Biennial Report (2015–2016) of PMD IVS Analysis Center

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Abstract The main activities carried out at PMD IVS Analysis Center during 2015 and 2016 are summarized in this report and plans for 2017 are briefly pointed out. Three main subjects were tackled during 2015 and 2016. One concerns the so-called space ties; in this framework a number of GNSS observation tests have been proposed, planned, and carried out with European VLBI antennas. A second investigation was dedicated to VLBI coordinate time series analysis and comparison with corresponding results from other space geodetic techniques involved in ITRF2014 computation. Finally, data processing of CONT campaigns have been carried out for studies on tropospheric parameter estimation from VLBI data and comparison with GNSS estimates at co-location sites.

1 General Information and Staff

The Department of Civil and Environmental Engineering (DICA) of the Polytechnic University of Milan hosts the Politecnico di Milano DICA (PMD) IVS Analysis Center (AC). Milan Polytechnic is the largest technical university in Italy with about 40,000 students. It offers undergraduate, graduate, and higher education courses in engineering, architecture, and design. The Milan Polytechnic has seven main campuses, two are in Milan city and five across Lombardy and Emilia Romagna. The majority of the research and teaching activities are located in the historical campus called Milano Leonardo. PMD AC is located at this campus, in particular it is supported by the Geodesy and Geomatics research area of DICA as far as hardware equipment, software licenses, and assistance are concerned. Members who cooperated with the activities of the PMD IVS Analysis Center in 2015 and 2016 are listed in Table 1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Working Location</th>
<th>Contribution to PMD</th>
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</thead>
<tbody>
<tr>
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<td>Support for data processing</td>
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Staff member contributions and working locations (see [1] and [2]) are indicated in the table as well.

2 Current Status and Activities

The main topics investigated during 2015 and 2016 continued to be related to the improvement of reference frames stability, to satellite/space geodetic intertechnique comparisons, and to troposphere parameter estimation from VLBI and GNSS observations at co-
location sites. The scientific software used for data processing and analysis was updated to the last version available, and some home made algorithms were improved.

### 2.1 Planning and Realization of VLBI Observations of GNSS Satellites

The activities related to the planning and realization of GNSS satellite observations by the VLBI technique (that started some years ago, see, e.g., [17] and [18]), were carried out during the biennium 2015–2016. In particular in this period the experiments were devoted primarily to test the use of the DBBC3 [20] for the acquisition of the strong satellite signal at Medicina VLBI station [3] and at the Sardinia Radio telescope (SRT) [4].

SRT is a large (64-m primary mirror with a 7.9 m secondary) radio telescope, fully steerable located in the province of Cagliari in Sardinia, inaugurated in 2013 (see Figure 1).

The use of the DBBC3 during VLBI observations of GNSS satellites has the advantage to automatically set the power attenuation on the very strong signal coming from the satellites. Then it also takes off the attenuation once the radio telescope receives the weak signal from celestial natural radio sources usually tracked during geodetic VLBI experiments.

One experiment was carried out on the 23 November 2015 on the single baseline between the VLBI stations Medicina and Wettzell. Three satellites for each constellation (GPS, GLONASS, GALILEO) were tracked, alternating satellite observations with natural radio source observations. The software used for scheduling GNSS and natural radio source observations was the VieVS satellite scheduling program [13], which is included as a module in the VieVS software [10]. First attempts of data correlation were successful, but the whole pipeline of the experiment data processing still needs to be completed.

A second experiment was carried out on the 23 May 2016; participating VLBI stations were Medicina, SRT, and Onsala85 [5]. This test was planned as a multi-station, multi-frequency, and multi-constellation experiment. In this case we observed not only GPS, GLONASS, and GALILEO, but also the Chinese BeiDou constellation, as it is shown on the skyplot of Medicina station in Figure 2. Some, still unresolved, problems were found during the correlation of the data from the Medicina VLBI station. Investigating the reasons and possible solutions of the problems are in progress.

### 2.2 Satellite/Space Geodetic Inter-technique Comparisons

We carried our investigations on time series of site coordinates belonging to the networks of the three microwave space-geodetic techniques: Global Navigation Satellite Systems (GNSS) [12], Very Long Baseline Interferometry (VLBI) [16], and Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS) [21].

Figure 3 shows the networks of sites belonging to all four satellite/space-geodetic techniques contributing to ITRF2014, Satellite Laser Ranging (SLR) [8] included, as of mid-2014. In preparation of the computation of the new realization of the International Terrestrial Reference Frame ITRF2014 [9] all ACs, belonging to individual satellite/space-geodetic services of the International Association of Geodesy (IAG)—the International DORIS Service (IDS), the International Laser Ranging Service (ILRS), the International VLBI Service for Geodesy and Astrometry (IVS), and the International GNSS Service (IGS)—reprocessed data ac-
We based our studies on the site positions extracted from combined reprocessed input time series submitted for ITRF2014 computation by IVS, IDS, and IGS official Combination Centers (CCs). We used a novel approach to study time series that is described in detail in [19]. The analysis consists of three main steps: detection and removal of documented and undocu-
mented discontinuities, modeling of the long-term signal (constraining the system dynamic in order to obtain cyclostationary residuals), residuals harmonic analysis by a non-linear least squares algorithm. Frequencies and amplitudes of the residual signals and their percentage of incidence were estimated. Two classes of residual signals related to seasonal and tidal effects were detected for all the three techniques. At the co-location sites (running regularly VLBI, GNSS, and DORIS observations) we estimated also velocities and their standard deviations (STD) obtaining a good agreement among the three techniques both in the horizontal (1.0 mm/yr mean STD) and in the vertical (0.7 mm/yr mean STD) component. Some sites show larger STDs, mainly due to lack of data, different data spans, or noisy observations.

This work was carried out in collaboration with KTU-GEOD Analysis Center (Karadeniz Technical University) and Department of Architecture and Design (DAD) of Polytechnic University of Turin.

2.3 Estimation of Atmospheric Parameters using VLBI and GNSS Data

During 2015 and 2016 the scientific software for VLBI and GNSS data processing was updated to the last version delivered by the universities developing and maintaining the software: the Department of Geodesy and Geoinformation of Vienna University of Technology and the Astronomical Institute of the University of Bern, respectively. The releases now running are the 2.3 for VieVS [7] and the 5.2 for Bernese software [11]. After a period of testing of the new software versions, CONT campaigns were processed using VieVS 2.3. At the VLBI stations co-located with GNSS permanent stations, we are going to process GNSS data too to estimate troposphere parameters using the Bernese 5.2. This work was developed in cooperation with the IVS AC-VIE at Vienna University of Technology (TU Wien). Analysis and comparisons of the results need to be completed.

Some tests, in collaboration with the IVS KTU AC, were carried out to analyze GNSS time series of ZTD (Zenith Tropospheric Delay) and IWV (Integrated Water Vapour) estimates.

3 Future Plans

The plans of PMD IVS Analysis Center for the 2017 and 2018 biennium concern the continuation of studies and experiments on the problem of co-location in space and on ground of the space-geodetic techniques VLBI and GNSS.

The studies and comparisons of the results from the three microwave space/satellite geodetic techniques (VLBI, GNSS, and DORIS) will be extended also to the SLR technique.

Studies on troposphere parameter estimation from VLBI and GNSS will also be continued and some investigations on ionosphere parameters are planned too.

Acknowledgements

We are grateful to the Department of Civil and Environmental Engineering (DICA) of Polytechnic University of Milan, in particular to the Geodesy and Geomatics Area for hosting and supporting the IVS PMD AC. Thanks are due to all the people contributing to activities of the IAG Services: IVS, IGS, IDS, and ILRS.

We thank KTU-GEOD IVS AC (Karadeniz Technical University) and IVS AC-VIE at Vienna University of Technology for their collaboration with some of the IVS PMD AC activities. In particular we thank A. Hellerschmied for having prepared the schedules of the tests mentioned in sub-section 2.1 and the staff at Medicina, SRT, Wettzell, and Onsala who contributed to the realization of the observations.

References

8. G. Appleby, J. Rodriguez, Z. Alhamimi, Assessment of the accuracy of global geodetic satellite laser ranging observations and estimated impact on ITRF scale: estimation of