Vertical Crustal Motion in the Western U.S. from GPS Vertical Position Time Series

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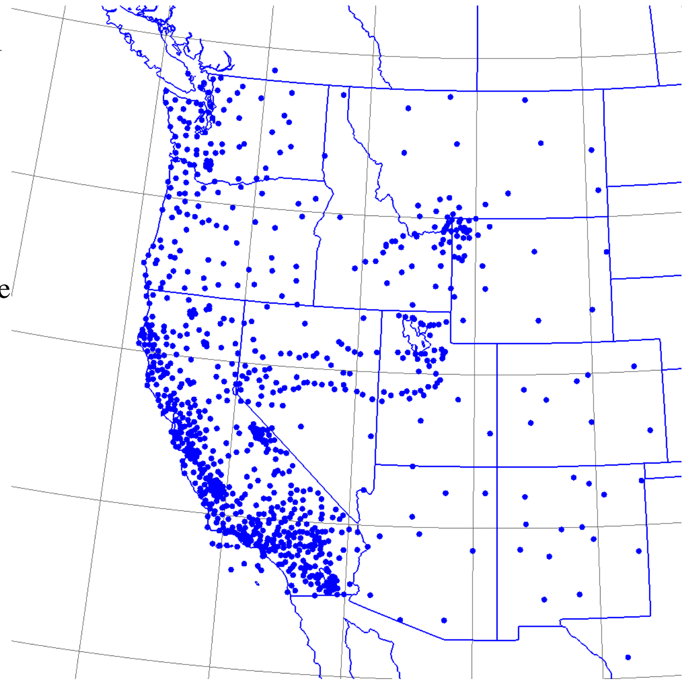
The goal of this work is to find regional-scale vertical motion of the crust in the western U.S. Geologically important vertical motion occurred over wide areas, such as the Colorado Plateau, the southern Rocky Mountains, and the Great Basin. Where are uplift and subsidence in the west today?

Geodesy-quality GNSS monuments have the potential to resolve vertical motions. Horizontal motions at such stations are resolved to better than 1 mm/year, and may exceed 25 mm/year. In the vertical component, problems in determining rates of motion are more severe. Noise sources are larger, and the precision of measurement is in principle not so good, compared to horizontal components. The expected rate of regional vertical motion is possibly in the range of plus or minus 1 mm/year, corresponding to 1 km of vertical elevation change in a million years. There is little geological evidence for more motion at present over wide areas. Yet elevation changes due to earth tides alone may exceed 10 mm/day, and ground water variations are another source of vertical noise. The expected vertical motions due to geological processes are smaller than noise sources in the GPS signal.



Initial processing shown here reduces annual variations, post glacial rebound, and other noise, and yields a preliminary map of regional-scale Vz (Figure 12). Important unresolved questions remain.

Data sources are PBO ".pos" files of time series of daily positions at each GPS station, both IGS08 and IGS05 solutions, of 23 June 2011.

This work is in progress and the results shown are preliminary. In this draft figures are shown with very limited text.

Figure 1. (upper right) Locations of 963 GPS stations with time series of position coordinates supplied by PBO.

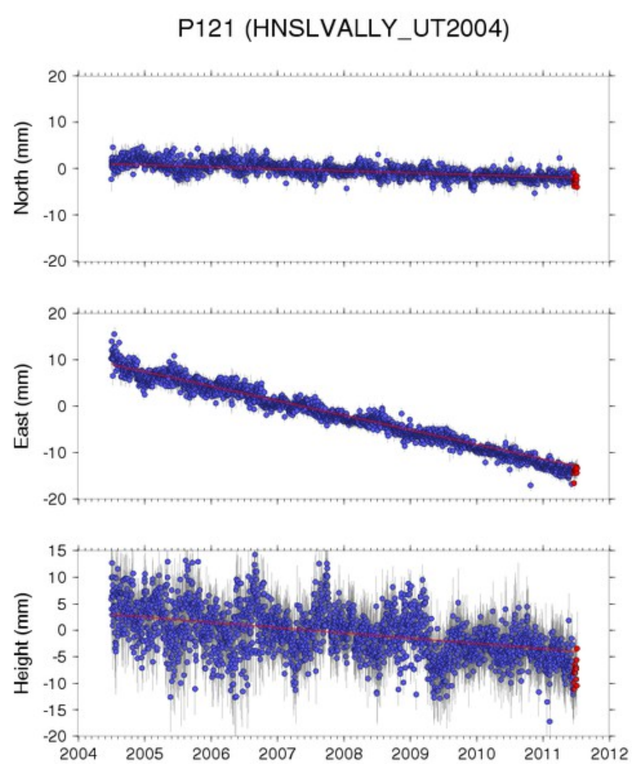
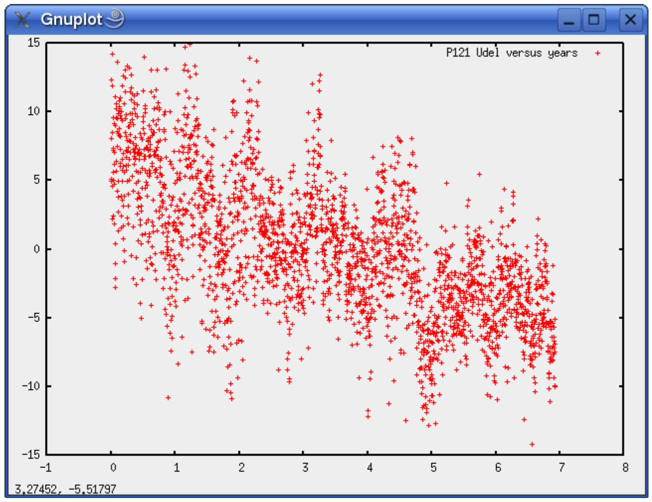


Figure 2. (lower right) Time series of changes in north, east, and altitude coordinates of the station P121, Utah.



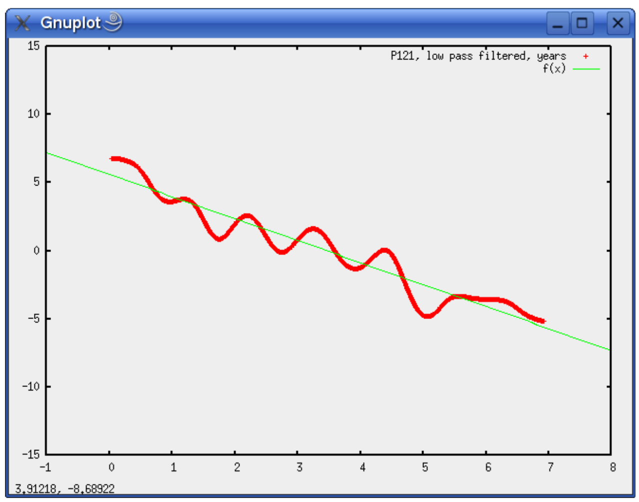


Figure 3. Processing to measure vertical rate of change begins with the time series of daily station altitudes provided by PBO (top graph, relative altitude, mm on left scale, for station P121), which is low pass filtered to remove frequencies whose period is less than a year (bottom graph; scales are the same for both plots). The slope of a linear fit to the filtered altitude time series in the second plot gives an estimate of the rate of vertical motion, in this case -1.62 mm/year. Horizontal axis is in years at the station.

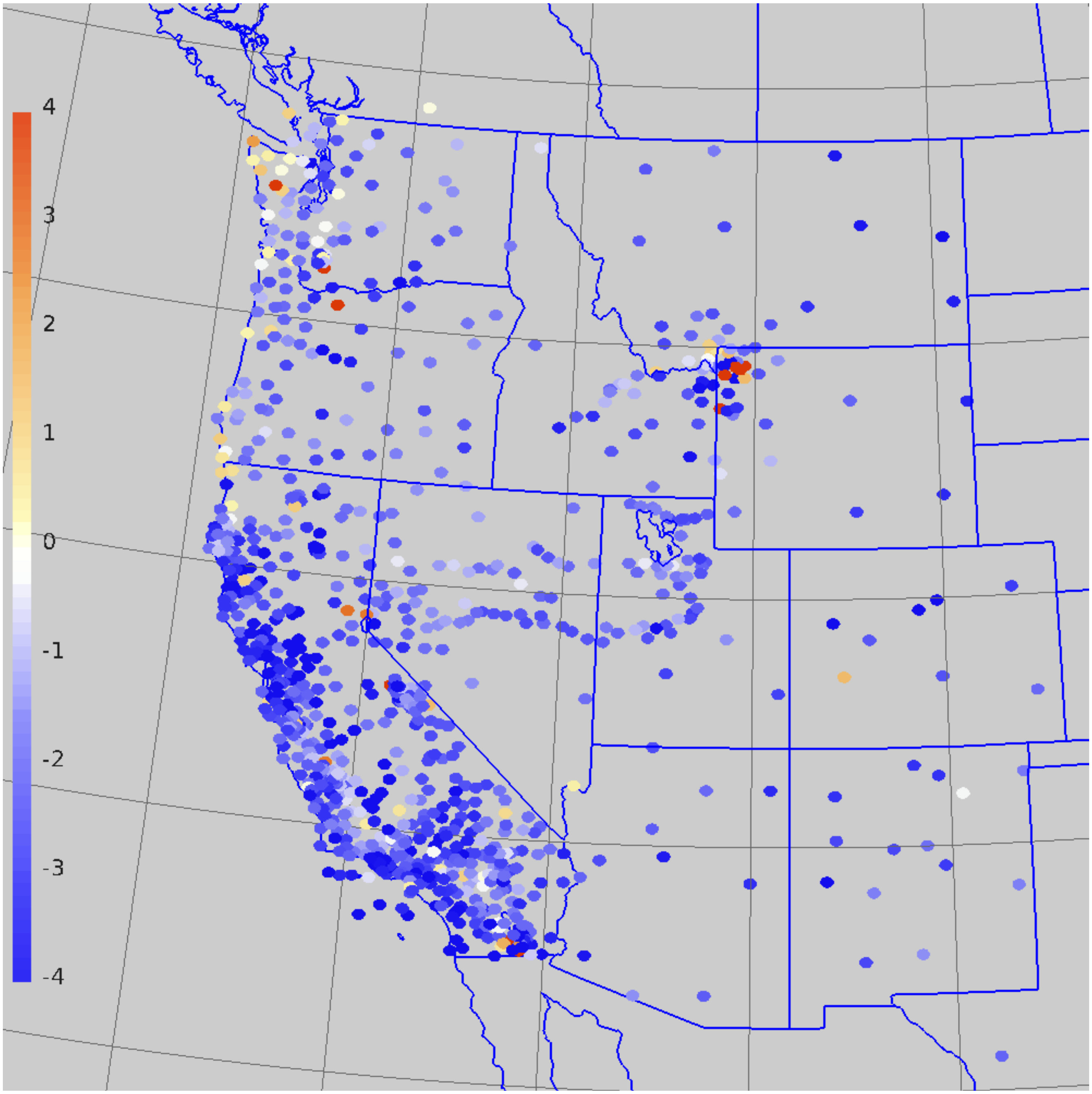


Figure 4. Vertical velocity estimates at 963 station locations in the western U.S., colored by value (mm/year), from the IGS08 solution stations' time series of 23 June 2011. Processing as shown in Fig. 2. Note that almost all stations in the west have negative values.

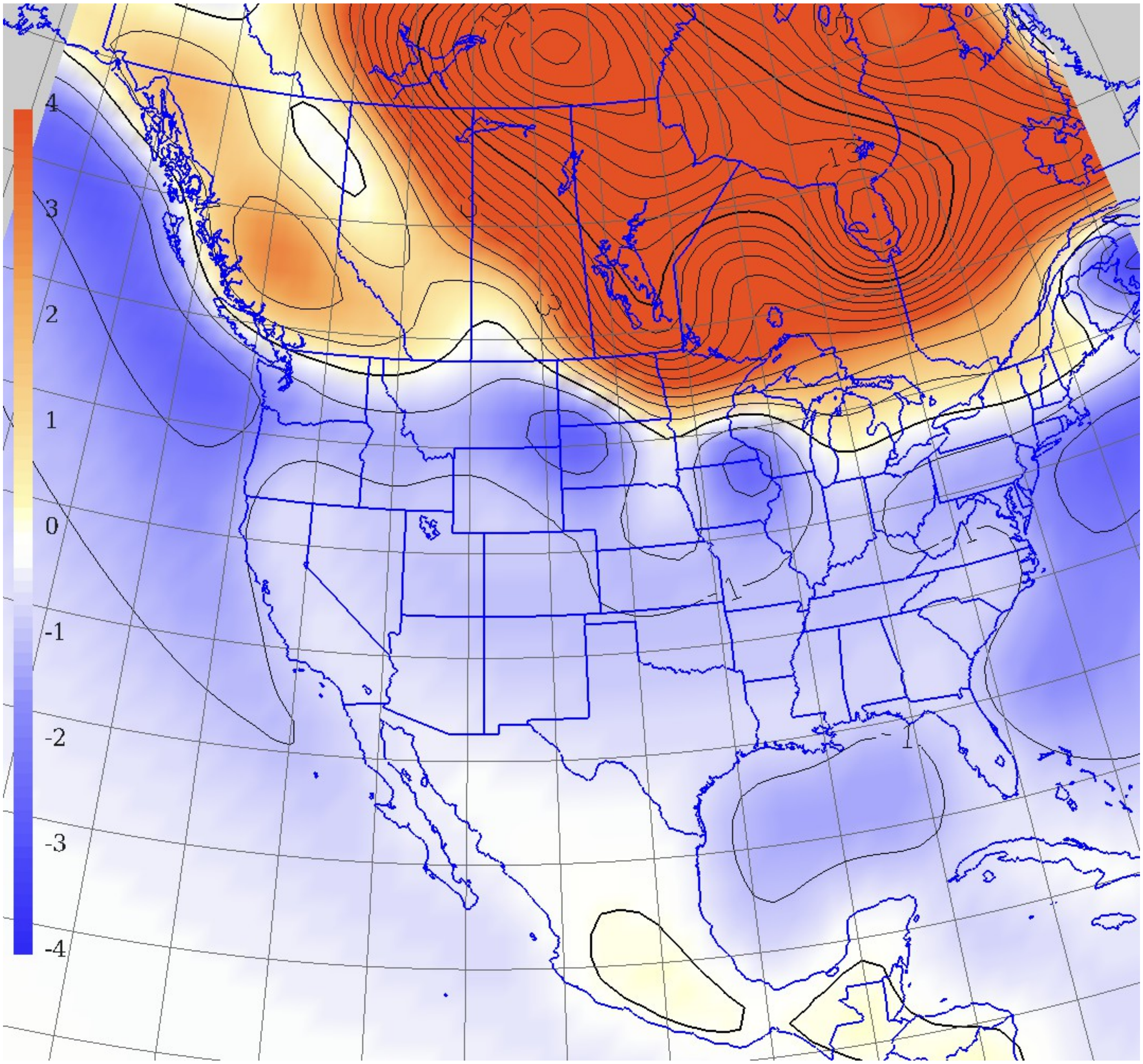


Figure 5. Rates of vertical motion expected from post glacial rebound, in part of North America, from the Wahr *et al.* model described in the text. Legend colors and contours show vertical speed values in mm/year. White is near-zero vertical speed; blues are negative (subsidence). Note the slight subsidence in most of the lower 48 states. Values in most of the western U.S. are in the range of 0 to -1 mm/year. The post glacial rebound signal is an important contribution to vertical motion in all of North America.

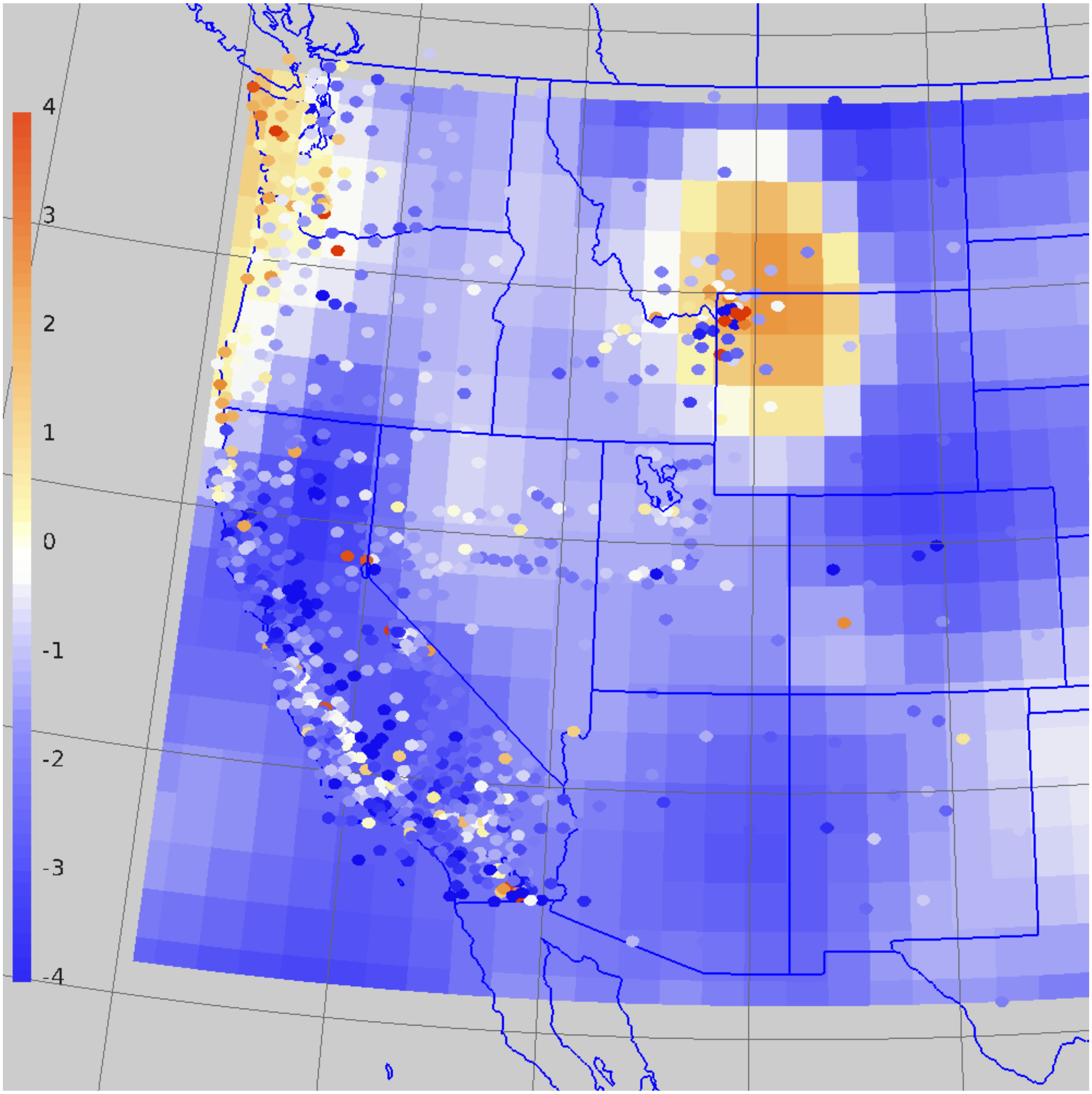


Figure 6. Results of removing the post glacial rebound model's vertical speed, from vertical speeds estimated from GPS vertical positions. Colored points are the GPS station locations, colored by the fitted GPS vertical speed at each station less the post glacial rebound vertical speed from the Wahr model at that station's location (color scale in mm/year). The background is a grid determined from these point values (same color scale). Gridding was computed with a Barnes analysis (1.0 degree by 1.0 degree grid cells, 2 passes, 2.5 degree search radius, gain 1.0). Grid cells entirely offshore are an artifact of gridding and not significant. Grid points with few nearby GPS stations have less reliable grid values. Local features will not appear due to the spacing of GPS stations, the averaging area in gridding, and the grid cell size used in gridding.

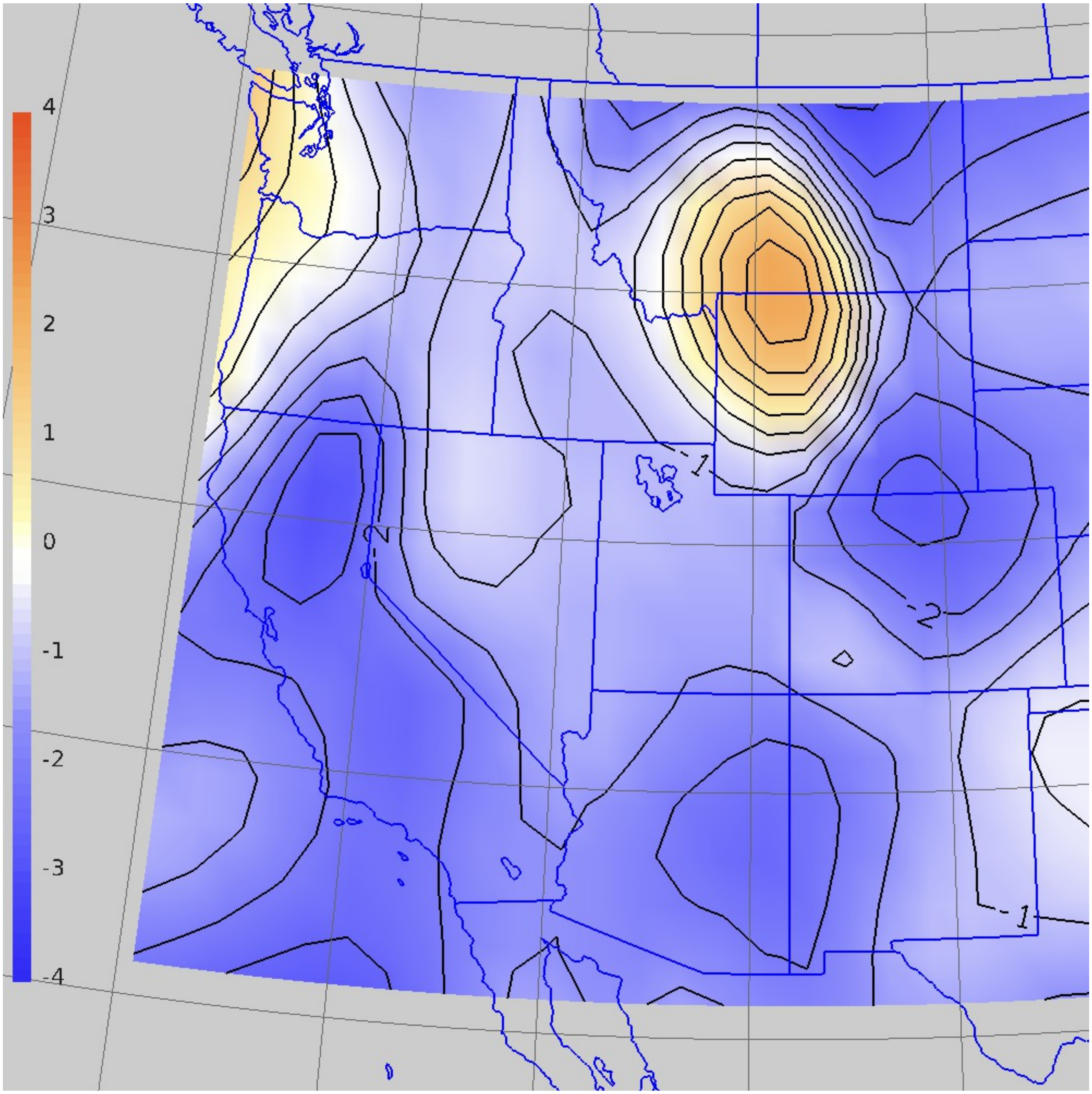


Figure 7. Contoured grid of Figure 6, with a background of colors derived from the same grid. Legend colors and contours show vertical speed values in mm/year. Contour interval is 0.5 mm/year. A region of positive value, up to 3 mm/year, is observed in the greater Yellowstone region, due to a few stations with high rates of positive vertical motion there (see Figure 8).

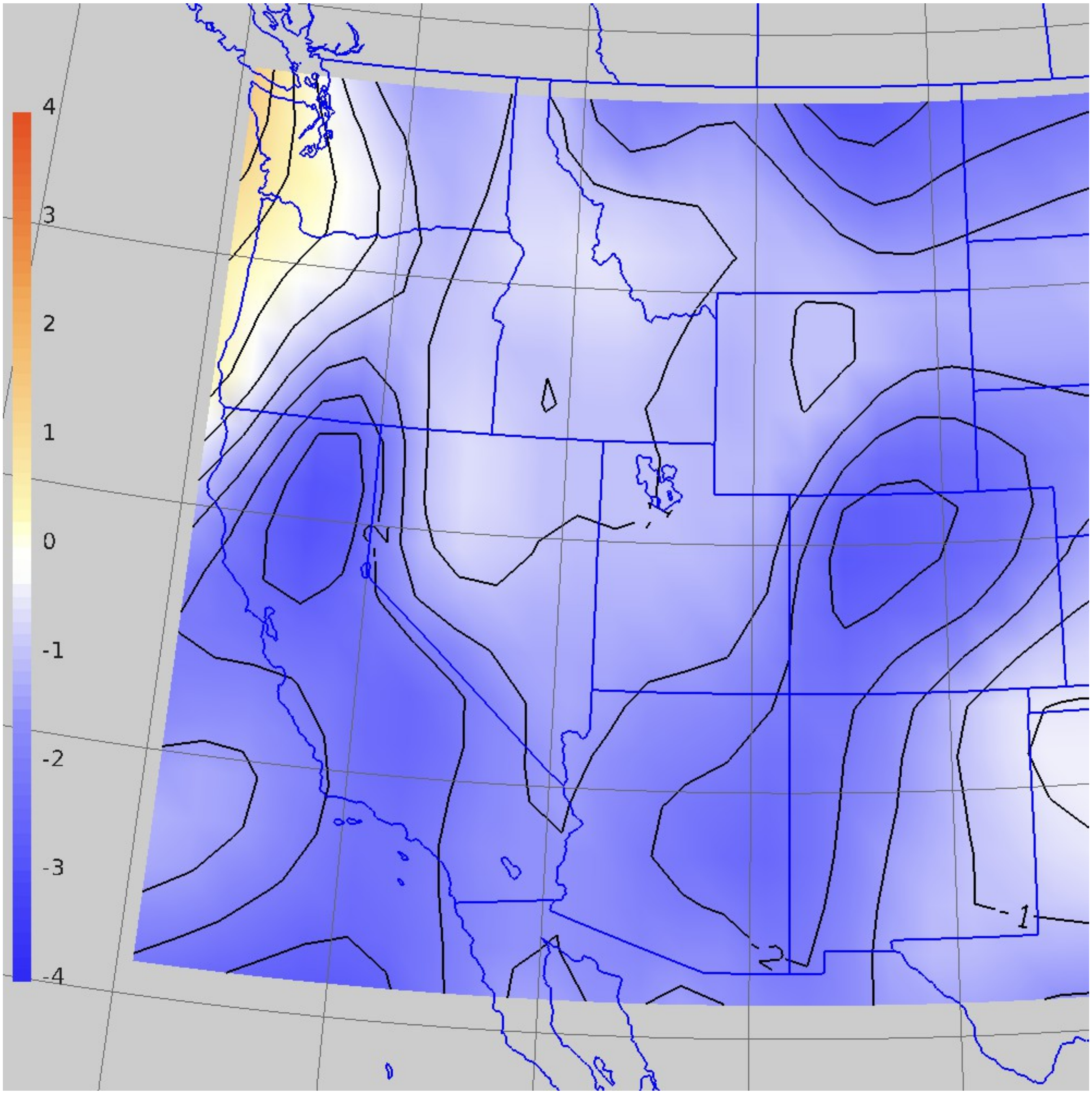


Figure 8. Same processing and data as in Figure 7, except for removing 22 stations in and near Yellowstone National Park, inside the bounds 44.3 to 45.0 North, 248.6 to 250.0 East, an area less than one grid cell, to remove the influence of local extremes in the Yellowstone area. Two other outlier stations were removed with atypical high local uplift, P006 (Lake Mead) and P029 (Montrose, Colorado).

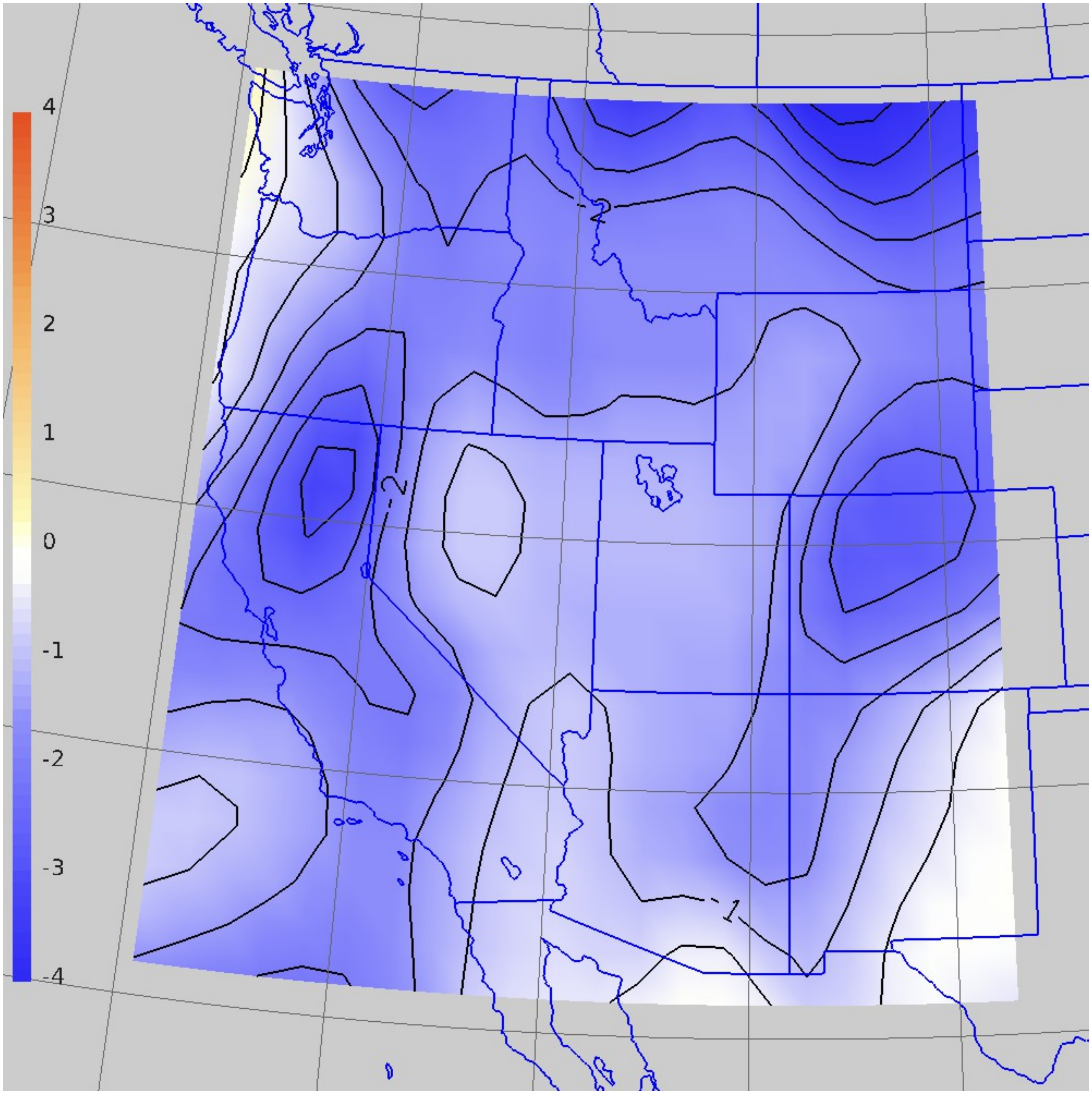


Figure 9. Same processing as in Figure 8, using for data the GPS position time series from the IGS05 solution of June 2011. The differences between Figures 8 and 9 are due to frame effects on GPS time series solutions; see next figure.

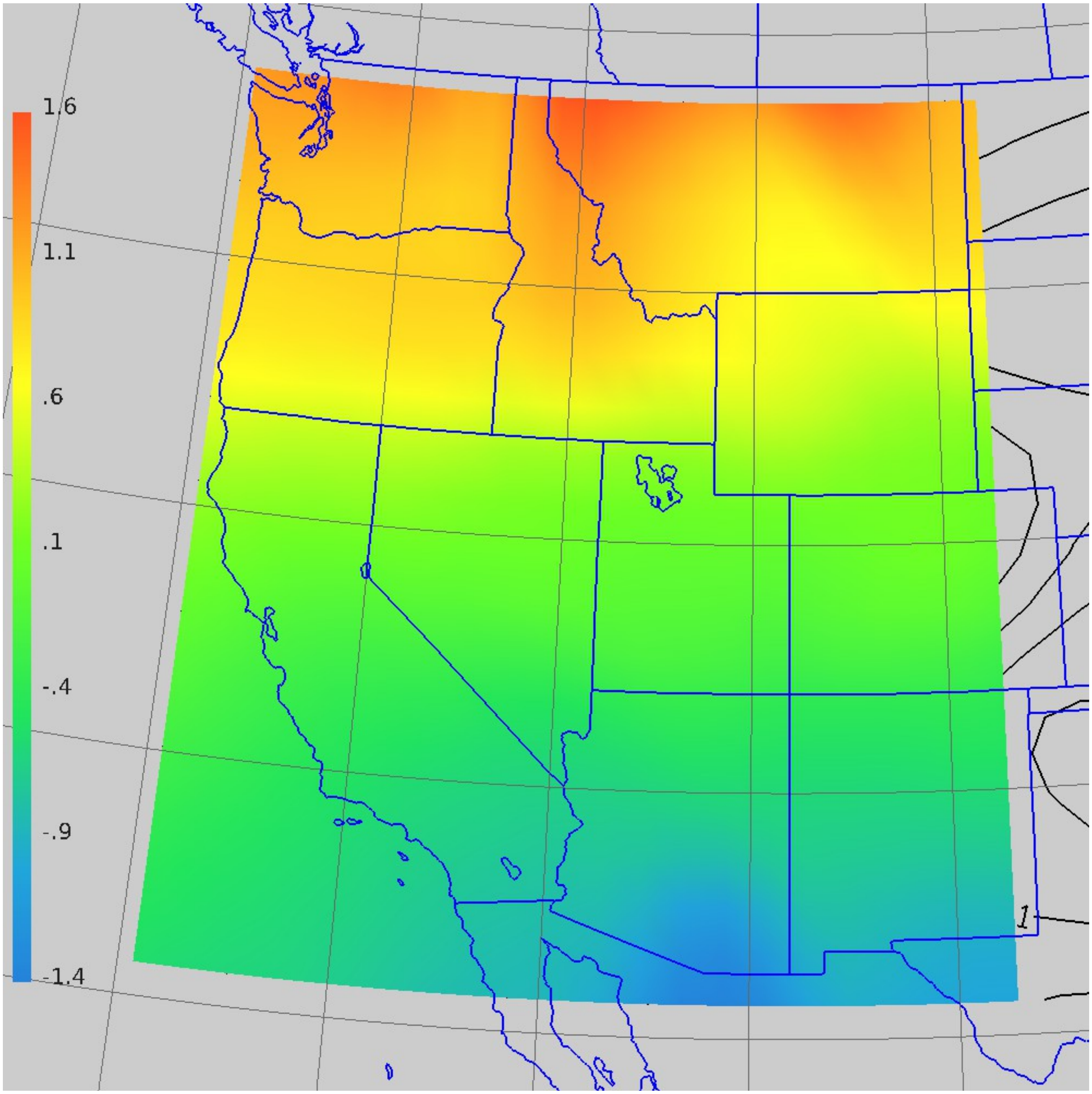


Figure 10. Difference of the two grids in Figures 8 and 9, the difference of the IGS08 time series-estimated field of Vz less the IGS05 time series-estimated Vz field. The systematic change (which happens to be largely in latitude) is caused reference frame based differences in the determination of altitudes at stations.

The reference-frame based differences in Vz shown in Figure 10 are larger in magnitude than measured station vertical velocities in many cases. It is possible other important reference-frame caused changes in vertical velocities exist which are not revealed by this difference. Since the effects of the reference frames on vertical velocities are unknown, relative vertical velocities are computed for this area, comparing Vz station values here to the average vertical velocity found in the presumably more stable eastern U.S.

For comparison, eight stations in the central interior of the lower 48 states were chosen which have good signal quality. The stations cover a wide area of stable interior platform, which is expected to have little vertical motion due to geological activity and post-glacial rebound.

The eight stations with their locations and Vz values (IGS08 solution of June 2011, corrected for post-glacial rebound) are listed in Table 1.

Table 1.

ID	lat	long	Vz (mm/yr)
ACSO	40.2324	277.0185	-0.759
JFWS	42.9143	269.7519	-1.951
KSU1	39.1008	263.3905	-1.695
NLIB	41.7716	268.4251	-0.876
P040	38.0715	257.3130	-0.982
P777	35.7027	267.4545	2.091
P778	35.2404	274.1851	-1.802
WMOK	34.7379	261.2195,	-2.704

The average Vz for these stations is -1.085 mm/year. Also, the average Vz for all PBO stations east of longitude 105 West and between latitudes 25.0 to 52.0 North is -0.855 mm/yr.

If we assume as a first approximation that eastern stations have near-zero vertical motion on average, then the IGS08 solution is shifting Vz by something close to -1 mm/year in the east. The western U.S. could have a different shift due to IGS08, but there is no way to determine what it is from this data.

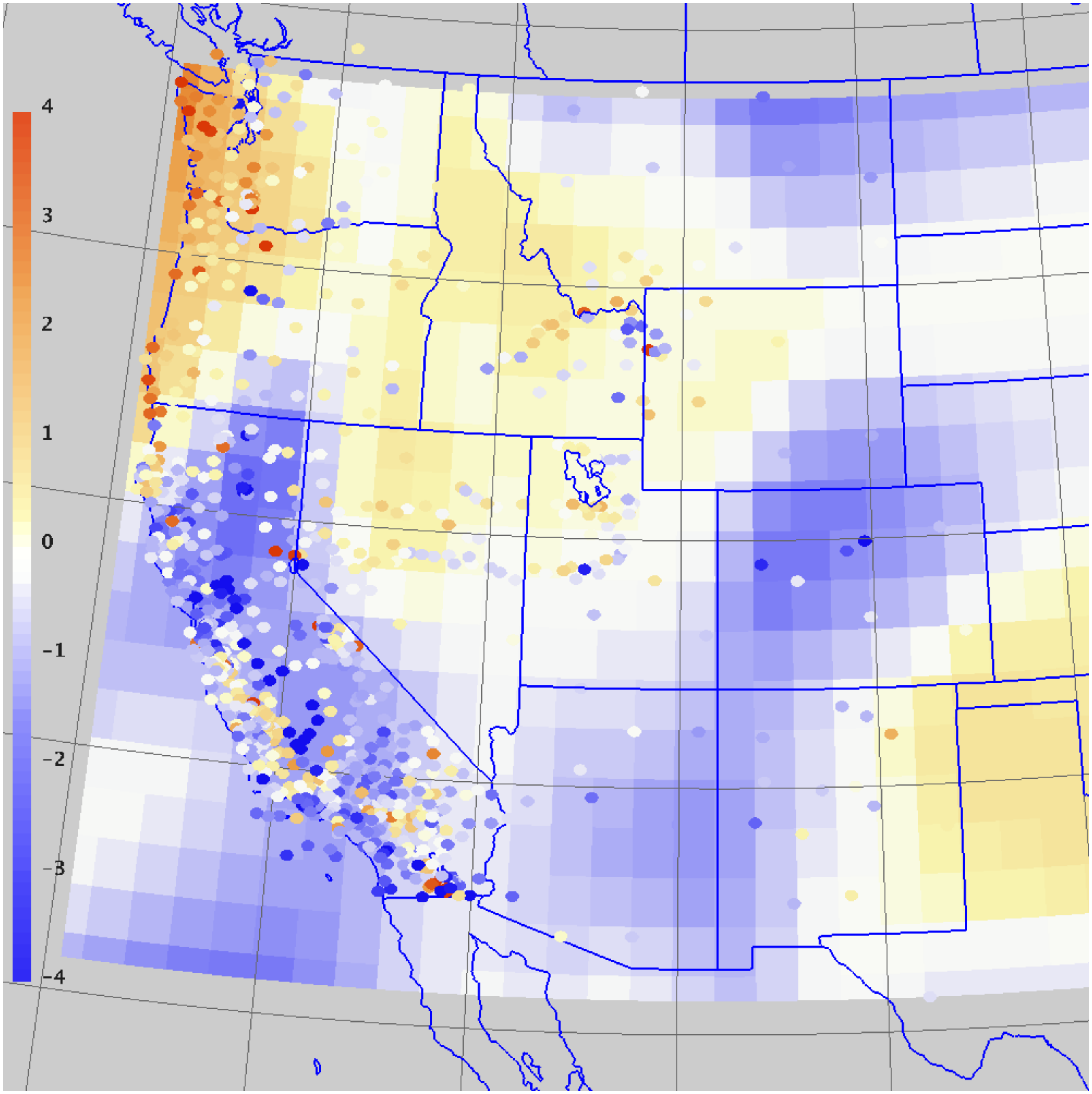


Figure 11. Relative vertical velocities at western PBO GNSS stations, compared to an average vertical velocity for eight stations in the central interior U.S.: the western station velocity values (shown in Figure 6) had 1.085 mm/yr added to them (see text). Station locations are colored by the relative vertical speed at each station (color scale in mm/year). The background is a grid determined from these point values (same color scale). Gridding was computed with a Barnes analysis (1.0 degree by 1.0 degree grid cells, 2 passes, 2.5 degree search radius, gain 1.0). All vertical velocities at stations were corrected for the post glacial rebound vertical speed from the Wahr model. Outlier stations, in the Yellowstone region and a few single stations in the interior west, were removed.

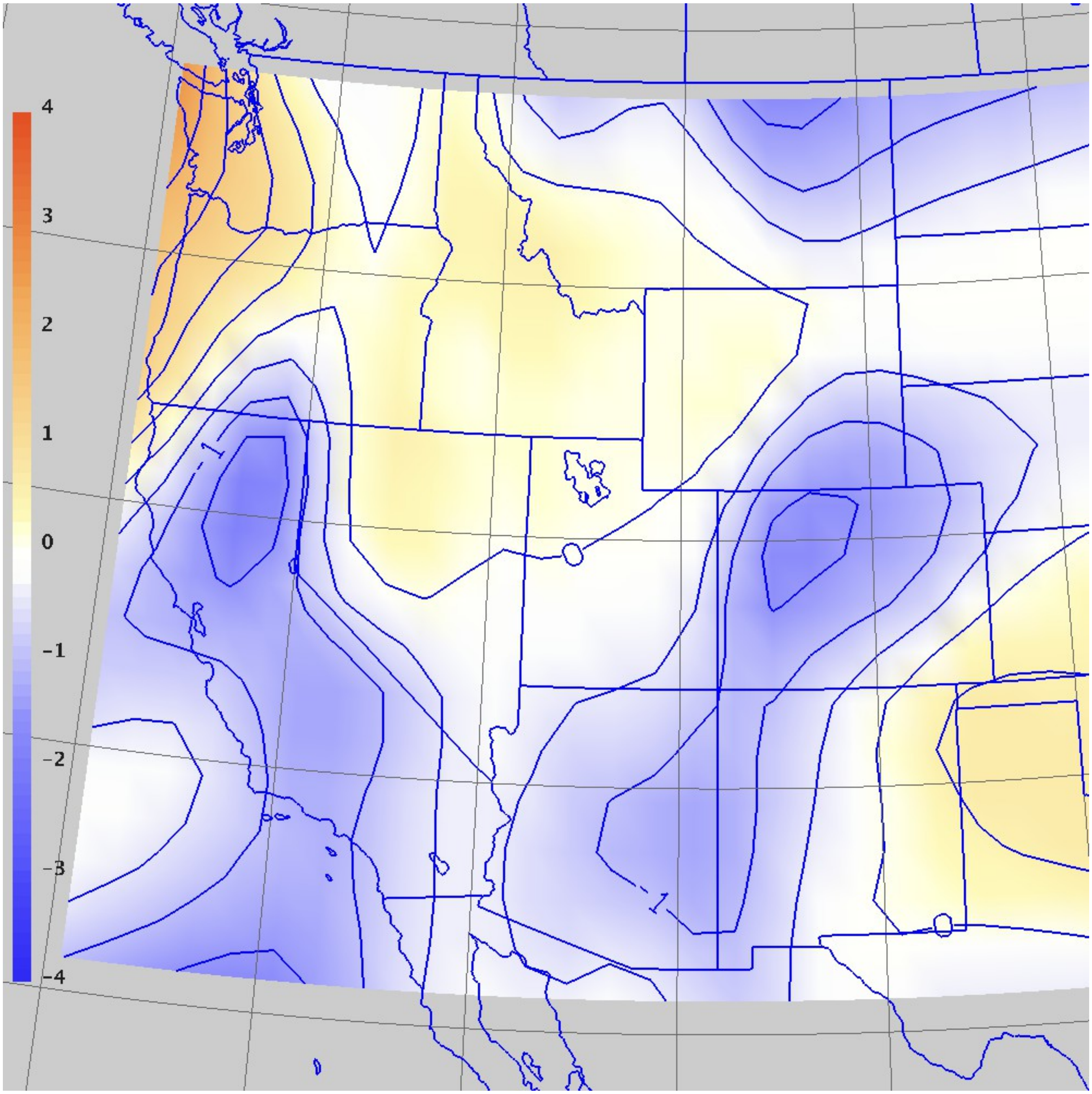


Figure 12. Initial estimate of regional vertical surface velocity in the western US, relative to the central interior platform: contours of the grid shown Figure 11, with a background of colors derived from the same grid. Colors and contours show vertical speed values in mm/year. Contour interval is 0.5 mm/year.

Subject to as-yet uncertain effects of the reference frame, this figure is a preliminary measure of regional vertical crustal surface velocities in the western U.S., with post-glacial rebound effects removed. The pattern of uplift near the coast north of Cape Mendocino is encouraging in that uplift is expected there due to subduction of the Juan de Fuca plate. Uplift around the Yellowstone-eastern Snake River Plain axis is also plausible.

Acknowledgment. John Wahr provided his numerical grid of post-glacial rebound motions, and also his model's values at the locations of the GPS stations used in this study.
This work is solely the work and responsibility of the author and does not express the position of any other person or agency.