Data-driven Modeling of the Global Equatorial Electrojet Variability Using Ground-based Magnetometer Data

Chuan-Ping Lien[1], Tomoko Matsuo[1], Astrid Maute[2], Claudia Stolle[3]

[1]University of Colorado Boulder, CO, USA, [2]High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA, [3] Leibniz Institute of Atmospheric Physics at the University of Rostock, Kühlungsborn, Germany

Introduction & Motivation

- The equatorial electrojet (EEJ) is an intense electric current flowing at the magnetic equator in the E region of ionosphere (Chapman, 1951; Forbes, 1981). EEJ can be characterized by using magnetic perturbations (ΔB) observations from magnetometers deployed on the ground and at LEO altitude.
- The day-to-day variation of ΔB signatures associated with EEJ is known to be mainly driven by the changes of diurnal and semi-diurnal tides, especially under solar minimum condition (Yamazaki et al, 2016). It is difficult to determined these day-to-day changes of the neutral wind globally using currently available observations.

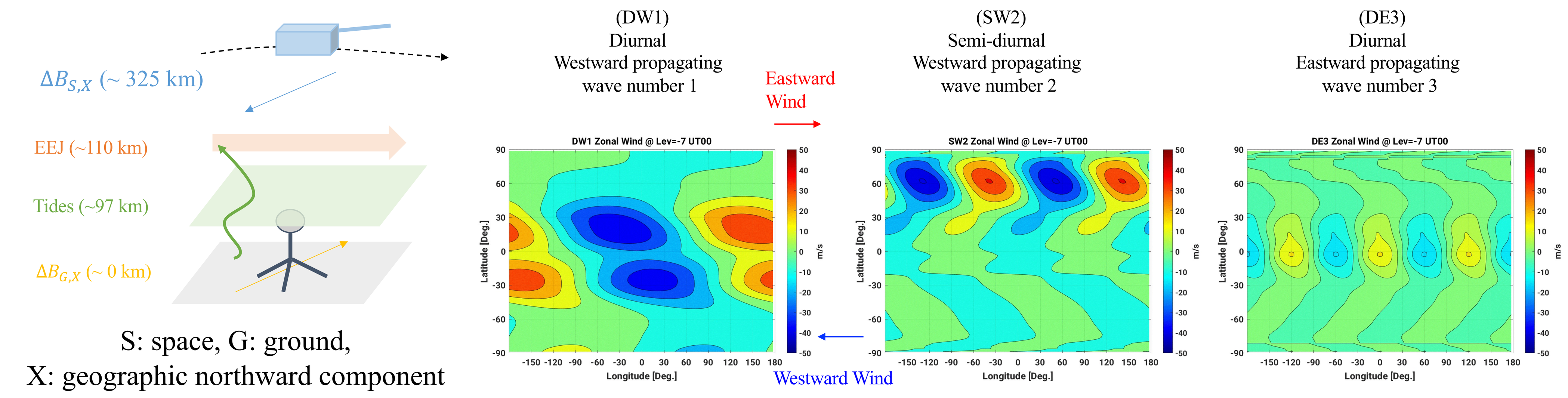


Figure 1, Introduction of the abbreviations of the tides and its relevance to EEJ, ΔB

Study Objective

In this study, we develop a new data-driven physics-based modeling approach to estimate the tidal amplitude and phase in all relevant parameters including the thermospheric winds at all latitude, at hourly cadence, using routinely available ground-based magnetometer data.

Method

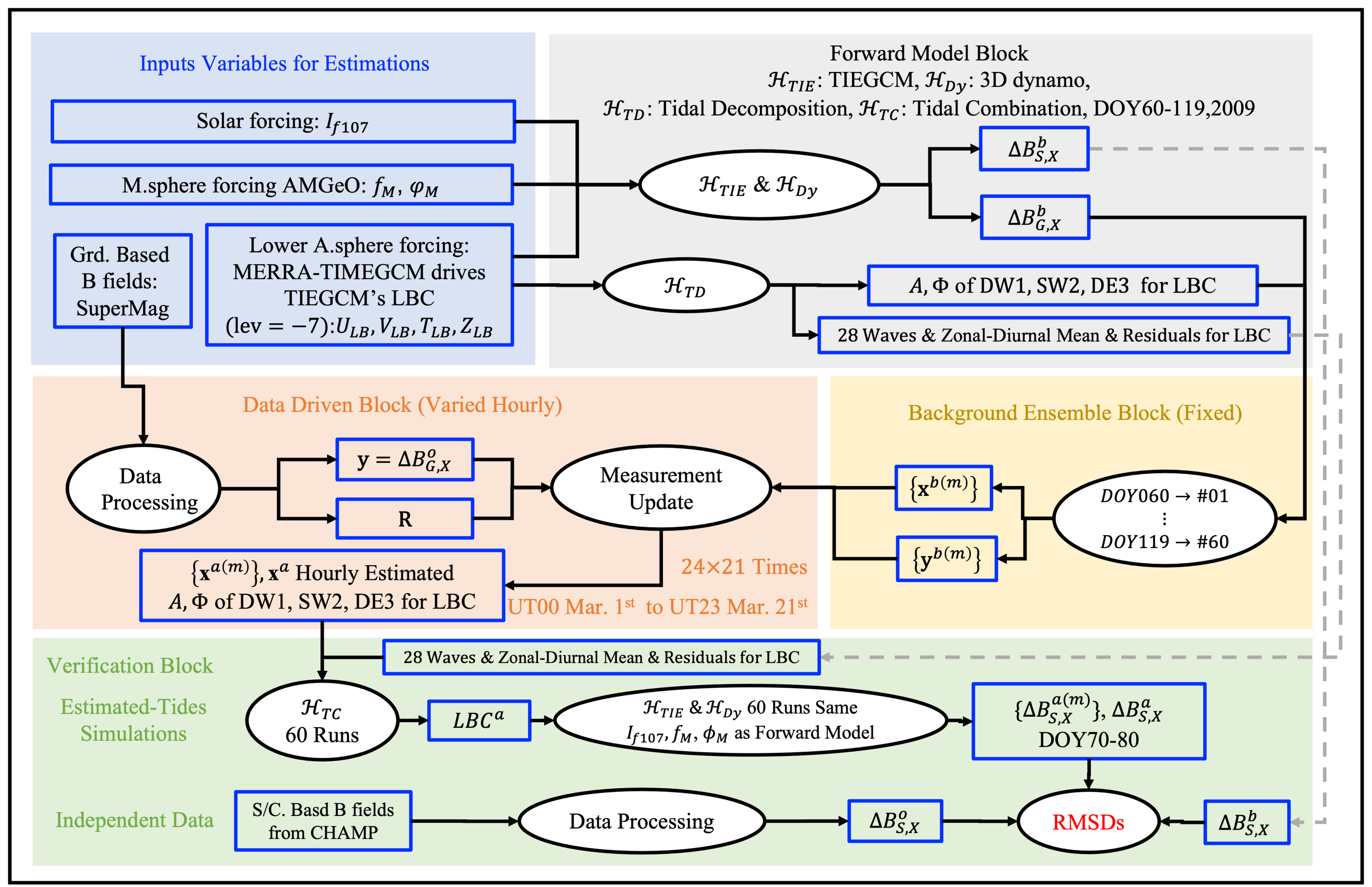


Figure 2, Schematic flow chart of estimation and verification

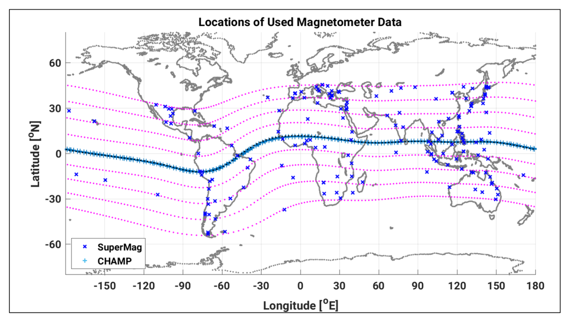


Figure 3: The distribution of used data

TIEGCM 2.0	Richmond et al., 1992, Qian et al., 2014
MERRA-TIMEGCM	Häusler et al.,2014
3D Dynamo	Maute & Richmond, 2017
Tidal Decomposition	Pedatella & Forbes, 2010 and Zhang et al., 2006
Ensemble Transform Adjustment Method	Matsuo and Hsu 2021
AMGeO	AMGeO Collaboration, 2019
SuperMag Data Service	Gjerloev., 2009
CHAMP Data	Rother and Michaelis, 2019

Table 1: Data resource

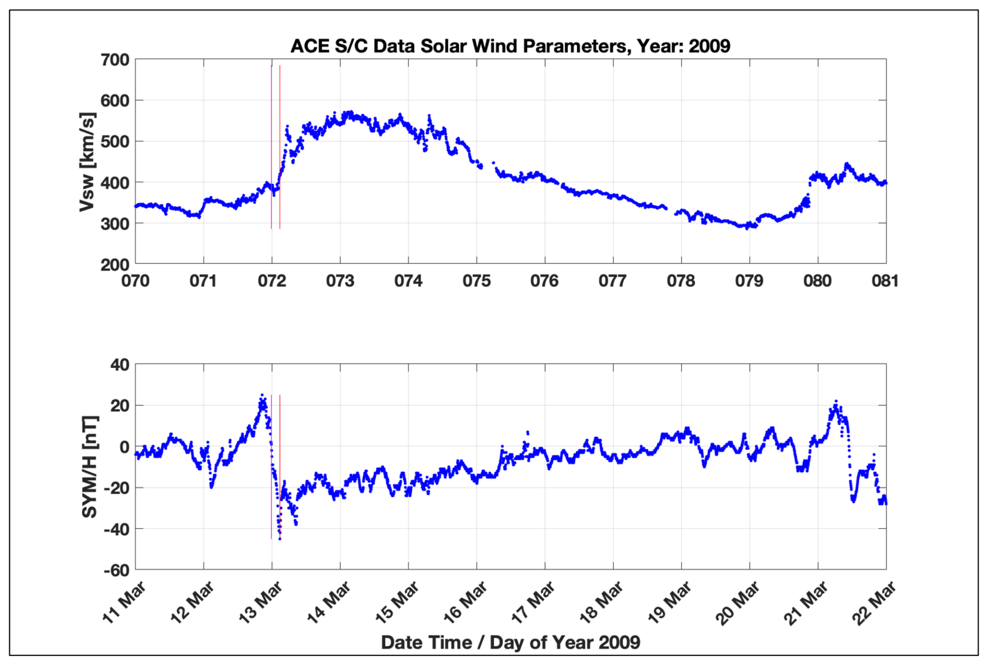
Conclusions

- A new data-driven approach to estimate hourly changes of tides associated with EEJ variation from ground magnetometer data is developed.
- The approach yields a better agreement of modeled and observed magnetic perturbations at LEO altitudes even over the Pacific Ocean.
- The analysis suggests that the day-to-day variation of SW2 tidal mode plays a key role in generating the variation of the EEJ.

Acknowledgments

The data used in experiments can be found on the Open Science Framework (doi:10.17605/OSF.IO/HC67V). We also appreciate the high-performance computing support from Cheyenne (doi:10.5065/D6RX99HX)716 provided by NCAR's Computational and Information Systems Laboratory, sponsored by the NSF. The MERRA reanalysis data can be obtained from the NASA Global Modeling and Assimilation Office website, https://gmao.gsfc.nasa.gov/reanalysis/MERRA/. The AMGeO can be downloaded from the University of Colorado Boulder website, https://amgeo.colorado.edu/. The ground magnetometer data obtained from the SuperMAG data service (http://supermag.jhuapl.edu/). The F10.7 index is obtained from the NASA OMNI Web page (https://omniweb.gsfc.nasa.gov/form/dx1.html) and the SYM/H index.

Results



- A case study is performed over the 11 days from March 11 to March 21, 2009. Magenta bars: storm onset. The red bars: minimum SYM/H index.

Figure 4: Geomagnetic (top) and solar wind activities (bottom)

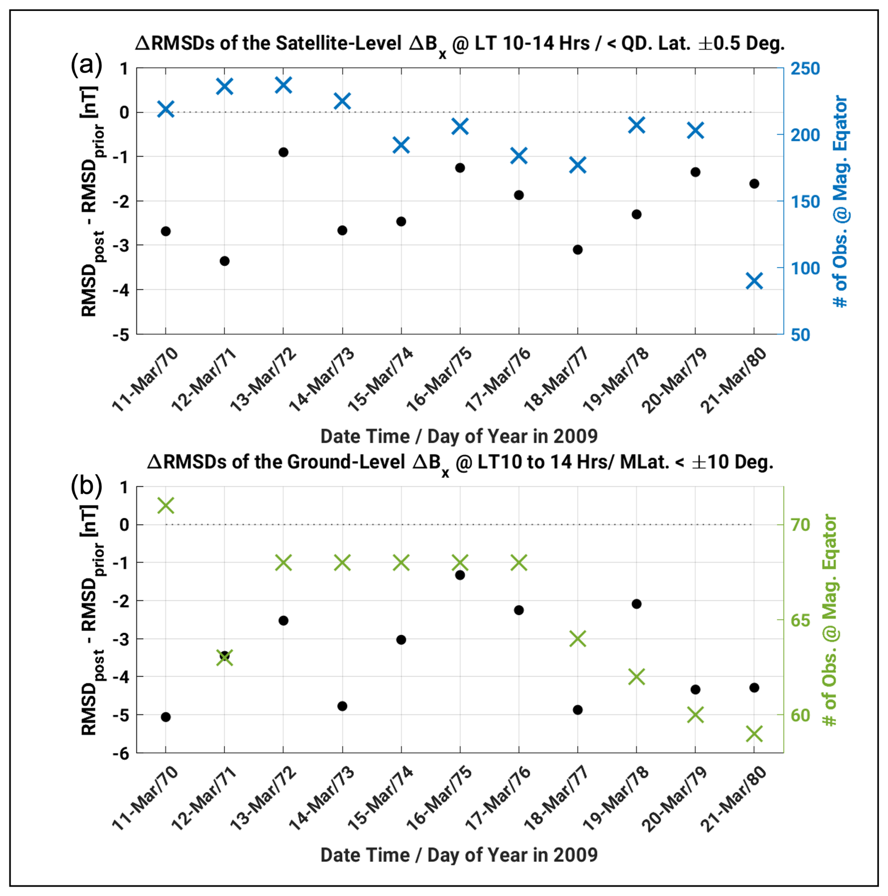


Figure 5: The improvements of model-observation agreement assessed by the difference of RMSD (left axis with black dots) between posterior and prior ΔB on satellite level within ±0.5° magnetic latitude (a), and on ground level ±10° magnetic latitude (b). The number of space-level (right axis with blue cross) and ground-level observations (right axis with green cross).

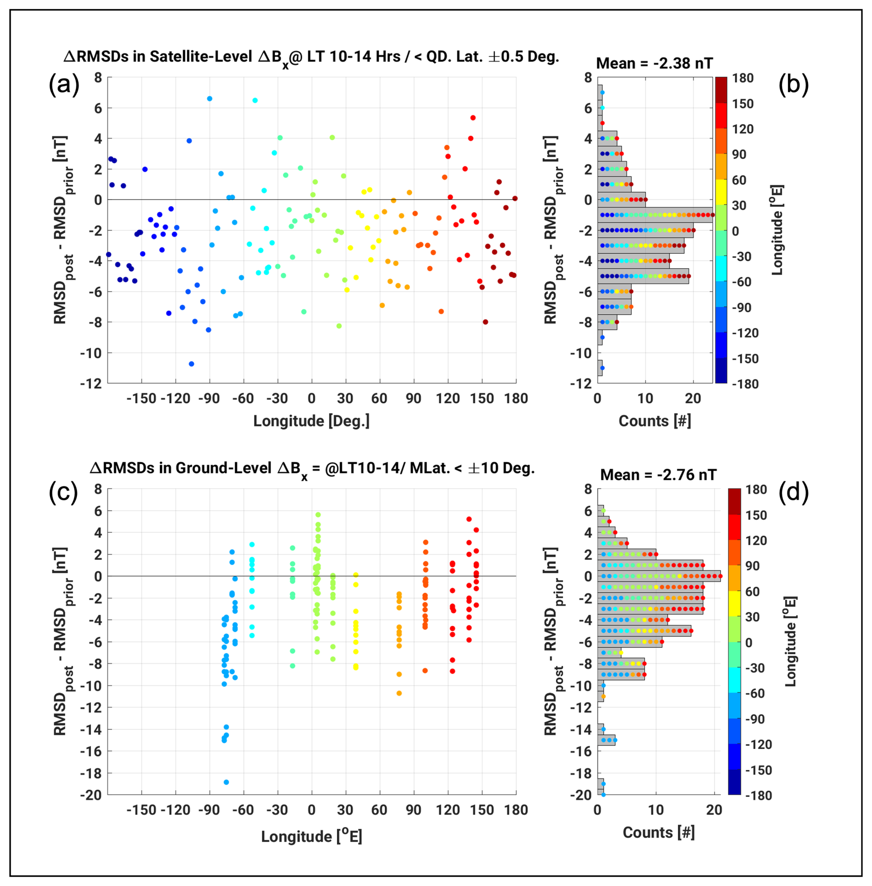


Figure 6: The difference of RMSDs of ΔB between posterior and prior grouped by longitude on satellite level (a) and on ground level (c), and the histogram on satellite level (b) and on ground level (d).

- Figure 5 and 6 imply that the estimation has the capability of improving the model-data agreement even over the ocean where there is a sparse distribution of ground-based measurements, e.g., over the Pacific ocean (around 165°E) and India ocean (around 60° to 90°E). .

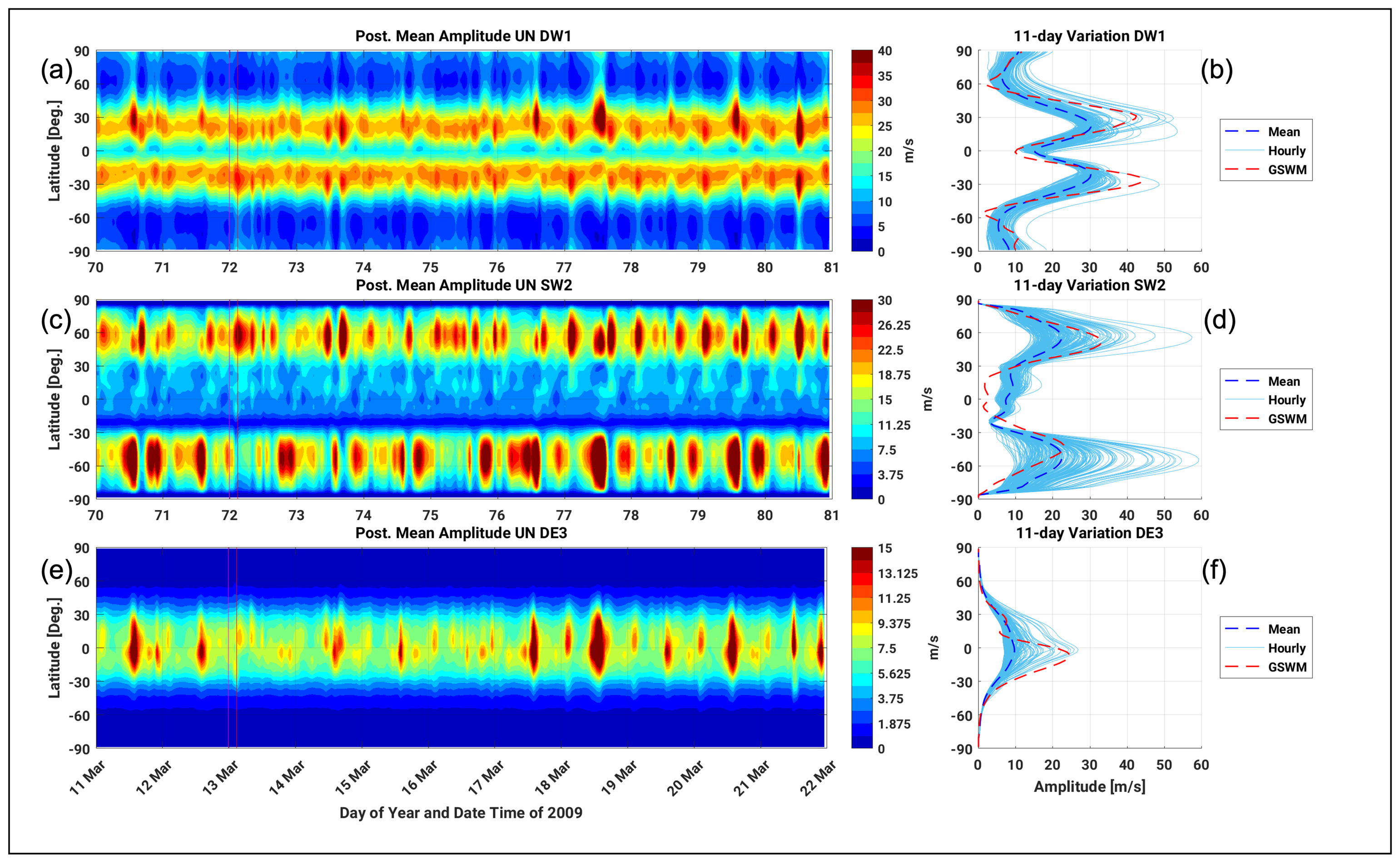


Figure 7: 11-day variations of the hourly estimated tides. The hourly variations of DW1 (a), SW2 (c) and DE3 (e) are the functions of time in day of year and geographic latitude. The comparisons of the hourly estimated tides (blue solid curves) with GSWM (red dash curves), and the 11-day averages of estimated tides (blue dash curves) are presenting in (b) for DW1, (d) for SW2 and (f) for DE3, respectively.

- $\Delta B_{EEJ,H}$ and V_z can be approximated by linear regression under moderate solar activity (Fang et al., 2008).
- The day-to-day variation of V_z is mainly driven by SW2 component (Fang et al., 2013).
- These results point out an important role of SW2 in driving the day-to-day variability of equatorial electrodynamics. It provides a further evidence in support of the arguments shown in Fang et al., 2008, 2013.