Overview

The current report presents the different activities held in 2016 by the components of the International DORIS Service (IDS). In a first step, we give the current status of the DORIS system (satellites and tracking network). In a second step, we provide the latest news of the IDS (Governing Board, Central Bureau, Data Centers). Then we focus on the most recent activities conducted by the Analysis Centers and the Analysis Coordination. The report ends with information about the meetings and the publications.

1 DORIS system

1.1 DORIS satellites

During this report period (2016), the number of DORIS satellites has increased to six (see Table 1).

Satellite	Start	End	Mission
SPOT-2	31-MAR-90 04-NOV-92	04-JUL-90 15-JUL-09	Remote sensing
TOPEX/Poseidon	25-SEP-92	01-NOV-04	Altimetry
SPOT-3	01-FEB-94	09-NOV-96	Remote sensing
SPOT-4	01-MAY-98	24-JUN-13	Remote sensing
SPOT-5	11-JUN-02	11-DEC-15	Remote sensing
Jason-1	15-JAN-02	21-JUN-13	Altimetry
ENVISAT	13-JUN-02	08-APR-12	Altimetry, Environment
Jason-2	12-JUL-08	–	Altimetry
Cryosat-2	30-MAY-10	–	Altimetry
HY-2A	1-OCT-11	–	Altimetry
SARAL	14-MAR-13	–	Altimetry
Jason-3	17-JUN-16	–	Altimetry
SENTINEL-3A	16-FEB-16	–	Altimetry

Table 1. DORIS data available at IDS Data Centers. As of December 2016

Two new satellites were launched in early 2016: Jason-3 and Sentinel-3B, both using the new 7-channel DG-XXS DORIS receiver on-board the satellite. The DORIS constellation then steadily increased, including currently six satellites at altitudes of 720 and 1300 km, with almost polar or TOPEX-like inclination (66 deg).

The DORIS system was 26 years old in 2016 and its performance remains unbeatable thanks to permanent enhancements to the system and its components. Thirteen DORIS receivers have flown on various Earth observation and altimetry missions since 1990, and many future missions currently under preparation should guarantee a constellation of DORIS contributor satellites up to 2030 and beyond:

- Sentinel-3B, Sentinel-3C and -3D (ESA/Copernicus) are under development, and expected for end 2017, 2020 and 2025.
- SWOT (Surface Water Ocean Topography) a joint project involving NASA, CNES, the Canadian Space Agency and the UK Space Agency, is planned for 2021.
- Jason-CS will ensure continuity from Jason-3 with a first launch in 2020 (Jason-CS1/ Sentinel-6A) and 2025 (Jason-CS2 / Sentinel-6B). The Jason-CS / Sentinel satellites are part of the Copernicus program and are the result of international cooperation between ESA, Eumetsat, the European Union, NOAA, CNES and NASA/JPL.
- HY2-C, HY-2D (CNSA/NSOAS) two Chinese missions flying DORIS are planned for 2019 and 2020 respectively. A further four missions (HY2-E, -F, -G and -H) are pending approval and planned from 2024.

1.2 DORIS network

DORIS has a globally distributed network of 56 permanent stations dedicated for orbitography and altimetry. Two additional DORIS stations are used for other scientific purposes: Grasse (France) and Wettzell (Germany).

The new DORIS station at the Geodetic Observatory Wettzell started work on September 27, 2016 with shifted frequencies to avoid internal jamming with the nearby stations of the permanent network. The most challenging requirement was to manage interferences with VLBI. After some months of intensive tests carried out on site, a compromise to minimize the constraints for both systems has been found. Greenbelt and Wettzell are now two examples of core sites complying with the GGOS requirements with the four space geodetic techniques (co-located DORIS/GNSS/SLR/VLBI).

Another main event of 2016 is the newly installed DORIS station at Managua, Nicaragua. Fully integrated within the data coverage map, this new station is also well located to provide reliable information on the Caribbean tectonic plate motion when combined with the DORIS station data of “Le Lamentin”.

This new DORIS site compensates for the decommissioning of Santiago with regard to the number of beacons of the permanent network, remained stable: 56 including 4 master beacons and 1 time beacon.

The extensive outage of 3 stations is to be noticed: Mahé, Santa-Cruz and Socorro. Nevertheless, the DORIS network provided a very reliable service with an annual mean of 89% of active sites thanks to the responsiveness and the combined efforts of CNES, IGN and all agencies hosting the stations: 8 failed beacons and 1 failed antenna were replaced and 2 antennas were relocated.

The development of the 4th DORIS beacon generation continued with the preliminary design review in July and everything is going according to the provisional schedule: detailed design review and manufacturing of a prototype in 2017, technical appraisal and testing in 2018 and start of the deployment in 2019.

The network monumentation was the subject of a global assessment in the JASR DORIS Special Issue performed by Saunier (2016) and based on three methods: mechanical laboratory study to see the behavior of the metallic structures, field measurements on the existing monuments, evaluation chart in order to have a grading and scoring of each monument. Elastics deformations for the standard monuments are less than one millimeter when undergoing extreme climatic conditions. Two thirds of the network monuments are compliant with standards. The field checks conducted in the last 15 years showed that 80% of the monuments are stable within a mm.

Co-location has always been a major objective for the DORIS network. We continuously increased the number of stations co-located with other space geodetic techniques and with tide gauges throughout the various phases in the network evolution.

In 2016 the following sites were visited:

- Managua, Nicaragua: new site
- Mariana Islands, USA: reconnaissance with a view to installing a new station
- Kitab, Uzbekistan: station re-location (200m South)
- Hartebeesthoek, South Africa: tracking oscillator replacement
- Wettzell, Germany: new site (IDS station)

Finally, the overall objectives for the next year are:

- Restarting at Socorro (Mexico) and Santa-Cruz (Galapagos, Ecuador)

- New stations at San Juan (Argentina) and Guam Island (USA)
- Re-location in Easter Island (Chile)
- Reconnaissance in Papenoo (French Polynesia), Manchuria (China) and Reykjavik (Iceland)

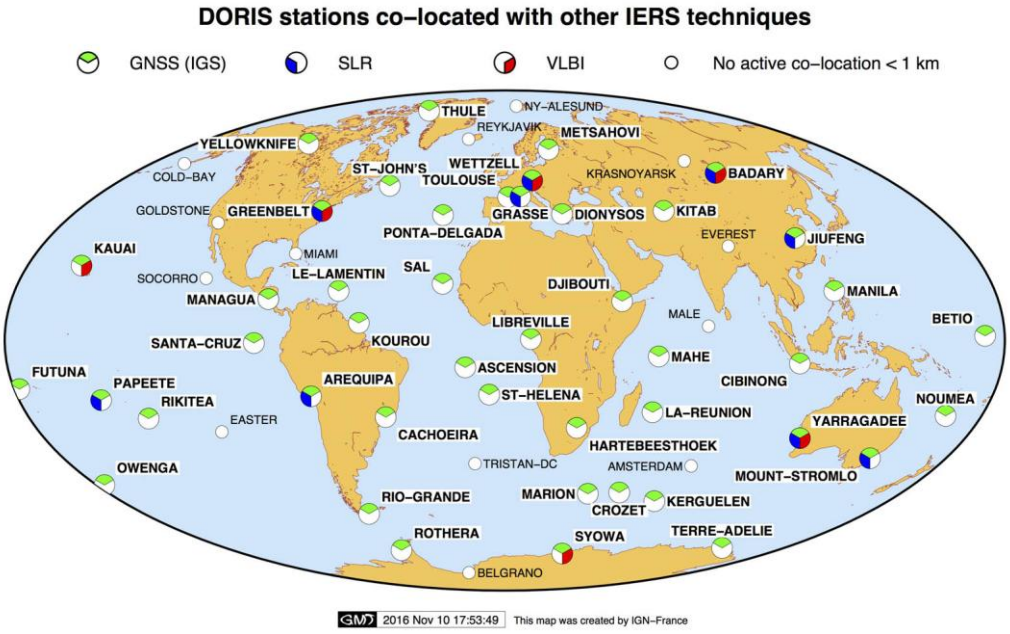

Fig. 1. The permanent DORIS network – 56 stations – and co-location with other IERS techniques (as of Nov. 2016).

2 IDS Governing Board

The term of three posts expired at the end of 2016. The holders of these posts are: Carey Noll as the Data Center representative, Pascal Willis as the Analysis Center representative, and Richard Biancale as one of the Members at Large. After the elections organized in fall 2016, the new members elected by the IDS Associates are:

- Frank Lemoine as the Analysis Center Representative,
- Patrick Michael as the Data Center Representative,
- Denise Dettmering as a Member-at-Large.

In addition, the IAG nominated Petr Stepanek as its representative to the IDS Governing Board (GB). Petr succeeds Michiel Otten who held that post for 8 years.

Guilhem Moreaux (CLS) was confirmed as the representative of the Combination Center (CC) within the GB after CNES/CLS was selected to run the IDS CC for a new period of four years (2017-2020).

In November, the Board elected Frank Lemoine as the new Chairman from January 1st, 2017.

Name	Institution	Country	Mandate
Richard Biancale	CNES	France	Member at large
Hugues Capdeville Jean-Michel Lemoine	CLS CNES	France	Analysis Coordination
Pascale Ferrage	CNES	France	System representative
Brian Luzum	GSFC	USA	IERS representative
Guilhem Moreaux	CLS	France	Combination Center representative
Carey Noll	GSFC	USA	Data flow Coordinator
Michiel Otten	ESOC	Germany	IAG representative
Jérôme Saunier	IGN	France	Network representative
Laurent Soudarin	CLS	France	Director of Central Bureau
Pascal Willis (chair)	IGN/IPGP	France	Analysis Center representative
Marek Ziebart	UCL	UK	Member at large

Table 2. Composition of the IDS Governing Board (January 2015 – December 2016)

3 IDS Central Bureau

In 2016, the Central Bureau (CB) participated in the organization of the AWG meeting held at the Faculty of Aerospace Engineering in Delft, Netherlands, on May 26 and 27, and of the IDS Workshop in La Rochelle, from October 31 to November 1. The CB documented the GB meetings held on these occasions. Between the meetings, the CB coordinates the work of the GB.

The CB managed the edition and publication of the 2015 IDS Activity Report. It also produced the IDS contributions to the 2015 IERS Annual Report, and to the Geodesist's Handbook of the IAG.

At its meeting in Washington in October 2015, the Governing Board asked the Central Bureau to consider the publication of a newsletter. The intention was to improve the flow of information within the community of providers and users of DORIS data and products, to highlight the activities of the groups

participating in the IDS, and to bring the DORIS and IDS news to a wider audience, from the host agencies to the other sister services. A draft was proposed in March 2016 by the Central Bureau to the Governing Board who accepted the concept. So, the IDS Newsletter is born. Three issues were published in 2016, #1 in April 2016, #2 in July, and #3 in December. The issues are distributed via email to the subscribers to the DORISmail and a number of identified managers and decision-makers. They are also available on the IDS website for downloading.

3.1 Data information service

The Central Bureau works with the SSALTO multi-mission ground segment and the Data Centers to coordinate the data and products archiving and the dissemination of the related information.

In 2016, this activity focused on:

- the delivery of Jason-3 data, auxiliary data and information related to this new mission.
- the delivery of Sentinel-3A data, auxiliary data and information related to this new mission.
- the delivery of the CNES orbits for Saral in GDR-E standards (file naming, store folders, description files).
  See [ftp CDDIS or IGN] pub/doris/products/orbits/ssa/README_SP3.txt

The Central Bureau also interfaced with the CDDIS staff, SSALTO, and the IDS components during the transition phase to the new file upload system at CDDIS.

3.2 IDS Web and ftp sites

The IDS Central Bureau (CB) maintains the IDS web (http://ids-doris.org) and ftp (ftp://ftp.ids-doris.org/pub/ids) sites.

Besides the regular updates of pages and addition of documents, the website was enriched with new pages and received some changes. The main new features of 2016 are the Youtube IDS channel and the upgrade of the website.

The IDS video channel has been created on Youtube to host a set of existing videos for outreach. New videos were also included. They show DORIS-equipped satellites in orbit. These videos have been produced with the Visualization Tool for Space Data (VTS) free software from CNES.
https://www.youtube.com/channel/UCiz6QkabRioCP6uEjkKtMKg

A new "Satellites" page has been added on the website. It provides access to a summary table of DORIS missions and satellite pages giving attributes, links to data files and VTS videos. The page also provides access to the VTS tool and predefined scenarios for DORIS missions, as well as directories of orbit files and quaternions.
http://ids-doris.org/satellites.html

A dedicated Newsletters page has been created. It contains the IDS Newsletters since April 2016.
http://ids-doris.org/report/newsletter.html

The main updates of the website, as well as the list of the new documents and files put on the ftp site, can be found in the 2016 IDS Activity Report (http://ids-doris.org/report/governing-board.html#activity).

3.3 DOR-O-T, the IDS Webservice

A new version of the IDS web service (http://ids-doris.org/webservice) will be proposed in early 2017. It will be based on the latest Highcharts/Highstock library. Improvements will be brought to make the service more ergonomic, simpler and more practical, especially on mobile devices.

4 IDS Data Centers

The IDS data flow organization remains the same. It is based on two data centers: one on the East Coast of the U.S. (CDDIS at NASA GSFC) and one in Europe (IGN in France). They are both exact mirrors of each other, and so, are able to continue on an operational basis, even if one of them is inaccessible due to a temporary failure.
These two data centers archive the DORIS data as well as the IDS products (station coordinates and velocity, geocenter motion, earth orientation parameters, ionosphere data, etc.).

The main events of the year are listed hereafter:

- Transition to the new CDDIS computer hardware was completed in late November 2016. This new system configuration now provides a more reliable/redundant environment (power, HVAC, 24-hour on-site emergency personnel, etc.) and network connectivity for CDDIS; a disaster recovery

system is installed in a different location on the GSFC campus. The new system location addresses a long-time concern for the CDDIS, namely, the lack of consistent and redundant power and cooling in its existing computer facility. Multiple redundant 40G network switches are utilized to take full advantage of a high-performance network infrastructure by utilizing fully redundant network paths for all outgoing and incoming streams along with dedicated 10G network connections between its primary operations and its backup operations. The CDDIS transitioned the majority of its operation services to virtual machine (VM) technology for both multiple instance services in a load balancing configuration which allows additional instances to be increased or decreased due to demand and allows maintenance (patching, upgrades, etc.) to proceed without interruption to the user or any downtime. CDDIS now utilizes a unified storage system (100 Tbytes in size) to easily accommodate future growth of the archive and facilitate near real-time replication between its production and disaster recovery sites.

- One requirement of the new CDDIS computer system involved a change to the file upload process. In the old system, CDDIS used ftp for delivery of data for the archive from both data centers and analysis centers. While this has worked well over the years, transition to the new system provided an opportunity to update this method to a web-based approach that can utilize a different user sign-on/authentication infrastructure. CDDIS developed a web-based application that allows users to use existing scripts without significant modification but also tie authentication into the NASA system. Staff worked with the groups who submit DORIS data and IDS products to CDDIS to transition their procedures to the new file upload system.

- CDDIS performed complete rewrite of its file ingest processing software in 2016. This rewrite incorporated numerous disparate programs developed over the years into a single, easily maintained software base which incorporates all the CDDIS requirements for data ingest while also allowing additional flexibility in meeting future metadata requirements. The software was initially modified for incoming GNSS files but will be extended to all incoming files, including DORIS data and products, in the near future.

5 IDS Analysis Centers and IDS Analysis Coordination

The activities of all the DORIS analysts of the past year 2016 have been dominated by the evaluation of the ITRF2014, taking into account that the

most recent DORIS satellites Jason-3 and Sentinel-3A where DORIS data are only available in RINEX format, and the analyzing of the sensitivity to the South Atlantic Anomaly (SAA) effect of their Ultra Stable Oscillator (USO).
IDS meetings were held in Delft (The Netherlands) for an Analysis Working Group, May 26-27, 2016 (hosted by Technical University) and in La Rochelle (France) for an IDS Workshop, October 31 November 01, 2016.
All the IDS ACs have to take the standard routinely processing again by taking into account the news data available of all satellites. The IDS includes six ACs and “de facto” three “associate analysis centers” who use seven different software packages, as summarized in Table 1. We also note which analysis centers on a routine basis perform POD analyses of DORIS satellites using other geodetic techniques (c.f. Satellite Laser Ranging (SLR), or GNSS). The multi-technique analyses are useful since they can provide an independent assessment of DORIS system performance, and allow us to more easily validate model changes and the implementation of attitude laws for the different spacecraft, in the event spacecraft external attitude information (in the form of spacecraft quaternions) is not available. We note that a representative of the Norwegian Mapping Authority (NMA) expressed in an interest in analysis of DORIS data, and also in multi-technique analyses. The participation of the NMA (Geir Arne Hjelle) and other potential IDS ACs should continue to be encouraged.

Following the DORIS processing for the realization of the ITRF2014, there were still many substantive issues that remained to be addressed, even with the current data already processed. Some issues as the jump in the DORIS scale (2012 and later) have been analyzed. The IDS scale jump in 2012 is fully explained by a variation in the number of low-elevation measurement included in the processing. Indeed, the increase of the scale factor for Jason-2 and Cryosat-2 is linked to the change of tropospheric model used by CNES in its POD processing (GDR standards): from CNET (GDR-C) to GPT/GMF (GRD-D). It causes a reduction in the amount of data marked as rejected in the doris2.2 file (input DORIS data file) and then, an increase of the data used considered to be good in CNES pre-processing. The larger number of data, especially at low elevation, could thus be the cause of the change we observe in the scale factor. The date of change is mission dependent. The scale increase of the multi-satellite solutions is due to the jump not at the same time of the Jason-2 and Cryosat-2 solutions but also of the HY-2A high scale. So, IDS ACs need to do their own pre-processing.

Group	AC	AAC	Other	Location	Contact	Software package	Multi-technique: DORIS +
ESA/ESOC	✔			Germany	Michiel Otten	NAPEOS	SLR, GNSS
Geodetic Observatory Pecny	✔			Czech Rep.	Petr Stepanek	Bernese	-
CNES-CLS	✔			France	Hugues Capdeville	GINS/DYNAMO	SLR, GNSS
NASA/GSFC	✔			USA	Frank Lemoine	GEODYN	SLR
IGN-JPL	✔			France	Pascal Willis	GIPSY/OASIS	-
INASAN	✔			Russia	Sergei Kuzin	GIPSY/OASIS	-
GFZ		✔		Germany	Sergei Rudenko Rolf Koenig	EPOS-OC	SLR, GNSS
CNES			✔	France	Alexandre Couhert	ZOOM	SLR, GNSS
TU Delft			✔	The Netherlands	Ernst Schrama	GEODYN	SLR

Table 3. List of IDS Analysis Centers, Associated Analysis Centers, and other groups participating in the analysis activities in 2016.

Since 2008, starting with Jason-2, satellites equipped with a DORIS receiver carry the new generation of receivers called DGXX which provides phase and pseudo-range measurements. They are distributed in a dedicated format, called RINEX/DORIS 3.0 derived from the GNSS RINEX format. One major advantage of these new measurements is that they are available with a very short latency. They also allow analysis centers to be less dependent on the CNES since the new data format provides the raw information that is necessary for computing the ionospheric delays and the precise time-tagging of the measurements. This was not the case for the former data format where this information was only given in a pre-processed form, following a pre-processing done by the CNES. While CNES supplies data files in doris2.2 and RINEX/DORIS 3.0 formats for the missions equipped with DGXX (Jason-2, Cryosat-2, HY-2A and Saral), only the latter format is available for the missions from Sentinel-3A and Jason-3 and following. Some recommendations on the practical implementation of the RINEX measurements in the POD software have been given at the last AWGs in 2016. A bug in time tagging from the PANDOR process inferred a high frequency noise in RINEW files. Another problem coming from

DIODE was removed as well. The relativistic propagation correction should include not only GM but also the J2 effect. The ionospheric correction has to be computed from RINEX file. ACs should take care that the iono-free phase center is shifted from the 2 GHz phase center by 6 mm on board and 19 mm on ground, so 25 mm at all. Values of CoP-CoM vector and beacon phase center height are newly given for RINEX in an IDS available document. All differences between 2.2 and RINEX data are now explained and the necessary corrections have been applied.

The IDS performed an assessment of the three realizations of the Terrestrial Reference Frame which are the outcome of the "ITRF2014 effort": the ITRF2014 (IGN), DTRF2014 (DGFI) and JTRF2014 (JPL). While ITRF2014 and DTRF2014 are formally similar, differing only by the Post Seismic Deformation (PSD) model which has been introduced in the IGN solution, the JPL solution is quite different, being a time series of weekly solutions obtained through a Kalman filter process. Due to editing criteria the JPL solutions contains less station at a given time than the two others, particularly at the beginning of the processed period, in 1993. The three TRF realizations have been evaluated in terms of DORIS observation residuals, orbit overlaps and transformation parameters of the DORIS network. All TRF realizations represent a clear improvement over the previous realization, ITRF2008. Based on the different criteria used for evaluation, it has been shown this is the ITRF2014 which presents the best overall performance. It is this model that will serve as a basis for the operational processing of future DORIS data. For that purpose the ITRF2014 needs to be supplemented (new DORIS stations not present in the ITRF2014 solutions, if necessary correction of the position and velocity for the stations which had a short observation interval in the ITRF2014). This extension of ITRF2014 for the DORIS network is called DPOD2014: an update the position/velocity of all stations is performed and aligned on the ITRF2014, leading to possible minor adjustment of older stations. A version of the DPOD2014 will be submitted by IDS Combination Center to the evaluation of the users at the beginning of 2017.
The behavior of the various DORIS on-board oscillators in the vicinity of the high radiation area "South Atlantic Anomaly" (SAA) has been studied. It has been shown by different ACs (and associated) that all DORIS receivers are frequency-sensitive to the crossing of the SAA, though at very different levels. Thanks to the extremely precise time-tagging of the T2L2 experiment on-board Jason-2, A. Belli and the GEOAZUR team showed that the DORIS on-board Ultra Stable Oscillator (USO) of Jason-2 is approximately 10 times less sensitive to the SAA than the one of Jason-1. IGN AC has shown that, thanks to the "DORIS PPP method" on uncorrected Jason-2 DORIS data, the positioning error due to the

SAA can reach up to 10 cm for some stations with this satellite. GRG AC and C. Jayles from CNES both showed that Jason-3 is also sensitive to the SAA, at a level which is lower than that of Jason-1, but still 4 to 5 times higher than that of Jason-2. The CNES POD team has shown that Sentinel-3A is also sensitive to the SAA. They, using an original method based on the clock determination of the GNSS receiver on-board Sentinel-3A, showed that it is possible with this method to obtain an accurate and continuous observation of the satellite's USO frequency excursions. One of the conclusions of these studies was that, while no noticeable effect of the SAA influence has been shown on POD or reference frame transformation parameters, there is an important impact on the station position estimation for some stations in the vicinity of the SAA area. Building accurate models of frequency variations in response to the temperature and to the SAA radiations for each DORIS USO is therefore a task that is encouraged by the IDS community for the accurate position estimation of all DORIS stations.
ACs have to complete their DORIS/RINEX data processing implementation in order to consider the data from Jason-3 and Sentinel-3A (available first quarter of 2016). The IDS will switch to ITRF2014 for operational products when the DPOD2014 will be available. The next IDS Analysis Working Group and Workshop meetings will be held in London (UK), May 22-24, 2017 (hosted by the University College London).

6 IDS Combination

In 2016, in addition to the routine evaluation and combination of the IDS AC solutions, the IDS Combination Center mainly worked on the DPOD2014 solution as well as on the DORIS evaluation of the DGFI, IGN and JPL ITRF2014 realizations. These two studies, which were respectively presented at EGU 2016 and AGU 2016, must be completed and will be the subject of two forthcoming papers. In addition to its contribution to three papers of the DORIS special issue of Advances in Space Research, the IDS Combination Center finalized its study on the evaluation of the DORIS horizontal and vertical velocities by comparisons with two global plate models (GEODVEL and NNR-MORVEL56) and with the GNSS solution ULR6 from La Rochelle University (see Moreaux et al., 2016).

Moreaux, G.; Lemoine, F.G.; Argus, D.F.; Santamaría-Gómez, A.; Willis, P.; Soudarin, L.; Gravelle, M.; Ferrage, P., 2016. Horizontal and vertical velocities derived from the IDS contribution to ITRF2014, and comparisons with

geophysical models, Geophysical Journal International, 207(1), 209-227, doi: 10.1093/gji/ggw265

7 Meetings

In 2016, IDS organized a meeting of the Analysis Working Group on May 26-27 at TU Delft (Netherlands) and a Workshop in La Rochelle (France), on October 31 and November 1.
All the presentations from these meetings are made available by the Central Bureau on the IDS website at:
http://ids-doris.org/report/meeting-presentations/ids-awg-05-2016.html
http://ids-doris.org/report/meeting-presentations/ids-workshop-2016.html

8 Publications

IDS published the 2015 activity report that was broadly distributed to all DORIS participants and relevant services (see http://ids-doris.org/report/governing-board.html#activity).

All DORIS related articles published in international peer-reviewed journals are available on the IDS Web site http://ids-doris.org/report/publications/peer-reviewed-journals.html.

Conclusions

2016 was a year marked by the launches of two new DORIS instruments onboard Jason-3 and Sentinel-3A, increasing the DORIS constellation to six.
Two new DORIS stations were installed at Managua (Nicaragua), and Wettzell (Germany). Wettzell, with Greenbelt, are the two examples of core sites complying with the GGOS requirements with the four space geodetic techniques (co-located DORIS/GNSS/SLR/VLBI).
The activities of all the DORIS analysts have been dominated in 2016 by the evaluation of the ITRF2014, taking into account Jason-3 and Sentinel-3A which DORIS data are only available in RINEX format, and by the analyzing of the sensitivity to the South Atlantic Anomaly (SAA) effect of their Ultra Stable Oscillator (USO). In addition to the routine evaluation and combination of the IDS AC solutions, the IDS Combination Center mainly worked on the DPOD2014

solution as well as on the DORIS evaluation of the DGFI, IGN and JPL ITRF2014 realizations

Laurent Soudarin, Pascale Ferrage, Jérôme Saunier, Carey Noll, Hugues Capdeville and Guilhem Moreaux.