Contribution of GPS Radio Occultation Technique in Climate Change

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Abstract: Radio occultation (RO) signals using Global Positioning System (GPS) received by a low Earth orbit (LEO) satellite provides reliable datasets for a variety of atmospheric parameters, such as temperature and electron density, that are being extensively used in climatological studies. Radio Occultation data is collected by measuring the changes in a radio signal as it is refracted in the atmosphere, allowing measurements of the physical properties (temperature and moisture) of the atmosphere to be taken. Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) was the first constellation of satellites which has the capability to get RO data in near-real-time. In this paper we shed light to the value of RO missions and the applications of RO observations in space weather and climate change. With COSMIC-2 satellites, a greater impact to study climate change is expected.

Key words: Radio occultation • Climate change • Global Positioning System

INTRODUCTION

Radio occultation (RO) is a new technique helpful technique for measuring the physical properties of a planetary atmosphere. This is a relatively new technique (first applied in 1995) for performing atmospheric measurements. It is used as a weather forecasting tool and could also be harnessed in monitoring climate change. The technique involves a low-Earth orbit satellite receiving a signal from a GPS satellite. This technique relies on the detection of a change in a radio signal as it passes through a planet's atmosphere, i.e. as it is occulted by the atmosphere. When electromagnetic radiation (light) passes through the atmosphere, it is refracted (or bent). The magnitude of the refraction depends on the gradient of refractivity normal to the path, which in turn depends on the density gradient. In the case of the neutral atmosphere, which occurred below the ionosphere, information on the atmosphere's temperature, pressure and water vapor content can be derived giving radio occultation data. Global Navigation Satellite System or Global Positioning System radio occultation is a type of radio occultation that relies on radio transmissions from GPS or from GNSS satellites.

For the first time, radio occultation (RO) technique began to sound the planets in 1960s when scientists from Stanford University studied the atmosphere of Mars using Mariner satellites [1]. In the 1980s, when GPS constellation works, same concept of RO technique used to study Earth’s atmosphere. Two GPS frequency bands were used are: L1 (1575.42MHz) and L2 (1227.60MHz) frequencies [2, 3]. The Global Positioning System/Meteorology (GPS/MET) mission launched in 1995 used RO technique in profiling Earth’s atmosphere and demonstrated that RO could provide accurate data. After the success of GPS/MET satellite, several satellite missions such as CHAMP, SAC-C, GRACE, METOP-A and COSMIC demonstrated that RO has the capability to provide accurate and precise profiles of electron density and temperature in Earth’s atmosphere and ionosphere. COSMIC mission was the first constellation of satellites which got RO data in near-real-time. COSMIC has produced enough global soundings each day (1500–2000) to demonstrate a significant, positive impact on operational weather forecasts.

This paper shed light to the value of RO study in climate change, space weather and the observations in atmospheric climatological studies using COSMIC satellites.

GPS Radio Occultation: When GPS signals hit the Earth at a tangent (Fig. 1), they're distorted by the atmosphere before continuing on their way. By monitoring these distorted signals, COSMIC can figure out the conditions of the atmosphere that did the distorting. Specifically, the temperature, pressure and wetness of the troposphere can be calculated.

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Fig. 1: Schematic diagram of Radio occultation signals using Global Positioning System received by a low Earth orbit satellite

Fig. 2: First sounding of Earth’s atmosphere from GPS/MET

**RO Observations:** By measuring the phase delay of radio waves at L1 and L2 frequencies from GPS satellites as they are occulted by Earth’s atmosphere (Fig. 1), accurate and precise vertical profiles of the bending angles of radio wave trajectories are obtained in the ionosphere, stratosphere and troposphere.

From the bending angles, profiles of atmospheric refractivity are obtained. The refractivity, $N$, is a function of temperature ($T$ in kelvin (K)), air pressure ($p$ in hectopascals (hPa)), water vapor pressure ($e$ in hPa) [4] and electron density ($ne$ in number of electrons per cubic meter),

$$N = 77.6 \frac{p}{T} + 3.73 \times 10^5 \frac{e}{T^2} - 4.03 \times 10^7 \frac{ne}{f^2}$$

(1)

The first term in (1) is proportional to pressure $p$ and is, therefore, related to the air density. The second term is proportional to vapor pressure $e$, which is directly related to atmospheric moisture. The two terms are often referred to as the dry and wet terms, respectively. Near the surface of the Earth and in relatively warm temperatures, the spatial variability in $N$ is dominated by changes in the second term [4].

In Eq. (1), $f$ is the frequency of the GPS carrier signal in Hz. Using $f$ equal to L1 and L2 in Eq. (1) produces two
measurements, which may be linearly combined to produce an ionosphere corrected estimate of N in the stratosphere and troposphere. The refractivity profiles can be used to derive profiles of electron density in the ionosphere, temperature in the stratosphere and temperature and water vapor in the troposphere [5].

**Results from RO Missions:** Many studies have demonstrated the power of RO to observe atmospheric phenomena for research, numerical weather prediction, benchmark climate observations and space weather/ionospheric research. Starting with GPS/MET, RO observations have been used in case studies of atmospheric phenomena, such as gravity waves, tropopause structures and tropical cyclones.

The first sounding of Earth’s atmosphere from GPS/MET showed a wave-like structure in the temperature profile between 25 and 35 km in the lower stratosphere (Fig. 2). At first it was not clear whether this was a real feature or not, but many subsequent soundings showed similar structures that proved to be manifestations of real gravity waves of various types [6].

**Climate Change Applications:** Radio occultation observations are well suited for establishing a stable, long-term record required for climate monitoring [7, 8, 9, 10]. In spite of the enormous importance of detecting climate trends, before RO there were no global atmospheric observing systems that could meet the stringent climate monitoring requirements of 0.5 K accuracy and better than 0.10 K decade [11]. RO observations meet these accuracy, stability and global sampling requirements. Ringer and Healy [12] showed that the signal of climate change over the coming decades should be clearly identifiable in radio occultation bending angle profile measurements. Their analysis of the predicted trends in bending angle in the tropics suggests that it might be possible to detect climate change signals within ten to sixteen years. Steiner *et al.* [13] pointed out that the RO data detected climate trends with a significant cooling of the lower stratosphere since 1995. Recently, Lackner *et al.* [14] demonstrating that a climate change signal in the geopotential height of pressure levels based on the RO climate record through 2010. Their studies were consistent with tropospheric warming.

**CONCLUSIONS**

Radio occultation is a proven high-impact and low-cost global observing system. It has strong contribution to weather, climate change and space weather with significant positive impact on weather forecasts. Also, it is very useful evaluate global climate models and analysis with monitoring climate change and variability with unprecedented. Moreover, it improves global weather analysis particularly over data void regions such as the oceans and polar regions.

With COSMIC-2, an even greater impact is expected. COSMIC-2 is a follow on of the successful COSMIC mission launched in 2006. COSMIC-2 is a 12-satellite constellation that will provide operational and research users with the next-generation Global Navigational Satellite System Radio Occultation (GNSS-RO) data.

**REFERENCES**


