Ionospheric Disturbances Generated by the 2022 Hunga Tonga-Hunga Ha'apai Eruption: Comparison of GITM simulations

COUP-4

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Introduction/Motivation

The extraordinary Hunga Tonga-Hunga Ha'apai (Tonga) Eruption has generated significant interest in the Ionosphere-Theremosphere's (IT) response to volcanic eruptions because of the global impacts that may have explanatory value to the community. A few include:

- Long lasting, horizontally broad, ionospheric hole [1].
- Modification of electric field systems [2].
- Ionospheric impact of Surface modes [3] and Global scale secondary gravity waves [4].

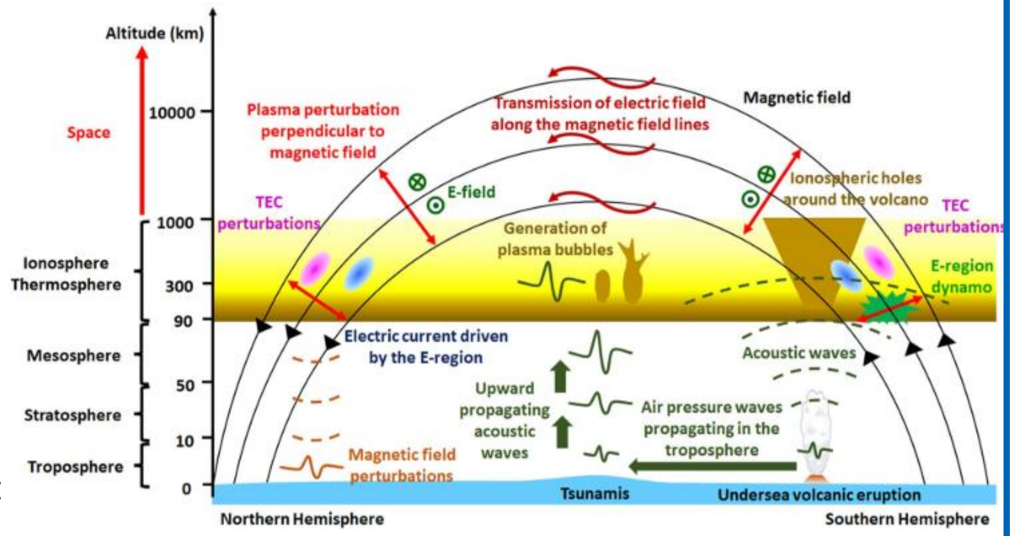


Fig 1. Atmosphere Ionosphere coupling during the Tonga event[5]

The Reason to study/model the event

1. What are the relative ionospheric and thermospheric impacts of the broad acoustic-gravity wave (AGW) spectrum excited by the event?
2. Can our models recreate significant features of the IT response and if not, why?
3. How can a detailed explanation of the event help us better predict natural hazards and their impacts on society?

The Focus of this study:

Drive the Global Ionosphere-Thermosphere Model (GITM) with inputs from high fidelity lower atmospheric models to capture different aspects of the dominant atmospheric wave response to the Tonga eruption.

Hunga Tonga Ha'apai (Tonga) Event

Date/Time: January 15th, 2022 from ~4-5 UT

- ~4-5 explosions within the first hour, with the second/third being the largest [1].

Location: 20.54° S, 175.38° W **VEI: ~6**

Plume Height: > 55 Km

Interesting aspects of the event

- AIRS data show Lamb and Perkins mode propagation in the troposphere [6].
- Large Neutral wind signatures in MIGHTI [7].
- Known to have affectively excited 3.7 mHz eigen mode of the earth [8].

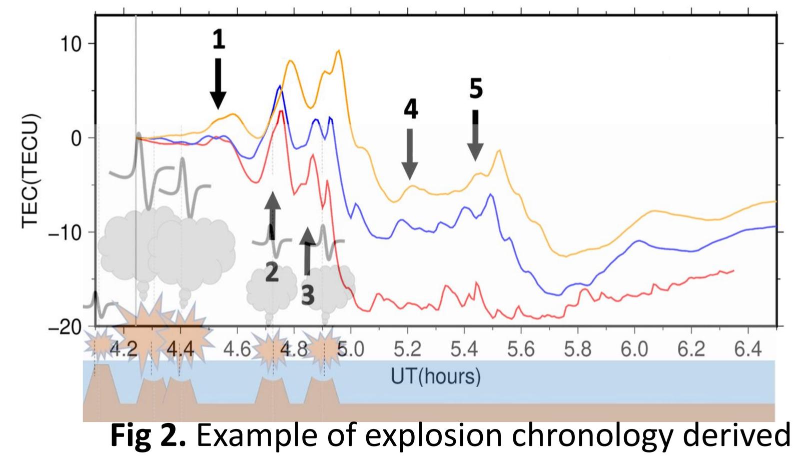
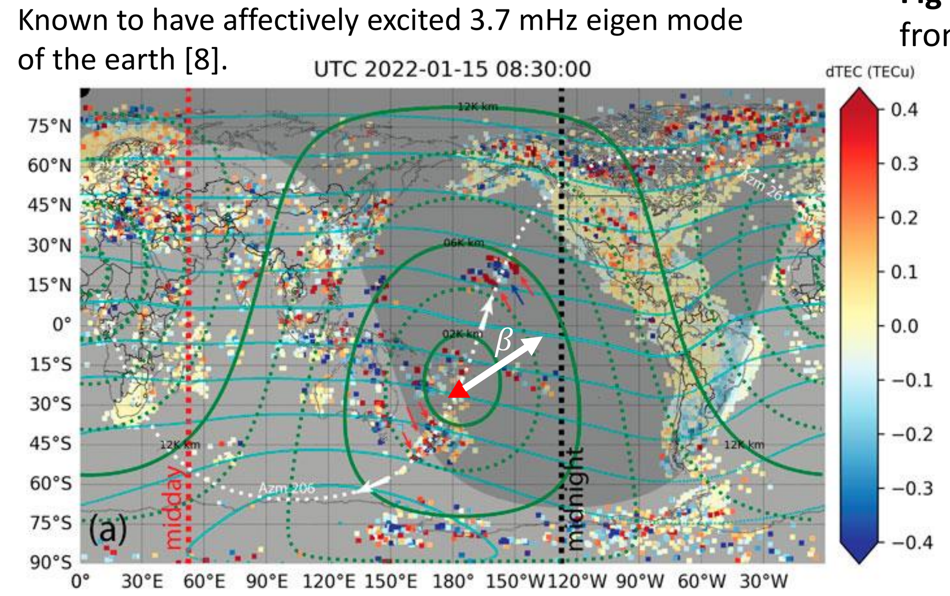


Fig 2. Example of explosion chronology derived from near field (< 2000 km) GNSS receivers (re-rendered)[1].



▲-Tonga location

Note: The GNSS data in this poster is selective. It is collected from regions along the great circle path shown in Fig.3 within a selected azimuthal range ($\pm\beta$) $\beta = 40$

GITM simulations are processed the same way, unless otherwise specified.

Fig 3. Example of Global TEC converge and Azimuthal span for measurements used.[9]

Methodology

Global Ionosphere Thermosphere Model (GITM) [3]

Why GITM for Meso-scale TAD-TID dynamics?

- Global Circulation Model that self consistently solves for the coupling in the IT system.
- GITM Allows for non-hydrostatic solutions.
- GITM can be driven by a 3D input domain.
- GITM can be coupled to NCAR 3Dynamo.

GITM-R is well equipped to capture the full spectrum of mechanical waves that may impact the IT!

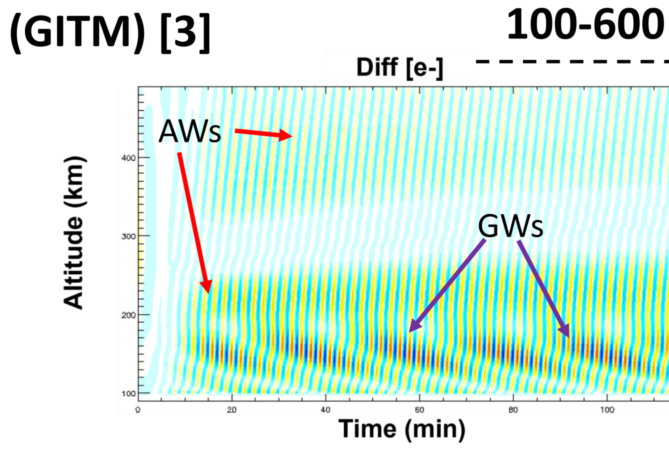
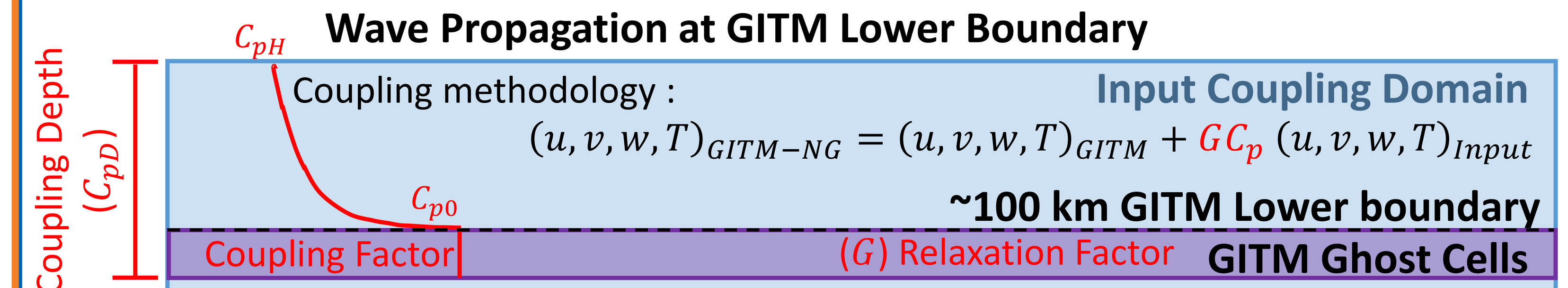


Fig 4. Example of AGWs in GITM-R simulation

Wave Propagation at GITM Lower Boundary



WACCM-X [3]

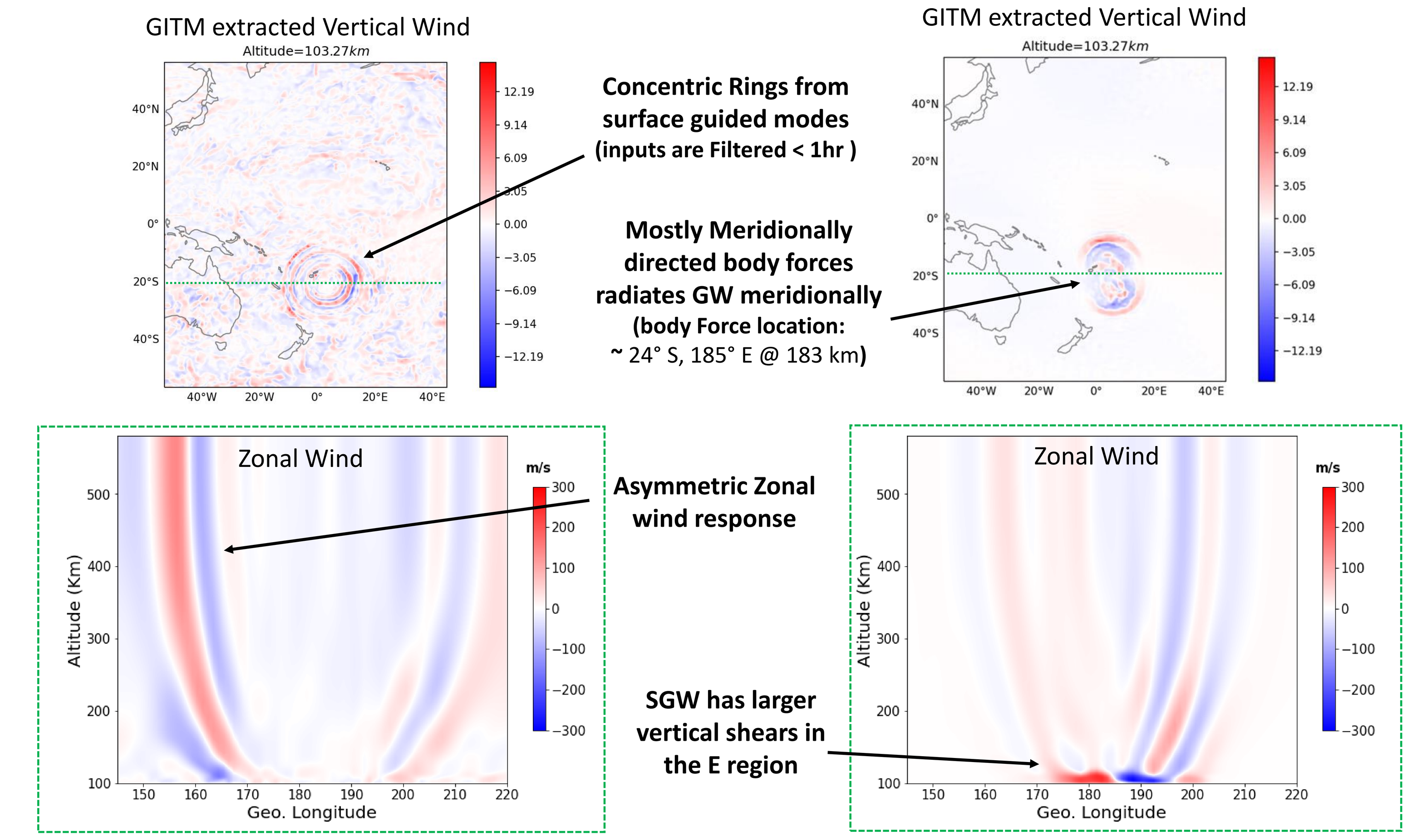
(Whole Atmosphere Community Climate Model)

Wave forcing primarily representing the L0 and L1 trapped pseudomodes (PSM).

HIAMCM [4]

(High Altitude Mechanistic General Circulation Model)

Wave forcing representing secondary gravity waves (SGW) generated by the breaking of primary waves



Figs 5. Example different forcing representing PSM (right) and SGW (left)

Important Simulation Parameters

Simulation Resolution: 1° x 1° (~100 km)

NCAR 3D Dynamo Resolution: ~ 2° x 2°

Solar Wind drivers

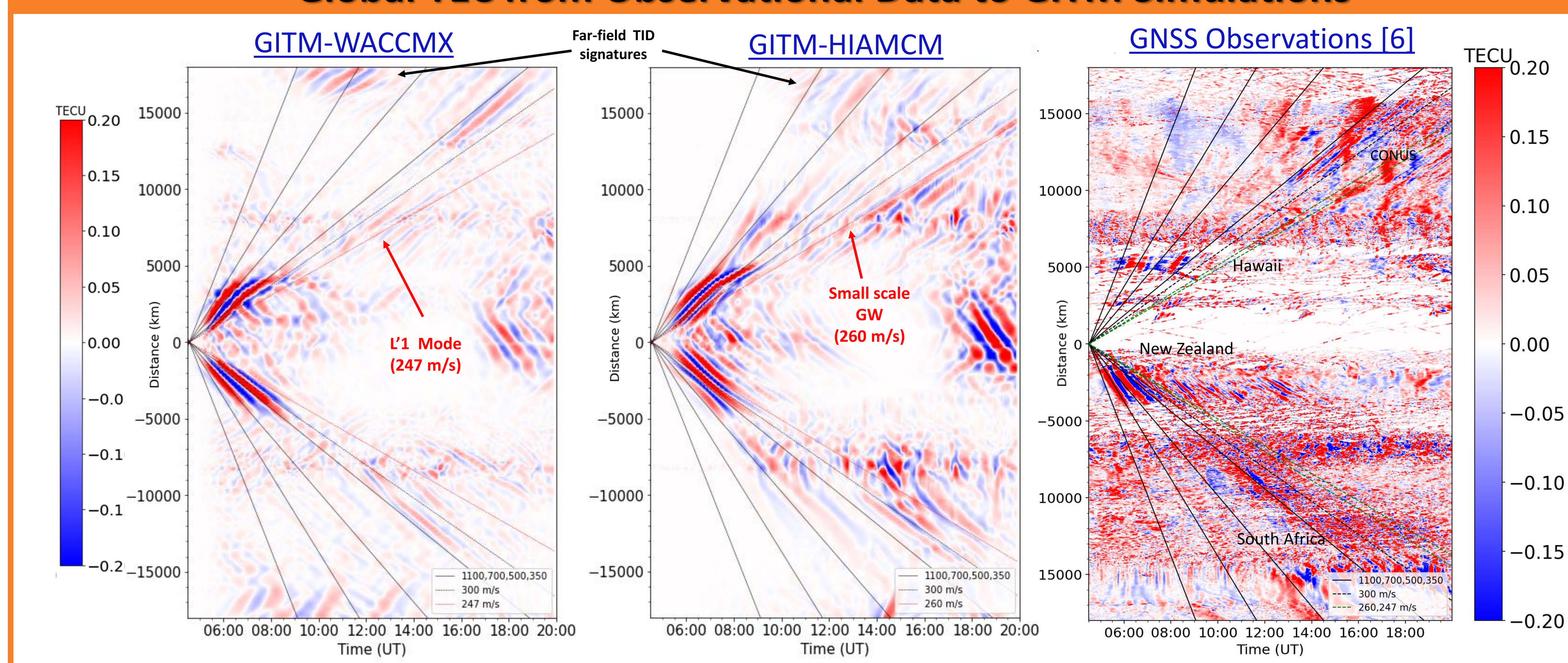
Important Coupling Parameters (CP1)

$C_{p0} = 25\%\ of\ origional\ value$

$C_{pH} = 1.0x10^{-5}$

$C_{pD} \sim 12\ km\ (98-110\ km)$

Global TEC from Observational Data to GITM Simulations



Figs 6. Example Global TID propagation form GITM driven simulation and GNSS observations

- PSM/SGW forcing create a rich spectrum of TADs which in turn induce a variety of TIDs with different phase speeds and periods.
- PSM/SGW forcing create far field TID signatures with SGW producing multiple far field wave packets.

Changing the Coupling Region Parameters

New coupling parameters (CP2)

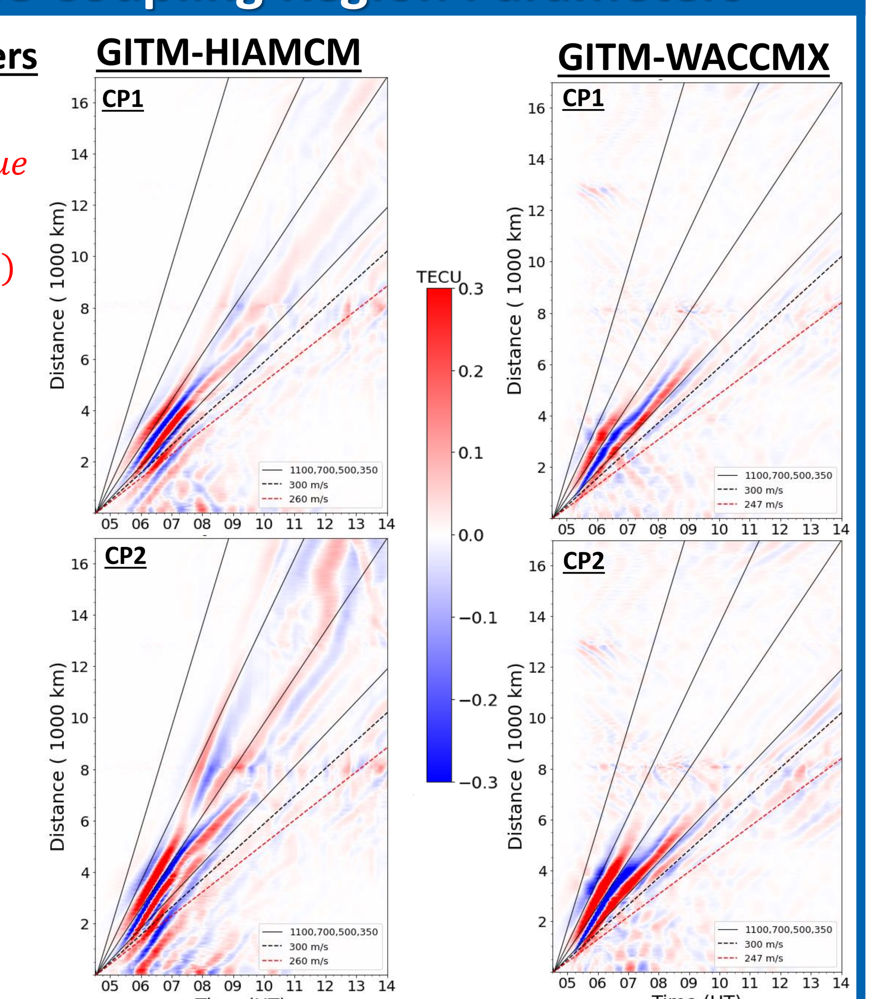
$C_{p0} = 5\%\ of\ original\ value$

$C_{pH} = 1.0x10^{-5}$

$C_{pD} \sim 32\ km\ (98-130km)$

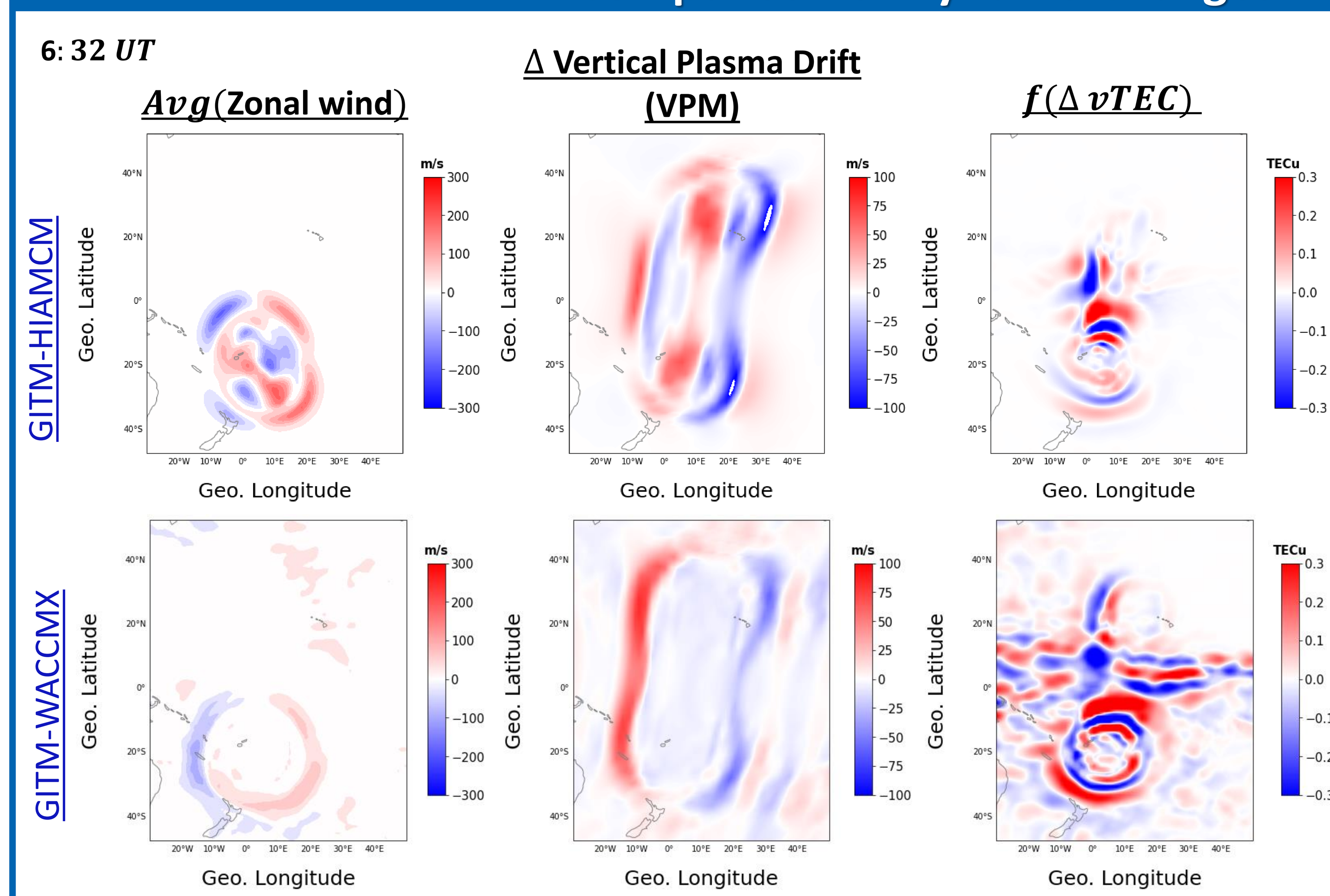
Using a deeper coupling region:

- Increases magnitude and phase speed of associated TIDs
- Makes the Far-field coupling with TAD more efficient.
- Increases neutral dynamo generated electric fields.



Figs 7. Comparison of Azimuthally averaged TID from GITM simulation using different coupling parameters

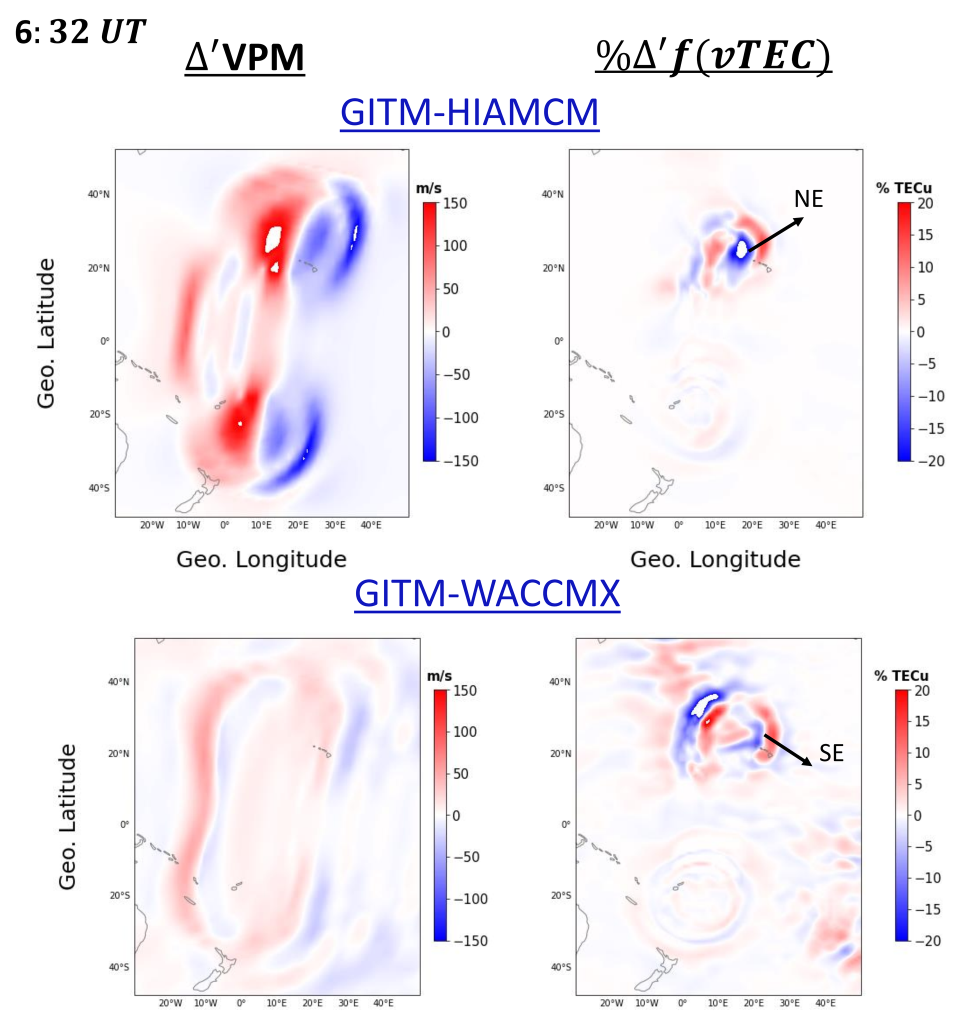
Comparison of Dynamo Changes



- PSM generates smaller scale, more variable, electrodynamic influences (due to relative size of Neutral perturbations ?)
- Large scale GWs (like SGW) could be more efficient at generating polarization electric fields.
- SGWs forcing leads to more prominent equatorial plasma drifts, and could be more effective at seeding instabilities.

Figs 8. Comparison of electrodynamic changes created by the different forcing mechanisms

Δ - Perturbation Run-Base Run $f()$ – high pass filter (1hr) $Avg()$ – Vertically averaged from 100-130 km



ΔTEC Comparison:

- Magnitudes of conjugate TIDs can change as much as 25 %
- Merid. Propagation direction of conjugate TIDs (over Hawaii) is opposite.
- Small magnitude (and scale) differences in the near field.

ΔV_{ExB} Comparison:

- Large Scale Asymmetry in ExB drift from SGW forcing
- Increasing the coupling region has more affect on SGW forcing

Figs 9. Difference between vertical ExB drift (left) and % dTEC (right) for driving with different coupling parameters

Δ'- ΔCp2 Run- ΔCp1 Run

Discussion & Conclusions

- PSM and SGW forcing produce a rich spectrum TIDs in the near field and GITM is able to reproduce the globally propagation of TIDs.
- SGW could be more efficient at seeding equatorial instabilities due to relative scale sizes of neutral and dynamo perturbations.
- Conjugate TIDs over Hawaii show opposite meridional propagation under PSM and SGW forcing.
- Using a deeper coupling region:
  - Increases magnitudes and Phase speeds of TIDs.
  - Makes far-field coupling of TADs more efficient.
  - Increases coupling with the neutral dynamo which can shows as large as 25% magnitude difference for nighttime TIDs.

Future Work: 1) Data model comparisons with ICON-IVM in the near field. 2) Coupling Comparisons with C_{pD}~ 50-100 km 3) GITM-R simulations for w/ simplified acoustic forcing [11]

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