An Atmosphere State Computation System Based on Radio Occultation Data

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***Abstract*—This paper describes an atmosphere state computing platform using radio occultation data. The main goal of this system is to provide the processed radio occultation raw data to make the numerical weather prediction (NWP) more accurate and to assist the science research. The concept, design and implementation of the new platform are presented. We focus on more accurate computation model, data quality control and the data processing speed.**

Keywords-radio occultation data; quality control; atmosphere state computing; parallel

I. INTRODUCTION

In recent years, with the development of the rockets and satellites technology, the Global Navigation Satellite System (GNSS) has been leading a revolution to the way that people live and work. There are several GNSSs in the whole world, such as American's Global Positioning System (GPS), European's Galileo Positioning System (GALILEO), Russian's GLONASS and China's BeiDou (COMPASS) Navigation Satellite System. GPS is the most mature and widely used navigation system. As a new direction of the GPS system applications, GPS radio occultation technique provides a new means of computing earth's atmosphere state for the numerical weather prediction and the relevant science research. It has the features of being not affected by the cloud effect and the limitation of ocean surface, having high vertical resolution, no need to check and the average global distribution. GPS radio occultation involves a low-Earth orbit (LEO) satellite receiving a signal from a GPS satellite. The signal has to pass through the atmosphere and gets refracted along the way. The magnitude of the refraction depends on the temperature and water vapor concentration in the atmosphere. The amplitude and frequency of the signals are taken as the raw radio occultation data. So, an atmosphere state computation system proposed in this paper that based on the processing of the raw GPS radio occultation data aiming to achieve more accurate values of the pressure, temperature and water vapor. Because of the large scale of the raw data, the computation system is accelerated with the parallelism of the program.

II. THEORETICAL PRINCIPLE

A. Radio Occultation Geometry

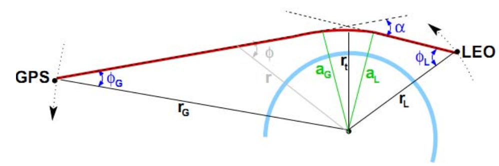

Figure 1. Radio Occultation geometry

The typical radio occultation geometry is sketched in Figure 1. A ray passing from a GPS to a LEO satellite through the atmosphere is refracted as a result of gradients in the refractive index, n. With the assumption of the spherical symmetry of the atmosphere, the vertical distance from the curvature center to GPS satellite rays and to LEO satellite rays is equal, $a_G=a_L$. This distance is called impact parameter, a.

$$a = rn\sin\varphi. \quad (1)$$

B. Radio Occultation Observation

A measured signal at time t can be described as a wave field with amplitude $A(t)$, wave vector $k = 2\pi f/c$ and phase path $\Psi(t)$

$$u(t) = A(t)\exp(ik\Psi(t)). \quad (2)$$

GPS satellite sends two L band radio signals (f_1=1.57542 GHz, f_2=1.22760 GHz). The signal rays which started from GPS satellite and passing through the ionosphere and neutral atmosphere, are affected by the ionosphere electronic density distribution and the gradients of the atmosphere refractivity. So the signals must do the ionosphere correction while computing bending angles using them. The paths of these rays would have different bending, thus it delays the time of the signals reaching the LEO satellite.

Due to the fact of knowing the accurate positions and velocities of GPS and LEO satellites, we could make a computation of deriving the total bending angle of the path. The whole atmosphere has the signal rays passing through from the top of the atmosphere to the surface of the Earth because of the relative motion of GPS and LEO satellites.

978-0-7695-4789-3/12 $26.00 © 2012 IEEE
DOI 10.1109/ICCIS.2012.64

Therefore, the vertical profiles of the bending angle could be easily archived.

C. Data Computing Procedure

What we get from the GPS radio occultation data access center is the Level 1a raw data, including the optical path length, phase path, frequency and the amplitude. Data processing procedure starts from the Level 1a raw data, which is subsequently converted the values of bending angle and refractivity, and then the temperature, pressure and water vapor of the atmosphere is achieved through retrieval computation method. The whole procedure is described in detail in [1] and a flow chart is displayed in Figure 2.

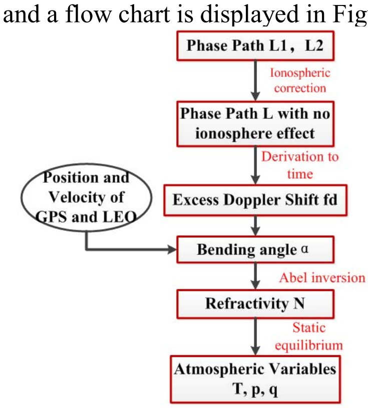

Figure 2. Flow Chart of Data Processing

III. THE COMPUTING PLATFORM

According to the raw data computing procedure, the computation platform has four function modules. The first module computes bending angle from signals' amplitude and phase, and the second computes refractivity from bending angle. In the third module, the atmospheric variables are computed from the data of bending angle and refractivity. As the large scale data may have bad ones, there is a quality control module in this platform to reject the bad data.

A. Amplitude and Phase to Bending Angle Module

This module computes the measured signal rays L1 and L2's amplitudes and phases as a function of time to achieve the profiles of bending angle, which is a function of impact parameter. These bending angle profiles could be doing the ionospheric correction in the next module and computed to achieve the refractivity.

Figure 3 shows example corrected bending angle profiles resulting from applying this module to process the input L1 and L2 amplitude and excess phase. The Y-axis is the geopotential height of the amplitude, phase and the bending angle. And the X-axis is the value of the variables.

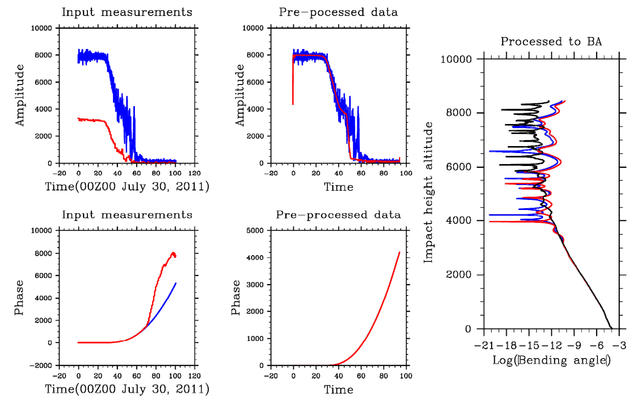

Figure 3. Example of processing radio occultation data using this module

Example L1 (blue) and L2 (red) amplitude and phase's measured data, preprocessed data and the resulting bending angle profiles computed using this module are shown in Figure 3. The black line of figure "Processed to BA" is the ionosphere corrected bending angle profile using L1 and L2 bending angles.

B. L1 and L2 Bending Angle to Refractivity Module

This module computes refractivity from the corrected bending angle data using abel inverse transformation.

Figure 4 shows the example of computing the bending angle and refractivity profile from the L1 and L2 bending angle data getting from last module. The bending angle profile showing with the black line in Figure 4 is corrected. Refractivity using this bending angle profile computed is shown with the blue line in the figure "BA-->N".

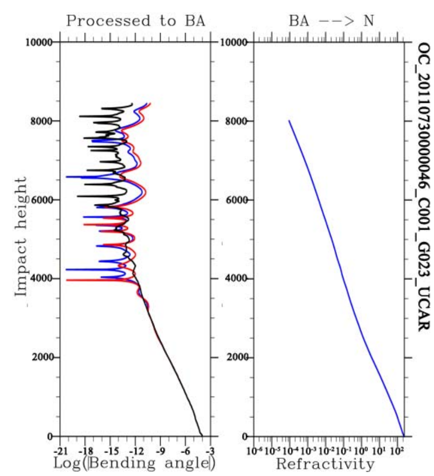

Figure 4. Computing refractivity from bending angle profile

C. Refractivity and Bending Angle's Retrieval to Atmosphere State Variables Module.

This module is the kernel part of the platform. The method of getting atmosphere state variables from the bending angle or refractivity profiles is called 1D-Variation Assimilation (1D-Var). Using this method, the state variables of atmosphere is computed in near real time.

Figure 5 shows the computed profiles of temperature, pressure and humidity using a calculated refractivity profile with the method. The Y-axis is the geopotential height.

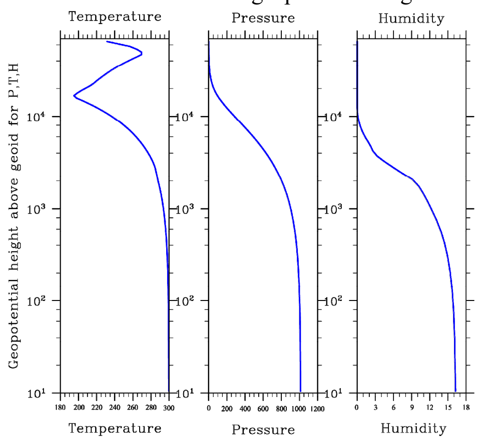

Figure 5. Computed atmosphere state from refractivity profiles

Figure 6 shows the retrieved profiles of temperature, pressure and humidity from a calculated bending angle profile with the method of 1D-Var.

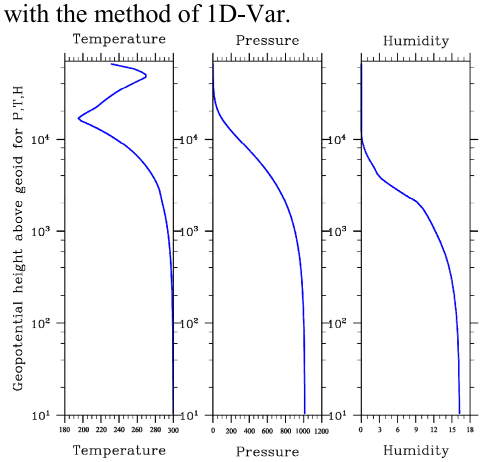

Figure 6. Retrieved atmosphere state from bending angle profiles

Through the method, the temperature, pressure and water vapor of atmosphere are computed in near real time. Comparing Figure 5 and Figure 6, bending angle is almost the same with refractivity in computing the atmosphere state. In theory, bending angle is more accurate than refractivity in the computation.

D. Quality Control Module

In a huge data processing procedure, the quality control module is absolutely necessary. There are boundaries, bad data and outliers in the data. There are four steps in this quality control module. After the four steps, about 2%~3% of the data is rejected.

- Check data with limits and boundaries.
- Reject bad data points with some principles.
- Statistics examination to find outliers.
- Error analysis to screen out data that in consistent with standards.

IV. PARALLELISM AND ACCELERATION

The amount of GPS radio occultation observation data is very huge per day. For example, it generates about 3000 radio occultation profiles each day. In consideration of the scale of data and the need of processing data in near real time, it is very necessary to parallelize and accelerate the platform to reduce the time of processing data for the target of offering data in near real time.

This platform will choose the frame of hybrid approach of OpenMP and MPI. For the massive data, we use domain decomposition to split data into uncoupled or loose coupled subdomains, distribute them to numerous computing nodes and exchange information through MPI. Within a node, we can unroll and parallel the large compute-intensive loops by OpenMP to exhaust the computing performance of CPU cores. Through parallelism, the program speed is about 1.4 times faster than before, and more work will do on it for the performance promotion of the platform.

V. CONCLUSION AND OUTLOOK

In this work，we present a parallelized computation platform that process raw GPS radio occultation data to achieve the state of atmosphere in near real time step by step, which can provide useful help in numerical weather prediction and science research, especially in the insufficient observation data areas.

This computation platform is an ongoing project and is still in active development. We will focus on developing more accurate computation model, data quality control and the framework of parallel accelerate.

ACKNOWLEDGMENT

This research is supported by National Science Foundation of China (NSFC) 41105063.

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