# One Decade of Strain in the Southern Cascadia Margin: Collaborative Research Between Humboldt State University and University of Alaska, Fairbanks

External Grant award number 01HQGR0152

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Program Element: Element II

Key Words: Neotectonics, Strain Measurements, GPS-Continuous, GPS-Campaign

## Investigations Undertaken

To investigate the transition zone between the northern San Andreas fault system and the southern Cascadia subduction zone, Humboldt State University and the University of Alaska-Fairbanks have been collecting GPS survey data in northern coastal California at locations initially surveyed in the early 1990's by various other groups. In 2002, Humboldt State University and University of Alaska-Fairbanks continued data collection and analysis of GPS survey data in northern coastal California. All raw GPS observations collected to date have been processed and final GPS station velocities have been estimated. See our submitted Final Technical Report for detailed analysis and processing procedures, surveyed sites and results.

This study builds upon initial GPS observations collected by the California Department of Transportation (CalTrans)(1993, 1994, 1998), the National Geodetic Survey (NGS)(1994, 1998), Stanford University (1994, 1995; Freymueller et al., 1999) and the U. S. Geological Survey (1996, 1999; Poland et al., 1999; J.Svarc, 2001, personal communication). Original data come from new observations made in 1999-2002. In 1999, many institutions and agencies helped collect data from 8 stations in northern California and southern Oregon. In 2000, Humboldt State University (HSU) surveyed 7 stations and installed 2 new stations for a total of nine stations. In May of 2001, HSU and University of Alaska-Fairbanks (UAF) completed a 2 week campaign-mode GPS survey where 31 stations were surveyed. Between July, 2001 and January 2002, 16 additional stations were surveyed. Of the 47 stations observed in the 2001 GPS campaigns, 19 of those stations were re-observed in the Summer and Fall of 2002 (Figure 1). In addition, 4 new stations were installed in 2002 and surveyed with GPS equipment for the first time (Figure 1). Processing follows procedures summarized in the Appendix of the submitted Final Technical Report. Most benchmarks resurveyed in this study are those of the California High Precision Geodetic Network (HPGN) jointly established in 1991 by CalTrans and the NGS.

An earthquake sequence from September through December, 1994 occurs within the time span of GPS observations. A $M_w$ 7 earthquake occurred Sept. 1, 1994, > 100 km offshore of Cape Mendocino (Dengler et al., 1995). Observed coseismic displacements (Dengler et al., 1995; M.H. Murray, 2000, personal communication) are used to interpolate displacement values for HPGN stations used in this analysis that do not have post-earthquake information (Figure 2). Interpolated values are used to adjust coordinates of sites surveyed immediately before the time of the earthquake, and the 'new' adjusted coordinates are used in the final velocity estimation (Figure 3).

GPS-derived station velocities (1993-2002) from 71 sites in North America help characterize deformation in northern coastal California and surrounding regions relative to stable North America (Table A). Average station velocity uncertainties are ~ 2 mm/yr (east-west) and ~1 mm/yr (north-south) at the 2-sigma (95%) confidence interval (Figure 3; also see Final technical Report).

**Results**

Based on GPS-derived station velocities (1993-2002) (Figure 4A), rates of deformation immediately south of the Mendocino triple junction are approximately 30 mm/yr directed to the northwest, whereas stations ≥40 km north of the Mendocino triple junction are moving approximately 10-15 mm/yr to the northeast. The transition zone from the northern SAF system begins across the Eel River Valley (near Ferndale, CA), and may be coincident with the southernmost active thrust faults within the upper plate (near Loleta, CA). GPS velocities sub-parallel to Gorda-North America convergence are consistently observed beginning immediately south of Trinidad, CA. This indicates that the transition from predominately translational strike-slip to predominately convergent subduction tectonics occurs over an ~ 80 km distance from the Eel River delta in Ferndale, CA to Trinidad, CA.. This transition zone experiences both types of deformation, strike-slip inland and contractional near the coast (Kelsey and Carver, 1988).

Using an elastic dislocation model to remove subduction-derived interseismic velocities from the observed GPS-derived velocities (Flueck et al., 1997) (Figure 4B), P-NA relative motion persists as much as ~ 40 km north of the latitude of the offshore Mendocino fault. Pacific-North America relative motion at Cape Mendocino (26.2 ± 0.6 mm/yr) is approximately half that observed at Pt. Reyes (46.6 ± 2.0 mm/yr) near San Francisco, consistent with its position east of the San Andreas fault. Progressive westward increases in station velocities at the latitude of Cape Mendocino (0106 to CME1, Figure 4) reflect dextral shear across the inland fault strands of the northernmost San Andreas fault zone. Station velocities increase across the northern Lake Mountain fault zone (6.4 ± 3.4 mm/yr) and across the northward projection of the Garberville fault zone (5.3 ± 3.5 mm/yr) (Figure 3). The observed relative station motion is more concentrated in the vicinity of the Lake Mountain fault zone and more distributed in the west near the northern Garberville fault zone.

Northern Sierra Nevada-Great Valley block motion is ~ 11 mm/yr directed to the northwest and continues northwest to within ~50 km of the coast at the latitude of Humboldt Bay. The direction of Sierra Nevada-Great Valley motion is obliquely convergent to the Pacific-North America relative motion direction (Figure 4B). Convergence of Sierra Nevada-Great Valley motion with the Klamath Mountains and the Coast Ranges begins ~ 130 km inland of the coast near Weaverville, CA (0217, Figure 4B). Even after removing the interseismic velocities, the northwestern end of the SNGV block, acting through the Klamath Mountains, converges to within ~ 50 km of the coast. The convergence of the northwestern edge of the Sierra Nevada-Great Valley block with the coastal regions therefore accounts for a portion of the observed contraction occurring north of the migrating Mendocino triple junction region. Upper plate contraction north of the Mendocino triple junction region near Humboldt Bay is driven not solely by Gorda-North America convergence, but in part by convergence of the Sierra Nevada-Great Valley block with coastal Pacific-North America relative motion. In addition, coastal northern California undergoes margin parallel shortening above the southern edge of the subducted Gorda plate.

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**Non-technical Summary**

Global Positioning System (GPS) survey data from 1993 to 2002 provide estimates of tectonic deformation of North America in northernmost California. This region experiences stress from three different sources, the northern San Andreas fault system, which separates the North America and Pacific plates; the southern Cascadia subduction zone, which separates the (offshore) Gorda and North America plates; and the northwestward encroachment of the Sierra Nevada-Great Valley block upon the Klamath Mountains and the coastal regions of northern California. From repeated periodic GPS surveys, these data indicate the northernmost projections of the San Andreas fault system are active and have measurable relative motion occurring across them. In addition, encroachment of the Sierra Nevada -Great Valley block may contribute up to half (2-4 mm/yr) of the observed geologic rate (~ 10 mm/yr) of contraction that occurs north of the Mendocino triple junction.

**Reports Published**

Williams, T.B., Kelsey, H. M. and Freymueller, J.T., 2002, Escape of Sierra Nevada-Great Valley block motion contributes to upper-plate contraction within the southern Cascadia margin near Humboldt Bay, California, EOS Trans AGU 83(47) Fall Meeting Supplement, Abstract S22B-1028.
Williams, T, B. and Kelsey, H. M. and Freymueller, J. T., 2002, The Geodetic signature of modern deformation within the southern Cascadia margin, northwestern California, Geological Society of American Abstracts with Programs, v. 43, no. 6, p. P-67.

**Availability of seismic, geodetic, or processed data.**

GPS survey data (RINEX files) currently available upon request (tbw3@axe.humboldt.edu) and from the UNAVCO project archive (http://archive.unavco.ucar.edu/) under the 'Cascadia 2001' project group name. RINEX data from 1999-2001 has been submitted to J. Svarc, USGS, Menlo Park, CA.

Files containing final station velocity estimates, model output, and interpolated coseismic earthquake displacements are also available upon request (tbw3@axe.humboldt.edu). Williams' M.S. thesis is available as a downloadable .pdf file (~ 45 Mb) from the HSU Geology web page (http://www.humboldt.edu/~geodept/RESEARCH/RESEARCH.HTM).

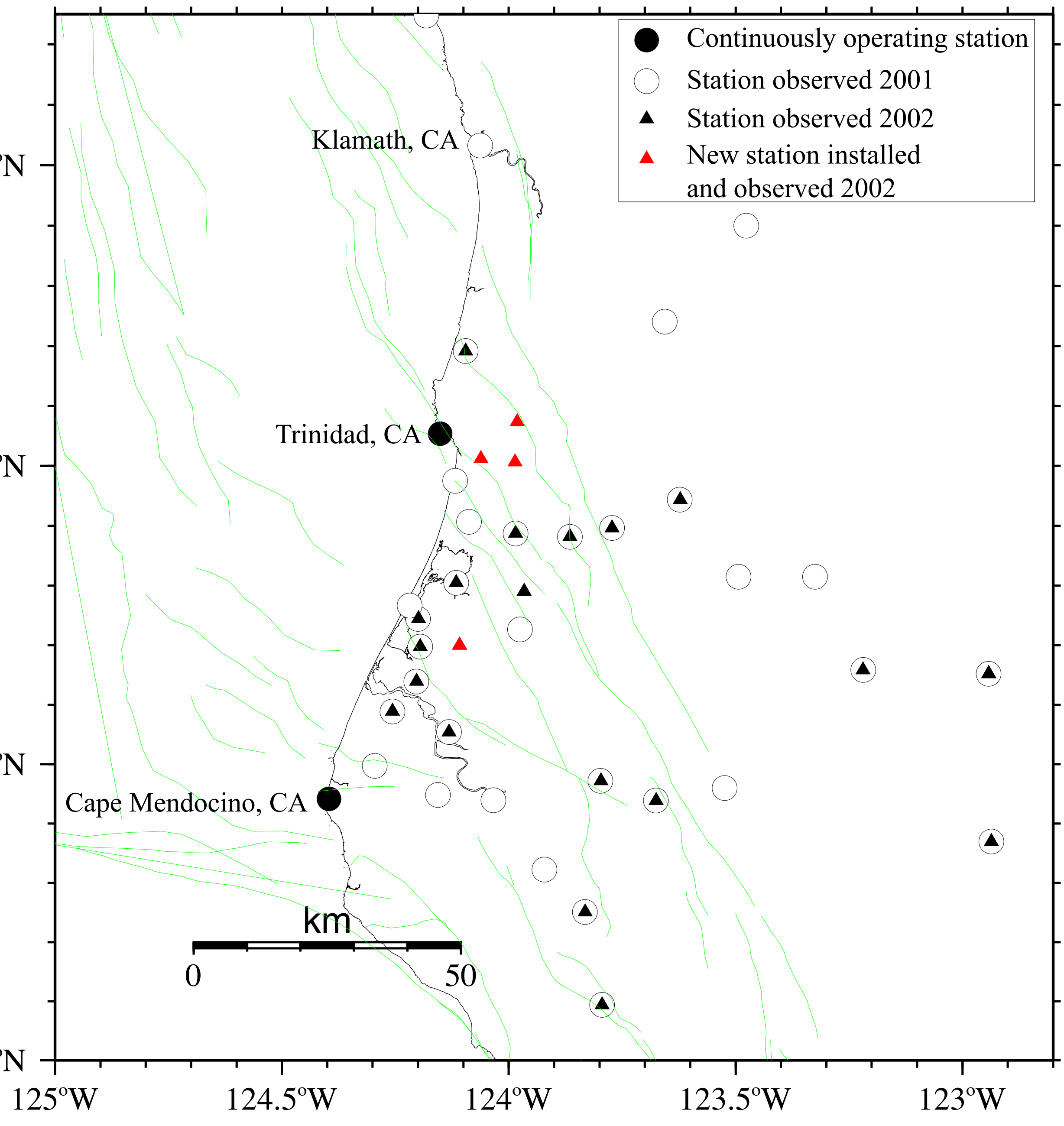


Figure 1. HSU-UAF GPS Survey Efforts 2001-2002

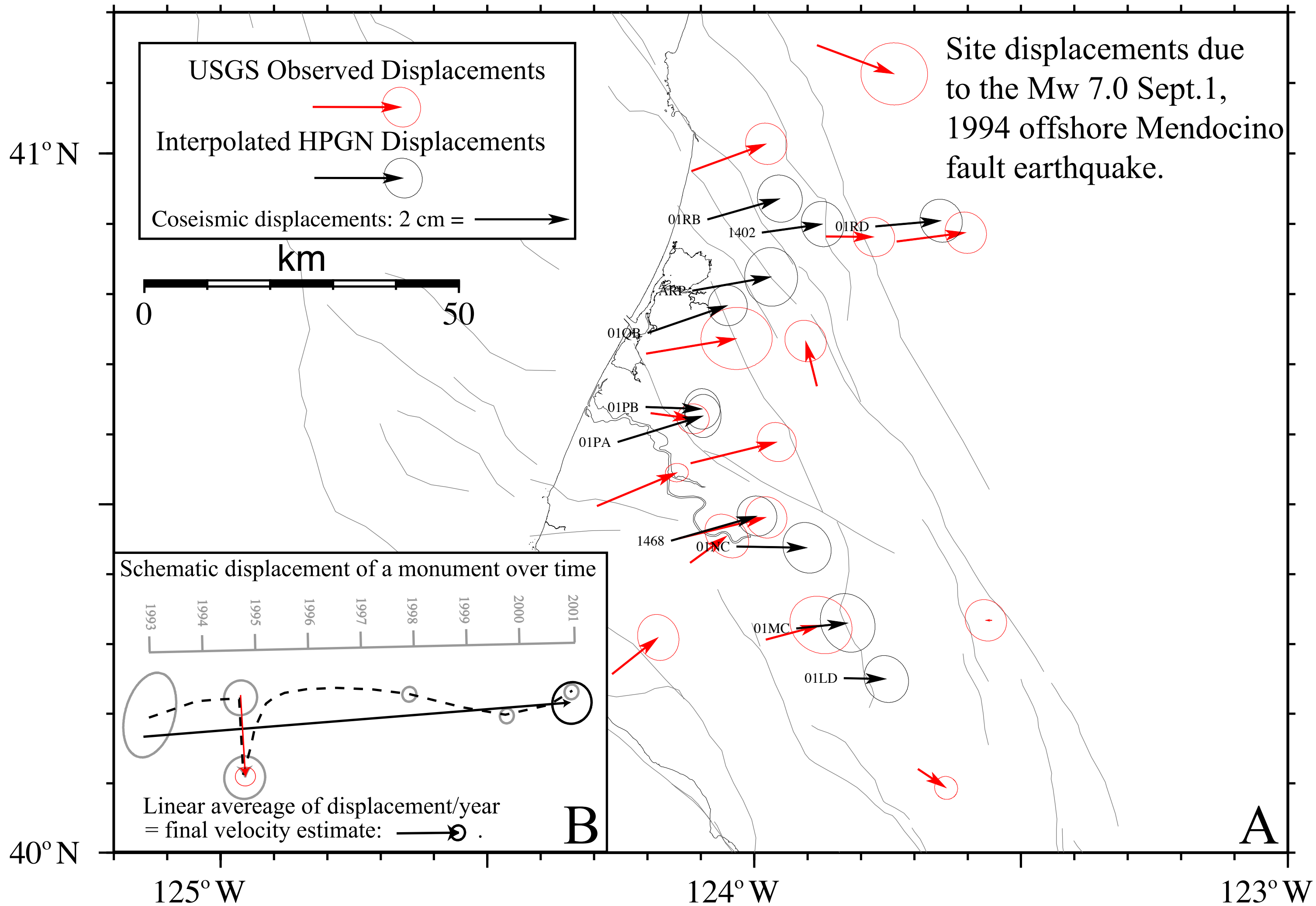


Figure 2. Observed and interpolated coseismic displacements related to the 1994 offshore mendocino fault earthquake (Dnegler et al., 1995; M.H. Murray, 2000, personal communication).

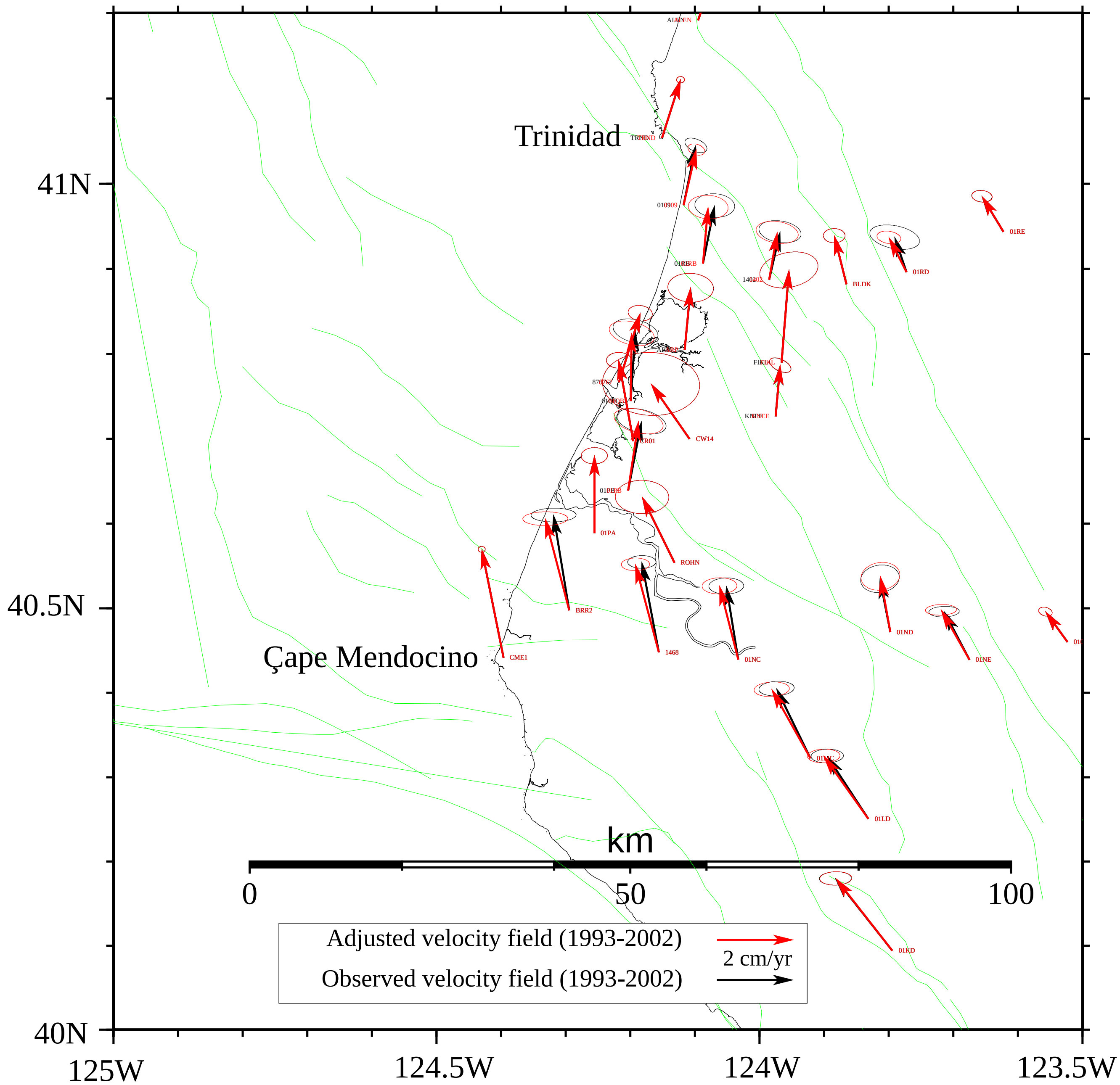


Figure 3. Velocities (1993-2002) adjusted for the Sept. 1, 1994 M=7 offshore Mendocino fault earthquake.

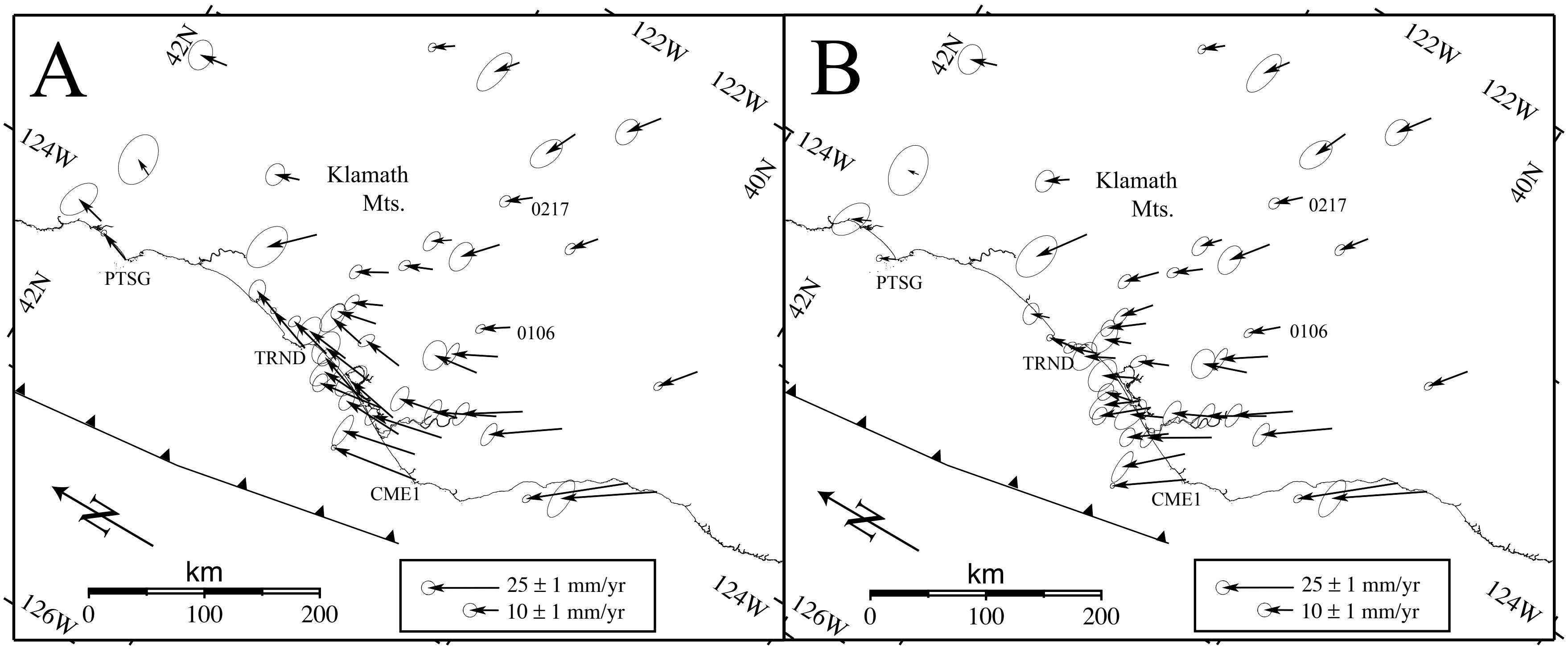


Figure 4. Oblique Mercator projection of the southern Cascadia subduction zone about a P-NA pole of rotation (Sella et al., 2002). The long axis is parallel to the direction of P-NA relative motion. A) Observed GPS station velocities (1993-2002). B) Residual velocities after subtracting the model estimates of interseismic strain accumulation on the southern Cascadia subduction zone (Flueck et al., 1997). The velocity field in (B) reflects the contribution of external forces acting on the southern Cascadia subduction zone other than subduction. The residual velocities are predominately sub-parallel to the Sierra Nevada- Great Valley block and the direction of P-NA relative motion along the northern San Andreas fault system. The barbed fault represents the model fault (Flueck et al., 1997) used in this analysis.