

# The observation and simulation of ionospheric response to CIR-induced geomagnetic activity on April 4, 2005

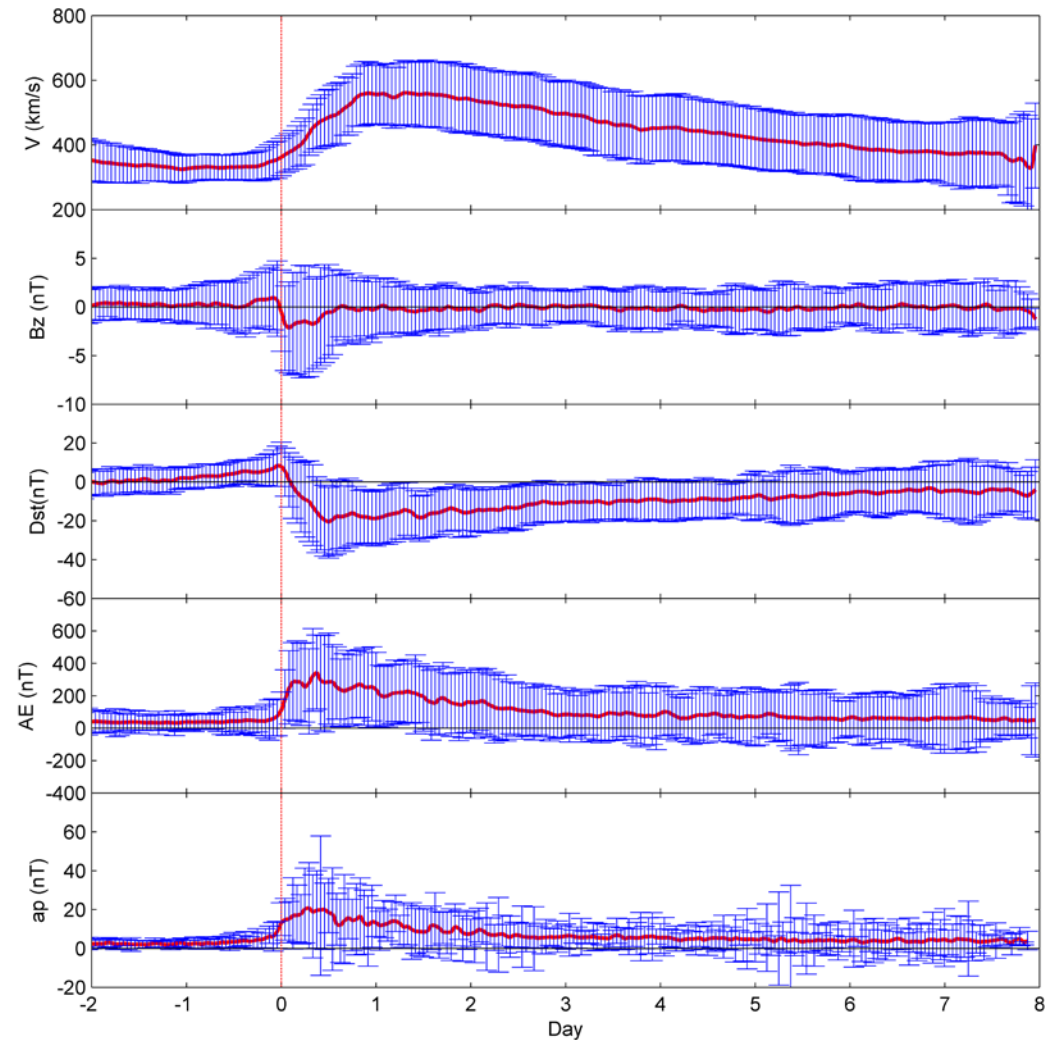
Yanhong Chen<sup>1</sup>, Wenbin Wang<sup>2</sup>, Siqing Liu<sup>1</sup>, Jiancun Gong<sup>1</sup>, Na Qiu<sup>1</sup>

<sup>1</sup>*National Space Science Center, Chinese Academy of Sciences, China*

<sup>2</sup>*High Altitude Observatory, National Center for Atmospheric Research*

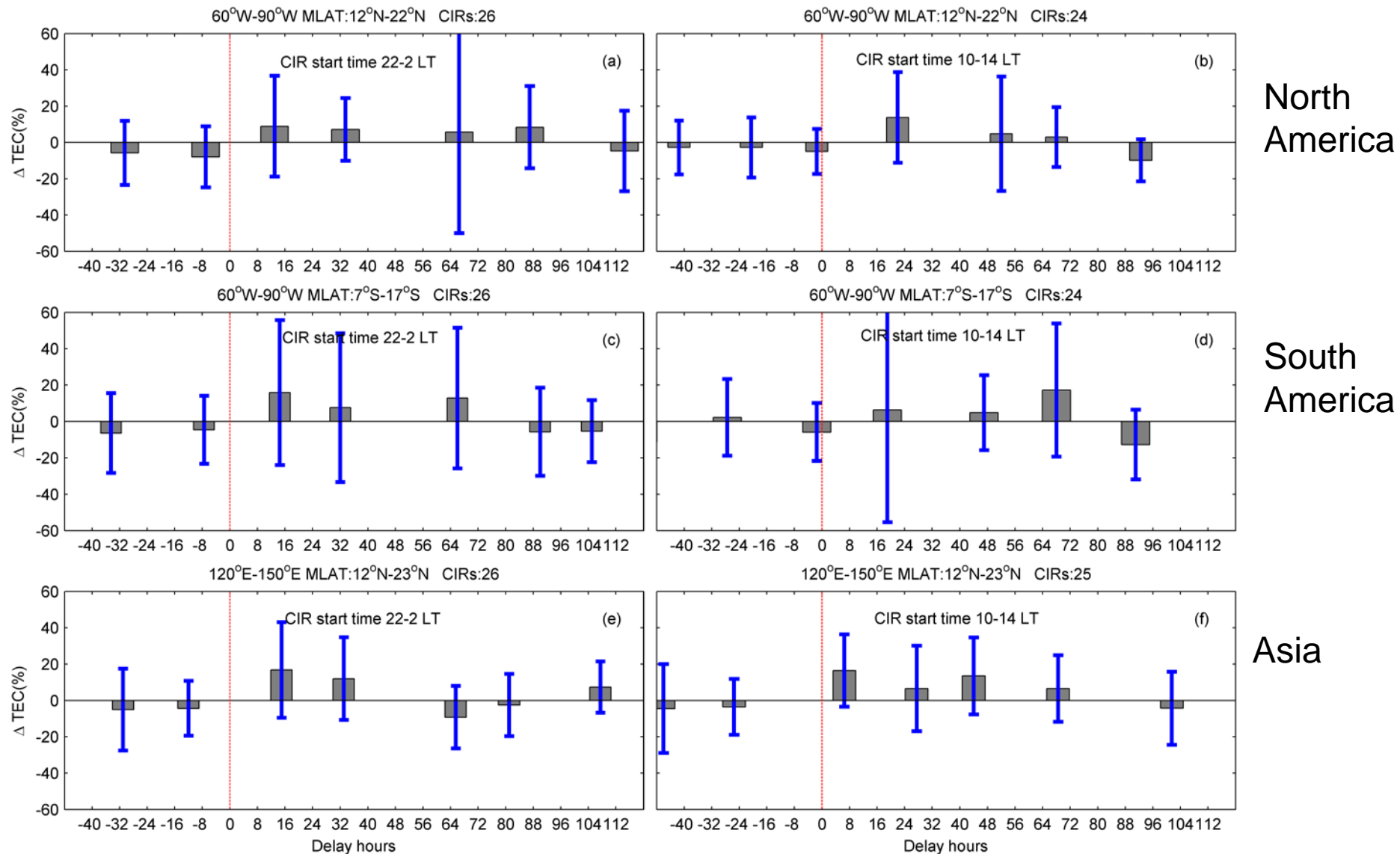
# Corotating Interaction Regions (CIRs)

- The corotating interaction regions (CIRs) are produced when high-speed solar wind streams originating from solar coronal holes interact with slow-speed solar winds.
- CIRs induce recurrent geomagnetic activity and perturb the ionosphere and thermosphere on a global scale as a result of energy and momentum deposition.
- Most of the geomagnetic activity induced by CIRs was minor to moderate.
- The geomagnetic activity did not return to their prestorm level for several days



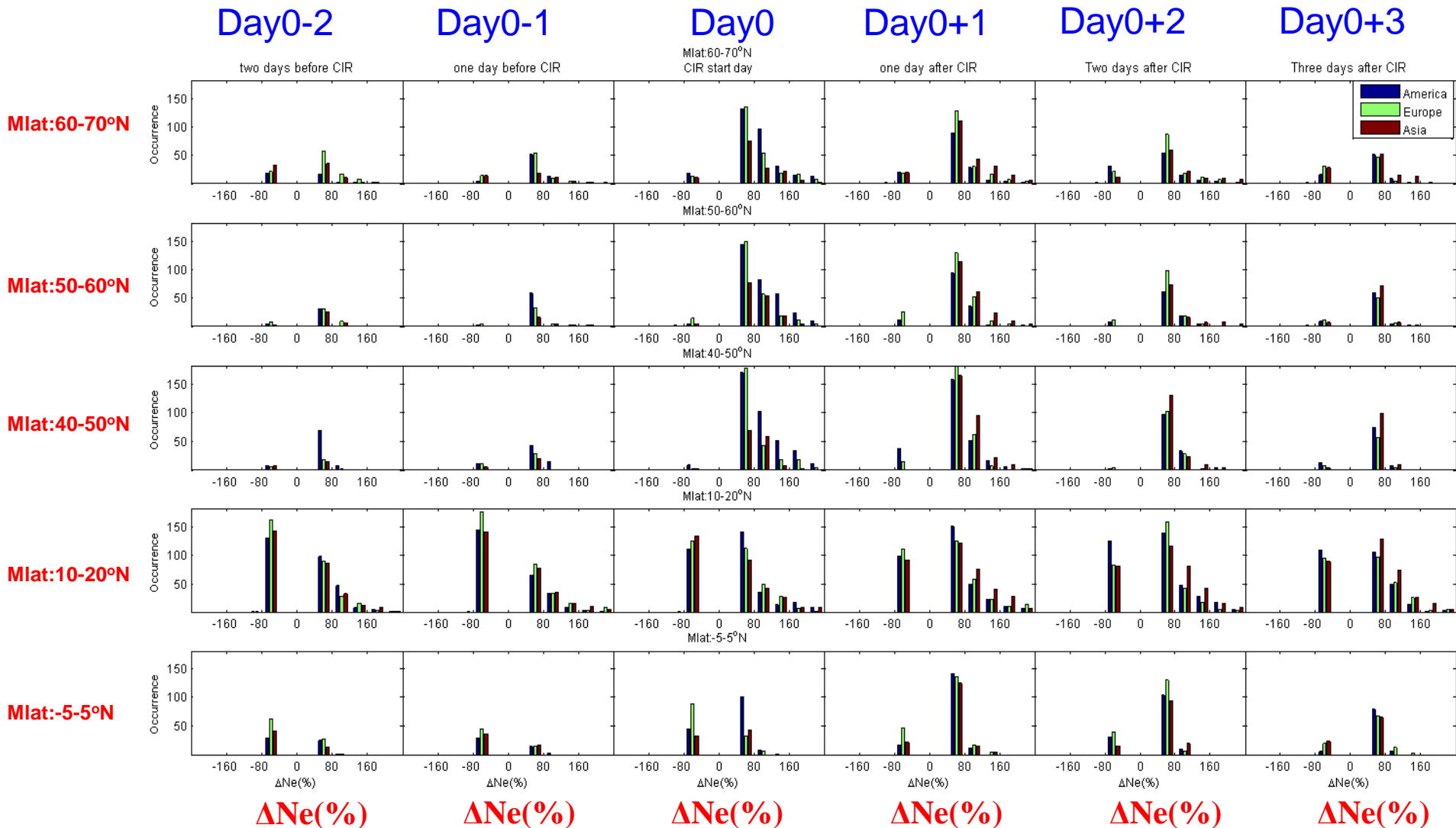
Superposed epoch results of solar wind speed, IMF  $B_z$ , Dst, AE and  $a_p$  indices for 79 CIR events from 2004-2009.

# Low latitudes(Mlat: 10°-22°)



Chen, Y., et al, JGR, 2015.

# CHAMP Ne difference — Daytime(8:00-18:00LT)



Day0=day CIR started

$$\Delta Ne(\%) = (Ne - Ne_{\text{median}}) * 100 / Ne_{\text{median}}$$

# Motivation

- What is the ionospheric temporal and spatial changes over the course of a CIR event?
- Can ionospheric physical model reproduce the variations during a CIR event?
- Ionospheric structure are controlled by several externally mechanism, such as penetration of electron field, neutral wind and composition. It is difficult to distinguish the effects of one forcing from another.
- The comparison of the model and observation can help to interpret the ionospheric change during a CIR event.

## Data

- ◆ Global ground GPS TEC, obtained from the Madrigal database at the MIT Haystack Observatory
- ◆ JPL TEC map
- ◆ Electron density, from the Challenging Minisatellite Payload (CHAMP) Planar Langmuir Probe (PLP) observations

## Model

- ◆ TIEGCM: Solves momentum, energy, and mass continuity for neutrals and ions, as well as neutral wind dynamo.
- ◆ Input Fields: Solar flux, auroral precipitation, high latitude convection electric field
- ◆ Output Fields: Electron density, Neutrals, Electric Field

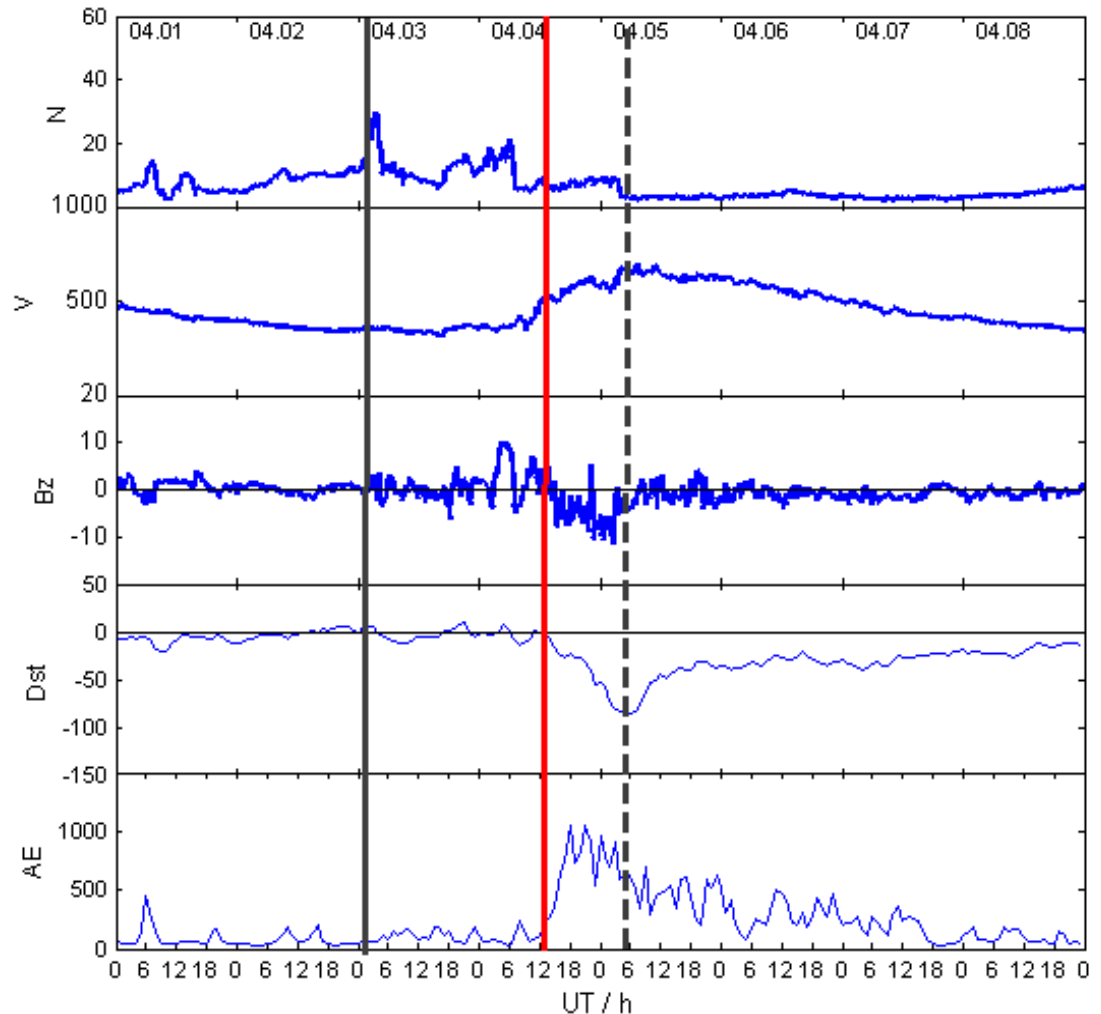
# The CIR induced geomagnetic storm on April 4, 2005

- Solar wind speed reaches 700 km/s on 5 April, then decreases slowly.
- Bz begin to oscillate after the CIR occurred, the minimum is -10nT.
- Dst, AE show the geomagnetic field disturbance last for 4-5 days.

Black: the start time of CIR, recorded in Jian(2006)

Dash: the end time of CIR

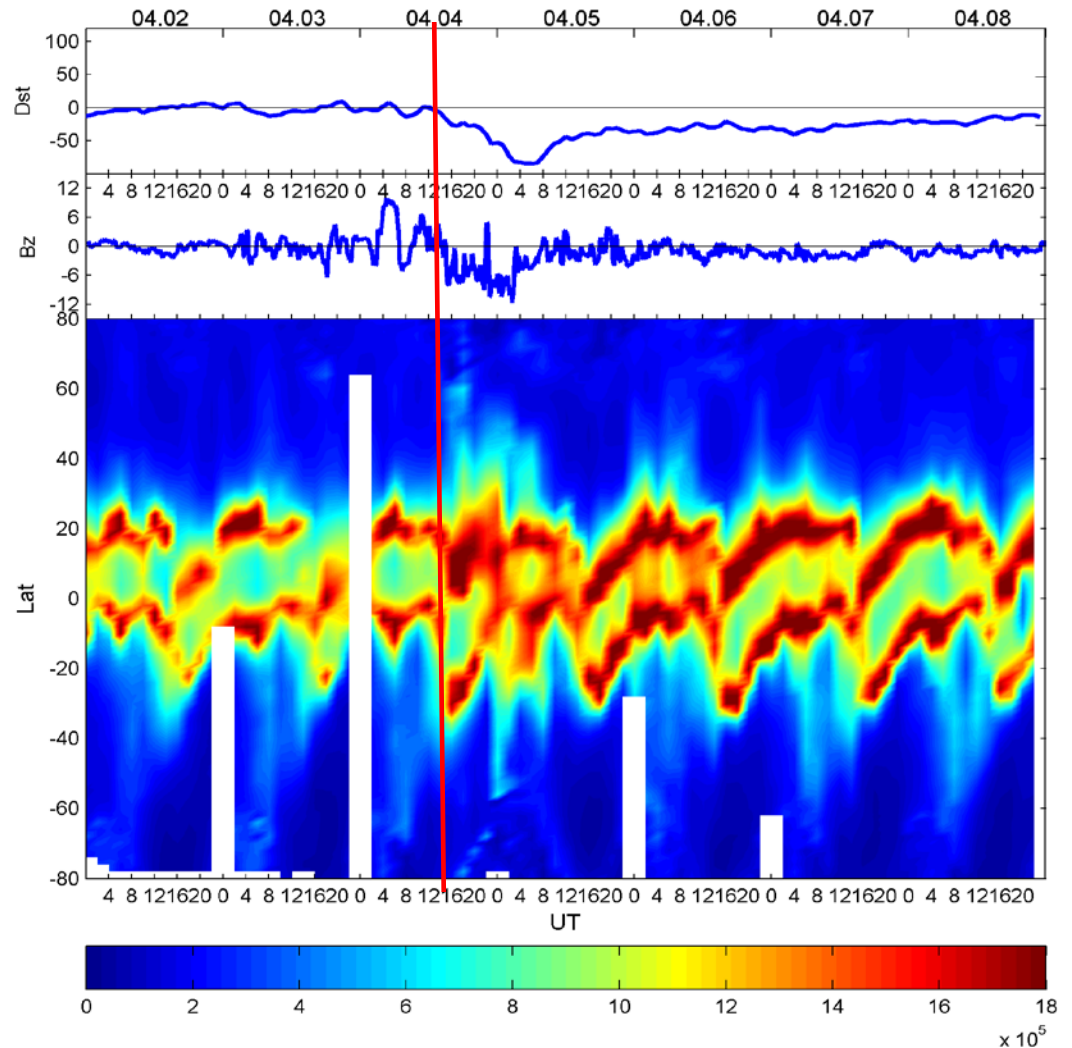
Red: the onset time of the geomagnetic storm



The solar wind , IMF Bz and geomagnetic indices from April1-8, 2005

# Electron density observation

- The electron density has a strong positive storm effect from high to low latitudes in the main phase of the geomagnetic storm. This positive storm response corresponds well to the solar wind condition when IMF Bz is southward.
- The positive storm effect at low latitudes lasts for more than 4 days.
- A decreased Ne region occurs in the middle to high latitudes on 5 April.

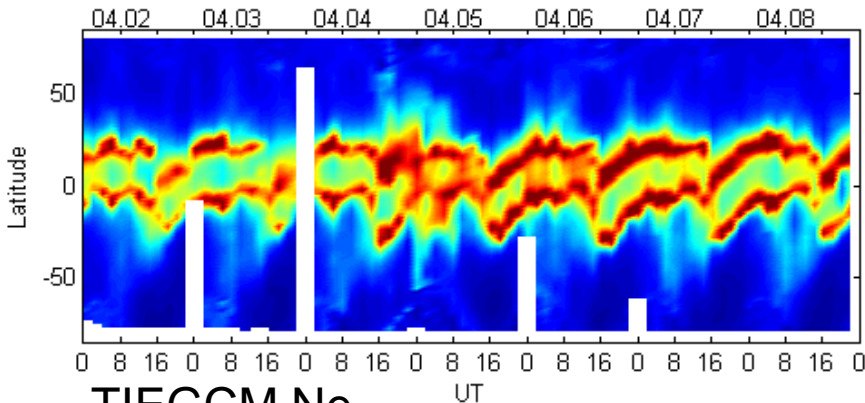


LT=13:00LT

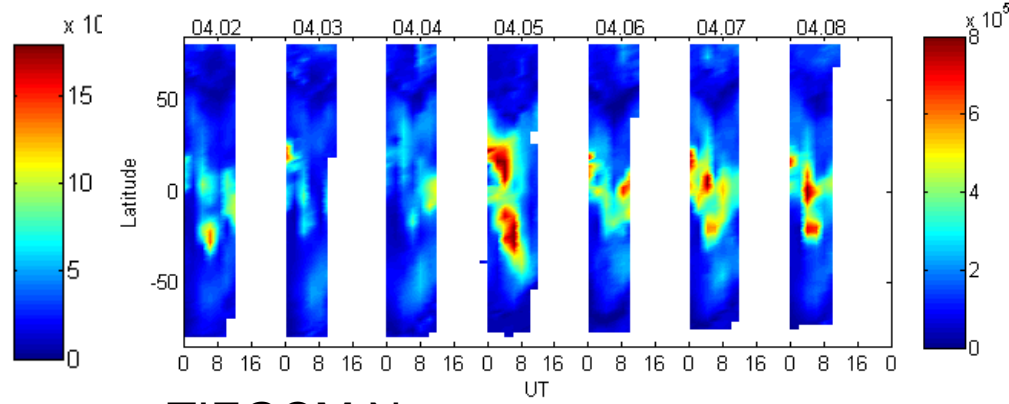


# The comparison of observation and simulation

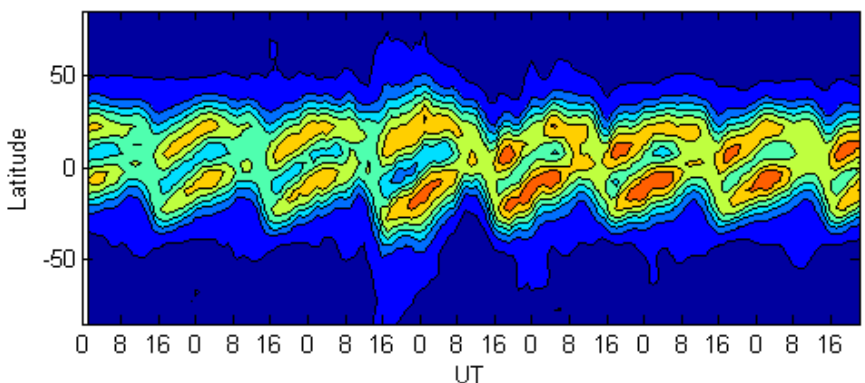
CHAMP Ne



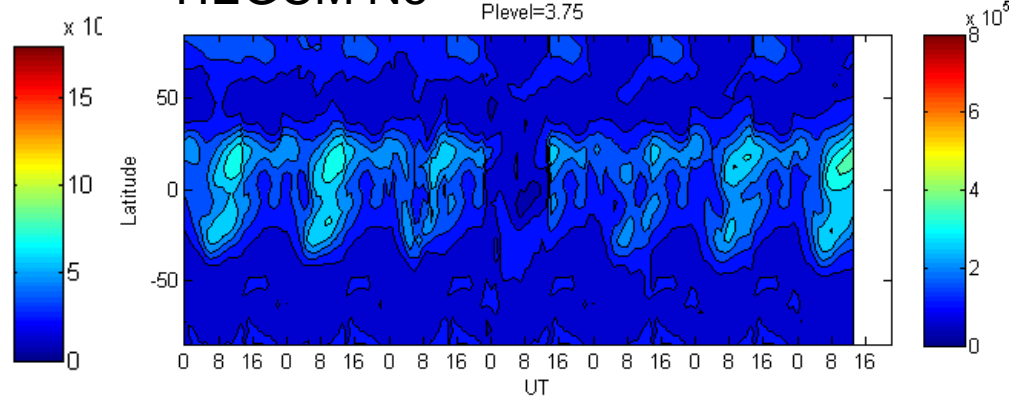
CHAMP Ne



TIEGCM Ne



TIEGCM Ne



Day(LT=13:00LT)

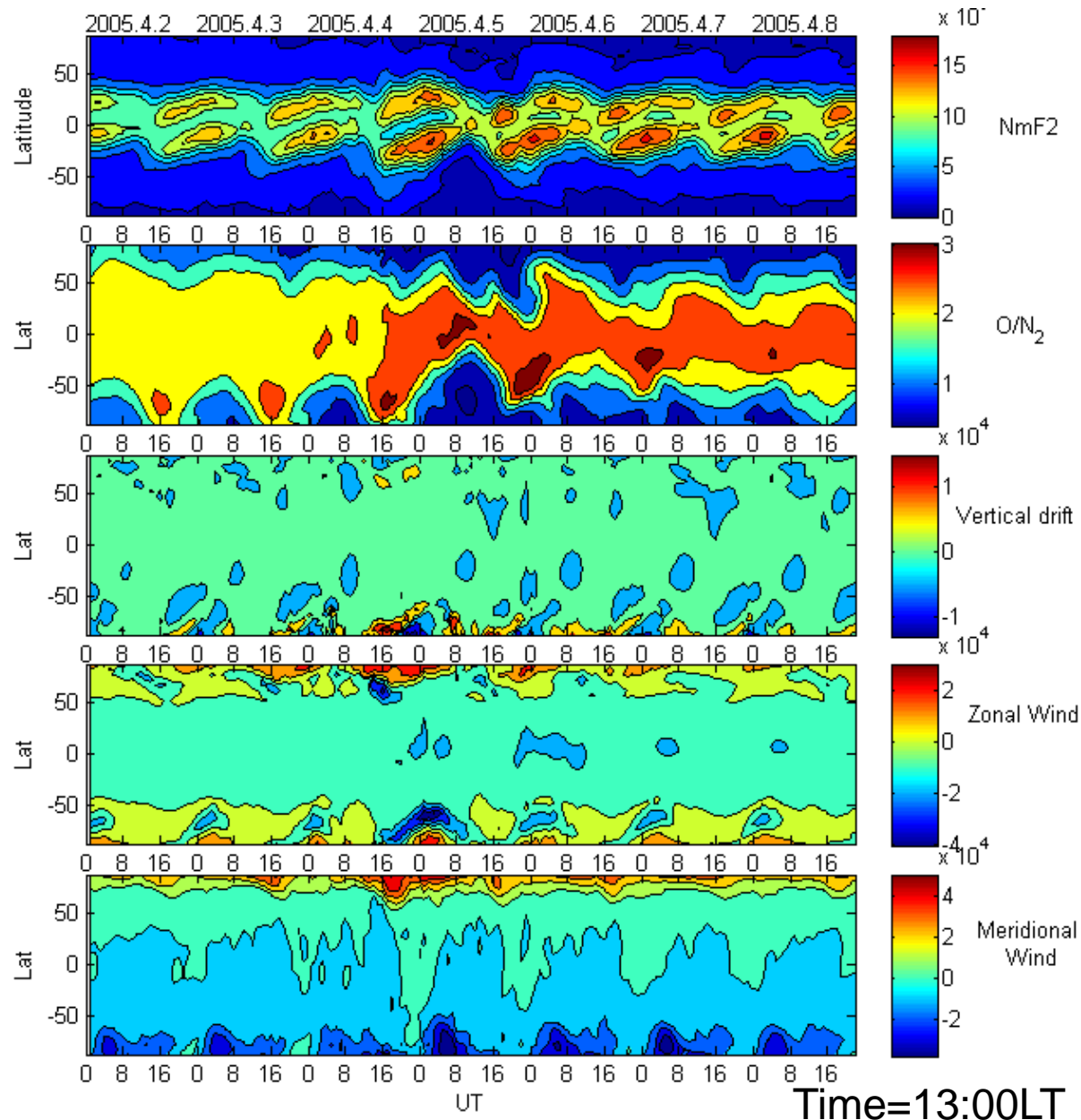
Night (LT=02:00LT)

Modeled Ne in good agreement with the CHAMP Ne

Difference exists between simulation and observation

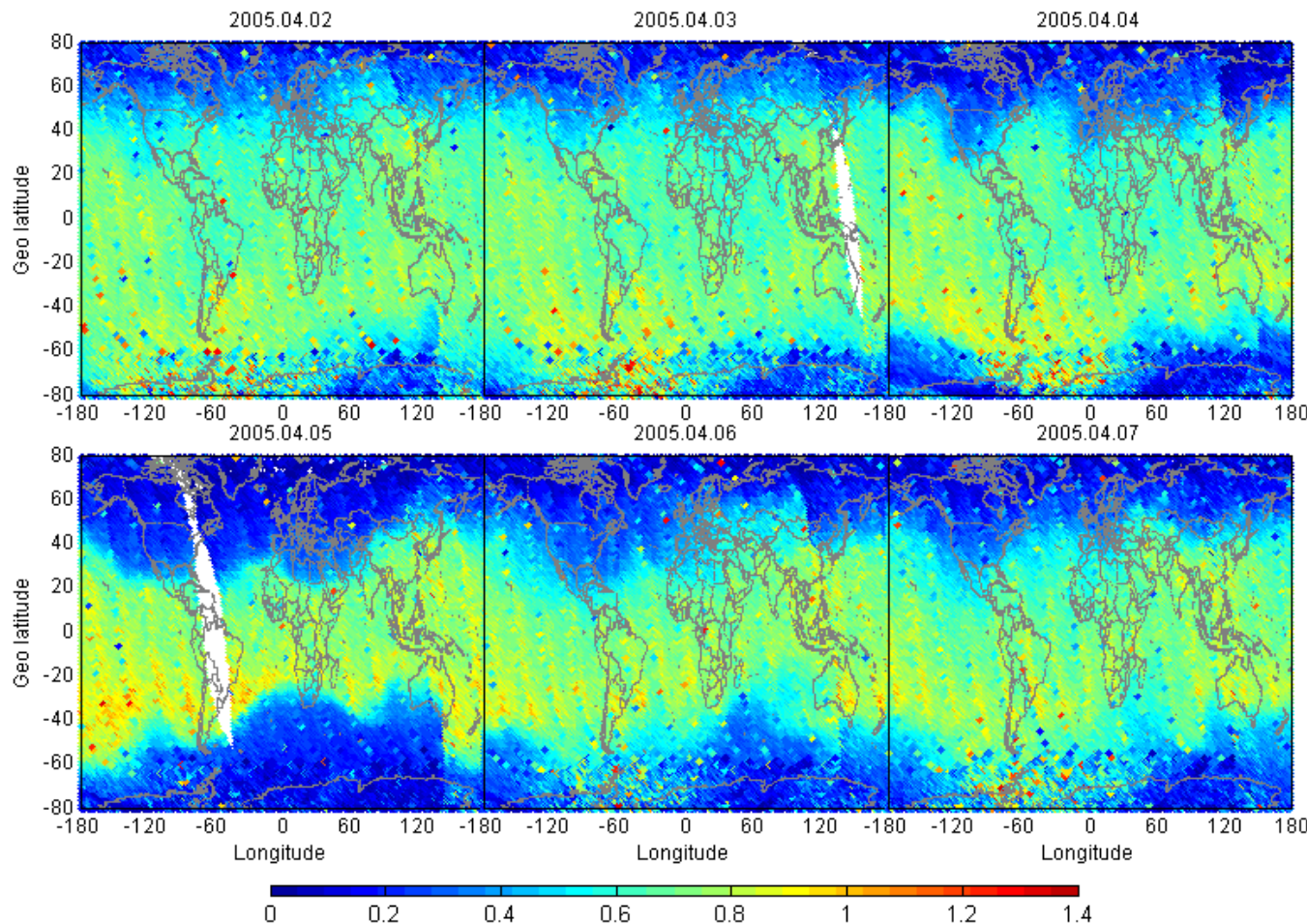
# TIEGCM- NmF2, O/N2, Vertical drift, Neutral wind

- O/N<sub>2</sub> decreased at high latitude, and the decrease moves to lower latitude after April 4, which is consistent with the negative response of Ne at high latitude.
- O/N<sub>2</sub> ratio indicates significant enhancement at middle to low latitude, very consistent with the enhancement of electron density.
- The vertical drift and neutral wind showed storm-time effect at high latitude.



GUVI O/N<sub>2</sub>

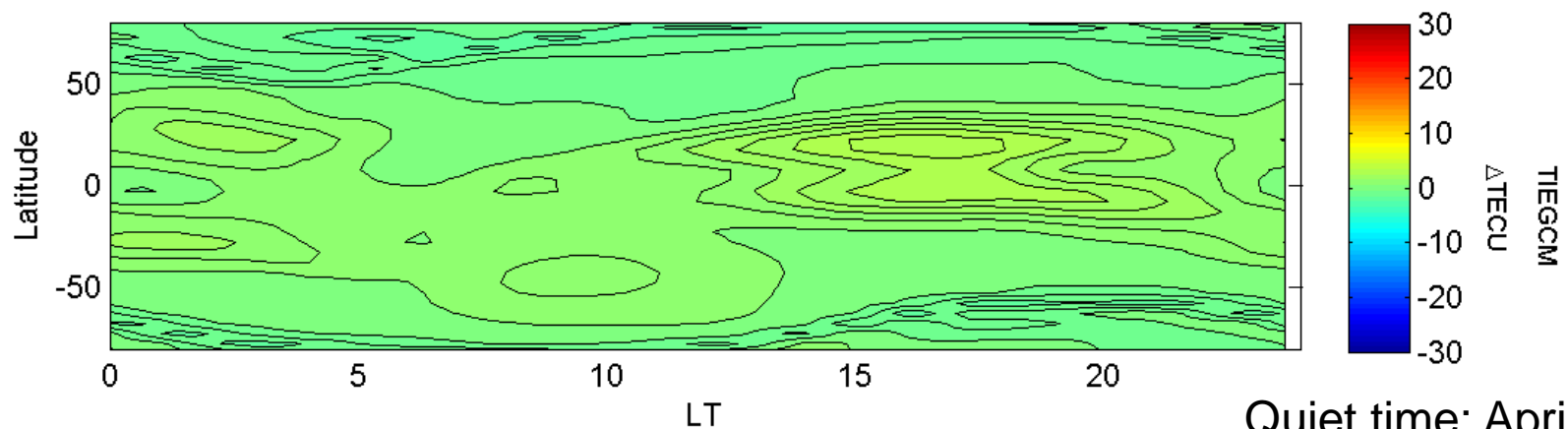
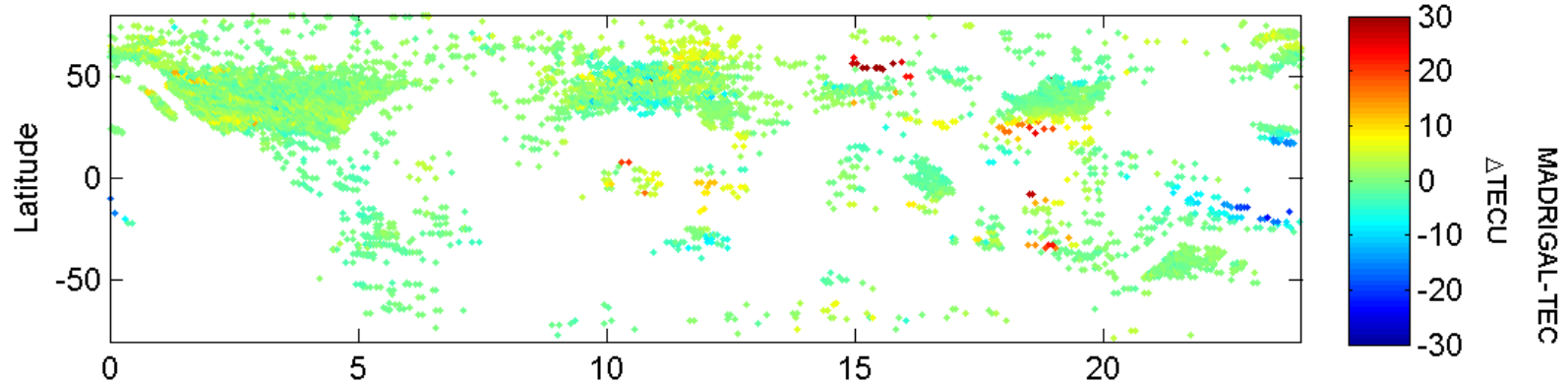
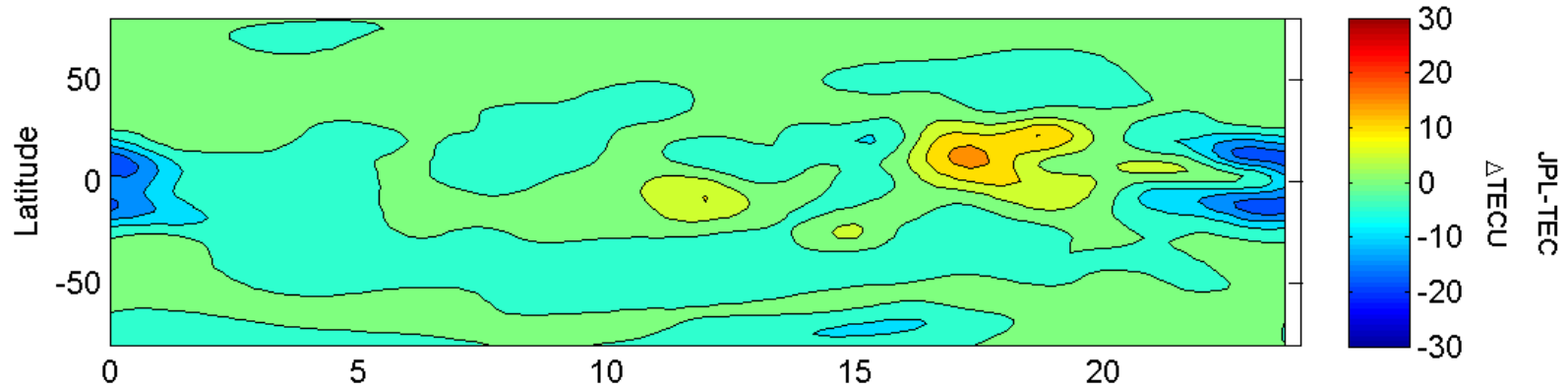
- The decrease of O/N<sub>2</sub> is significant on April 4 and this decrease moves to lower latitude on April 5 and continues for several days. This verifies the composition change causing negative response at middle to high latitude.
- At middle to low latitude, there is a slight enhancement of O/N<sub>2</sub> after April 4, significant on April 5.



LT ~10:00

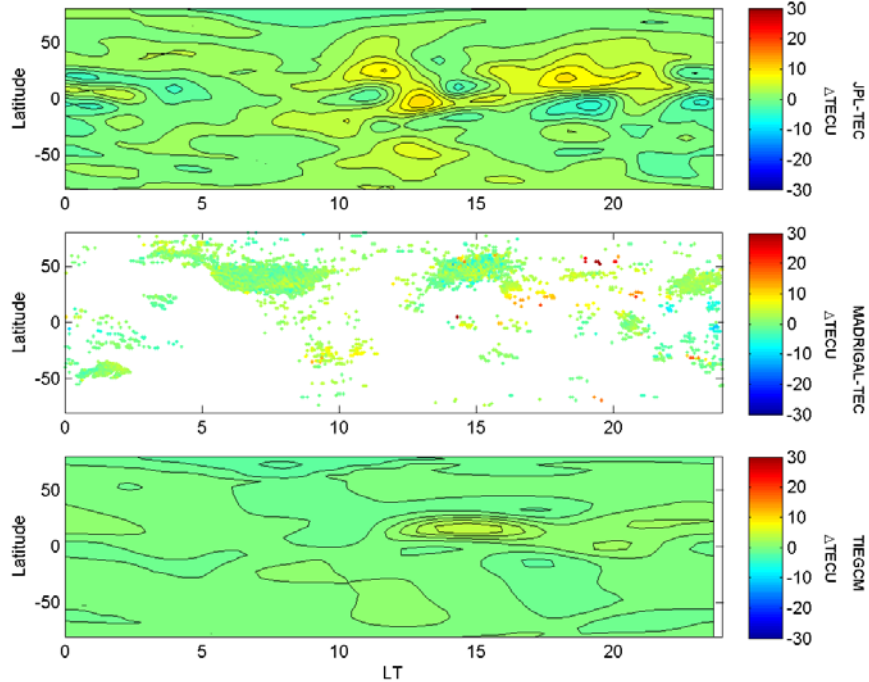
# The observation and simulation for TEC

2005.04.03 UT=10:00

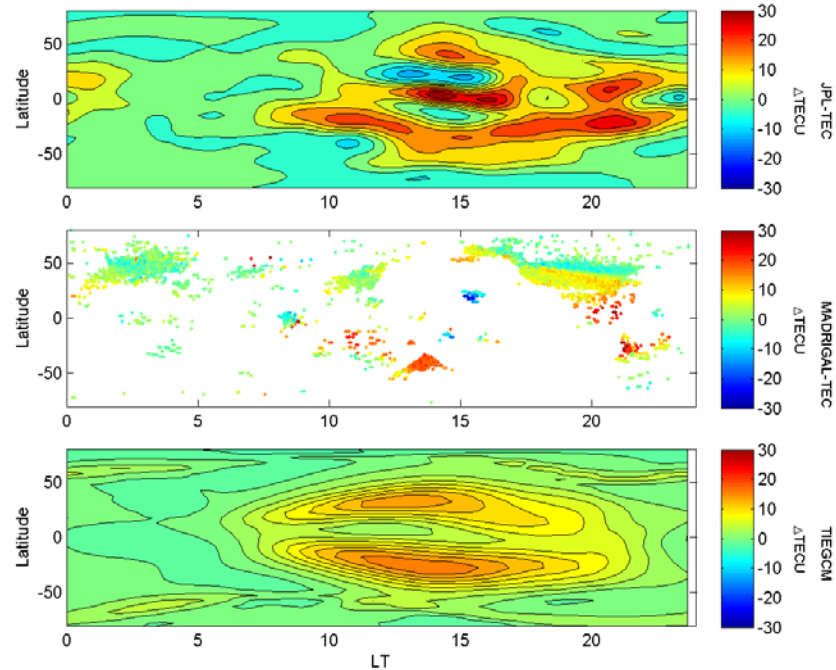


Quiet time: April 1, 2005

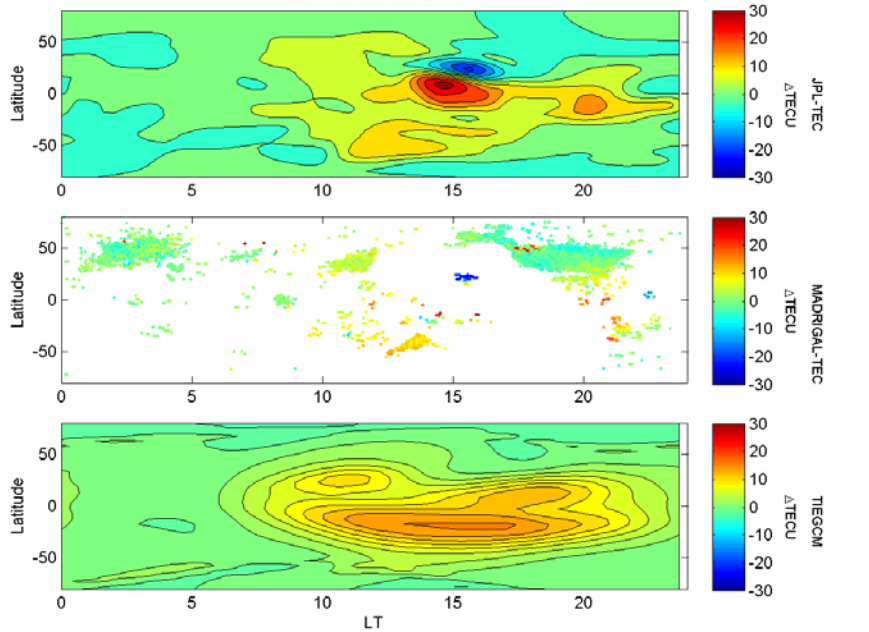
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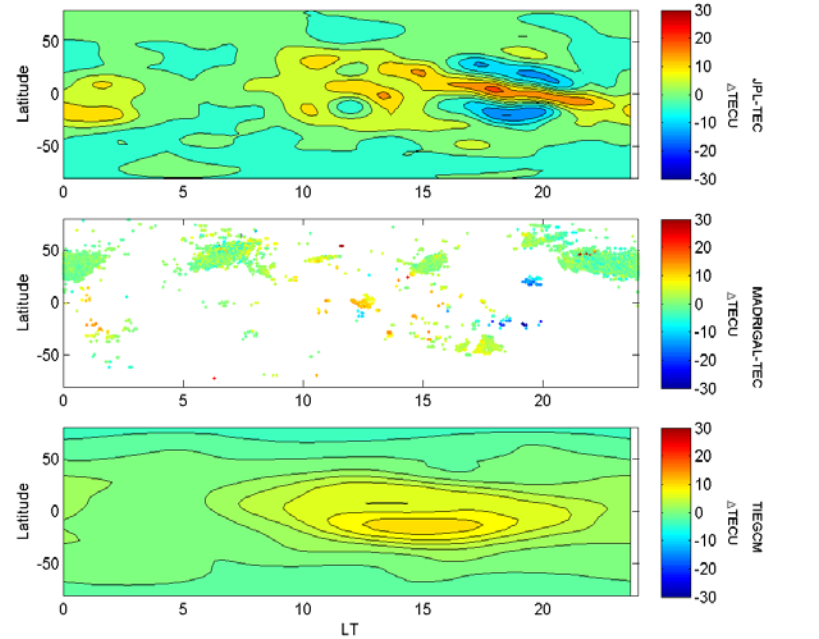
2005.04.05 UT=02:00



2005.04.06 UT=02:00



2005.04.07 UT=06:00

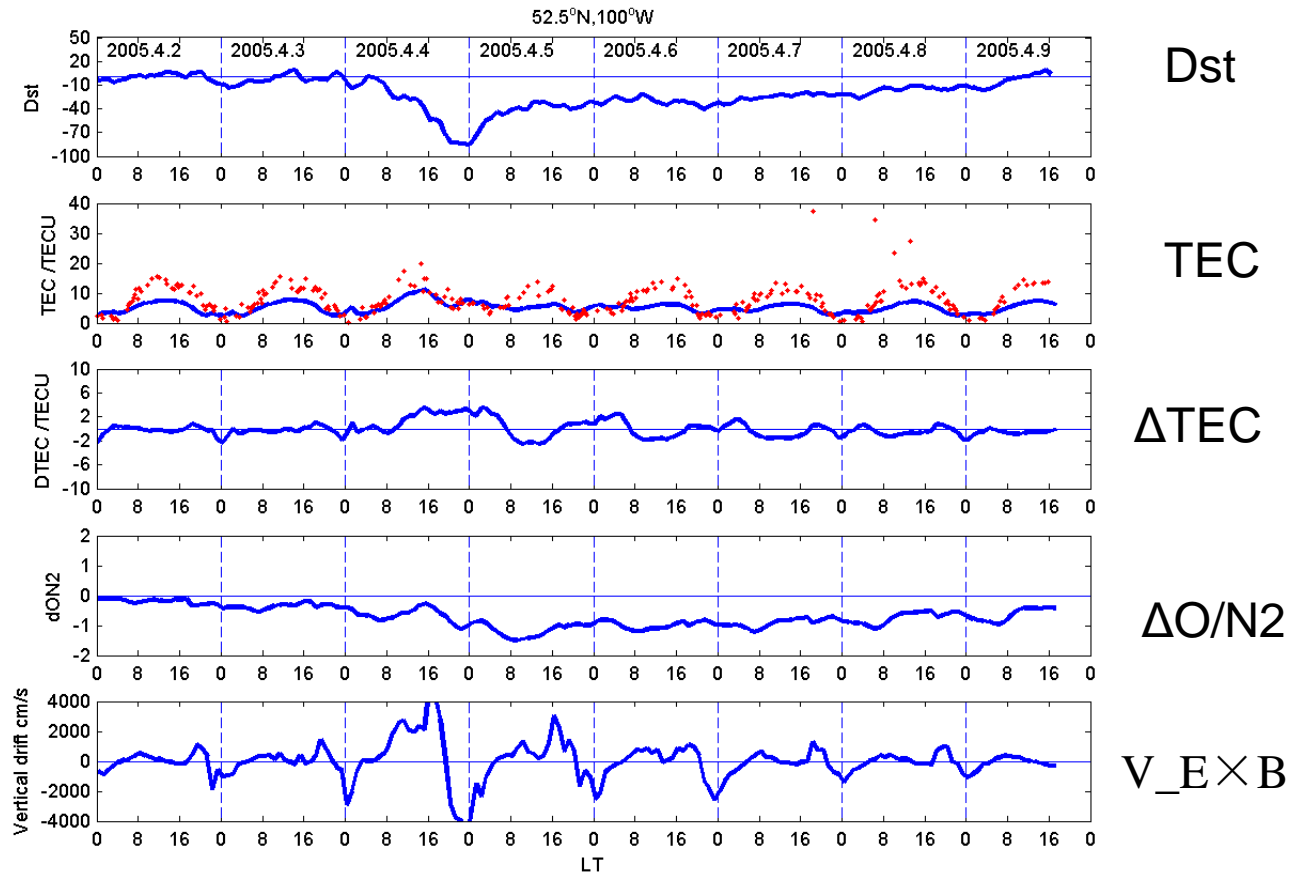


# The GPS-TEC and simulation for TEC, O/N2, $V_E \times B$

- TEC from observation and model result show a positive effect followed by a negative response at high latitude.
- The vertical drift enhance obviously on April 4.
- the negative is related to the decrease of O/N2

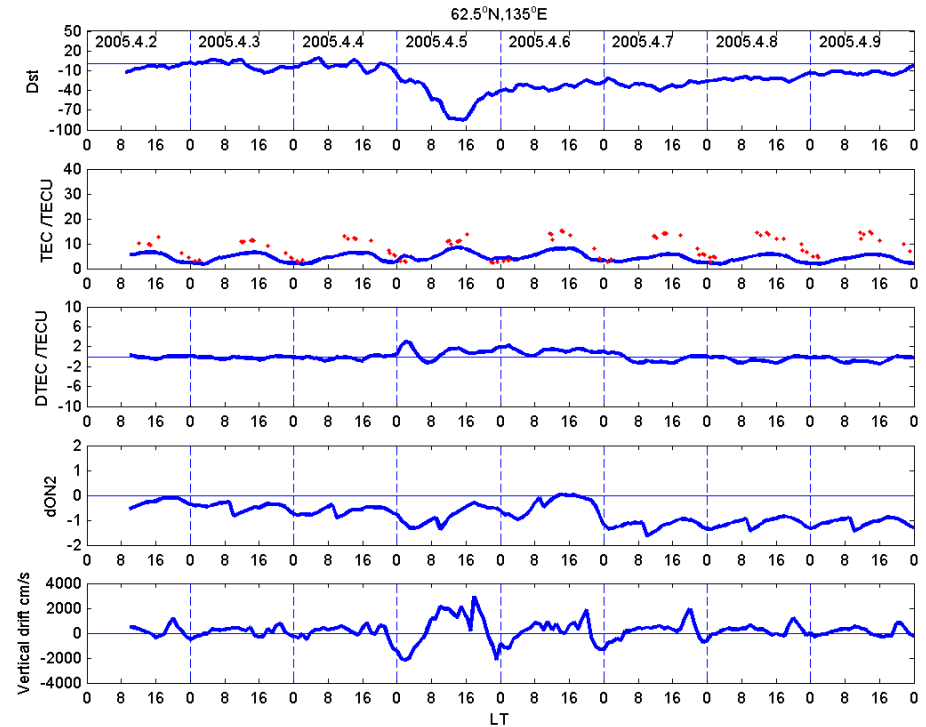
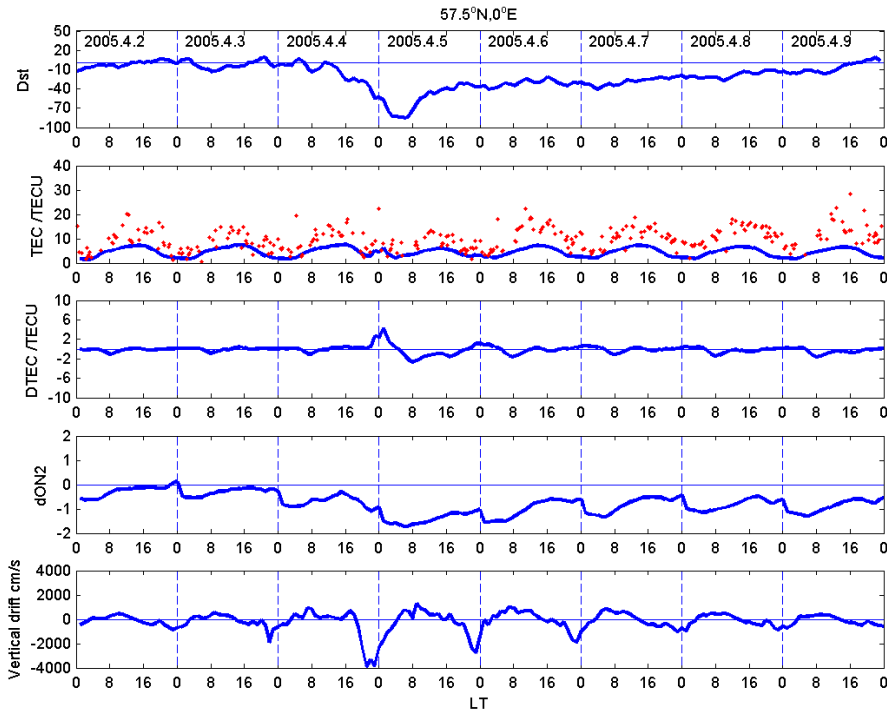
Blue: Outputs from TIEGCM

Red: observation from Madrigal TEC



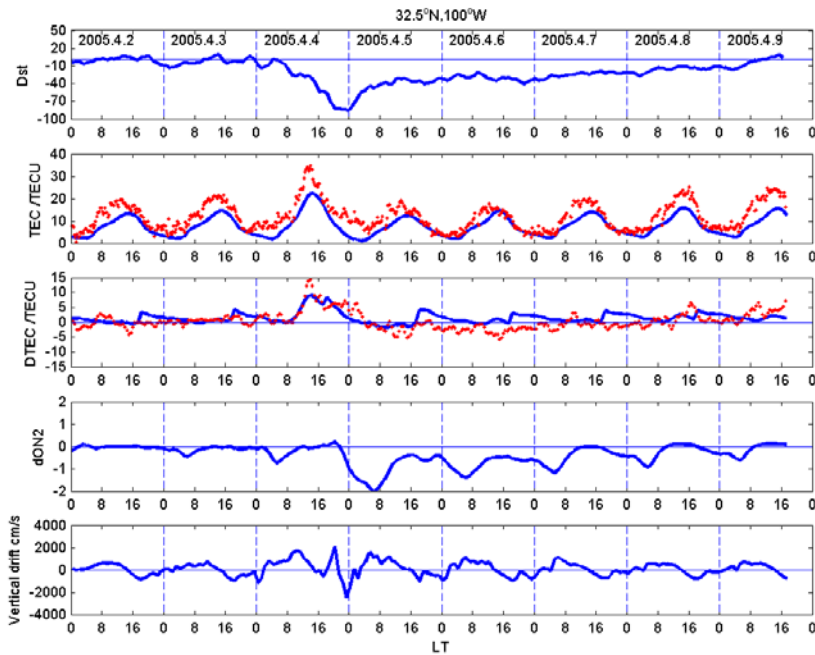
## High latitude- European Sector

## High latitude- Asian Sector



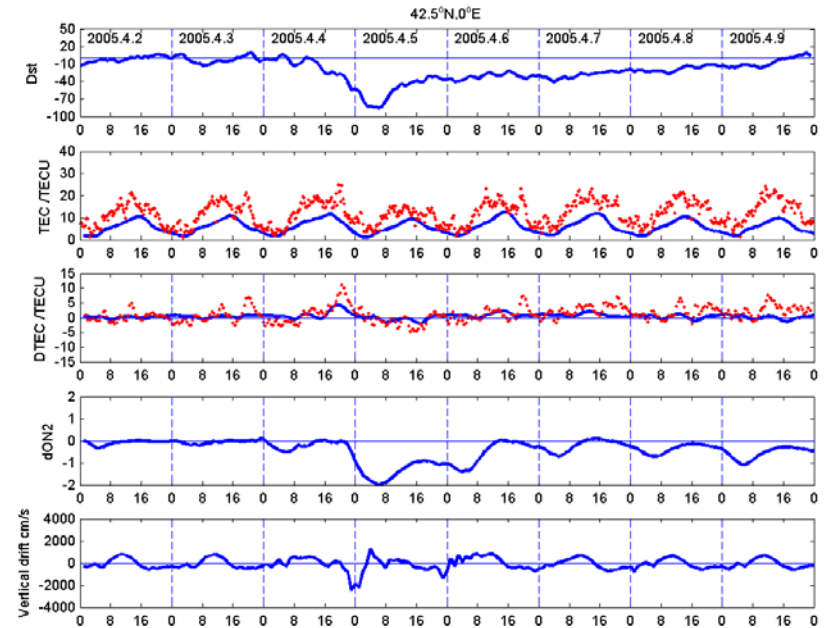
- The TEC at the high latitude of European sector shows a short-time positive response at night
- At Asian sector, TEC shows two day's positive effect, the vertical drift and O/N2 increase simultaneously
- There is a weak negative response which is related the decrease of O/N2

# Middle latitudes

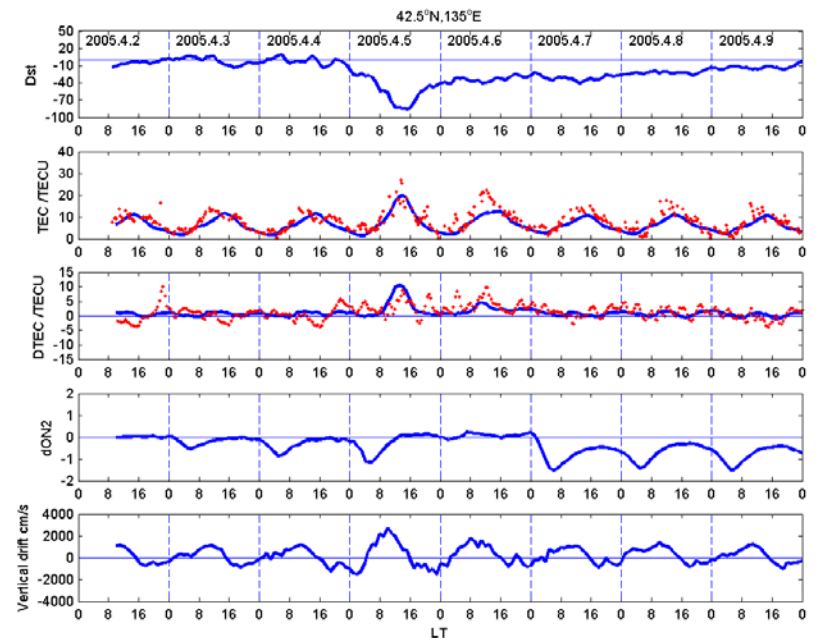


## North America

- The daytime positive is significant in north American and Asian sectors. The vertical drift seems to be the reason causing the storm-time TEC enhancement.
- In North American sector, the subsequent negative continued for several days.



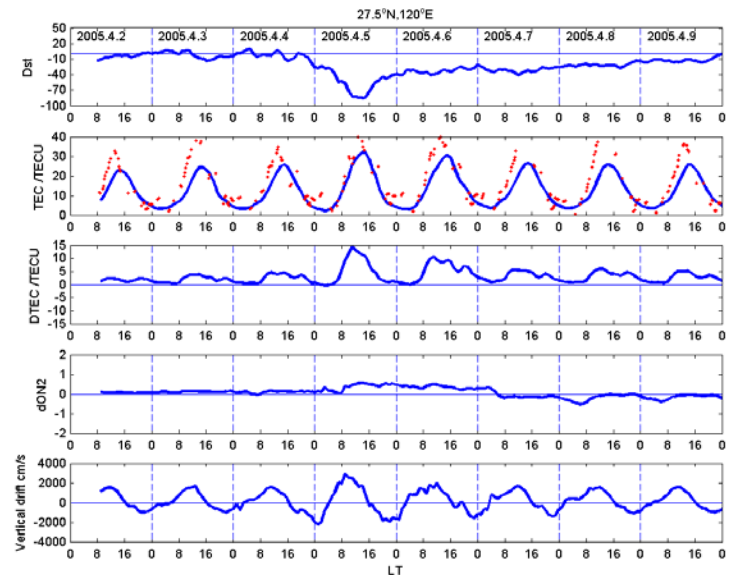
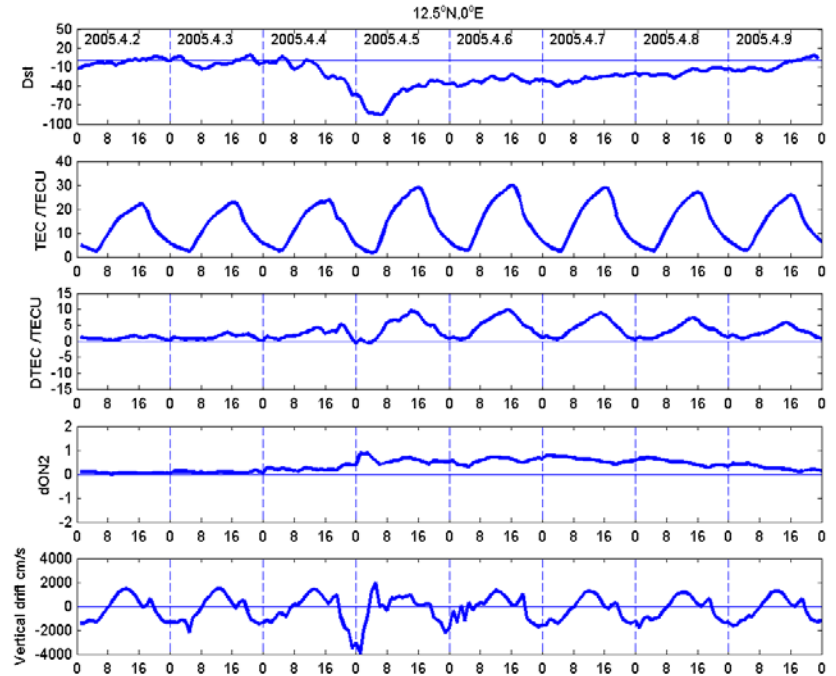
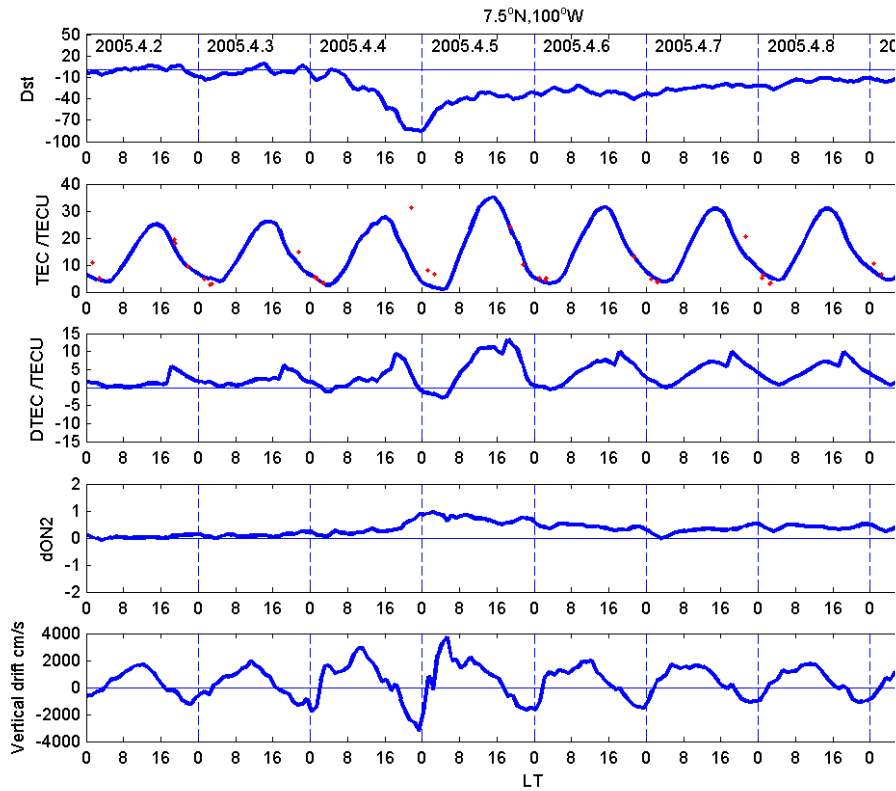
European Sector



Asian Sector



# Low latitudes



- In the main phase, the daytime positive is significant in Asian sector. The vertical drift increase during the main phase.
- From April 5-7, TEC shows a positive effect at all longitudes
- The ratio of the O/N2 enhanced significant during the recovery time.

# Summary

- The ionosphere has a positive response from high to low latitude during the CIR event occurred on April 4, 2005. At high latitude, after the positive response, there is a negative effect lasted for about 2 days. At low latitude, the positive effect can last for 2-4 days.
- The TIEGCM can well reproduce the storm-time positive and negative effect in daytime, while it underestimates the magnitude of TEC enhancement.
- The model and observation verify O/N2 decrease causing the negative response at middle and high latitude. The model output indicates the electric field is one of the reason for the positive response at middle to high latitude.
- At low latitude region, the electric field and composition (O/N2) changes jointly responsible for the positive response during 1-2 days after the geomagnetic storm started. The long-duration (>2 day) positive effect during the recovery time at low latitude is related to the O/N2 enhancement.

# ACKNOWLEDGEMENTS

- The GPS TEC data used were obtained from the Web site <http://madrigal.haystack.mit.edu>.
- GIM data were provided by JPL
- The CHAMP data were provided by GFZ-Potsdam.
- The GUVI O/N2 data were from the Website: <http://guvi.jhuapl.edu/sit/gallery>

# Thanks for your attention!

