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GNSS reflectometry and remote sensing: New objectives and results

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Abstract

The Global Navigation Satellite System (GNSS) has been a very powerful and important contributor to all scientific questions related to precise positioning on Earth's surface, particularly as a mature technique in geodesy and geosciences. With the development of GNSS as a satellite microwave (L-band) technique, more and wider applications and new potentials are explored and utilized. The versatile and available GNSS signals can image the Earth's surface environments as a new, highly precise, continuous, all-weather and near-real-time remote sensing tool. The refracted signals from GNSS radio occultation satellites together with ground GNSS observations can provide the high-resolution tropospheric water vapor, temperature and pressure, tropopause parameters and ionospheric total electron content (TEC) and electron density profile as well. The GNSS reflected signals from the ocean and land surface could determine the ocean height, wind speed and wind direction of ocean surface, soil moisture, ice and snow thickness. In this paper, GNSS remote sensing applications in the atmosphere, oceans, land and hydrology are presented as well as new objectives and results discussed.

Keywords: GNSS; Multi-path; Radio occultation; Remote sensing; Reflectometry

1. Introduction

The Global Navigation Satellite System (GNSS), including the Global Positioning System (GPS) in the United States, the Russian GLONASS, the European Galileo and the Chinese COMPASS (Beidou), can be characterized as a highly precise, continuous, all-weather and near-real-time microwave (L-band) technique with signals through the Earth's atmosphere. These characteristics of GNSS imply more and wider applications and potentials. When the GPS signal propagates through the Earth's atmosphere, it is delayed by the atmospheric refractivity, which results in lengthening of the geometric path of the ray. In 1992 when the GPS became fully operational, Ware (1992) suggested limb sounding the Earth atmosphere using GPS atmospheric delay signals. On 3 April 1995, the small research satellite of Microlab-1 was successfully put into a Low Earth Orbit (LEO) to validate the GPS radio occultation method (Feng and Herman, 1999). Since then, the GPS/Meteorology Mission (GPS/MET) using the radio occultation technique has been used to produce accurate, all weather, global refractive index, pressure, density profiles in the troposphere, temperature with up to the lower stratosphere (35–40 km), and the ionospheric total electron content (TEC) as well as electron density profiles (Rocken, 1997; Hajj and Romans, 1998; Syndergaard, 2000; Derek and Benjamin, 1999), to improve weather analysis and forecasting, study climate change, and monitor ionospheric events.

In addition, surface multi-path is one of main error sources for GNSS navigation and positioning. It has recently been recognized, however, that the special kind of GNSS multi-path delay reflected from the Earth's surface, could be used to sense the Earth's surface environments. Hall and Cordey (1988) first addressed the Bistatic radar using L-band signals transmitted by GPS proposed by the European Space Agency (ESA) as an ocean scatterometer. Rubashkin (1993) demonstrated the concept of

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bistatic radar sensing of the ocean surface using two satellites with a transmitter in a low Earth orbit and a receiver in geosynchronous orbit. Martín-Neira (1993) proposed and described an altimeter system using ocean GPS reflections to measure sea surface heights. Katzberg and Garrison (1996) proposed the reflection of the GPS signal from the ocean for ionospheric measurements by adding a GPS receiver and downward-pointing antenna to any satellites, and evaluated the feasibility and effectiveness. Later a number of experiments and missions using GPS reflected signals from the ocean and land surface have been tested and applied, such as determining ocean surface height, wind speed and wind direction of ocean surface, soil moisture, snow and ice thickness (Komjathy et al., 1999; Rius et al., 2002; Wagner and Kloko, 2003; Germain et al., 2004; Komjathy et al., 2004; You et al., 2004; Kostelecký et al., 2005; Thompson et al., 2005; Gleason et al., 2005).

Therefore, the versatility and availability of GNSS reflected and refracted signals result in many new applications. The sensitivity of these signals to propagation effects is useful for various environmental remote sensing. This paper will address new objectives and results of GNSS remote sensing in the atmosphere, oceans, land and hydrology as well as new opportunities for future missions.

2. GNSS atmospheric remote sensing

Due to the atmospheric refraction, GPS signals propagate through the Earth atmosphere along a slightly curved path and with slightly retarded speeds (Fig. 1a). For a long time, the delay of GNSS signals in the troposphere and ionosphere was considered as a nuisance, an error source, and now it has been used to determine the useful atmospheric parameters, including tropospheric water vapor, temperature and pressure, and ionospheric total electron content (TEC) and electron density profile (e.g., Jin et al., 2006). Nowadays, a number of GPS radio occultation (RO) missions have been successfully launched for atmospheric and ionospheric detections and climate change related studies, such as the US/Argentina SAC-C, German CHAMP (CHAllenging Minisatellite Payload), US/Germany GRACE (Gravity Recovery and Climate Experiment), Taiwan/US FORMOSAT-3/COSMIC (FORMOsa SATellite mission-3/Constellation Observing System for Meteorology, Ionosphere and Climate) satellites, the German TerraSAR-X satellites and the European MetOp. These GPS RO satellites together with ground-based GPS observations have provided the high-resolution tropospheric water vapor, pressure, temperature, tropopause parameters, ionospheric TEC and electron density profiles, which were consistent with traditional instruments observations at comparable accuracies (e.g., Schmidt et al., 2005, 2008; Jin et al., 2006, 2007). For example, Fig. 2 shows ionospheric electron density profiles from ground-based GPS tomography reconstruction over South Korea on 28 October 2003 at UT 13:00 (Jin et al., 2006). These ground-based and space-borne GPS observations can provide important

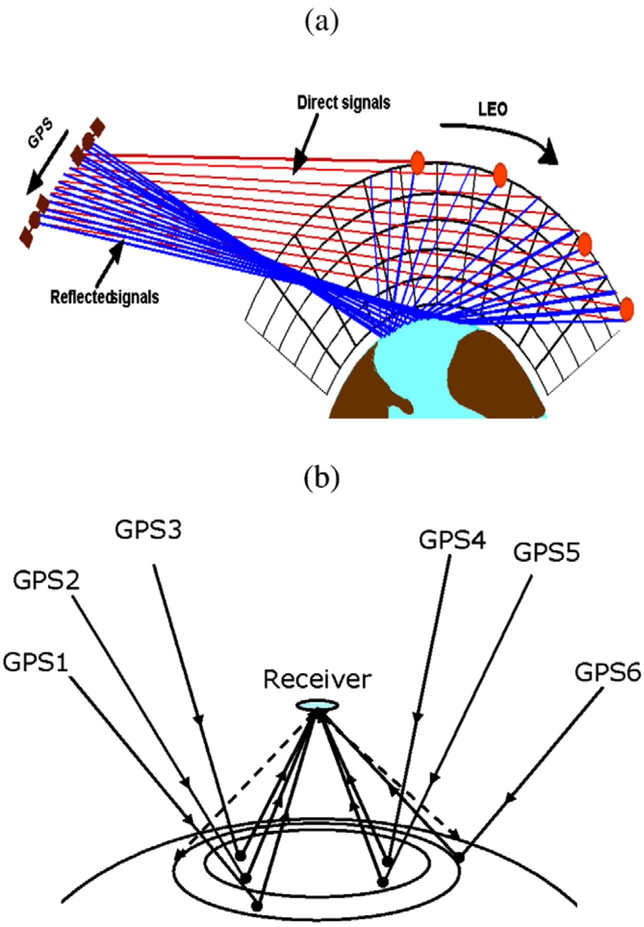

Fig. 1. GNSS refracted and reflected signals and geometry (Yunck, 2003).

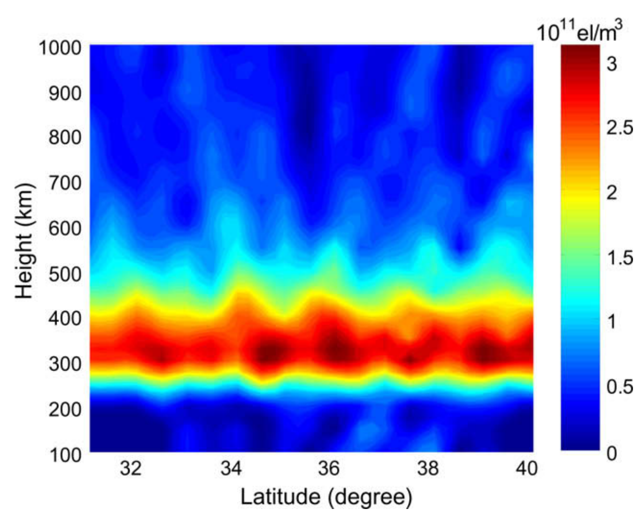

Fig. 2. Ionospheric electron density profiles from ground-based GPS tomography reconstruction over South Korea on 28 October 2003 at UT 13:00.

3-D ionospheric profile information related to various activities and states in the ionosphere, particularly for solar flares and geomagnetic storms (e.g., Jakowski et al., 2007; Jin et al., 2008).