Plate Boundary Observatory Analysis using the Ambizap GPS Processing Algorithm

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OVERVIEW

In GPS positioning, resolution of the integer cycle ambiguity in the carrier phase data improves precision and accuracy significantly, typically by a factor of 2-3 in relative longitude [*Blewitt et al.*, 1989]. Theoretical properties of ambiguity resolution are here exploited to derive a very rapid algorithm applicable to GPS precise point positioning (PPP). Since its invention by *Zumberge et al.* [1997], PPP has become popular for regional GPS network processing, because processing time scales linearly with the number of stations N and it closely reproduces the global solution (exactly for stations used for orbit determination). However, the processing time for ambiguity resolution scales as N^4, losing the practical advantage of the initial PPP.

A well-known property of ambiguity resolution is that the sum of integer ambiguities associated with two sides of a triangular (3-station) network equals the integer ambiguity for the third side (for observations to the same pair of satellites). More generally, the ambiguity resolution of any linearly independent set of N-1 baselines is sufficient to completely solve the problem. This property leads to the conclusion that the estimated vector between a pair of stations is insensitive to data from the rest of the network. Thus the entire solution can be constructed from the analysis of N-1 station pairs, which implies an ambiguity-resolved solution that scales linearly with N.

"Linear independence" requires that no selected baseline vector can be constructed by the sum of any other selected vector. Each station is connected to the network by at least one baseline, and can be connected a maximum of N-1 times (the "hub and spoke" limit). Thus care must be taken not to count PPP data twice for stations that are used in more than one baseline.

The "ambizap" algorithm was designed and implemented to satisfy the properties of (1) linear independence of data, (2) insensitivity of ambiguity-resolved baselines to data from the rest of the network, (3) reduction to the original PPP solution for stations that cannot be connected to the network by ambiguity resolution, and (4) not counting data twice. The N-1 baselines are chosen to minimize the baseline distance at each step in the selection, so as to maximize the probability of success at each step in resolving the integer ambiguities. No "bootstrapping" is performed (accouting for ambizap's exceptional speed) except within the set of ambiguities associated with each baseline. For this reason, tests show that ambizap works best if nearest neighbor distances are < 500 km. Since ambizap is intended to be applied to GPS networks with hundreds (or more) stations, this is not a serious practical limitation.

Tests show that a 98 station network is resolved on 1 cpu in 7 minutes versus the 22 hours it takes using the current GIPSY-OASIS II method – nearly a factor of *200* improvement in speed. The resulting station coordinates agree to 0.8 mm RMS, smaller than the daily repeatability (approx 3 mm for PPP), and so are "near-optimal." A block-diagonal covariance is also produced which closely approximates the rigorously formal variances of station and baseline coordinates, suitable for subsequent strain analysis.

In addition to reducing processing time, linear schemes readily lend themselves to parallel processor implementation. Thus real processing time can be reduced by several of orders of magnitude for extremely large networks. For example, on our 40 cpu cluster, the above 98 station network can be resolved in ~15 seconds, a factor ~5000 faster than the standard approach. The ambizap algorithm allows for very rapid, multiple reanalysis of extremely large networks, and makes trivial the addition of extra stations or subnetworks to an existing solution.

Application of the ambizap algorithm greatly improves the analysis of crustal movement in regions such as the western North America, which have dense overlapping GPS networks. For example, a network solution from one day of the ~1000 station Plate Boundary Observatory can be produced in about 7 min on a 40-cpu cluster (4.5 min PPP + 2.5 min ambizap).

A future development (in collaboration with JPL) is to integrate the algorithm into global network processing such that the station coordinate solution will benefit from the improved orbits, clocks, Earth rotation, and geocenter resulting from ambiguity resolution.

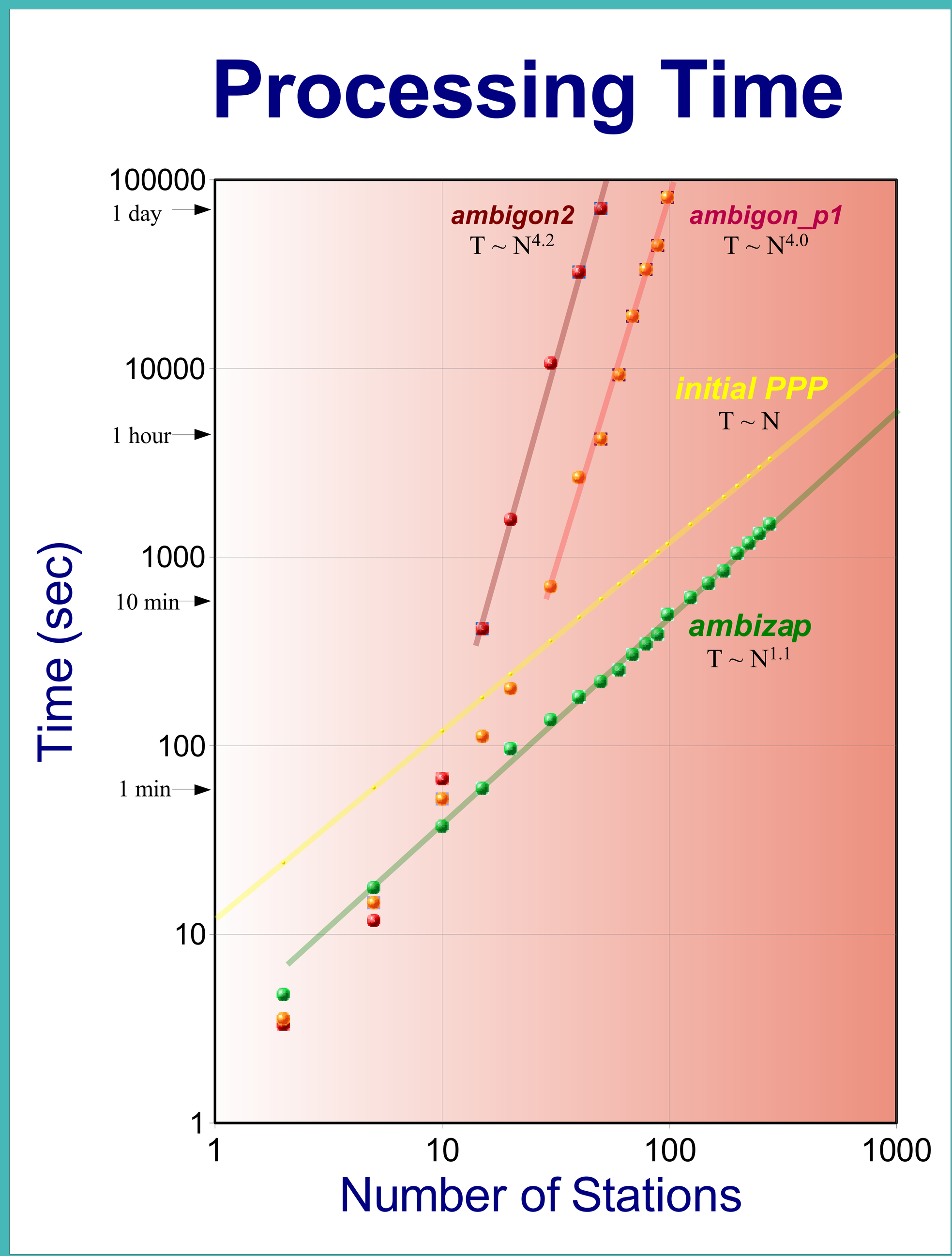


Figure 1. Processing time versus number of stations for currently used algorithms (red) and the new *ambizap* algorithm (green) described here. The current algorithms shows tends to 4th power behavior for large networks, whereas the new algorithm remains approximately linear with processing time. For comparison, PPP is also shown (yellow), which is a necessary preliminary step for all algorithms.

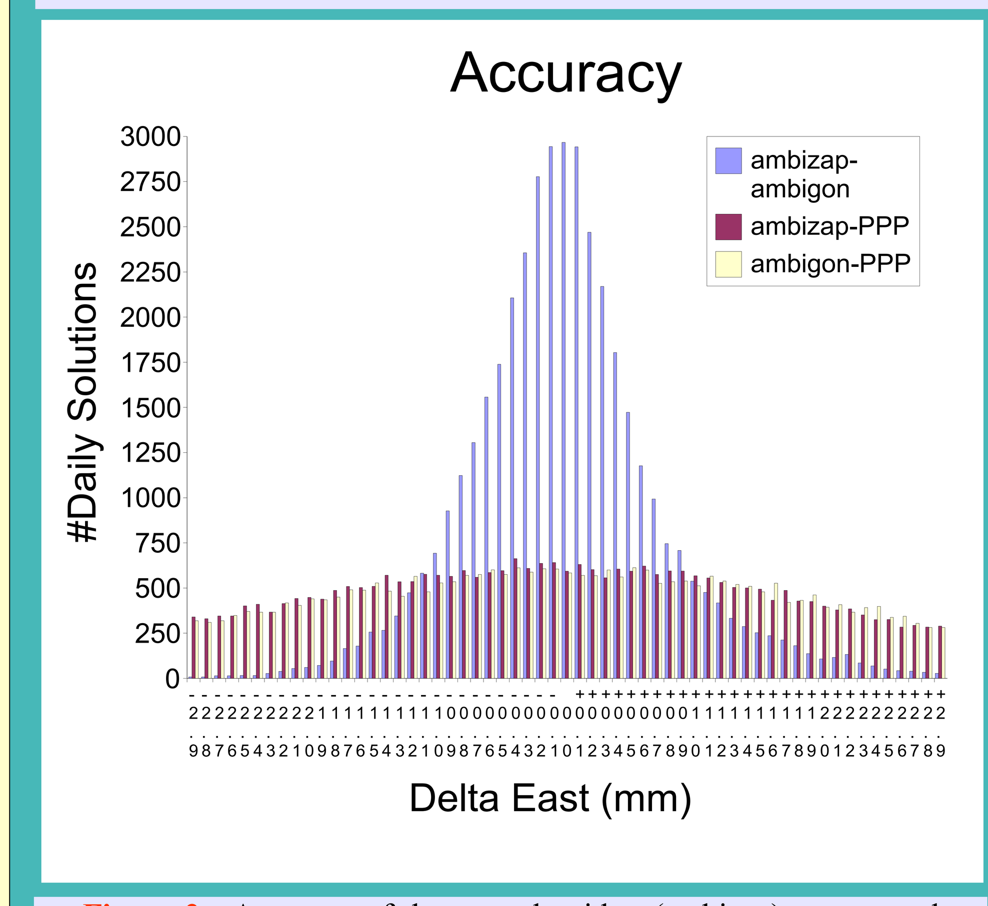
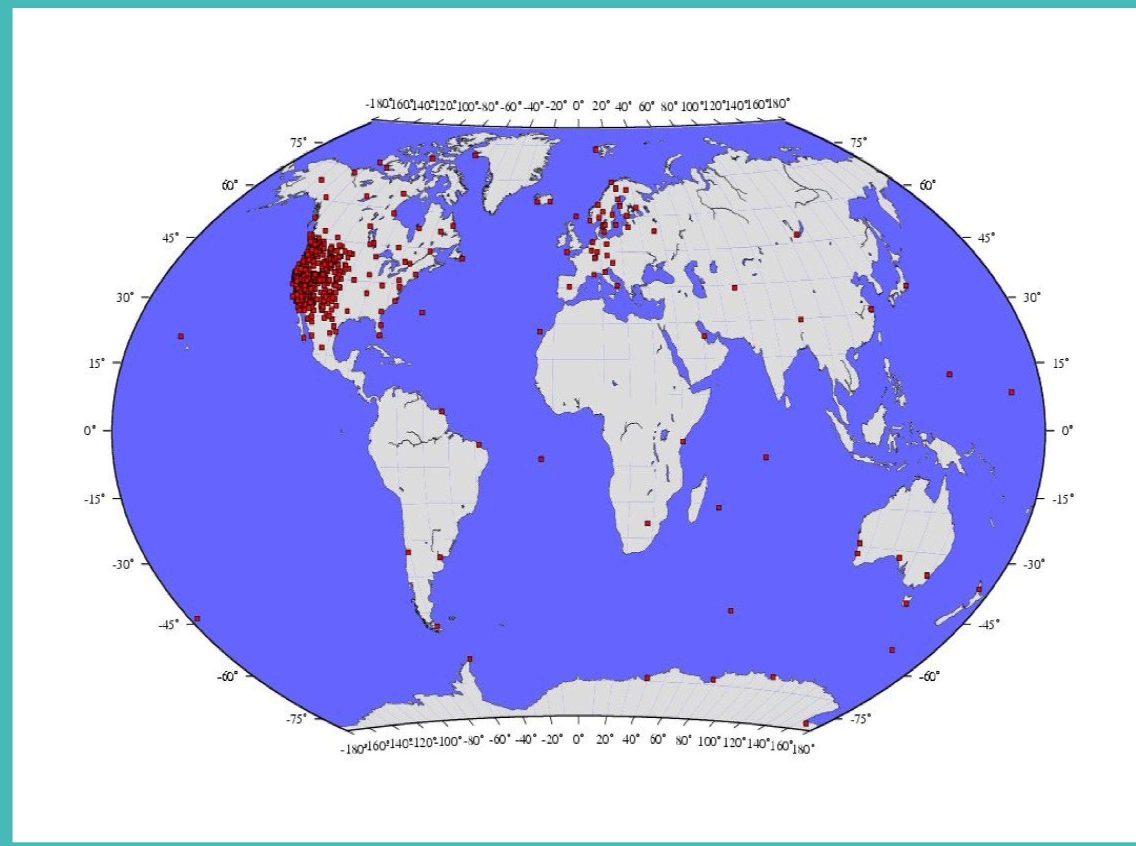
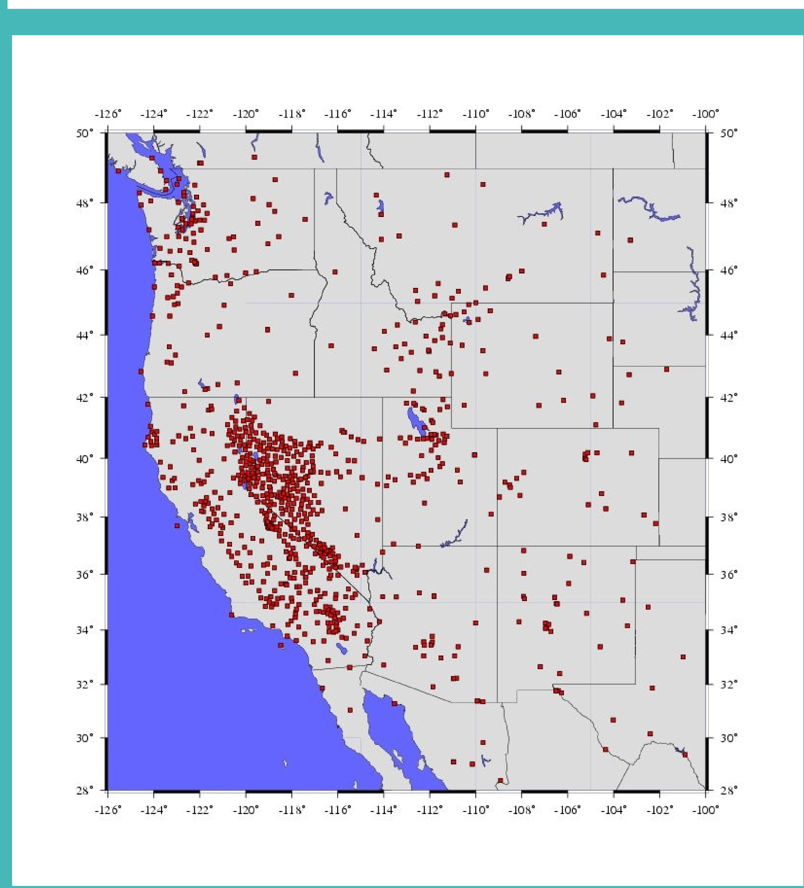


Figure 2. Accuracy of the new algorithm (ambizap) as assessed by comparison with the current algorithm (ambigon). Also shown for comparison are agreements of both algorithms with initial PPP. The East component is the one most influenced by ambiguity resolution. The RMS difference between ambizap – ambigon is 0.78 mm as compared to 3.3 mm RMS for ambizap-PPP and 3.4 mm for ambigon -PPP.





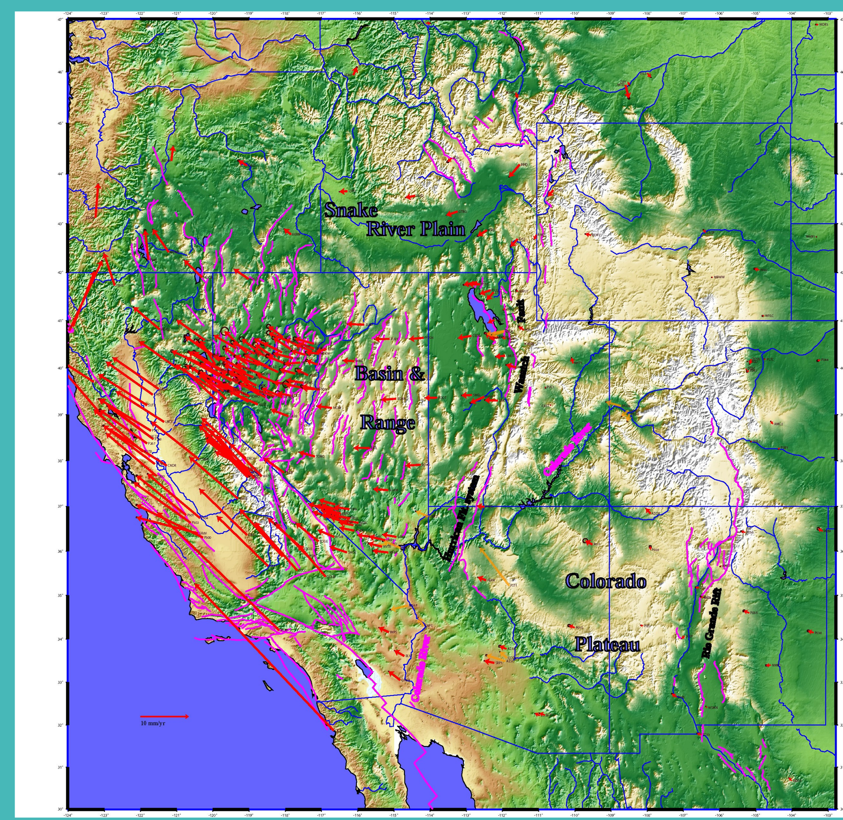


Figure 3. ~1000 station network processed using ambizap (up to ~700 per day). Networks include IGS, PBO, CORS, SCIGN, PANGA, EBRY, BARGEN, EUREF and our own NEARNET. All available data from 1994-2007.

(Left): Global map.

(Lower Left): Western US map.

(Lower Right): Resulting velocity solutions in our realization of a stable North American Reference Frame (SNARF). See poster by Kreemer et al. (on rotation of the Colorado Plateau).

CURRENT STATUS AND FUTURE PROSPECTS

- Ambiguity resolution of ~700 station networks (including PBO) takes ~1 hour on one ~3 GHz cpu for 24 hours of data (Figure 3). Cluster processing is linear, and thus takes ~1.5 minutes on our 40-cpu cluster.

- "Networks" are no longer a meaningful concept in the processing, except in the sense that the resulting solutions relate to one dense, global network. Thus no decisions are required at any stage as to "which subnetwork?" a station belongs. This greatly facilitates the administration of data processing for new PBO sites coming on line every week.

- All data we have in hand since 1994 from IGS + SCIGN + BARGEN + BARD + PANGA + EBRY + EUREF + CORS + NEARNET were processed in 7 days on a 40-cpu cluster (PPP + ambizap). See Figure 3. For interpretation of results, including rotation of the Colorado Plateau, see the poster here by Kreemer et al.

- Ambizap has been upgraded to allow for the addition of extra stations or subnetworks to an existing solution without having to reprocess data from stations in an existing solution. The resulting solutions agree to << 1 mm with reprocessed network solutions.

- Progress has been initiated toward implementation of ambizap by JPL into a future official release of GIPSY OASIS II, following the use of PPP engine "gd2p.pl".

- A preliminary design has been developed to interface ambizap with full-covariance solutions involving global network processing and GPS orbit determination. This will allow for ~1000 station routine analysis as part of the IGS Analysis Center at JPL.

ACKNOWLEDGMENTS
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