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A comparative and numerical study of effects of gravity waves in small miss-distance and miss-time GPS radio occultation temperature profiles

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Abstract

The Global Positioning System (GPS) Radio Occultation (RO) technique has global coverage and is capable of generating high vertical resolution temperature profiles of the upper troposphere and lower stratosphere with sub-Kelvin accuracy and long-term stability, regardless of weather conditions. In this work, we take advantage of the anomalously high density of occultation events at the eastern side of the highest Andes Mountains during the initial mission months of COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate). This region is well-known for its high wave activity. We choose to study two pairs of GPS RO, both containing two occultations that occurred close in time and space. One pair shows significant differences between both temperature profiles. Numerical simulations with a mesoscale model were performed, in order to understand this discrepancy. It is attributed to the presence of a horizontal inhomogeneous structure caused by gravity waves.

Keywords: Gravity waves; Stratosphere; Radio occultation; Numerical simulation

1. Introduction

A radio occultation (RO) occurs whenever a satellite from the Global Positioning System (GPS) network at an altitude about 20,000 km rises or sets from the standpoint of a Low Earth Orbit (LEO) satellite receiver at a height of some 100 km and the ray from the transmitter traverses the atmospheric limb. When the radio signal passes through the atmosphere its phase is perturbed in a manner related to the refractivity along the path. In Fig. 1 we represent a scheme for the corresponding atmospheric sounding. Vertical scanning is provided by the relative motion of both satellites. An atmospheric profile of refractivity can then be retrieved and such quantities as atmospheric density, pressure, temperature and moisture can be derived. The horizontal and vertical resolution of the observations in the stratosphere are estimated to be around 150 km and 1.4 km, respectively (Kursinski et al., 1997). The combination of global coverage, sub-Kelvin temperature accuracy, good vertical resolution, long-term stability and the absence of limitations imposed by weather conditions make this technique unique (see e.g. Wu et al. (2006)).

Different works (see e.g. Jiang et al. (2002) and Preusse et al. (2002)) have shown a persistent wave activity in the upper troposphere and lower stratosphere at mid-latitudes in the southern hemisphere close to the Andes range. In Fig. 2 we show a scheme of the geometry presented by the Andes Mountains, the phase surfaces of stationary gravity waves (GW) expected from mountain forcing (called mountain waves) and the direction of a typical line of sight (LOS) between one GPS and one LEO satellite, all of them horizontally projected. The mountain topography forcing has been considered to be the cause of the intense observed wave activity.

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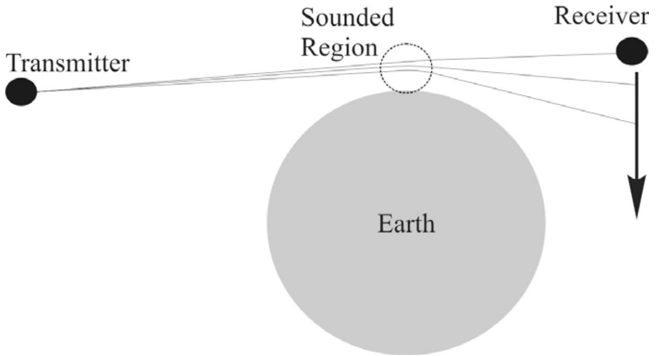

Fig. 1. A schematic representation of atmospheric profiling by the occultation of a GPS satellite observed by the receiver on a LEO satellite. Distances are not to scale.

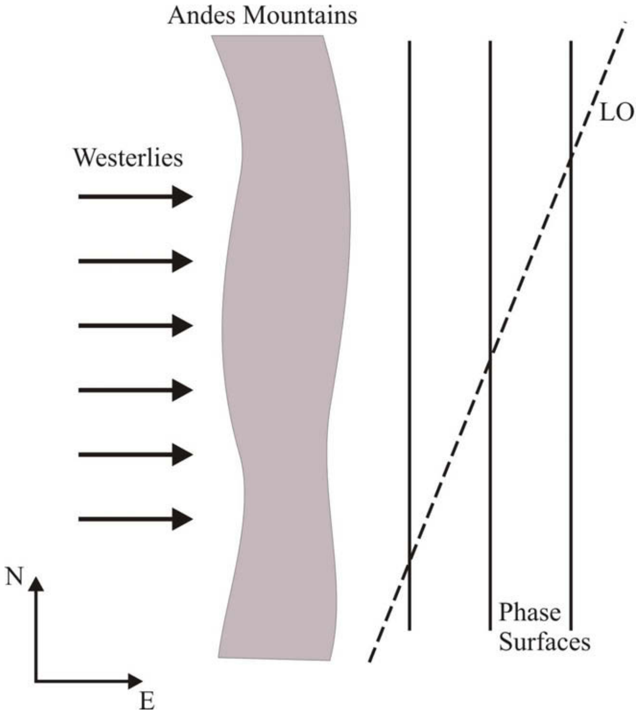

Fig. 2. A scheme of the horizontal geometry presented by the Andes Mountains, the phase surfaces expected from GW generated by topographic forcing of typical westerlies and a LOS.

COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) is a six LEO satellites constellation, launched in April 2006, which accumulates a larger number of occultations per day than any previous mission (Liou et al., 2007). In this work, we take advantage of the anomalously high density of COSMIC occultation events at the eastern side of the highest Andes Mountains during the initial mission months.

As mentioned above, the southern Andes mid-latitude region exhibits high GW activity. Another advantage of this zone is that mountain waves are well suited for our study because they have small phase speeds with respect to the ground, which means that no significant changes may be expected for a few hours. We compare nearby occultations in order to determine the reliability of this technique to detect waves. Emphasis of previous work relied on accuracy or precision (see e.g. Hajj et al. (2004)). However, GPS RO may be particularly sensitive to the angle between the LOS and the orientation of a wave field (see e.g. Alexander et al. (2008)). We focus on this type of potential difficulty, where a horizontal inhomogeneous two-dimensional structure may significantly affect the measurements. In general, if results from nearby GPS RO pairs differ, three sources may be responsible for the observed discrepancies: (i) the time or space separation (we tried to minimize this problem by constraining both factors), (ii) accuracy or precision of the technique (Kuo et al. (2005) demonstrates roughly 0.5 K precision of GPS RO temperature profiles, so significantly larger variations should be resolved), (iii) different horizontal atmospheric structure found along diverse LOS or diverse lines of tangent points (LTP, the line that connects all the observational tangent points). Assuming that we have been able to narrow the first two sources of discrepancies we explore the third alternative. In particular, in high wave activity regions these differences may become large. The retrieved value at each point of the LTP corresponds to a weighted integral along the LOS (which may be crossing waves or any other horizontal inhomogeneous atmospheric structures) rather than to point measurements (Alexander et al., 2008). A LOS along wavefronts may lead to rather different results than a LOS perpendicular to them.

2. Selected study cases

Within the high wave activity region mentioned above, de la Torre and Alexander (2005) found that the area 30–40S, 70–65W showed particularly significant values when analyzing fluctuations in GPS RO temperature profiles. From 669 profiles obtained by COSMIC between April 2006 and July 2007 in this zone, 50 pairs of them occurring within 2 h and 200 km of one another were found. The amount of close encounters diminished with time as the six satellites moved apart from their common launch orbit. We have chosen two nearby pairs among the 50 ones to perform our study.

Pair 1 occurred on 27 December 2006 at, respectively, 1:18 and 2:53 UT and the distance and time between both occultations were, respectively, 97 km and 95 min. Pair 2 occurred on 3 February 2007 at, respectively, 16:27 and 18:05 UT and the corresponding values were 79 km and 98 min between both events. Pair 1 is 1 of 5 cases among the 50 pairs where one LOS corresponds to the NE–SW direction, whereas the other points in the NW–SE direction. Both RO of pair 2, on the other hand, have LOS in NE–SW orientation, whereas they have a similar separation in time and distance as both RO of pair 1. Fig. 3 shows the sets of LOS and the LTP for each occultation of both pairs. Topography is also included for reference. The approximate horizontal drifts of the tangent points in the

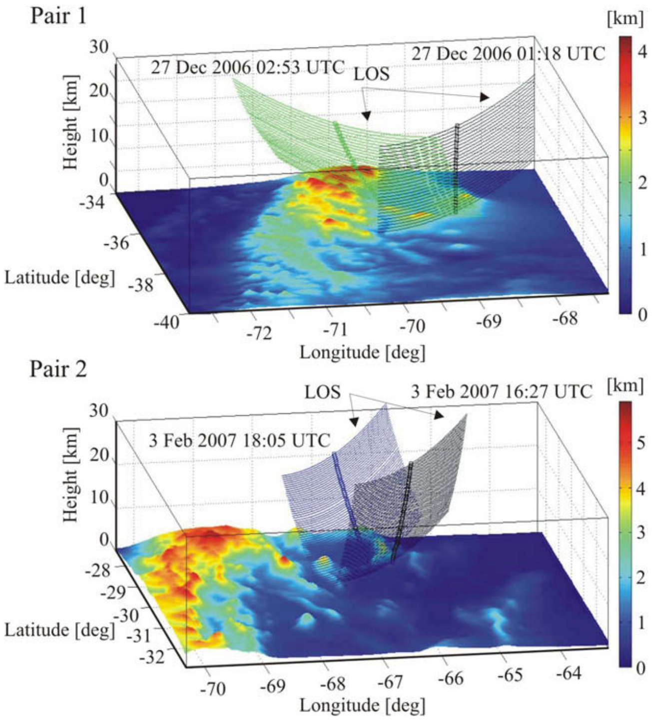

Fig. 3. Set of LOS (lines) and LTP (darker points in the middle of each LOS) for pairs 1 and 2. Vertical and horizontal scales differ (each degree equals approximately 100 km).

regions here analyzed are, respectively, in chronological order of the RO 38, 87, 38 and 106 km.

3. Analysis

In Fig. 4 pair 1 shows a significant difference between both RO temperature profiles, whereas pair 2 exhibits a reasonable agreement (notice however that this is a less active region). Numerical simulations with a mesoscale model were performed in order to verify if this discrepancy could be attributed to the different geometrical perspectives of the two occultations in pair 1. Wheather Research and Forecasting (WRF) model version 2.1.2 simulations were performed to analyze this occultation pair. Runs were driven by assimilated lateral boundary conditions and sea surface temperature from NCEP (National Center for Environmental Prediction) reanalysis. We employed three nested domains with horizontal grid spacing of 36 km, 12 km and 4 km, respectively. Computational time steps were close to 30 s. Profiles were extracted from the 4 km grid nest of the simulations along the LTP.

Fig. 5 shows simulations for both events of Pair 1. The temperature value in each point of the simulated profiles is a weighted average along the corresponding LOS. There is a general bias of the WRF model results for altitudes above ~18 km and the phase of the wave in Fig. 5b is shifted by about 90° with respect to the observations. However, the model simulations confirm the pronounced wave structure in the profile measured at 2:53 UT and the relative absence of waves in the profile measured on 1:18 UT and hence demonstrate that the different perspective of the two LOS cause the differences in the two profiles. This happens because the values at each point of the LTP are not localized values but rather weighted averages along the LOS. The observed atmospheric structures are considered to be mountain waves because the wave fronts remain stationary with respect to the ground over several hours during the simulation (not shown). Wavefronts stay nearly aligned with the North–South direction (almost parallel to the mountains). Typical amplitudes were not larger than a few K, horizontal wavelengths were on the order of 100 km and the waves were observed above a height about 8 km.

4. Conclusions

Horizontal inhomogeneous atmospheric structure caused by mountain waves along the LOS may have significant effects (some K) on the GPS RO temperature profiles in the upper troposphere and lower stratosphere. This problem is related to the spherically symmetric atmosphere assump-

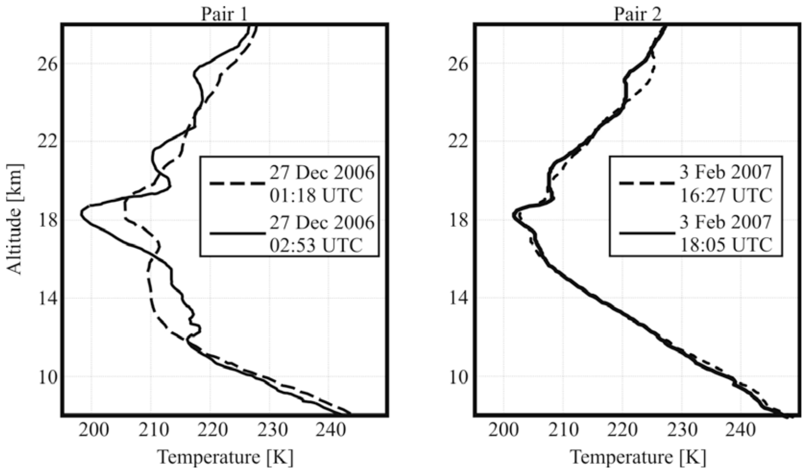

Fig. 4. GPS RO temperature profiles for pairs 1 and 2.

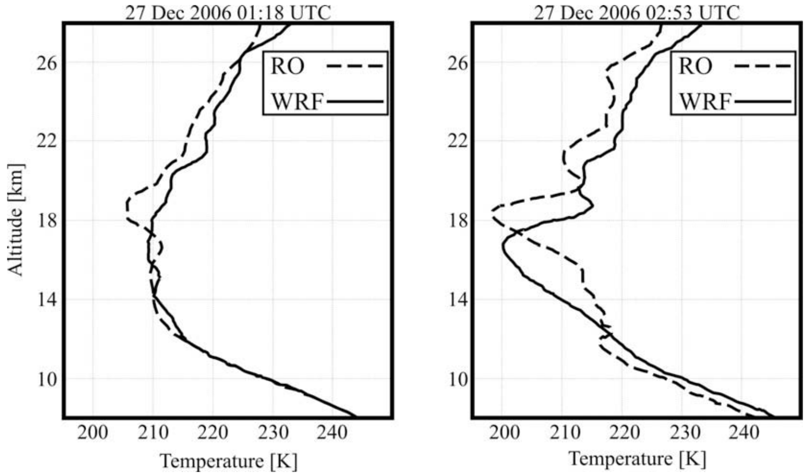

Fig. 5. GPS RO temperature profile and corresponding numerical simulation for both occultations of pair 1.

tion that is part of the retrieval algorithm. Large scale horizontal inhomogeneous structures have already been shown to cause large discrepancies between GPS RO observations and in-situ point measurements in the lower troposphere. However, such an effect in the upper troposphere and stratosphere was not known well.

We compared two pairs of GPS RO temperature profiles measured at small miss-distance and miss-time by the COSMIC constellation over a region of high GW activity. The observed GW structures are very sensitive to their relative orientation with respect to the LOS. In the first pair, pronounced wave structures were observed only in one of the two profiles. This difference is not due to instrumental and retrieval errors or spatial or temporal variations of the wave field and can therefore only be explained by the different viewing direction when observing the two profiles. This is corroborated by mesoscale model simulations of the considered cases. Miss distance and miss time are similar for profile pair 2, but the differences between the two profiles are much smaller because the two LOS are similarly aligned (however, it cannot be discarded that a smaller discrepancy appears because the latter pair is in a less wave active region). The use, interpretation or comparison of GPS RO temperature profiles requires detailed consideration of the viewing geometry, as they may be significantly affected by horizontal inhomogeneous atmospheric structures like GW.

Acknowledgements

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