Study Tonga Eruption Using TIEGCM: A Nested Grid Approach

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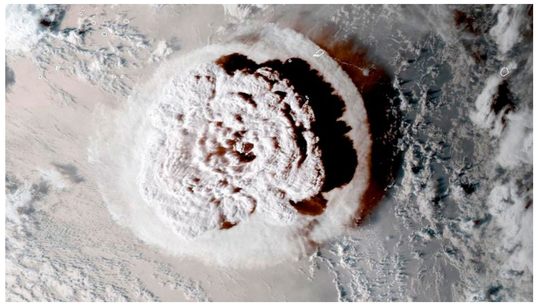
Introduction

Hunga Tonga-Hunga Ha'apai volcano eruption on January 15, 2022, triggers large atmospheric disturbances in the lower atmosphere. The upper atmosphere is also significantly impacted by the waves induced during the eruption and manifest various neutral and electrodynamic responses.



As an example, concentric ring structures are found in TEC measurements which can be traced back to the eruption (Zhang et al., 2022). In this study, we attempt to model this event using TIEGCM with the nested grid extension developed by the authors.

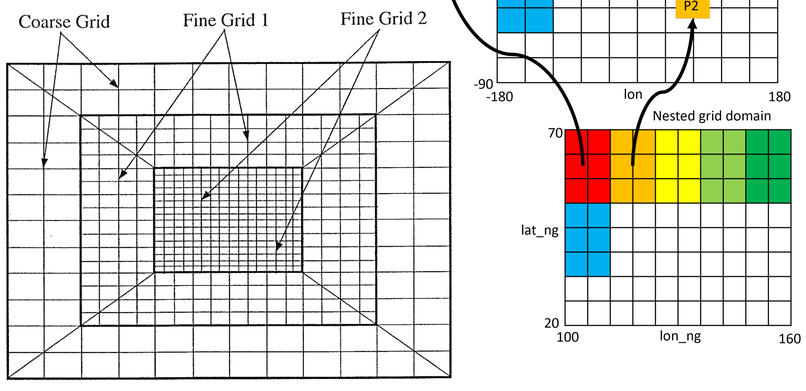
Model Description

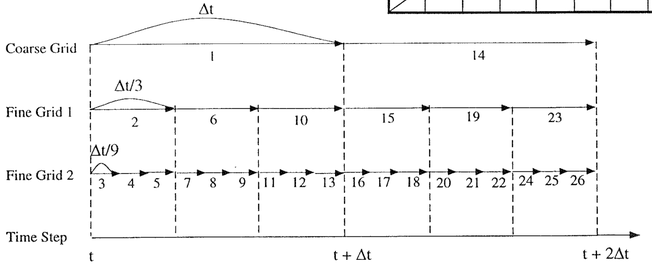
Nested grid TIEGCM provides a regional view of IT system with high resolution while not drastically increasing computation.

- Include all neutral and electrodynamic calculations
- Nested grid region and resolution is provided by users in the input file; Multi-level nesting is also provided as an option
- Fully parallel, optimized on supercomputers

Nested Grid and Global Domain

1. Global domain is first advanced.
2. Nesting boundaries are interpolated in time.
3. Nested grid are advanced for several sub cycles.
4. Fields in nested grid are mapped back to global domain.

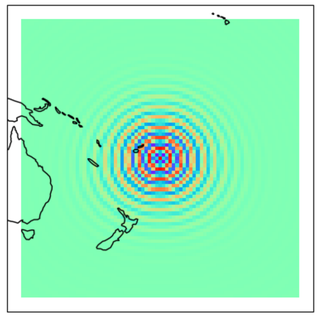




- Each process covers a few longitudes and latitudes.
- In one process, the coverage of full domain and nesting domain may not overlap.

Experiment Design

When the disturbances propagate upward to the thermosphere, it is likely that certain spatial structures are developed.

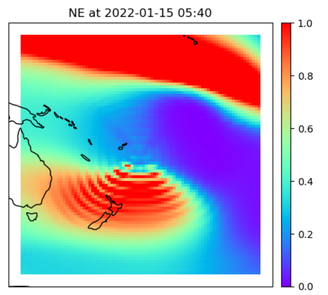


However, due to the lack of information about the specific form of the thermospheric disturbances, we must make a guess. We approximate it as a regional heating term in the thermodynamic equation at the lower boundary (~100km). The specific form of heating is a 2D outward propagating surface wave with a Gaussian shape spatial decaying factor:

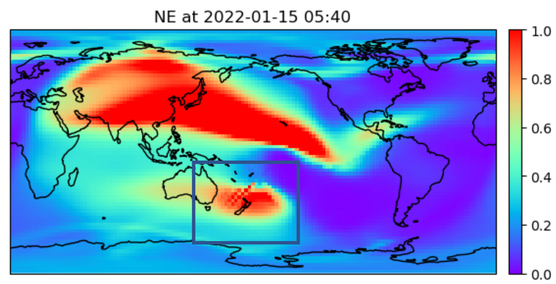
$$Q = A\cos 2\pi(r/\lambda - t/\tau)\exp\left(-r^2/2\rho^2\right)$$

Simulation Results

We perform a series of controlled experiments, the ones with significant ionospheric responses (electron density) are shown below:



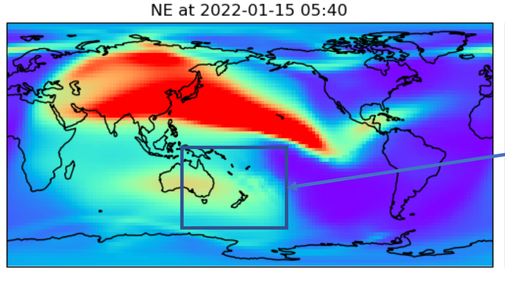
λ=3°, ρ=10°, τ=20min. At ~250km, electron density perturbation is showing wave signals. Atmospheric waves carry disturbances and manifest in ionosphere.



Discussion

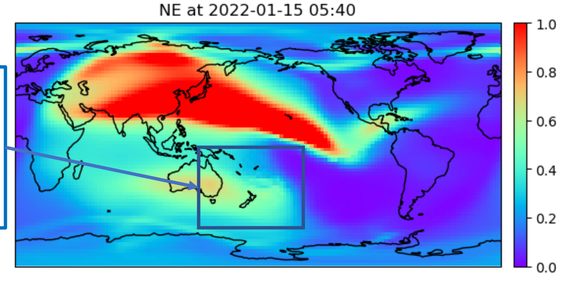
Decreasing λ means smaller scale waves, which essentially depends on the model resolution. Wave period τ will also affect the propagation of waves and eventually the IT impacts. For example, with heating only in the global domain (left) or very long period (stationary waves, right), electron density doesn't show wave impacts.

Heating only in Global Domain



No significant electron density perturbations

Heating Term with τ→∞



Acknowledgement

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