GNSS Radio Occultation Techniques and Applications at KMA

JaeGwan Kim, Chu-Yong Chung, and SeongHun Cheong

National Meteorological Satellite Center of KMA

National Meteorological Satellite Center, 64-18 Guam-gil, Gwanghyewon-myeon, Jincheon-gun, Chungbuk, 27803, Republic of Korea

KimJGwan@korea.kr

Abstract

The Korea Meteorological Administration (KMA) forecasts the weather using a Numerical Weather Prediction (NWP) system. National Meteorological Satellite Center (NMSC) of KMA has been supporting satellite data to Numerical Modeling Center of KMA for data assimilation since 2011. NMSC provides not only meteorological products of satellite but also ground and space based Global Navigation Satellite System (GNSS) data for NWP model. In addition, we have been studying on techniques of GNSS Radio Occultation (RO) to improve the accuracy in retrieving atmospheric vertical profiles. Also, we have developed monitoring system for GNSS RO data to monitor acquisition and to analyze data before transmission to NWP system. We are also studying about GNSS RO data preprocessing progress in order to understand principles more well for meteorological application. In this presentation, we will show some results on the KMA's NWP model of the GNSS RO data.

Ⅰ. Introduction

National Meteorological Satellite Center (NMSC) which belongs to Korea Meteorological Administration (KMA) has been operating two geostationary meteorological satellites, COMS and GK2A, since 2011 and 2019 respectively.

▣ **COMS: Communication, Ocean, and Meteorological Satellite (The 1st satellite of the KMA)**
- Operation Orbit: 128.15E / 35,800 km above the Equator
- Meteorological Imager (MI), one of 3 payloads has 1 visible (1km) and 4 infrared (4km) channels
- 16 baseline products from the COMS MI observation

▣ **GK2A: GEO-Korea Multi-Purpose Satellite – 2A (The 2nd satellite of the KMA)**
- Operation Orbit: 128.25E / 35,800 km above the Equator
- Advanced Meteorological Imager (AMI) has 16 channels (500m & 1km for VIS, 2km for IR)
- 52 baseline products from the GK2A AMI observation

Also, NMSC has been supporting satellite data to KMA's NWP system for data assimilation since 2011. As a part of data support, NMSC has been studying about processing data and application to NWP system.

▣ **GNSS RO Data Processing Techniques**
- NMSC is studying RO data processing techniques for better understanding and utilization

▣ **GNSS RO Data Application**
- NMSC provides GNSS RO data to Numerical Modeling Center of KMA for the NWP application

Ⅱ. GNSS Radio Occultation Techniques at KMA

Basic theorems of retrievals using GNSS RO data

▣ **Bending Angle** *from Geometric Optics*
- Bourger's rule

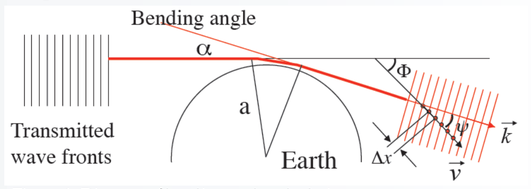


Figure 1. Diagram of bending angle calculation

- From POD, location of source and receiver orbit, v $\rightarrow \Phi$
- Measure Doppler shift,

$$f_d = \frac{1}{\Delta t} = \frac{v}{\Delta x} = \frac{v}{\lambda}\cos\psi = f_T \frac{v}{c}\cos\psi$$

$\rightarrow \Psi$,
- Compute the bending angle

$$\alpha = \Phi - \psi$$

▣ **Refractivity** *from Bending Angle*
- Abel transform

$$\alpha(a) = -2a\int_a^\infty \frac{1}{\sqrt{x^2-a^2}}\frac{d\ln(n)}{dx}dx \quad \Leftrightarrow \quad n(a) = \exp\left[\frac{1}{\pi}\int_a^\infty \frac{\alpha(a')}{\sqrt{a'^2-a^2}}da'\right]$$

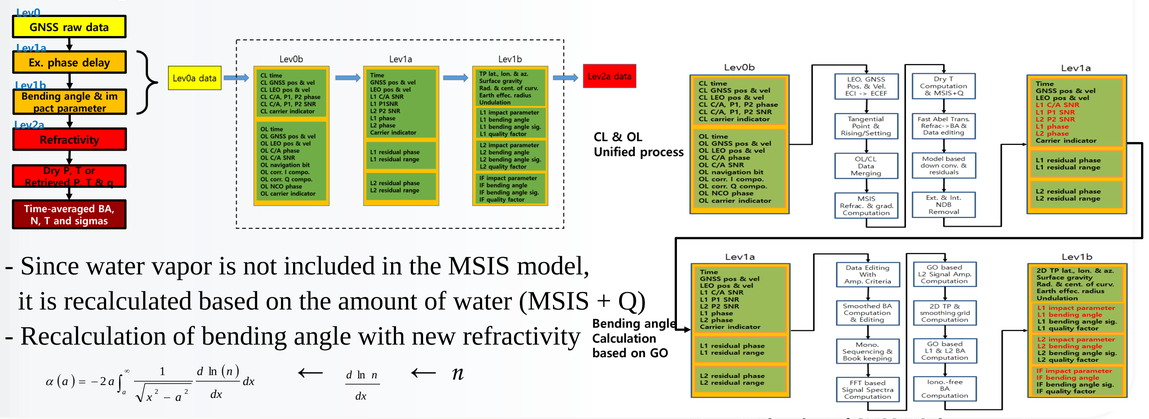
▣ **Atmospheric profile** *from Refractivity*

$$N = (n-1)\times 10^6 = a_1\frac{P_d}{T} + a_2\frac{P_w}{T^2} - 40.3\times 10^6\frac{n_e}{f^2} + a_w W_w + a_i W_i$$

- Where, P_d: Dry pressure
  P_w: Water vapor partial pressure
  $a_1 = 77.6\ K\cdot hPa^{-1}$
  $a_2 : 3.776\times 10^5\ K\cdot hPa^{-2}$
  $a_w : 1.4\ m^3/g$
  $a_i : 0.6\ m^3/g$

NMSC has been investigating and working on the processing of GNSS RO raw data to secure its preprocessing technology before calculation of bending angle and refractivity.

▣ **Development of frequency downward transformation and phase-evaluation technique using Climate Model (MSIS) for Open Loop (OL) signal processing**
- MSIS: Mass Spectrometer and Incoherent Scatter neutral atmosphere model
- Processing level: Lev0b → Lev1a → Lev1b



- Since water vapor is not included in the MSIS model, it is recalculated based on the amount of water (MSIS + Q)
- Recalculation of bending angle with new refractivity

$$\alpha(a) = -2a\int_a^\infty \frac{1}{\sqrt{x^2-a^2}}\frac{d\ln(n)}{dx}dx \quad \leftarrow \quad \frac{d\ln n}{dx} \quad \leftarrow \quad n$$

Figure 2. Flowchart of GNSS-RO data processing

Ⅲ. GNSS Radio Occultation Data Application at KMA

KMA's Numerical Modeling Center (NMC) utilizes GNSS RO data to assimilate to the NWP system for the numerical weather forecast .

▣ **KMA's NWP System**

▷ **Numerical Model: UM for KMA (for Global)**
- Spatial resolution: N1280 (≒10km), L70
- Target length: 288 hours (00, 12 UTC)
  87 hours (06, 18 UTC)

▷ **Analysis Scheme: 4DVAR**
- Analysis time: 00, 06, 12, 18 UTC
- Assimilation window: -3 hours ~ +3 hours of Analysis time

▣ **Satellite Data Usage at KMA's NWP System**

▷ **KMA uses GNSS-RO data for NWP model**

▣ **Data Impact Evaluation using FSO (Forecast Sensitivity to Observations)**

▷ **FSO is a diagnostic tool to monitor the observation impact on the NWP model**
- Evaluation Period; ***@2014/2015 Winter case***
- Contributions;
  Satellite(50%) > Surface(22%) > Upper(9%)
- Satellite Impacts;
  LEO (>70%), **especially *GNSS-RO (~5%)***

(━ : Operation , ━ : Evaluation in Progress)

Type(Sensor)	Satellite	Variables (control variables)	Model domain		
			Global	E-ASIA	Local
ATOVS(G,L) (AMSU-A/B, MHS,)	NOAA(15,18,19) MetOp-A/B	Radiance(t,q)	○	○ : Operation Terminated	
AIRS	Aqua	Radiance(t,q)	○		
IASI(G,L)	MetOp-A/B	Radiance(t,q)	○		
Satwind(GEO,LEO)	COMS, Meteosat-7, MSG, GOES, MTSAT, Aqua, NOAA	U,V (IR, WV, VIS channels)	○		△
Scatwind(ASCAT)	MetOp-A/B	U,V at 10 meter over ocean	○		○
GNSS-RO	COSMIC, GRACE, GRAS, KOMPSAT-5	Bending angle, Impact parameter(t,q)	○		
Ground-based GNSS	AC: NMSC, KASI, NGII(G,L), METG(G)	Zenith Total Delay(t,q)	△		○
CSR	COMS	Radiance (WV channel/q)	○		△
Soil Moisture(ASCAT)	MetOp-A/B	Soil moisture	○		

Figure 3. KMA's NWP models (Upper) and Satellite data usage (Lower)

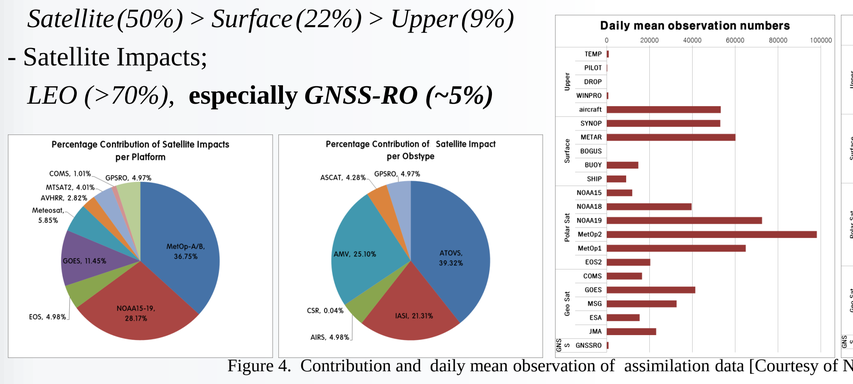


Figure 4. Contribution and daily mean observation of assimilation data [Courtesy of NMC]

- ***ⓑ2015 Summer and 2015/2016 Winter case*** ☞ GNSS-RO data impact on the model is 2~4%

▣ **RO data contribution**

▷ GNSS-RO data obviously contributes for reduction in forecast error.

☞ ***GNSS-RO data is worthy of notice for the KMA's NWP system.***

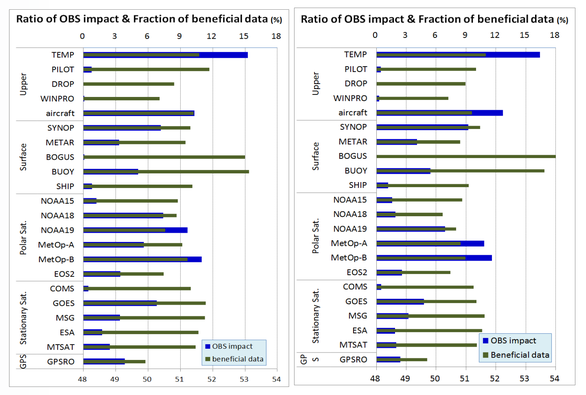


Figure 5. Ratio of observation data and Fraction of beneficial data [Courtesy of NMC]

Ⅳ. GNSS RO Data Monitoring System

NMSC has developed monitoring system for GNSS RO data of KOMPSAT-5 to monitor acquisition and to analyze data before transmission to NWP system.

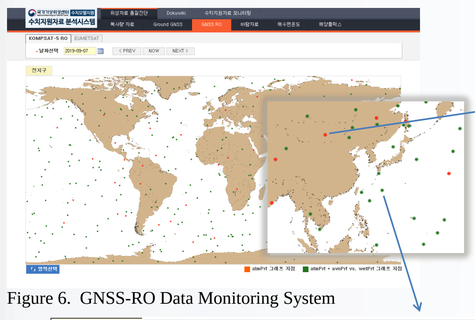


Figure 6. GNSS-RO Data Monitoring System

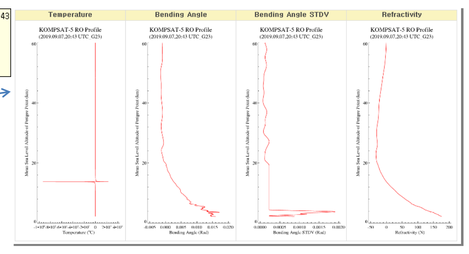


Figure 7. Atmospheric Profiles from KOMPSAT-5 RO data

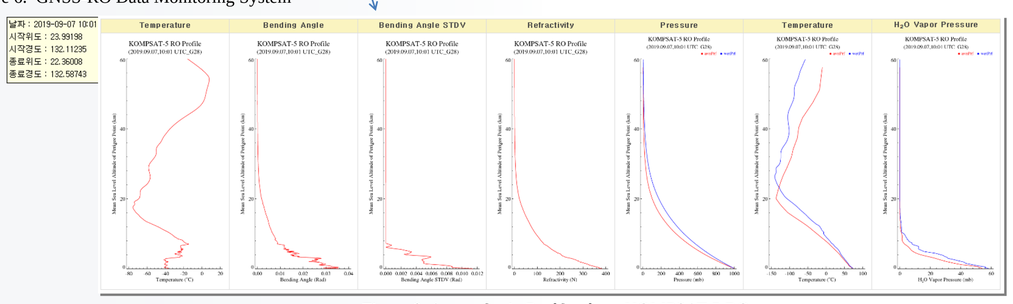


Figure 8. Atmospheric Profiles from KOMPSAT-5 RO

Summary and Future Works

▣ **National Meteorological Satellite Center (NMSC) of KMA provides meteorological products of satellite and ground/space based GNSS data to KMA's NWP system for data assimilation.**

▣ **For better understanding of GNSS-RO data application, we are studying RO data processing for NWP application especially preprocessing steps i.e. raw data processing.**

▣ **Numerical Modeling Center (NMC) of KMA has been operating KMA's NWP system and they analyzed Forecast Sensitivity to Observations (FSO).**
- **It brought positive impact on KMA's NWP model with GNSS RO data assimilation and for that reason, we hope to get the data more and more.**

▣ **NMSC also has developed monitoring system for GNSS RO data of KOMPSAT-5 to monitor acquisition and to analyze data before transmission to NWP system.**

▣ **Analyzing characteristics of GNSS-RO data for quality control and investigating an impact of GNSS-RO data on KMA's NWP model in operation will be continued.**