# 3.3 Analysis Coordinator

## Introduction

This is my last annual report as IERS Analysis Coordinator and I am leaving this position in the capable hands of Robert Heinkelmann from GFZ Potsdam. In this final report, I will address issues of providing realistic error estimates for user of IERS products especially those products such as SINEX files where the full analysis of IERS products is possible. This issue is not just an IERS issue but rather the services that submit products to the IERS. The IERS is in a position to provide guidelines to the services as to the importance of providing realistic uncertainties and explanation of how these uncertainties should be interpreted. The other issue to be addressed is the distribution of IERS products in the modern era where protocols such the file transfer protocol (ftp) are being increasingly a computer security risk. Associated with this task is also the issue of generating and disseminating higher level products that a large user community can easily access and use for their own, often innovative, analyses.

## Error assessment

We discuss two aspects of error assessment here. The first aspect is how to release products that have realistic standard deviations associated with them. The topic is problematic because of temporally correlated noise in the products. But current standard deviations and their associated covariance matrices in, for example, SINEX files are not even close to realistic. Again the assessment of the variances of results in products is an issues for the services not just the IERS. For IVS and ILRS combined SINEX files, variance factors of 50 are needed to generate realistic short period noise estimates i.e., the day-to-day or week-to-week scatter of position estimates derived from IVS and ILRS SINEX files is of order 7 times larger than the standard deviations of these position estimates given in the SINEX files. For users of IERS products, this difference is very confusing. Users questions would include confusion about the day-to-day scatter being real motions of the sites since they are so much larger than the standard deviations? If the standard deviations seem to have such large “errors”, how large are the errors in estimates themselves? The IERS products are most useful and would have widespread support, if outside users are encouraged to use the products. To encourage outside users to examine and use the IERS products, we should be supplying the “best” estimates of the uncertainties and how to interpret those uncertainties.

As an example of the issues associated with reported standard deviations and to look at an on-going issue with the ITRF, we examine results from VLBI and SLR collations where both systems are located at the same facility. The scale difference between VLBI and SLR will be the primary focus. These analyses are based on session (IVS) and weekly (ILRS) SINEX files. The approach is to combine the VLBI and SLR separately and "predict" the other system coordinates using the survey tie information available for the ITRF ftp site.

In our comparisons, we compare both time series behavior and the scale estimates as assessed by the mean height differences at the collocated sites. There are 25 VLBI/SLR sites within 10 km of each other and 17 pairs of these have VLBI and SLR velocities with both standard deviations < 1 mm/yr. (Three of the pairs are one VLBI station with two SLR stations and so of the 17 there are only 14 distinct locations). Of these 17, there are (disappointingly) only 6 pairs that have survey ties between the VLBI and SLR reference points in the ITRF2014 site-tie files. Given the investment in these collocated sites, it seems short-sighted not to have survey ties to link the systems especially since we have only one third of the possible ties.

For the processing here, we used the ILRS SLRa ITRF2014 SINEX files (ends 2015.0) and the IVS on-going files in ITRF2014 systems (ended September 2018 for this report). We start the analyses in 1996 to be consistent with GPS and to avoid low quality early solutions.

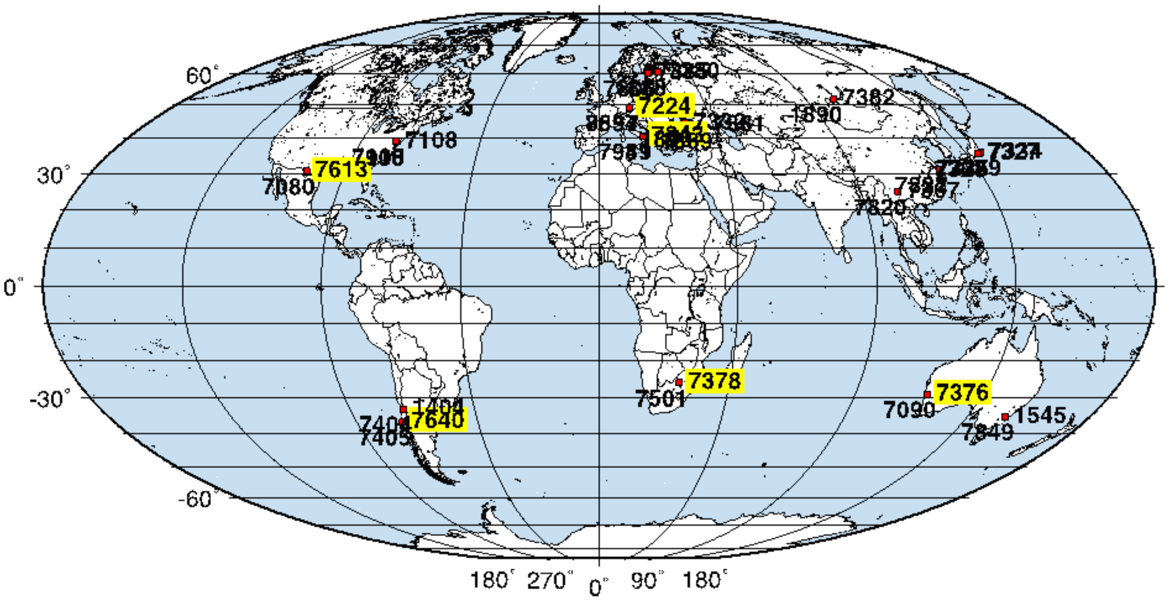


Fig. 1: *Map of collocates VLBI and SLR sites. Yellow highlights are those sites with survey ties in the ITRF2014 SINEX tie files.*

As an example of the time series results and the issues with standard deviations, we show results for Wettzell, Germany. The SLR site is 8834 and the VLBI site is 7224. The time series are generated in "smoothing" Kalman filter using the MIT GLOBK program. For VLBI and SLR separately, all SINEX files are combined in the Kalman filter with positions, velocities and time-series offsets estimated. Post-seismic deformation models were applied apriori based on the ITRF 2014 values. The combined positions and velocities are aligned to ITRF2014 using only translations, rotations and their rates. No scale parameters are included and heights are heavily downweighed in the estimation of the transformation parameters. The time series are generated in the back/smoothing Kalman filter run with each day aligned with rotation and translation to the aligned results from the forward Kalman filter run. The process noise was large (1 m standard deviation for one day separations) and so the "smoothing" filter did not smooth the results.

Figures 2–5 show the time series residuals for Wettzell. We also show the plots for these residuals that are available on the ITRF2014 web site (http://itrf.ign.fr/ITRF_solutions/2014/ITRF2014.php). Unfortunately, only plots of these residuals are easily assessed. ASCII files with the residuals are available upon request and such restrictions on access to results reduces the number of users who would be willing to look more carefully and perform their own analyses of ITRF products.

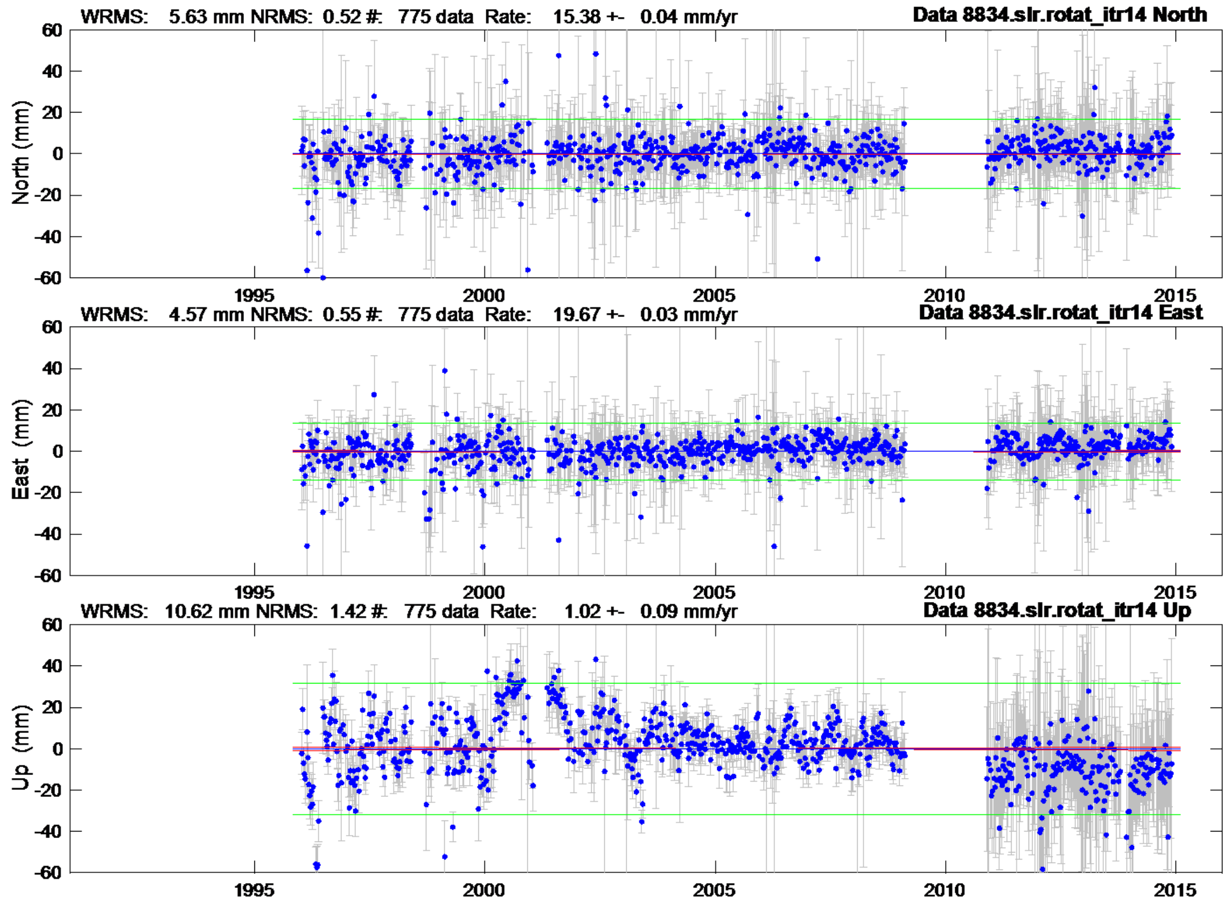


Fig. 2: *SLR time series residuals from the Kalman filter back solution. A variance factor of 50 needed to be applied the ILRS SINEX files to generate error bars that matched the week-to-week scatter. SINEX files before 1996 were not included in the analysis.*

The figures (2–4) illustrate that the error bars being displayed on IERS ITRF products and in the SINEX files are far smaller than they should be given the session-to-session and week-to-week scatter of the position residuals. The figures also show that our residuals are similar to those from the ITRF2014 analysis although this comparison can be easily made graphically because files with the residuals in machine readable form are only available upon request. This seems to be an unwarranted extra step for users who would like to examine the residuals more closely.

In this analysis we were also able to compare our height estimates of the VLBI and SLR sites with the site ties between them. The results are shown in Table 1 where the difference in height between our estimate for the VLBI and SLR stations and the ITRF2014 inferred values with the SINEX site ties applied. The difference between the SLR and VLBI values is our estimate of the scale difference between the systems based solely on the collocated sites with site ties. (The ITRF2014 scale difference estimate use many more sites because this estimate uses stations linked by GPS or DORIS sites.) The mean height difference between VLBI and SLR, excluding TIGO/CONZ, is 3.9 mm which is equivalent to 0.6 ppb. This difference is about half the ITRF2014 value but again is based solely on VLBI and SLR stations that are collocated. The TIGO/CONZ results are likely anomalous due to the complex post-seismic motions after the large earthquake near Concepcion on 27 February 2010.

Table 1: *Average height differences between GLOBK analysis and ITRF2014 with survey ties applied. Most important here is the difference between VLBI and SLR.*

| **Station** | **$\triangle$U VLBI (mm)** | **$\triangle$U SLR (mm)** | **VLBI-SLR (mm)** |
|---|---|---|---|
| Wettzell | $-11.9 \pm 0.5$ | $-13.0 \pm 1.9$ | $+1.1$ |
| Matera | $-1.2 \pm 0.6$ | $-10.7 \pm 0.8$ | $+9.5$ |
| Yarragadee | $8.0 \pm 0.6$ | $0.8 \pm 0.7$ | $+7.2$ |
| Hartebeesthoek | $-2.9 \pm 0.8$ | $-3.2 \pm 1.3$ | $+0.3$ |
| McDonald, TX | $-0.5 \pm 0.8$ | $-2.0 \pm 0.9$ | $+1.5$ |
| TIGO/CONZ | $-11.5 \pm 2.7$ | $1.6 \pm 2.1$ | $-13.1$ |

We are also able to estimate scale changes, again expressed as height changes, from the VLBI and SLR solutions and compare them to estimates from GPS. These results are shown in Figure 6. For VLBI, the mean is 0.5 mm with a root mean scatter (RMS) scatter of 2.8 mm based on 2603 session values. For SLR the mean is -3.6 mm with RMS 3.0 mm for 969 weekly values. This difference between VLBI and SLR is very consistent with the values from the mean height differences although for these analyses all VLBI and SLR sites were used. The precision of the GPS results is very clear but the average value is based on matching the average scale from SLR and VLBI through the satellite antenna phase center location. There is a scale rate of 0.2 mm/yr which was not present in the ITRF2008 system.

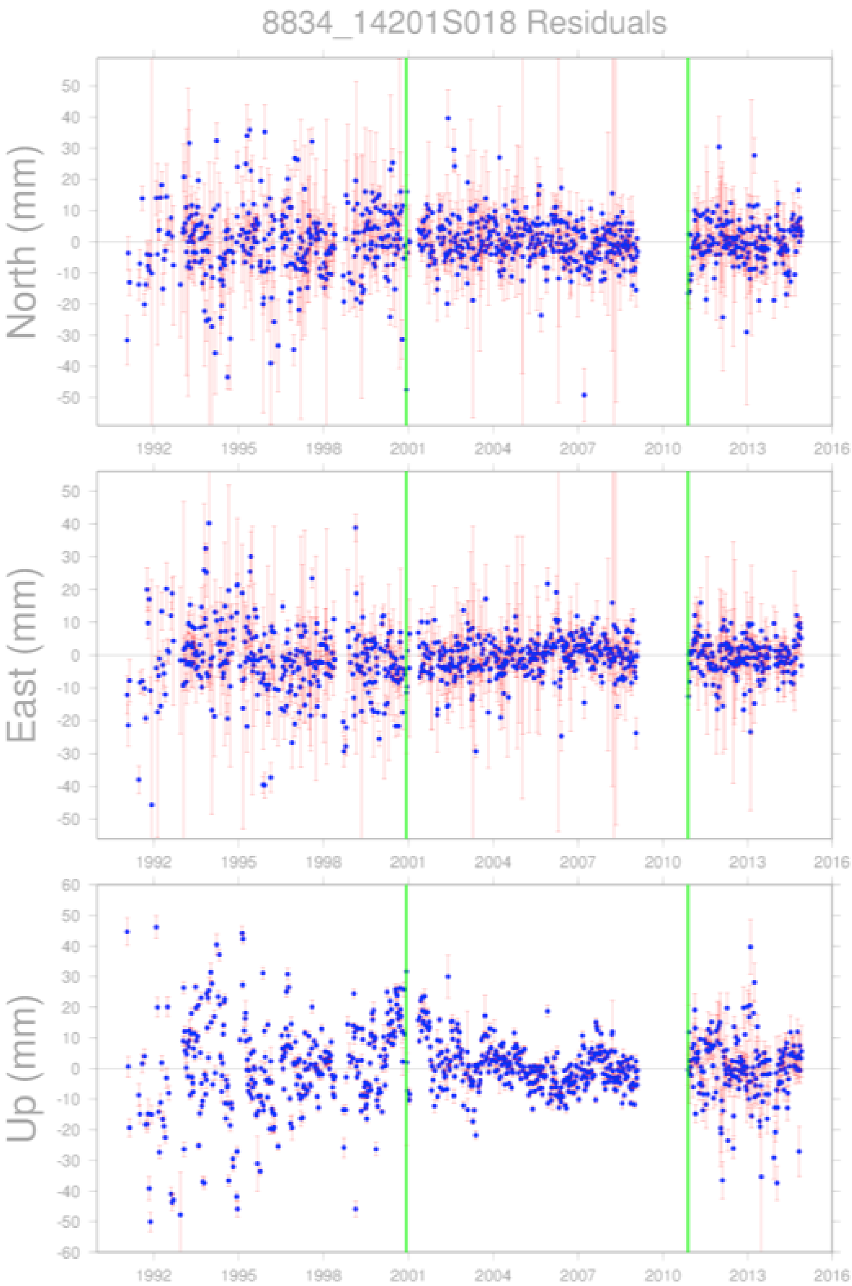


Fig. 3: *The SLR equivalent type residual plot available from the ITRF2014 web site. Notice here that the error bars are not representative of the week-to-week scatter.*

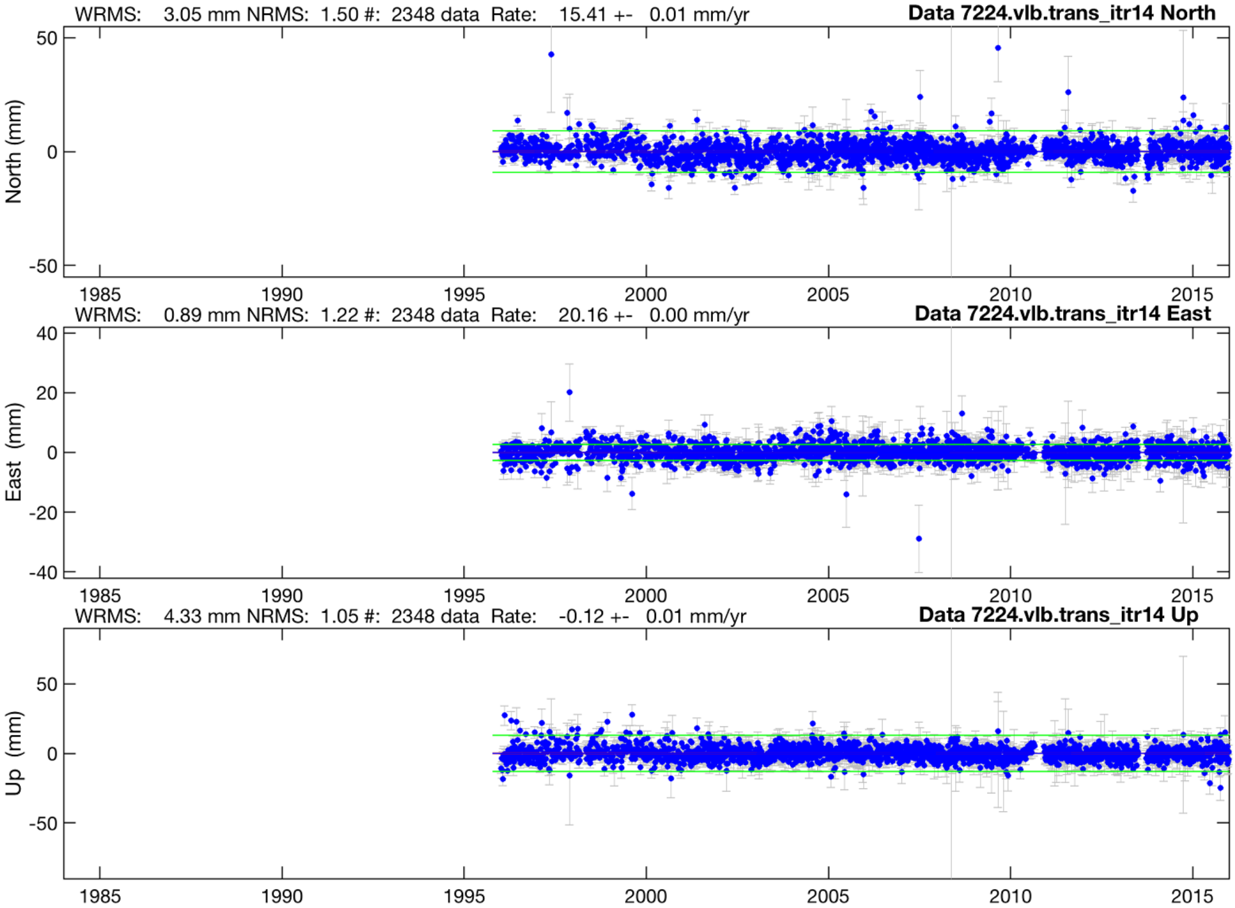


Fig. 4: *VLBI time series residuals from the Kalman filter back solution. A variance factor of 50 (same as ILRS) needed to be applied the IVS SINEX files to generate error bars that matched the session-to-session (24hr) scatter. SINEX files before 1996 were not included in the analysis.*

## IERS product distribution

An action item for the next analysis coordinator could be to form a working group to make recommendations about the distribution of IERS products. As noted above, the distributed products from the IERS and the IERS services should provide realistic variances especially in their SINEX files. It also seems important there be generation and distribution of the "consensus" position time series and EOP estimates in simple ASCII files (for general community) and SINEX (for experts). There have been a number of interesting phenomena that have been found in GPS time series because non-expert users can access these results and do their own analyses. Examples include slow slip events and hydrological loading signals. Distribution of products to non-expert users can raise issues with mis-interpretations (e.g., understanding the impacts of estimating scale in reference frame realizations when hydrologic loading signals are being studied) but the experience from the IGS is that the benefits from a large community that has an interest in seeing the products continued outweigh the possible problems. For GPS position time series, there are multiple locations a user can go and download results for stations they are interested in. For most of the IERS services, it is very difficult to find higher level products that users can analyze themselves.

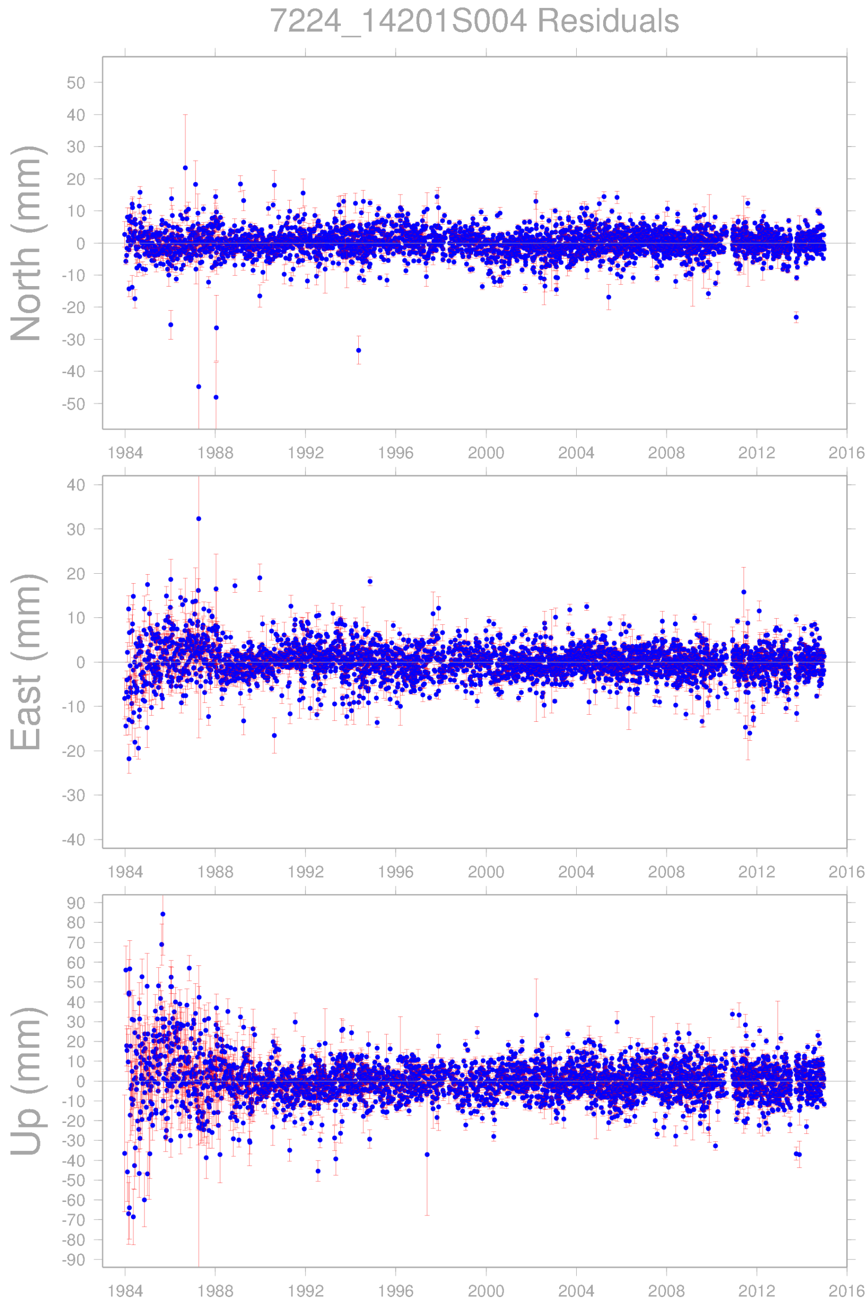


Fig. 5: *The VLBI equivalent type residual plot for the VLBI sites available from the ITRF2014 web site. Notice here that the error bars are not representative of the session-to-session scatter.*

The other product distribution issue that will need to be addressed is the file transfer protocol (ftp). The method of data access will almost certainly go away over the next few years due to the security risks associated with using it both to retrieve data and to host it. CDDIS has

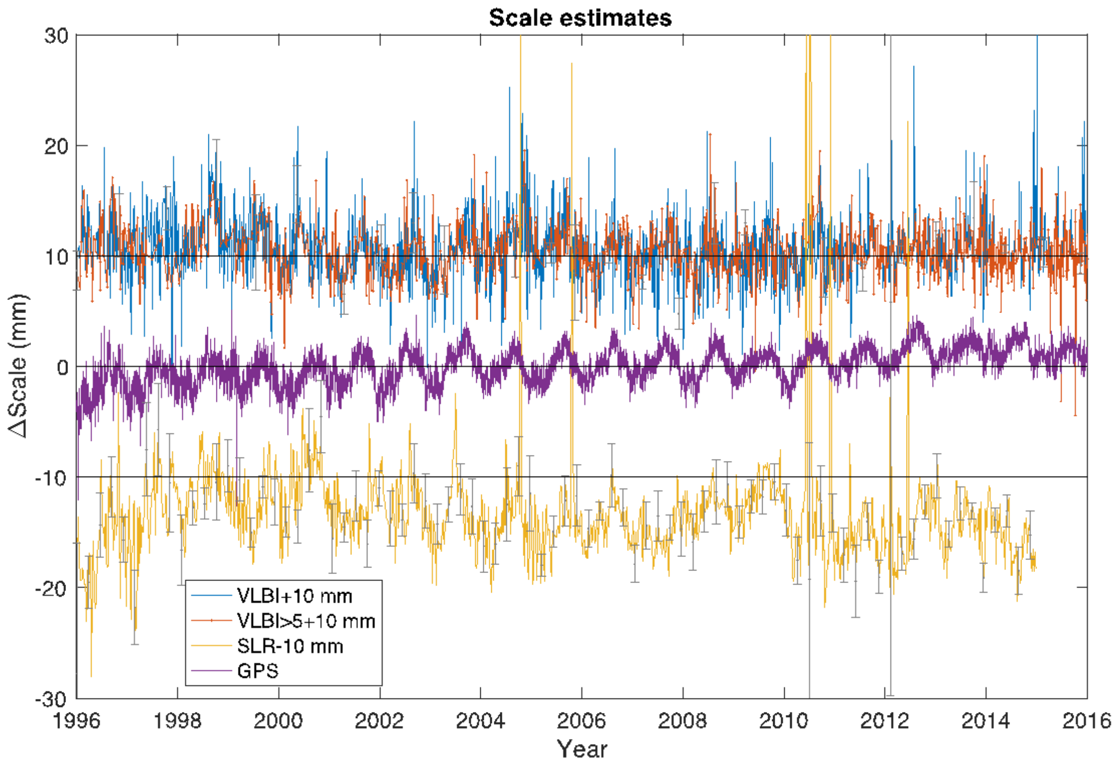


Fig. 6: *Time series of scale estimates expressed as height differences from VLBI (blue, all results, dark brown values with standard deviations less than 5 mm) offset by +10 mm, GPS (purple) and SLR (light brown) offset by -10 mm.*

already stopped using ftp for product uploads (curl replacement) and Apple operating systems (OS) no longer include FTP in new OS distributions. HTTPS is the likely replacement for ftp which would keep similar functionality as now (use curl or wget to access) but users will need to be informed and educated about changes in access methods. Implementation of web services is another approach and product delivery can more tailored to users requirements. Some IERS products are available through web services e.g., https://www.iers.org/webservices. Other groups such as UNAVCO provide interactive forms that allow users to create web service URL's which they can then modify to make more general calls (see e.g., https://www.unavco.org/data/web-services/documentation/documentation.html#!/gps/getPositionByStationId).

The Working Group should address both of these issues and strongly encourage the IERS services to make higher level products available so that a large community can assess and use them easily. The development of a large user community will ensure that there is strong support for continued generation of IERS products.

*Thomas Herring*