The Impact of Lower Atmospheric Forecast Errors on Ionospheric Conditions During Geomagnetic Storms using WACCM-X 2.2

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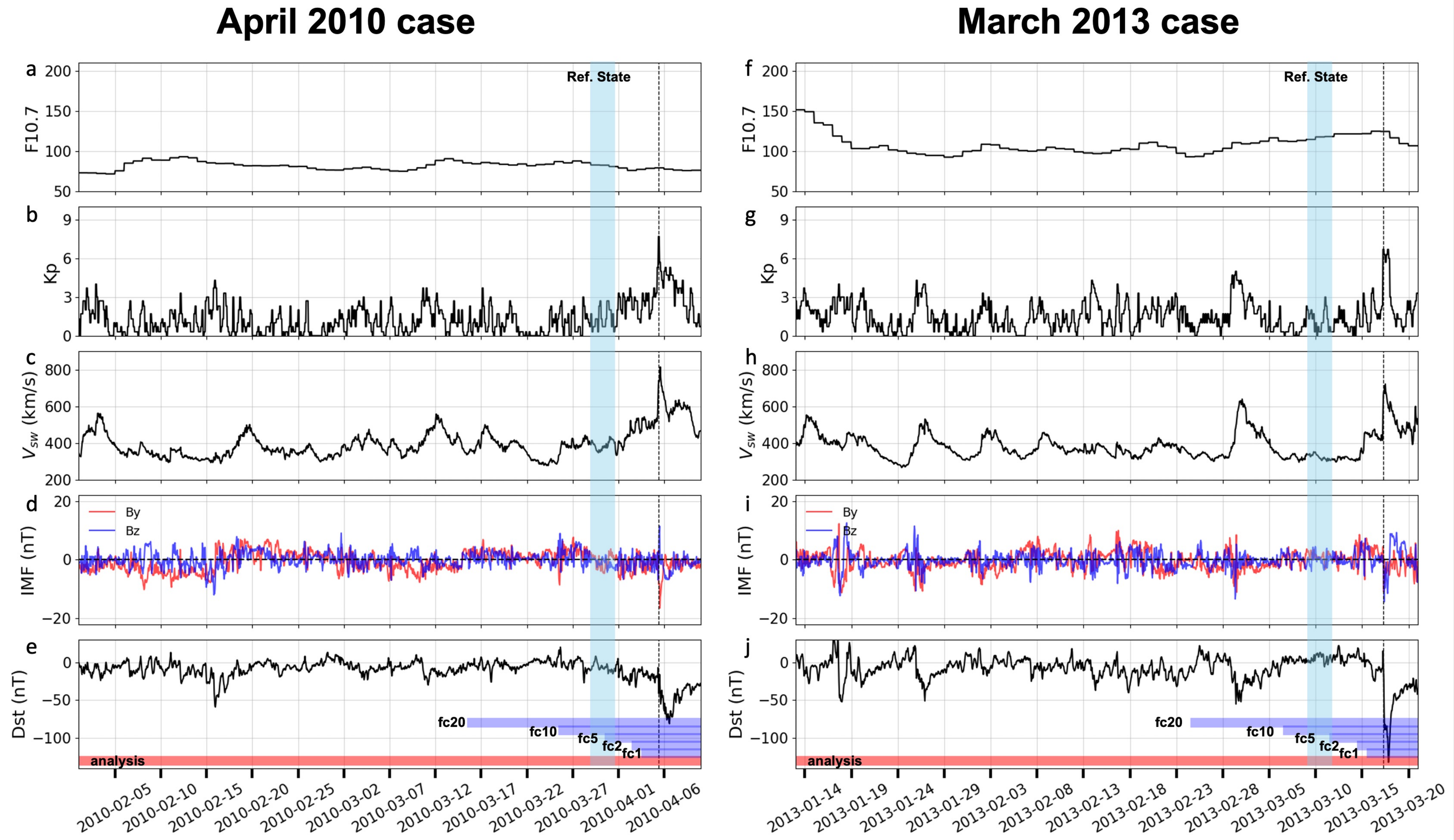
Introduction

- ✓ Previous studies have elucidated the influence of the lower atmosphere on the ionosphere, and it is important even during geomagnetic storms.
- ✓ These findings suggest that incorporating lower atmospheric information into a whole atmospheric model for ionospheric forecasts can offer potential benefits.
- ✓ Nonetheless, the real-time integration of such data into models presents notable challenges.
- ✓ How many days at least in advance do we need to integrating lower atmospheric data to enhance ionospheric forecasting accuracy?

Experiment Design: WACCM-X 2.2

❑ Geomagnetic indices and Experiment design of WACCM-X

April 2010 case | March 2013 case

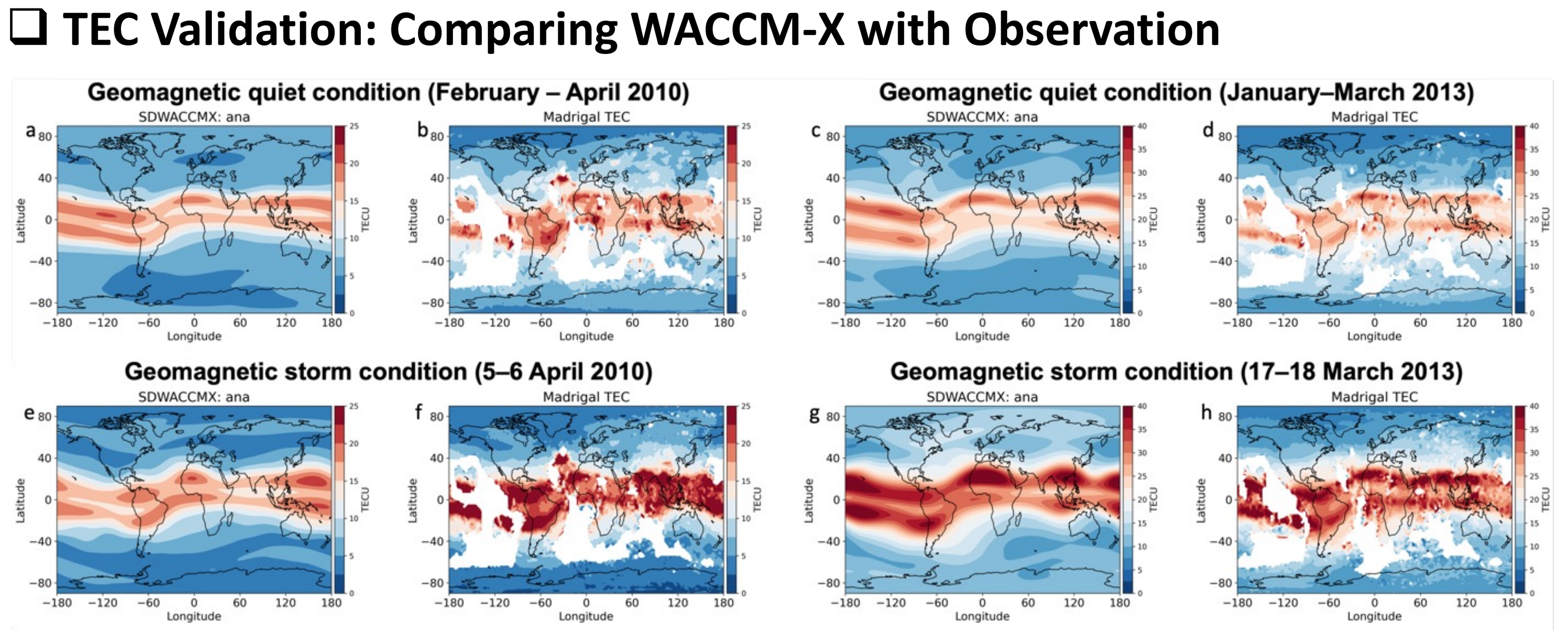


Analysis run: constrained by MERRA2 throughout the simulation period

Forecast(fc) run: analysis run is used as initial conditions to conduct 33 days hindcasts initialized on 20, 10, 5, 2, and 1 day before the storm onset time ('fc+lead time' → fc20)

✓ high-latitude electric potential → Weimer model / D-region chemistry

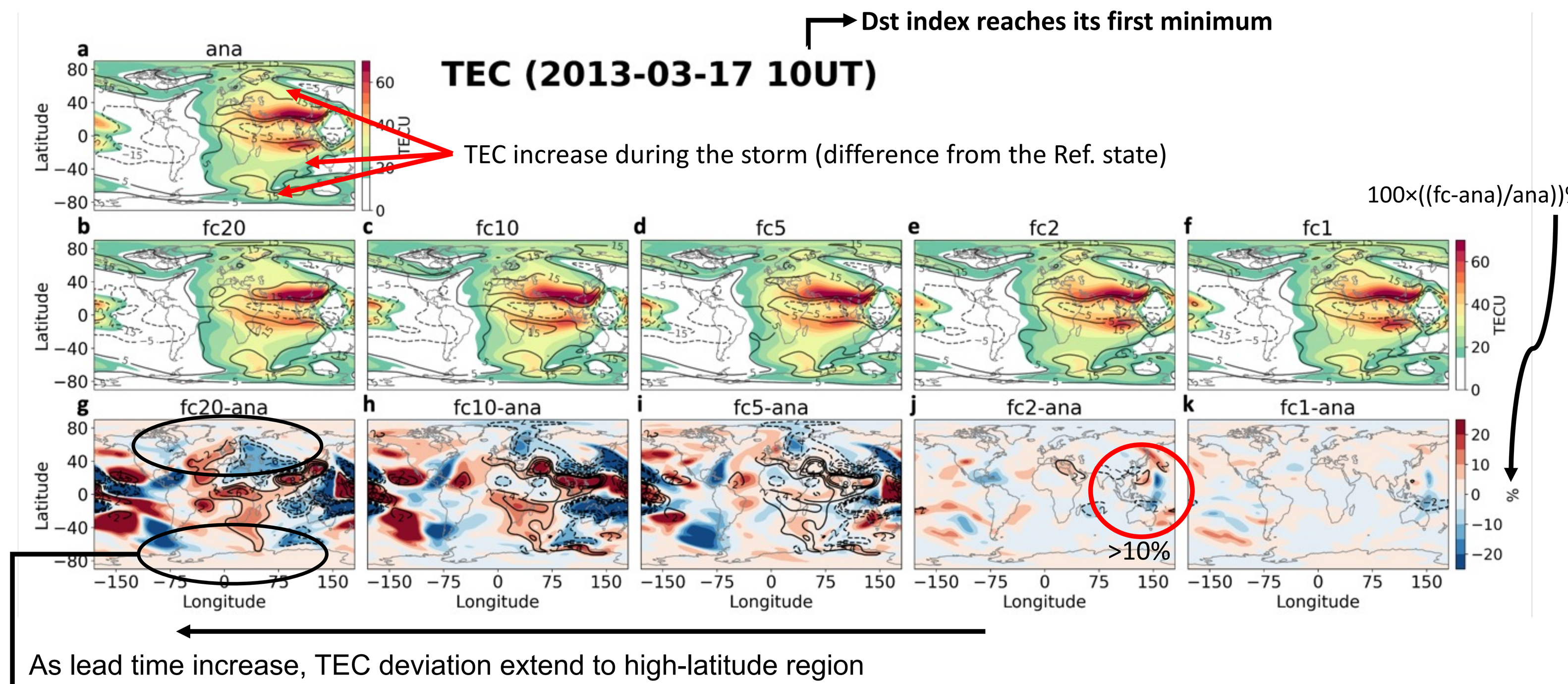
❑ TEC Validation: Comparing WACCM-X with Observation



- Quiet/Storm periods: 60-day / 2-day TEC averages
- The model generally captures the location/width of EIA under all conditions.
- 2013 results are more consistent with observations than 2010.
- 2010 TEC well-matched in quiet periods; 5 TECU underestimation in storm.
- However, model captures EIA expansion to mid-latitudes during 2010 storms.
- Because the 2013 results are consistent better with observations, we will focus primarily on the 2013 case.

Result 1

❑ Impacts of Lower Atmospheric Forecast Errors on IT system

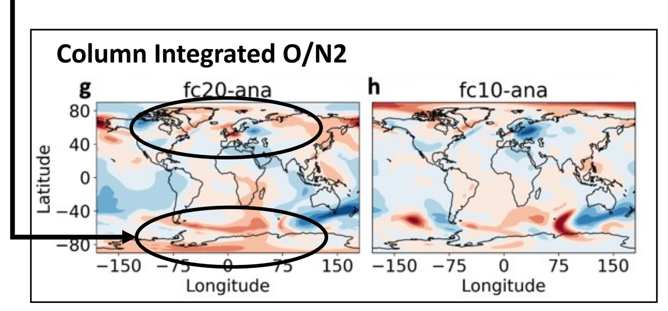


Geomagnetic storm responses

- TEC enhancement along the auroral oval and inside the polar cap region
- Poleward expansion of the EIA crest → prompt penetration electric fields associated with a dominant southward Bz

Lower atmospheric fc errors → Ionosphere

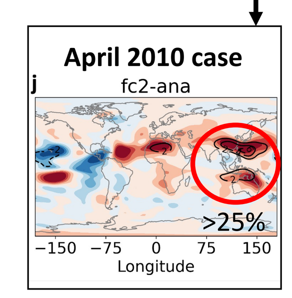
- Increasing lead time → deviations from the analysis run become pronounced.
- fc2 (2010case) >25%: stronger geomagnetic activity → longer optimal lead time.
- ΔTEC extend to high-latitude regions (lead time↑) → global impacts of lower atmospheric fc error on the ionosphere.



high-latitude ΣO/N$_2$

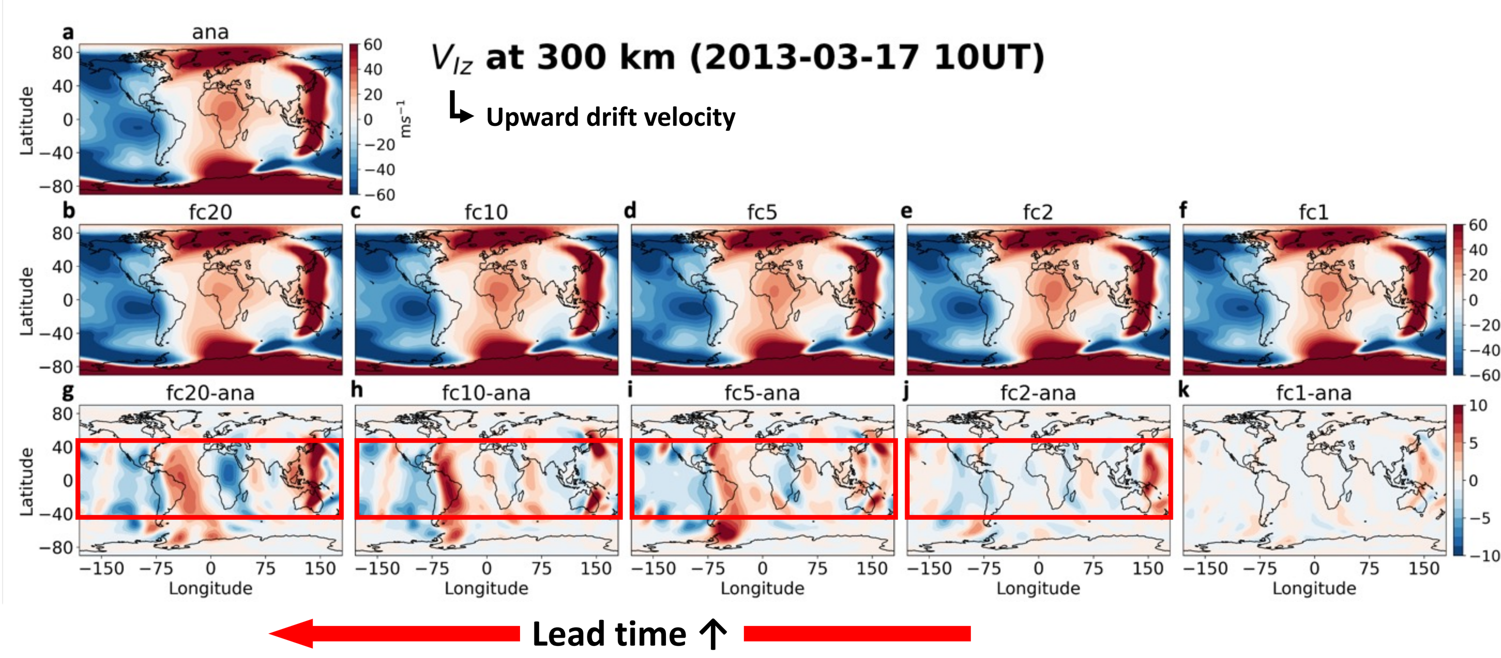
→ Emerge around ten days after the forecast starts (high-lat.)

Δlower atmospheric dynamics → Δmeridional circulation → variation in O/N2 (Yamazaki & Richmond, 2013)



TEC forecast errors in the low-latitude region

- Although variations in the ΣO/N2 ratio can explain TEC deviations in the high-latitude region in the fc run with longer lead times, they are insufficient to account for the TEC forecast errors in the low-latitude region.



- As the leads times increases, it is evident that the "fc–ana" in the V_{Iz} becomes more pronounced, particularly in the **low- and mid-latitude regions**
- These differences start to become noticeable once the lead time exceed one day.
- Such deviations impact the convergence or divergence of the EIA.

Conclusion

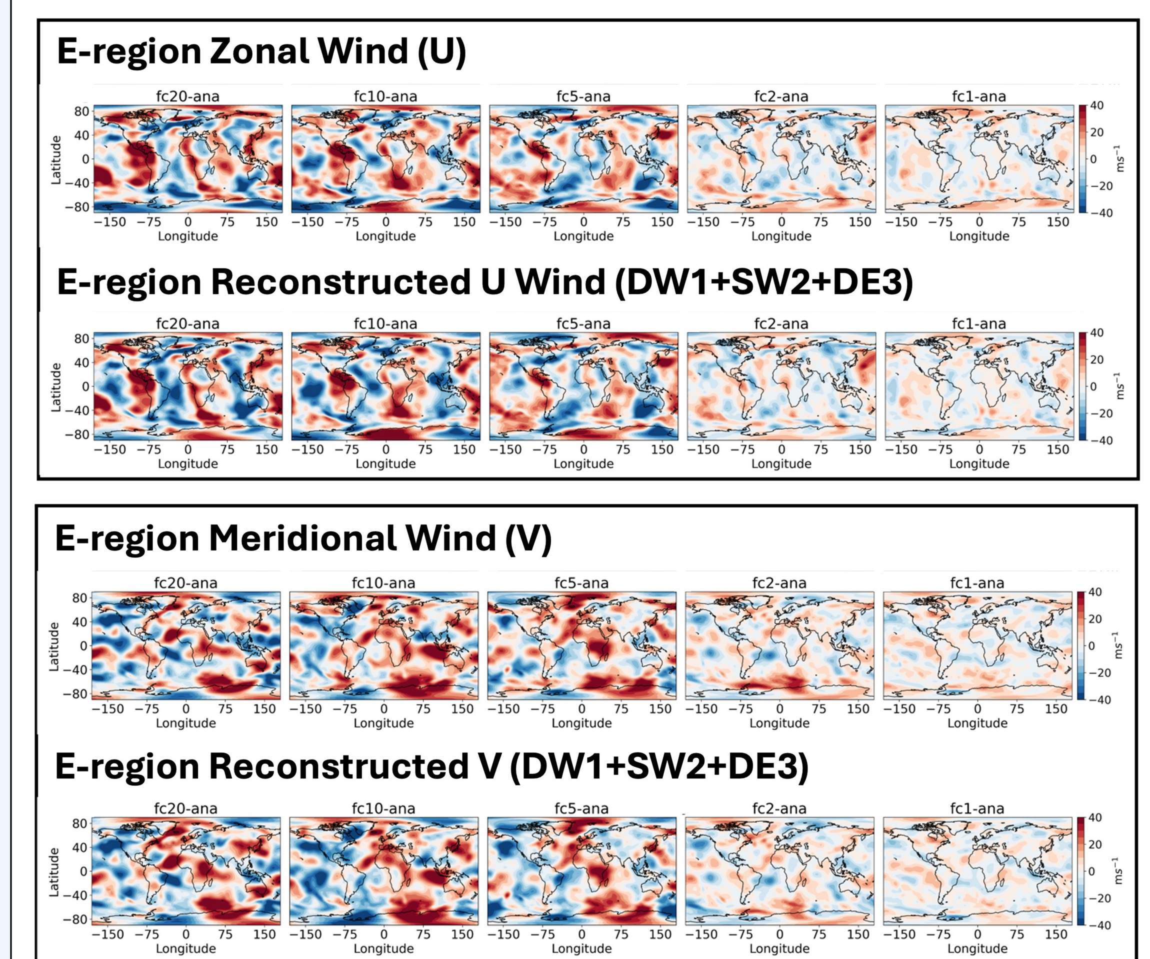
- This study investigates forecast errors from lower atmosphere impacts on IT system prediction, using WACCM-X for April 2010 and March 2013 storms.
- Biases in TEC start in the equatorial region within 1–2 days and spread to high latitudes beyond 10 days.
- The key influences on TEC biases are deviations in SW2 and DE3 tides within the dynamo region, which are related to forecast errors in high-latitude wave forcing.

Result 2

❑ Low-latitude E-region horizontal wind and tidal waves

- Daytime **F-region V_{Iz}** is primarily influenced by the **E-region dynamo.**
- Atmospheric tides from the lower atmosphere → E-region horizontal winds
- Fc errors in tidal waves from the lower atmosphere → IT system ?!

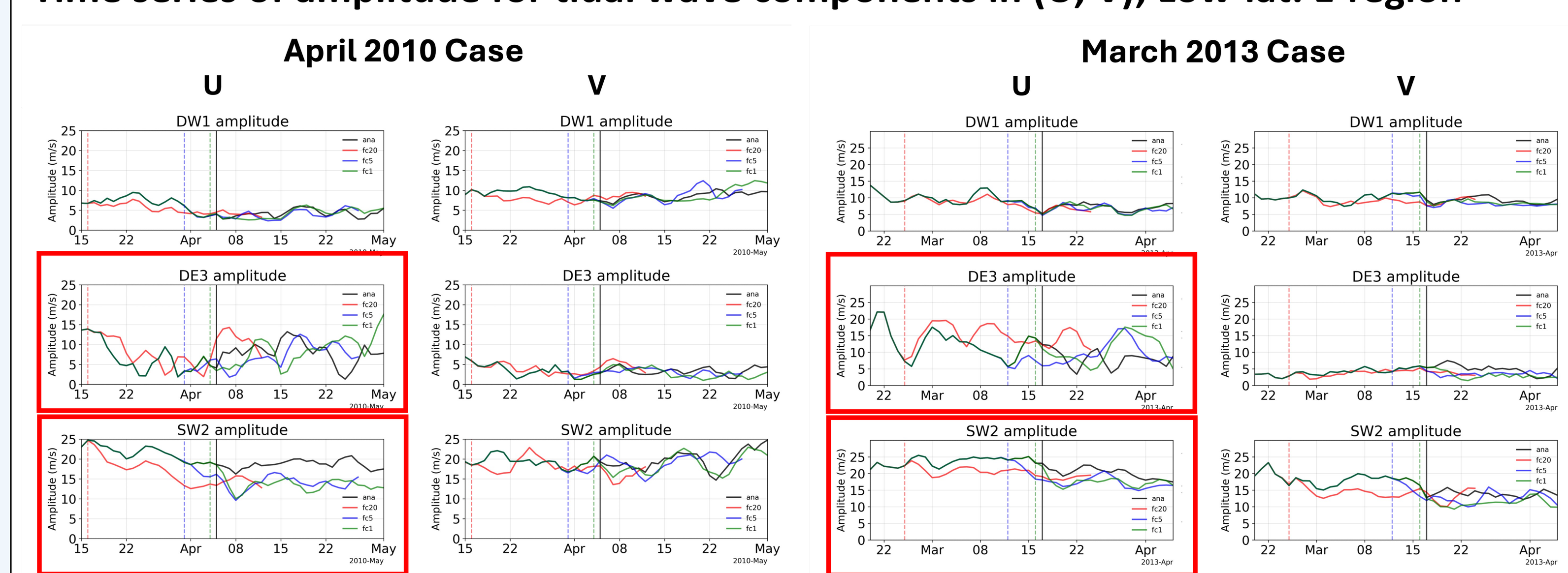
Difference between "fc-ana"



Fc errors in **reconstructed winds** are closely consistent with the **overall wind** fc errors

Inaccuracies in fc tidal wave lead to **discrepancies in (U, V)** structures of the low-latitude E-region.

Time series of amplitude for tidal wave components in (U, V); Low-lat. E-region



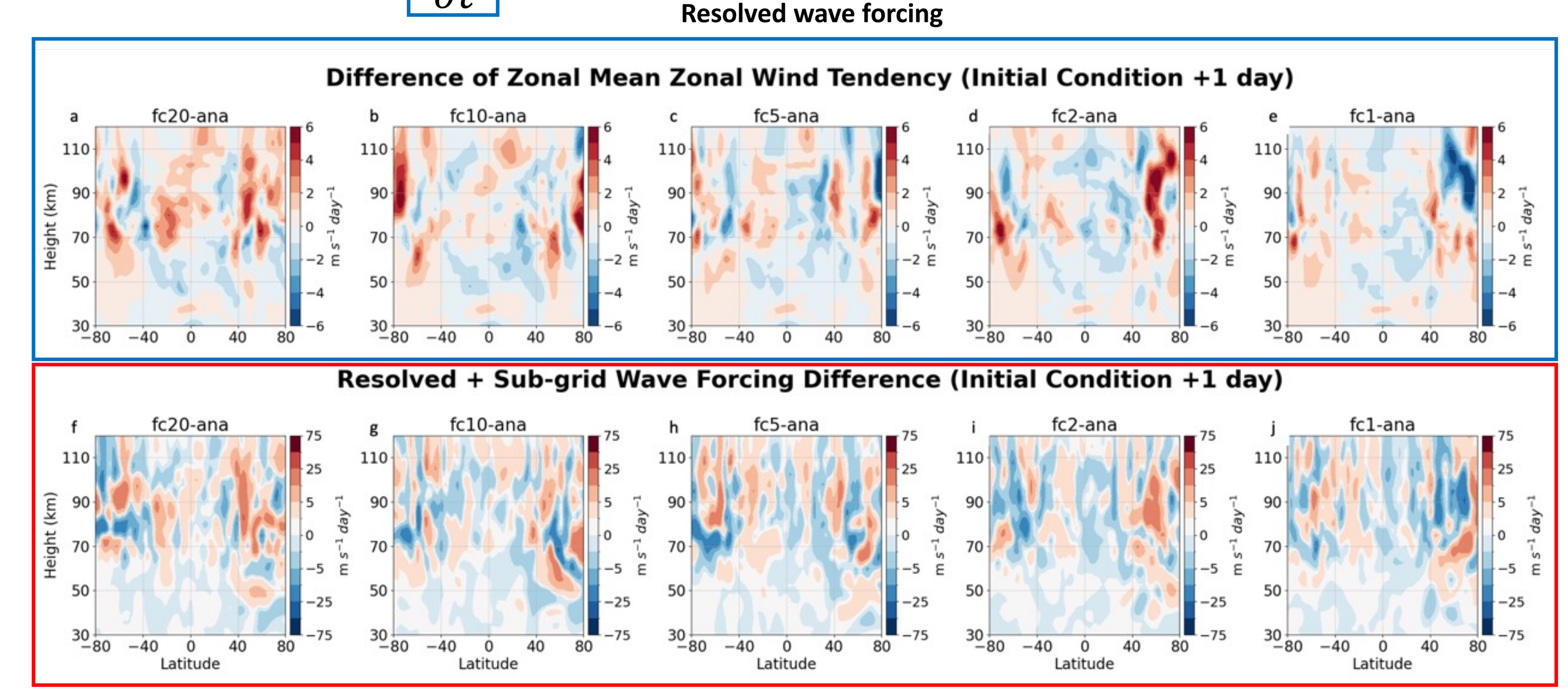
Amplitudes of SW2 in fc runs → decrease of about 5–10 m s^{-1} as lead time increases!

❑ Forecast Errors in the Zonal Mean Zonal Wind and Wave Forcing

- Tidal waves → classical tidal theory → global normal mode
- Discrepancies in (U, V) start from high-latitude regions → can alter the latitudinal structure of SW2 or DE3.
- One of the main factors to changes in high-lat. Wind is the wave forcing

$$\frac{\partial \bar{u}}{\partial t} = \cdots + (\rho_0 a \cos\phi)^{-1} \nabla \cdot F + \bar{X}$$

Sub-grid wave forcing ($\bar{X}$); Resolved wave forcing ($(\rho_0 a\cos\phi)^{-1}\nabla\cdot F$)



- Fc errors in wave forcing lead to discrepancies in $\bar{u}$ → influence the tidal waves → winds in the E-region → affect the V_{Iz} (F-region) → ionosphere structure!