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Estimating Fault Slip Rates and Deformation at Complex Strike-Slip Plate Boundaries

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Modeling GPS velocity fields in seismically active regions worldwide indicates deformation can be efficiently and usefully described as relative motions among elastic, fault-bounded crustal blocks. These models are providing hundreds of new decadal fault slip rate estimates that can be compared with the (much smaller) independent Holocene (<10 ka) to late Quaternary (<125 ka) rates obtained by geological methods. Updated comparisons show general agreement but a subset of apparently significant outliers. Some of these outliers have been discussed previously and attributed either to a temporal change in slip rate or systematic error in one of the estimates. Here we focus particularly on recent GPS and geologic results from southern California and discuss criteria for assessing the differing rates.

In southern California (and elsewhere), subjective choices of block geometry are unavoidable and introduce significant uncertainties in model formulation and in the resultant GPS fault slip rate estimates. To facilitate comparison between GPS and geologic results in southern California we use the SCEC Community Fault Model (CFM) and geologic slip rates tabulated in the 2008 Uniform California Earthquake Rupture Forecast (UCERF2) report as starting points for identifying the most important faults and specifying the block geometry. We then apply this geometry in an inversion of the SCEC Crustal Motion Model (CMM4) GPS velocity field to estimate block motions and intra-block fault slip rates and compare our results with previous work.

Here we use 4 criteria to evaluate GPS/geologic slip rate differences. First: Is there even-handed evaluation of random and systematic errors? ‘Random error’ is sometimes subjectively estimated and its statistical properties are unknown or idealized. Differences between ∼equally likely block models introduces a systematic error into GPS rate estimates that is difficult to assess and seldom discussed. Difficulties in constraining the true initiation date of offset of geomorphic markers by faulting can introduce uncertainties much larger than quoted random errors. Second: Are rate estimates obtained by more than one geodetic or geologic method? For example, agreement between GPS and InSAR slip rate estimates on the Altyn Tagh and Haiyuan faults of Tibet make the geodetic estimates more reliable. Similarly, dating of multiple offset markers of differing age across these faults supports the consistency of the geologic rate estimates. Third: Is proposed rate change mechanism consistent with examples of changes in style and rate of deformation preserved in the geologic record? For example, temporal evolution of the multi-stranded San Andreas system during the past 5-10 Ma (Powell & Weldon 1992; Graymer et al. 2002) indicates activation and deactivation of different faults within the system accompanied by consequent changes in fault slip rate and/or creation of new crustal blocks. Fourth: Is there a quantitative analysis of mechanism proposed to explain rate change? Candidate mechanisms meriting quantitative analysis include (1) changes in frictional resistance of faults and creation of new fractures due to progressive rotation of irregularly shaped blocks, (2) episodic subduction of buoyant lithosphere, and (3) changes in the plate geometry (and so the forces acting) at major continent/ocean plate boundaries (e.g. Late Cenozoic migration of Mendocino triple junction off California).

In most parts of southern California—for example, north of the San Andreas Big Bend and SE of Los Angeles–our block geometry closely resembles that assumed in previous studies (McCaffrey 2005 JGR; Meade & Hager 2005 JGR; Becker et al. 2005 GJI). In these regions GPS slip rates can be reliably estimated and values for individual faults generally agree from one study to another and are also consistent with geologic estimates. However, there is no consensus on block geometry in the Transverse Ranges, Los Angeles Basin and Central Mojave Desert, where CFM faults are densely distributed, UCERF2 slip rates on several faults are comparable, and a simple block description may not be useful. It is notable that a number of documented disagreements between GPS and

geologic slip rates occur on faults in these complex deforming zones (e.g. central Garlock fault, Eastern California Shear Zone, Big Bend San Andreas), in part reflecting the substantial epistemic uncertainty in GPS rate estimates for these faults.