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Ionospheric Tomography using A Regional GPS Network over South Korea

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Abstract. The vertical profiles of electron distribution near the low and mid-geomagnetic latitudes have been investigated by the computerized tomography method using Algebraic Reconstruction Technique (ART). The slant total electron contents (STEC) data for ionospheric tomography were measured at a regional GPS reference network of nine stations that have been operated by Korea Astronomy and Space Science Institute (KASI). The results from tomographic reconstruction method are in good agreement with profiles obtained by Ionosonde near the KASI GPS stations. The electron density profiles reconstructed by the tomographic method were compared with the results from Ionosonde and IRI-2001 model. GPS tomography reconstruction plays an important role of complementary measurements of Ionosonde in ionospheric structure.

Key words: ART, STEC, Ionosonde, IRI-2001

1 Introduction

Over the past decade, GPS has become a valuable tool for determining total electron contents (TEC) of ionosphere and so on. Nowdays, in order to study the characteristics of ionosphere, the existing global and regional networks of GPS stations have been commonly used. GPS-to-ground signals trace out a network of measurements through the ionosphere. However, the geometry does not map easily into a plane for tomographic inversion and the need to extend conventional imaging techniques to three dimensional imaging has arisen (Bust et al., 2001); Hernandez-Pajares et al., 2000).

Dual-frequency observations of GPS signals provide a relative ionospheric delay of the two-frequency electromagnetic waves traveling through a dispersive medium. The relative total electron contents along the line of sight can be derived from this delay (Lanyi and Roth, 1998).

Since Austin et al.(1986) first proposed the possibility of studying the ionosphere using satellite radio tomography, tomographic reconstruction of the ionosphere and plasmasphere electron density has become a popular and successful means of studying the detailed features of the ionosphere and plasmasphere. Generally, tomographic technique is a mathematical method that is used to model ionosphere. Tomographic ionosphere model is often compared with the measurements of incoherent backscatter radars and ionosondes(Hernandez-Pajares et al., 2000).

An ionospheric tomography model can describe the ionosphere field in a three-dimensional frame instead of a two-dimensional frame as used by previous methods (Gao and Liu, 2002).

This paper presents ionospheric tomography over South Korea derived from KASI GPS network. The independent verification of the reconstructed electron density profile is also presented.

2 Background

2.1 Precise TEC Calculation

Basically, in order to estimate the electron density distribution with height of ionosphere, the calculation for slant TEC (STEC) or vertical TEC (VTEC) has to be initially implemented (Hernandez et al., 1999). When using the dual-frequency GPS data, it is available to estimate precisely the TEC. Code measurements (P1, P2) are expressed as follows (Gao and Liu, 2002).

$$P1(k) = \rho + c(\delta t^s - \delta t_r) + \frac{40.3}{f_1^2}TEC(k) + \varepsilon_{trop} + \varepsilon_m + \varepsilon_{L1} \quad (1)$$

$$P2(k) = \rho + c(\delta t^s - \delta t_r) + \frac{40.3}{f_2^2}TEC(k) + \varepsilon_{trop} + \varepsilon_m + \varepsilon_{L2} \quad (2)$$

where ρ is the true geometric range between receiver and satellite (m), δt^{s} is the satellite clock error with respect to GPS time (s), δt_{r} is the receiver clock error with respect to GPS time (s), ε_{trop} is the troposphere delay error, ε_{m} is the multi-path error and ε_{L_i} (i = 1,2) is the noise on L1/L2 GPS signals.

On the occasion of using carrier phase data, the following linear combination equation is formed.

$$I_{\phi} = \{(\phi_1 - \frac{f_1}{f_2}\phi_2) - (N_1 - \frac{f_1}{f_2}N_2)\} \cdot \frac{f_2^2}{f_2^2 - f_1^2} \quad (3)$$

where f_1 (1575.42 MHz) and f_2 (1227.60 MHz) are frequencies on L1 and L2 respectively, ϕ_1 and ϕ_2 are carrier phase measurements, N_1 and N_2 are integer ambiguities, I_{ϕ} is the ionosphere delay on L1.

Due to the existence of ambiguities, the absolute ionosphere delay on the carrier phase cannot be determined. However, the differential ionospheric delay over two consecutive epochs can be determined if there is no cycle slip occurrence(Cannon, 1997).

2.2 Basic Function

Ionosphere can be divided into volumn pixels, voxels to construct computer tomography. Voxel is the element in a three-dimensional environment. Voxels in the Earth's ionosphere are indicated with latitude, longitude and height. Assuming straight line approximation, those voxels illuminated by the ray will be a basic function equal to 1 and 0 otherwise, delta function. In case of KASI network, two-dimensional voxels was considered as follows.

$$d_{ij}(\phi, h) = \begin{cases} 1 & \text{if cell illuminated by ray} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

As seen in Fig. 1, KASI network has consisted of nine GPS reference stations and GPS reference stations of KASI have been more widely distributed on the latitude (Choi et al., 2005).

Fig. 2 shows the ray path of GPS signal observed by the specific GPS reference station in KASI network. If GPS signals pass voxels, as mentioned equation 4, basic function should be 1; otherwise it should be 0 (zero).

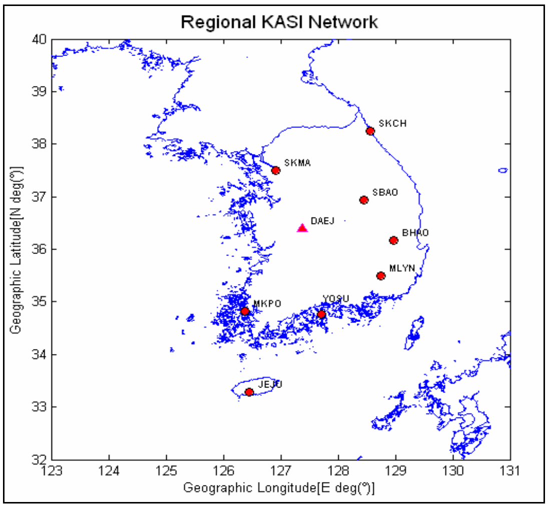

Fig. 1 The Distribution of GPS reference stations in a regional KASI network

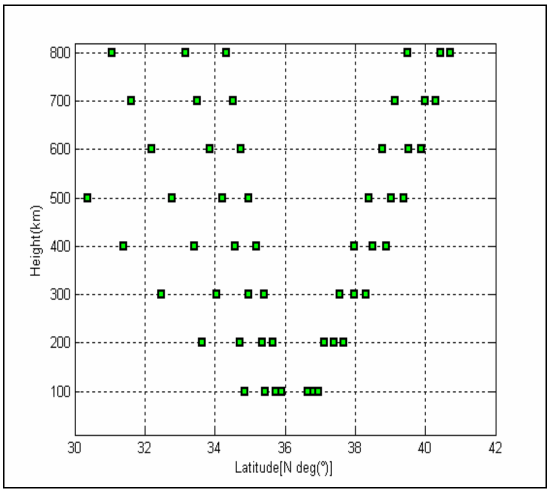

Fig. 2 GPS signals passing voxels with two-dimensional frame

2.2 Basic Function

One of the most commonly used inversion techniques is algebraic reconstruction technique (ART). The initial guess with the experimental TEC data in an interactive is required in the ART algorithm. ART algorithm can be implemented as the following equation (5).

$$N^{k+1} = N^{k} + \lambda_k \frac{STEC_i - \sum_{j=1}^{M} d_{ij} n_j^k}{\sum_{j=1}^{M} d_{ij} d_{ij}} D_i \quad (5)$$

where D_i is the row of D, k is the iteration number, and λ_k is the relaxation parameter. The relaxation parameters, λ is usually confined to the interval $0 < \lambda < 2$ and is the same for all iterations.

The ART algorithm, which can converge quickly in an iterative fashion compared to other reconstruction algorithms, is the preferable algorithm to use with ionospheric reconstruction in a region like the GPS network in South Korea.

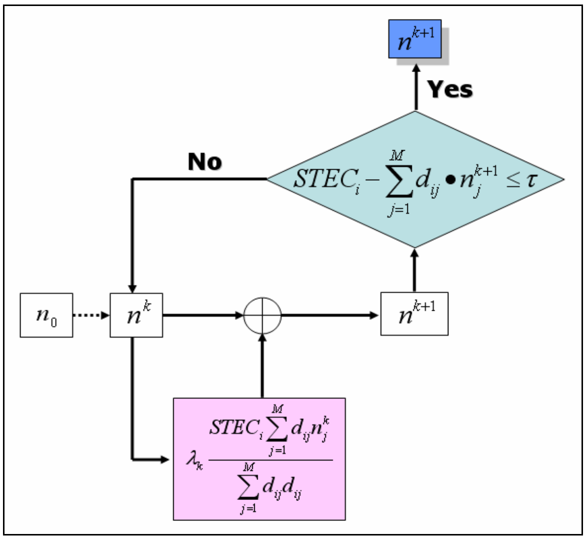

Fig. 3 ART algorithm scheme

As mentioned above Fig. 3, the ART algorithm requires some initial values of the quantity to be reconstructed. For example, these initial values can be obtained from models such as IRI-2001 (International Reference Ionosphere), chapman profile models or Ionosonde based on the measurement data. IRI-2001 model requires further optional input parameters to get a true density profile. Input parameters for IRI-2001 model can be obtained from Ionosonde measurement data.

3 Data Processing

Tomography reconstructions based on KASI GPS network data have been performed for the ionosphere over narrowly limited South Korea.

The geographical region to be reconstructed is set by geographic latitude and height. The full extent of latitude is from 31° to 40° N on the geophysical coordinates and that of the height is set within the limits of up to 1,000km on Earth. The spatial resolution for the height is also set in 10km. The elevation of the satellite at each GPS reference station has been set greater than 15°.

If there are not enough GPS signals passing virtual voxels over South Korea, the height precision of the electron density profile is significantly affected by data gaps. In case of that, it can be required sophisticated interpolation method. We use IDW(Inverse Distance Weighted) interpolation technique in model.

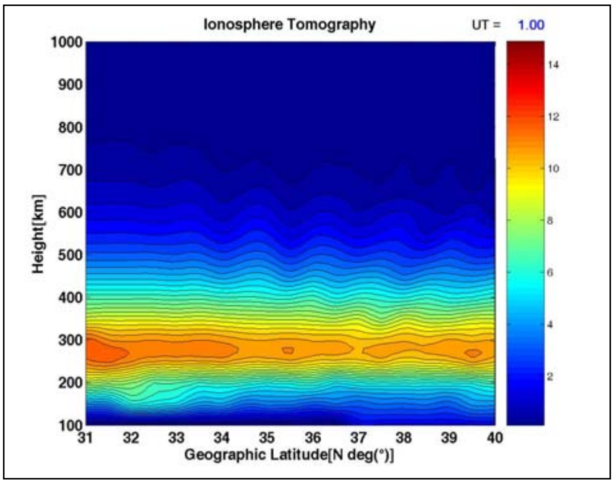

Fig. 4 The reconstructed electron density profile along the height over South Korea at 1:00 UT(10:00 LT) on July 1, 2003

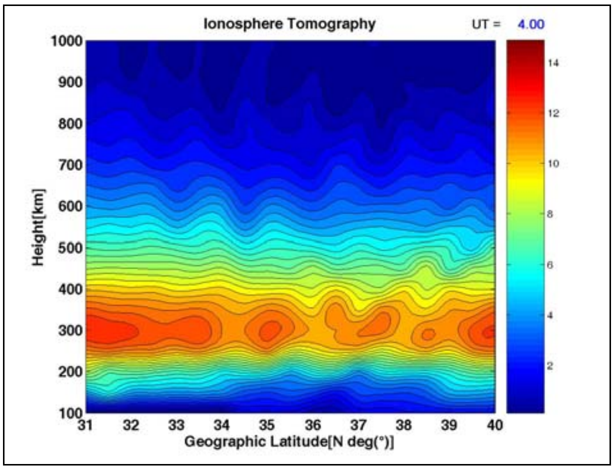

Fig. 5 The reconstructed electron density profile along the height over South Korea at 4:00 UT(13:00 LT) on July 1, 2003

Fig. 4 obtained from data recorded at 1:00 UT (10:00 LT), shows the high density distribution at 31°~32° N. Fig. 5 and 6 show examples of typical images of the dayside ionosphere obtained during the quiet period on July 1, 2003. Above on images, the bar unit of the column density is about $1.0 \times 10^5 electron / cm^3$.

The peak height of the electron density distribution in Fig. 5 is about 300km and there is no a large difference of the electron density distribution between 31° to 40 °N because of a narrow region. But as seen in Fig. 5, at top-side ionosphere over 500km, the electron density at 4:00 UT(13:00 LT) is higher than that of at 1:00UT in Fig. 4. that is, the status of ionosphere depends on daily variation.

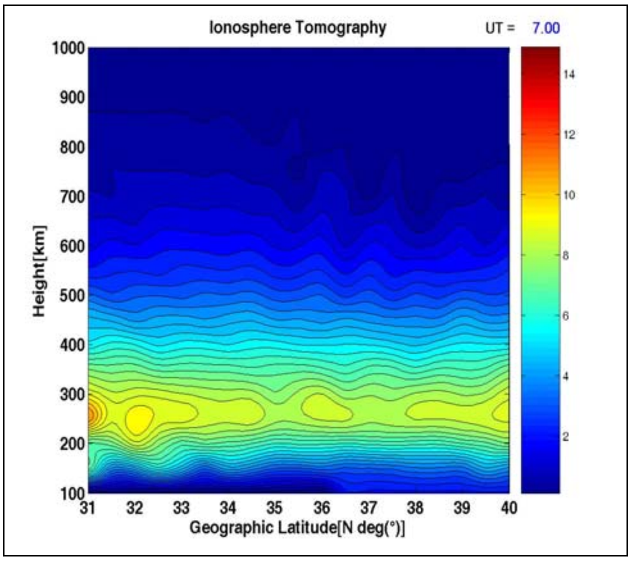

Fig. 6 The reconstructed electron density profile along the height over South Korea at 7:00 UT (16:00 LT)on July 1, 2003

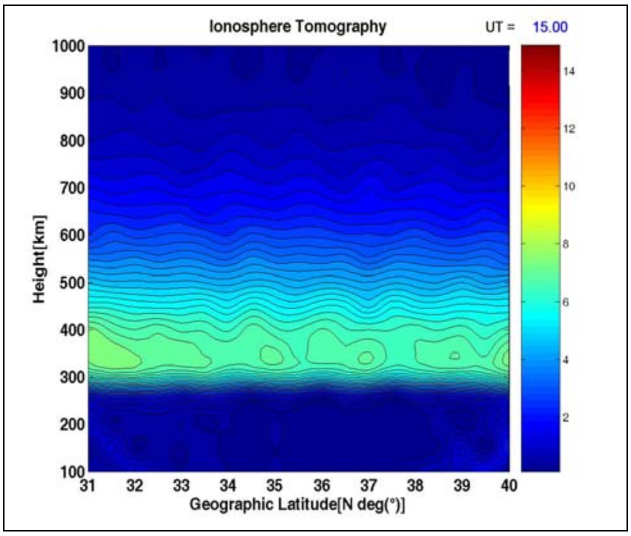

Fig. 7 The reconstructed Electron density profile along the height over South Korea at 15:00 UT(24:00 LT) on July 1, 2003

Fig. 7 shows the electron density distribution obtained from GPS data at 15:00 UT(24:00 LT). The important thing is that the peak height of the electron density value, calculated from GPS reconstruction, between the dayside and the night-side is different. As mentioned above, the peak height of the electron density value at the dayside is about 300km in Fig. 6 whereas that at the night-side is about 350km as seen in Fig. 7.

Fig. 8 shows that the electron density profiles (blue circles) reconstructed by GPS are verified with the corresponding density profile (red dots) measured by Ionosonde at 37.5°N. The electron density profile by IRI-2001 (green dots) is also presented.

Table 1 shows the RMSE between the reconstructed tomography by GPS and results from IRI-2001 and Ionosonde. It also shows that GPS reconstruction model is well consistent with Ionosonde measurement, but is not consistent with IRI-2001 empirical model.

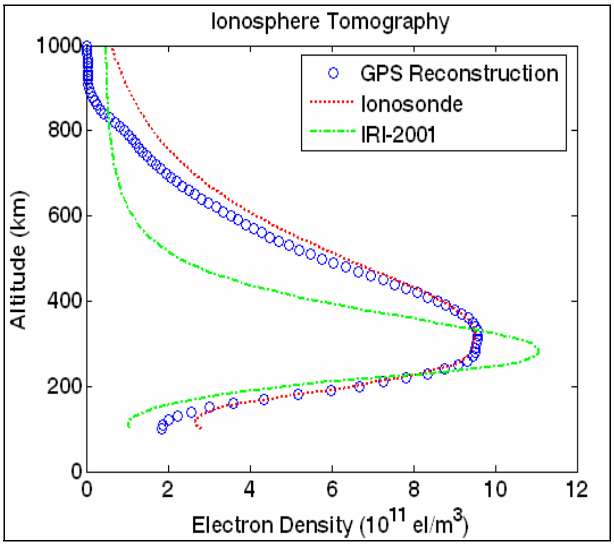

Fig. 8 The electron density profiles plotted by GPS reconstruction, IRI-2001 and Ionosonde

Tab. 1 Comparison of GPS reconstruction and IRI-2001 and Ionosond

Models	RMSE($10^5 el/cm^3$)
GPS Re. – Ionosonde	0.590
GPS Re. – IRI2001	1.850

4 Summary and Conclusions

The GPS reconstruction for ionospheric density profile was performed by KASI GPS network. ART algorithm was used to estimate the precise density profile over South Korea. But ART algorithm has a disadvantage requiring the initial values despite the fast convergence.

In order to estimate the electron density profile in ionosphere, it is necessary to be considered the determination of the precise STEC (Slant TEC) which is calculated by a regional or global GPS network. In this paper, there is good agreement at the bottom side between the profile of GPS reconstruction and the profile of Ionosonde, but less for the topside. We have shown that the electron density in the height of the ionosphere is changed with time.

In conclusion the electron density profile obtained by the tomographic reconstruction method is in excellent agreement with profile obtained by Ionosonde measurement data. We have shown that high resolution density profile can be also achieved when using GPS data based on the network frame.

References

Bust G.S., Coker C., Coco D.S., Gaussiran T.L., Lauderdale T. (1993) ***IRI data ingestion and ionospheric tomography***. PAdv. Space Res, 157.

Choi B.K., Park J.U., Jeong J.K., Park P.H. (2005) ***Near Real-time Ionospheric Modeling using a Regional GPS Network***. Journal of Astronomy and Space Science, 283-292.

Cannon M.E. (1997) ***Satellite Positioning***. ENGO 561, The University of Calgary, Canada.

Hernandez M., Liao X., Liu Z.Z. (1999) ***New approaches in global ionospheric determination using ground GPS data***. Journal of Atmospheric and SolarTerrestrial Physics, 1237-1247.

Hernandez-Pajares M., Juan J.M., Sanz J. (2000) ***Application of ionospheric tomography to real-time GPS carrier-phase ambiguities resolution at scales of 400-1000km and with high geomagnetic activity***. Geophys. Res. Lett, 2009.

Gao Y., Liu Z.Z. (2002) ***Precise Ionosphere Modeling Using Regional GPS Network data***. Journal of Global Positioning Systems, 28-24.

Lanyi G.E., Roth T. (1998) ***A comparison of mapped and measured total ionospheric electron content using global positioning system and beacon satellite observations***. Radio Science, 483-492.

Austen J.R., Franke S.J., Liu C.H. (1986) ***Application of computerized tomography techniques to ionospheric research***. Ouluensis Universitas, Oulu Finland, 25-35.