Volcano-generated Ionospheric Disturbances: Comparison of GITM-R Simulations with GNSS Observation

COUP-06

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Motivation and Introduction

Several studies have revealed the measured ionospheric disturbances induced by volcanic eruptions, but little has been done to recreate such events through simulation. Data-model comparisons can lead to deeper understandings of physical phenomena and help to validate physical understanding. The focus of this study is to simulate ionospheric Total Electron Content (TEC) variations induced by volcanic eruption using the Global Ionosphere-Thermosphere model (GITM) and subsequently compare these simulations with Global Navigation Satellite System (GNSS) data.

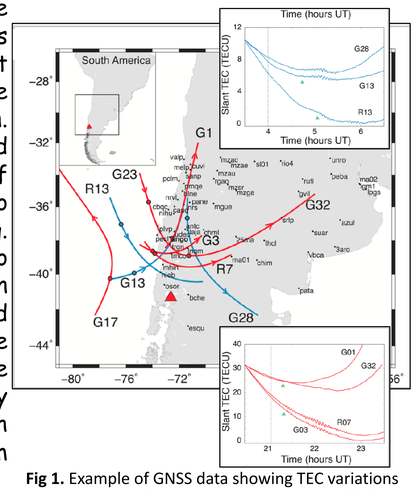


Fig 1. Example of GNSS data showing TEC variations caused by Calbuco Eruption (re-rendered)[5]

Methodology

Volcanic eruption is more or less like a point source at a fixed geographic location causing relatively localized perturbations. Simulation using GITM-R provides the ability to capture subtle waveform characteristics in the regions close to the volcano.

GITM-R features:

- Multi-layer patches allows GITM-R to save computational resources
- Local grid refinement allows for more reasonable boundary conditions to be imposed on regional layers [3].

Location: 35°x35° at (41°S, 73°W)

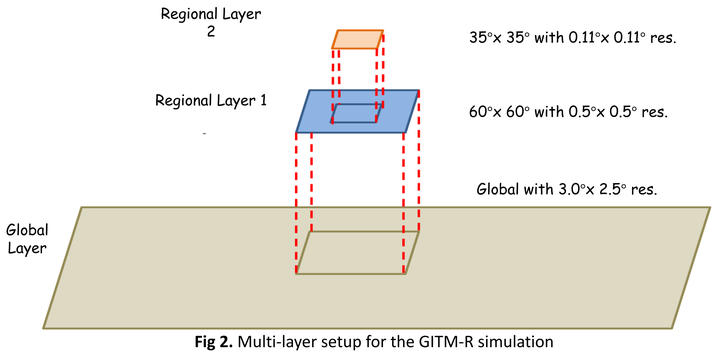


Fig 2. Multi-layer setup for the GITM-R simulation

Two forcing functions were applied to the temperature distribution at GITM's lower boundary to simulate the disturbance caused by the eruption. The literature search revealed possible values for most of the undefined parameters associated with these forcing functions, such as:

- wavelength of ~83.6 km [1]
- frequency range of 1-10 mHz [4]
- wave speed of ~900-1200 m/s [5]

These values provide an initial forcing function for which the results were computed and compared to the GNSS data. The comparisons yield insight into which parameters should be adjusted for data-model comparison. Stationary observers were added to GITM-R, via ground based receiver locations from Schults, to create plots for comparison with the 2015 Calbuco event [5].

Forcing Functions

The lower boundary of GITM-R is ~100 km altitude and thus it was of interest to hypothesize what form a volcanic perturbation might take at this boundary assuming relatively simple initial waveforms. The two forcing functions discussed in this study are

Oscillatory Ring (OR): $F(r,t) = \left[\frac{A_p}{2}\cos\left(\frac{2\pi}{\lambda}(r - r_{cen.} + r_s)\right) + \frac{A_p}{2}\right]\cos(ft)$

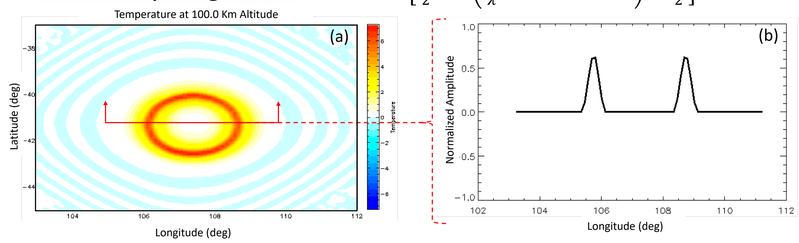


Fig 3. 2-D map of lower boundary perturbation for OR(a). Section cut of normalized OR perturbation (b)

Radial Wave Packet (RWP): $F(r,t) = A_p \sin\left(\frac{2\pi}{\lambda}(r - r_{cen.}) - ft\right)$ moving at v_{ws}

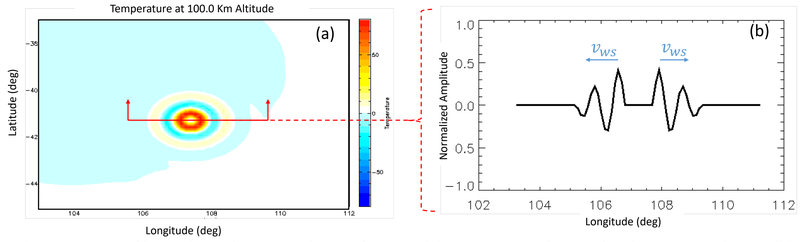
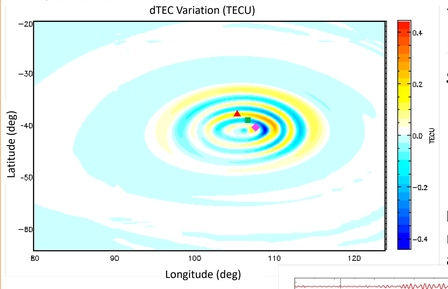


Fig 4. 2-D map of lower boundary perturbation for RWP (a). Section cut of normalized OPS perturbation (b)

OR TEC Variations and Comparison

Characteristics of Forcing Function

- Amplitude: 25 K
- Frequency: 0.004 Hz
- Wavelenath: 51.3 km



Three stationary observers located at ground based receivers sampling at a rate of 15 secs. [5].

- ▲ Trgn location : (38°S, 73°W)
- ■ Nieb location : (40°S, 72°W)
- ◆ Bche location : (41°S, 71°W)

Fig 5. Two dimensional TEC map showing variation relative to local background for the case of OR forcing after one hour

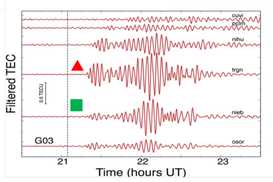


Fig 6. Filtered slant TEC response for Calbuco eruption. Grey line indicates time of eruption. [5]

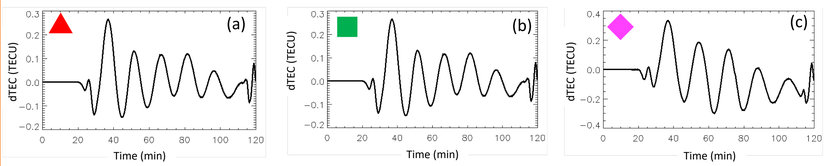


Fig 7. TEC variations, over time, relative to local background for (a) Trgn, (b) Nieb, and (c) Bche

- Frequency of TEC perturbation: ~ 0.001 Hz (T =1,000 s)
- Maximum Magnitude of 0.35 TECU is close to observational result of 0.45 TECU [5]

RWP TEC Variations and Comparison

Characteristics of Forcing Function (v_{ws} = 1100 m/s)

- Amplitude: 100 K
- Frequency: 0.01 Hz
- Wavelenath: 83.6 km

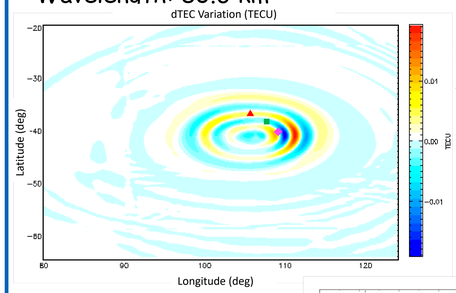


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Fig 8. Two dimensional TEC map showing variation relative to local background for the case of SWP forcing after one hour

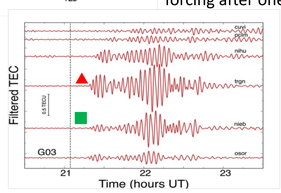

Fig 9. Filtered slant TEC response for Calbuco eruption. Grey line indicates time of eruption. [5]

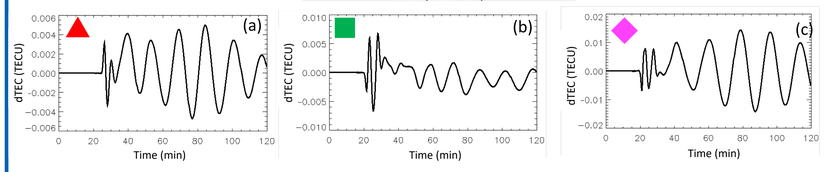

Fig 10. TEC variations, over time, relative to local background for (a) Trgn, (b) Nieb, and (c) Bche

- Two TEC waveforms: initial wave packet and aftermath, different frequencies (~0.004 Hz (T = 250 s) and 0.001 Hz (T = 1,000 s))
- Small magnitude

Summary & Conclusions

- Two proposed lower boundary forcing functions : Oscillatory Ring (OR) and Radial Wave Packet(RWP)
- OR perturbation: unable to reproduce the apparent frequency of observational results but gave decent agreement with the maximum amplitude
- RWP perturbation: two observed TEC waveforms, First waveform has a similar frequency as that of observational results, both waveforms have amplitude significantly smaller than observed results.
- Conclusion: the first TEC waveform of the RWP seems to better represent the waveform from observational data, More work can be done to replicate this waveform and to increase its magnitude to better agree with observational results.

References

[1] Heki (2006), doi:10.1029/2006GL026249
[2] Deng et al., in preparation
[3] Lin et al. (2017), doi:10.1002/2016JA022930
[4] Dautermann et al (2009), doi:10.1029/2008JB005722
[5] Shults et al. (2015), doi:10.1002/2016JA023382