Terrestrial Reference Frame Maintenance

Environmental Issues and Monumentation

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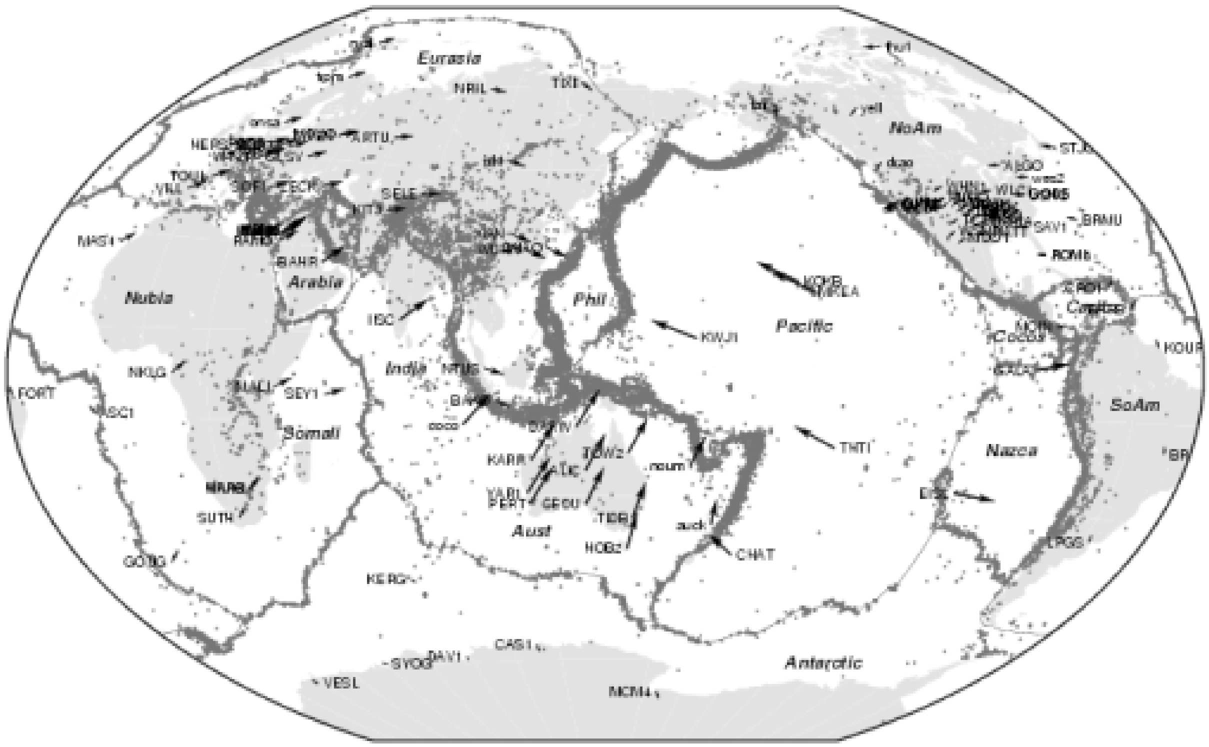
Acknowledgments

- Simon Williams, Y. Bock, P. Fang, P. Jamason, R. M. Nikolaidis, L. Prawirodirdjo, M. Miller, D. J. Johnson, Error Analysis of Continuous GPS Time Series, J. Geophys. Res., in press, 2004.
- John Langbein and Y. Bock, High-Rate Real-Time GPS Network at Parkfield; Utility for Detecting Fault Slip and Seismic Displacements, Geophys. Res. Lett., in press, 2004.
- Linette Prawirodirdjo and Y. Bock, Instantaneous Global Plate Motion Model from 12 Years of Continuous GPS Observations, submitted to JGR, 2003.

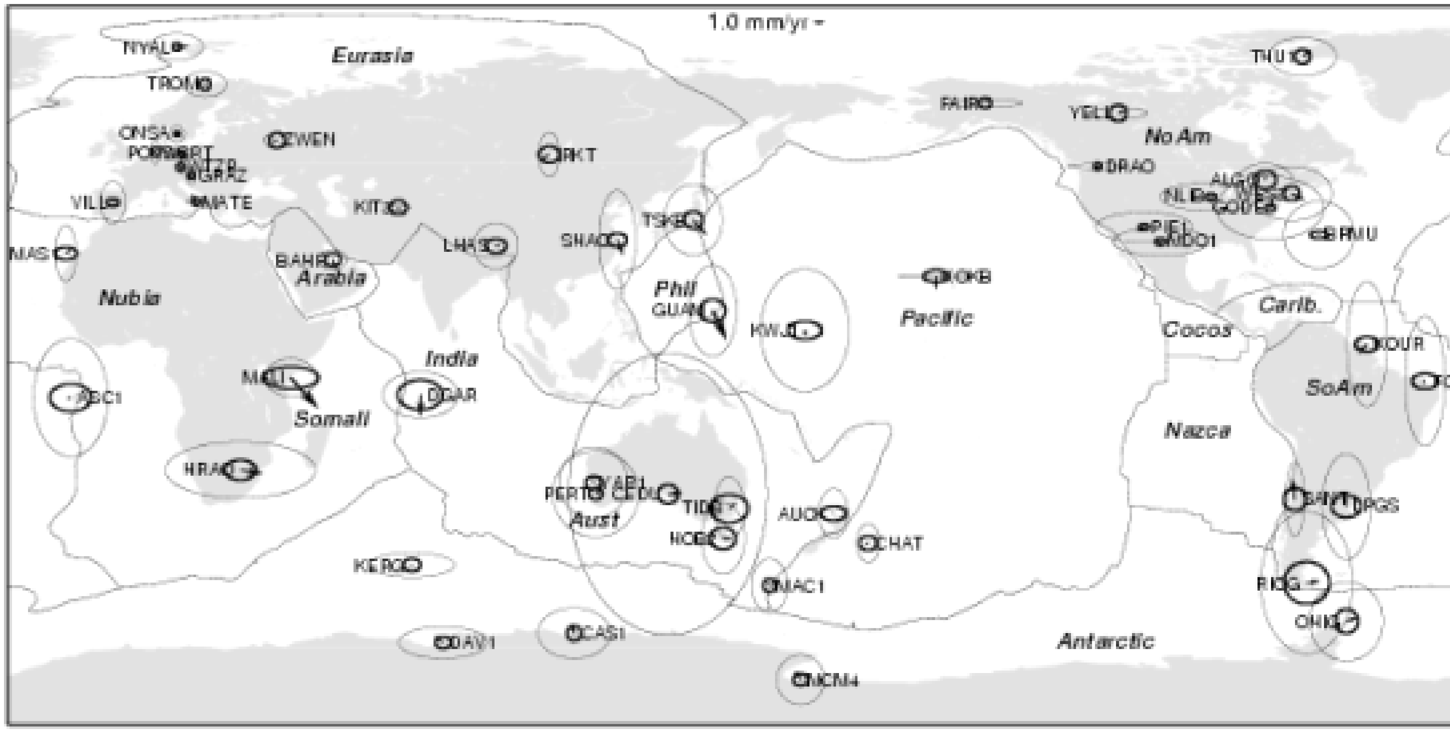
Terrestrial Reference Frame



Realize terrestrial reference frame for the deformable Earth by estimating the coordinates and velocities of global tracking stations. Site velocities are used to determine the rotation vectors of major and minor tectonic plates, and microplates.

In the context of TRF's, besides rotations, all non-tectonic effects can be considered noise.

Improved ITRF2000 Velocities



SOPAC has refined the ITRF2000 velocities for 133 global sites by modeling position time series spanning 1991-2003 for non-linear effects and temporal correlations.

Elements of Improved Analysis

- Modeling position time series for seasonal effects (annual and semi-annual) present in all series, seismic deformation, instrument offsets, and velocities.
- Screening sites with anomalous motions: seismic, anthropogenic effects, elastic strain, glacial isostatic adjustment (GIA), site specific – trees, snow, fences, and other obstructions, multipath and signal diffraction.
- Evaluating the noise properties of position time series through spectral analysis and maximum likelihood estimation, to improve uncertainties of velocity estimates and identify problem sites.
- Assessing the effects of monumentation to identify anomalous sites and as a guideline for future sites.

Modeling Position Time Series

- Site motion is modeled at each site in each direction (north, east, up) as:

$$y(t_i) = a + bt_i + c\sin(2\pi t_i) + d\cos(2\pi t_i)$$
$$+ e\sin(4\pi t_i) + f\cos(4\pi t_i) + \Sigma_j\, g_j H(t_i - Tg_j) + v_i$$

- The weighted least squares solution for the model parameters is:

$$\mathbf{x} = [\, a \;\; b \;\; c \;\; d \;\; e \;\; f \;\; \mathbf{g}]^T$$

$$\mathbf{y} = \mathbf{Ax} + \mathbf{v}$$

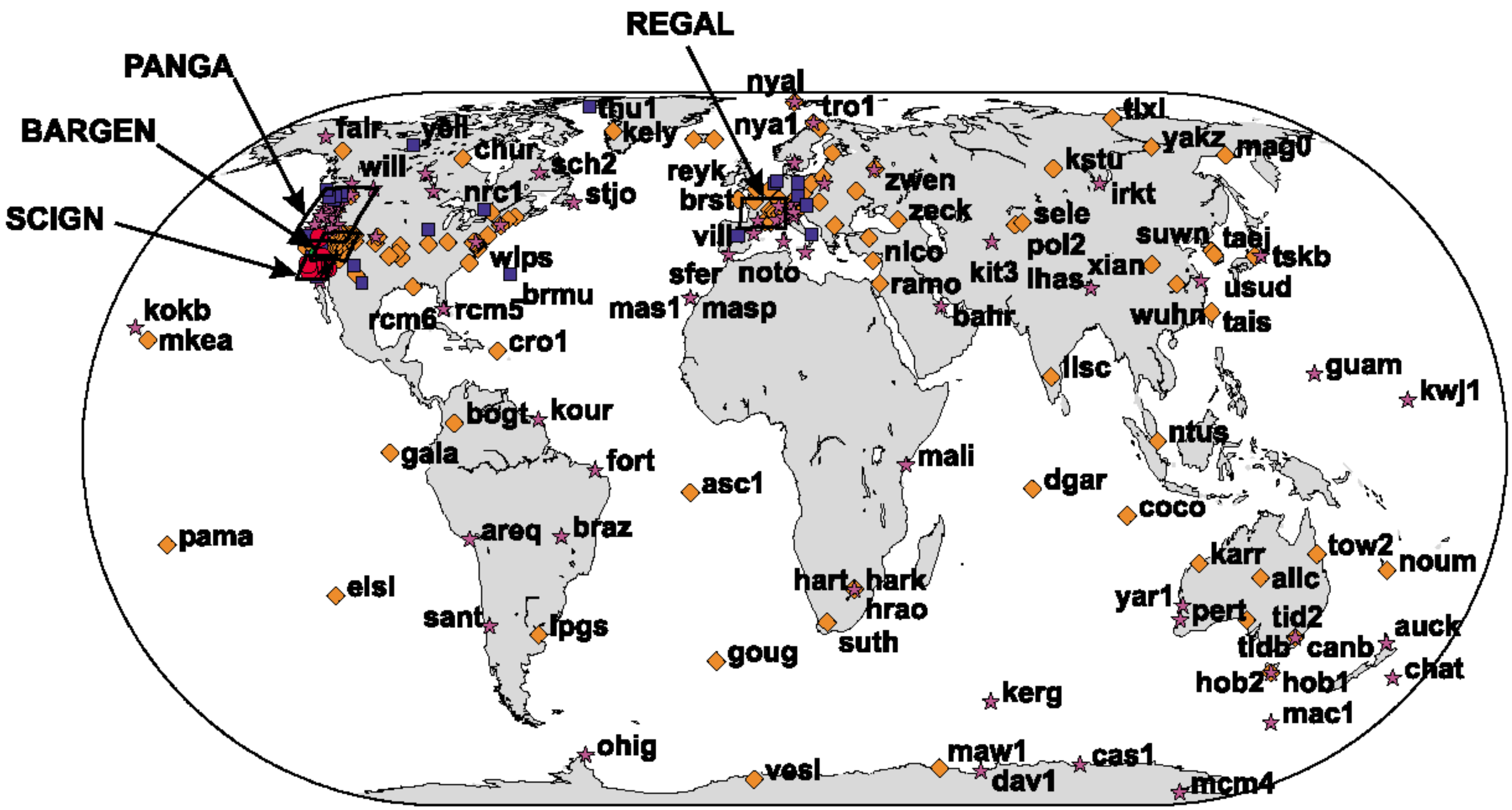
$$\underline{\mathbf{x}} = (\mathbf{A}^T\mathbf{C}_v^{-1}\mathbf{A})^{-1}\mathbf{A}^T\mathbf{C}_v^{-1}\mathbf{y}$$

$$\underline{\mathbf{C}}_x = \chi^2(\mathbf{A}^T\mathbf{C}_v^{-1}\mathbf{A})^{-1}$$

- The observation covariance matrix is constructed with a white noise + colored (power law) noise model, with noise amplitudes determined for each site by maximum likelihood estimation:

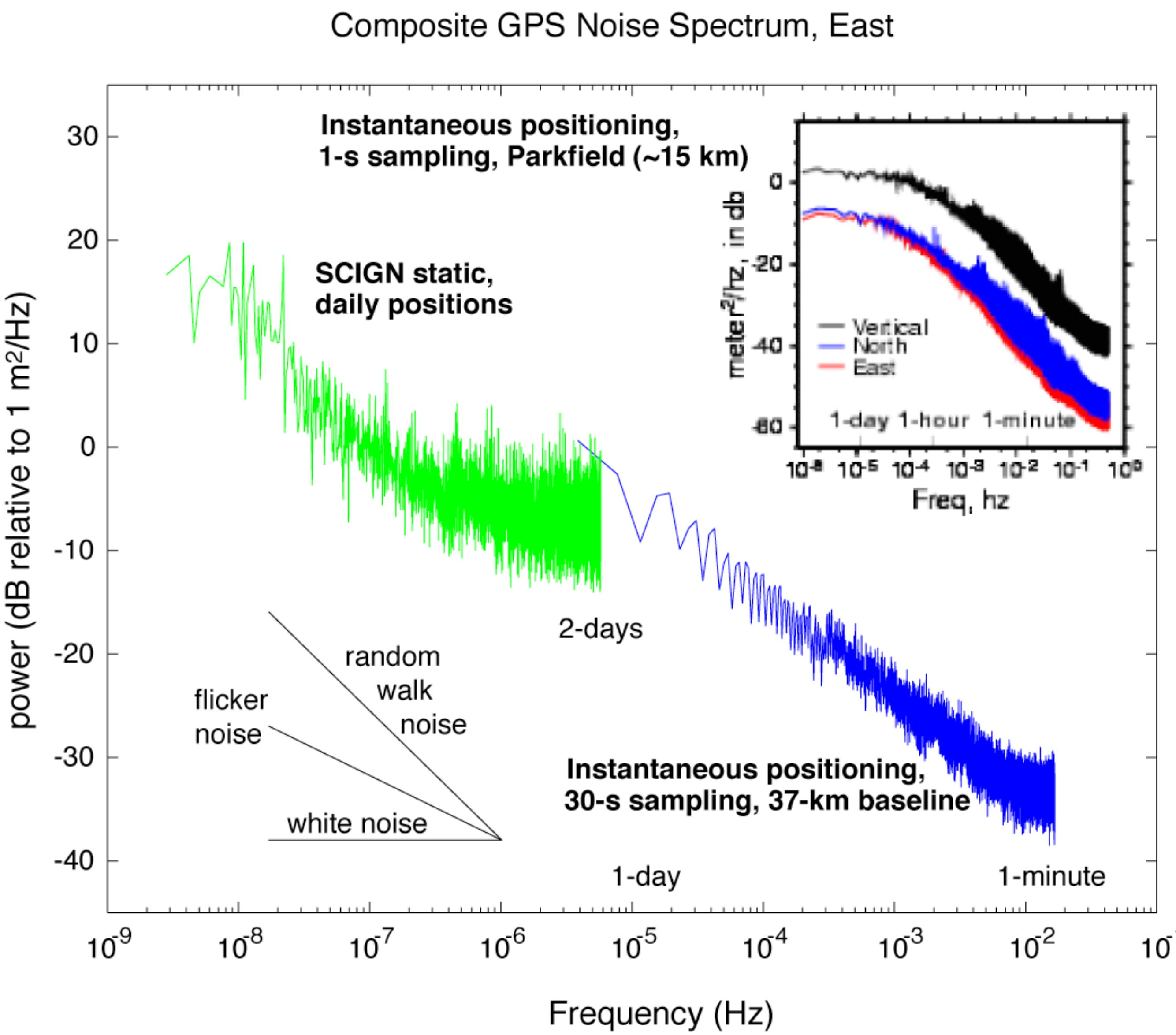
$$\mathbf{C}_v = a_w^2\mathbf{I} + b_\kappa^2\mathbf{J}_\kappa$$

Global GPS Stations: Noise Study



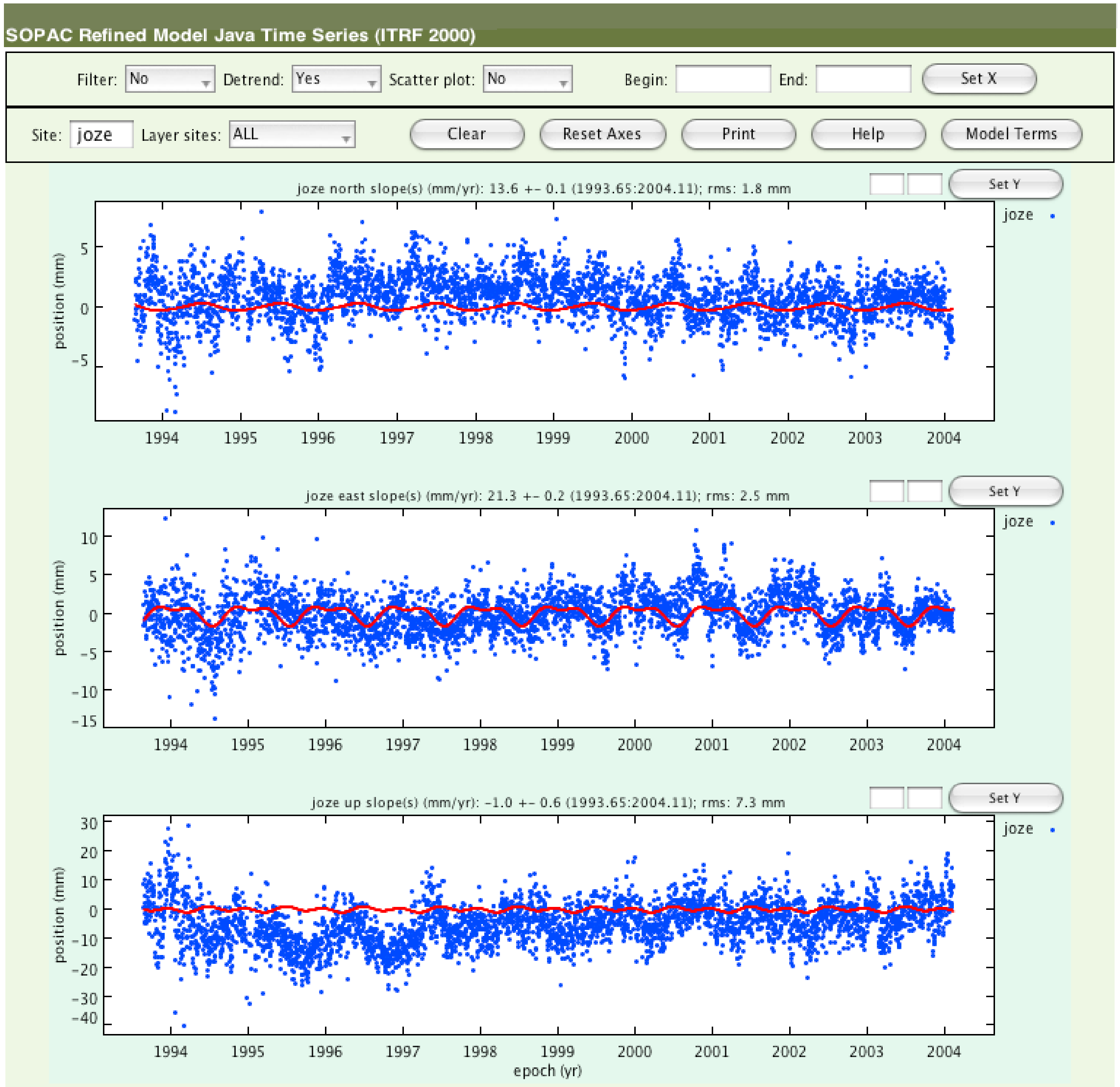
MLE analysis of 414 sites in 9 different GPS solutions

Statistical Correlations in Position Time Series



Global solutions are dominated by spatially correlated and latitude dependent flicker noise. Magnitudes of white noise and flicker noise components are a good indicator of site problems.

Decade-Long Position Time Series



High-quality site:

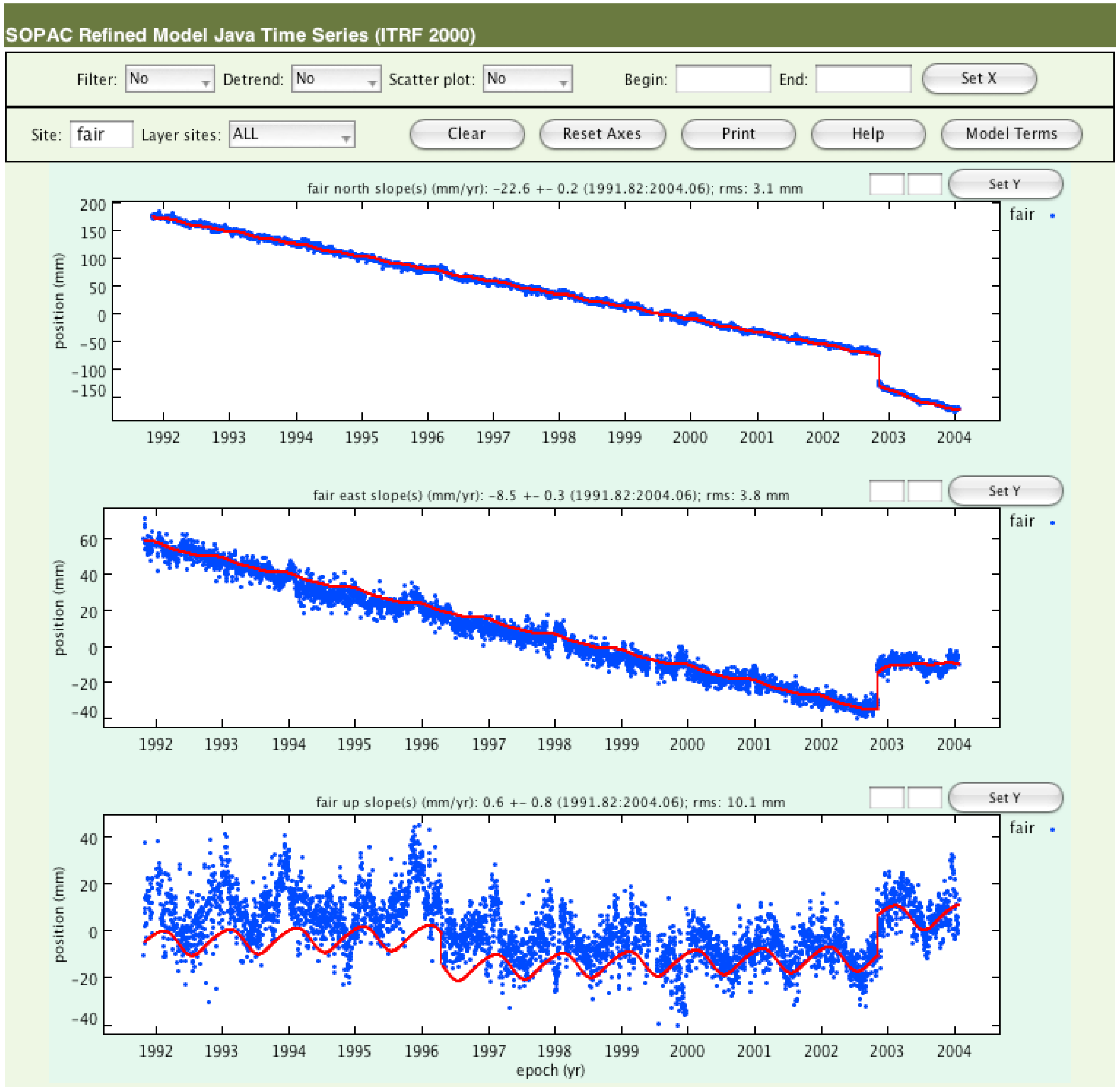
rms: 2 mm H; 7 mm V

Rate: ± 0.15 mm/yr H; ± 0.6 mm/yr V

Seasonal Effects

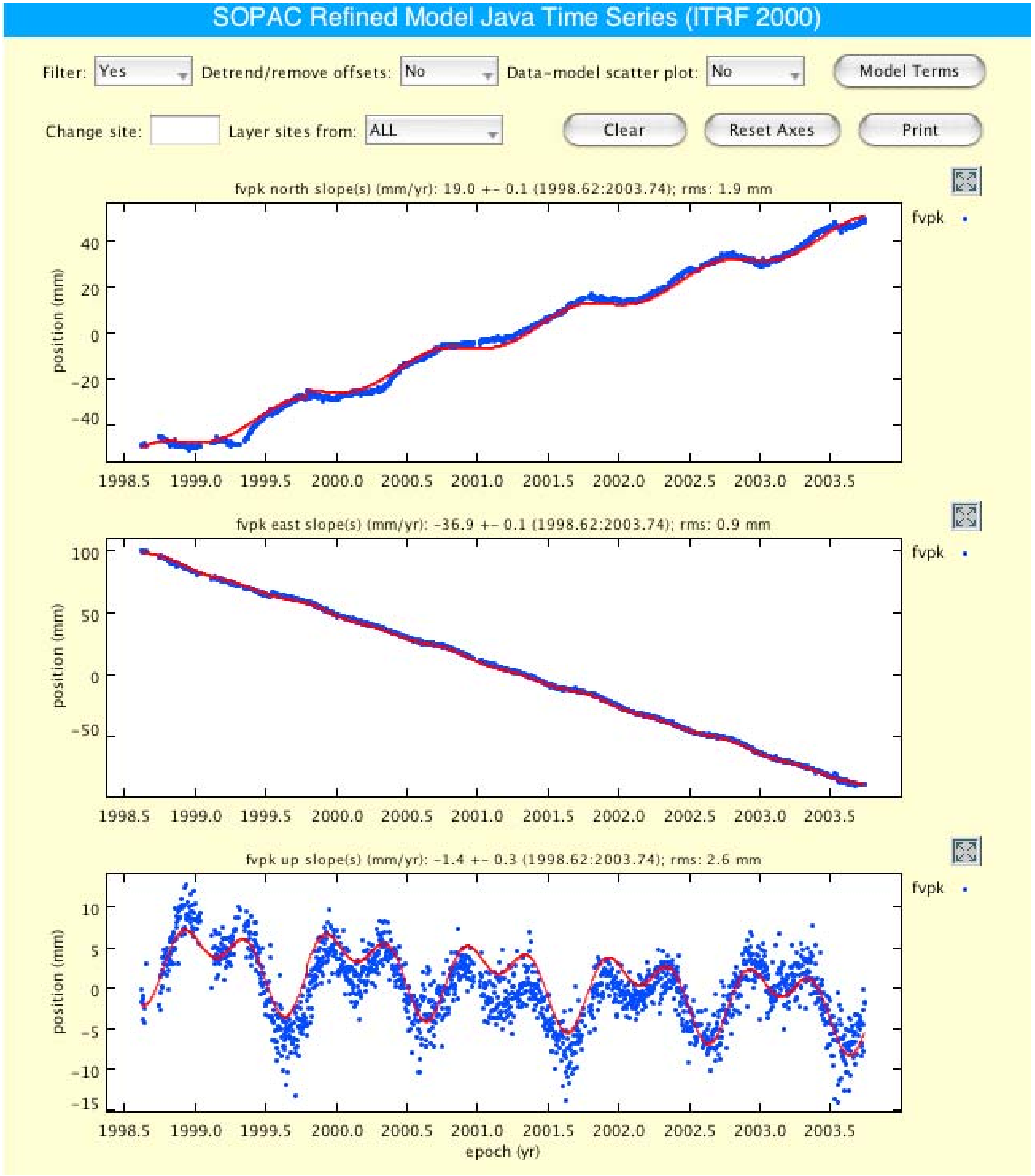
Improvement of positions with time.

Fairbanks Time Series



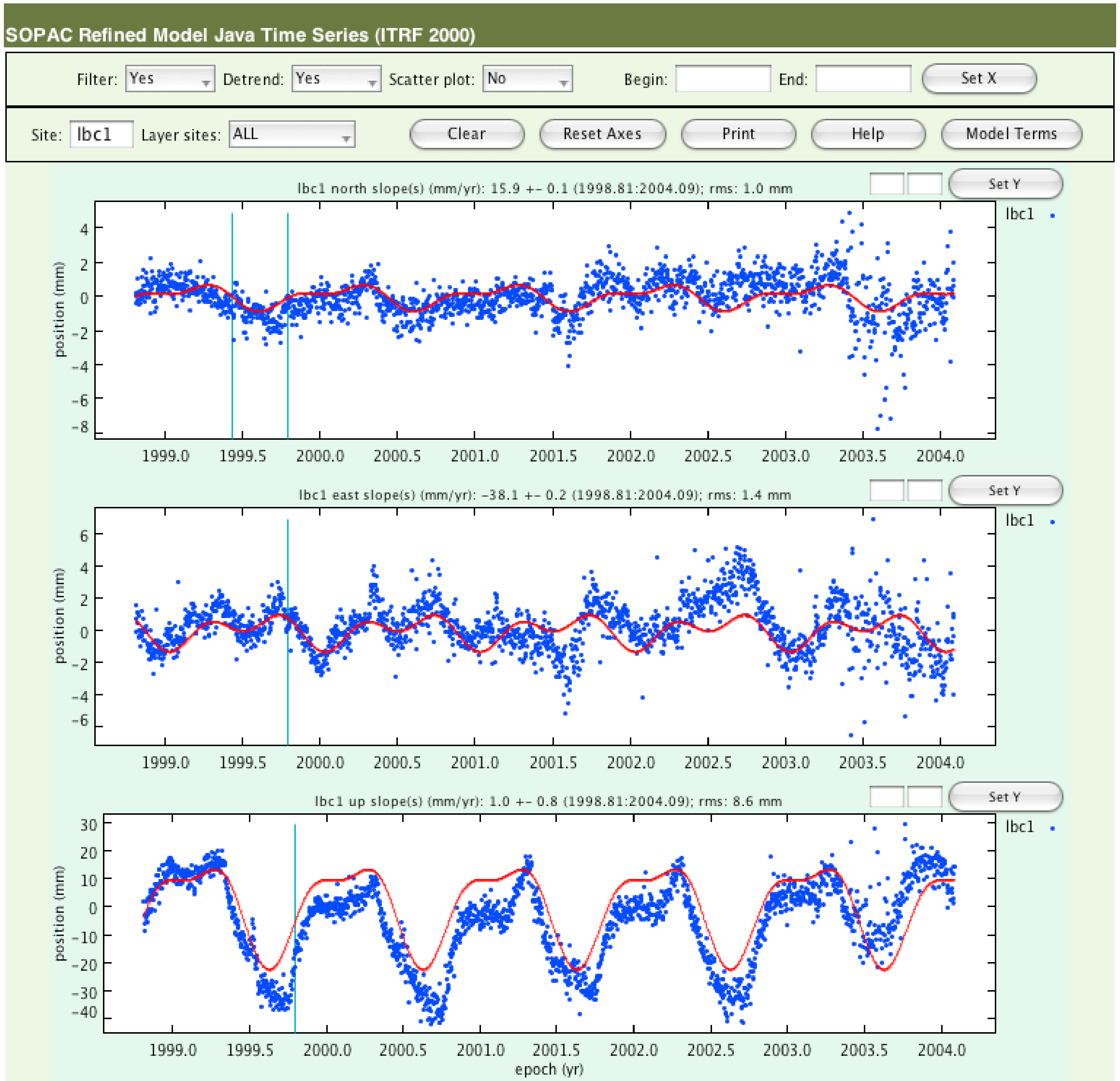
Ten-year+ velocity record disrupted by Dec 2002 Denali fault earthquake resulting in large coseismic and postseismic effects.

Environmental Effects



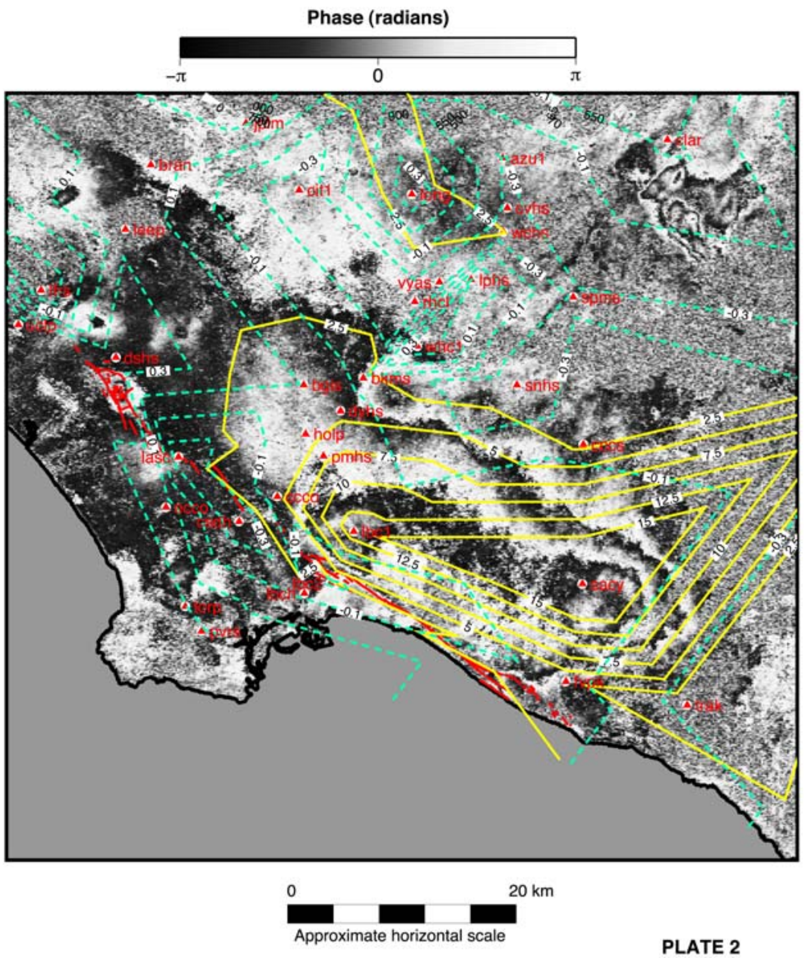
Coordinate time series for SCIGN site FVPK. Anomalous vertical <u>and</u> horizontal motions are due to annual variations in the elevation of the water table induced by groundwater pumping. Also steady subsidence effect.

Environmental Effects



Coordinate time series for SCIGN site LBC1 in southern California. Anomalous vertical <u>and</u> horizontal motions are due to extraction of fluids – water and oil.

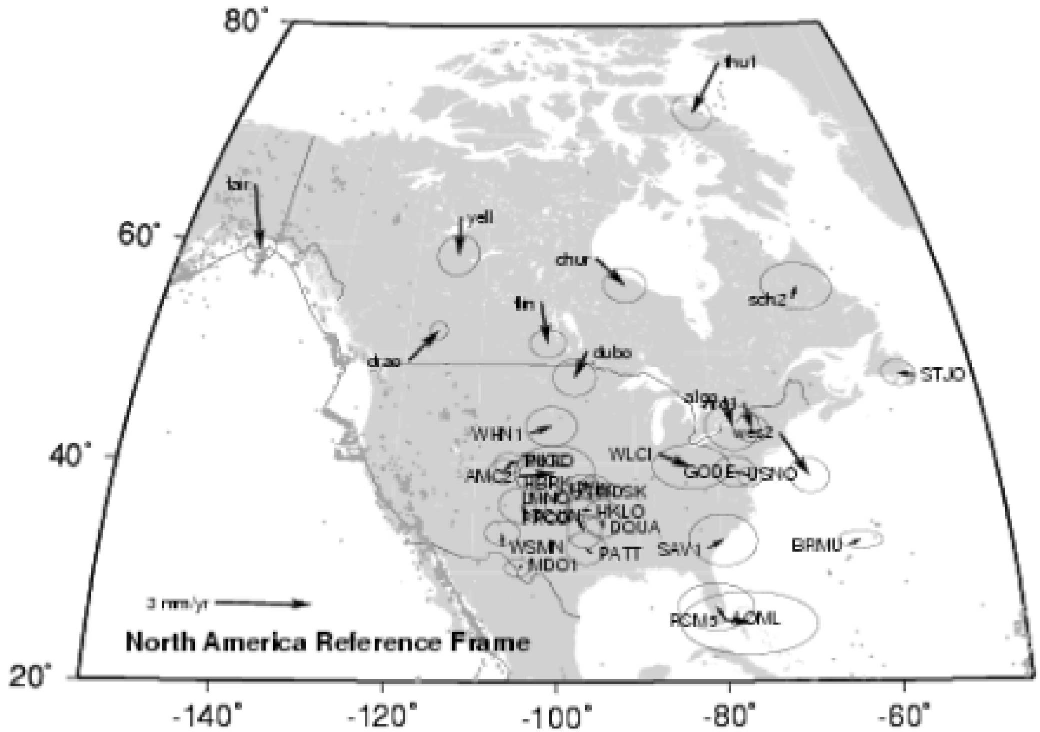
Environmental Effects



Vertical motions in Los Angeles from InSAR and GPS measurements. The LA basin becomes inflated in April which is consistent with water table measurements and the end of the rainy season. The spatial pattern of the amplitude of the annual signal (solid yellow contours in mm) derived from SCIGN sites is consistent with the shape of the interferometric SAR fringes (black/white image).

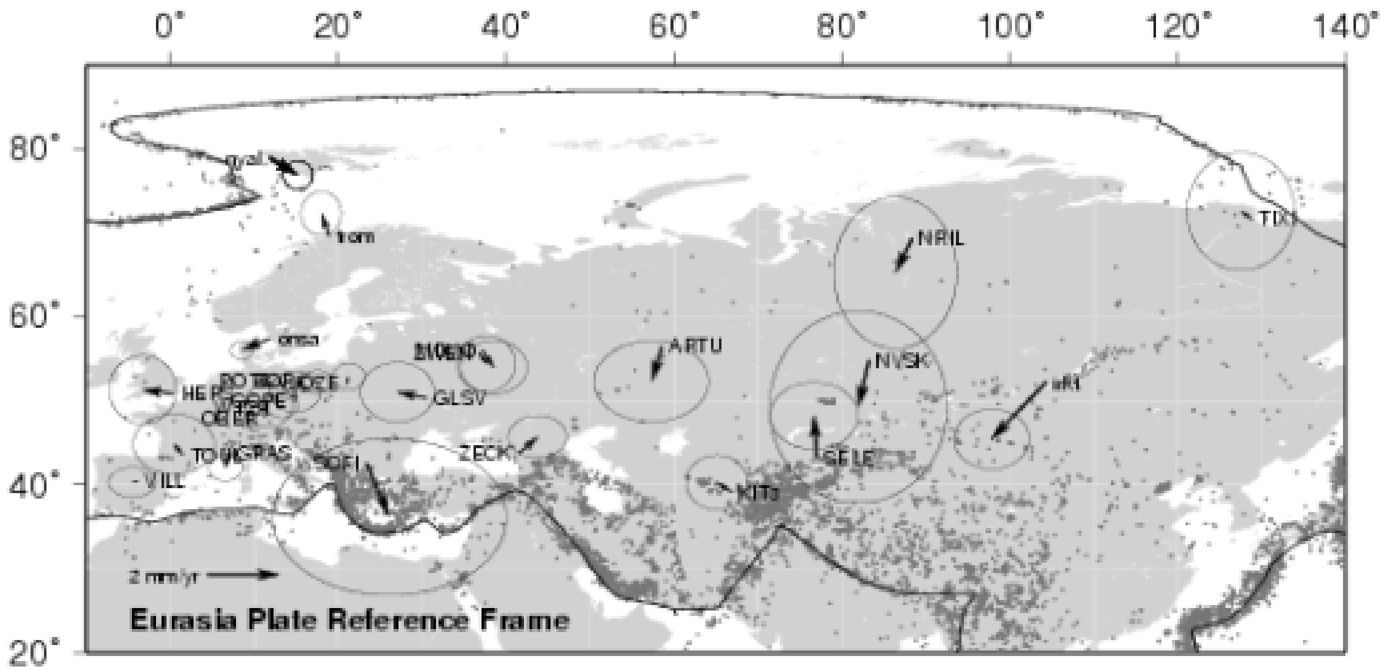
Watson, Bock, and Sandwell, JGR, 2002.

North America Frame



Residual velocities relative to North America. Stations used to define NA plate vector are labeled in capital letters. Excluded sites for seismic motions (FAIR), GIA (ALGO, CHUR, FLIN, DRAO, YELL, THU1) with horizontal bleeding.

Eurasia Frame



Residual velocities relative to Eurasia. Stations used to define Eurasia plate vector are labeled in capital letters. Excluded sites for elastic deformation (BRUS, KOSG -- Rhein Graben; IRKT – Baikal Rift), GIA (NYAL, ONSA, TROM) with horizontal bleeding.

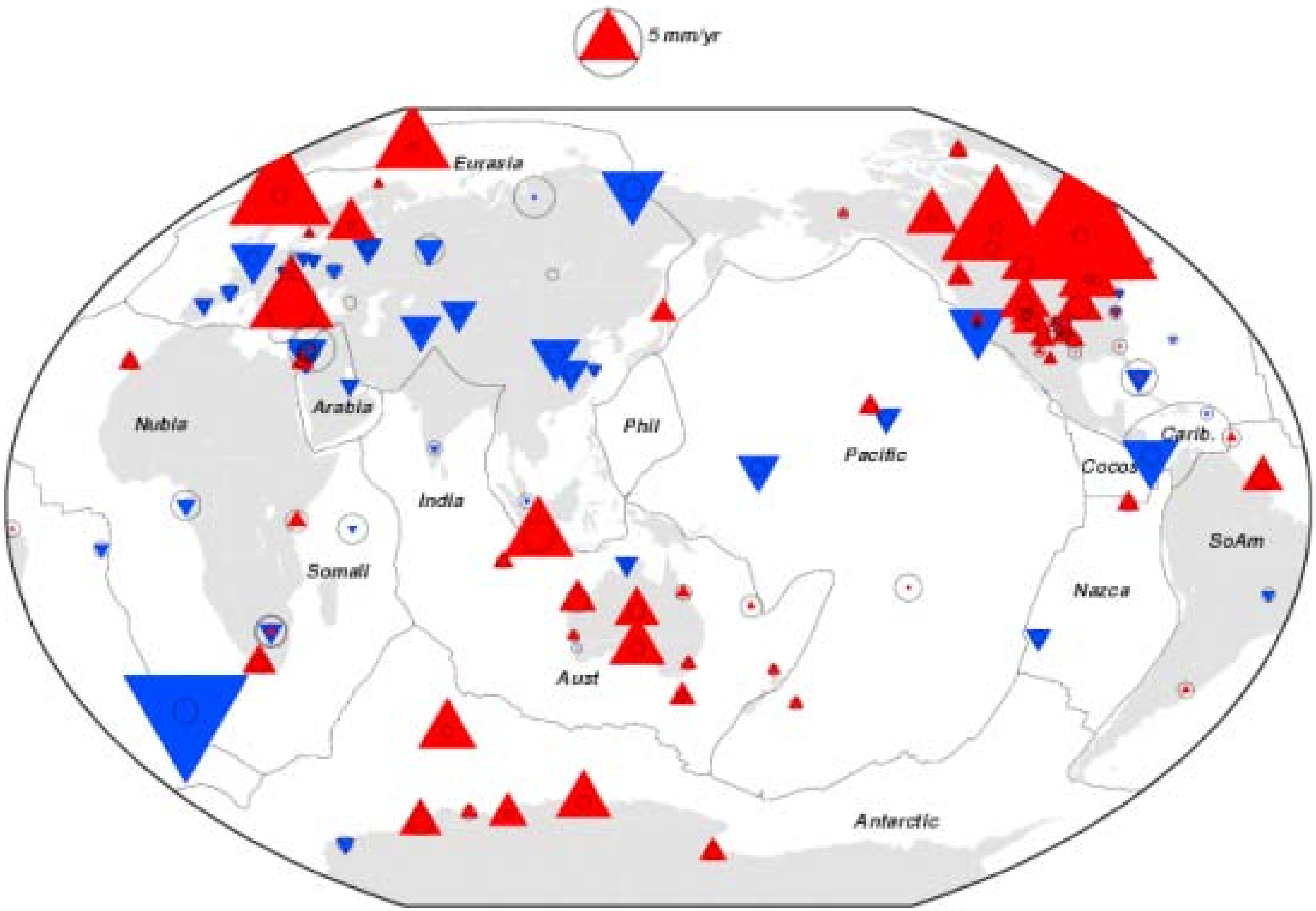
Major Plate Vectors

Table 2. Major plate angular velocities relative to ITRF2000

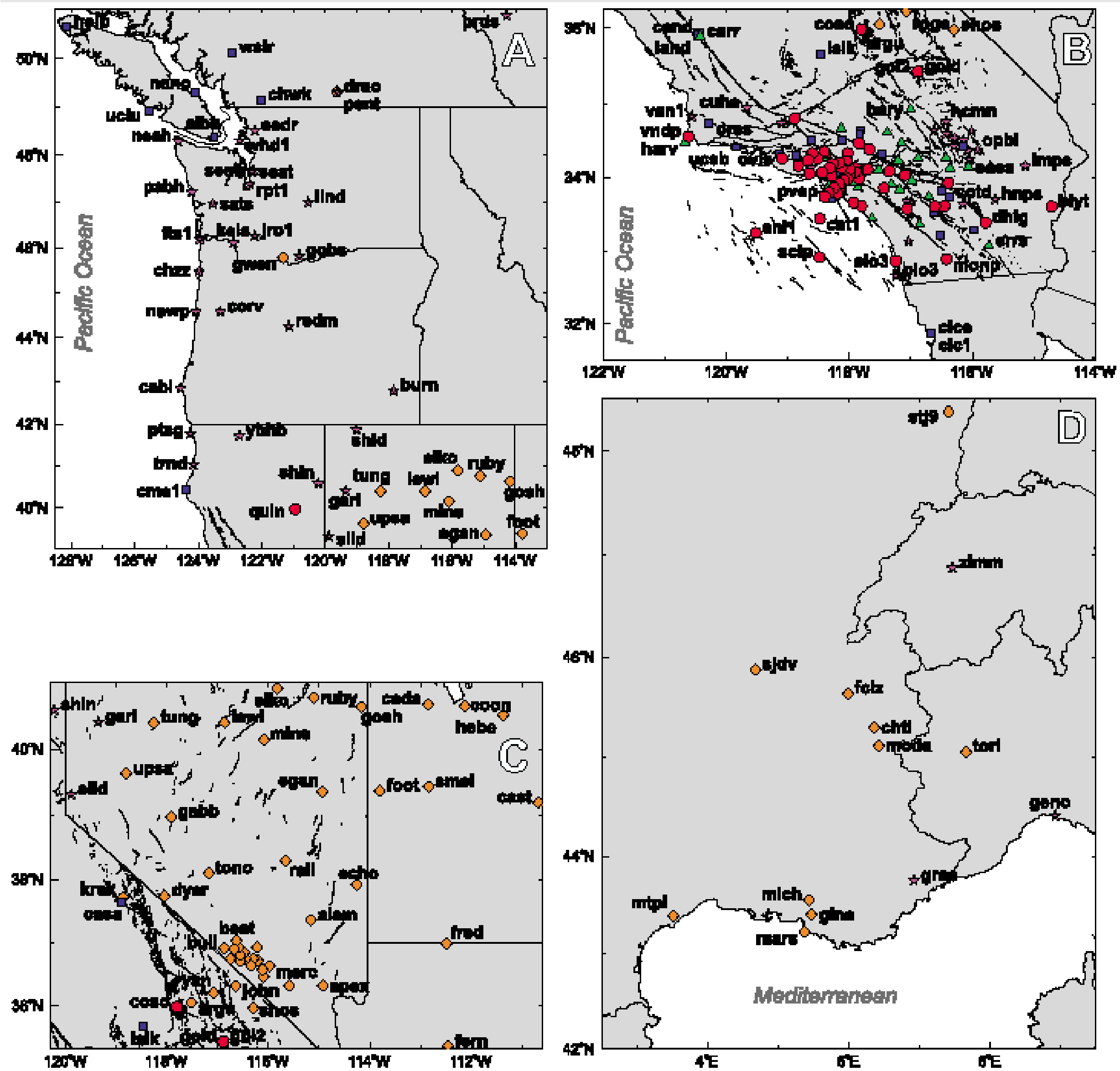
Plate	Latitude	Longitude	ω	Error Ellipse (deg.)			χ^2	N
	(deg.)	(deg.)	deg/Myr	σ_{maj}	σ_{min}	Azim.		
Anta	60.683	-125.655	0.222±0.006	0.77	0.56	8	1.6	6
Aust	33.472	37.590	0.618±0.003	0.93	0.18	154	1.2	9
Eura	57.019	-99.868	0.260±0.002	0.74	0.17	50	1.0	21
Noam	-3.583	-84.702	0.200±0.003	0.87	0.25	101	1.3	22
Pacf	-63.832	110.161	0.670±0.003	0.59	0.28	2	1.2	5
Soam	-21.086	-135.798	0.108±0.003	6.33	1.80	171	0.4	5

Plate abbreviations are given in Table 1. ω is positive for anti-clockwise rotation. σ_{maj} and σ_{min} are the major and minor axes of the pole error ellipse, with the azimuth of the major axis given CCW from East. χ^2 values, given for estimates performed in this study, refer to the sum of squared weighted residuals, normalized by the degrees of freedom. N is the number of stations used to estimate block rotation parameters.

Vertical Motions

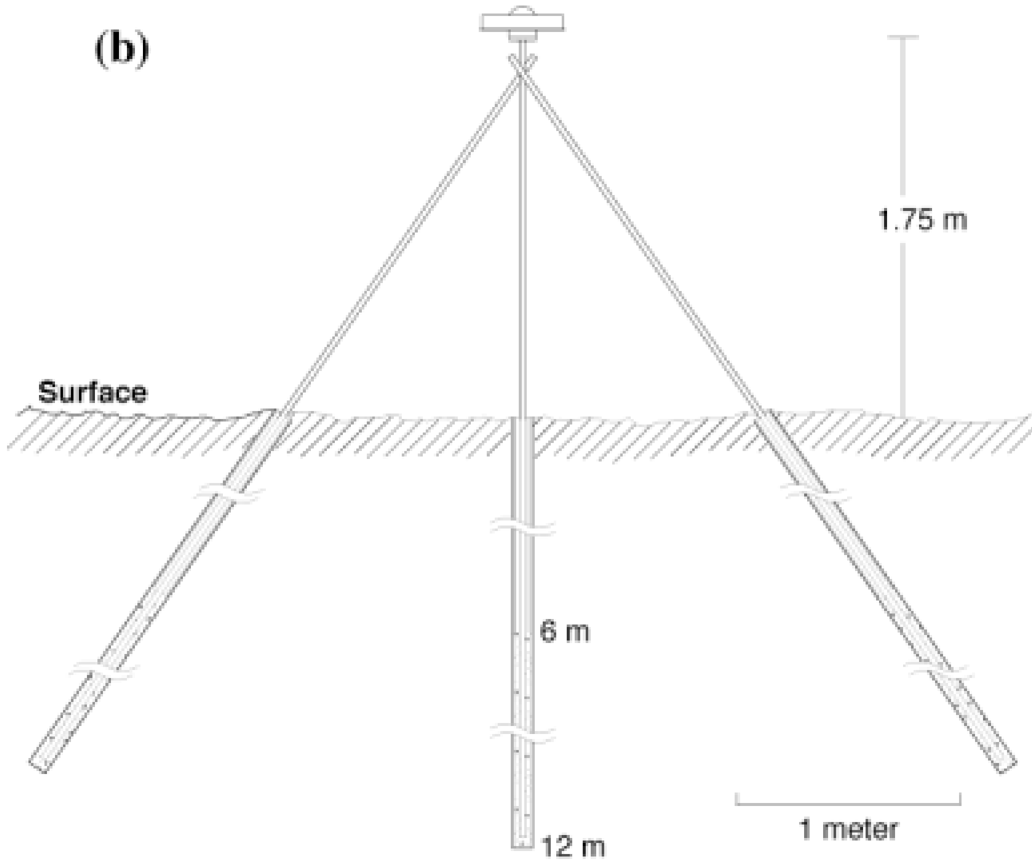


Regional Networks



Global solutions are dominated by spatially correlated and latitude dependent flicker noise. These effects can be reduced regionally by common-mode filtering. Monumentation and environmental issues become more important at regional scales.

Monumentation



SCIGN Deep Drill
Braced Monument

Monumentation Results

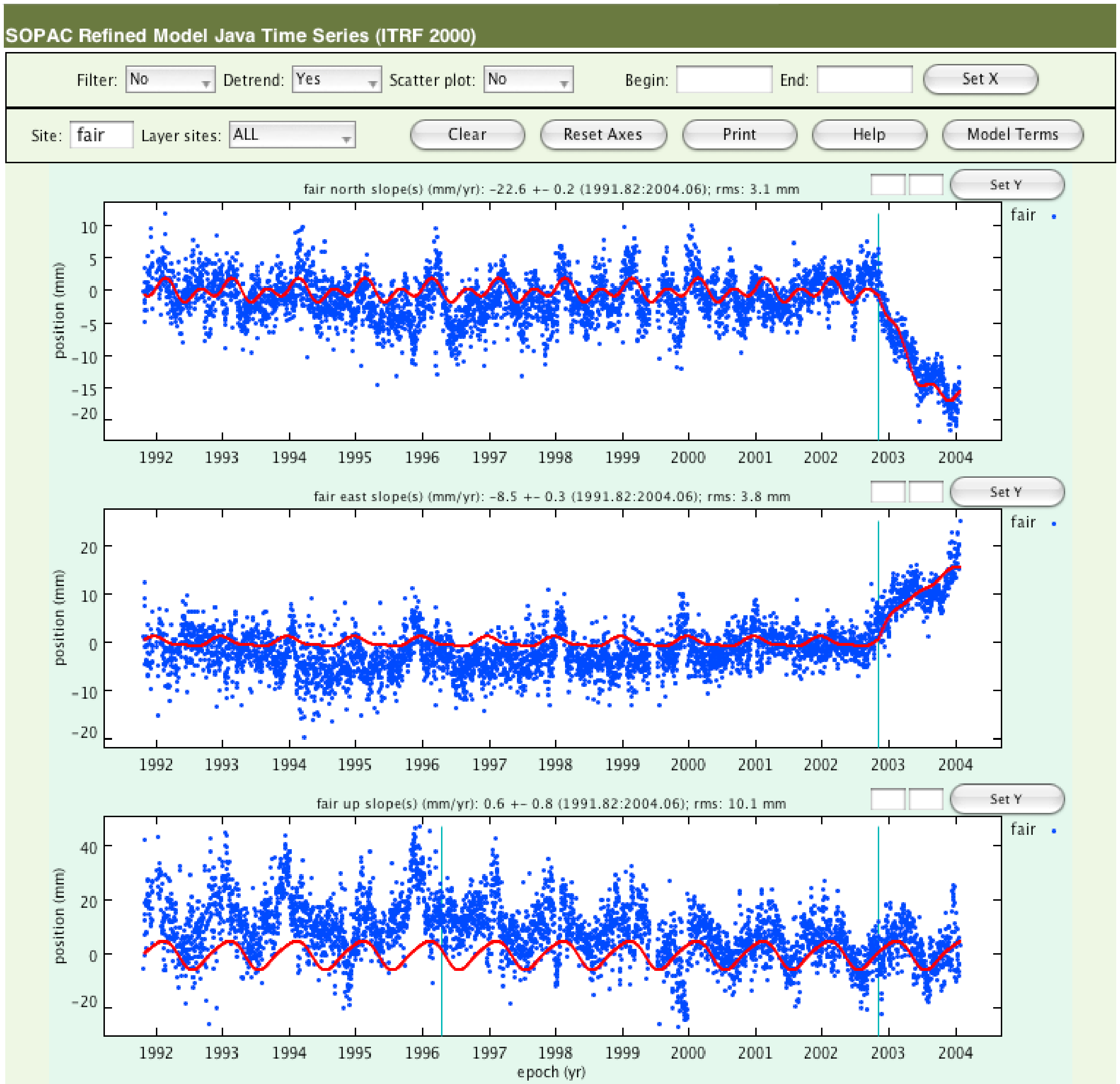
Monument Type	Number of monuments	North b_{-2} mm/$yr^{1/2}$	North MC Test %	East b_{-2} mm/$yr^{1/2}$	East MC Test %	Up b_{-2} mm/$yr^{1/2}$	Up MC Test %
Tests on Random Walk Noise Parameter (b_{-2})							
Deep Braced	96	1.6	0.0	1.6	1.4	4.2	0.0
Roof/Chimney	11	2.0	61.0	2.0	72.2	5.2	45.7
Metal Tripod	11	2.2	71.1	2.5	86.2	7.3	91.7
Rock Pin	8	2.7	89.9	2.3	80.0	7.1	86.8
Steel Tower	10	2.4	81.2	3.1	97.1	7.8	95.3
Concrete Slab	4	3.3	93.6	2.0	57.9	10.0	95.5
Concrete Pier	6	4.4	99.9	3.3	97.3	15.2	100.0
Oil Platform	1	13.3	96.6	3.9	85.1	14.0	90.9

Monument Type	Number of monuments	North T yrs	North MC Test %	East T yrs	East MC Test %	Up T yrs	Up MC Test %
Tests on Time to 1 mm/yr							
Deep Braced	96	0.6	0.0	0.6	0.0	1.3	0.0
Roof/Chimney	11	1.0	83.9	0.8	55.5	3.3	97.9
Metal Tripod	11	0.9	69.2	0.9	73.6	2.4	82.0
Rock Pin	8	1.2	90.2	0.8	64.9	3.0	92.1
Steel Tower	10	1.0	87.3	1.4	97.4	3.0	94.2
Concrete Slab	4	1.2	73.2	0.9	65.5	4.4	91.3
Concrete Pier	6	1.6	92.7	1.1	79.3	6.4	99.5
Oil Platform	1	2.1	92.5	1.2	70.0	5.9	87.0

Conclusions

As position time series get longer, improvements in the terrestrial reference frame and its maintenance will depend more on minimizing environmental and monumentation problems. Thus, global sites need to be upgraded to the same standards as the best regional networks (e.g., PBO).

Fairbanks Time Series - Detrended



rms: 3-4 mm H; 10 mm V

Rate: ± 0.2 mm/yr H; ± 0.8 mm/yr V

Seasonal Effects, Coseismic and Postseismic Deformation

Fairbanks Model Terms

Refined Model Terms (neu) [Documentation]

```
site: fair

                    n component
    slope 1: -22.38 +/- 0.03 mm/yr (1991.8206 - 2004.0642)
 ps decay 1:  19.83 +/- 0.91 mm (2002.8425); tau: 190 days
 * offset 1: -53.36 +/- 1.00 mm (2002.8425)
     annual:   0.92 +/- 0.17 mm; phase: 0.63
semi-annual:   1.16 +/- 0.16 mm; phase: 1.83

                    e component
    slope 1:  -8.21 +/- 0.02 mm/yr (1991.8206 - 2004.0642)
 ps decay 1: -15.46 +/- 0.77 mm (2002.8425); tau: 190 days
 * offset 1:  21.74 +/- 0.85 mm (2002.8425)
     annual:   0.94 +/- 0.14 mm; phase: 0.18
semi-annual:   0.39 +/- 0.14 mm; phase: 5.79

                    u component
    slope 1:  -0.98 +/- 0.07 mm/yr (1991.8206 - 2004.0642)
   offset 1: -11.62 +/- 0.47 mm (1996.2937)
 * offset 2:  17.13 +/- 0.43 mm (2002.8425)
     annual:   5.34 +/- 0.23 mm; phase: 0.26
semi-annual:   1.09 +/- 0.23 mm; phase: 3.35

----------------------------------------------------------
          *: coseismic offset
   ps decay: postseismic decay
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