A STUDY ON THE FLUCTUATION OF THE TERRESTRIAL IONOSPHERE
FOR THE RADIO OCCULTATION MEASUREMENTS OF PLANETARY IONOSPHERES

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1. Introduction

We are preparing for the radio occultation measurements by the Mars spacecraft Nozomi, which was launched in July 1998, and by the lunar spacecraft SELenological and ENgineering Explorer (Selene), which will be launched in 2003. Radio occultation measurement is carried out by using a spacecraft which emits unmodulated radio waves to the Earth [*Fjeldbo et al.,* 1968]. The phases of radio waves are perturbed when the rays pass through the planetary atmosphere. The density profiles of the neutral atmosphere and electrons will be derived from the phase perturbation assuming the spherical symmetry of the atmosphere. The information on the nightside ionosphere of Mars is based on the observations by the Mars 4 and 5 and the Viking orbiter [*Lindal et al.,* 1979]. The detection of the lunar ionosphere by radio occultation technique was reported in the Luna 22 mission [*Vyshlov,* 1976]. We try to obtain the electron density profiles of these ionospheres in the Nozomi and Selene missions. The data recording system is illustrated in Figure 1.

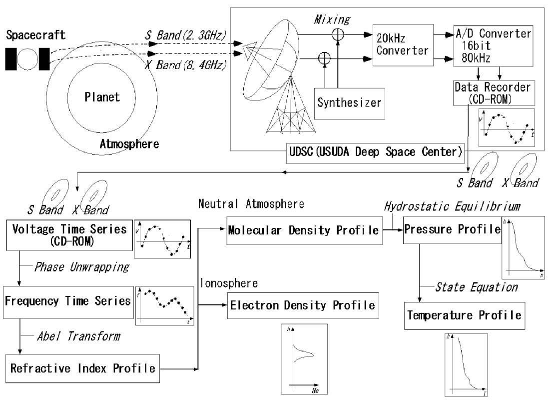

Figure 1: Data recording system at Usuda Station and the data processing procedure.

The error sources of radio occultation measurements are: (1) fluctuation of the plasma density in the terrestrial ionosphere, (2) fluctuation of the plasma density in the interplanetary space, (3) fluctuation of the frequency of oscillator, (4) recording error at the ground station, and (5) deviation of the atmospheric structure from spherical symmetry. The effect of the interplanetary plasma on the radio occultation measurements can be negligible if the ray path is far from the sun, because the power of the fluctuations in the time scale of the radio occultation measurement is small [*Woo et al.,* 1979]. Here we examine the first error source, the density fluctuation in the terrestrial ionosphere.

The fluctuation of the terrestrial Total Electron Content (TEC) along the ray path between the spacecraft and the receiving station will be estimated from two coherent signals transmitted from several Global Positioning System (GPS) satellites. We can obtain the TEC information over Japan from the GPS network of the Geographical Survey Institute (GSI) in Japan, GPS Earth Observation Network (GEONET) [*Saito et al.,* 1998].

2. Feasibility study to detect planetary ionospheres

The possibility of the detection of the Martian nightside ionosphere and the lunar ionosphere at each local time is investigated for the summer and winter cases. We regard the fluctuation of the terrestrial ionosphere as a noise. Then, the signal-to-noise ratio R is defined as

$$R = \frac{I_{planet}}{I_{earth}}, \tag{1}$$

where I_{planet} is the maximum total electron content along the ray path in the planetary ionosphere and I_{earth} is the typical fluctuation magnitude of the total electron content of the terrestrial ionosphere. The detection possibility P at each local time is defined as

$$P = \frac{N_{detectable}}{N_{all}} \times 100, \tag{2}$$

where $\mathrm{N}_{detectable}$ is the number of samples whose R value is more than 2, 5, and 10, and N_{all} is the total number of samples at each local time.

We calculate I_{planet} of the Martian nightside ionosphere and the lunar ionosphere assuming that the spacecraft moves in a direction perpendicular to the ray path. For the calculation of the Martian nightside ionosphere, the electron density profile observed by the Viking mission is adopted. The adopted velocities of the spacecraft are the maximum and minimum velocities in the model orbit of Nozomi. For the calculation of the lunar ionosphere, the electron density profile observed by the Luna 22 mission is adopted. The adopted velocity is taken from the planned orbit of Selene. The maximum total electron content along the ray path and the time scale of the observations calculated above are summarized in Table 1.

The raw data of the terrestrial TEC is the slant columns along the ray paths of GPS satellite-ground receiver pairs. As I_{earth}, the standard deviation of the fluctuation of the TEC is calculated after removing a long time scale variation which is obtained by 10 minutes running average. Since we are interested in the short time scale component of the fluctuation in the terrestrial ionosphere, the trend component due to the variation of the path length in the terrestrial ionosphere associated with the movement of the GPS satellite and long time scale variations is removed. The sampling interval of the raw TEC data is 30 seconds. We use the data obtained under the condition that Kp index is in the range between 0 and 2−.

The results are shown in Figure 2. December is more suitable for the measurement than July because of the smaller fluctuation of the terrestrial ionosphere in December. Daytime is suitable for the measurement in July, while nighttime is suitable for the measurement in December.

3. Estimation of the fluctuation of the terrestrial ionosphere along the ray path

There are several ways to estimate the fluctuation of the TEC of the terrestrial ionosphere by using the GPS network. In general, it is difficult to find a GPS satellite-ground receiver pair whose ray path is close to the ray path of the radio occultation measurement of the planetary atmosphere. Therefore, we use TEC data by many GPS satellite-ground receiver pairs to estimate the fluctuation of the terrestrial ionosphere along the ray path of the radio occultation.

We assume that the fluctuation of the terrestrial ionosphere is localized on the 300 km altitude surface, which is the altitude of the F-region peak according to the IRI90 model [*Saito et al.,* 1998]. Then, the TEC fluctuation along the ray path of each GPS satellite-receiver pair is considered to have its origin at the intersection where the ray path crosses the 300 km surface.

Table 1: Maximum total electron content along the ray path and time scale of the observations.

Ionosphere	**I** [$\times 10^{16}$ m^{-2}]	**Time scale**
Mars (nightside)	0.26	Several minutes
Moon*	0.05	Several tens seconds

*Very thick ionosphere reported by the Luna 22 mission is adopted.

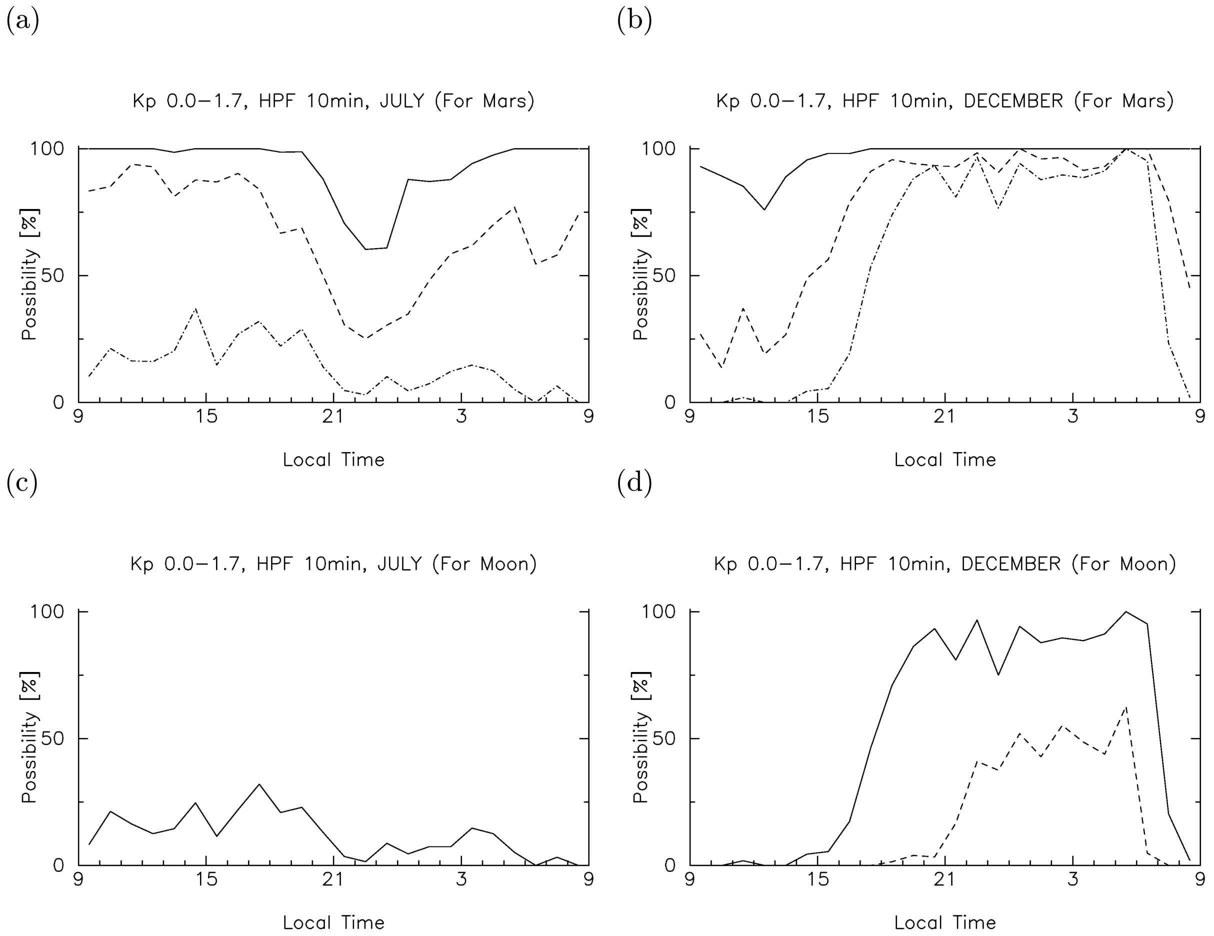

Figure 2: Possibility of the detection of the Martian nightside ionosphere in (a) July 1999 and (b) December 1999 and that of the lunar ionosphere in (c) July 1999 and (d) December 1999. Solid curve, dashed curve, and dot-dashed curve indicate the possibilities when the signal-to-noise ratio is required to be larger than 2, 5, and 10, respectively.

To convert the slant column along the ray path of GPS satellite-ground receiver pairs to the vertical column at the intersection, the observed TEC is multiplied by the ratio of the thickness of the ionosphere to the length of the ray path within the ionosphere, on the assumption that plasma in the ionosphere exists between 250 km and 450 km altitudes. The TEC value at the intersection of the ray path of the radio occultation is estimated by averaging the above TEC values inside a circle with the center at the intersection. The averaged value is converted to the slant TEC along the ray path of the radio occultation.

The feasibility of this method is tested by regarding one GPS satellite as the Nozomi or Selene spacecraft. The TEC data belonging to this "target GPS satellite" is not used in the above estimation procedure. The radii of the circle adopted are 20 km, 30 km, and 40 km. Since we got similar results for these radii, only the results for the 30 km radius are presented. The width of the running average to remove the trend component is 10 minutes.

An example of the feasibility test is shown in Figure 3 (a). In this case, the satellite "No. 16" is the target satellite which gives the true TEC value, while the TEC data by the satellite "No. 14" is used for the estimation. The direction of the satellite No. 14 is separated from that of the satellite No. 16 by approximately 70°. Before 1630 LT, the wavelike fluctuation observed by the target satellite No. 16 is well reproduced by the estimation which uses the data obtained by the satellite No. 14. After 1630 LT, however, the true and the estimated fluctuations are out of phase. A possible reason is that the fluctuation of the terrestrial ionosphere is no longer localized on the 300 km surface after 1630 LT. When the ray paths become longer as the satellites

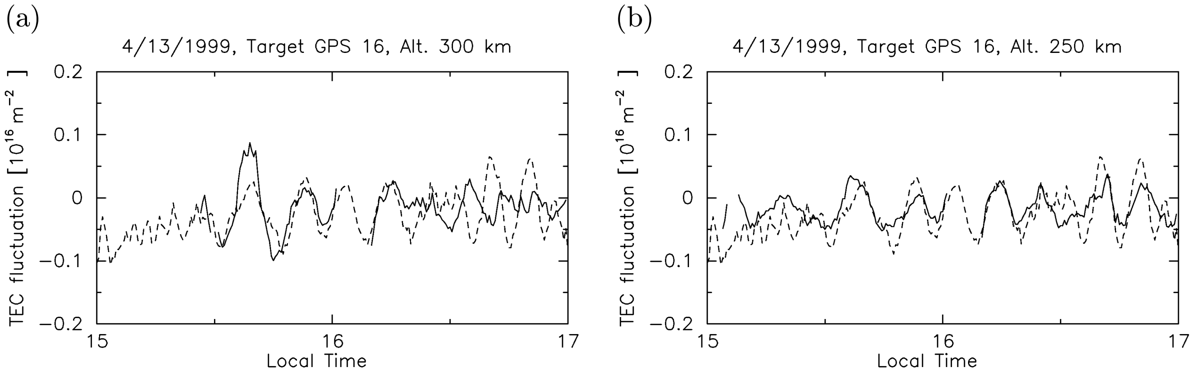

Figure 3: A feasibility test to estimate the TEC fluctuation along the ray path of a target satellite by using the TEC data observed by another GPS satellite. Dashed curve is the "true TEC" observed by the target GPS satellite No. 16, while solid curve is the "estimated TEC" which are the averages of the TEC values by the satellite No. 14 at surrounding points. The TEC fluctuation is assumed to be localized on the (a) 300 km and (b) 250 km surface.

move to low elevations, the error caused by this assumption becomes larger.

A better agreement between the true TEC and the estimated TEC is obtained as shown in Figure 3 (b) when the altitude of the ionospheric fluctuation is assumed to be 250 km. Therefore, the most suitable surface altitude can be determined so that the difference between the TEC distributions obtained by several GPS satellites may be minimum.

4. Conclusion

We focus on the fluctuation of the terrestrial ionosphere, which is a serious error source when we try to obtain the information on planetary ionospheres by the radio occultation measurement. The periods of suitable conditions for the measurement are revealed using the TEC data obtained by the GPS network. The method for the estimation of the fluctuation of the terrestrial ionosphere along the ray path by using the GPS network is presented.

References

Fjeldbo, G., and V. R. Eshleman, The atmosphere of Mars analyzed by integral inversion of the Mariner IV occultation data, *Planet Space Sci., 16*, 1035-1059, 1968.

Lindal, G. F., H. B. Hotz, D. N. Sweetnam, Z. Shippony, P. Brenkle, G. V. Hartsell, R. T. Spear, and W. H. Michael, Jr., Viking radio occultation measurements of the atmosphere and topography of Mars: Data acquired during 1 Martian year of tracking, *J. Geophys. Res., 84*, 8443-8456, 1979.

Saito, A., S. Fukao, and S. Miyazaki, High resolution mapping of The perturbations with the GSI GPS network over Japan, *Geophys. Res. Let., 25, 16*, 3079-3082, 1998.

Vyshlov, A. S., Preliminary results of circumlunar plasma research by Luna22 spacecraft, *Space Res., XVI*, 945-949, 1976.

Woo, R. and J. W. Armstrong, Spacecraft radio scattering observations of the power spectrum of electron density fluctuations in the solar wind, *J. Geophys. Res., 84*, 7288-7296, 1979.