A GLOBAL SOLUTION FOR PLATE KINEMATICS

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Recent advances in space geodetic analysis include enhanced numerical modeling capabilities and improvements in many of the physical models used to analyze Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI) and Global Positioning System (GPS) data. This progress will ultimately allow for the efficient simultaneous determination of epoch geodetic positions and site kinematic motion from these observations. We present a new interim solution, in which improved a priori models and constants have been adopted, and in which the following relative rate data sets have been combined to form the solution for site kinematics: (1) LAGEOS I SLR rates based on observations spanning 14 years (1980-1994) (2) VLBI rates based on 13 years (1980-1993) of observations and (3) GPS rates based on 2 1/2 years (1991-1993) of IGS observations. The kinematic frame for the solution is defined through the adoption of NUVEL-1A no-net-rotation velocity for three sites nominally located on the North America plate. The results from the new solution are compared with geophysical models of station motion and indicate that the correction for geochronologic time scales absorbs the discrepancy in relative rates noted previously.

The determination and monitoring of the kinematic behavior of points on the Earth's surface provides important information that is useful in constructing comprehensive dynamic models of regional scale and global scale tectonics. Here, we wish to report on the latest results from a combination solution for the motions of Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI) and Global Positioning System (GPS) observation sites distributed around the world. The solution presented here provides an extension and update to previous combination solutions [*Robbins et al.*, 1993, *Torrence et al.*, 1994]. The present solution combines relative rate information and their uncertainties following the network adjustment procedure outlined in *Robbins et al.* [1993]. The relative rates span 51 SLR sites, 58 VLBI sites and 41 GPS sites. Many of these sites are shared across technologies. Figure 1 shows the locations of the sites involved; those with vectors attached are the sites to be discussed here. Those without vectors mark the locations of DORIS and TRANET tracking sites for which tectonic motions will be estimated in future solutions.

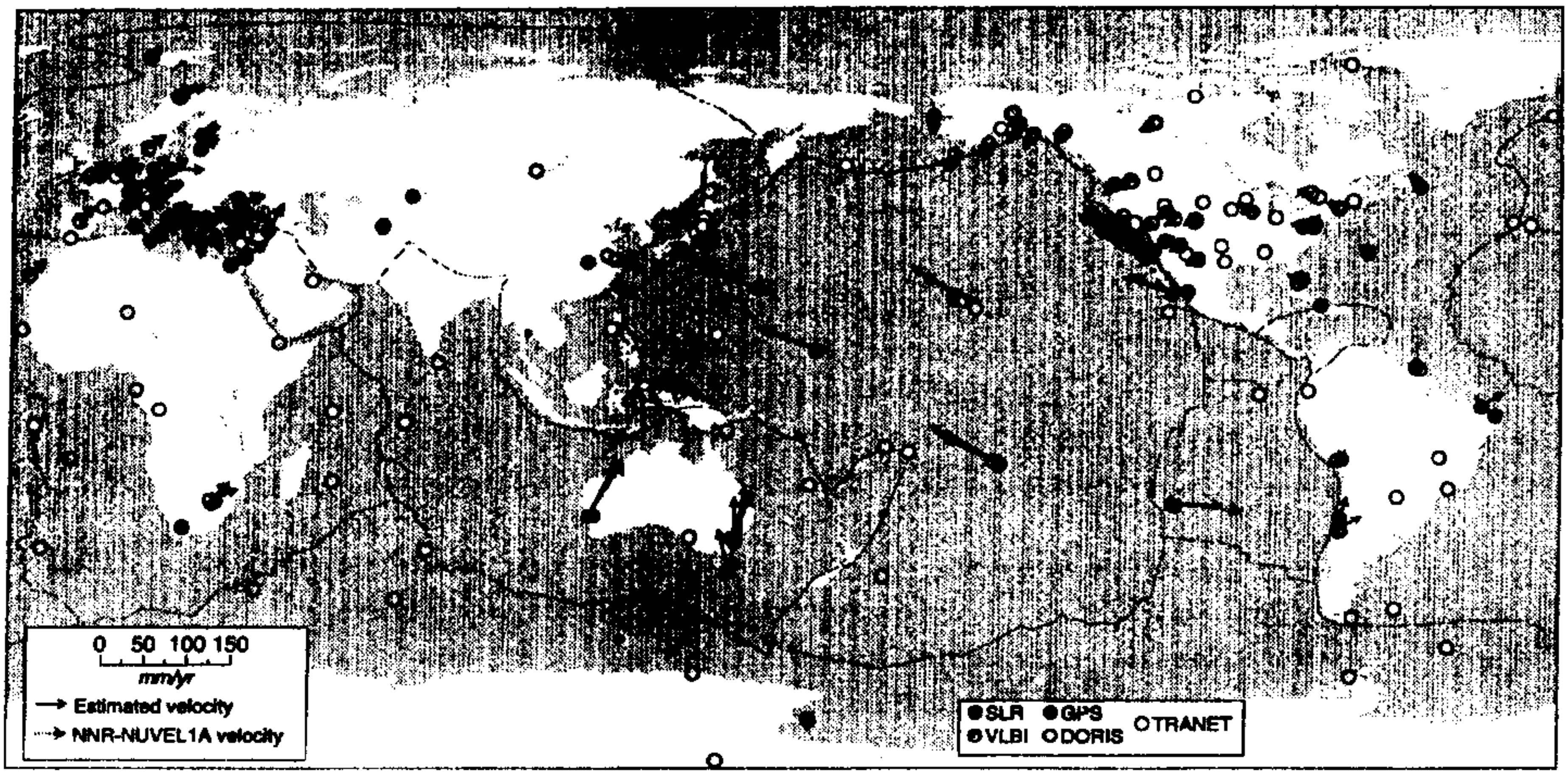

Figure 1. Locations of the SLR, VLBI and GPS tracking sites used in this study. Please refer to Figures 2 through 5 for more detailed velocity maps. Additionally, the locations of DORIS and TRANET sites are shown. In the near future, a combination solution will be developed linking all five of these technologies.

The relative rates used as the input parameters for this combination solution were derived from estimates of horizontal velocities independently determined by each technology. The SLR rates come from the SL8.6 solution which is based on more than 14 years of SLR observations spanning 1980 to mid-1994 [*Robbins et al.*, 1994]. The VLBI rates are from the GLB932 solution computed by the VLBI analysis team at Goddard Space Flight Center. This solution is the same as that submitted to the International Earth Rotation Service in early 1994. It spans the period between 1980 through 1993. The GPS solution comes from the Jet Propulsion Laboratory. It spans 2 1/2 years (Jan., 1991 to Sept., 1993) of International GPS Service (IGS) observations and was described by *Heflin et al.* [1993]. The GPS relative rates are unchanged from those used in *Torrence et al.* [1994].

Utilizing the algorithm described by *Robbins et al.* [1993], the relative rates were combined to form a least-squares solution for site velocities. This was done within a kinematic reference frame defined by the adoption of the NUVEL-1A model [*DeMets et al.*, 1994] placed in a No-Net-Rotation (NNR) frame [*Argus et al.*, 1991] to describe the motion for the sites: Greenbelt, Maryland (SLR & GPS); Westford, Massachusetts (SLR, VLBI & GPS) and Gilmore Creek, Alaska (VLBI and GPS). All of these sites nominally lie on the North America Plate; therefore, the definition of the kinematic frame is based on a single plate. The motions for the remaining sites in the global network refer to this frame.

In Figures 2 through 5, the site motions are shown in detail by region along with their predicted motions from the NNR-NUVEL1A model. The motion vectors estimated here are shown with error ellipses representing 1-σ uncertainties. In general, the largest error ellipses

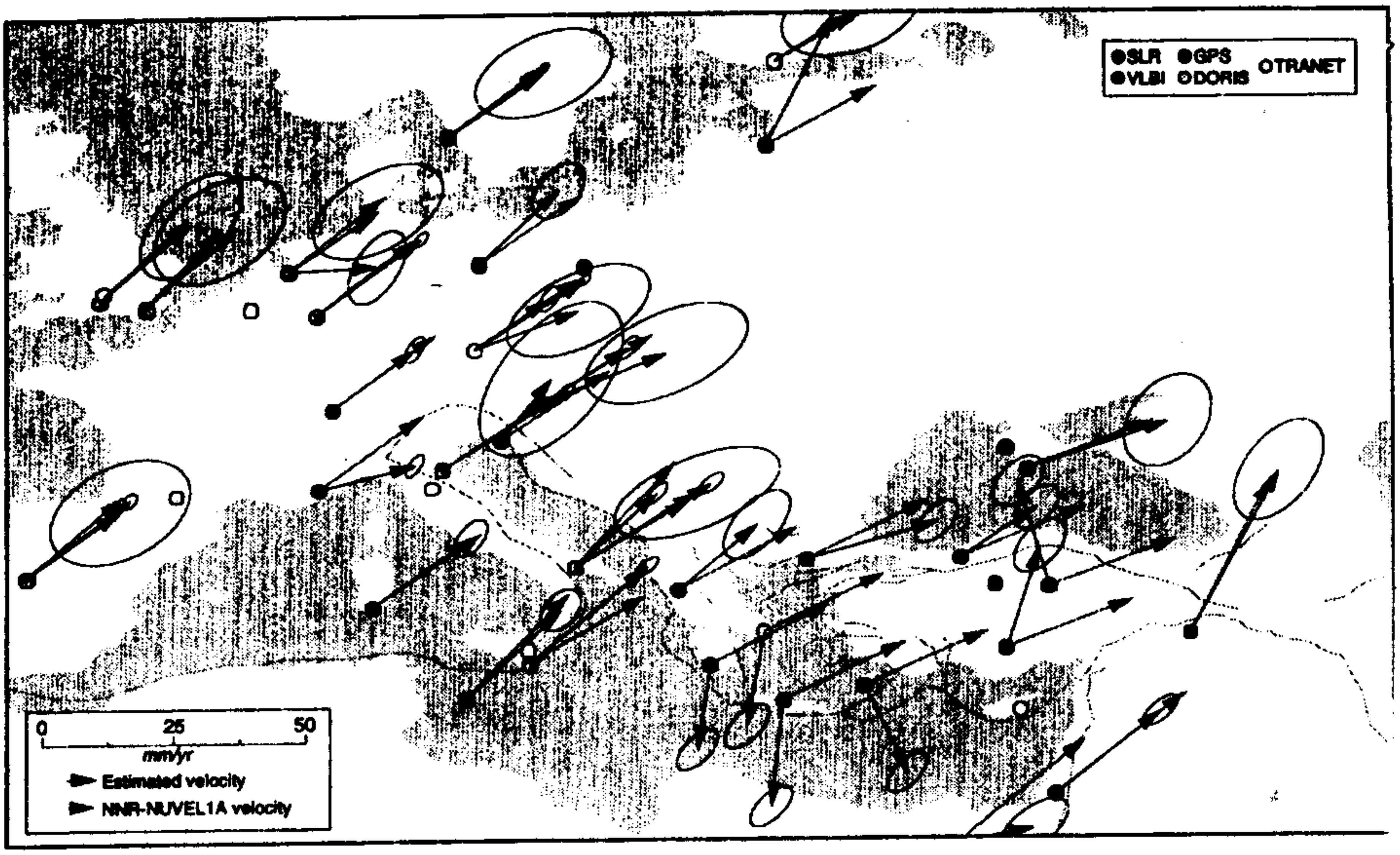

Figure 2. Vector motions of SLR, VLBI and GPS tracking sites in Europe. The NNR-NUVEL1A velocities are given for each site based on the plate upon which they reside. Error ellipses represent 1-σ uncertainties.

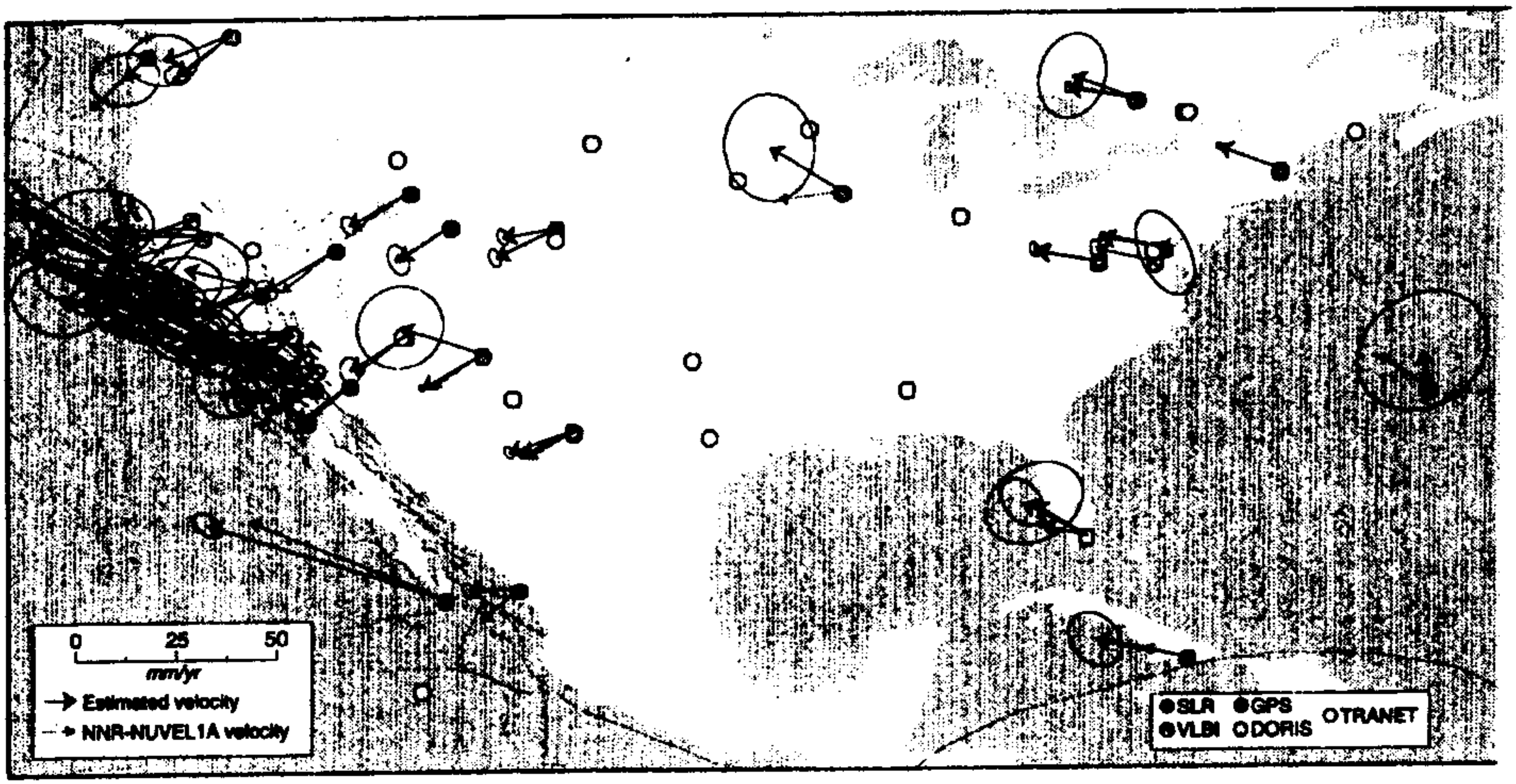

Figure 3. Vector motions of SLR, VLBI and GPS tracking sites in North America. See Figure 4 for detail in western North America. The NNR-NUVEL1A velocities are given for each site based on the plate upon which they reside. Error ellipses represent 1- σ uncertainties.

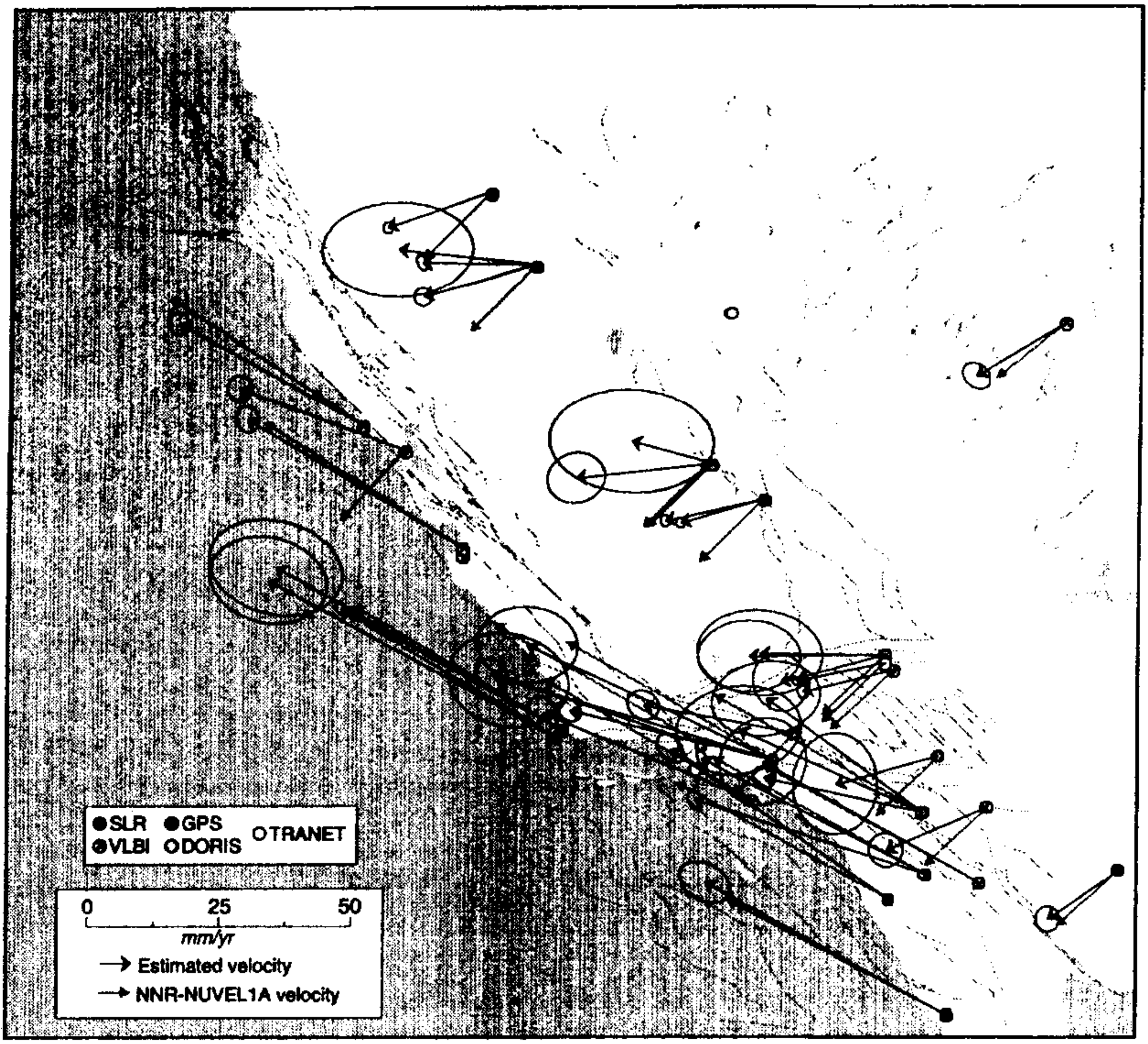

Figure 4. Vector motions of SLR, VLBI and GPS tracking sites in western North America. The NNR-NUVEL1A velocities are given for each site based on the nominal plate upon which they reside. Error ellipses represent 1-σ uncertainties.

are associated with GPS determined results. This is due to the short time span for which GPS observations have been taken at the IGS sites. However, the GPS results generally agree (to within their uncertainty) with the other technologies for those locations where a comparison can be made. A comprehensive tectonic interpretation of these results would require a fairly lengthy paper. For general overviews, we refer the reader to *Robbins et al.* [1993] and *Robaudo and Harrison* [1993]. We will highlight here, only a small part of these results and their implications.

The subduction of the Philippine and Pacific plates under the Eurasian plate provides the forcing mechanisms related to the intense seismic activity and volcanic processes which dominate the land forms across the region. In Figure 6, velocity vectors for the tracking sites across the region are shown relative to Eurasia. It can be easily seen within this frame that the motion from the subduction is transferred into the over-riding plate. This is particularly notable

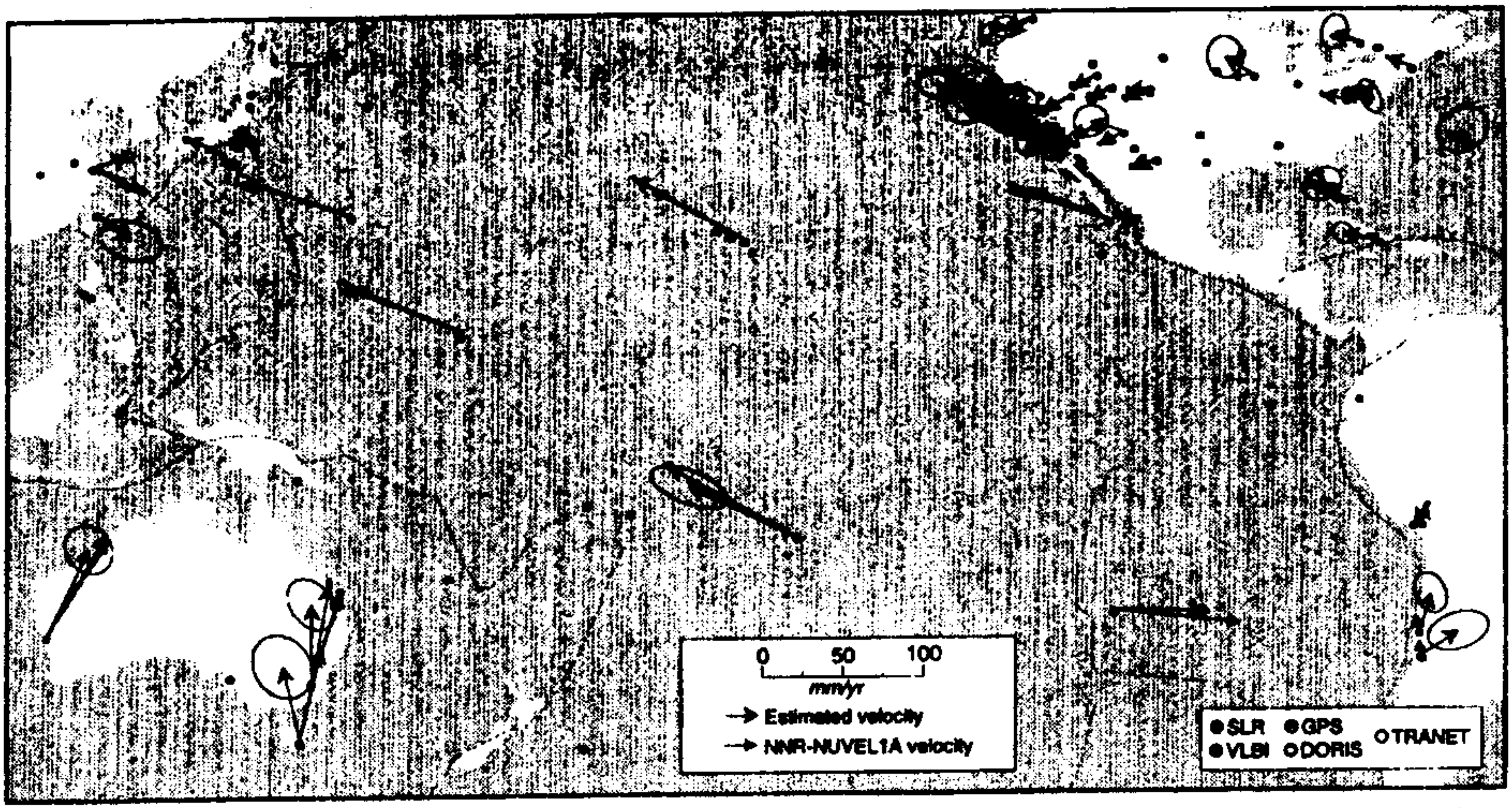

Figure 5. Vector motions of SLR, VLBI and GPS tracking sites across the Pacific Basin. The NNR-NUVEL1A velocities are given for each site based on the nominal plate upon which they reside. Error ellipses represent 1- σ uncertainties.

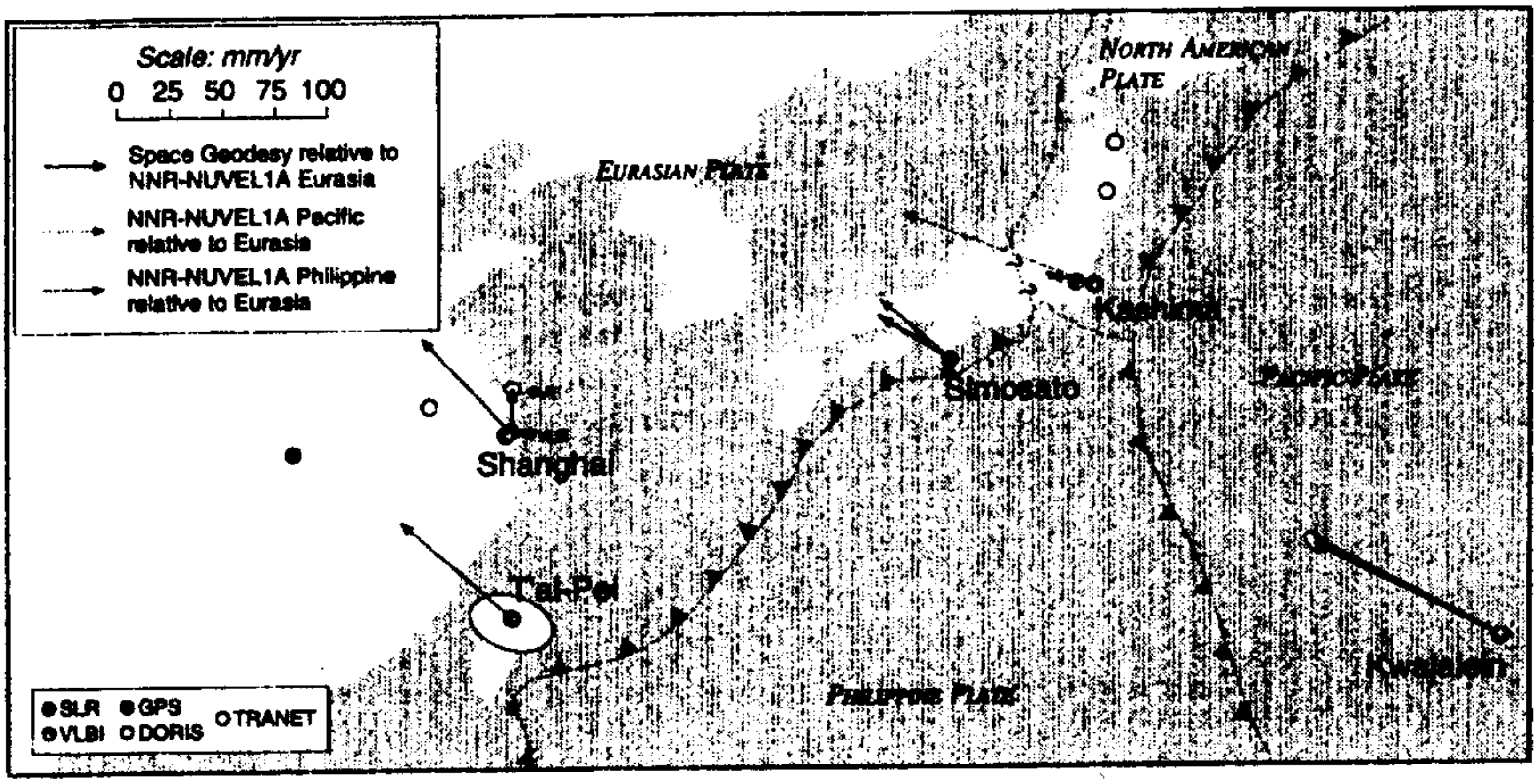

Figure 6. Vector motions of SLR, VLBI and GPS tracking sites in the Far East. The space geodetic estimated vectors and the NUVEL-1A vectors are given with respect to Eurasia as noted. Error ellipses represent 1- σ uncertainties.

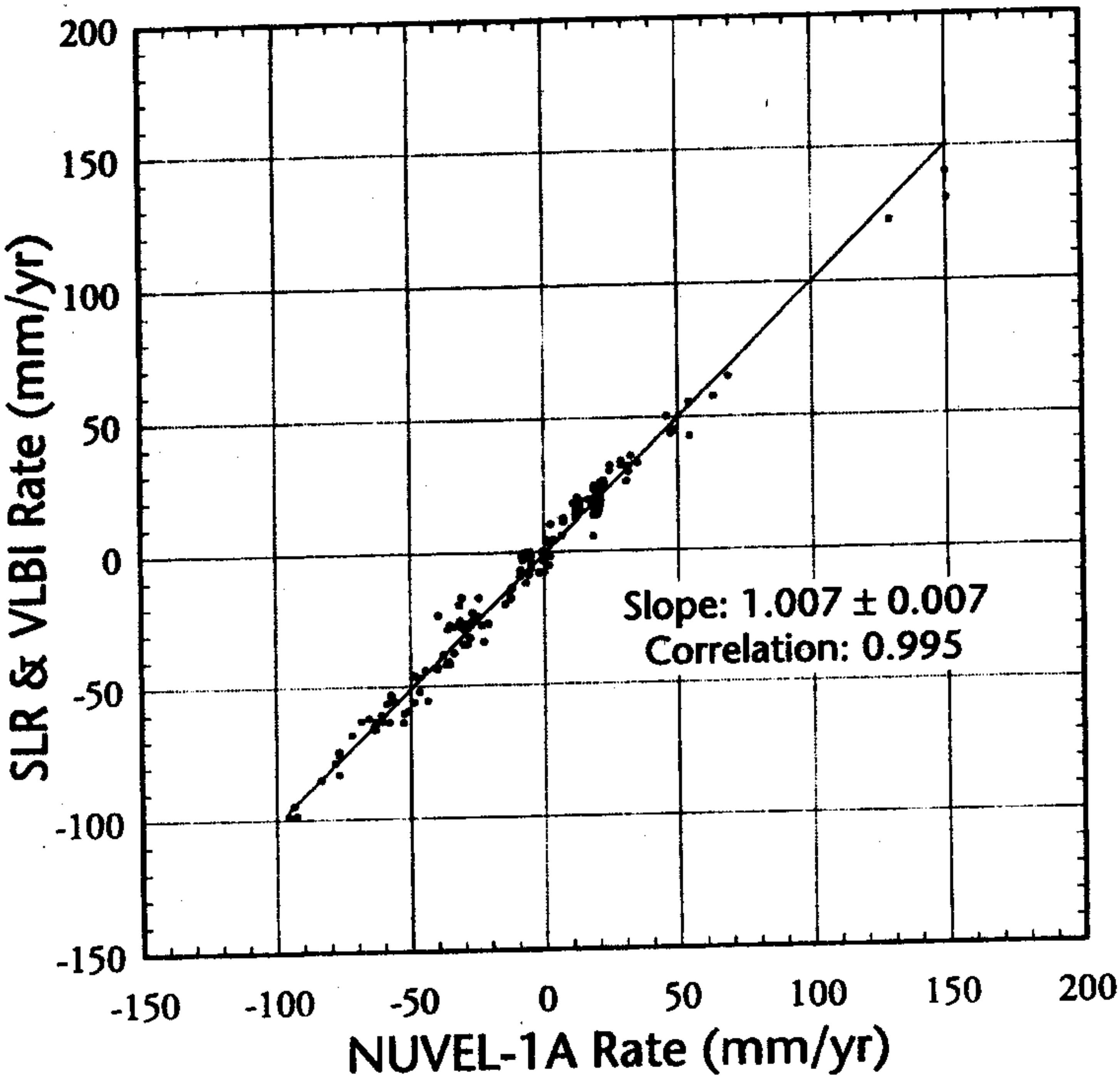

Figure 7. Correlation chart comparing relative rates from SLR and VLBI with those predicted by the NUVEL-1A [DeMets et al., 1994] model. 23 sites located well away from plate boundaries on 6 plates were used to provide 182 relative rates which sample 15 plate boundaries. A slope of 1 indicates that the three million year average rates agree with the 14 year rates determined from space geodesy.

for Simosato, Japan and partly so for Kashima, Japan as was noted in *Robaudo et al.* [1993] and *Robbins et al.* [1993]. However, the results for T'ai-Pei, on the island of Taiwan, and Shanghai, in mainland China, show little suggestion of strain transfer. In the case of Shanghai, one might not expect much strain transfer since Shanghai is well over 800 km away from the Nansei Shoto trench axis which separates the Philippine and Eurasia plates. At T'ai-Pei, there might be some expectation of transferred strain since the site is about 300 km from the trench axis, but, at this time, the GPS result cannot clearly distinguish any motion of this sort.

Finally, we show in Figure 7, the correlation chart which compares the relative rates estimated from 14 years of space geodetic tracking (SLR and VLBI) with the three-million year averaged relative rates predicted by the NUVEL-1A model. This latest geological model takes into account revisions to the geochronologic time scale which caused the original NUVEL-1 model

[*DeMets et al.*, 1990] to be systematically too young (and therefore, slower) by approximately 6% [*DeMets et al.*, 1994]. A discrepancy between space geodetic rates and NUVEL-1 rates had been noted in past analyses [*Smith et al.*, 1990 and *Robbins and Smith*, 1990] and the correction to the geochronologic time scale essentially removes this discrepancy. The obvious conclusion is that plate motions seem not to vary as a function of the scale of time, at least with respect to recent geologic time. This means that large-scale plate motions appear to occur as a continuous process as opposed to being more episodic in nature.

In the near future, solutions will be made to estimate tectonic motions of tracking sites involving the use of tracking data and relative rate information from five distinct space geodetic technologies. As seen from the distribution of sites in Figure 1, the results from such a solution will provide valuable information regarding the current kinematics of regions of the world which have remained poorly sampled by space geodetic technologies.

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