GNSS Radio Occultation Observations as a Data Source for Ionospheric Assimilation: COSMIC-1 & COSMIC-2

Xinan Yue (*xinanyue@ucar.edu*), William S. Schreiner, Ying-Hwa Kuo

COSMIC Program Office, University Corporation for Atmospheric Research, Boulder, CO, USA

1. GNSS Radio Occultation Technique:

- With a Global Navigation Satellite System (GNSS) receiver on board a low-Earth orbiting (LEO) satellite, the amplitude and phase of GNSS radio signals can be measured very precisely as the GNSS satellite is occulted by Earth's ionosphere and atmosphere, which can be used to derive ionospheric electron density information and atmospheric temperature and water vapor.

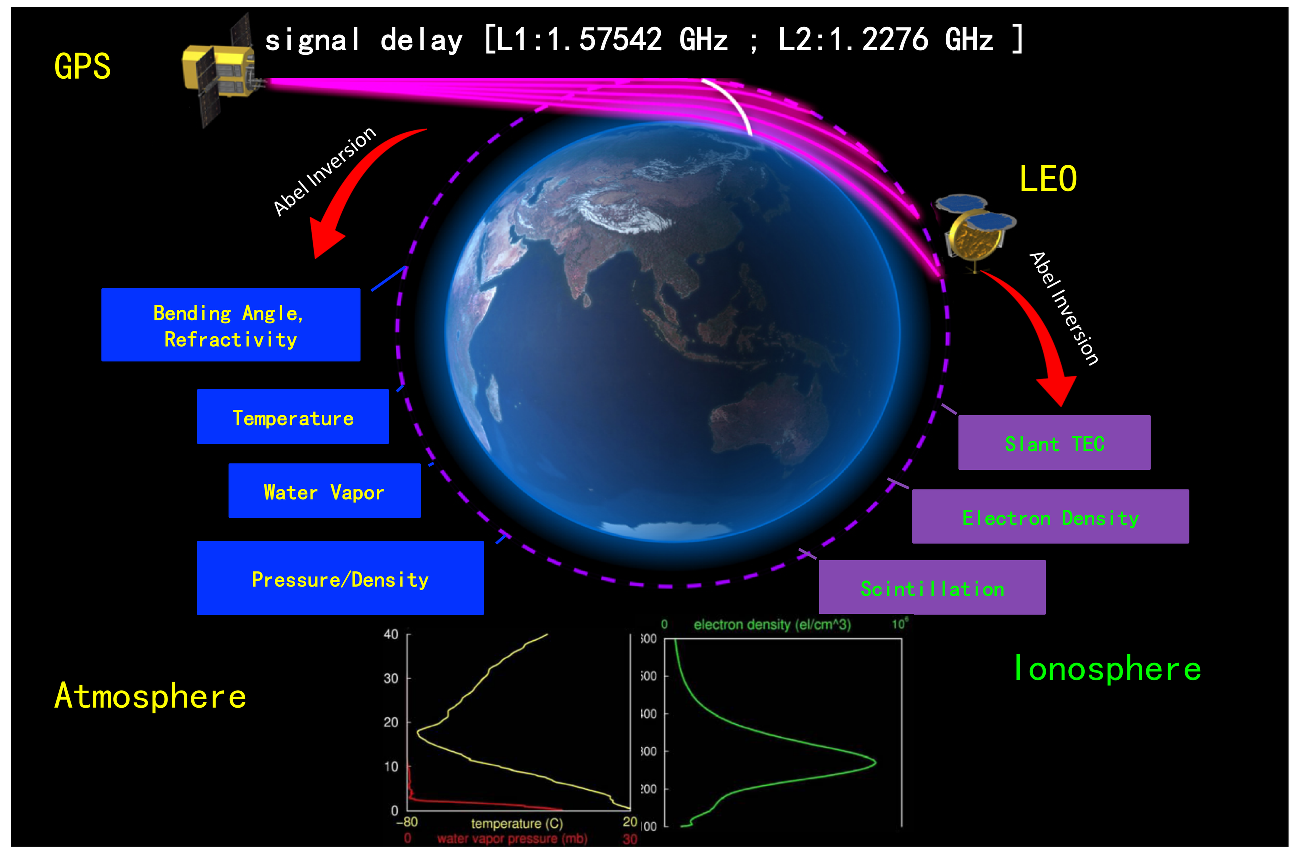


Figure 1. Demonstration of how GNSS RO works.

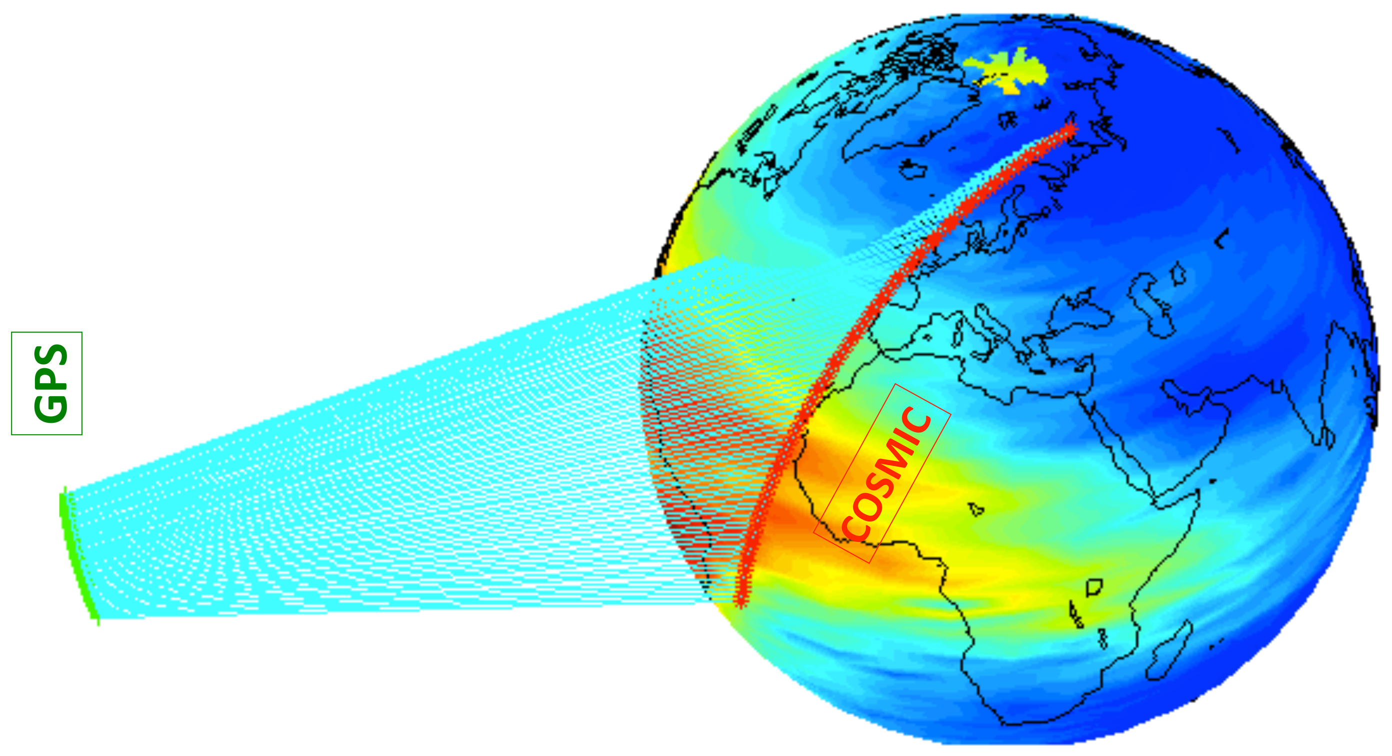


Figure 2. Geometry of a real COSMIC RO event.

2. COSMIC Mission:

- The joint Taiwan-United States FORMOSAT-3/COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate) mission, hereafter called COSMIC, is the first satellite constellation dedicated to remotely sense Earth's atmosphere and ionosphere using GPS radio occultation technique with near real-time data delivery. The occultations yield abundant information about neutral atmospheric temperature and moisture as well as space weather estimates of slant total electron content, electron density profiles, and an amplitude scintillation index, S4.

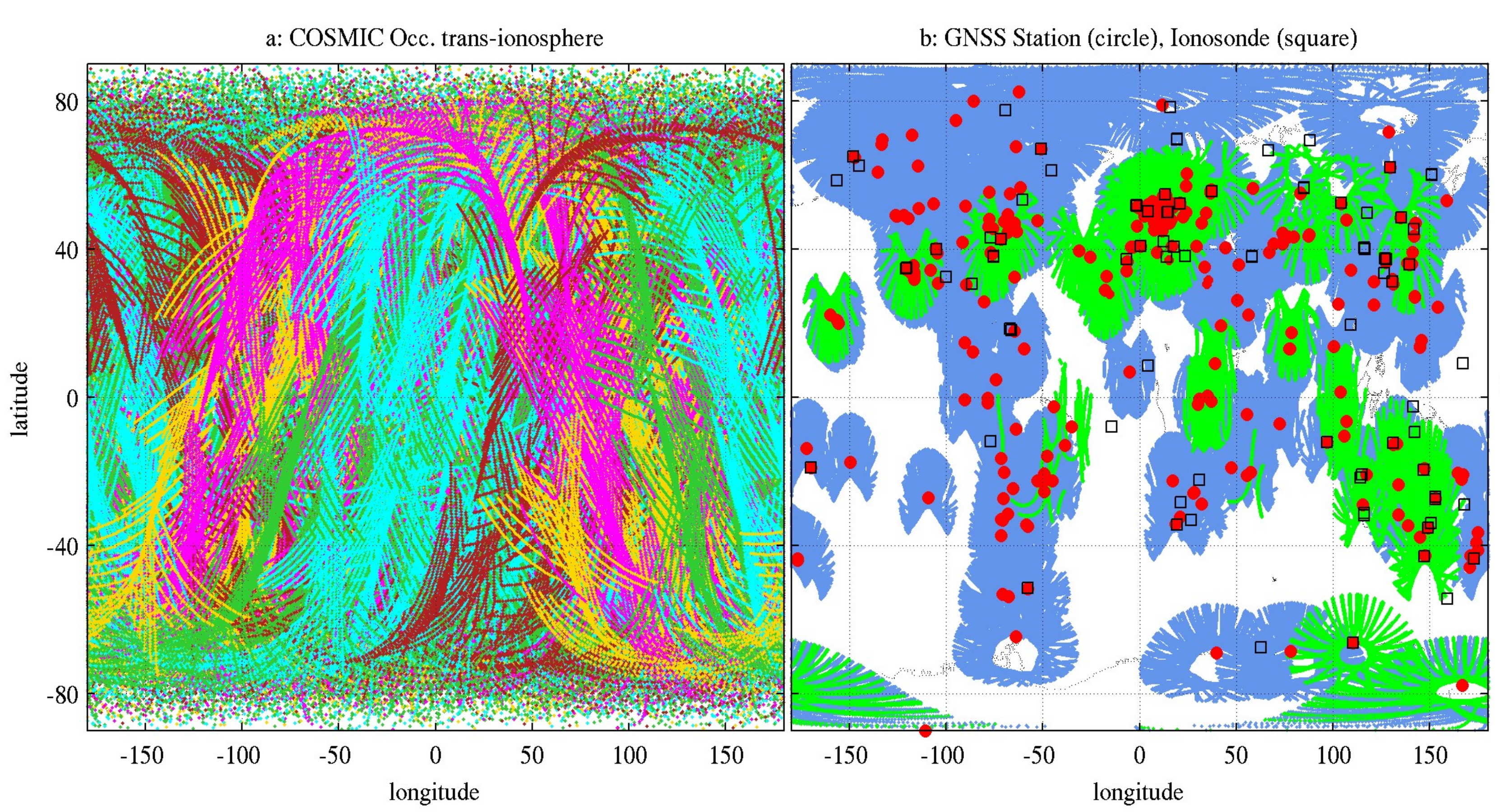


Figure 3. a: Daily trans-ionospheric coverage of COSMIC RO events; b: Daily coverage of pierce-point of global IGS observations and stations (circle) and ionosondes (square).

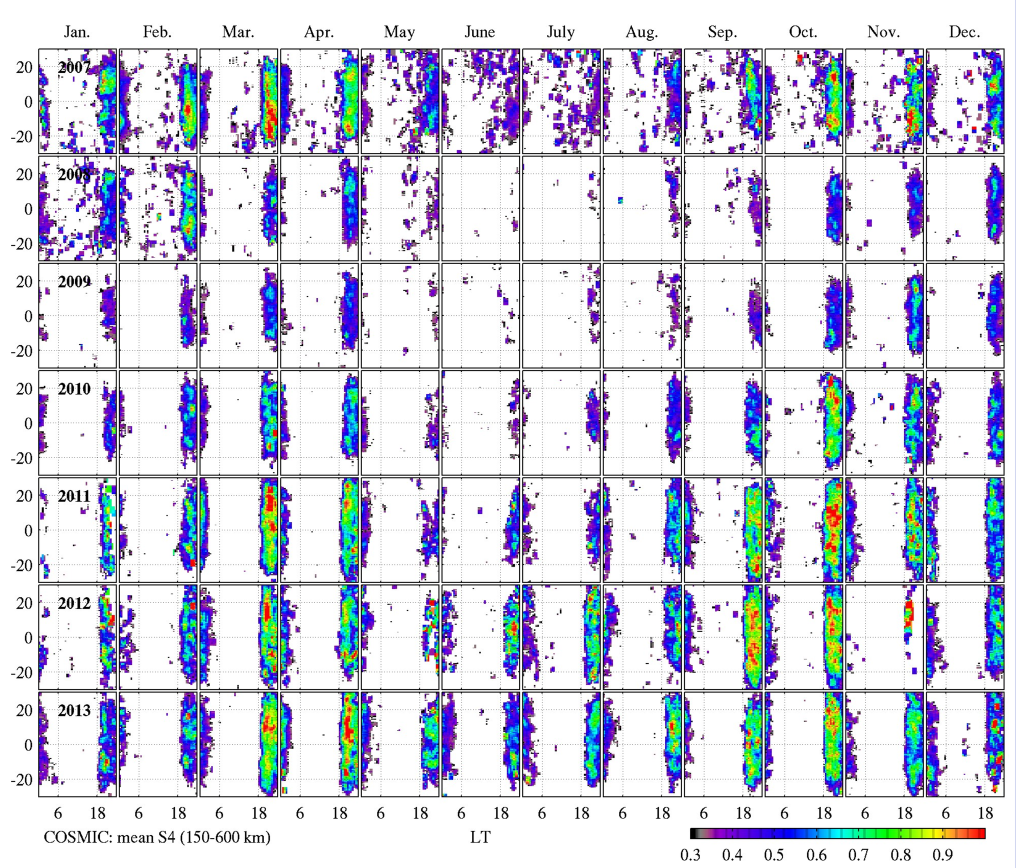
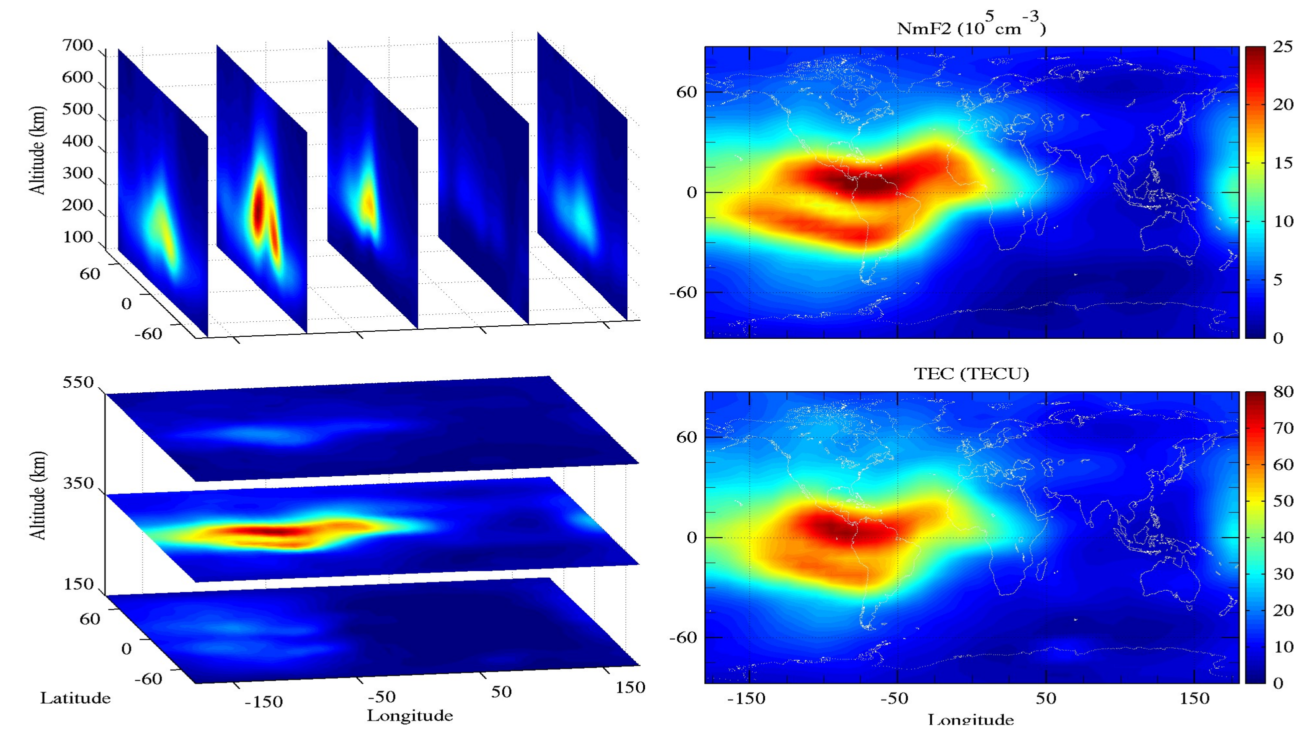


Figure 4. COSMIC Observed F layer S4 index: Seasonal variations during 2007-2013.

3. Ionospheric Data Assimilation based on COSMIC Observations:

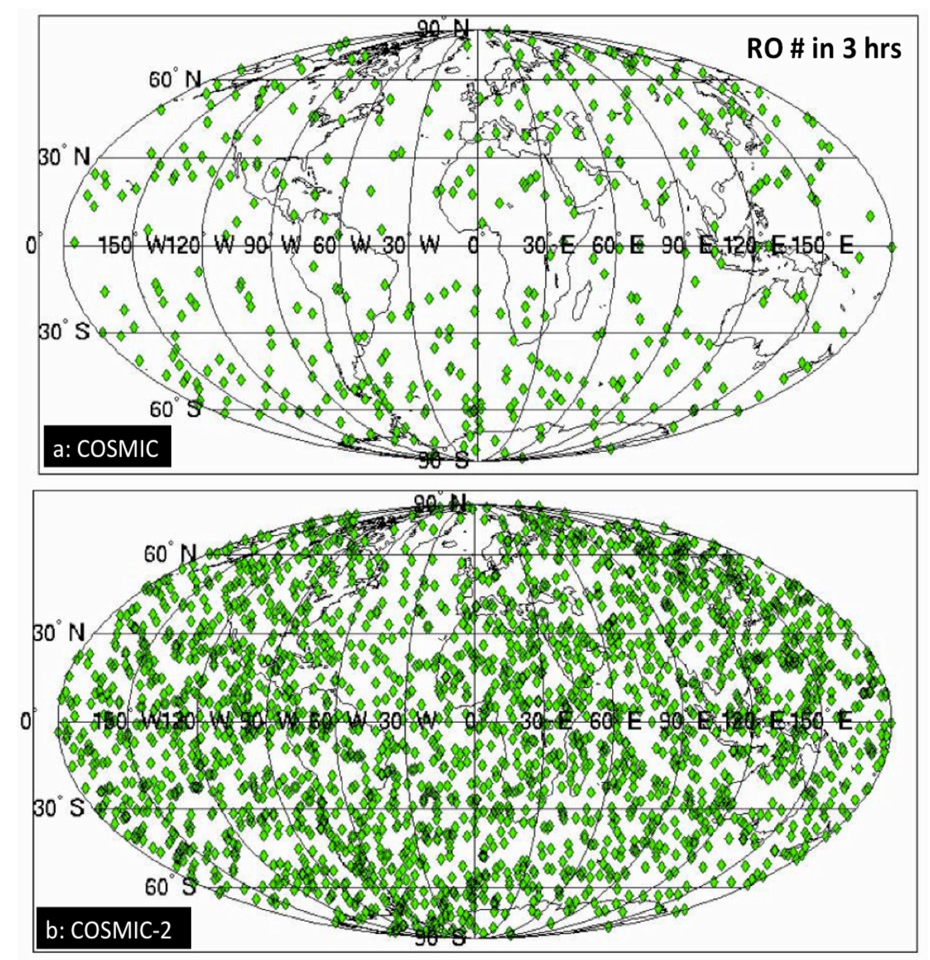


- COSMIC RO data has been used in the data assimilation systems by the community. We have done a global ionospheric electron density reanalysis during 2002-2011 by assimilating almost all the available data especially LEO based RO data simultaneously. The output of the reanalysis are 3-D gridded ionospheric electron densities with temporal and spatial resolutions of 1 h in universal time, 5° in latitude, 10° in longitude, and ~30 km in altitude.

Figure 5. Example of the reanalyzed monthly global 3-D electron density and the corresponding peak density (NmF2) and vertical TEC map at 1900 UT in September 2006.

4. COSMIC-2 Mission:

- With the success of COSMIC, the United States and Taiwan are moving forward with a follow-on RO mission named FORMOSAT-7/COSMIC-2 (COSMIC-2), which will ultimately place 12 satellites in orbit with two launches in 2016 and 2019. COSMIC-2 satellites will carry an advanced GNSS RO receiver that will track both GPS and Russian GLONASS signals, with capability for eventually tracking other GNSS signals from the Chinese BeiDou and European Galileo system. COSMIC-2 will provide 4-6 times (10-15× in the low latitudes) the number of atmospheric and ionospheric observations that were tracked with COSMIC. The first launch of COSMIC-2 will each have two other space weather payloads, a Ultra High Frequency (UHF)/L-band/S-band RF Beacon transmitter and the Ion Velocity Meter (IVM) instrument to measure in-situ ion density and three-dimensional plasma drifts. The IVM observations will be quite useful in low latitude ionospheric weather studies. Higher quality and quantity of COSMIC-2 data will potentially enhance the ionospheric nowcast and even forecast capabilities.



RO Payload	Satellite	Space Weather Payload
IGOR GPS ~2,000 per day	6 LEO satellites ~72° inclination ~800 km altitude ~61 kg >0.68 for 2 years launched 2006	TIP TBB
TriG GPS+ GLONASS >8,000 tropo per day >12,000 iono per day	First Launch	
	6 LEO satellites ~24° inclination ~520 km altitude ~215 kg >0.66 for 5 years ~launch 2016	IVM RF Beacon
	Second Launch	
	6 LEO satellites ~72° inclination ~720 km altitude ~215 kg >0.66 for 5 years ~launch 2019	TBD

Figure 6. Comparison between COSMIC (a) and COSMIC-2 (b) in RO events during 3 hours (left) and key parameters (right).

Table 1. Space Weather Products and Accuracy Requirement for COSMIC-2

Instrument	Parameter	Observation Range	Accuracy
TGRS	Relative TEC	0–2000 TECU	0.3 TECU
	Absolute TEC	0–2000 TECU	3 TECU
	Electron density profile	3×10^{10}–10^{13} el · m^{-3}	Less than the greater of 10^{11} el · m^{-3} and 20%
	Amplitude scintillation (S4)	0.1 to 1.5	0.1
	Phase scintillation (σ_φ)	0.1 to 20 rad	0.1 rad
IVM	Ion density	10^9–5×10^{12} m^{-3}	5%
	Ion composition	0–1	5%
	Ion velocity	Cross track: ±1000 m/s; In track: ±1000 m/s	Cross track: ±5 m/s; In track: ±10 m/s
RF Beacon	Amplitude scintillation (S4)	0.1 to 1.5	0.1
	Phase scintillation (σ_φ)	0.1 to 20 rad	0.1 rad

5. References:

- Yue, X., et al., (2012), Global 3-D ionospheric electron density reanalysis based on multisource data assimilation, *J. Geophys. Res.*, 117, A09325, doi:10.1029/2012JA017968.
- Yue, X., W. S. Schreiner, N. Pedatella, R. A. Anthes, A. J. Mannucci, P. R. Straus, and J.-Y. Liu (2014), Space Weather Observations by GNSS Radio Occultation: From FORMOSAT-3/COSMIC to FORMOSAT-7/COSMIC-2, *Space Weather*, 12, doi:10.1002/2014SW001133.
- Yue, X., W. S. Schreiner, Y.-H. Kuo, J. J. Braun, Y.-C. Lin, and W. Wan (2014), Observing system simulation experiment study on imaging the ionosphere by assimilating ground GNSS, LEO based radio occultation and ocean reflection, and cross link, *IEEE Trans. Geosci. Remote Sens.*, 52(7), 3759–3771, doi:10.1109/TGRS.2013.2275753.