Simulation of Gravity Waves Generated by Tonga-Hunga Volcano Eruption Using Nested-Grid TIEGCM

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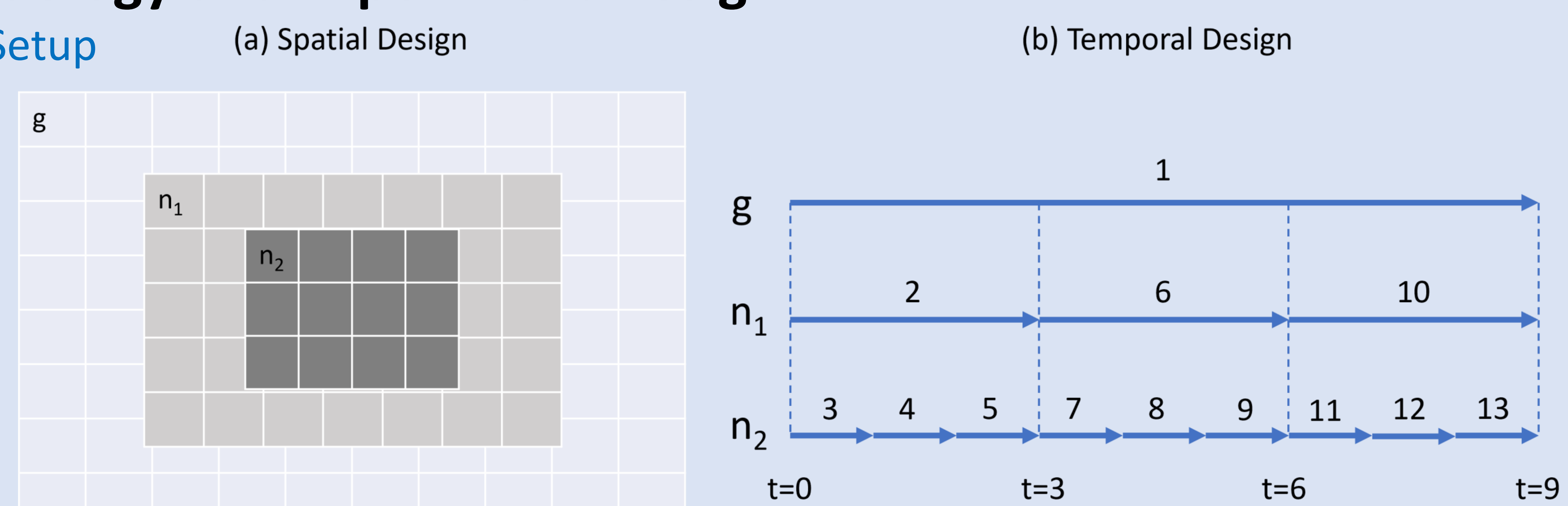
Abstract The Hunga Tonga-Hunga Ha'apai volcano eruption on January 15th, 2022, triggered rich atmospheric GW activities, which were later detected by various observations. We performed a model study of the GW propagation using TIEGCM, which is by far one of the first few I-T model studies of Tonga eruption. Different from the standard global uniform resolution setup, we implemented a high-resolution mesh inside a regional domain (nested grid) in addition to the global low-resolution mesh. By further nudging GW fields at lower boundaries from the high-resolution WACCM-X simulations, the nested-grid TIEGCM (TIEGCM-NG) successfully reproduced the wave propagation processes in the I-T system. From the simulation results, the critical parameter to simulate the GW propagation is the horizontal resolution. Inside the high-resolution nested region, GWs with horizontal wavelengths of ~400km and periods of 10-30min can propagate outward and upward and produce significant ionospheric disturbances close to observations, while outside at low-resolution region, only long-wavelength low-frequency waves survive.

Methodology and Experiment Design

Nesting Setup

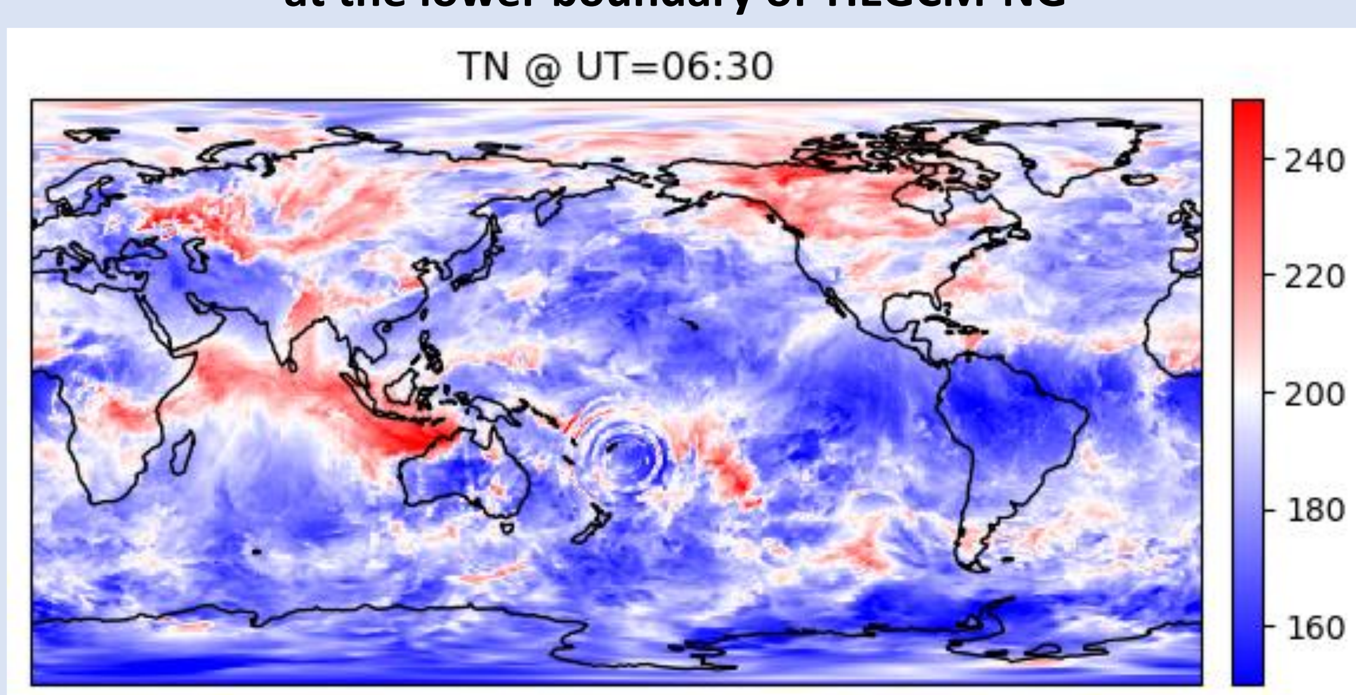


- Passing information across different levels through mapping of boundaries.
- Time integration starts at the coarsest level and then goes to the next nested level with the boundary condition obtained from the coarser level.

Nudge WACCM-X Fields

Gravity waves from a high-resolution WACCM-X SE simulation is used as the lower boundary of TIEGCM-NG. To further support the GW propagation, WACCM-X SE fields are nudged for 2 scale heights near the TIEGCM-NG lower boundary with a decreasing relaxation factor.

WACCM-X SE temperature extracted at the lower boundary of TIEGCM-NG



Control Experiments

1. Global uniform 2.5° resolution grid + WACCM-X SE nudging
2. Global uniform 2.5° resolution grid with 80°×80° nested region of 1° resolution + WACCM-X SE nudging

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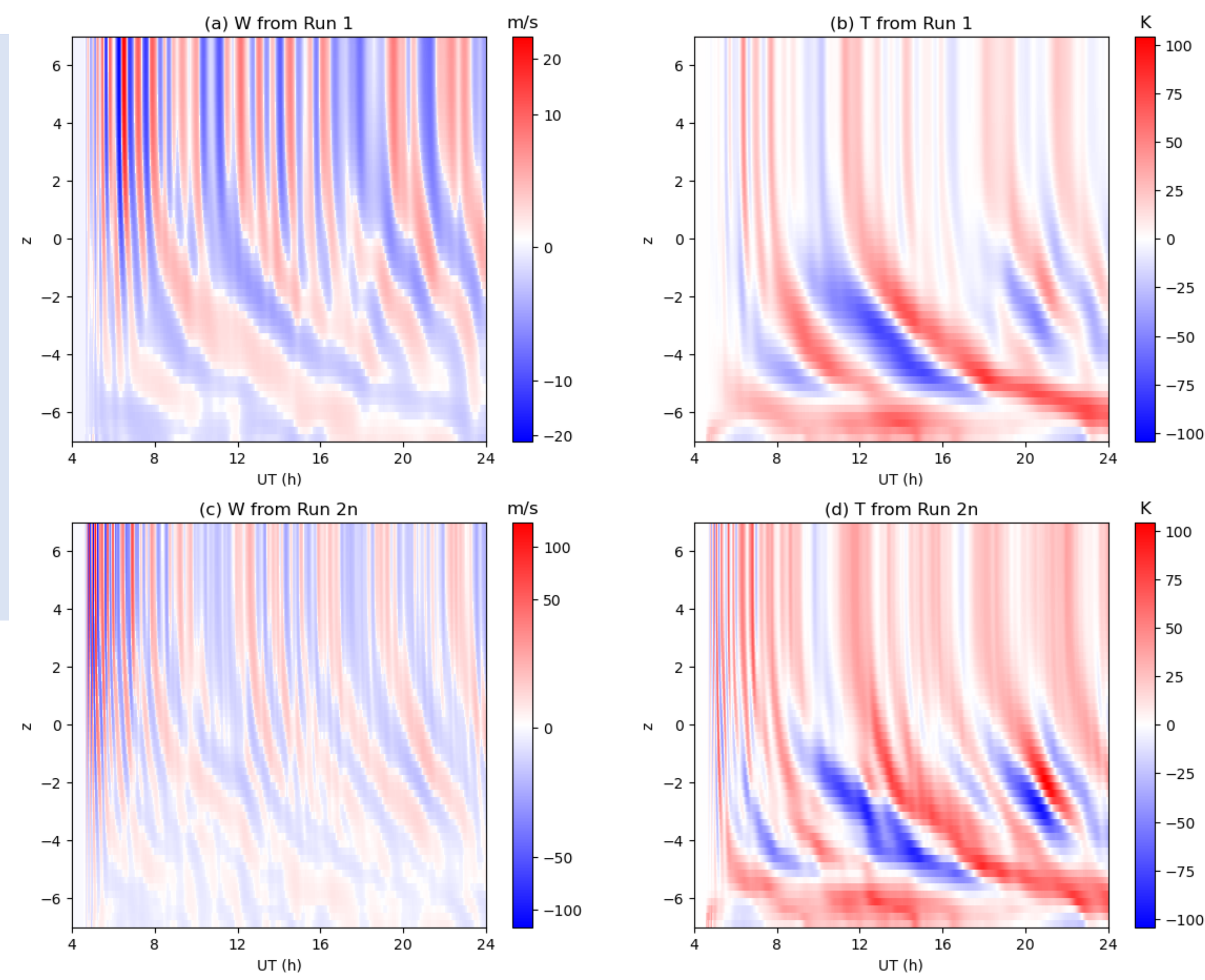
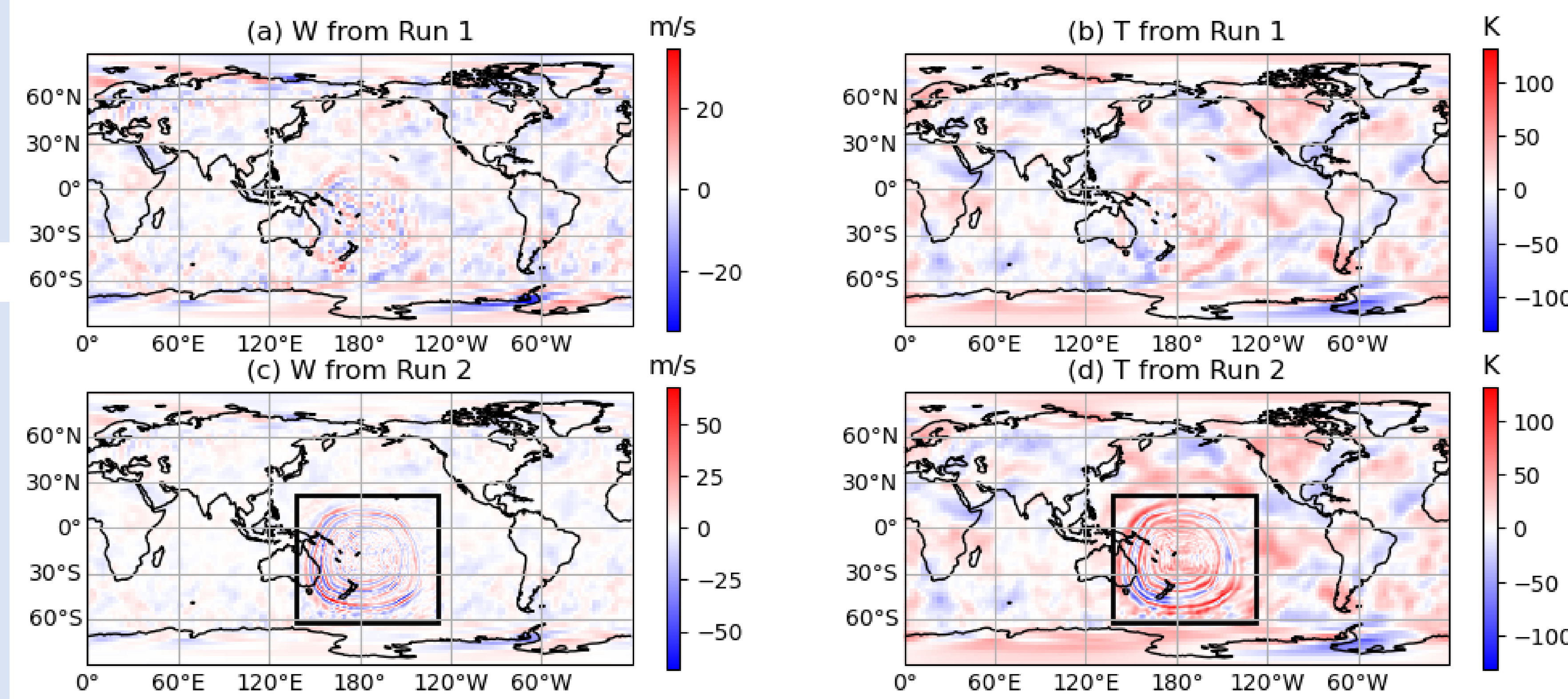
Model Results and Conclusions

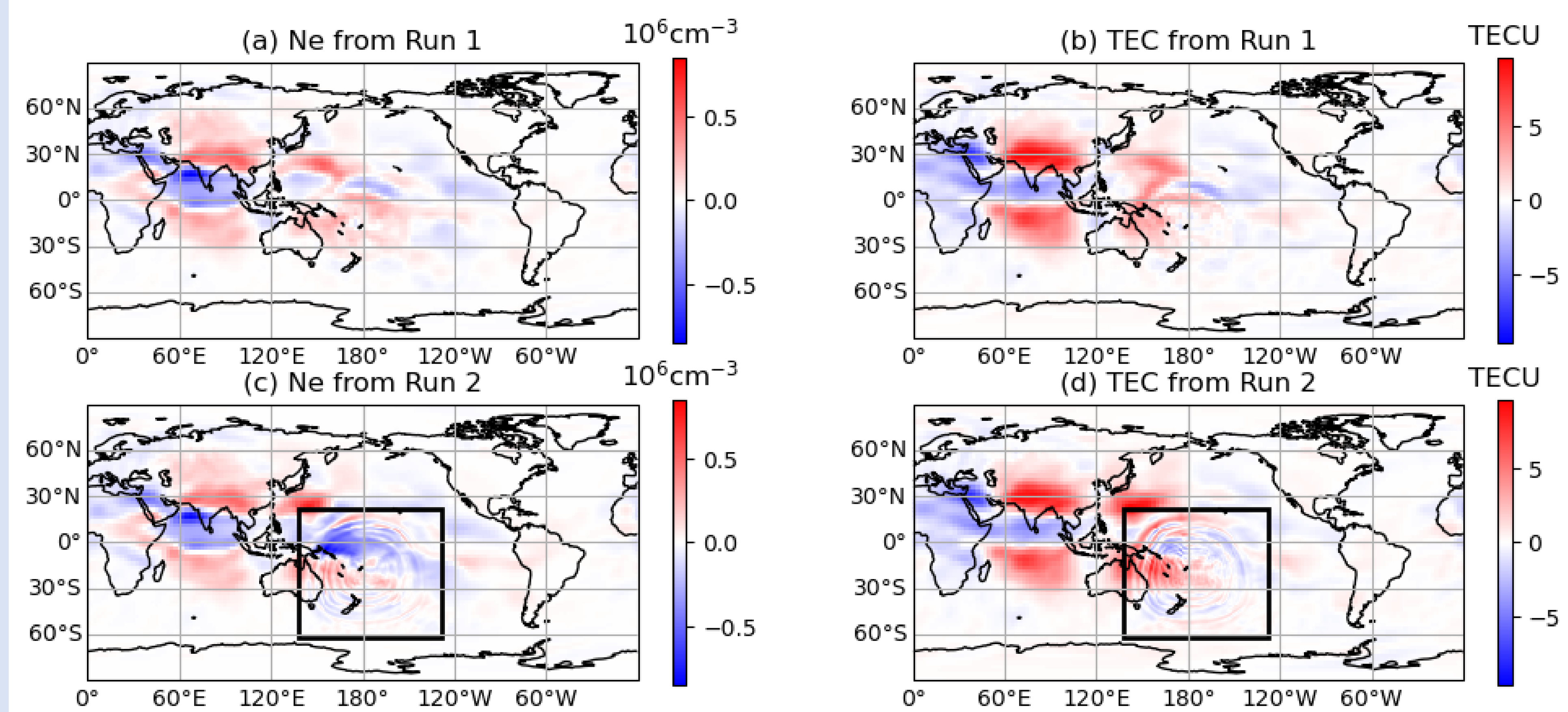
The wave signatures are present at high altitudes in both runs, but the wave amplitude of the vertical wind is significantly larger in Run 2n than in Run 1, over 100m/s compared to less than 30m/s. Above z=0, the vertical wavelengths become large due to increased diffusivity, while Run 2n tends to show higher-frequency perturbations (10-20min) than Run 1 (~40min).

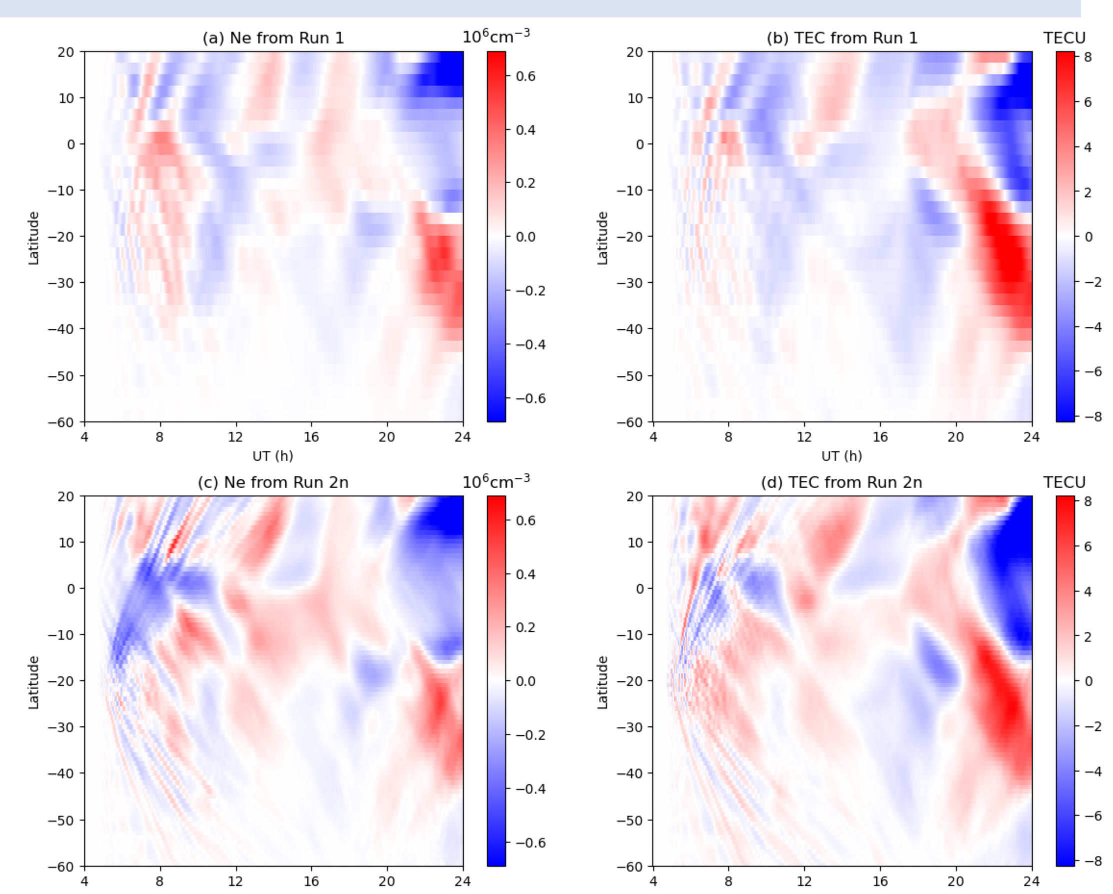




In Run 2, the wave components of short wavelengths (~4°≈400km) dominate the nested domain; while in Run 1, only waves with much longer wavelengths (~20°≈2000km) survive. Also, wave amplitudes in Run 2n are significantly larger than that in Run 1.

In Run 2, the shorter wavelengths (~400km) carry the most wave energy in the wave propagation; but in Run 1, due to the insufficient horizontal resolution (250km), the wave components below 500km are dissipative and will be eventually removed from the wave spectra.





- The large GW amplitudes cause significant ionospheric perturbations. The concentric ring structure is clear, on the order of 10^5cm^{-3} and 5TECU, at a similar level of GNSS TEC observations. In contrast, though electron density perturbation is present in Run 1, the wave pattern is on a much larger scale and the magnitude is smaller. In both runs, the wave patterns are clearer in the north direction than the south direction because the electron density peaks at a northern latitude.
- The speed of TID is estimated to be 300m/s, of a similar magnitude as TAD, which indicates that the source of TID is most likely the neutral variation resulting from volcano eruption. The estimated TID speed is in accordance with the slow mode of the near-field variations in TEC observations.