Analysis of GPS, VLBI and DORIS input time series for ITRF2014

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Abstract In this work we have compared the Up component time series reprocessed in view of the new ITRF2014. The solutions that we have considered are the combinations of individual submissions of the Operational Analysis Centers (ACs) as official IVS, IGS and IDS products. We have modelled time series as discrete-time Marcov processes, we have detected and removed discontinuities from data time series and estimated trends (long term signals). A frequency analysis making research of residual periodic signals and identification of the common ones to all the three space geodetic techniques has been performed. Preliminary results on co-located sites are shown.

Keywords VLBI, GPS, DORIS, time series, harmonic analysis, ITRF2014

1 Introduction

A new determination of ITRF (called ITRF2014) is underway, at this aim several Analysis Centers of IVS, ILRS, IGS, IDS reprocessed all data available till the end of 2014. Reprocessing efforts continued with the approach, started with ITRF2005 and continued with ITRF2008, of using time series of station positions and Earth Orientation Parameters (EOPs) to take into account for realization of ITRF both for station non-linear motions and discontinuities (Altamimi et al., 2007), and also to evaluate the stability over time of frame parameters (origin and the scale) important for studies of Earth sciences. All the space geodetic techniques contributing to ITRF2014 used recommendation indicated in the call for partecipation (see `http://itrf.ensg.ign.fr/ITRF\_solutions/2013/CFP-ITRF2013-27-03-2013.pdf`).

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The solutions were calculated using IERS Conventions IERS (2010), including updates at `http://tai.bipm.org/iers/convupdt/convupdt.html`. It was not required to apply any geophysical fluid loading effect correction, except tidal load and other displacements for which the models are given in IERS Conventions 2010. However, it is envisaged that the individual Analysis Center solution will be corrected for non-tidal atmospheric loading during the ITRF generation, using a unique loading model provided by the IERS Global Geophysical Fluid Center (GGFC).

In this study we have analysed intra–technique combined solutions of the Up component time series for all the stations, whose coordinates have been estimated in the ITRF2014 solutions, belonging to the international space geodetic technique Services: IVS, IDS, IGS. The SLR time series are not included because at the time of this study the official solution for coordinate time series was not yet ready, it is planned to carry out a study also on SLR solutions once them will be officially available.

VLBI, GPS and SLR stations co-located with DORIS sites are shown in Fig. 1. For each technique Up component time series are modeled as discrete-time Marcov processes, see Sec. 2.

The method we have used for the time series analisys and the detection of periodic signals is that described in Roggero (2015). Some examples will be given for the Ponta Delgada site where GPS/GLONASS and DORIS stations are co-located since several years. The presence of anomalous behaviours common to the three techniques is investigated for the Up component time series by analysing in frequency and amplitude the signals of the permanent stations. The harmonic analysis has been carried out globally for stations (belonging to each VLBI, GPS and DORIS network), having with a long time history and good sampling. Comparisons among obtained results for each of the three techniques have been made in Sec. 3

2 Time series analysis

To obtain high accuracy multi-year solutions one key task is to assess the quality of the underlying coordinate time series. The new calculation of ITRF2014 represents a good opportunity for

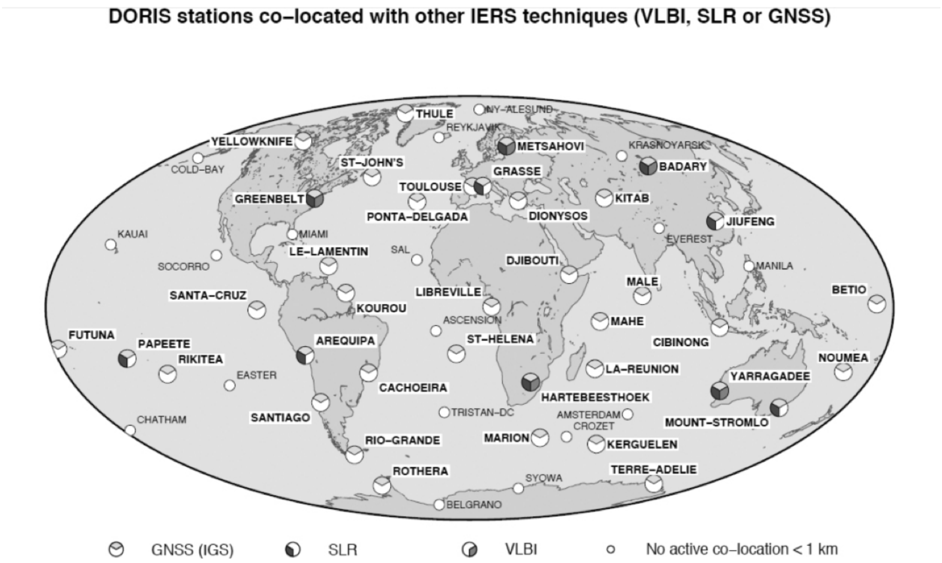

Fig. 1 DORIS stations co-located with other space geodetic techniques: VLBI, SLR and GNSS (credit by IDS)

this aim, since all the campaigns covering almost the full history of observations of each technique contributing to ITRF (VLBI, GPS, SLR, DORIS) have been reprocessed at international ACs conforming to the same general analysis strategy, following the same IERS recommendation (with indication of possible departures) and using specific model updates. Solutions to be included in the ITRF2014 were submitted in SINEX format, station coordinate time series are estimated daily for GNSS, session-wise from VLBI, and weekly for DORIS and SLR. In this work we have focused our attention on the intra-technique combined official solutions for coordinate time series delivered by CLS (Collecte, Localisation, Satellites, France) for DORIS, by BKG (Bundesamt für Kartographie und Geodäsie, Germany) for VLBI, and by IGN (Institut National de l'information geographique et forestriere, France) for GPS. We will process also SLR data as soon as the official calculations will be available. In particular we have analysed the Up component time series of all the sites belonging to the different networks IVS, IGS, IDS and we plan to extend the study also to horizontal components in further steps of this study.

We have modeled Up component time series as a discrete-time linear system described by a finite state vector evolving with known dynamics. In fact it has been shown by Albertella et al. 2005, and Tornatore and Cazzaniga (2009), that the system has an optimal solution, the algorithm was then modified by Roggero (2012) to estimate also a bias vector correspondent to jumps in the time series. Once discontinuities and outliers are identified, an iterative procedure called Detection, Identification and Adaptation (DIA) in Teunissen (1998) was adopted to make the decomposition of the time series. The long term signal has been modelled as the sum of following components: linear trend, non linear and non periodic signals plus periodic signals with period larger than the time series length. Harmonic analysis on residuals obtained after detrending data was carried out using the Frequency Analysis Mapping On Unusual Sampling (FAMOUS) software (Mignard, 2003). Among several different approaches available for harmonic analysis the FAMOUS software is particularly suitable for our analysis since it is designed to search for sets of frequencies in discrete irregular sampled data sets that's the case of our solutions: daily for GPS, weekly for DORIS and session–wise solutions, unevenly sampled, for VLBI.

Different IGS permanent stations coordinates time series have been analysed using these algorithms, among them we have chosen to show in this work time series modelling for Ponta Delgada, where both GPS/GLONASS and DORIS stations are active. The 22nd European VLBI for Geodesy and Astrometry (EVGA) Working Meeting has been held in Ponta Delgada that is the largest municipality and administrative capital of the Autonomous Region of the Azores in Portugal and is located in the island of Sao Miguel. The Azores archipelago is formed by nine islands, and their origin is directly related with the tectonic movements of three plates: the African, the American and the Euroasian. This makes the Azores a very important area from the geological point of view since they demark the frontier of these three plates. It is matters of investigation if Ponta Delgada belongs to the Eurasian or African Tectonic Plate. Fig. 2 shows a picture of the GPS/GLONASS station based on the roof of the Geo-Sciences Building of the University of Azores.

The GPS/GLONASS station of Ponta Delgata is an IGS station named PDEL, managed by DGTerritorio (`http://www.dgterritorio.pt/`). It has an external quartz clock and is active since 2000. During data processing only GPS data were used to calculate the solution and not the GLONASS. According to our time serie analysis of the Up component of Ponta Delgada (PDEL) station, the GPS time series is modelled as in Fig. 4.

It appears clearly in the figure that the time series of PDEL shows a discontinuity on the day 97 of 2008 correspondent to a

Fig. 2 GPS/GLONASS station at Ponta Delagada, Sao Miguel, Azores

Fig. 3 DORIS station at Ponta Delagada, Sao Miguel, Azores

known discontinuity: antenna and receiver change. A mean velocity of -1.79 mm/yr has been estimated for the GPS station.

Concerning the DORIS site (see picture shown in Fig. 3) it is also installed on concrete beam on the roof of a 3 storied building. The first station called PDLB was installed on the 02/11/1998 and removed 21/08/2001, then the present PDMB station was installed on the 22/08/2001.

A co-location between the two stations PDLB and PDMD was measured giving a negligible distance in X,Y,Z of a few millimiter each (precision 1 mm) reported in the logfile of the station. A little jump of 4.3 mm has been estimated in the Up component at the epoch when the station was changed, see the two time series of PDLB and PDMB stations displayed together in Fig. 5. In the DORIS time series clearly appear also gaps in data acquisition that according to logfile are generically due to corrupted data and failures.

The values of the estimated velocity is -2.16 mm/yr for the present PDMD station, this value is not very different from that found for GPS antenna (-1.79 mm/yr) PDEL, showing a good agreement on estimated velocities by the co-located GPS and DORIS techniques. However the PDMD value is very different from that of the previous DORIS station PDLB that is equal to -8.57 mm/yr. It has to be noticed that data of PDLB are more scattered than those of PDMD and the covered time interval is very short. This confirms how estimated velocity values can change according to time interval considered, especially when it is very short and data are very noisy the values of the estimated velocities can not be very reliable. At the site of Ponta Delgada also meteorological instrumentations are present like humidity, pressure and temperature sensors. The co-location measurement carried out at the site are:

1. Tide Gauge co-location with DORIS station (measured 10/1998 and 08/2001)
2. GNSS and current DORIS PDMD distance in X,Y,Z a few meters, accuracy 10 mm, tie measured on 01/08/2001
3. VLBI-GNSS (VLBI portable observation at the level of 10 mm accuracy)

More details on values of these past co-locations can be found on the logfile of the stations both for PDEL and PDMD. Anyway all the local tie campaigns are quite dated, it would be useful to repeat co-location campaigns also in view of the new VLBI Global Observing System (VGOS) antenna recently installed at Santa Maria island.

3 Harmonic Analysis

The procedure applied for the analysis of all time series (Up component) estimated in view of ITRF2014 for the sites belonging to networks of IVS, IGS and IDS, had the aim to remove discontinuities, estimate velocities, remove non linear long term trends and residual calculation.

This was done to obtain residuals having statistical properties that vary cyclically with time so that harmonic analysis could be applied. However obtained residuals still present some limitations to apply harmonic analysis, since they do not fulfill completely all the requirements of a standard harmonic analysis, like long time series, constant sampling rate, equally weighted data values, no presence of gaps.

For all of these reasons we carried out residual harmonic analysis using the non linear least square algorithm implemented in the software called FAMOUS (**?**). The signals estimated by FAMOUS were studied in frequency and amplitude stacking the power spectra in order to detect the most significant effects. Then a global analysis of detected signals over the total number of stations was performed, excluding only those sites having time history shorter than 10 years.

The results of our harmonic analysis presented three classes of signals, related to seasonal, orbital (GPS draconitic) and tidal effects. The minimum sampling frequency (Nyquist frequency) for weekly time series is 14 days, around this value a strong signal has been also detected and can also be attributed to tidal model errors. Values for the detected signals, period and amplitude, for GPS, VLBI and DORIS sites (only signals that passed FAMOUS significance tests are reported) can be found in Tab. 1 and in Tab.2. The values inside square brackets in Tab.1 are the percentages of incidence, that is the number of stations in which the signal has been detected over the total number of stations. All

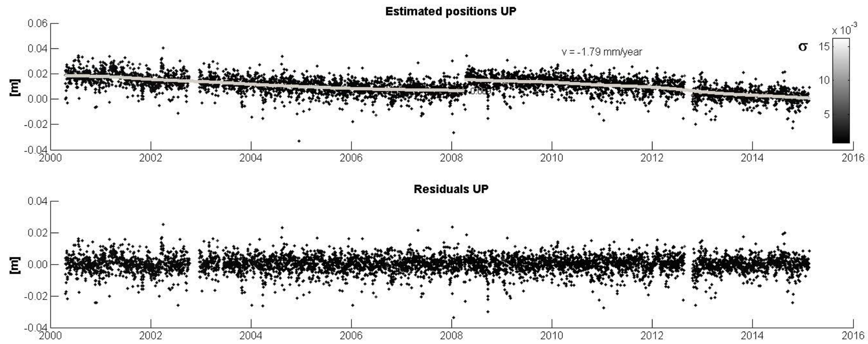

Fig. 4 Up component time series plus estimated long term signal (top), and residuals almost cyclostationary (bottom) for Ponta Delgada GPS station (PDEL). The grayscale color bar represents the σ of the Up component

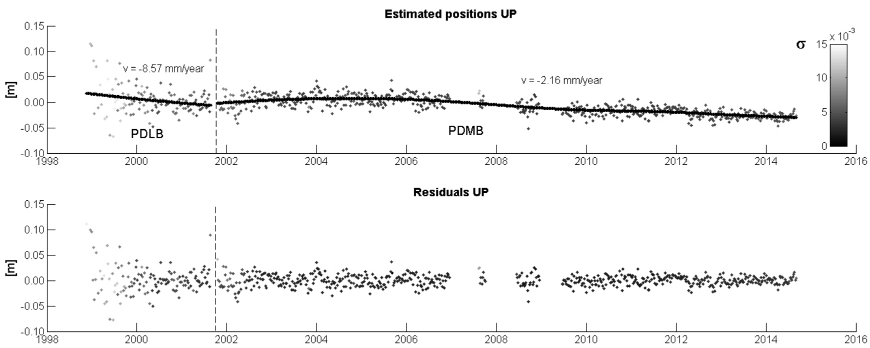

Fig. 5 Up component time series plus estimated long term signal (top), and residuals almost cyclostationary (bottom) for Ponta Delgada DORIS stations (PDLB and PDMD). The grayscale color bar represents the σ of the Up component, that is higher during the first years of PDLB observations

expected and detected draconitic, solar and tidal harmonic have comparable periods for the GPS technique. Among all the detected annual signals two of them with 14 days and 1 year (solar) period are common to all the 3 techniques.

4 Conclusions

In view of the calculation of ITRF2014, input time series from the four space geodetic techniques have been reprocessed till the end of the 2014 according to same recommendation. Therefore combined intra-technique time series solutions constitute a huge homogeneous data set. In this work we have applied the same method for time series analysis in particular of the Up component of GPS, DORIS and VLBI sites estimated during reprocessing procedure. Once we have detected and removed time serie discontinuities, we have estimated trends and removed them obtaining almost cyclostationary stochastic process, whose statistical properties vary periodical.

The adopted algorithms, in this work, have made harmonic analysis possible and reliable almost on all our set of data even when we do not have constant sampling rate, and short gaps are still present in the time series. Among the detected annual signals two of them with 14 days and 1 year (solar) periods are common to all the 3 techniques, detailed investigation on the geophysical origin of these signals nature are necessary to make a correct interpretation.

An extended version of this work is going to be published on the Journal Advances in Space Research (ISSN: 0273-1177), Special Issue: Applications of DORIS data.

Table 1 Signal mean amplitudes estimated for GPS, DORIS and VLBI sites (only signals that passed FAMOUS significance tests are reported).

	mean amplitude [mm]						
	GPS			DORIS		VLBI	
cpy	draconitic	solar	tidal	solar	tidal	solar	tidal
1	3.5 [1.7%]	4.4 [50.2%]	1.3 [3.1%]	10.3 [15.0%]		2.5 [5.5%]	
2	1.7 [37.5%]	1.9 [15.1%]	2.9 [4.0%]	8.8 [3.9%]			
3	1.5 [20.2%]	1.6 [7.5%]		7.5 [9.2%]			
4	1.6 [27.7%]	1.2 [1.9%]	1.2 [1.9%]				
5	4.1 [4.0%]						
6	1.0 [7.1%]						
7	1.4 [2.2%]						
12			7.3 [6.5%]		6.1 [18.3%]		4.7 [8.2%]

Table 2 Expected and estimated signal periods at GPS, DORIS and VLBI sites (only signals that passed FAMOUS significance tests are reported).

	Period [days]									
	Expected			GPS			DORIS		VLBI	
cpy	draconitic	solar	tidal	draconitic	solar	tidal	solar	tidal	solar	tidal
1	351.2	365.3	164.0	350 ±1	365±5	163±2	363±10		365±2	
2	175.6	182.6	82.0	176±3	182±2	82±1	183±3			
3	117.1	121.8		117±1	122±1		118±3			
4	87.8	91.3	41.0	88±1	91±1	41±1				
5	70.2			70±1						
6	58.5			59±1						
7	50.2			50±1						
12			13.7			14±1		15±1		13±2

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