Simulation of Tropical Cyclone Induced Gravity Wave Perturbations in the Upper Atmosphere

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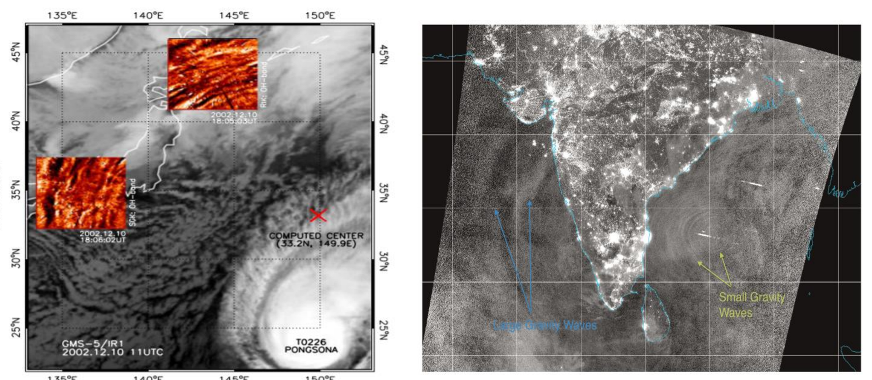
Introduction

Gravity waves (GWs) play important roles in atmospheric. Previous researches have proved severe weather system like tsunamis, convective storm and tropical cyclone can induce gravity waves in concentric patterns.

The tropical cyclone (TC) is a generic term for a rapidly rotating low-pressure system. It can induced **concentric gravity waves (CGWs)**, which are capable of upward from convective sources in the troposphere to the ionosphere modulating the intensity of TEC and creating **concentric traveling ionosphere disturbances (CTIDs).**

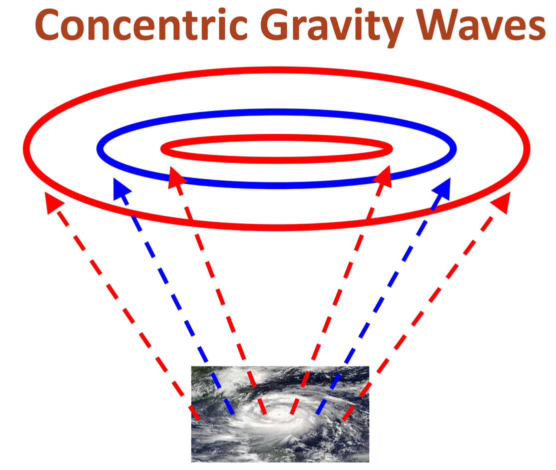
There are already lots of **observation** of CGWS base on ground-based airglow imagers and spaceborne instruments. Using **the global ionosphere–thermosphere model (GITM) to simulate the TC induced CGWs** the TC induced CGWs, we can better learn about physical mechanism of the wave propagation.



OH airglow imaging system [Suzuk et al., 2013] — DNB observations [Yue et al., 2014]

Observation of TC induced CGWs

Concentric Gravity Waves

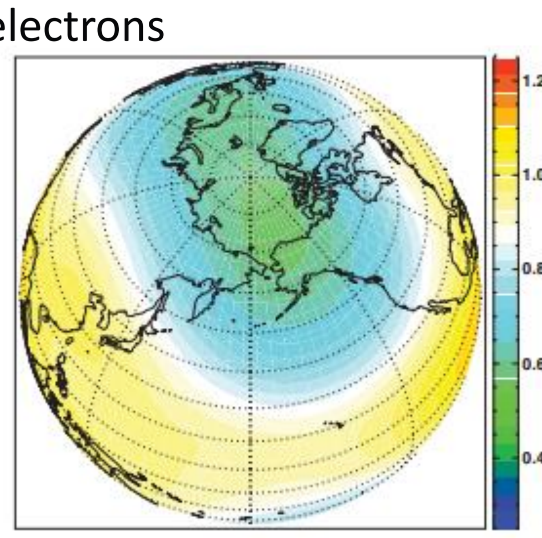


The Tropical Cyclone

Model Description

The global ionosphere–thermosphere model (GITM) [Ridly et al.2006]

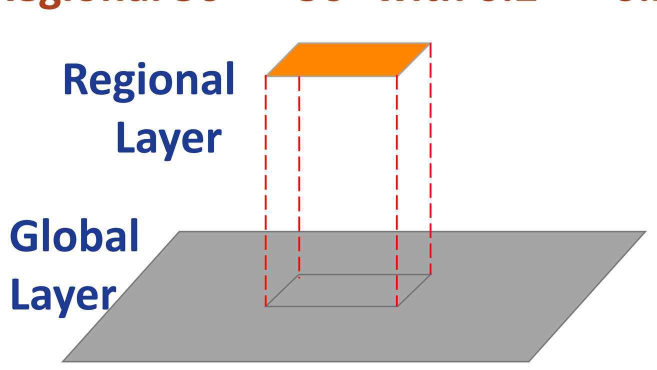
- 5 neutral, 5 minor neutral species & 9 ions and electrons
- Flexible 3D grid resolution
- Neutral and ion densities, velocities, and temperatures are solved self-consistently



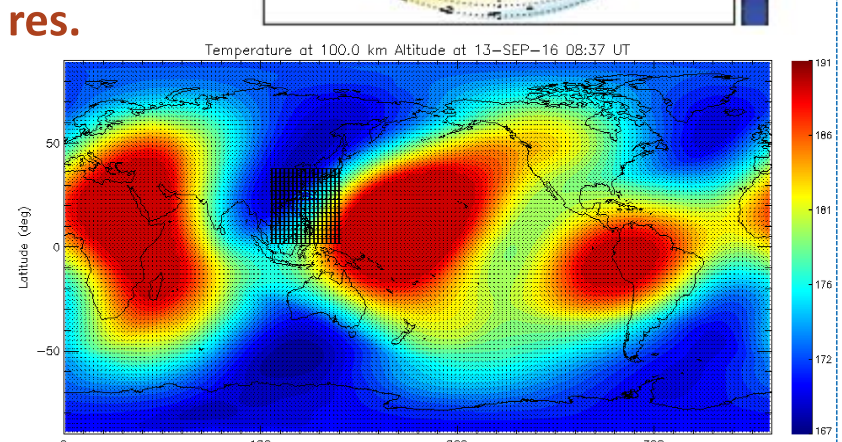
GITM-R (Local Grid Refinement)

- 2 way coupling
- Reduce computational costs
- Provide more details about a certain region

Regional 36° × 36° with 0.2° × 0.2° res.



Global with 2° × 2° res.
[Deng et al., in preparation]

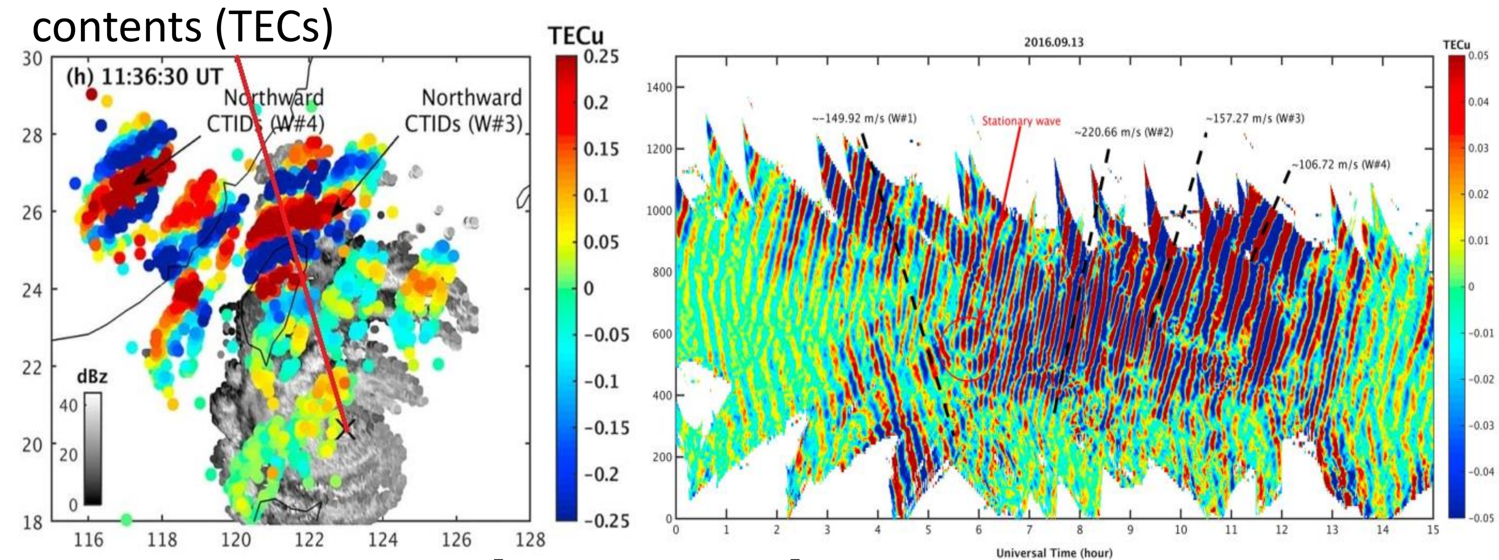


Global and regional grid of GITM-R

Simulation of the typhoon Meranti(2016)

Wave pattern of "Meranti"

- **The center of the wave:** tropical cyclone best track dataset
- **The wave patterns:** the time evolution of band-pass filtered total electron contents (TECs)



[Chou et al., 2017].

Simulation setup

Initialize the simulation

Run for 24h to reaching a quasi-steady state under relatively quiet conditions.

Imposed concentric wave:

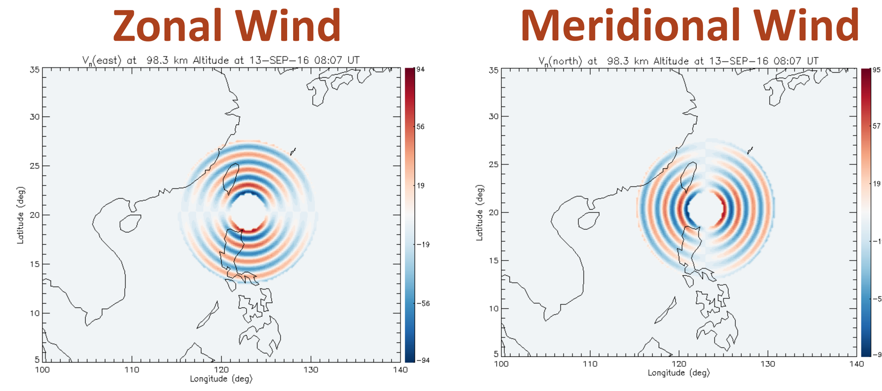
The **concentric cosine wave** with amplitude of 100 ms^{-1} has been imposed to the neutral wind at the lower boundary at 100 km altitude.

Perturbation forcing of concentric waves

- **Wavelengths**: 170 km
- **Phase velocities**: 157 m/s
- **Wave period**: 83s

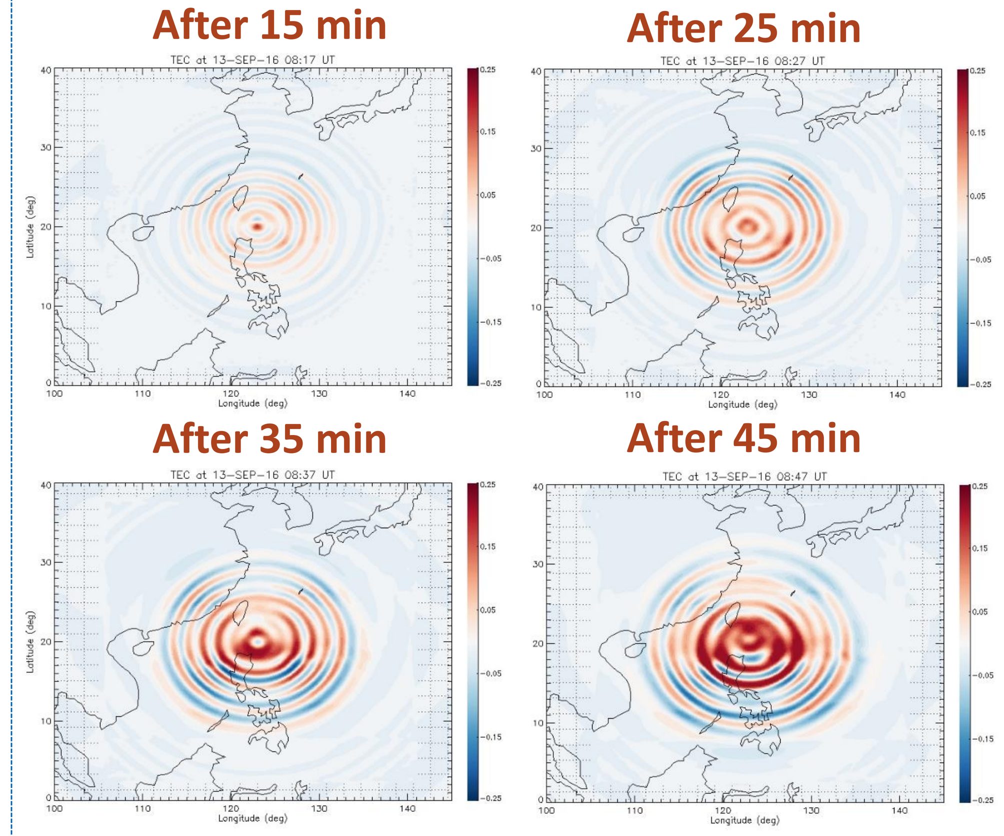
$$\delta v = A \times \cos[\frac{2\pi}{170}(x - ut)]$$

Zonal Wind — Meridional Wind



Result 1: TEC perturbation

After 15 min — After 25 min — After 35 min — After 45 min



Simulate the typhoon Mranti in 2016.

The time evolution of TEC perturbation within 1 hour:

- Wave propagate with time
- Amplitude attenuates along distance.
- Max value reach 0.25 TECu

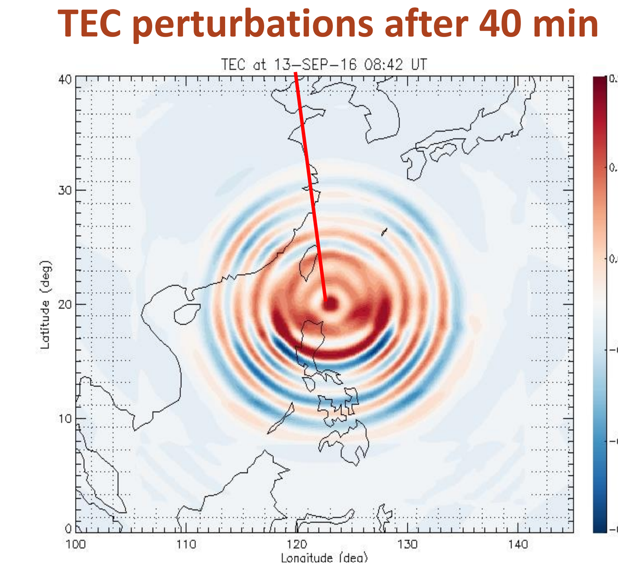
Fig 1. TEC perturbation after 15, 25, 35, 45min simulated by GITM

Result 2: Comparation between GTIM-R & GNSS

Compare of TEC perturbations

- **GITM dTEC**:
  Horizontal Wavelength: ~200km
  Amplitude: ~0.1 TECu
- **GNSS dTEC**:
  Horizontal Wavelength : ~170km
  Amplitude: ~0.25 TECu
- Wave length and amplitude comparable.

TEC perturbations after 40 min



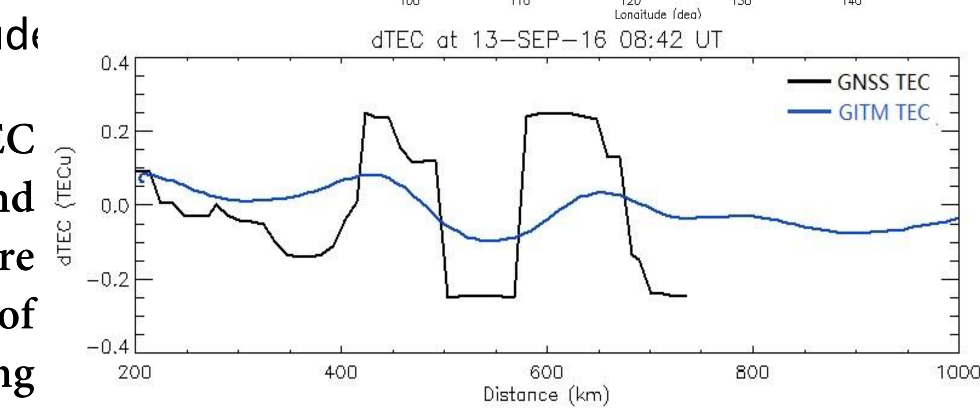
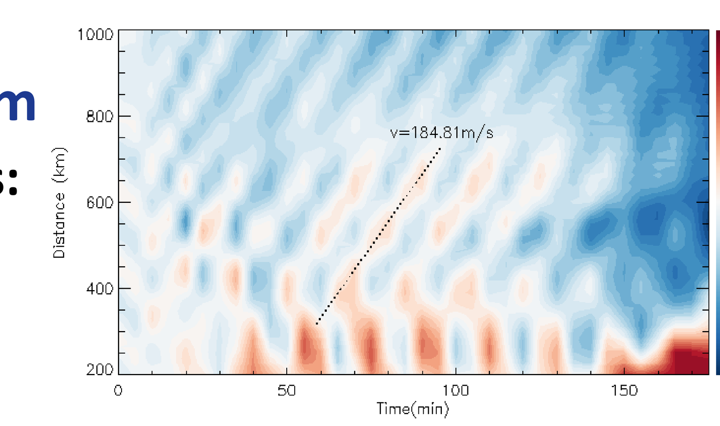


Fig 2. Compare of TEC perturbation from GNSS and GITM. The vertical axes are distances between the eye of typhoon and each grid along the red line before.

Comparation of TEC keogram

Phase speed of ionospheric CTIDs:

- **CTID from GITM**: 184.8 m/s
- **CTID from GNSS**: 157.3 m/s.
- Wave velocity are comparable.



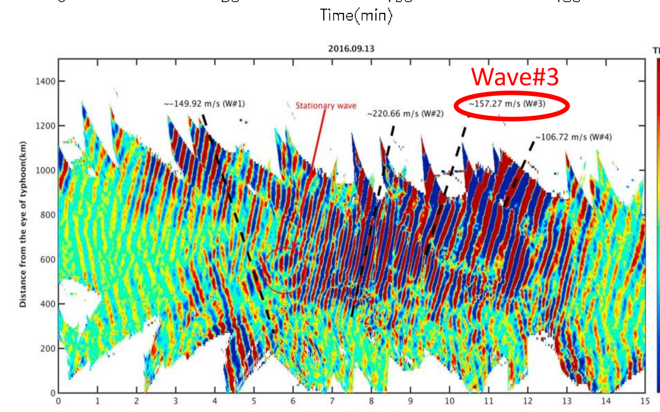


Fig 3. TEC-time-distance referring to the position of the eye of typhoon. The slant lines denote the phase velocities of the ionospheric disturbances.

Reference

[1] Ridley A J, Deng Y, Toth G. The global ionosphere–thermosphere model[J]. Journal of Atmospheric and Solar-Terrestrial Physics, 2006, 68(8): 839-864.
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[3] Suzuki S, Vadas S L, Shiokawa K, et al. Typhoon-induced concentric airglow structures in the mesopause region[J]. Geophysical Research Letters, 2013, 40(22): 5983-5987.
[4] Yue J, Miller S D, Hoffmann L, et al. Stratospheric and mesospheric concentric gravity waves over tropical cyclone Mahasen: Joint AIRS and VIIRS satellite observations[J]. Journal of atmospheric and solar-terrestrial physics, 2014, 119: 83-90.

Summary

1. A 3-D nonhydrostatic local-refined model, GITM-R, is used to simulate TC-caused upper atmospheric disturbances.
2. The simulation results reveal a clear scenario of ionospheric CTIDs aroused by TC induced CGWs.
3. Comparison with observed TEC CTIDs (Chou et al., 2017) shows that GITM performs reasonably well in simulating the ionospheric perturbations over Taiwan caused by the TC "Meranti".