The ionospheric forecasting by coupled thermosphere-ionosphere data assimilation system

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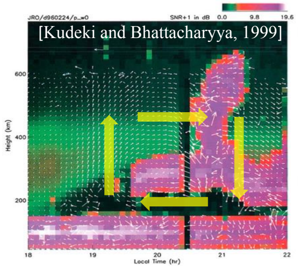
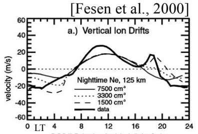
We report that assimilating COSMIC ionospheric profile of radio occultation (RO) and ground-based GPS total electron content (TEC) observations into a coupled thermosphere-ionosphere model, TIEGCM, by using the ensemble Kalman filter (EnKF). Results show the improvement of specification of eastward pre-reversal enhancement (PRE) electric field during the geomagnetic quiet conditions and accuracy of electron density forecasting during the geomagnetic storm conditions. The improvement of dusk-side PRE electric field calculation is achieved primarily by intensification of eastward neutral wind in the assimilation system, which provide preferable conditions and obtain a strengthened PRE magnitude closer to the observation. For the storm time cases, two different high-latitude ion convection models, Heelis and Weimer, are further evaluated in the assimilation system. Results show the better forecast in the electron density at the low-latitude region during the storm main phase and the recovery phase. The well reproduced eastward electric field at the low-latitude region by the assimilation system reveals that the electric fields may be an important factor to have the contributions on the accuracy of ionospheric forecast.

Evening plasma convection vortex

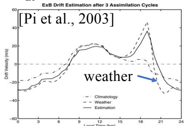


- Recently, the pre-reversal enhancement (PRE) of vertical plasma drift is considered as a part of the evening plasma convection vortex driven by the neutral wind and ion drag effects [e.g., Kudeki and Bhattacharyya, 1999; Rodrigues et al., 2012].
- The evening plasma convection vortex, eastward in the F layer, westward in the E layer, and upward around dusk, gives a new insight into PRE formation.

Model reproduced PRE



- Fesen et al. [2000] showed that TIEGCM could reproduce PRE with the assumption of low electron density in the *E* region.



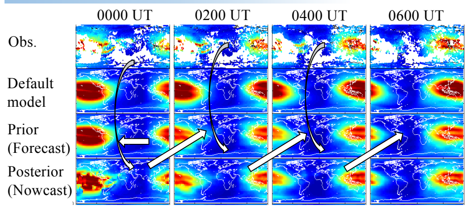
- Adjustment of PRE *ExB* drift was first reported in assimilation work by Pi et al. [2003] using a parameterization of *ExB* vertical drift.

Purpose and method in this study

- To demonstrate and examine the PRE modeling by assimilation of COSMIC RO data (ionPrf) and total electron content (TEC) observations into the TIEGCM.

Assimilation of RO density and TEC → Updating model neutral winds → Calculate the modeled electric field → Obtain the vertical *ExB* drift (PRE)

Ionospheric data assimilation system



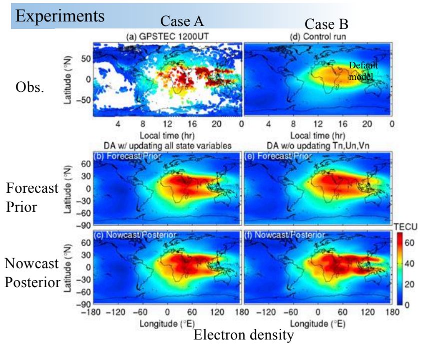
- It is important to employ the posterior/nowcast results as the initial conditions for the model forecast procedure.
- Although the model cannot reproduce the truly plasma structure, it can get the better plasma structure or better forecast results after the data assimilation.

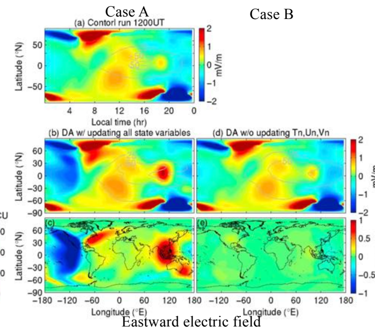
Case A: Updating *Ne*, [O+], [O1] [O2], Tn, Un, and Vn

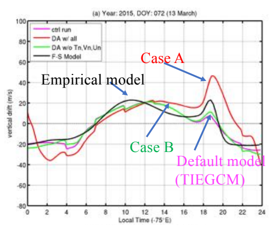
Case B: Updating *Ne*, [O+], [O1] [O2]

- In order to exam how the importance of neutral wind (or PRE strength) updating by DA, we performed two experiments with (Case A) and without (Case B) updating neutral winds.

Experiments

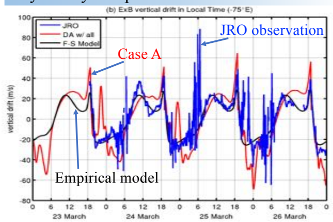




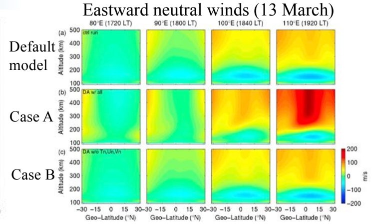


- The DA with the case of updating neutral wind assimilation has the stronger PRE feature (red curve).

Day-to-day comparison

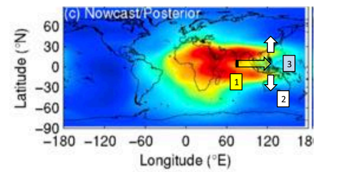


- Through validations, the magnitude of PRE *ExB* drift from DA system is comparable to the observations, but with some discrepancies occurring after 2100 LT.



- Case A shows the F-region eastward neutral wind becomes stronger and the low-altitude westward wind becomes weaker, which leads to PRE strengthening.

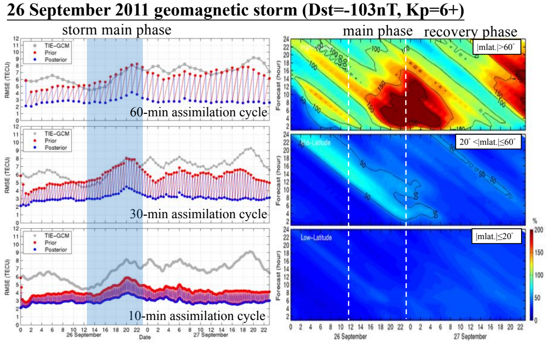
How does the DA work?



[1] The eastward neutral wind becomes stronger due to the decrease of electron density by DA (low ion-neutral collision frequency).
[2] The strong winds push the electron density upward/poleward by the strong PRE *ExB* drift, which leads the low electron density around the magnetic equator region [3].

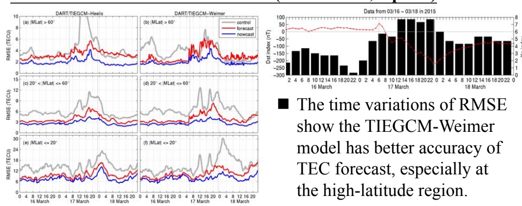
Ionosphere forecast during storm conditions

26 September 2011 geomagnetic storm (Dst=-103nT, Kp=6+)

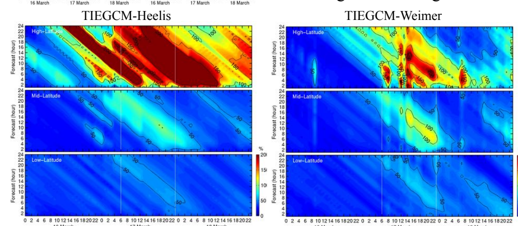


- The high latitude ion convection model is only employed Heelis model in this storm case.
- Results show that the shorter (10-min) updated cycle can respond to the rapidly change of geomagnetic storm and then obtain the more accuracy of forecast in the TEC.
- The 24-h forecast show that at high latitude region, the forecast result become worse during the storm main phase, but at the lower latitude regions show the better forecast capability, even during the storm main phase.

17 March 2015 St. Patrick's storm (Dst=-223nT, Kp=7+)



- The time variations of RMSE show the TIEGCM-Weimer model has better accuracy of TEC forecast, especially at the high-latitude region.



- 24-h forecast results indicate that the forecast time is longer at the low-latitude than other latitudes and difficult to forecast the high-latitude TEC during the 2015 St. Patrick's Day storm for both forecast models.

Summary

- The self-consistent thermosphere-ionosphere coupled assimilation system successfully improves the PRE modeling while adjusting model parameters in agreement with the plasma convection vortex theoretical explanation of PRE.
- The capability of ionosphere forecast by this assimilation system during two storm conditions (26 September 2011 storm and 17 March 2015 St. Patrick's storm) were performed in this study.
- The result suggests that the EnKF assimilation system with shorter assimilation-forecast cycling (10-minute in this study) may lead to better accuracy in the model forecast of ionospheric electron density during the geomagnetic storm even in the presence of forecast model biases.

Future works

- Assimilation of neutral wind observations from ground-based Fabry-Perot interferometer (FPI) or satellites may be helpful in future study for the mechanism of the PRE *ExB* drift discrepancies after 2100 LT.
- Since the low-altitude forces also strongly affect the the morphology of ionosphere, the low-altitude assimilation will be further considered in the next generation of data assimilation system, whole atmospheric data assimilation system.

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