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Wave Perturbation – Global Ionosphere Thermosphere Model (WP-GITM)

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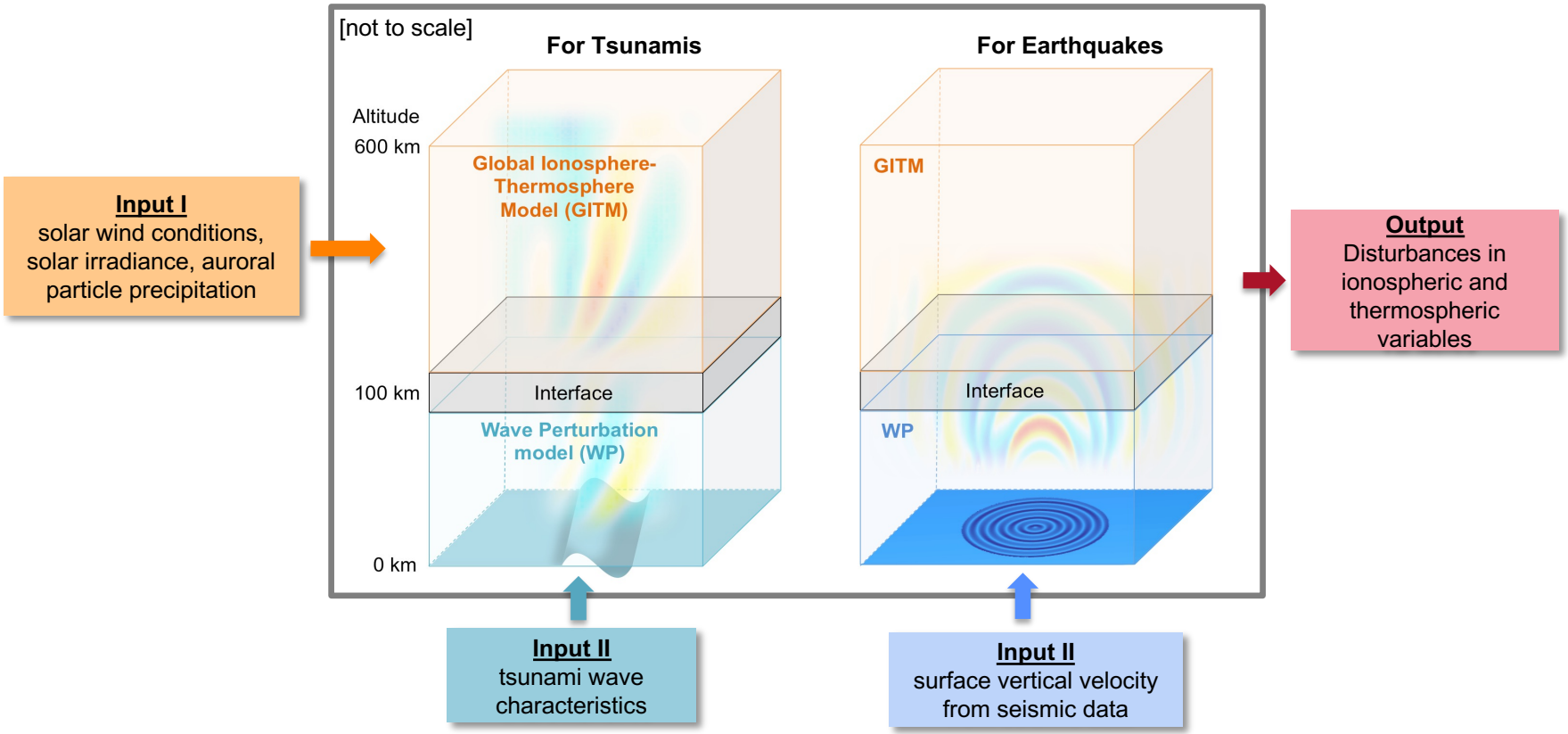
Introduction

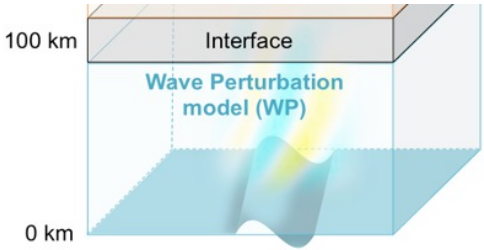
- Background:
  - Ocean surface displacement during tsunamis and ground shaking during earthquakes can excite upward-propagating acoustic-gravity waves in the neutral atmosphere.
  - As the acoustic-gravity waves propagating upward, their amplitudes grow with altitude to conserve energy due to the decreasing background air density.
  - When the acoustic-gravity waves reach the ionosphere, they induce ionospheric plasma disturbances [e.g., Davies & Baker, 1965; Calais & Minster, 1995; Artru et al., 2005; Liu et al., 2006; …].

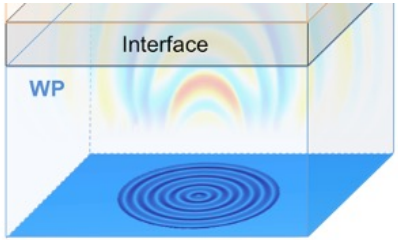
- Motivation:
  - The tsunami-ionosphere and earthquake-ionosphere coupling processes are not well understood.
  - As more observational data are being collected and analyzed, numerical models [e.g., Heki & Ping, 2005; Rolland et al., 2011, 2013; Zettergren et al., 2015, 2017; Inchin et al., 2020, 2021] have been developed to investigate the physics behind the tsunami/earthquake-ionospheric coupling. Most models either reply on empirical models of the neutral atmosphere and ionosphere or does not solve the ionospheric electrodynamics, transport, and chemistry self-consistently.
  - **To overcome these limitations, we have developed tsunami/earthquake-ionosphere coupling model Wave Perturbation-GITM (WP-GITM).**

WP-GITM Infrastructure



Wave Perturbation (WP) model



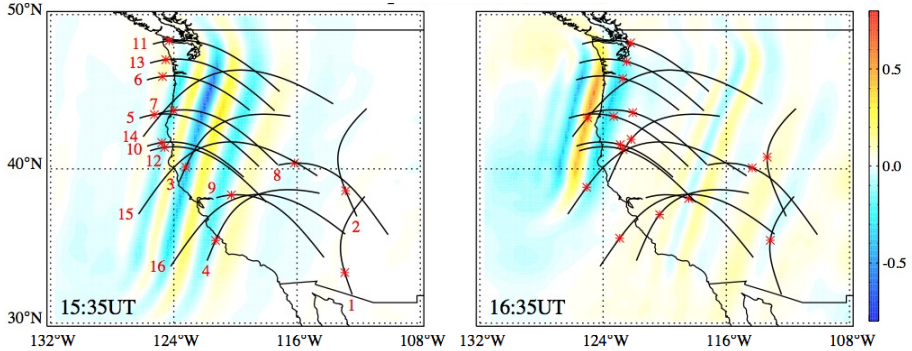


Key Features:

- Propagates acoustic-gravity waves from the ground to ~ 100 km altitude in the neutral atmosphere.
- Based on analytical solutions derived from polarization relations
- Input ground perturbations as plane waves (tsunami) or point sources (earthquake) or extended sources (earthquake)
- Neutral quantities perturbed: density, wind (longitudinal, latitudinal, and vertical), temperature
- A number of assumptions: isothermal atmosphere, no wave dissipation, etc.

WP-GITM for Tsunami-Ionosphere Coupling

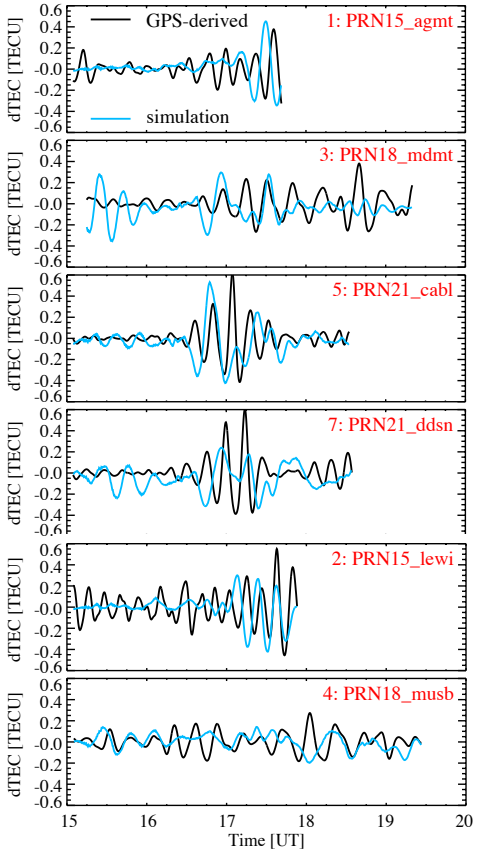
WP-GITM Simulated TEC Perturbations [TECU] for 11 March 2011 Tohoku-Oki Tsunami Arrival at the US West Coast



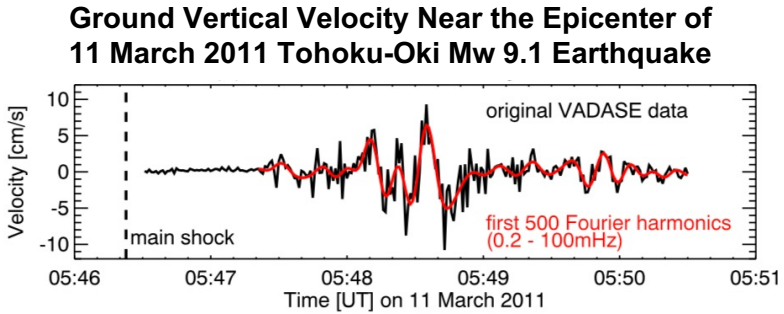
WP-GITM reproduces the observed tsunami-driven TEC perturbations reasonably well.

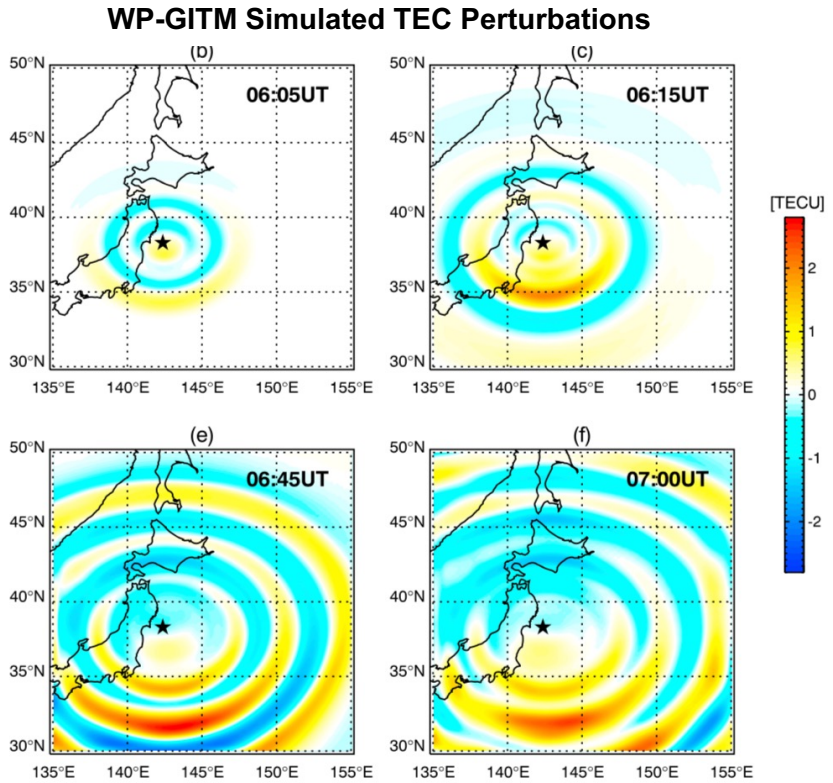
Meng, X., A. Komjathy, O. P. Verkhoglyadova, Y.-M. Yang, Y. Deng, and A. J. Mannucci (2015), A new physics-based modeling approach for tsunami-ionosphere coupling, Geophys. Res. Lett., 42, 4736–4744, doi:10.1002/2015GL064610.

Comparison with GPS-derived TEC Perturbations



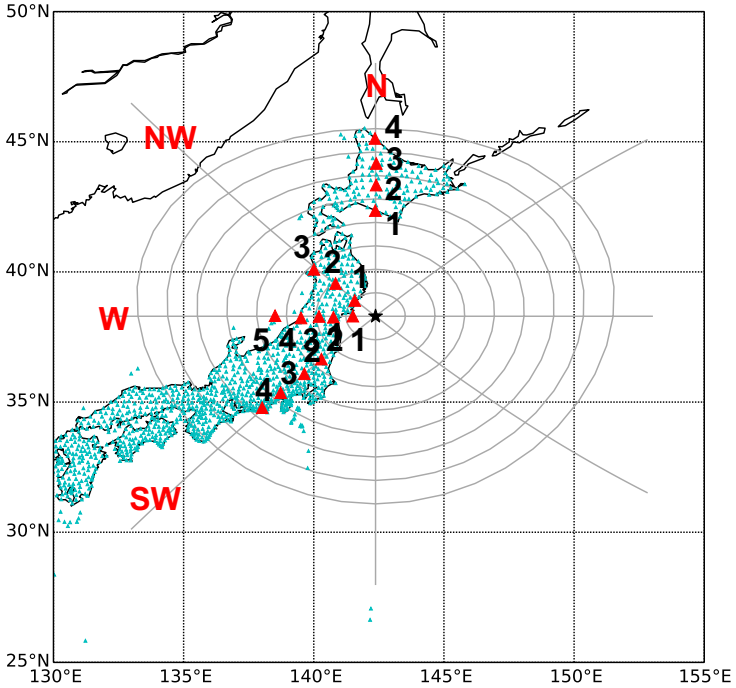
WP-GITM for Earthquake-Ionosphere Coupling: Point Source



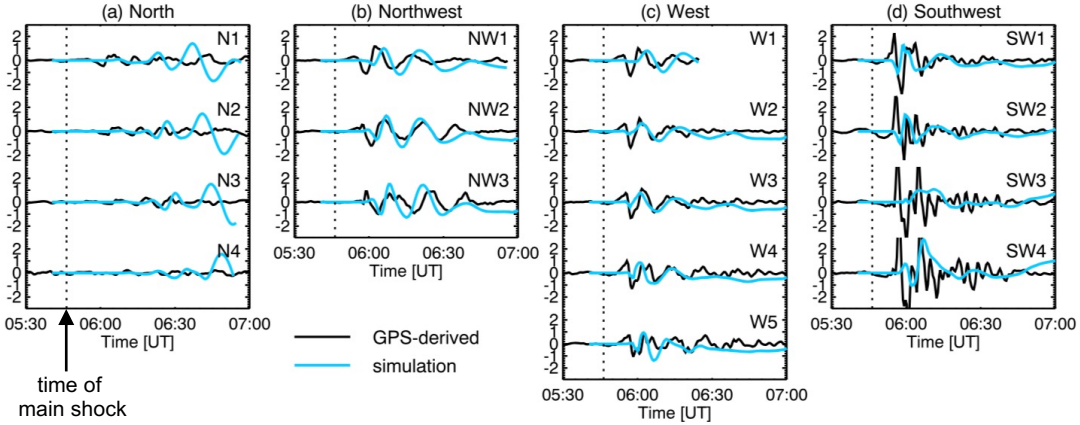


- WP-GITM with a point seismic source captures the epicentral crustal motion induced atmospheric acoustic-gravity waves.
- The ground motion is specified by seismic measurement at a location nearby the epicenter.

WP-GITM for Earthquake-Ionosphere Coupling: Point Source



WP-GITM-simulated Vs GPS-derived TEC Perturbations for 11 March 2011 Tohoku-Oki Mw 9.1 Earthquake



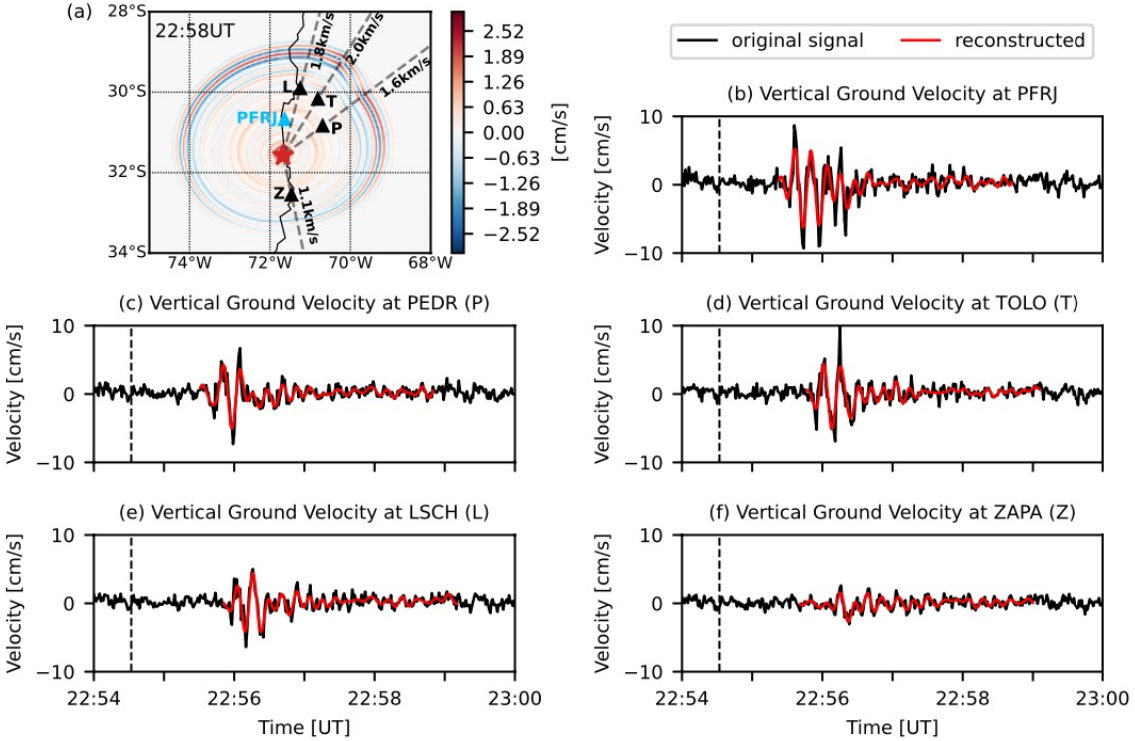
Meng, X., Verkhoglyadova, O. P., Komjathy, A., Savastano, G., & Mannucci, A. J. (2018). Physics-based modeling of earthquake-induced ionospheric disturbances. Journal of Geophysical Research: Space Physics, 123, 8021–8038. https://doi.org/10.1029/2018JA025253

WP-GITM for Earthquake-Ionosphere Coupling: Extended Source

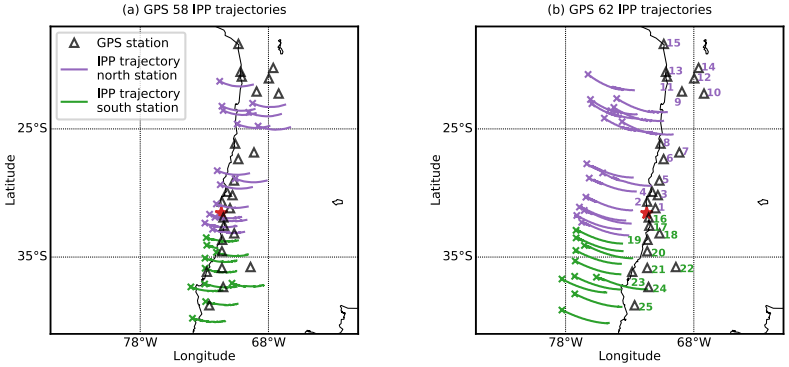
- WP-GITM with extended seismic source captures acoustic-gravity waves induced by both the epicentral crustal motion and the propagating seismic waves.
- The ground motion is specified by seismic measurement at multiple locations surrounding the epicenter.

Meng, X., Ravanelli, M., Komjathy, A., & Verkhoglyadova, O. P. (2022). On the north-south asymmetry of co-seismic ionospheric disturbances during the 16 September 2015 Illapel M8.3 earthquake. Geophysical Research Letters, 49, e2022GL098090.

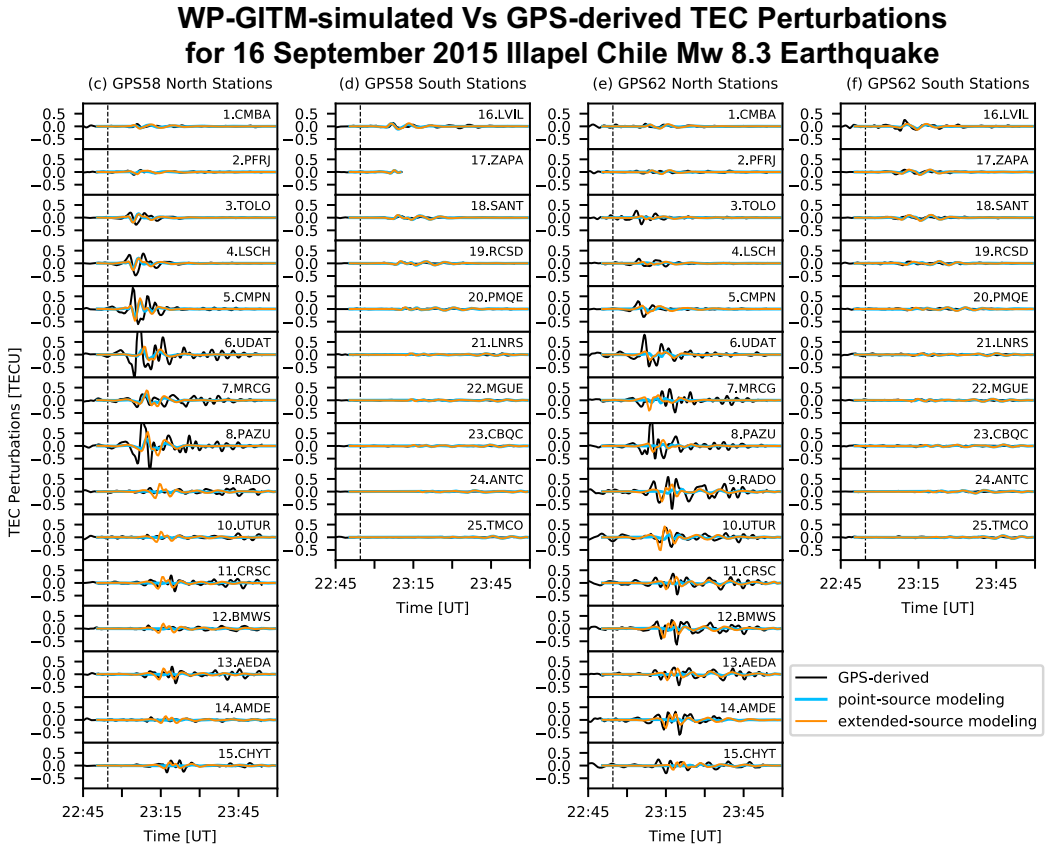
Ground Motion During 16 September 2015 Illapel Chile Mw 8.3 Earthquake



WP-GITM for Earthquake-Ionosphere Coupling: Extended Source



- The extended-source modeling generates distinctively larger TEC perturbations than the point-source modeling does, leading to a better agreement with the GPS-derived TEC perturbations.



Summary

- WP-GITM is a physics-based tsunami/earthquake-ionosphere coupling model and has been successfully applied to simulate the travelling ionospheric disturbances during several tsunami/earthquake events.
- WP-GITM is open source and available at the GITM repository: https://github.com/aaronjridley/GITM.
- WP-GITM is being actively maintained and developed.
- For questions and/or collaborations, please contact xing.meng@jpl.nasa.gov

Acknowledgement

- Prof. Aaron Ridley at the University of Michigan for developing and sharing GITM.
- NASA Headquarters, NASA ROSES 2011 GNSS, 2015 ESI, 2016 LWS, and 2018 ESI programs.
- Seismic data: special thanks to the VADASE Team at the University of Rome "La Sapienza," Italy for providing the ground motion data.
- Solar and interplanetary data: J. H. King and N. Papatashvilli at AdnetSystems, NASA GSFC and CDAWeb provided the OMNI data (http://cdaweb.gsfc.nasa.gov/istp_public/). The F10.7 and hemispheric power data were obtained from NOAA ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP/ and (legacy-www.swpc.noaa.gov/ftpmenu/lists/hpi.html)
- The computing resources were provided by the JPL high-performance computing and the NASA High-End Computing Program through the NASA Advanced Supercomputing Division at Ames Research Center.

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