**Appendix C:** Estimation of fault slip rates in the conterminous western United States with statistical and kinematic finite-element programs

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## Overview

The estimated fault slip rates obtained from models NSHM-WUS_2013001 and NSHM-WUS_2013002 (which are referred to as "the Bird model" or "the NeoKinema model" in some parts of the NSHM2014 report) were obtained through 3 sequential processing steps:

1. Statistical modeling of geologic offset-rates with program Slippery.
   Direct evidence from dated offset features on each fault, and/or indirect evidence from dated offset features on other faults of the same type in the same tectonic province, are combined to obtain the "pure-geologic" probability density function (PDF) for each component of offset-rate on each fault. Additional constraints such as geometric compatibility, plate tectonics, geodesy, and stress directions are not used in this phase of the study.
2. Combined geologic/geophysical inversion for offset rates with program NeoKinema.
   The "pure-geologic" offset rates from the previous step (with their uncertainties) are combined and balanced against additional constraints from GPS geodesy, plate tectonics, geometric compatibility (*i.e.*, continuum stiffness), and principal stress directions. A kinematic finite-element solution with program NeoKinema provides trace-averaged mean offset-rates for each component of offset on each fault. A simple geometric post-processing step combines these offset-rate components with the model fault dips to obtain the model predictions for rake and slip-rate of each fault.
3. Manual adjustments to some slip-rates in California.
   Following intensive review of model predictions by local geologic experts, some model predictions were adjusted to become (barely) consistent with additional information which had not been used in the previous modeling steps.

Each step is described further in a corresponding section of this Appendix C, and most fully in the previously-published papers cited below. The final model pair is also analyzed and displayed in the UCERF3 time-independent-model report (now in preparation), both in its main text and in its own Appendix C on Deformation Models.

All programs (both source codes and executables), input datasets, output datasets, post-processed reports, and graphical map files associated with this work are available online at the URL of:
http://peterbird.name/oldFTP/NeoKinema/Orogens/WUS_for_UCERF3_and_NSHM2014/
Because length-limits on the present Appendix do not permit the inclusion of figures, readers are particularly invited to look into the folders named 3_graphics_files along each model branch.

## 1. Statistical modeling of geologic offset-rates with program Slippery

*Bird* [2007] presented definitions, assumptions, equations, and a computational algorithm for automated, objective assignment of probability density functions (PDFs) to the scalar, positive offset-rate component(s) of any active fault. These methods were translated into Fortran 90 source code in program Slippery.f90, and compiled into executable Slippery.exe (for the 32-bit Windows operating system). This program can be used to analyze a single fault, but is more powerful when used to jointly (and iteratively) analyze all the active faults in a single tectonic province, such as California, or the conterminous western United States.

Omitting details and equations, the essential steps are as follows: Fault slip-rate is separated into strike-slip (*R* = right-lateral or *L* = left-lateral) components and dip-slip components. The dip-slip components can be expressed either by relative-vertical (throw) rates (*N* = Normal or *T* = Thrust), or by trace-perpendicular relative-horizontal (trace-perpendicular heave) rates (*D* = Detachment for opening, or *P* = thrust Plate for convergence). The following combinations expressing oblique slip are permitted: *LN, LT, LD, LP, RN, RT, RD, & RP*; such combinations are analyzed as two independent processes although they refer to the same fault. Then, each offset distance and its uncertainty (or inferred uncertainty, if not explicitly stated by the original author) is converted to a PDF for the amount of offset. Different functional forms are used for offset distances that are best-estimates, minima, or maxima. Additional uncertainty is added to very small offsets to reflect possible changes in elastic strain around the fault (*i.e.*, a non-integer number of “seismic cycles,” if such cycles even exist). Then, the age of the offset feature and its uncertainty (or inferred uncertainty) is converted into a PDF for the age. Different functional forms are used for ages which are best-estimates, minima, or maxima. An empirical adjustment is applied to ages from $^{14}C$ or cosmogenic-nuclide methods which may contain inheritance. Then, the PDFs for offset distance and age are convolved (using one of two alternate integral equations) to obtain the PDF for one component of offset rate on that one fault, based on a single offset feature.

If a fault has no dated offset features, it is assigned a “prior default” PDF which is the composite of the rates of all the faults of the same tectonic style in the same province which did have data. For example, a normal fault with no dated offset feature is assigned *N* = 0.183 mm/a, with standard deviation of 0.343 mm/a and 95%-confidence lower and upper limits of 0 and 1.09 mm/a, respectively. A thrust fault with no dated offset feature is assigned *T* = 0.228 mm/a with standard deviation of 0.691 mm/a and 95%-confidence lower and upper limits of 0 and 2.41 mm/a, respectively.

If the fault has one dated offset feature, then an elementary logic-tree expresses the higher probability (ranging from 95% down to 50%) that the dated offset feature is relevant to neotectonics and correctly interpreted, and a complementary branch expresses the lesser probability (ranging from 5% up to 50%) that the dated offset feature is irrelevant or misinterpreted—in which case the prior default rate PDF should apply. These percentages were inferred empirically by bootstrap methods in *Bird* [2007], and depend on the age of the offset feature and the nature of the literature source (primary, secondary, or tertiary). Faults with more than one dated offset feature have more complex logic-trees, expressing every possible permutation of relevant/correct and irrelevant/incorrect data.

Note that this method does not require knowledge of the dip of the fault. It is only later, when (or if) the dip-slip component of slip-rate is computed and combined with the strike-slip component in the Pythagorean theorem to obtain the total slip-rate, that the dip angle must be chosen. Within program Slippery, dip-slip is represented by a throw-rate (N or T) or a heave-rate (D or P), whichever is most closely related to the original data from the field.

Another interesting aspect of the Slippery method is that it gives zero consideration to offset rates quoted by authorities. It only uses (and combines) the offset distances (and senses) and ages of offset features found in the USGS data archive and/or in the literature. Thus, it ignores all "received opinion" and also serves as a check on the calculations of others. Also, I never combine an offset amount from one reference with an age from another reference, unless a USGS data editor or published author explicitly states that this is appropriate.

This method was applied by *Bird* [2007] to 2 compilations of dated offset features: his Table 1 referred to a personal compilation of data from the peer-reviewed literature in the conterminous western US; his Table 2 referred to a USGS compilation of Quaternary dated offset features for UCERF2 faults in California. Because of variations in fault names and traces between databases, it is not always possible to relate these old results to the faults in the current UCERF3 and NSHM2014 models; however, such comparisons are useful wherever possible.

For this project, I computed a new solution for all active faults in the conterminous western US ***except*** those in California, in November 2012. For consistency, this new solution kept the prior default offset-rate PDFs for each fault type (*L, R, N, T, D, P*) as previously inferred by *Bird* [2007] for the conterminous western US. However, the fault names are those of the NSHM2014 model, and the table of offset distances and associated ages is new. Spreadsheet f_NSHM-WUS_NoCA_2012-complete_output.xls (in the archive whose link was given on the first page of this Appendix) gives these results, along with brief tabular summation of the input data and its sources. It is "complete" in two senses; it has at least a nominal entry for every Quaternary-active fault in the conterminous western US (outside California), and it makes use of all the published accounts of dated offset features known to me at that time.

I used two primary sources of data on offsets and ages:

(1) ***USGS Quaternary Fault and Fold Database ("Qfaults").***
I read the "Slip rate category" section of each "Complete" report, and also read the "Dip" and/or "Age of faulted surficial deposits" sections if necessary to clarify ambiguities. I have referenced what I found as, *e.g.*, "USGS Q. Fault & F. D., 2012: 829a, #149" in which 2012 refers to the year in which I accessed the database, 829a is the fault or fault-segment number, and #149 is the data source quoted within that "Complete" report page. I have not taken the time or space to copy names of the authors of Qfaults pages; interpretations of those writers (and data with no further citation, which is presumably their own) is merely attributed to "author(s)".

I should clarify here how I handled certain ambiguities in these reports:

(a) Many Qfaults authors writing about normal or thrust faults quoted "slip rates" even though the available data and context made it fairly clear that these were actually throw rates. I usually assumed that "throw rate" was meant for any N- or T-sense data unless a specific fault dip angle was mentioned.

(b) Certain Qfaults authors writing about strike-slip faults, and lacking any along-strike offsets, have referred to scarp heights or other potential (although dubious) throw-rate indicators, and may even have used them in "slip rate" calculations. I have been careful not to enter these as offsets of type R or L.

(c) When no better age was available, I have sometimes accepted “Holocene” or “latest Quaternary” or “Late Quaternary” or “Middle Quaternary” or “Early Quaternary” or “Pliocene” or “Miocene” as quantitative ages appropriate for measured offset features, and assigned them the numerical age ranges found in the Qfaults Glossary. I also stretched these designations to include “latest/Late/Middle/Early Pleistocene” even those these are arguably not quite the same. However, I have typically not accepted “Quaternary” without an epoch or other subdivision qualifier, because it is too generic, and could be interpreted as simply identifying the rate that the author wants *Quaternary* F. & F. D. to accept as the best available estimate. I have occasionally referred to Wikipedia for ages of famous volcanic tuff (and/or tuffaceous sandstone) beds when these are not given in the Qfaults report.

***(2) My own long-running summary of dated offset features in western North America***, which has fallen somewhat out-of-date since its last refresh in 2008. However, it sometimes captures data which was published after the comparable Qfaults report page. (Many of these date from 1999.) Also, I sometimes include offsets of dated pre-Quaternary features not mentioned by the Qfaults authors. (Program Slippery “discounts” such older features with an internal logic-tree which estimates the chance that this older offset is relevant to neotectonics.) These data have short citations such as, *e.g.*, “Stewart, 1998 (scarp height only)” or “Pezzopane and Weldon, 1993, QFFD: 829a, #149]”. In the latter example, a note was added to show that this source was also read and referenced by the Qfaults author; however, I prefer to use my old notes from the original source, and not substitute second-hand versions of the offsets and ages (by citing Qfaults instead).

All offset rates, rate limits, and standard deviations in the table are in units of millimeters per year (mm/a). All are quoted to 3 significant digits to avoid unnecessary rounding, even though the original input data often had only 0.5~1 significant digits.

In the spreadsheet can be found offset-rate estimates and limits for each dated offset feature. However, the most useful products are the rows with “Reference” of “combined offset rate (*n* data)” and with “S” (for Slippery) in the Grade column. I have highlighted these in boldface.

This new analysis of pure-geologic offset rates for active faults (outside California) was provided on 26 November 2012 to the other deformation modelers in the NSHM2014 project, and may have been used by some of them as prior constraints or geologic target rates.

## 2. Joint geologic/geophysical inversion for offset rates with program NeoKinema

NeoKinema is a *kinematic* finite-element (F-E) program; that is, it combines kinematic data from both geologic and geophysical sources to infer what the surface of the Earth *is actually doing*. (In contrast, most other F-E programs are *dynamic* F-E programs, which assume the physics and the material properties and the boundary conditions, and use these to predict what the Earth *ought to be doing*.)

The domain of a NeoKinema F-E grid is the 2-D spherical surface of the Earth. Thus, all nodes are on the surface, and all elements are spherical triangles on the surface. This surficial character of the grid permits a large number of surface nodes (~10,800) and many (~21,300) small F-Es, for good spatial resolution. NeoKinema does not use special fault elements; instead, any number of faults can cut through any triangular element, adding to its compliance and its target strain-rate. It is recommended that grids be edited manually (with interactive program OrbWin) to create narrow 2-km-wide “corridors” of elongated elements along most fast-slipping faults.

However, where there are complex “nests” of slow-moving faults, or where there is no GPS data available (*e.g.*, offshore), such manual regridding is optional.

The primary time-scale of a NeoKinema velocity solution is “long-term-average” corresponding to a number of seismic cycles (if such cycles even exist) or many thousand years. This makes a good match with time-independent, Poissonian, quasi-stationary seismic hazard models like NSHM2014 and the time-independent version of UCERF3. However, most GPS data is collected in short interseismic periods, during which the shallow seismogenic parts of most active faults are temporarily locked. To permit such GPS data to be used as constraints, the program “corrects” any long-term-average velocity field to a short-term interseismic velocity field, and *vice versa*. This is done by summing the solutions for the expected coseismic displacements of the shallow, temporarily-locked fault patches, using established dislocation-in-elastic-halfspace solutions. To allow this correction, the dips of active faults, their lower interseismic locking depths, and their interseismic character (creeping or locked?) must be specified as input data for each fault. The quality of this “correction” is initially very rough in any run of NeoKinema, but it improves as the solution is iterated to self-consistency.

Within each iteration (out of 45 total) in a NeoKinema solution, the horizontal components of the long-term-average velocities of the nodes are computed by maximization of an objective function which has a weighted-least-squares character. The objective function of NeoKinema is a nondimensional functional of both dimensional model predictions ( $p$ ) and corresponding dimensional data values ( $r$ ), normalized by dimensional covariance matrix ( $\tilde{C}$ ) or by individual datum standard deviations ( $\sigma$ ):

$$\Pi \equiv -\left(\vec{p}-\vec{r}\right)^{\mathrm{T}}\left[\tilde{C}_{\mathrm{GPS}}^{-1}\right]\left(\vec{p}-\vec{r}\right)-\frac{1}{L_0}\sum_{m=1}^{M}\int_{\mathrm{length}}\frac{\left(p_m-r_m\right)^2}{\sigma_m^2}\,\mathrm{d}\ell-\frac{1}{A_0}\sum_{n=1}^{3}\iint_{\mathrm{area}}\frac{\left(p_n-r_n\right)^2}{\sigma_n^2}\,\mathrm{d}a \qquad (1)$$

where the first term is a quadratic form involving the great vector of all geodetic horizontal-velocity components and its covariance matrix $\tilde{C}_{\mathrm{GPS}}$, the second term concerns the $M$ long-term fault offset-rates $r_m$ with their uncertainties $\sigma_m$, and the third term concerns the constraints on sizes and orientations of distributed permanent deformation-rate tensors (in 2-D, with 3 independent components) in between the mapped faults. Note that this objective function gives a value that is independent of the sizes of the finite elements into which the length and area integrals are subdivided.

This objective function includes two “tuning” parameters: (1) trace length for unit weight of long-term offset-rate data, $L_0$; and (2) area receiving unit weight in continuum stiffness and isotropy constraints, $A_0$. (Both are relative to constant unit weight of point-based geodetic data.) Adjustment of these two values controls the relative quality of the fits to geodetic data (best fit with large $L_0$ and large $A_0$), geologic data (best fit with small $L_0$ and large $A_0$), and continuum constraints (including both minimization of strain-rate and orientation of strain-rate; best fit with large $L_0$ and small $A_0$).

The quality of any particular model is described by 3 dimensionless misfit measures, each of which is a root-mean-square norm ( $N_2$ ) of a vector of nondimensionalized misfits to data:

$$N_2^{\text{geodetic}} \equiv \sqrt{\frac{1}{2B}\sum_{b=1}^{B}\left(\vec{p}_b - \vec{r}_b\right)^{\mathrm{T}}\left[\tilde{C}_b^{-1}\right]\left(\vec{p}_b - \vec{r}_b\right)} \qquad (2)$$

where $B$ is the number of geodetic benchmarks and this error measure at each benchmark involves only the local (2×2) covariance of its 2 horizontal components $\tilde{C}_b$; and

$$N_2^{\text{stress}} \equiv \sqrt{\frac{1}{\sum a_i}\sum_{i=1}^{elements} a_i \left(\frac{p_i - r_i}{\sigma_i}\right)^2} \qquad (3)$$

where the $a_i$ are the areas of the finite elements, and the predictions and data are both transformed versions of the azimuth of the most-compressive principal horizontal strain-rate. One important objective in modeling is to bring these measures below ~2, and as close as possible to 1. (Fits with $N_2 < 1$ could be considered overconstrained; there would be some risk of fitting the high-frequency noise in the data as well as its useful low-frequency signals.)

In previous projects we used a parallel measure of the misfit to long-term geologic offset rates, weighted only by trace-lengths (and inversely by datum variances). However, this measure gave potentially misleading results by suggesting a better fit than had actually been achieved. This is due to the very nonuniform populations of fault offset rates. Somewhat like earthquake moments in a seismic catalog, they span many orders of magnitude (*e.g.,* 4.6 orders, from 0.001 mm/a to 40 mm/a, in this project). Also like earthquakes, the small rates are far more numerous than the large rates, which occur on only a few first-order fault trains (San Andreas, Mendocino, *etc.*). Finally, there is a tendency for many datum standard deviations to be the same order-of-magnitude as the rate (at least for relatively well-constrained rates). A weighted-least-squares algorithm like NeoKinema will always fit those data best which have the smallest standard deviations. So, NeoKinema routinely matches with great precision all of those slow offset rates which also have small standard deviations. An inappropriate misfit measure can make this look like a successful fit to all offset rates, when in fact the fit to the rates of first-order faults may be unacceptable. After some experimentation, I programmed a better misfit measure in which, prior to the $N_2$ (RMS) norm operation, the dimensionless misfits are each weighted by the seismic potency rate of their associated fault. (Seismic potency rate is the product of seismogenic fault area and slip rate.) For stability of this measure, I use the greater of the model or datum slip-rate to determine this relative weight within the misfit measure. This new misfit measure is called the "potency" misfit:

$$N_2^{\text{potency}} \equiv \sqrt{\frac{1}{\sum\sum \ell_{im} w_m h_{im}^{\text{sup}}}\sum_{i=1}^{elements}\sum_{m=1}^{M} \ell_{im} w_m h_{im}^{\text{sup}} \left(\frac{p_{im} - r_m}{\sigma_m}\right)^2} \qquad (4)$$

where $\ell_{im}$ is the trace-length of fault *m* in element *i*, $w_m$ is the down-dip width of the seismogenic portion of fault *m*, and $h_{im}^{\text{sup}}$ is the greater of the model heave-rate or datum heave-rate. In practice, I find that criterion $N_2^{\text{potency}} < 2$ implies a reasonably good fit to offset-rates on first-order faults as well as minor faults.

The most detailed reference on the equations behind NeoKinema is the technical appendix Supplemental Material S1 (sm001.pdf) of *Liu & Bird* [2008], which is also available from the file-set of this project under filename Appendix-Algorithm_of_NeoKinema.pdf. It gives all fundamental equations in matrix form and in spherical coordinates. More qualitative descriptions, with applications to specific active orogens, can be found in *Bird & Liu* [2007: California], *Liu & Bird* [2008: Asia], *Bird* [2009: western US], *Howe & Bird* [2010: Europe], and *Rucker* [2008, 2009: Philippines].

For this project, NeoKinema was upgraded to version 3.0 (of 2012.12.06) with the addition of important new features. First, dips of faults are no longer limited to preprogrammed values based on tectonic style, but can (optionally) be read from the fault-trace input dataset. Second, lower and upper limits can be placed on each offset-rate of each active fault (if desired). Specifically, imposing a lower limit of zero (or higher) on each offset rate will prevent rake-reversals, in which the model fault slips in the wrong direction. Additional changes included improvements in memory usage, iteration strategy, and error-capture checks. Full details about NeoKinema version history can be found within comment lines in the source code file, NeoKinema.f90.txt.

The model domain of the current models was bounded on the East by the meridian 103°W. It was bounded on the West by the continental rise at the outer edge of the California borderland, or by the Cascadia trench. (Note that these models do not actually include the Cascadia subduction zone fault.) On the North, the grid extended to 50°N, or 1° into Canada. On the South, the grid extended a comparable distance into Mexico.

The eastern part of the North grid boundary (opposite Idaho, Montana, and North Dakota) was fixed to the stable North America plate (NA of *Bird* [2003]). The West grid boundary, in latitudes South of the Mendocino fracture zone, was fixed to the Pacific plate (PA of *Bird* [2003]). Relative rotation PA-NA was taken from the Euler pole of *Gonzalez-Garcia et al.* [2003] (49.890°S, 102.989°E, 0.7660°/m.y.), which Bird [2009] determined to be the best available description of the motion of the easternmost parts of the Pacific plate. Other boundaries were left nominally free (but in practice were constrained by adjacent GPS velocities just inside the model domain).

Input datasets used to produce the current models included:

Fault traces, dips, and predominant rakes inside California were from UCERF3 Fault Model 3.1 (in model NSHM-WUS_2013001) or 3.2 (in model NSHM-WUS_2013002), edited by Timothy Dawson of CGS. However, some vertical or near-vertical dips in these datasets were not used if the corresponding rake indicated dip-slip motion; instead, these dips were allowed to default to NeoKinema's internal expectations of 20° for thrusts and 55° for normal faults.

Fault traces, dips, and predominant rakes outside California were from the NSHM2014 model edited by Katherine Haller of USGS, including all updates to the NSHM2008 fault model.

Geologic target offset-rates (with standard deviations, lower limits, and upper limits) for faults outside California were from the analysis reported in section 1 of this Appendix C.

Geologic target offset-rates (and standard deviations) for faults in California were either based on the UCERF3 table of Quaternary offset features edited by Timothy Dawson of CGS (for faults with at least one offset feature) or were default prior rates and uncertainties from the program-Slippery analysis of the western US by *Bird* [2007]. Lower and upper limits on offset-rates of faults in California were taken from the UCERF3 Geologic Deformation Model of Timothy Dawson and Raymond Weldon in cases where: (i) their limits were similar to those of *Bird* [2007], or (ii) their limits were broader than those of *Bird* [2007]; or (iii) their limits were based on geologic data not considered by *Bird* [2007]. However, in cases where their limits were substantially narrower than the limits of *Bird* [2007], and no new data had been added, the looser limits of *Bird* [2007] were applied. Furthermore, any fault which was known to have oblique slip, but which lacked a geologic constraint on one component (strike-slip or dip-slip) was modeled with no upper limit on its slip rate.

Horizontal velocities of GPS benchmarks, with their uncertainty ellipses, were taken from the NSHM2014 compilation by Robert McCaffrey. Specifically, I used his adjusted model `wus5_omeS` which had been corrected by subtracting velocity components that are due to elastic strain from temporary locking of the Cascadia subduction zone thrust fault, and adding some additional uncertainty to account for the error implicit in this correction. (This is necessary for internal consistency because the NeoKinema model domain does not include the Cascadia thrust.) By an iterative process, I removed from this dataset any benchmark which fell into the same finite-element as a fast-slipping (>1 mm/a) fault; this is necessary to prevent model artifacts that would otherwise result from the limited spatial resolution of my F-E grids.

Azimuths of most-compressive horizontal principal stresses were obtained from quality-A and quality-B data in the World Stress Map 2008 dataset of *Heidbach et al.* [2008]. Most of these are from focal mechanisms of shallow earthquakes, but in certain districts there are also data from wellbore breakouts and/or hydrofracture experiments and/or overcoring.

Each NeoKinema calculation was performed on a 32-bit, 3 GHz, Windows XP Pro computer with 1.5 GB of memory, requiring about 3 hours.

After some systematic experimentation (8 models), the NeoKinema tuning parameters were set to $L_0 = 2\times10^4$ m and $A_0 = 2\times10^8$ m$^2$. That is, the geologic rate on each 20-km-length of fault trace has the same weight as the velocity of a single geodetic benchmark, and the continuum-stiffness and stress-direction constraints for each (14.1 km)$^2$ patch of ground have the same weight as the velocity of a single geodetic benchmark. These values serve to balance the fit to the different classes of data, without over-fitting any of them. The RMS continuum deformation rate was set to the value of $\mu = 5\times10^{-16}$ /s which was previously determined optimal by *Bird* [2009].

***Residual Misfits***

The overall performance of the two final preferred models is shown by their residual $N_2$ misfits (where lower numbers are better, values near 1 are ideal, and values over 1 indicate some misfit exceeding that expected from aleatory uncertainties in the measurements):

| $N_2$ type | NSHM-WUS_2013001 | NSHM-WUS_2013002 |
|---|---|---|
| Continuum | 1.356 | 1.383 |
| Stress | 2.564 | 2.448 |
| Offset-rate | 0.932 | 0.905 |
| Potency-rate | 1.621 | 1.587 |
| Geodetic | 2.295 | 2.292 |

Another common measure of the residual misfits in weighted least squares models is normalized chi-squared (which can be computed for each class of data constraint). These values are simply the squares of the $N_2$ values quoted above:

| Normalized chi-squared type | NSHM-WUS_2013001 | NSHM-WUS_2013002 |
|---|---|---|

| | | |
|---|---|---|
| Continuum | 1.839 | 1.913 |
| Stress | 6.574 | 5.993 |
| Offset-rate | 0.869 | 0.819 |
| Potency-rate | 2.628 | 2.519 |
| Geodetic | 5.267 | 5.253 |

### 3. Manual adjustments to some slip rates in California

The UCERF3 review process examined the predictions of these (and other) deformation models for fault slip rates in California at a series of 4 "fault-by-fault" review sessions in January-February 2013 in Menlo Park and Pasadena, California. These were attended by numerous expert tectonic geologists, who were able to provide reactions and input based on both the peer-reviewed published literature and the non-reviewed "gray literature" of USGS NEHRP Final Technical Reports, other consulting reports, and unpublished work. In some cases, it became clear that certain fault traces in the UCERF3 Fault Models 3.1 and 3.2 were incomplete or incorrect, or that additional geologic offset-rate constraints existed which had not been collected into Timothy Dawson's UCERF3 database (or into my earlier 2007 compilation). In cases where I decided that their input (if received earlier) would have altered my input datasets and thus my model results, I agreed to make manual adjustments to certain fault slip-rates, to bring them within the bounds suggested by this new information.

The decision to make manual adjustments, rather than revise and recompute the models, was based on firm and imminent deadlines in the UCERF3 and NSHM2014 processes. Any recomputation would have resulted in small changes to the model slip-rates of many surrounding faults (which had already passed review), requiring a lengthy and tedious re-review and perhaps further iterations.

It is true that manual adjustment of any fault slip-rate, following a NeoKinema solution, creates incompatibilities in the solution if the long-term (non-elastic) continuum strain-rates of neighboring finite-elements are not adjusted to compensate. Usually this is impossible or impractical to do without a full recomputation. However, by this time we were aware that the UCERF3 leadership had decided to assign zero weight to the logic-tree branch "Deformation Model Based" at the "Off-Fault Spatial Seis PDF" node. Therefore, these local inconsistencies had no effect on UCERF3 predictions of seismicity or seismic hazard in California, and were allowed to persist in these models. Similarly, off-fault deformation rates were not used in NSHM2014 models, either.

A complete list of manual adjustments, with rationales and supporting references, may be found in file manual_adjustments_20130223.doc, in the archive whose link was given on the first page of this Appendix C. This list may also be incorporated into the NeoKinema section of Appendix C: Deformation Models of the UCERF3 time-independent model report (now in preparation).

No manual adjustments were made to slip rates of any faults in the other conterminous western United States, outside of California.

The final model slip-rates of all faults are contained in files (of the same archive)
NSHM-WUS_2013001_rake_and_sliprate_per_fault.xls and
NSHM-WUS_2013002_rake_and_sliprate_per_fault.xls,
where (as explained previously) model 2013001 used UCERF3 Fault Model 3.1 in California, and model 2013002 used UCERF3 Fault Model 3.2 in California. Except at points very close to

the California border, these two models are almost identical in the other conterminous western United States. These same files also contain columns with model predictions of rake, and with subdivision of each slip-rate into 2 of its 3 vector-component rates (Dextral, and Opening).

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