2017–2018 Report of the IVS Associate Analysis Center PMD

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Abstract The activities related to geodetic VLBI performed at the IVS AC PMD during 2017 and 2018 were focused on different topics that are detailed below. As in previous years, routine computations of European baselines were carried out.

For the Ny-Ålesund VLBI station detailed studies have been executed on velocity estimations and comparisons with results from geodetic satellite techniques. In parallel, investigations on running or preparing VGOS stations were developed. In particular, the RFI threat to the new broadband system, due to several new commercial services that operate in VGOS bands, wasinvestigated. This work was developed also under the framework of the Committee on Radio Astronomy Frequencies (CRAF).

From the observation point-of-view, AC PMD has coordinated the three Italian VLBI stations (Matera, Medicina, and Noto) for the realization of the experiment *s7615b* on phase referencing VLBI observations of the Chang'E-3 lander.

Another topic investigated at PMD was under the COST project Action ES1206. In particular, several simulations and comparisons of different algorithms developed to detect inhomogeneity in the GPS Integrated Water Vapor (IWV) time series were tested. These studies can be applied in the future also to the VLBI IWV time series.

1 General Information

No relevant changes with respect to the previous biennium (2015–2016) have occurred at the Politecnico di Milano DICA (PMD) IVS Analysis Center (AC) concerning its location, funding agency, and staff members.

2 Current Status and Activities

2.1 European VLBI Experiments and Investigations on Ny-Ålesund Observatory

European sessions carried out since 1990 through the end of 2018 have been processed. Most recent modeling conditions and different values for parameterizations have been tested. Solutions have been calculated with the VieVS (Vienna VLBI Software) software versions 2.3 and 3.0 [1], developed by the members of the VLBI group of the Institute of Geodesy and Geophysics (IGG), Vienna University of Technology (TU Wien). European site coordinates and baseline lengths (with respective variance-covariance matrices) have been estimated to study their temporal evolution. The adjustments were performed using single session approach.

Detailed studies were dedicated to the Arctic station of Ny-Ålesund. In particular, we have derived velocities from the VLBI coordinate time series (N, E, Up) and compared them to those derived from the International Terrestrial Reference Frame (ITRF2014) [2]. Furthermore, motions derived for Ny-Ålesund

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(ITRF2014) were compared with the three space geodetic techniques VLBI, GNSS, and DORIS. Earlier studies have revealed inconsistent results among different observing techniques. Discontinuity or jump detections and estimations are recognized as a critical issue for offset-related velocity biases. In order to further reduce effects due to non-coherent processing strategies, we have used the same methods for all techniques to handle and estimate discontinuities. The harmonic analysis shows also some differences in the detected periodic signals frequency, phase, and amplitude, which are clearly of non-geophysical origin. These studies are near to be submitted for publication.

2.2 VGOS Stations

Threats to the frequency spectrum observed by VGOS stations have been increasing very fast during the last years. Currently the most remarkable risks are represented by the upcoming 5G infrastructure for cell phone & Internet and upcoming satellite-based Internet infrastructure like SpaceX/Starlink or OneWeb, which will occupy massively frequency bands in the range of 2–14 GHz [3]. This will limit the possibility to observe undisturbed up to 1-GHz-wide spectral bands in the VGOS mode. Tools to carry out compatibility studies have been developed [4], and simulations have demonstrated that separation zones for 5G base stations from radio telescope sites in Europe are reaching 200 km.

VGOS came up too late to claim the entire 2–14 GHz range for the exclusive use of VLBI; however, since the VGOS range covers many Radio Astronomy Service (RAS) bands, VGOS radio telescopes may be registered as RAS sites. A site registered as an RAS one should then be protected from strong signals according to RAS bands and other bands where footnotes in the regulations apply in favor of RAS.

5G, for example, will make use of up to 2.69 GHz and RAS is primary user of 2.69–2.70 GHz. As the VGOS range covers many RAS bands, it is higly recommended that VGOS radio telescopes register as RAS sites [5].

At PMD AC a list of approximate coordinates for VGOS sites was compiled, distinguishing radio telescopes already observing from those still under tests, or in contruction, or with plan approved. The list has been updated various times thanks to the collaboration with several IVS Members and in particular with the VGOS Technical Committee (VTC). The list of VGOS sites as of May 2019 is reported in Table 1, where approximate geografic coordinate values and antenna dish sizes can also be found.

The stations are also shown in Figure 1, where the three International Telecommunication Union (ITU) region borders [6] are also indicated. The ITU is the authority responsible to regulate globally the spectrum management. The treaty organization that deals with radio waves is the Radiocommunication Sector of the ITU (ITU-R). It divides the world into three administrative regions R1, R2, and R3.

The interests of the European radio astronomers in ITU-R1 are represented by the Committee on Radio Astronomy Frequencies (CRAF) [7], an Expert Committee of the European Science Foundation (ESF) [8]. Similar organizations to protect radio astronomy interests also exist for the Americas (Committee on Radio-Frequency, CORF) [9] in ITU-R2 and for the Asia-Pacific region (Radio Astronomy Frequency Committee, RAFCAP) [10] in ITU-R3.

2.3 Inhomogeneity Estimations in IWV Time Series

Under COST Action ES1206 Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC), the sub-WG *Data Homogenization* was set to tackle first on the IGS repro 1 tropospheric dataset as a case study. Among its activities, the Working Group carried out the following:

- inventory of the existing homogenization software to study GNSS tropospheric delay and water vapor time series;
- production of synthetic datasets (based on characteristics of the IGS repro 1 dataset, and with known offsets included);
- benchmark (blindly) the performance, weakness and advantages of each method using statistical scores, CRMEs, and trend differences;
- assessment of different methods for computing trends and their uncertainties in the time series.

Table 1 Approximate coordinates of the VGOS sites currently running, under tests, in construction, or planned, together with their respective ITU Region and dish size.

ITU Region	Country	Common name	North Latitude			East Longitude			Dish size
			[°]	[′]	[″]	[°]	[′]	[″]	[m]
R1	Finland	Metsähovi	60	13	4.8	24	23	38.4	13.2
R1	Germany	Wettzell N	49	8	38.4	12	52	40.8	13.2
R1	Germany	Wettzell S	49	8	34.8	12	52	40.8	13.2
R1	Italy	Matera	40	38	56.4	16	42	18.0	(13.0)
R1	Italy/Jp	MBL1 Medicina	44	31	29.95	11	38	43.28	2.4
R1	Norway	Ny-Ålesund N	78	56	34.8	11	51	18.0	13.2
R1	Norway	Ny-Ålesund S	78	56	34.8	11	51	18.0	13.2
R1	Portugal	Flores	39	28	1.2	−31	−13	−37.2	13.2
R1	Portugal	Santa Maria	36	59	6.0	−25	−7	−33.6	13.2
R1	Russia	Badary	51	46	12.0	102	14	2.4	13.2
R1	Russia	Svetloe	60	31	48.0	29	46	48.0	13.2
R1	Russia	Zelenchukskaya	43	47	16.8	41	33	54.0	13.2
R1	South Africa	Hartebeesthoek	−25	−53	−16.8	27	41	9.6	13.2
R1	Spain	Gran Canaria	28	1	33.6	−15	−40	−15.6	13.2
R1	Spain	Yebes	40	31	22.8	−3	−5	−16.8	13.2
R1	Sweden	Onsala NE	57	23	38.4	11	55	12.0	13.2
R1	Sweden	Onsala SW	57	23	34.8	11	55	8.4	13.2
R2	Brazil	Fortaleza	–	–	–	–	–	–	(12.0)
R2	USA	GGAO	39	1	19.2	−76	−49	−37.2	12.0
R2	USA	Kokee	22	7	33.6	−159	−39	−54.0	12.0
R2	USA	McDonald	30	40	48.0	−104	−1	−26.4	12.0
R2	USA	Westford	42	36	46.8	−71	−29	−38.4	18.3
R3	Australia	Hobart	−42	−48	−21.6	147	26	16.8	12.0
R3	Australia	Katherine	−14	−22	−30.0	132	9	7.2	12.0
R3	Australia	Yarragadee	−29	−2	−49.2	115	20	45.6	12.0
R3	China	Seshan13	31	5	56.4	121	11	56.4	13.0
R3	China	Tianma13	31	5	27.6	121	8	13.2	13.0
R3	China	Urumqi13	43	28	16.0	87	10	40.0	13.2
R3	Tahiti (FR)	Tahiti	−17	−31	−4.8	−149	−26	−13.2	12.0
R3	Japan	Kashima34	35	57	21.26	140	39	36.37	34.0
R3	Japan	MBL2 Koganei	35	42	28.55	139	29	16.55	2.4
R3	Japan	Ishioka	36	6	10.8	140	5	20.4	13.2
R3	Thailand	Chiang Mai	18	51	56.0	99	13	3.4	(13.0)

The work is nearly finished and a corresponding manuscript is going to be submitted. The COST Action being ended, this work is now continued in the framework of the IAG WG 4.3.8 "GNSS Tropospheric Products for Climate."

2.4 Chang'E-3 Observations

Chang'E-3 is an unmanned lunar exploration mission operated by the China National Space Administration (CNSA), incorporating a robotic lander (see Figure 2 [11]), and China's first lunar rover. It was launched in December 2013 as part of the second phase of the Chinese Lunar Exploration Program. The planned landing site was Sinus Iridum, but the lander actually descended on Mare Imbrium (see Figure 3 [12]).

An experiment of Chang'E-3 lander observations at X-band in phase referencing VLBI mode was planned and carried out at the following interval: UTC 2017-06-15 21:30 – 2017-06-16 03:10. The experiment on Chang'E-3 lander has been called *s7615b*.

The three Italian VLBI stations Medicina (32 m), Noto (32 m), and Matera (20 m) joined the experiment. The AC PMD supported and coordinated the three stations during the preparation and running of the experiment. A preliminary ad-hoc test at the three stations was also planned and realized on 13 and 14 of June

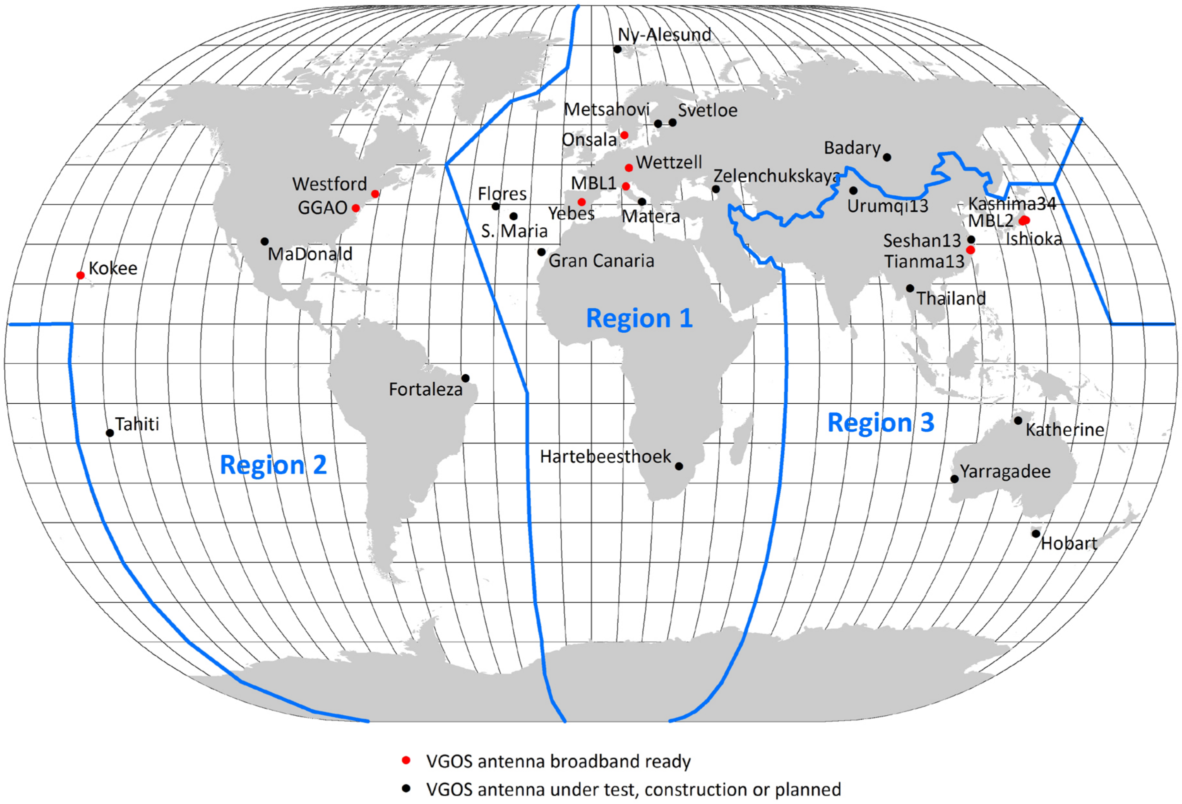

Fig. 1 Distribution of the current and future VGOS sites in the three ITU Regions.

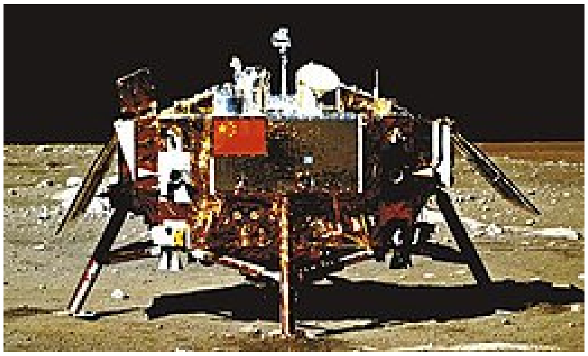

Fig. 2 Chang'E-3 lander on the lunar surface.

Fig. 3 Mare Imbrium where the Chang'E-3 lander descended.

2017. The three Italian antennas tracked the lander using a step-wise tracking mode.

The tones transmitted by the lander are:
8450.75 MHz
8466.15 MHz
8470.00 MHz (carrier)
8673.85 MHz
8489.25 MHz
8496.00 MHz (downlink signal)

Four DOR at 8450.75 MHz, 8466.15 MHz, 8673 MHz, and 8489.25 MHz

Data recorded at each station were transferred and correlated at SHAO. Good fringes to the lander were obtained between Chinese and Italian stations.

3 Future Plans

About data processing, it is foreseen to continue at PMD the data processing of European legacy VLBI stations, and to start analysis of experiments where VGOS stations are involved. Analysis of time series of baselines and site coordinates will be continued and it is planned to broaden the study to time series of tropospheric and ionospheric parameters both for VLBI and GNSS techniques. The work to find out the best algorithms to be applied to detect inhomegeneity will be deepened. As concerns the observations of space probes and GNSS satellites through VLBI technique, it is planned to carry out activities in collaboration with national and international observatories and research centers.

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