

Uncertainty in the Motion of the North American Plate and its Impact

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"In theory, there is no difference between theory and practice, but in practice there is."

UNCERTAINTY IN THE MOTION OF THE NORTH AMERICAN PLATE

Past estimates of the motion of the North American plate in ITRF generally do not agree within uncertainties. This suggests that systematic errors have been ignored or underestimated. We focus on two sources of uncertainty or bias between plate angular velocity estimates: **errors in the underlying reference frame**, and the **geographic limitations of stable North America**. We compare the Sella et al. (2007) and SNARF angular velocities for North America, along with REVEL (Sella et al., 2002), which is based on ITRF97.

1. How Well Do We Know the ITRF?

Although all realizations of the ITRF are meant to reflect the same underlying reference system, in practice all ITRF frames have been subtly different. The main differences have been in the origin of the frame (geocenter and geocenter rate). This was made clear in the change to ITRF2005 but actually all past ITRF models effectively had geocenter rates relative to each other. ITRF2000, ITRF2005, and the initial SNARF realization all have geocenter rates relative to each other at the 1-2 mm/yr level. ITRF97 differs from later ITRFs by >3 mm/yr. These differences map directly into differences in estimated plate motions. Argus (2007) and Argus (this session) show that these differences even impact relative plate motions, not only absolute motions.

2. Impact of Biases Between Frames

The frame differences are greatest in the Z-direction, which translates into a difference in the north velocities for equatorial to mid-latitude sites, and mainly a vertical difference for high latitude sites. The frame differences mean that site velocities and plate angular velocities in each frame are biased relative to other frames. The REVEL model (Sella et al., 2002) used ITRF97, and predicts a very different motion for North America.

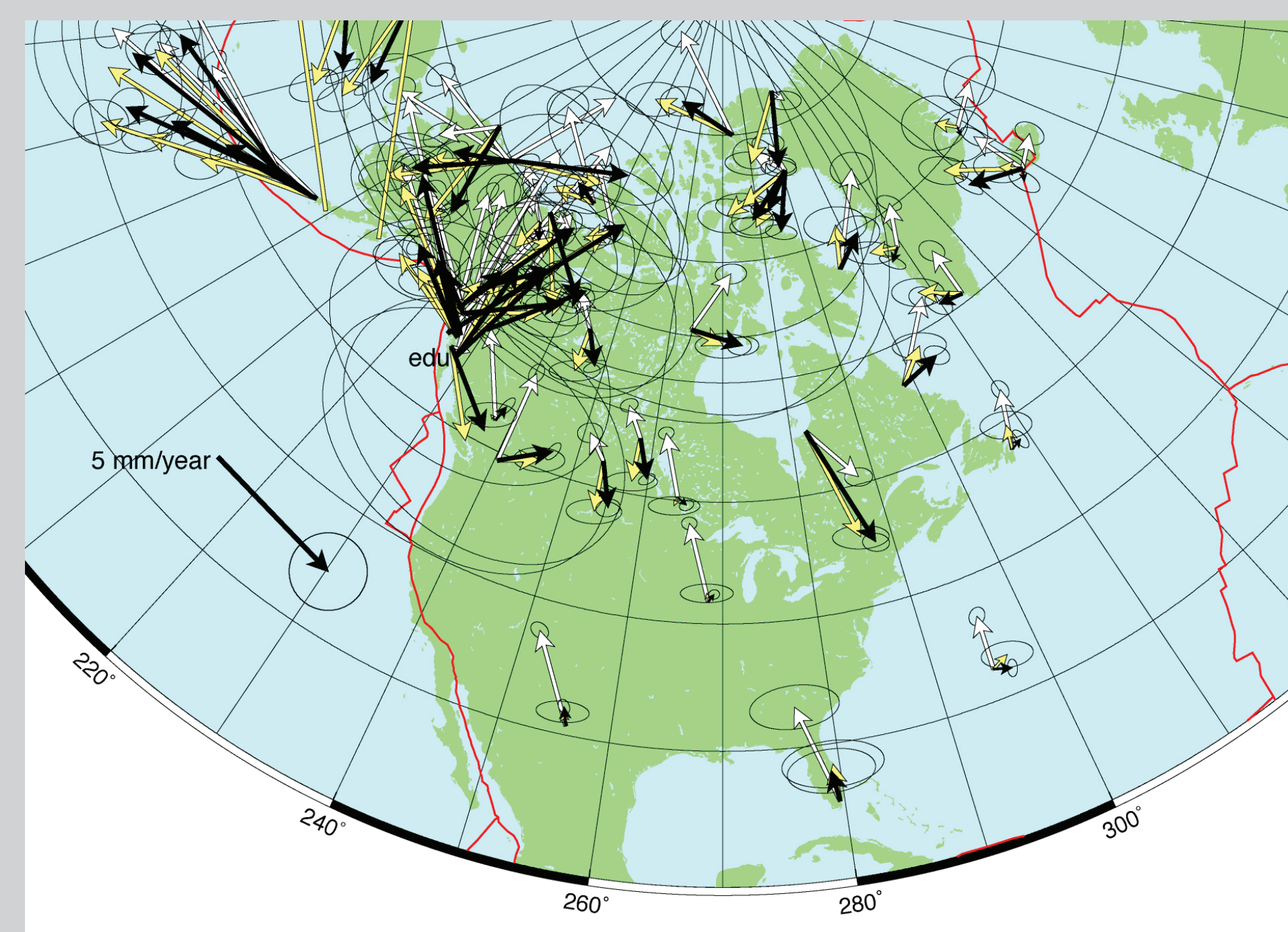


Figure 2. Velocities relative to NOA using different realizations: BLACK: Sella et al. (2007) WHITE: SNARF V1.0 YELLOW: REVEL-2000

The Sella and SNARF realizations are indistinguishable in the southeastern US but differ by >1 mm/yr in Alaska. REVEL is very different, but if the time series is expressed in ITRF97, REVEL predicts site motions very well.

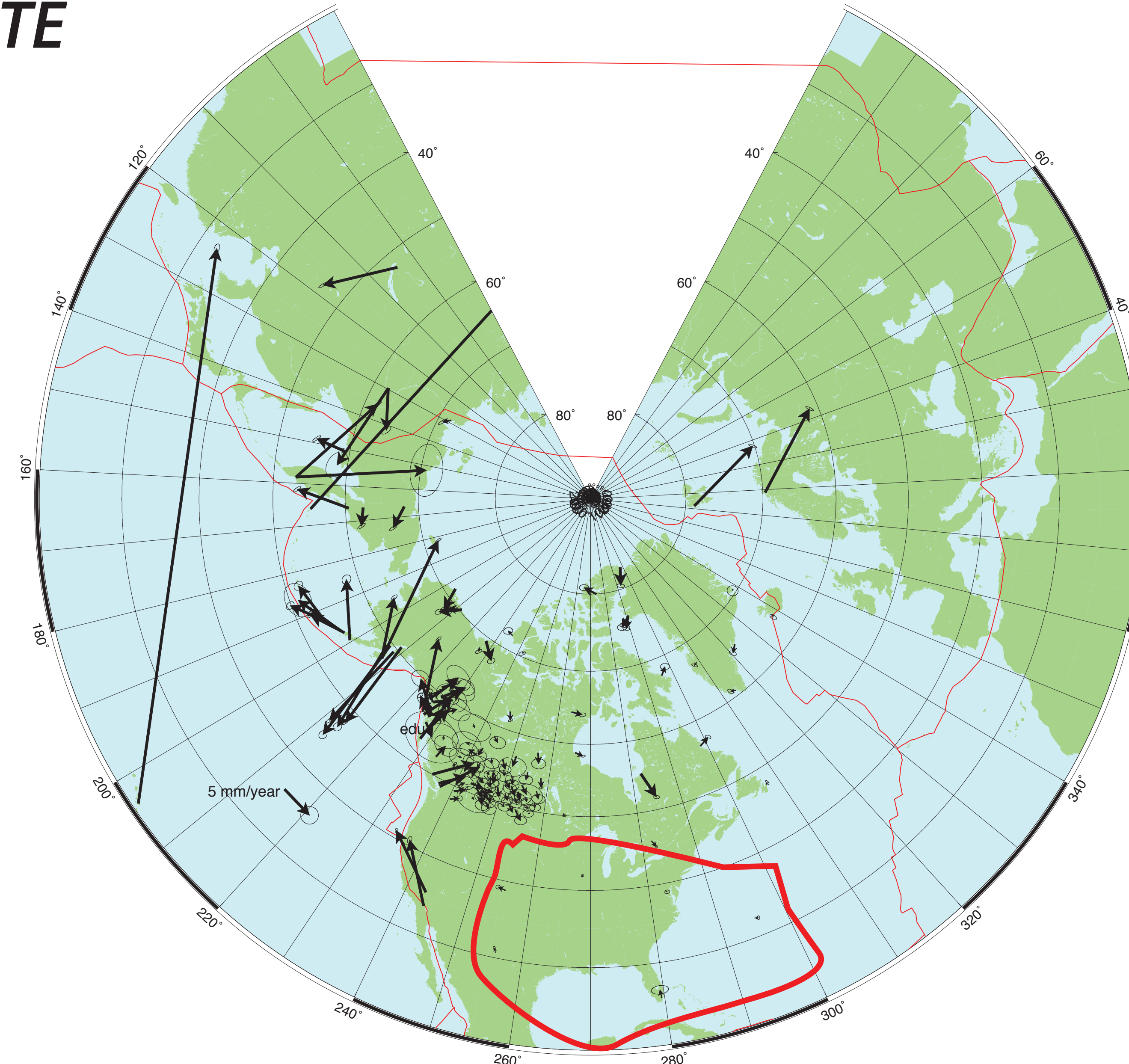


Figure 1. Velocities relative to North America as defined by Sella et al. (2007). Data span 1993-2006, including continuous and selected campaign GPS sites. Red line outlines the rough limits of geodetically stable NOAM.

3. Quantifying ITRF Uncertainty

Sella et al. (2007) and SNARF both used ITRF2000. But ITRF2005 velocities differ from ITRF2000 by ~2 mm/yr in the Z-direction. A conservative approach is to assume that the present uncertainty in the ITRF is equal to the difference between the two most recent models, or 1.8 mm/yr in Z velocity.

4. How Do The Latest Models Differ?

Sella et al. (2007) and SNARF model predictions agree to within 0.1-0.2 mm/yr in the southeastern US, but differ by 0.5 mm/yr at San Francisco, and > 1 mm/yr at Alaska. This is an inevitable result of the limited size of geodetically stable NOAM (due to tectonic deformation and GIA). The difference between the two is a small rotation about the Florida Panhandle. Small biases in site velocities in the SE US are amplified into much larger differences in model predictions far to the west and northwest.

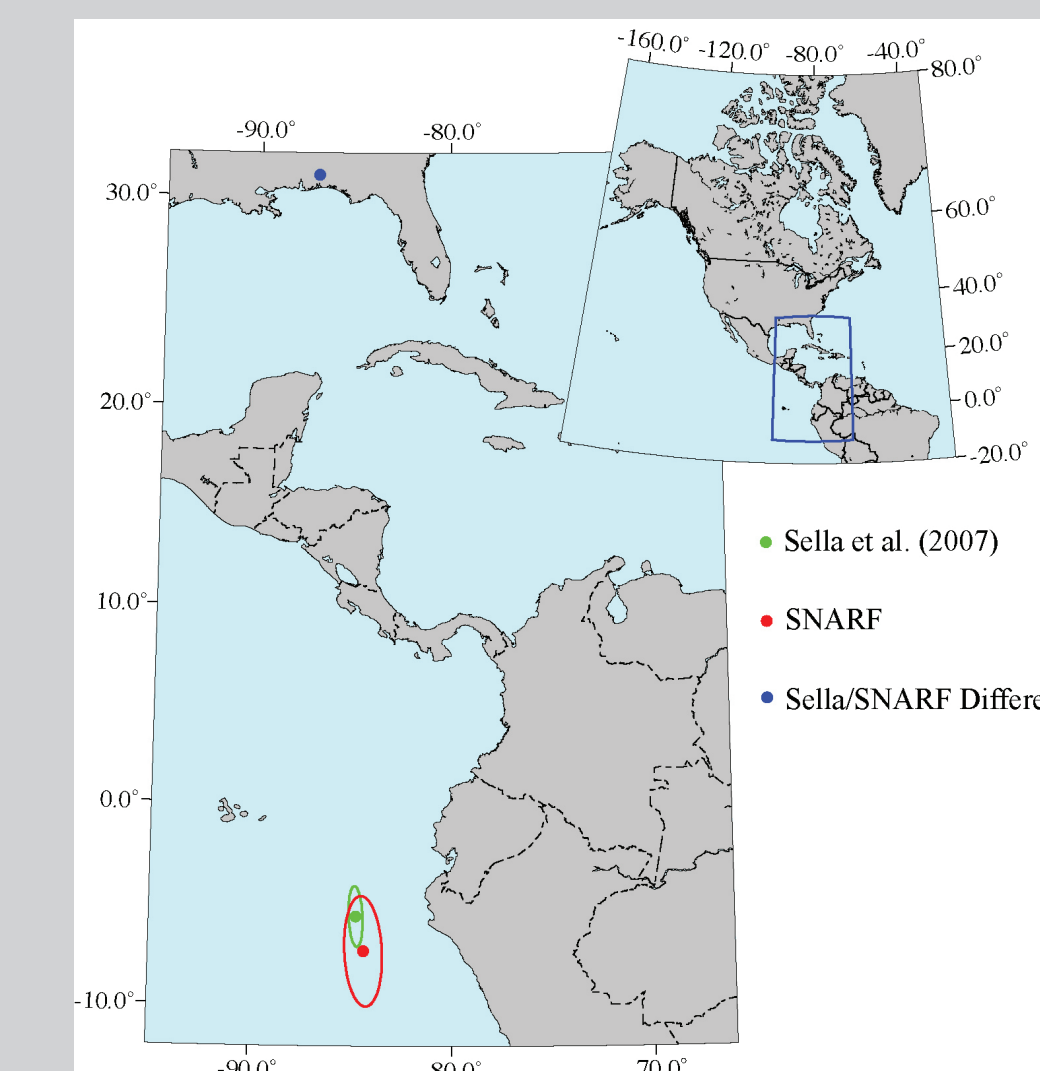


Figure 3. Sella and SNARF NOAM poles and the pole of the difference between them.

IMPLICATIONS

Relative GPS positions and velocities (lengths and length rates) are still determined nearly an order of magnitude more precisely than the ITRF or a plate-fixed frame. The frame is a limiting error source.

5. What Part of the Plate Angular Velocity is Least Precise?

The location of the difference pole between the Sella and SNARF models is easily understood if you consider what part of the plate angular velocity vector is constrained by a single GPS site. Express the angular velocity in the local east-north-radial coordinate system of the site. The radial component of the angular velocity vanishes in this system and is undetermined, and the east and north components can be estimated directly from a single site velocity.

$$\underline{\omega} = \omega_x \hat{x} + \omega_y \hat{y} + \omega_z \hat{z}$$

$$\underline{\omega} = \omega_e \hat{e} + \omega_n \hat{n} + \omega_r \hat{r}$$

$$\underline{v} = v_e \hat{e} + v_n \hat{n} = \underline{\omega} \times \underline{r}$$

$$v_e \hat{e} + v_n \hat{n} = (\omega_e \hat{e} \times R\hat{r}) + (\omega_n \hat{n} \times R\hat{r}) + (\omega_r \hat{r} \times R\hat{r})$$

$$v_e \hat{e} + v_n \hat{n} = R\omega_n \hat{e} - R\omega_e \hat{n} + 0\hat{r}$$

The local vertical component of the plate angular velocity is completely undetermined by a single site. When multiple nearby sites are used, their vertical vectors will be similar and this component will be weakly determined. Only when sites with local vertical vectors that are very different are used will all components of the plate angular velocity be equally precise.

$$\begin{aligned} \omega_e &= -v_n / R \\ \omega_n &= +v_e / R \\ \omega_r &= ? \end{aligned}$$

6. Toward a More Realistic Plate Angular Velocity Covariance

We augment the covariance of the plate angular velocity and of site velocities relative to the plate to account for the systematic biases between current angular velocity estimates.

The augmented covariance has two parts:

- (Plate) – augment the covariance of the plate angular velocity estimate by an uncertainty proportional to the difference between the Sella and SNARF angular velocities.
- (Frame) – add a perfectly correlated $\sigma = 1.8$ mm/yr to all Z velocities.

When this is done via a proper full covariance matrix, relative velocity uncertainties are essentially unaffected.

Conclusions

- Absolute site velocity precision is limited by uncertainty in the ITRF geocenter; a conservative estimate of the uncertainty is given by the difference between ITRF models.
- The component of the NOAM angular velocity that is least precise is equivalent to a rotation about a pole in the southeastern US. This is due to geometric limitations. The difference between recent angular velocity estimates projects to a ~0.5 mm/yr uncertainty in San Francisco and a >1 mm/yr uncertainty in Alaska.
- We should consider augmenting the covariance of plate angular velocities.