NCURO DATA RETRIEVAL ALGORITHM IN FORMOSAT-3 GPS RADIO OCCULTATION OBSERVATION OF GRAVITY WAVE ACTIVITY

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ABSTRACT

Radio occultation (RO) has been used in the planetary science since Microlab-1 was launched in 1995. With the RO technique, the profiles of atmosphere and the global atmospheric data can be obtained. In 2006, Taiwan launched six low Earth orbit (LEO) satellites as the RO constellation mission, known as FORMOSAT-3. In order to retrieve the RO data from original data, a retrieval algorithm, NCURO, is developed. The input of NCURO algorithm is mainly the excess phase of GPS signal, and the output is the dry pressure and dry temperature. Using temperature profiles retrieved by NCURO algorithm, temperature perturbation and potential energy of gravity wave have been evaluated. In this paper, the retrieval algorithm and the global distribution of energy of gravity waves are described and demonstrated.

KEY WORDS: GPS, Radio Occultation, FORMOSAT-3, NCURO

1. INTRODUCTION

RO technique has been applied to investigate the atmosphere of planets in the solar system for decades. It is based on the fact that the radio waves are bent and delayed due to the gradient of the atmospheric refractivity along the ray path. By analyzing the excess phase of the radio waves, the profiles of atmospheric parameters can be retrieved. With the advent of Global Positioning System (GPS), it becomes possible to retrieve the refractivity and temperature profiles of the Earth's atmosphere using the occultation technique.

In 2006, Taiwan launched six LEO satellites for a RO mission. The name of the mission is Constellation Observing System for Meteorology, Ionosphere and Climate (FORMOSAT-3/ COSMIC, or FORMOSAT-3). The amount of the RO data supplied by FORMOSAT-3 is expected to be 2500-3000 sets per day. The RO data of FORMOSAT-3 is freely provided by TACC and COSMIC Data Analysis and Archive Center (CDAAC).

In order to thoroughly understand the process of the data retrieval and obtain as much as possible the

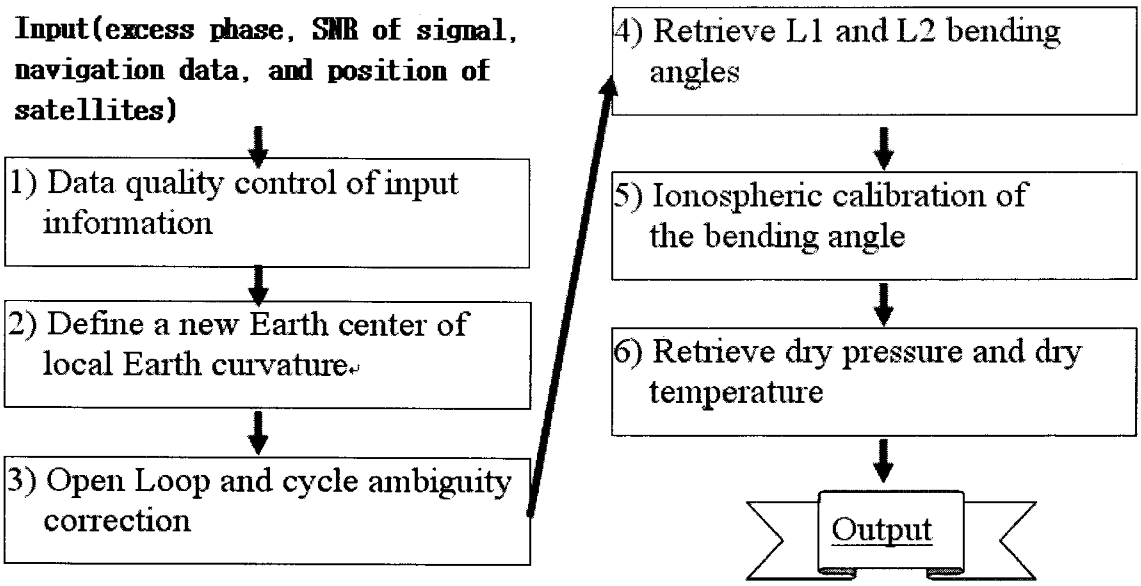

Figure 1. Flow chart of the NCURO retrieval algorithm.

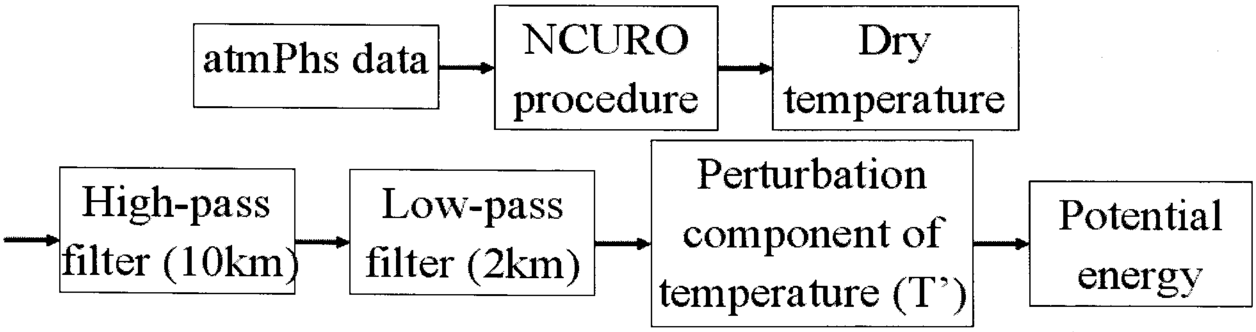

Figure 2. Procedure of analyzing gravity wave.

information for the weather prediction, a retrieval algorithm, NCURO algorithm, is developed. Based on the geometrical method, the NCURO algorithm uses the excess phase of the GPS signal to obtain the profiles of atmospheric pressure and temperature.

Gravity wave plays an important role of atmosphere. Jet stream, surface topography, and tropical convection are related to gravity wave. The reasons why gravity wave occurs are topographic generation, convective generation, shear generation, geostrophic adjustment, and wave-wave interactions. In this paper, the method to observe gravity wave mentioned in [1] by using the RO data is used. In what follows, the NCURO algorithm is first summarized in Section 2. In Section 3, the method to analyze RO data is described. The result and conclusions are displayed in Section 4.

2. NCURO RETRIEVAL ALGORITHM

The flow chart of NCURO data retrieval algorithm is shown in Figure 1. The inputs are excess phase of L1 and L2 band of GPS signal, signal to noise ratio of signal, navigation data, and position of GPS and LEO satellites. The retrieval process is described as follows:

a. Preliminary data quality control in input information.
   If the quality of data is bad, the process of retrieval will stop. In order to avoid this problem, the program will ignore the data and go on to next.
b. Define a new Earth center of local Earth curvature.
   In NCURO algorithm, the atmosphere of the Earth is assumed to be spherically multi-layered. However, due to the oblateness of the Earth, the retrieved temperature may possess a bias. We use Syndergaard's method [2] to correct it.
c. Open Loop and cycle ambiguity correction.
   In GPS signal, it use phase shift keying to combine the phase and navigation message. It causes the GPS phase has half phase shift. We use the method in [3] to correct it.
d. Retrieve L1 and L2 bending angles.

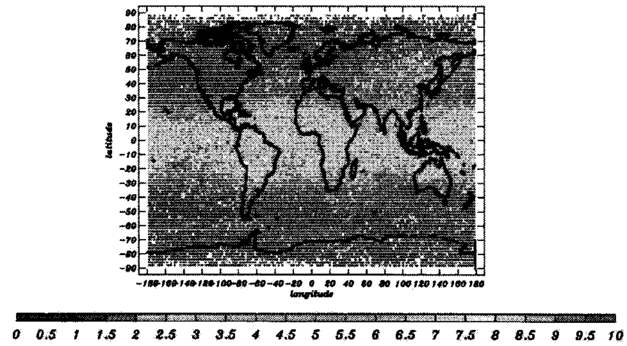

Figure 3. Potential energy distribution of gravity wave analyzed by using FORMOSAT-3 data.

e. We use Snell's law to get the impact parameter. Then follow the method of geometrical optics and use the position of GPS and LEO satellites to get bending angle.
f. Ionospheric calibration of the bending angle.
   We use NCURO to retrieve bending angle is assumed the neutral atmosphere. And the ionosphere will affect the results. We use the method in [4] to cancel the effect of ionosphere.
g. Retrieve dry pressure and dry temperature
   We use Abel transform to transfer bending angle to refractive index of atmosphere. Then use the method in [5] to get the profiles of dry pressure and dry temperature.

3. GRAVITY ANALYSIS

The energy of gravity wave can be written as

$$E = \frac{1}{2}\left[\overline{u'^2} + \overline{v'^2} + \overline{w'^2} + \left(\frac{g}{N}\right)^2 \overline{\left(\frac{T'}{\overline{T}}\right)^2}\right]$$
$$= E_k + E_p \qquad (1)$$

, which E_k and E_p are kinetic energy and potential energy, respectively. The form of E_k and E_p are given by

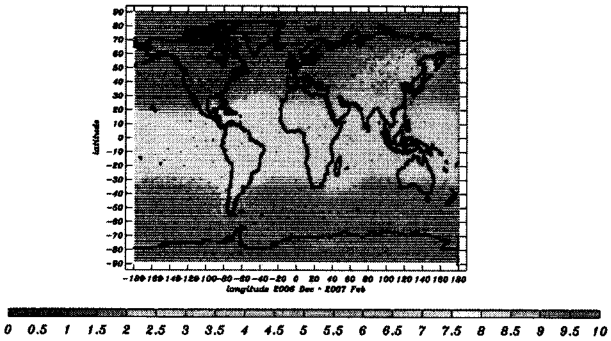

Figure 4. Potential energy distribution of gravity wave analyzed by using FORMOSAT-3 data after smoothing.

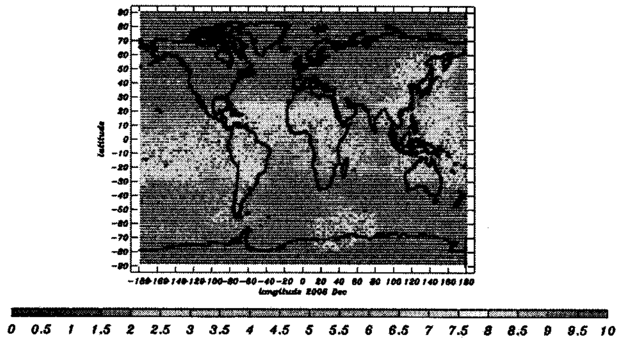

Figure 5. Potential energy distribution of gravity wave analyzed by using FORMOSAT-3 data of December, 2006, after smoothing.

$$E_k = \frac{1}{2}\left[\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right]$$

$$E_p = \frac{1}{2}\left(\frac{g}{N}\right)^2 \overline{\left(\frac{T'}{\overline{T}}\right)^2} \qquad (2)$$

, where u', v', and w' are velocity perturbation, $\overline{T}$,and T' are background temperature and temperature perturbation. Otherwise, T' can be written as

$$T'(z) \Rightarrow \overline{T'^2} = \frac{1}{z^{\max} - z^{\min}} \int_{z^{\min}}^{z^{\max}} T'^2 \, dz . \qquad (3)$$

Because lack of velocity information, it only can get the potential energy by using the retrieval temperature. The analysis procedure is shown in Figure 2.

The input is excess phase of the GPS signal. After going through NCURO retrieval algorithm, the retrieved dry temperature profiles of atmosphere are obtained. Secondly, make the dry temperature profiles go through high-pass filter and low-pass filter [6] to remove the background temperature and noise and get the temperature perturbation profiles. Substituting the temperature perturbation profiles into (2) and (3), the potential energy of gravity wave is obtained.

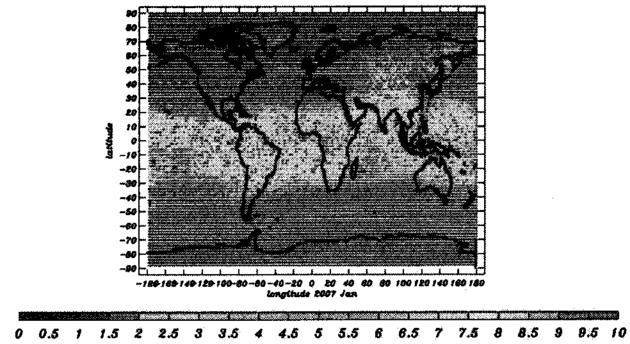

Figure 6. Potential energy distribution of gravity wave analyzed by using FORMOSAT-3 data of January, 2006, after smoothing.

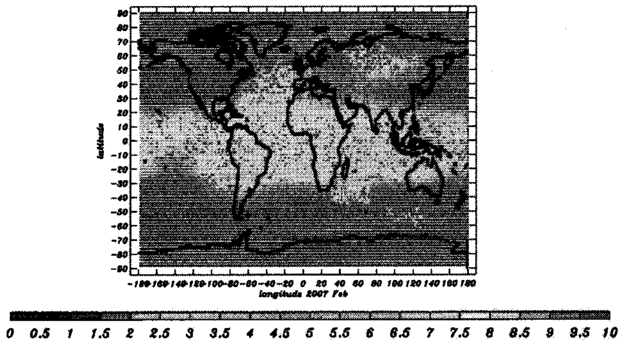

Figure 7. Potential energy distribution of gravity wave analyzed by using FORMOSAT-3 data of February, 2006, after smoothing.

4. RESULTS AND CONCLUSIONS

We have analyzed FORMOSAT-3 radio occultation data from December 2006 to February 2007, and the number of the retrieval data is about 95000. We focus on the altitude from 20 km to 30 km and obtain the potential energy of gravity wave in this time period. We have used 180×90 grids and each grid is 2 degree × 2 degree. Putting the retrieval data into the grids, the average potential energy of gravity wave is obtained. The result is shown in Fig. 3. In order to remove the noise, we use the smoothing method mentioned in Tsuda et al. (2000) [1]. The result is shown in Fig. 4, which is in agreement with the result in Tsuda et al. (2000)[1]. And the gravity wave potential energy distributions in each months are shown in Fig. 5, Fig. 6, and Fig. 7.

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