne GPS sensorcraft for Earth science.

Equipped with a cell-phone chip, each orbiter will send its data directly to a computer which, within minutes, will generate and distribute finished science products. No special ground systems are needed for tracking or data downlink, and operations crews would be eliminated. These modest components can in principle be packaged in a tiny spacecraft weighing just a few kilograms.

Another view holds that these same virtues will make the GPS sensor irresistible as an add-on to constellations already planned. The miniature receiver/processor can assume the functions of several discrete spacecraft subsystems, lowering mass, power, and cost in a cascade of economies, while providing a valuable new science dimension. The cost of adding GPS science to a suitable constellation would be small.

In the immediate future, the latter scenario may be more likely. The investment needed to realize the sensorcraft concept is not trivial and science agencies tend to proceed with caution. The vision of great constellations has instead been taken up by industry, which has already deployed several commercial constellations, and to a lesser extent by the military. Together these constellations will comprise hundreds of spacecraft wonderfully suited to GPS occultation sensing. Whichever direction the future takes it promises to be a rewarding one for those engaged in exploring our complex Earth system.

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