A Bayesian Approach for Inter-plate Coupling Models in Subduction Zones

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1. Introduction
Our primary goal is to characterize the extent of apparent plate coupling on the subduction zone megathrust with the eventual goal of understanding variations in fault zone rheology. In this initial study, in order to demonstrate the basic approach, we adopt a simple kinematic backslip model (Savage, 1983). This study differs from most (but not all — e.g., see Segall, 2002) analogous studies in that we use a Bayesian approach wherein we ask for a single optimum model, rather than for a posteriory estimates of the parameters. This approach also allows us to explicitly define physically plausible a priori uncertainty on data uncertainties and model parameters, as opposed to assuming everything follows Gaussian statistics.

The Bayesian approach inherently depends on an ability to routinely compute millions of forward models that are consistent with a priori constraints and available geodetic measurements. Such computations are now viable with available computational resources. We apply this methodology to invert for a series of synthetic cases motivated by the desire to understand the state of inter-seismic coupling in geodetic observations. Specifically, we implement a Markov Chain Monte Carlo sampler. The inversion is a Bayesian approach wherein we ask not for a single optimum model, but rather for a posteriori estimates of the parameters along with the Euler pole of the relative plate motion. This parameterization of the Euler pole describing the relative convergence of the plates is important to always look to the a-priori (no data) results of the inversion without constraints and any other constraints, the a-priori probability is not constant over the plate interface (see discussion below, the a-priori estimates of the 100% apparent coupling distribution associated with these earthquakes. We show in the next figure the 100% apparent coupling probabilities obtained as a result of the inversion using Kendrick et Al. 2001 dataset.

7. Inversion with GPS data
Using the GPS data from Kendrick et Al (2001). The GPS velocities are an integrated interseismic velocity field for the Central Andes and is obtained from repeated surveys spanning from January 1999 to March 2001, just before the occurrence of the 2001 Arequipa Earthquake in southern Peru. This data is processed from several GPS campaigns (CAP and SNAP projects) with observed GPS velocities extracted from one GPS station to another, from 2 years to a maximum span of 7 years. This heterogeneity in time span is well reflected in the uncertainties of the Central Andes interseismic velocity fields.

Since this dataset was obtained prior the occurrence of 2 big earthquakes (Arequipa 2001, Piocco 2007, both in Peru) we can infer possible causal relationships between the probability of 100% apparent coupling along the plate interface and the co-seismic slip distribution associated with these earthquakes.

We show in the next figure the 100% apparent coupling probabilities obtained as a result of the inversion using Kendrick et Al. 2001 dataset.

8. Discussion
The aim of this study was to demonstrate the feasibility of using GPS velocity data to estimate the state of coupling on the plate interface. Our results show that the GPS velocities can be used to constrain the state of coupling along the plate interface.

In our case, the entire coupled zone must lie between seafloor (trench) depth and a maximum depth. In the absence of data and any other constraints, the a-priori PDF for each knot would be uniform, white = uncoupled) and the second one is a “hand-made” model which is 100% coupled from the trench to 50km depth, and then has a linear transition to be uncoupled below 50km depth. Note that the prediction both models explain equally well the dataset, suggesting big uncertainties in the estimated model parameters. A way to approach this problem is to represent the whole family of solutions by like we did with the coupling probability maps, or look for the mean, median, etc. The next 2 figures show the percentage of the best suited sampled models, which we will do in the near future.

Note the importance of sampling the whole range of possible values for the model parameters, i.e., to properly sample their uncertainties. In the next 2 figures we show 2 possible cases to be considered as “good solutions” of the posed problem. The first one is the Maximum Likelihood model obtained from the inversion of the whole GPS dataset (trench = coupled, white = uncoupled) and the second one is a “hand-made” model which is 100% coupled from the trench to 50km depth, and then has a linear transition to be uncoupled below 50km depth. Note that the prediction both models explain equally well the dataset, suggesting big uncertainties in the estimated model parameters. A way to approach this problem is to represent the whole family of solutions by like we did with the coupling probability maps, or look for the mean, median, etc. The next 2 figures show the percentage of the best suited sampled models, which we will do in the near future.