## 3.7.2 Working Group on Combination

The major three items addressed in this report are (1) the ongoing research in the German GGOS-D project, (2) the development of software by a few groups to combine the space geodetic techniques on the observation level, and (3) the Unified Analysis Workshop in December 2007 in Monterey. A lot of additional material concerning combination may be found in Section 3.6 of this report. The huge amount of combination work done for the ITRF generation is described in Sections 3.5.5. and 3.6.1. and will not be addressed here.

### GGOS-D Project

Since GGOS-D is one of the major projects presently aiming at a rigorous combination of the different space geodetic techniques, we will shortly present the status of the project here. By the end of 2007, the time series of SINEX files from the individual space techniques except DORIS were all available, processed in a homogeneous way according to well-defined common standards. The software packages involved were modified to follow these standards not only concerning modelling, but also parameterization. A DORIS solution with daily resolution was contributed by Pascal Willis. This solution did not follow yet all the details of the standards agreed upon in the GGOS-D project. A solution according to the GGOS-D standards is planned, however. For VLBI as well as SLR, two solutions were generated based on two independent software packages. For GPS, the second solution is not yet finished for the entire time interval from 1994 to 2006.

Combination tests have been performed with the various series concerning:

- Combination of the technique-specific solutions (VLBI, SLR)
- Combination of troposphere zenith delay and gradient parameters derived from VLBI and GPS solutions
- Combination of subdaily ERPs from GPS and VLBI
- Combination of UT1–UTC from VLBI and LOD from GPS
- Combination of nutation offsets from VLBI and nutation rates from GPS
- Local ties between the individual techniques

The generation of a full TRF solution based on these homogeneous, reprocessed solutions is a primary goal of the project, but has not yet been finished.

Detailed comparisons have been made, however, between these reprocessed series and the corresponding series of the IAG Technique Services and the IERS. These comparisons show the refined quality of the reprocessed series. Especially in the case of GPS a

considerable improvement in consistency and homogeneity has been achieved compared to the official IGS solutions. A planned reprocessing organized by the IGS will most probably cure this deficiency in the next 1–2 years.

More information about the project GGOS-D is available at <http://www.ggos-d.de> and in the papers listed at the end of this report.

## Combination of the Space Geodetic Techniques on the Observation Level

In the last few years some groups and institutions started to work hard on the combination of the major space geodetic techniques on the observation level. The first question certainly is, to what extent a rigorous combination can be done on the normal equation (or variance-covariance) level (by one or more software packages) and where a combination on the observation level is a necessity.

If we assume that the computers at our disposal have infinite resources (memory, CPU time, disk space, ...) and that we are able to achieve that a set of software packages is using exactly the same models and parameterizations, a combination including all common parameters is feasible on the normal equation level and is fully equivalent to a combination on the observation level. Since our computer resources are not infinite, however, and the various software packages are still quite diverging there are some good reasons to integrate the techniques on the observation level, within one unique software package:

- The capability to process all the different observation types in one software system is ideal in the sense that the consistency of the models (standards and conventions) and parameterizations is guaranteed. On the longer run it is extremely demanding to keep different software packages to conform to the same models and parameterizations etc. With only one package, the software updates will more or less automatically be realized for all observation types, reducing the work load significantly compared to a group that might be using different packages for different observation types.
- The estimation of parameters with a very high temporal resolution or the estimation of stochastic quantities is possible and poses no problems. With more than one package involved, the size of the normal equation systems to be generated and then combined to encompass all the common parameters (e.g., clock parameters of ultra-stable oscillators connected to the VLBI and the GPS instrumentation) might just be too large to handle, especially with the full variance-covariance information.
- It is possible to set up a variance-covariance component estimation based on the original observations to improve the weighting of techniques and observation groups with respect

to each other to answer questions such as “Is an elevation-dependent weighting reasonable?”, “For which techniques should it be done?”, etc.).

- For some possible future applications like observations from satellites with VLBI senders, GPS receivers and SLR retro-reflectors onboard (co-location in space) or satellites with a radio telescope onboard observing quasars will ask for orbit determination based, e.g., on GPS and VLBI observations. Since orbit force models and orbit parameterization are not well-standardized, it would be very difficult to use different software packages in this case. Most of the VLBI packages of today have no orbit determination capability anyway.

The development of a software package that is capable of processing all the major space geodetic techniques at a very high level of sophistication is a long-term goal that requires many man-years of work. It has to be said, that for the majority of problems to be addressed nowadays (weighting factors between techniques, local tie issues, handling of systematic biases, …), the necessary studies can already be done based on normal equation systems or variance-covariance solutions.

Presently, the major software developments in this field are taking place at the Goddard Space Flight Center (GSFC; software GEODYN), at the Groupe de Recherches de Géodésie Spatiale in Toulouse (GRGS; software GINS/DYNAMO), at the GeoForschungs Zentrum in Potsdam (GFZ; software EPOS), and at the Astronomical Institute, University of Berne and Technical University of Munich (AIUB and TUM; software BERNESE).

Recently the processing of VLBI data has been implemented into GEODYN, making it thus suitable for the processing of the major techniques. GINS/DYNAMO is capable of analyzing (among others) GPS, SLR, DORIS and VLBI data. Even the processing of LLR data is part of GINS and the GRGS activities. GRGS is processing and combining all the techniques now on a routine basis. The combination is done based on normal equations. The GFZ software EPOS has been used since a long time to analyse a large variety of observation types (GPS, SLR, DORIS, altimetry XO, inter-satellite measurements, …). Only VLBI is not yet included in this package. The BERNESE GPS Software is presently being modified to allow for the processing of SLR measurements to LAGEOS-type satellites, VLBI, DORIS and gravity mission data.
Other packages might follow.

One of the problems faced by an institution working on a combination on the observation level is the fact, that the institution or group has to understand all the processing details of all the major space geodetic techniques. In principle, such an institution has to reach the level of performance in processing the various space geo-

detic techniques that is equal or close to the performance of the best analysis centers of the corresponding service. In addition, the group has to be able to process large amounts of data from all the major techniques. To gain the experience to process 10–20 years of data from each of the techniques is a non-trivial and extremely time-consuming effort. As long as the solutions produced by an institution combining the techniques on the observation level are not among the best of the various technique services, it will be difficult to compete with a combination based on the solutions of the individual services. But, as computers get faster and faster, and cheaper as well, these processing capabilities will eventually arise.

## Unified Analysis Workshop in Monterey, 2007

This was the first workshop under the umbrella of both GGOS and IERS, with themes concerning the common, integrating and unifying aspects of the analysis of the individual space geodetic techniques. Participation was on invitation only and the participants were selected by the individual services to have a high level of expertise present at the workshop for the themes to be discussed.

A detailed description of the Unified Analysis Workshop is given in Section 4.2

## Meetings and Workshops

See Section 3.3 “Analysis Coordinator” (this volume) for a detailed list.

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