Evaluating a Long Short-Term Memory (LSTM) network for GNSS high-rate time series analysis

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We present a neural network optimized for producing GNSS displacements to explore machine learning capabilities in forecasting ground motions for earthquake early warning and to improve our understanding of ground motion in real-time. For earthquake early warning, displacements at GNSS receivers are currently being incorporated into the ShakeAlert system, but displacements in real-time are problematic due to issues with phase ambiguity fixing, cycle slips, and loss of satellite lock as well as dilution of precision from satellite network geometry. These errors can lead to anomalous motions of up to a meter. Raw GNSS observations for velocities can utilize orbits (relative positions) and remove uncertainties caused by path errors, leading to a higher precision observation than the displacements. In general, peak ground velocity is diagnostic of earthquake damage and displacement is diagnostic of total moment release, so obtaining these observations at the highest fidelity is crucial for rapid earthquake source estimation. Since processing raw GNSS velocities gives a higher precision observation, we aim to derive displacements from velocities using a machine learning approach. We use a Long Short-Term Memory (LSTM) network for time series prediction of the GNSS displacements. The input variables for the model are three-component GNSS velocities derived from the SNIVEL software package, with the possibility of including signal to noise and phase observables, and the output variable is the GNSS displacement time series. The GNSS displacement is validated against the displacements computed with the precise point positioning code GipsyX. With over 2250 1-Hz observations from 82 different events ranging from M4.9 to M9, we have ample data to train, validate, and test the network on. We train several instances on random selection of train/validation/test split for redundancy. By computing the GNSS displacement from GNSS velocities, we produce a higher precision observation, a low-cost method for monitoring deformation without the traditionally high overhead associated with real-time GNSS processing, and the possibility of direct onboard receiver transmission of displacements.

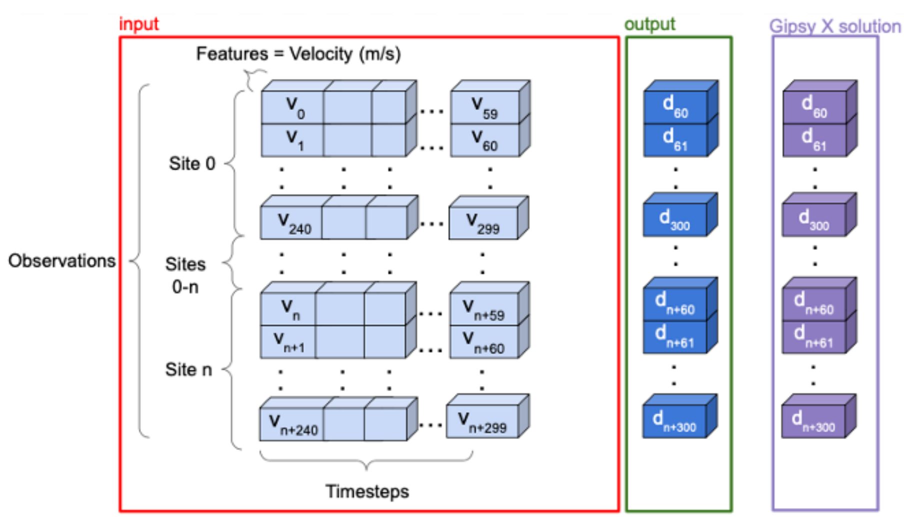

Figure 1: Schematic diagram of input/output architecture per observation where the inputs are the velocity time series and the output is the corresponding predicted displacement time series, compared with the actual post-processed GipsyX solution to assess accuracy.