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An ionospheric assimilation model along a meridian plane

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ABSTRACT

In this paper, we developed a two-dimensional ionospheric assimilation model that assimilates the observations of peak electron density of F2-layer (NmF2) and the peak height of F2-layer (hmF2) derived from five ionosonde stations along the 120°E meridian, using three-dimensional variation techniques (3DVAR) based on a physics-based ionosphere theoretical model. The assimilation system can well produce the assimilated results along the 120°E meridian plane by using the data of NmF2 and hmF2 at five ionosonde stations from Mohe (52.0°N) to Sanya (18.3°N). The root mean square error (RMSE) between the analysis results of the assimilation model and the ionosonde observations is much lower than that between the results from international reference ionosphere (IRI) and the ionosonde observations. In addition, we carried out the assimilation test by taking the IRI results as the observations to check the assimilated results in the regions without observations. The assimilated result in the southern hemisphere (RMSE=0.29) is much worse than that in the northern hemisphere (RMSE=0.10) because no observations in the southern hemisphere were used. If the data derived from the four ionosonde stations in Australia are used, the assimilated result in the southern hemisphere would be much more accurate. In addition to NmF2 and hmF2, the assimilation model can also adjust the total electron content (TEC). The RMSE between the TEC after assimilation and the observed GPS TEC is much lower than that between the TEC from the IRI model and the observed GPS TEC.

1. Introduction

The ionosphere has been studied extensively for more than 60 years, and it is now well-known that it exhibits a significant variation with altitude, latitude, longitude, time of the day, solar cycle, season, and geomagnetic activity. Numerous empirical, analytical, parameterized, and physics-based theoretical models of the ionosphere have been developed for several decades to reproduce ionospheric variations under various geophysical conditions. There are many physics-based theoretical models currently available, such as the TIGCM model of NCAR (Roble et al., 1988), the FLIP model of Alabama University (Richards and Torr, 1985), the SUPIM model of Sheffield University in the U.K. (Bailey et al., 1997), the CTIP model (Millward, 1993), the GTIM model constructed in the Phillips Laboratory (Anderson, 1973), the Sami2 model of the U.S. Navy Research Lab (Huba et al., 2000), and the GCITEM model of the Institute of Geology and Geophysics of Chinese Academy of Sciences (Ren et al., 2009).

The physics-based theoretical models take into account various chemical, transport, and radiative processes that operate in the ionosphere-thermosphere system. Thus, physics-based ionosphere theoretical models reproduce many of the observed climatological features. The ionosphere-thermospheric system is controlled by the effects of solar, interplanetary, magnetospheric, and mesospheric processes. These processes have significant day-to-day variation, which cause significant day-to-day ionospheric variation, which is referred to as *ionospheric weather*. However, the physics-based ionosphere theoretical models generally fail in reproducing ionospheric weather due to the lack of reliable specifications of the ionospheric drivers, which include thermospheric composition and winds, equatorial and high-latitude electric fields, and high-latitude particle precipitation.

Currently, the most promising models for ionospheric weather specification are data- assimilation models that combine physics-based models of the ionosphere with observations. Data-assimilation models have been used extensively over the past decades in meteorology and oceanography for both specifications and forecasts. In recent years, ionospheric data assimilation has become a new focus. Many famous data assimilation models, such as the University of Southern California/the Jet Propulsion Laboratory Global Assimilative Ionospheric Model (Hajj et al., 2004; Wang et al., 2004) and the Utah State University Global Assimilation of Ionospheric Measurements (Schunk et al., 2004; Scherliess et al.,

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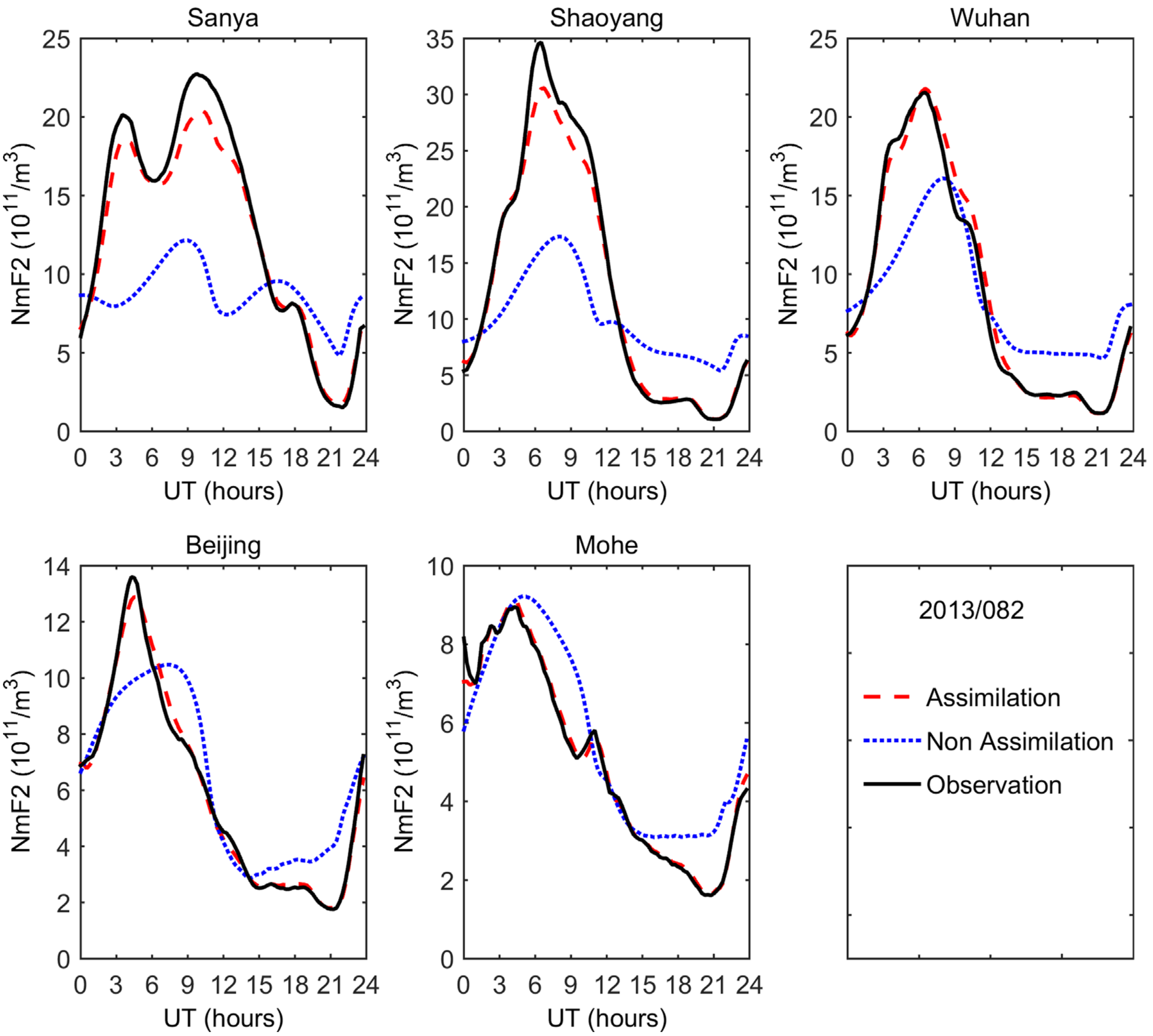

Fig. 1. Comparison of the assimilated NmF2 (dashed lines) and observed NmF2 (solid lines) at five ionosonde stations on DOY 82 in 2013. The model background NmF2 (dotted lines) is also plotted in Fig.1.

2006), usually assimilate multiple observations, including GPS–TEC, satellite, and radar observations. They use Kalman Filter, three- or four-dimensional variational techniques to obtain accurate nowcasts and forecasts of the ionosphere. Some other ionospheric data assimilation models also exist (e.g., Bust et al., 2004; Scherliess et al., 2009; Yue et al., 2012; Pezzopane et al., 2011).

Most of the assimilation models mentioned above use GPS-derived TEC, which can supply high spatial and temporal coverage. However, they require enormous computing resources and are time-consuming. The peak electron density of the F2 layer (NmF2) and the peak height of the F2 layer (hmF2) derived from ionograms constitute the two most important parameters for determining electron density height profiles. There are five digital ionosonde stations routinely operating along the 120°E meridian plane in China. Thus, we developed a data assimilation model based on the data from the ionograms and a physical-based theoretical model. The assimilation model does not use the whole electron density height profiles, but rather utilizes the two key parameters, NmF2 and hmF2, as background parameters. Thus, this assimilation model can be much faster than models based on the whole electron density height profiles. If the observations from ionograms in Australia are added to the assimilation model, the assimilation model can well produce electron density profiles in middle and low latitudes along the 120°E meridian plane.

2. Ionospheric background model and data descriptions

In the assimilation method proposed in this work, the Theoretical Ionospheric Model of the Earth in the Institute of Geology and Geophysics, Chinese Academy of Sciences (TIME-IGGCAS) (Yue et al., 2008) has been used as a background model. It solves the 2-D coupled equations of mass continuity, momentum, and energy for three dominant ions: O^+, H^+, and He^+. The distributions of the grid points along the geomagnetic field line are given according to the method of Millward (1993). The model also calculates the values of concentrations of three minor ions, ${N_2}^+$, ${O_2}^+$ and NO^+, in the E and F region under the assumption of photochemical equilibrium. The neutral temperature and densities are taken from the NRLMSIS-00 model (Picone et al., 2002), and the NO concentration is calculated from an empirical model developed by Titheridge (1997). The neutral winds are supplied by the HWM-93 model (Hedin et al., 1996). The photoelectron heating effect is similar to that of Millward (1993). At lower altitudes (below 300 km), the photoelectron heat is produced locally. At higher altitudes (above 300 km), the photoelectron heat comes from local sources and also from sources in the opposite hemisphere. The $E \times B$ vertical drift velocity is calculated by the empirical vertical drift model (Scherliess and Fejer, 1999). TIME-IGGCAS can reproduce most of the regular and anomalous features of the ionosphere, such as the formation of the equatorial ionization anomaly,