Supporting Information for "Detection of Traveling Ionospheric Disturbances in Near-Real Time Mw 7.8 and Mw 7.5 Kahramanmaraş Earthquake Sequence"

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Contents of this file

Introduction

The supporting information provided consists of Figures and Tables. The data was provided by Léo Martire from the Jet Propulsion Laboratory (JPL) in April, 2023 and is sourced from JPL's GNSS Upper Atmospheric Real-time Disaster Information and Alert Network (GUARDIAN) (Martire et al., 2022). Phase synchrony processing was completed in Python with the SciPy scipy.signal library.

References

Liaw, R., Liang, E., Nishihara, R., Moritz, P., Gonzalez, J. E., & Stoica, I. (2018). Tune: A research platform for distributed model selection and training. *arXiv preprint arXiv:1807.05118*.

Martire, L., Krishnamoorthy, S., Vergados, P., Romans, L. J., Szilágyi, B., Meng, X., ... Bar-Sever, Y. E. (2022). The guardian system-a gnss upper atmospheric real-time disaster information and alert network. *GPS Solutions*, *27*(1), 1521-1886. Retrieved from `https://doi.org/10.1007/s10291-022-01365-6` doi: 10.1007/s10291-022-01365-6

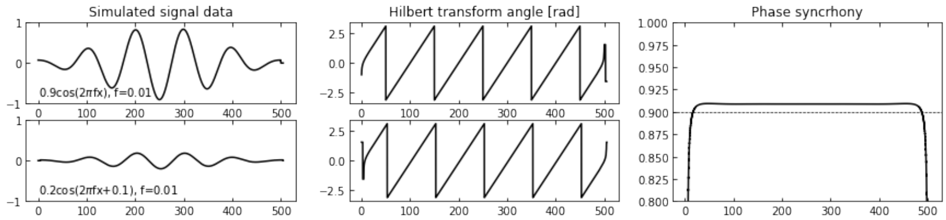

Fig. S1. Example on simulated data of the phase synchrony measurement. The left plots show two simulated waves with the same frequency, but different amplitude and phase shift. The center plot shows their respective Hilbert transform angles. The right plot shows their phase synchrony measurement. In this example the phase synchrony has exceeded the 0.9 threshold, therefore these two signals would pass the phase synchrony filter. A disparity in frequency will reduce the phase synchrony measure.

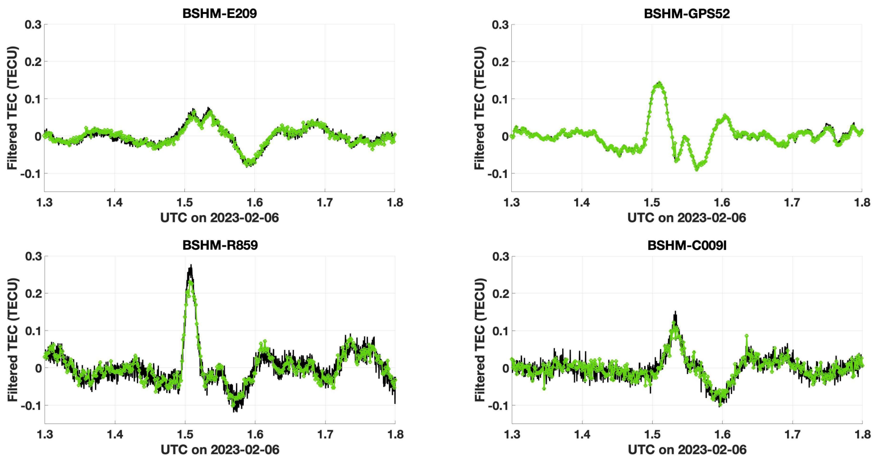

Fig. S2. Comparing GUARDIAN real-time dTEC data in green vs post-processed dTEC data in black for station BSHM between 01:18 to 01:48 02-06-2023 UTC, we see that the GUARDIAN real-time data is in agreement with the post-processed. We also note the small ionospheric disturbance shown in these plots, beginning at approximately 01:30 UTC, 13 minutes after the first M_w 7.8 earthquake event, with the largest amplitude just under 0.3 TECU.

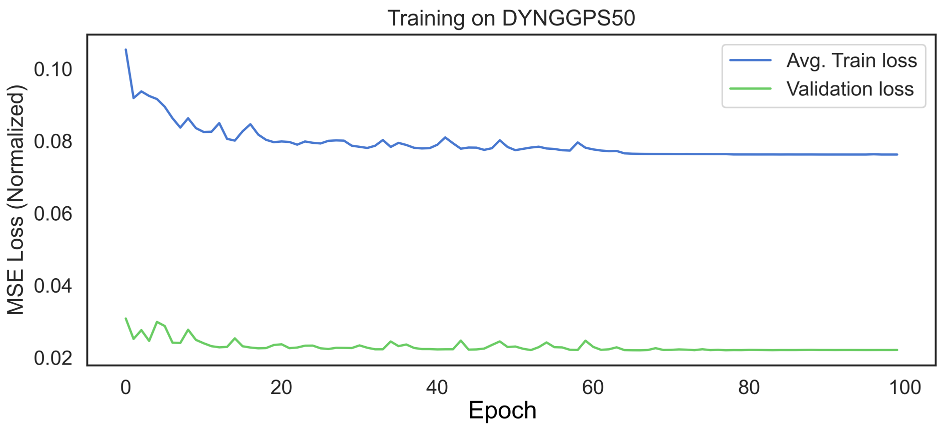

Fig. S3. Training and validation loss, mean square error, over training epoch for the LSTM model for station DYNG and satellite GPS SVN 50.

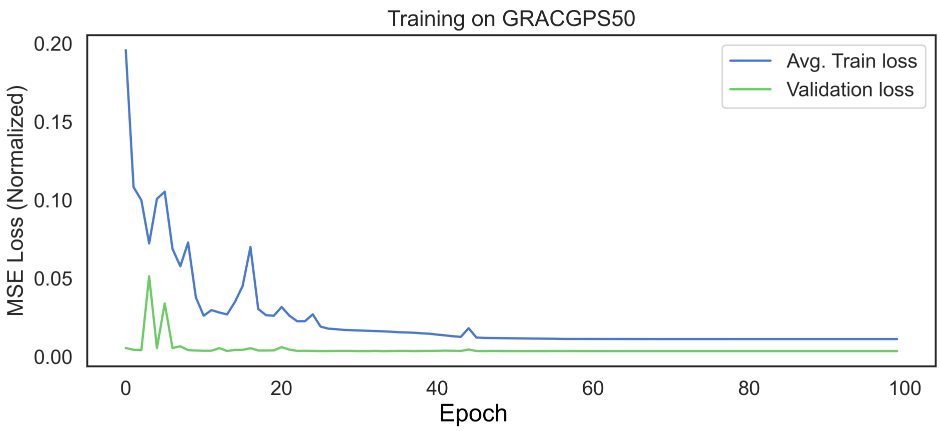

Fig. S4. Training and validation loss, mean square error, over training epoch for the LSTM model for station GRAC and satellite GPS SVN 50.

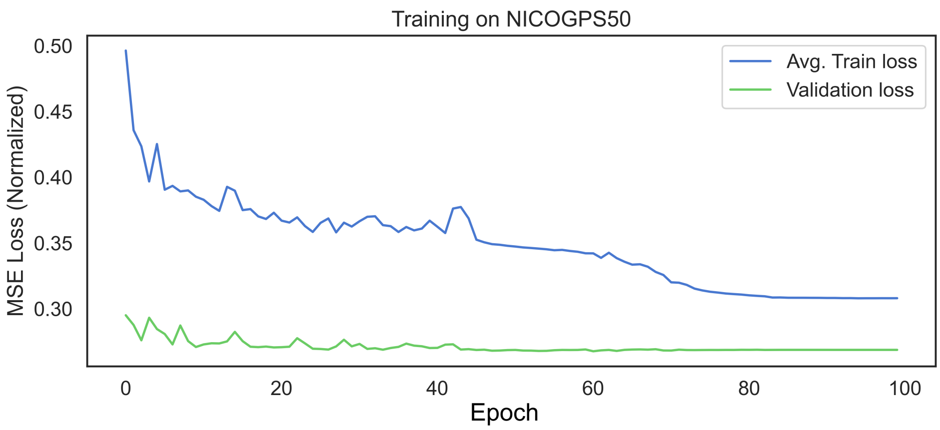

Fig. S5. Training and validation loss, mean square error, over training epoch for the LSTM model for station NICO and satellite GPS SVN 50.

Table S 1. Three Hub station and satellite pairs for LSTM training of three models for use across all test data

Training Station	Training Satellite	Test Stations	Test Satellites
NICO	GPS50	BSHM, NICO	All constellations
DYNG	GPS50	DYNG, MATZ	All constellations
GRAC	GPS50	GRAC, MADR, TLSE	All constellations

Table S 2. Layers and hidden unit Ray Tune (Liaw et al., 2018) results for LSTM hyperparameter tuning based on minimizing the loss function, mean square error (MSE), on the validation data. Batch size and learning rate are held constant at 128 and 0.0002 respectively. Learning rate will be optimized using the ReduceLROnPlateau optimizer, part of the PyTorch library. The three lowest MSE loss values per station are shown in bold text. The lowest MSE loss value is highlighted with an asterisk.

Station	Satellite	LSTM layers	LSTM hidden units	Normalized MSE (loss) [TECU]	Ray Tune iteration
DYNG	GPS50	1	64	0.0220464	2
DYNG	GPS50	1	128	0.0213898	8
DYNG	**GPS50**	**1**	**256**	**0.0204046***	10
DYNG	**GPS50**	**1**	**512**	**0.0206808**	10
DYNG	GPS50	2	64	0.0227238	2
DYNG	GPS50	2	128	0.0263033	1
DYNG	**GPS50**	**2**	**256**	**0.0208433**	10
DYNG	GPS50	2	512	0.0270466	1
DYNG	GPS50	4	64	0.0239675	1
DYNG	GPS50	4	128	0.0256491	2
DYNG	GPS50	4	256	0.0225462	2
DYNG	GPS50	4	512	0.0230659	2
GRAC	**GPS50**	**1**	**64**	**0.00340245**	10
GRAC	**GPS50**	**1**	**128**	**0.00335272**	10
GRAC	GPS50	1	256	0.00343302	1
GRAC	GPS50	1	512	0.00498964	10
GRAC	GPS50	2	64	0.00361435	2
GRAC	GPS50	2	128	0.00630827	1
GRAC	**GPS50**	**2**	**256**	**0.00326762***	10
GRAC	GPS50	2	512	0.00398823	10
GRAC	GPS50	4	64	0.0047045	1
GRAC	GPS50	4	128	0.00518423	2
GRAC	GPS50	4	256	0.00475413	1
GRAC	GPS50	4	512	0.00403785	1
NICO	GPS50	1	64	0.261729	1
NICO	**GPS50**	**1**	**128**	**0.242811**	10
NICO	GPS50	1	256	0.26278	1
NICO	GPS50	1	512	0.244278	10
NICO	**GPS50**	**2**	**64**	**0.239978***	10
NICO	GPS50	2	128	0.26295	1
NICO	GPS50	2	256	0.245555	4
NICO	GPS50	2	512	0.244315	10
NICO	GPS50	4	64	0.245265	8
NICO	GPS50	4	128	0.256232	2
NICO	**GPS50**	**4**	**256**	**0.241563**	10
NICO	GPS50	4	512	0.251934	2

Table S 3. Batch size Ray Tune (Liaw et al., 2018) results for LSTM hyperparameter tuning based on minimizing the loss function, mean square error (MSE), on the validation data. The top result from tuning for LSTM layers and hidden units are tested against 4 different batch size options. The lowest MSE loss value is highlighted with an asterisk.

Model	Batch size	Normalized MSE (loss) [TECU]	Ray Tune iteration
DYNG 1 layer 256 hidden units	**64**	**0.0204046***	10
DYNG 1 layer 256 hidden units	128	0.0212168	10
DYNG 1 layer 256 hidden units	256	0.0216469	2
DYNG 1 layer 256 hidden units	512	0.0232461	1
GRAC 2 layer 256 hidden units	64	0.00312246	10
GRAC 2 layer 256 hidden units	128	0.00387824	4
GRAC 2 layer 256 hidden units	**256**	**0.00312077***	10
GRAC 2 layer 256 hidden units	512	0.00334956	10
NICO 2 layer 64 hidden units	64	0.25183	8
NICO 2 layer 64 hidden units	128	0.242234	10
NICO 2 layer 64 hidden units	**256**	**0.240971***	10
NICO 2 layer 64 hidden units	512	0.253256	4