Investigating Slow Slip: Development of an Adjoint-Based, Time-Dependent Inversion Scheme

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Investigating the nature of slow slip deep beneath the earth in different parts of the world is beset with multiple uncertainties, for example, noisy and incomplete data, sparse spatial and temporal data sampling with regards to various geodetic datasets, flawed parameterization, and incomplete physics and geological description of the earth processes involved. The same sources for error hold for any study of short-term, active tectonics problems. As a part of IOM (Inverse Ocean Modeling) initiative, a variational data assimilation scheme developed for ocean modeling, we added tools for active tectonic problems as one of its new client. The IOM requires the client model to provide a tangent-linear (TL) of the non-linear dynamic model and an adjoint (ADJ) of the TL in a gradient-based search algorithm. Our client model is GeoFEST (Geophysical Finite Element Simulation Tool), a 3D visco-elastic finite element forward model that is also a part of QuakeSim, a NASA Earth Science Enterprise Project simulation toolbox. GeoFEST is suited for modeling broad class of active tectonics problems, including slow slip. As a client for IOM, we developed TL and ADJ for GeoFEST. The IOM is a modular implementation of a variational data assimilation scheme that allows for errors in data, the model, adjoint forcing, and initial and boundary conditions. Here, we present this approach as an adjoint-based, time-dependent inversion for slow slip analysis using both IOM and GeoFEST together. Our adjoint-based, time-dependent inversion scheme here for slow earthquakes is one possible initial application from a broad-based tools developed by us for variational data assimilation in active tectonics.

We map the spatial sub-surface forcing variations, both in strike-slip and dip-slip in a localized region, and the time history for slow slip using CGPS (Continuous GPS) data. We explore the issue of resolution in inverting for forcing causing the slow slip events and optimal array design using simple models and synthetic CGPS datasets. Some specific tests presented are: 1) Resolvability of the depth of the localization of slow slip, and accurate time detection in presence of different signal-to-noise ratio, and other limitations in the data. 2) Can our technique resolve multiple sources for slow slip within the regional fault or faults from the GPS data? 3) What array design, precision, and quality of CGPS stations is needed to accurately observe and analyze different slow slips? To contribute toward future development of new techniques, our software tools could be used to assist in the design of the ongoing and future observatory experiments in different tectonic settings, such as EARTHSCOPE, HiNET, etc., and also possibly map and predict the migratory pattern of the slow slips in real data.