Finding and Defining the Edges of Stable North America: Reference Frame Effects vs. Real Tectonics

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Summary

The main significance of the new Stable North American Reference Frame (SNARF) is to provide a unique reference frame in which to analyze and interpret GPS velocities in the Pacific-North American plate boundary zone. SNARF is determined while taking into account the effect of glacial isostatic rebound, but is not implicitly constrained to yield crustal velocities across the western margin of the stable continent that are consistent with other geophysical and tectonic indicators. For instance, one would expect SNARF-fixed velocities east of the Rocky Mountains and Rio Grande Rift to be insignificant from zero, but the question is still open whether they are. Furthermore, there is a significant level of seismicity east of the Rockies (Figure 1), and a majority of the activity is found to be associated with ancient structures (mainly rifts and cratonic margins) (Figure 2), with New Madrid the most well-known example. Because it is still unclear whether strain accumulation along New Madrid is occurring and whether it is geodetically detectable, it may be fruitful to investigate possible strain accumulation elsewhere in the central U.S. Moreover, the extent of GIA-related strain in this area is not been unequivocally identified.

SNARF-fixed velocities may be instrumental in defining the western edge of the stable continent. However, our ability to find and define the edge of the stable continent relies generally on the adequateness of SNARF and may depend particularly on the way we realize the SNARF-fixed velocity field. To address these issues we derive two GPS velocity fields for a ~500 station network across the North American continent, one solution is in a SNARF frame and another in our own definition of stable NA. Data come from a variety of continuous GPS networks

We find that ITRF velocities transformed into the official SNARF velocity solution yields an incorrect and misleading velocity field in the central U.S. Based on our own (preferred) velocity field, we suggest that velocities can only be estimated in the SNARF frame when time-series analysis is done based on daily positions in SNARF.

Our velocity field (Fig. 5) indicates that the Great Plains are part of stable NA but that it is uncertain whether the stable region extent up to the Wasatch range in Utah. Southern Montana and western Texas move relative to the stable plate. The latter leaves answers open whether the Rio Grande is active, but does suggest a zone of strain accumulation in southern Oklahoma, along an ancient zone of weakness.

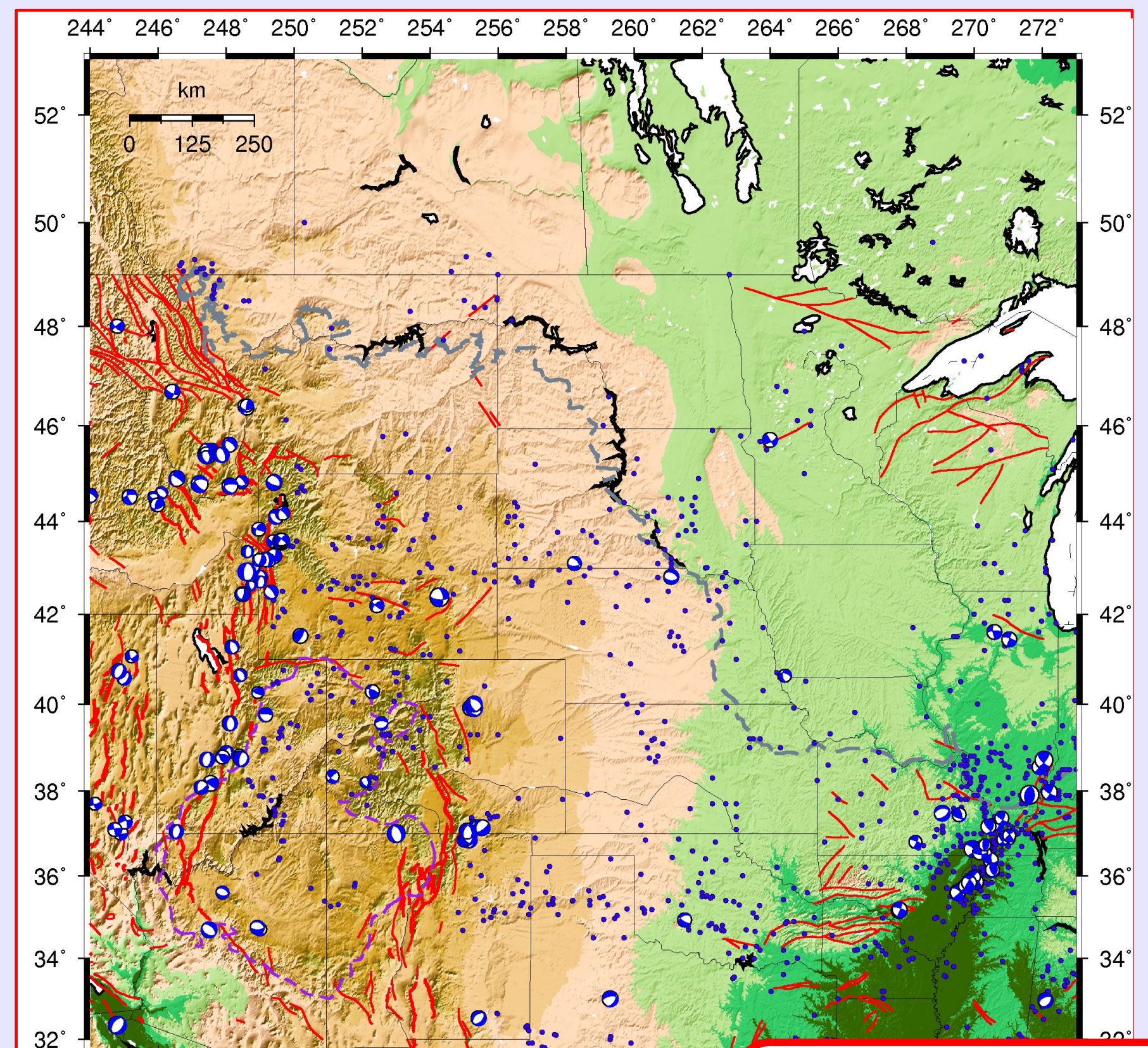


Figure 1 *(Above). Seismicity distribution (Mueller et al. 1997), focal mechanisms (Saint Louis Univ. and Berkeley catalogs), and Quaternary faults (thick: USGS fault and fold database – thin: other) for the Rocky Mtn-Great Plains region. Colorado Plateau is outlined by dashed purple line. Thick gray dashed line is furthest extent of Wisconsin Glaciation.*

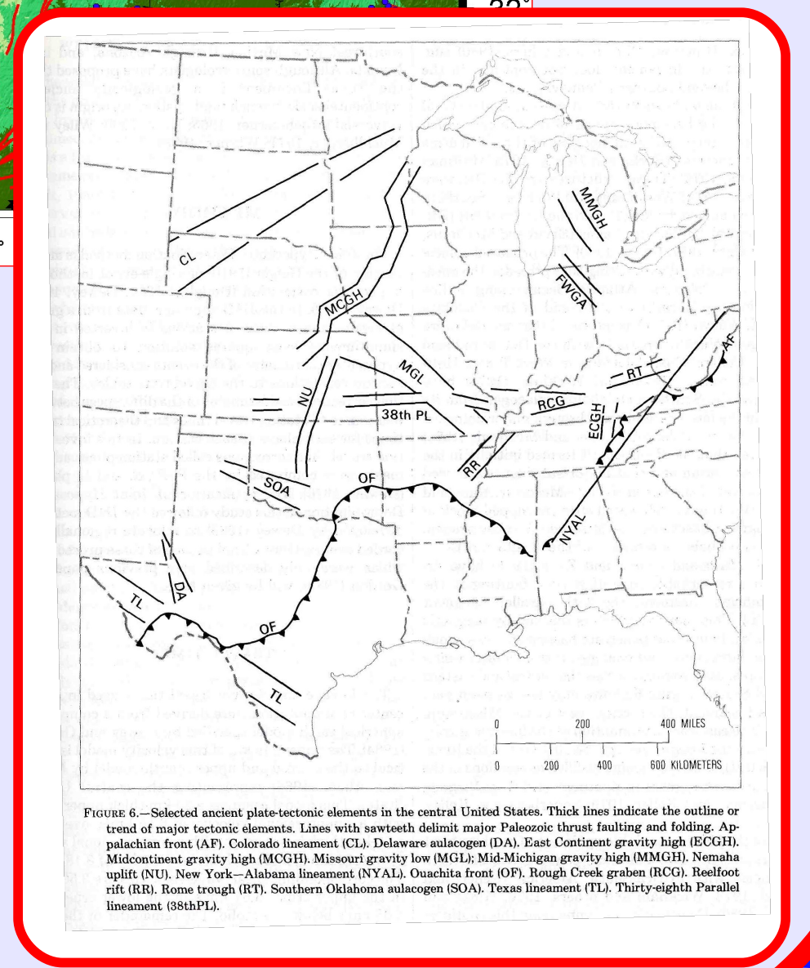


FIGURE 6.—Selected ancient plate-tectonic elements in the central United States. Thick lines indicate the outline or trend of major tectonic elements. Lines with sawteeth delimit major Paleozoic thrust faulting and folding. Appalachian front (AF). Colorado lineament (CL). Delaware aulacogen (DA). East Continent gravity high (ECGH). Midcontinent gravity high (MCGH). Missouri gravity low (MGL); Mid-Michigan gravity high (MMGH). Nemaha uplift (NU). New York–Alabama lineament (NYAL). Ouachita front (OF). Rough Creek graben (RCG). Reelfoot rift (RR). Rome trough (RT). Southern Oklahoma aulacogen (SOA). Texas lineament (TL). Thirty-eighth Parallel lineament (38thPL).

Figure 2 *(inset right). Major (pre-)Cambrian plate tectonic elements in central U.S. (from Gordon, 1988). Much of the seismicity in the central U.S. can be associated with these structures, most notably New Madrid.*

Velocity Fields

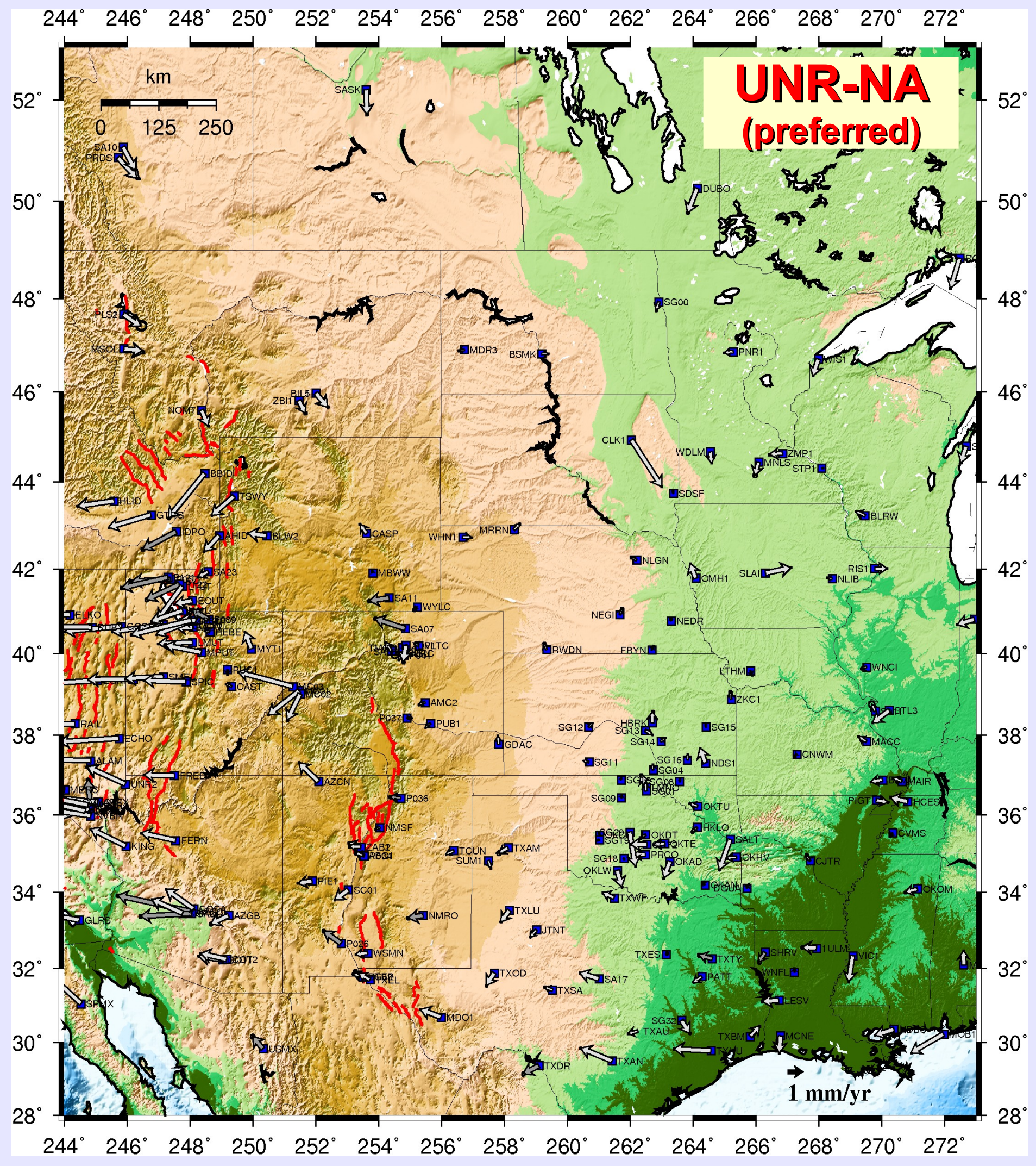


***Figure 5**. Velocities relative to the UNR-NA frame. White/gray velocities are for sites with >3yr or >2.5yr of data, respectively. Some consistent key observations are that Great Plains behave very rigid and belong to stable NA, and west Texas and eastern New Mexico experience general westward motion. We summarize all observations in the conclusions.*

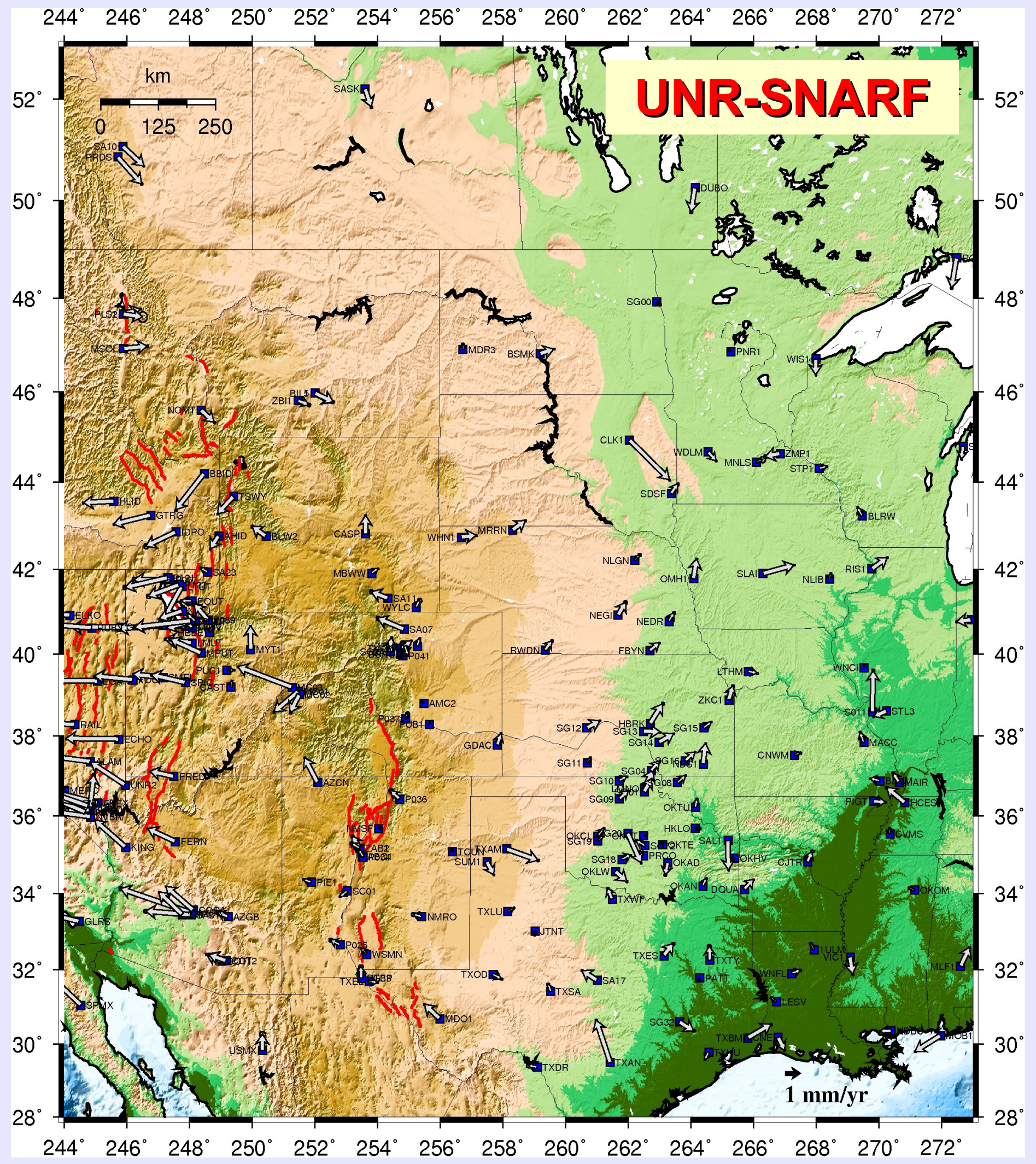


***Figure 6**. Same as Fig. 5 but velocities relative to the UNR-SNARF frame. One consistent key feature is the NNE motion of the Great Plains between Oklahoma and Nebraska, similar to the findings of Calais et al. (2006) who used a similar frame definition.*

Conclusions

Reference Frame

- ***Transformation of ITRF velocities into SNARF leads to an incorrect and misleading velocity field in the central U.S.***
- ***Like our UNR-NA solution, SNARF velocities should be inferred using daily position time-series in SNARF frame***

Tectonics

The velocity field in Fig. 5 suggests:

- ***GIA related horizontal velocities are identifiable NE of line furthest glacial extent.***
- ***Uncertain source of SE motion of southern Montana***
- ***Great Plains area (from Oklahoma to Nebraska) does not internally deform and moves with stable North America.***
- ***Consistent and significant W to SW motion of western Texas and eastern New Mexico is observed***
- ***Velocity field suggests possible strain accumulation along the southern Oklahoma aulacogen, and area with relative high seismicity rates (Fig. 1-2)***
- ***No coherent strain or change in velocities is observed across the Rocky Mtns and Rio Grande Rift***
- ***Rapid increase of motion (~2.5 mm/yr) across the Wasatch Range fault system in central Utah***
- ***Rapid SW increase of motion in eastern Idaho, away from Yellowstone***
- ***Up to ~1 mm/yr of extension between south central New Mexico and south central Arizona: southern Basin & Range still active ?***
- ***Local strain accumulation at New Madrid ??***

GPS Solutions

We create two different GPS velocity solutions, one that is relative to our own definition of North America ("UNR-NA") and one that is transformed in to the official SNARF solution ("UNR-SNARF"). Both solutions are estimated using the GIPSY-OASIS II precise point precision software (Zumberge et al., 1997). Satellite orbits and clocks were obtained from JPL. Carrier-phase ambiguities are resolved using our new algorithm (see Blewitt and Kreemer poster "next door").

UNR-NA

For this solution we selected 25 sites that had data for most of the period from 1 Jan, 2002, till 07 March, 2007, had no offsets and are away from the plate boundary zone and GIA signal (Fig. 3). Using the no-net rotation constraint for these sites we estimated daily 7-parameter transformation from a loosely constrained solution to our stable NA definition (see Blewitt and Kreemer poster "next door" for more details). We applied this transformation to obtain position estimates for all our sites (Fig. 3) in our UNR-NA frame.

UNR-SNARF

For this solution we used JPL's ITRF00 and IGS05 X-files for the same time interval. We estimated for an offset when the frame changed on 03 Nov, 2006. Velocities in this frame were then transformed into the official SNARF velocities using the velocities at 84 collocated sites. We performed spatial filtering to remove common-mode errors following (Marquez-Azua and DeMets, 2003)

Fig. 4 shows a comparison of the RMS (or residual velocity) for the 15 sites that both frames have in common. Except for two outliers (SLAI, STJO) the RMS values for both frames are of the same order of magnitude and equally distributed.

Velocities

We estimated velocities from the time-series in either frame for all sites with >3yr of data. While estimating velocities we simultaneously solve for an annual and semi-annual signal and any offset that has been recognized.

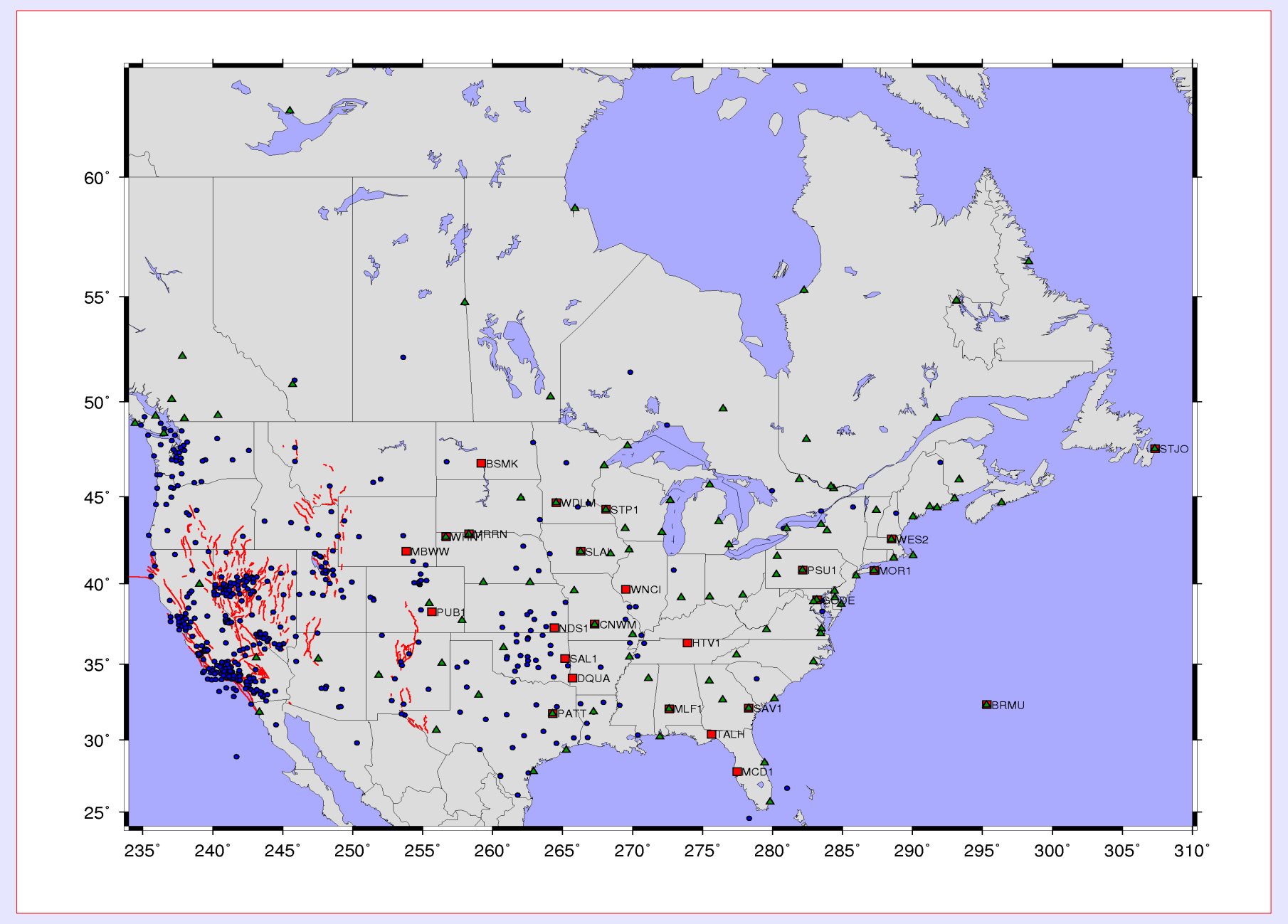


***Figure 3** (Above). Site locations (excluding those in northern Canada and Alaska):*
Blue circles; sites analyzed in this study
Green triangles: sites part of the official SNARF solution
Red squares: sites used to estimate our own North America frame (UNR-NA)

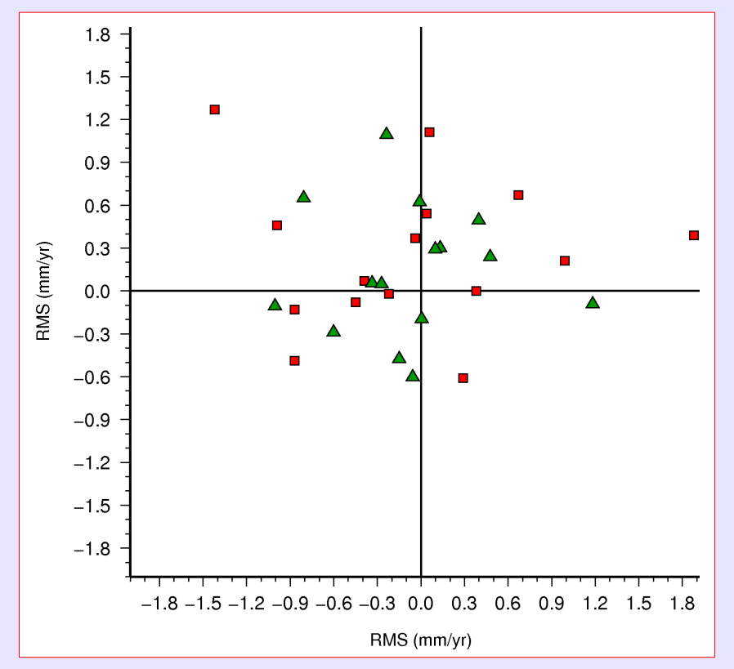


***Figure 4** (Left). RMS scatter of the UNR-NA (red squares) and UNR-SNARF (green triangles) velocities at the 15 sites in common between both frame definitions*

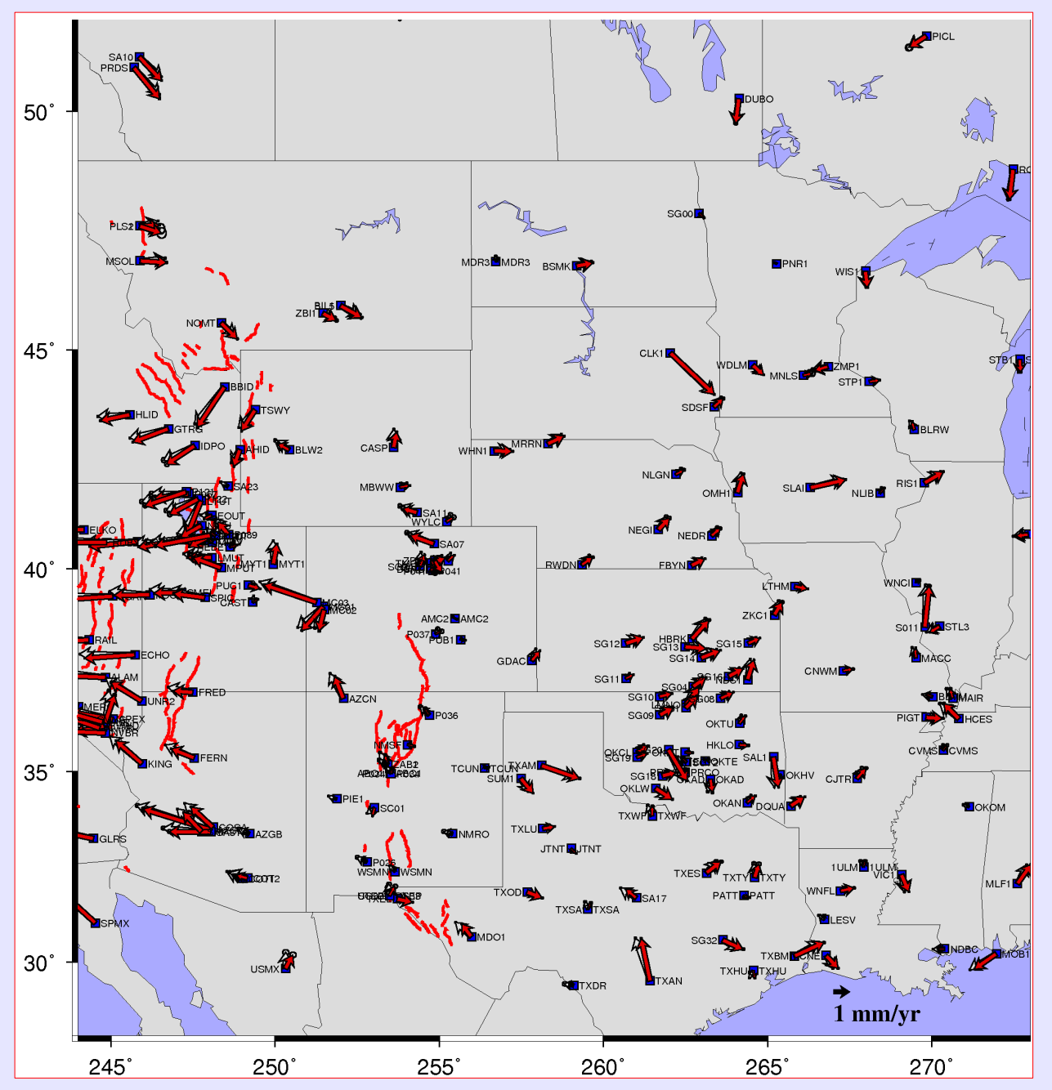
Testing SNARF

The results from the velocity fields in the panel above suggest that when transforming ITRF velocities into the SNARF frame that this may lead to apparent velocities in the Great Plains area that are difficult to explain. Calais et al. (2003) obtained a similar velocity field based on a similar definition of SNARF. We show here (Fig. 7) that the characteristics of the Great Plains velocity field in is independent of whether the transformation involves only 3 parameters (i.e., only a rotation rate) or more parameters (e.g., also accounting for a translation rate). However, further west the effect of number of parameters used in the transformation because significant. If the transformation involves a translation rate in addition to a rotation rate velocities in the Basin and Range and on the Colorado Plateau are slightly slower and slightly more southward.

We also tested whether the NNW motion in the Great Plains could be the result of the large geographic extent of the SNARF sites (including the GIA affected area). We therefore rotated our ITRF solution into the official SNARF solution using only the velocities at 15 sites common with those used in our UNR-NA frame definition (Fig. 8). As an independent test we have simply minimized our ITRF velocities at those 15 sites. For both solutions our not significantly different than those in Fig. 6.

These tests suggest that the anomalous NNW motion of the Great Plains is inherent in the solution being based on ITRF. Transformations into SNARF are thereby somehow affected, and we recommend the transformation into SNARF to be done for the daily position estimates rather than velocities.

***Figure 7**. Velocities in the UNR-SNARF frame. White vectors are same as in Fig. 6 and red vectors are obtained when the transformation to SNARF involves a rotational rate in addition to a rotation rate.*



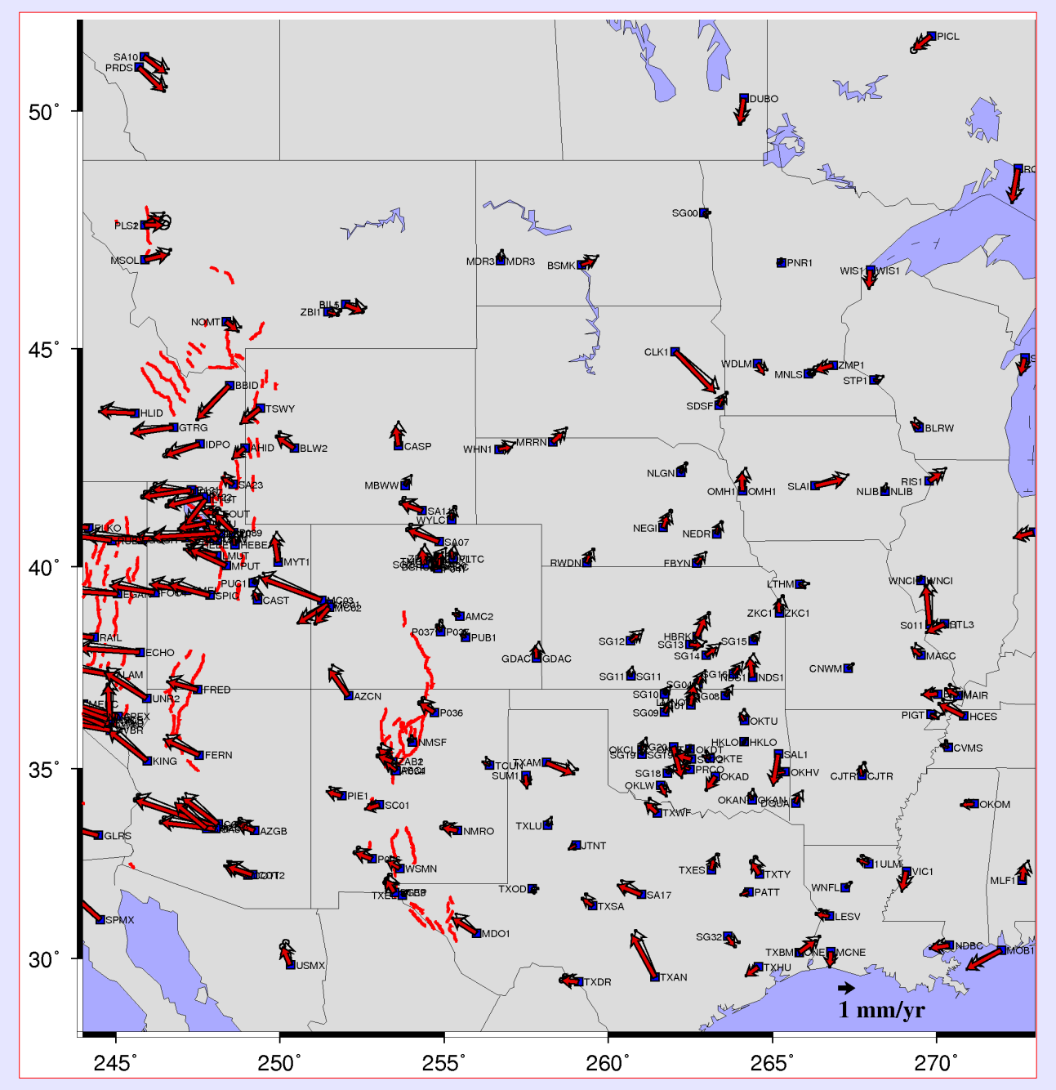


***Figure 8**. White velocities are in a version of UNR-SNARF that only used for the rotation the velocities at the 15 sites common between SNARF and those used in our UNR-NA definition (Fig. 3). Red velocities are relative to a frame where we simply minimized the ITRF velocities at the 25 sites used to define UNR-NA (Fig. 3).*

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