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GLOBAL IMAGES OF IONOSPHERIC ELECTRON DENSITY OBTAINED WITH THE GPS RADIO OCCULTATION TECHNIQUE

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The effects of the Earth's neutral atmosphere and ionosphere on signals of the Global Positioning System (GPS) present themselves as a source of error for navigation on the one hand and a very effective means for studying the Earth's neutral atmosphere and ionosphere on the other hand. After reviewing the effects of the ionosphere on the GPS signal including phase delay, bending and scintillation, we will present how these effects are used to map electron densities and irregularities in the ionosphere. Particularly we will talk about the GPS radio occultation technique and how it provides a powerful method for monitoring the ionosphere.

The idea of using radio occultations to sense the neutral atmosphere and the ionosphere was first used in planetary exploration, and has a heritage of about 30 years. As part of NASA's Mission To Planet Earth program, scientists at JPL (Yunck T. P. et al., *Proc. of IEEE position location and navigation symposium*, Orlando, 1988) proposed putting a receiver on a Low-Earth Orbiter (LEO) to track GPS as it occults behind the ionosphere and neutral atmosphere (Fig. 1). The bending induced by the atmosphere on the signal (α in Fig. 1) is detectable through the extra Doppler shift induced on the signal. Using a spherically symmetric model of the ionosphere in the locality of the tangent point of the occultation (defined as the point on the link that is closest to the Earth's center), a refractivity profile of the atmosphere can then be obtained from the bending information via an Abel integral transform. This concept was first realized with the launch of MicroLab-1 in March 1995 by the Orbital Sciences Corporation, a satellite that has a 730 km altitude, 70° inclination satellite and carries a JPL developed space qualified GPS receiver. The experiment, known as GPS/MET and managed by the University Corporation for Atmospheric Research, has successfully demonstrated the usability of the GPS radio occultation signals to obtain accurate profiles of temperature in the upper troposphere and lower stratosphere. Profiles of electron densities are also obtained in the ionosphere and are currently being examined to estimate their accuracy by comparing them to models such as the Parametrized Ionospheric Model (PIM) and ionospheric images obtained from ionosondes and incoherent scatter radars.

A single antenna in a LEO tracking GPS with a 360" field-of-view will observe about 750 globally distributed occultations per day. Due to a narrower field-of-view of the GPS/MET antenna and memory limitations on board the satellite, only 100-150 occultations per day are collected from the GPS/MET. A representative coverage of the occultations for one day are shown in sun-fixed coordinates in Fig. 2, where each line corresponds to one occultation. Because the coverage is shown as a function of sun-fixed longitude (which is equivalent to local time), and the fact that the occultations are scattered around the LEO orbit, the LEO samples the ionosphere at about the same latitude and local time for every LEO revolution. The width of the spread of occultations around the

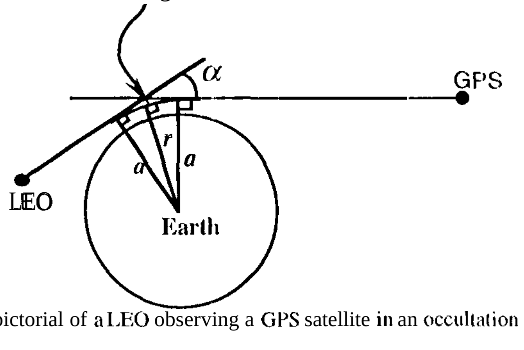

Fig. 1: A pictorial of a LEO observing a GPS satellite in an occultation geometry

LEO track is determined by the width of the field-of-view of the receiving antenna (which is ±30° for GPS/MET).

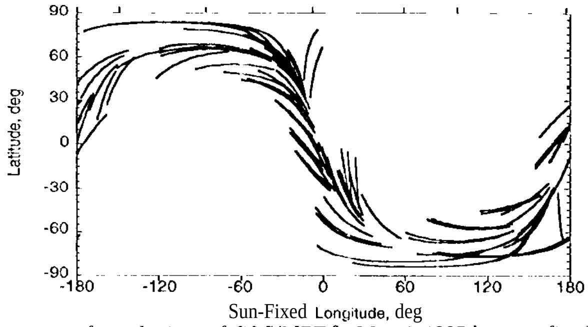

Fig. 2: The coverage of occultations of GPS/MET for May 4, 1995 in a sun-fixed coordinates,

Fig. 3 shows examples of electron density profiles obtained from four occultations that took place on May 4, 1995 between GPS/MET and different GPS satellites. The profiles shown are obtained from consecutive orbits (as indicated from the UT) at about the same geodetical latitude and local time. For comparisons, profiles obtained from the ionospheric Parameterized Model (PIM) are also shown. Observations of this kind provides powerful (and relatively inexpensive) means of monitoring changes in the ionosphere that are taken place on an hourly basis. Fig. 4 shows more examples of electron density profiles obtained at close geodetical latitudes (60-70N) and between 18:34 local time (extreme left) and 23:12 (extreme right),

Our presentation will explain the radio occultation technique and show results from the GPS/MET experiment in the ionosphere. We will also present results on applying tomographic imaging techniques to the same data type and show 3-D images of electron densities and irregularities in the ionosphere.

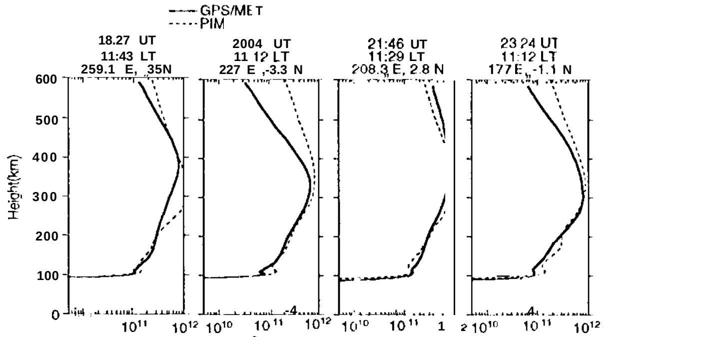

Fig. 3: Examples of electron density profiles (e/m^3) obtained from GPS/MET and PIM for equatorial latitude at about the same local time. Indicated on the Fig. are geodetic latitude and longitude, universal time (UT) and local time (LT)

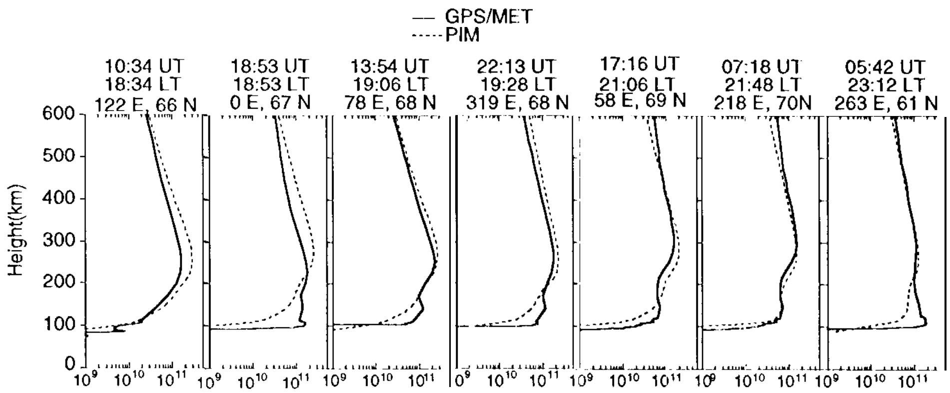

Fig. 4 Same as Fig. 3 but for high northern latitude profiles.