We have contributed to the development of the Community Geodetic Model (CGM) by designing and implementing software utilities to read, reformat and combine time series which are available from operation analysis centers. These analysis centers currently include GAGE; University of Nevada, Reno; USGS; JPL and SOPAC.

PI Floyd attended the Community Geodetic Model workshop at Scripps Institution of Oceanography in March 2018, at which he began to take a lead role in the GNSS component of the CGM, at the request of Jessica Murray of the USGS, who had previously led CGM organization and efforts with others. PI Herring attended the same workshop remotely.

We have previously established and presented that a significant factor affecting the fit of time series to estimate velocity and other common parameters is the consistency of defined discontinuities. This is one preliminary metadata product that we therefore identified and designed during the activities leading up to the March 2018 workshop and as part of our current award (18116). We have taken the lists of discontinuities used and published by each analysis center, and combined and deduplicated these lists to produce one “master” list, which will serve as the basis of the CGM time series analysis. The current list is a concatenation of discontinuity times from many different sources and we will review the list and remove those entries that do not show significant discontinuities in time series. When such a list is defined, verified and implemented, the resulting estimates of velocity, seasonal terms and offsets show extremely good agreement for well-behaved sites between products from each of the analysis centers.

We have led the efforts to implement two algorithms to fit time series to generate GNSS-derived velocities for the CGM: tsfit (e.g. Herring 2003), which is part of the GAMIT/GLOBK software package (Herring et al., 2018; http://geoweb.mit.edu/gg/); and Hector (Bos et al., 2013; http://segal.ubi.pt/hector/). This is compared against other algorithms designed and implemented by other contributors (e.g. MIDAS, Blewitt et al., 2016; analyze_tseri, Dong et al., 2002; est_noise, Langbein, 2004). During the March 2018 workshop and since, it has also become obvious that estimating the secular velocity from some time series works very well at some sites but not for others. On closer inspection, the sites whose secular velocities disagree between algorithmic approaches, to beyond their relative uncertainties, are those that have been perturbed by post-seismic motions or have unstable (noisy) or incomplete time series.

We have therefore worked to develop a utility to use the latest release of Hector, which is now able to estimate such non-linear terms in the presence of temporally correlated noise. The utility consists of a shell script to read in a standard time series “.pos”-format (e.g. https://www.unavco.org/data/gps-gnss/derived-products/docs/NOTICE-TO-DATA-PRODUCT-USERS-GPS-2013-03-15.pdf), which we have successfully petitioned the CGM to adopt, and to fit linear, seasonal and offset
terms. The latter of these would be defined by the CGM discontinuities list, described above.

As a result of our previous research into combining various analysis centers’ products, we alter the UNR solution due to its estimation and removal of a scale factor when defining the reference frame, which affects the vertical component of the time series (Herring, 2015; Herring et al., 2016), as well as a systematic bias in the east component of some sites due to a sign error in the antenna calibration models used in the processing. Both are corrected by adding back the scale (height) factor at each site and adding an east offset to those sites affected. We now note that all versions of MEaSUREs products (from SOPAC, JPL and combined) appear to show a systematically smaller seasonal signal in the up component of time series (Figure 1), which will need to be investigated further and possibly corrected or aligned with other analysis centers’ products. Furthermore, MEaSUREs products, in particular, are subject only to episodic updates, once every few months. Therefore, our envisaged role of “CGM cGNSS Combination Coordinator” is necessarily an active role, requiring constant manual verification and, where necessary, intervention. As can also be seen in Figure 1, there are missing (not yet updated) time series values from different analysis centers. The combination coordinator will also need to carefully assess the impact of missing centers on combination. Artifactual offsets in the time series due to changes in the analysis centers included in the combination are to be avoided.

Hector is now able to estimate such non-linear parameters in the presence of temporally-correlated noise is significant because both impact the precision of the resulting velocities: if a linear trend misrepresents a time series with non-linear characteristics, the uncertainty will be inflated as well as the velocity estimate being inaccurate; if non-linear terms are corrected used to fit a time series but temporally-correlated noise is not estimated simultaneously during this process, the resulting velocity estimate may be quite accurate but the precision is artificially good.

Figure 2 shows a comparison between velocities estimated by three of the most agreeable algorithms tested at the March 2018 workshop: tsfit, Hector and est_noise. As is evident from the area between the Salton Sea and the US-Mexico border, which is affected by post-El Mayor Cucapah earthquake motion, the algorithms disagree here due to that non-linear motion while agreeing to well within the uncertainties everywhere else. There are a few outliers that are also clear, which must be investigated on an individual basis to determine if the highly disagreeable velocities are an artifact of some aspect of the algorithms or a poor site which should be removed completely from the CGM.
Figure 1: Comparison of ingested time series (JPL, PBO, UNR, MEaSUREs) and the current CGM combination showing smaller seasonal signals in the MEaSUREs solutions (top three lines).

Figure 2: Comparison of velocities estimated using three algorithms: tsfit, Hector and est_noise. These three algorithms generally agree well except, currently, at certain individual sites likely with short or noisy time series (random blue and white vectors in both figures around Los Angeles) and in areas affected by post-seismic motion (systematic white arrows between Salton Sea and US-Mexico border in right figure).
References


