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DORIS data analysis strategies

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Abstract

The goal of this paper is to summarize the present DORIS data analysis currently performed for the International DORIS Service (IDS) among the various analysis groups, to provide an analysis of the recent improvements and also of the current deficiencies. We will then propose some recommendations for the future.

These recommendations will be presented and openly discussed at the IDS Plenary Session in Paris, May 3-4, 2004.

A recommendation means that we can identify the problem and that we can provide a tentative solution (as well as a deadline to verify that at a future IDS meeting if that recommendation was effectively implemented or not). In our opinion, this simple step-by-step approach could help us improve the current IDS operations and start an effective synergy between all IDS participants.

1. Introduction

Since July 2003, the International DORIS Service (IDS) is now a service of the International Association of Geodesy [Tavernier et al., 2002; Willis et al., 2004a]. A service is defined by its products, how they are generated, how they are validated and how they are effectively used or not by all types of users. A service with no products or no users has no meaning and no future.

2. Organizational Aspects

2.1 IDS Products

Since the start of the IDS, some Analysis Centers (ACs) have done a lot of development to validate their current DORIS data processing and to automate as much as possible their DORIS analysis center activity.

The table below summarizes the current DORIS Analysis Centers (AC)

Product	Delay	Current AC	Previous AC	Proposed AC	Combined Product
cumulative solution (positions/ velocities)	6 months	IGN/JPL LEGOS/CLS U. Texas		INASAN Geosci Australia IAA	No
weekly series	6-8 weeks	IGN/JPL SSALTO	INASAN SOD	LEGOS Geosci Australia IAA	No
monthly series			IGN/JPL INASAN LEGOS/CLS SSALTO	Geosci Australia IAA	No
geocenter	4-8 weeks	IGN/JPL	LEGOS/CLS	INASAN	No
EOP	4-8 weeks	IGN/JPL	LEGOS/CLS	INASAN	No
iono			SSALTO		No
orbits			LEGOS/CLS	U Texas	No

Table 1: Current IDS products (April 2004). The term "Current AC" corresponds to AC regularly submitting products. The term "Previous AC" corresponds to Analysis Centers that have already submitted such products but not recently. "Proposed AC" corresponds to groups who have express their willingness to participate in the IDS but who have not yet submitted any solution.

Several conclusions can be drawn from this table. First of all, the IDS is presently proposing a lot of different products. This is a very challenging goal. However, there is no "IDS product" as such as it would be expected from an IAG Service as there is actually no combination regularly delivered using results from different analysis centers. We must also say that in some cases (e.g. time series analysis, geocenter) some combination tests were performed so we may not be too far away from generating true "IDS products". It is also important to know if and how these products are used. If some are not used, we need to decide to stop them or to modify them to better suit the needs of the potential users. Or we could also make some efforts to convince the potential users to consider these products. At least, we should not stay passive.

Presently, there is no information available to know whether current IDS products are effectively used at all. In some cases, two products could even be seen as in competition between each other (e.g. weekly sinex solutions vs monthly sinex solutions, or generating free-network solutions as well as projected and transformed ITRF2000-like sinex solutions that create a duplication of efforts from the same group). Other products could be generated if needed (SSALTO solutions from MOE orbits instead of POE orbits;

geocenter and EOP from groups already producing geodetic time series) if there would be a real need and if these ACs would find it important to contribute more. All these activities represent a significant amount of work and allocated resources, we should use it wisely. It is important to be sure that all the present IDS products are effectively required and used. It could also be important to compare the present DORIS products with the products already offered by other technique centers services.

However, we should also note that the IDS is a new service and that its products are not well-known to the scientific community. We should not judge the value of the present products on their current level of usage. In some cases, the IDS will have to advertise more for its products.

The IERS now clearly expect that the Technique Centers like IDS will regularly provide products (obtained from internal combination) and monitor the quality of these products through internal validation.

> *Recommendation 2.1:* IDS should conduct a survey to understand how its products are currently used and how similar products from other Technique Service (TS) such as IGS, ILRS and IVS are used. The survey should also point out products that are considered as useful but that are not presently used as they could. If possible the survey should also address the impediments that might presently prevent potential users to use the current products. After this survey, IDS should decide on the list of the products to generate and also when necessary propose products to be stopped.

None of the present products are presently combined nor even externally validated. We assume here that there is at least some internal validation done by each AC. Other services (eg International GPS Service) would not accept this present type of products. Within the IGS, when a new product is foreseen, there is first a project to verify that the product is technically feasible, that it is operationally possible, that several groups are willing to participate and to assess its accuracy and reliability and to better define it in terms of delays and generation procedure. The product is then generated and after some time, it is declared as a real "IGS product". We could envision such a similar procedure for IDS products.

Finally some products may not be needed anymore. Is there still a use for cumulative solutions (positions and velocities for all stations), while ITRF is now using almost only time series of solutions? Should such cumulative solutions use DORIS-DORIS local tie information coming from IGN/SIMB (DORIS beacon installation and maintenance service)? What type of weighting for the local tie information? Free-network solution or ITRF2000 type? How frequent (6-month, 1 year?). Optimize for prediction (now) or for the mean epoch value (name of stations after and before breaks). We need to better define the IDS products as such.

It is clear that there is still a need for cumulative solutions for POD purposes, especially for altimetry mission. However, what is really important for these groups is that the

DORIS, GPS and Laser coordinates (and velocities) are expressed in a unique terrestrial reference frame highly precise and reliable for Mean Sea Level investigations.

> Recommendation 2.2: A procedure must be explicitly stated to formally accept a DORIS product as such, including a technical feasibility study and a validation component. We should presently start assuming that no such IDS product exists presently and to generate them one by one using a standard procedure.

The DORISMail has been quite useful to broadly distribute information of general interest among the DORIS community. However, there is now also some new type of information still related to DORIS but which only interest a selected number of people. Such information is for example:

- submission or resubmission of new DORIS data by CNES
- submission or resubmission of new DORIS products by an IDS Analysis Center
- technical discussion on open issue related to DORIS data analysis

In our opinion, these new types of mails are going to increase with time, especially after the start of the IERS Pilot Campaign of Combination. In order to keep the DORISMail for general information for a large audience, we propose to create a new email Bulletin Board (DORISReport). The IGS has recently done a similar splitting as more and more people were complaining that the reports were of no direct interest for most people. The distribution list of the DORISReports could include at least people involved in the DORIS data distribution at CNES, people involved in operational Data Center and Data Analysis activities and also people regularly using the IDS individual solutions or products (IDS internal combination and validation, IERS combination centers,…).

> Recommendation 2.3: Split the current DORISMail into DORISMail (general information for a large DORIS audience) and DORISReports (regular reports for Analysis Centers).

2.2 IDS Analysis Centers

Secondly, it can be seen from table 1 that several groups have produced results in the past for the IDS or are planning to do so in a near future. However, presently two groups (IGN/JPL and SSALTO) provide DORIS results in a continuous and timely manner, even if the SSALTO group does not exactly comply to the general IDS specifications (presently point positioning using fixed orbits and fixed EOPs without covariance information in SINEX). It must also be noted that a third group (LEGOS/CLS) is also expected to distribute individual solutions on a regular basis within the next few months (before July 2004), resuming their past activity. There are also groups willing to produce new solutions and/or new types of products that could be derived from their own solutions (INASAN). There are also new groups considering to participate in the IDS (TU Prague) and several groups with appropriate software and competences that could participate in the IDS. So the situation described in table 2 is not so bad and should be improved soon.

None of the current groups propose to generate solutions for all products and it is not a requirement. But for each product, several groups have produced results or at least have the capability to do so. In any case, more than 3 groups (if possible, using different software packages) are required for each product in order to derive a precise and reliable combination.

We should now try to understand why some groups stopped their activities and facilitate their return and/or the encourage implication of new groups. In some cases, the question of the long-term funding to support these types of activities is of critical interest for the ACs. It is especially true when long-term commitments are requested. In any case, we absolutely need more active groups to really sustain the long-term interest of the IDS itself and to generate a real and friendly competition between all analysis groups.

> *Recommendation 2.4:* It is important that more Analysis Centers participate in the generation of the IDS products. Groups wanting to participate must receive some help from the already existing AC. It is also important to understand why some groups stopped delivering results and to encourage them to resubmit new results.

Some groups have provided or plan to provide multi-technique solutions for orbits or geodetic products. These products can provide unique contributions and exceptional accuracy. IDS should consider incorporating such types of solutions, which do not appear presently in any of the individual Technique Centers but are in fact natural for DORIS (multiple-techniques POD for altimetry missions).

3. Inputs for DORIS analysis

3.1 DORIS data delivery schedule

The IDS ACs totally relies on CNES for the availability of the DORIS data as the data distribution is centralized due to very own nature of the DORIS system. Since the last 6 months, very significant improvements have been made by CNES in the DORIS data delivery schedule [Noll et al., 2004]. Typical delays are now 20 days for TOPEX, 30 days for Jason, SPOT2,4, and 5 and 50 days for ENVISAT. This is also true for metadata (attitude and maneuvers files) that are now regularly delivered at the IDS Data Centers in a timely manner. Some other metadata are not yet available (quaternions for Jason and mass evolution for all DORIS satellites).

It is now really possible for some DORIS groups to participate in the next IERS campaign [Rothacher, Web] for which the requested deadlines are 6 to 8 weeks after the last measurement before generating a unified solution (DORIS-only solution). Several proposals were sent out by different IDS ACs, more would be very much welcome.

> Recommendation 3.1: The IDS thanks the CNES for the improvement made recently in the DORIS data delivery (including Envisat data) and request to have access to all DORIS data no later than 6 weeks after the day of the last

measurement to really allow the generation of a unified DORIS weekly solution within the IERS time constraints.

3.2 Correcting the DORIS/Jason data from the South Atlantic Anomaly effect

Concerning the DORIS/Jason data, it is now well-known that the South Atlantic Anomaly has a significant effect on the DORIS/Jason on-board oscillator, creating systematic errors that affect the geodetic results (more than POD results), making them almost totally useless to generate any of the currently considered IDS geodetic products [Willis, 2004b]. Recent studies have shown [JM Lemoine] that it is possible to derive a simple correction model, using Topex/Jason observed frequencies differences. Such a model takes care of most of the effect for orbit determination. However, for ground positioning results, this effect still cannot be totally compensated. Furthermore, there is also some evidence that more and more DORIS/Jason data will be rejected during the preprocessing performed at CNES/SOD. There is on-board the Jason satellite a second DORIS receiver for back-up that could be turned on at any time by CNES to verify if the second oscillator is as sensitive as the other to radiation over the South Atlantic Anomaly. However, we cannot be certain that the second receiver will perform better than the present one, but there is a chance that it may do so. CNES has previously asked to IDS to assess if such a change should be considered useful for the IDS activities or if the present Jason problem can be overcome by corrections methods.

> Recommendation 3.2: In order to use the DORIS/Jason data to generate the geodetic IDS products, the IDS encourages CNES to turn on the back-up DORIS receiver on-board the Jason satellite to test if its oscillator would be less sensitive to radiations over the South Atlantic Anomaly within the next three months. This change of receiver should be done as soon as possible. The IDS will then investigate if the new receiver performs better for geodetic applications and provide some feed-back to CNES.

3.3 What is an IDS station?

Concerning new DORIS stations, a lot has been done recently by the IGN/SIMB and by CNES to provide information on a timely basis to the AC though the DORISMails (name of the station, acronym, domes number, start of operation, a priori coordinates and velocities when available,..).

However, in a few cases, the first weeks or months of observations have been definitively lost as the new data were not incorporated rapidly enough in the general DORIS data delivery operational scheme.

Sometimes a beacon is also not considered to be part of the permanent network and is then not delivered, even if this station could be of specific interest to the IDS (collocation with other techniques). Things need to be clarified here.

Table 2 show example of data distribution release schedule for recent DORIS stations. It can be seen that the situations are very different from one station another and that sometimes several months of DORIS data have been lost forever, as there is no plan for CNES to reprocess later the stations that were not considered by then as part as the DORIS operational network for Precise Orbit Determination.

Sometimes, data delivery is delayed due to a late DORISMail announcing the station (usually when IGN/SIMB is waiting for precise a priori coordinates), sometimes not.

DORIS acronym	Start of observation (Year-DoY)	DORISMail date	DORISMail number	Start of data delivery (Year-DoY)	Data loss (in days)
THUB	2002-285	2002-304	205	2002-331	46
KOLB	2002-316	2002-344	208	2002-321	5
SALB	2002-346	2003-017	216	2002-356	10
MANB	2003-057	2003-083	232	2003-064	7
HEMB	2003-080	2003-101	236	2003-105	25
SPJB	2003-231	2003-241	260	2003-246	15
GAVB	2003-270	2003-288	266	2003-336	66
YASB	2003-331	2003-353	282	2003-356	25
JIUB	2003-344	2003-358	283	N/A	≥ 113
CROB	2003-355	2004-036	299	2004-031	41
MSPB	2004-031	2004-105	313	N/A	≥ 61
BELB	2004-037	2004-065	306	2004-083	46
CADB	2004-085	2004-100	312	N/A	≥ 7

Table 2: DORIS data delivery at IDS Data Centers for recently installed stations. Current status on April 19, 2004.

> Recommendation 3.3: CNES, in liaison of the IGN/SIMB and the chairman of the Station Selection Group, should maintain a list of stations that participate in the IDS, through the DORIS permanent network or through DORIS campaigns as organized by the Stations Selection Group.

For stations outside the permanent network, no data are presently delivered at the IDS Data Centers. Some tests have been conducted between CLS and IGN/JPL, showing that the current delivery procedure for such additional stations would create errors in the DORIS data that are larger than what is currently found in the data of the permanent tracking network.

> Recommendation 3.4: Tests should be conducted between CLS and 1 or more AC to finalize the delivery of DORIS data for stations outside the permanent network.

3.4 Access to DORIS raw data

Presently, only groups in Toulouse have access to the raw DORIS data. Some groups have expressed their willingness to process DORIS using directly data at a lower pre-processed level (AIUB, IGN/JPL). A proposal was done by CNES (Jean-Paul Berthias) for a RINEX format that could take into account DORIS data type.

> Recommendation 3.5: CNES should define a new DORIS format for a lower preprocessed level and should make available some test data sets for all satellites during a short period of time to let the IDS AC investigate about the potential advantages of these new types of DORIS data.

3.5 DORIS constellation of satellites

Several groups have shown that the accuracy of the DORIS products has been increased with the availability of new DORIS satellites missions. It is absolutely critical for the IDS AC to have access to a large number of DORIS satellites data. In the future, several DORIS missions are foreseen, starting with Cryosat in late 2004 [Tavernier, 2004]. NPOESS seems also a good candidate for carrying DORIS receivers within the activities of the IDS. It is a NOAA mission for environment studies (http://www.ipo.noaa.gov/). Discussion with other Space Agencies should be initiated as early as possible to maintain the number of satellites of the DORIS constellation at a high level.

However, it must also be noted that several DORIS satellites have continuing to record data long after their expected lifetime. These satellites, such as SPOT-2, TOPEX and SPOT-4 could now die at any time.

> Recommendation 3.6: IDS request CNES to officially ask for the release of the DORIS/Pleiades data for scientific uses within the IDS and also to investigate the possibility to add future DORIS receivers on-board future other Space Agency missions, specially constellation of satellites such as NPOESS to ensure the current number of DORIS receivers in flight or even to increase it.

4. Models and estimation strategy

4.1 Stategy for evaluating and adopting new models

Presently the ACs are using different software packages, different models and different analysis strategies. This is not a weakness but in fact, it is a strong point that could lead us to improve all our results through internal IDS comparisons. However, in some cases, some new models really supercede the others and should be recommended for all AC. These models should be tested by the different groups of the IDS and when one model is really far better than the others, it should be adopted by all ACs or at least clearly recommended. If several models provide similar results, the ACs should be free to make their own choice, as long as this choice is clearly documented.

A first campaign of this type has been conducted by the Analysis Coordinator concerning the new gravity fields issued from the GRACE mission. A clear recommendation should be made to the ACs, when the results of this campaign are available.

Concerning time series of products, there is presently an open question that would required to be discussed between groups in order to adopt a common strategy: Should we update the models as soon as we have an improvement (then the series is potentially inhomogeneous) or should we stick to the same product generation procedure (then the products is not the best possible)? Usually, inhomogeneity is often far more troublesome for analysis than small incremental improvements, which would be implemented together at some clearly defined and agreed-upon point.

> Recommendation 4.1: The Analysis Coordinator, after discussion with the ACs and with the product users (starting with IERS) should define a clear strategy of how improving current products without loosing the homogeneity and the continuity of the time series. A trade-off compromise should be found.

4.2 Evaluation of tropospheric correction

Presently, other models are under investigation. For instance, different approaches are used for the tropospheric correction (using the CNES correction, estimating a parameter per pass, eventually using time constraints, using meteorological models,…). For instance, some groups (IGN/JPL, U. Texas) are using time constraints on the tropospheric parameters to provide better results for POD as well as for geodetic products. A similar campaign could be initiated on this specific aspect, taking into account that a similar campaign of observations (CONT-02) has already been conducted between VLBI and GPS.

> Recommendation 4.2: ACs should compare their current DORIS models and analysis strategies, starting with the tropospheric corrections for which several groups have really different approaches.

4.3 Potential investigation of other analysis models

Some other models, like surface force models, could require some comparisons between ACs that could profit to new ACs as well as to already active ACs:

- drag parameter estimations
- solar pressure
- albedo

Just as an example, in order to show the current correlation between SPOT drag parameters (estimated without any constraints every 6 hours and independently per satellite), figure 1 displays the time evolution of the SPOT drag parameters over a long time period. It is easy to see that the individual satellites results are highly correlated. It is known that the drag parameters are related to errors in the thermospheric density model,

especially the semi-annual variation at low solar activity and solar EUV flux variation during high solar activity. This fact could be used to estimate new thermosphere models (such as DTM2000) using this data or even to contribute to an ongoing calibration of such a model in near real-time. The correlation could also be used to develop new DORIS analysis strategies by adding constraints on the estimated drag parameters.

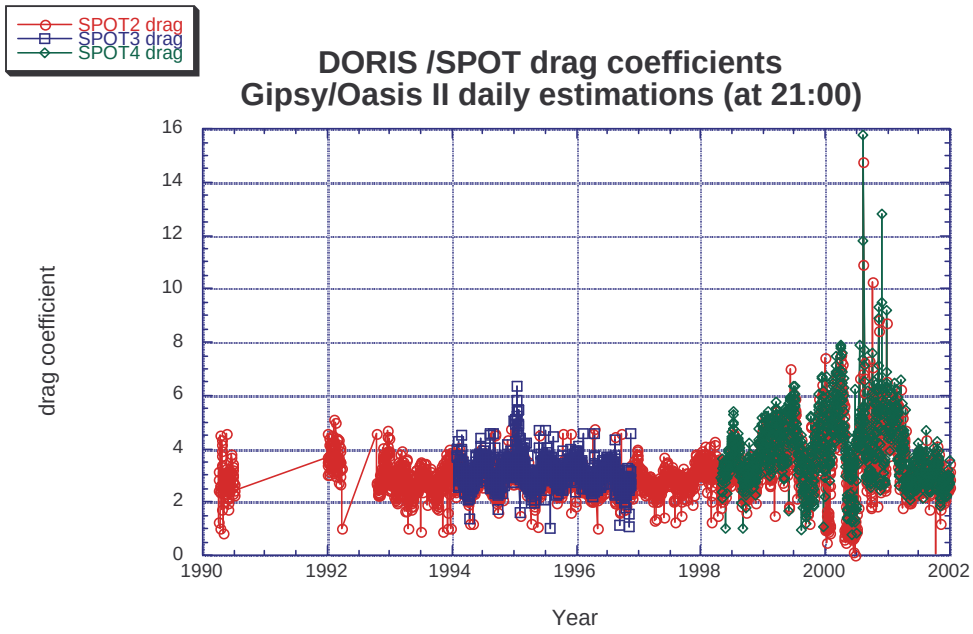

Figure 1: Long-term Time evolution of the DORIS/SPOT drag parameter from the IGN/JPL combined solution. Drag is estimated every 6 hours, without any constraint, independently for each satellite. Atmospheric model used is DTM94.

It is also important to note that some groups [Doornbos et al., 2004, Willis et al., 2004c] have started to look into details to DORIS residuals from different ACs. This could give the IDS community a valuable new tool to investigate systematic errors from commonly used models used in DORIS data analysis.

As all these models and analysis strategies cannot be tested at once, discussion between AC should be conducted between groups to better define priorities for such future investigations.

4.4 Systematic errors found in Terrestrial Reference Frame maintenance

The DORIS system has several advantages compared to GPS for the determination of the height of the stations. The network is very stable (only a very limited change of on-site equipment at each station for very long period of times), there are only 2 types of antennas, due to the antenna technology the antenna pattern is much more stable, DORIS results are not sensitive like GPS to the existence or not of protection radomes on site,… So DORIS could play an important role for terrestrial reference frame maintenance for the height and for the scale factor.

However, it can be seen from Figure 2 that the DORIS solutions (at least the IGN/JPL) suffers from a systematic bias, extremely stable with time.

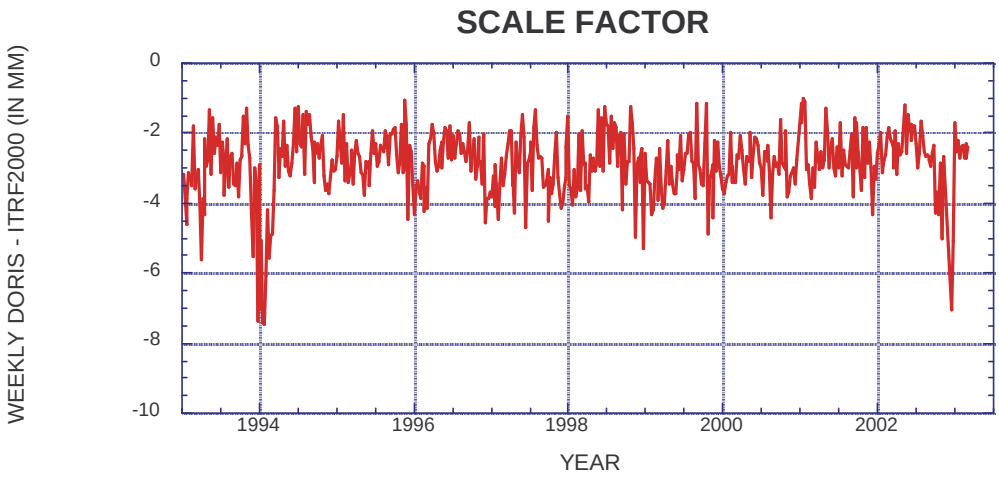

Figure 2: DORIS scale factor. Weekly comparisons of IGN/JPL free-network solutions to ITRF2000 reference frame.

It is clearly the responsibility of the IDS to study if this systematic error is due to the DORIS system itself or to an artifact in the present data analysis from the ACs and to understand the reasons for such a bias (about –2.5 ppb = 11.5 mm in the height of all stations). This could be investigated by comparing different ACs solutions together and also with other references, such as ITRF-type or multiple-techniques solutions.

Some techniques (GPS) have developed ways [Schmidt, 2004] to palliate such problems by estimating satellite antenna patterns and/or estimating ground receiver phase center variations models (PCV). The IDS as a group could raise a similar question and decide whether it is wise (or not) and how it could be possible to correct the DORIS data and/or the current data analysis to obtain a DORIS that could be calibrated at a specific epoch and that could remain exactly aligned with the present ITRF2000 realized scale.

> Recommendation 4.3: The IDS, in collaboration with the ITRF Product Center should investigate if the scale bias between DORIS solutions and the ITRF is inherent to the DORIS system or if it is inherent to a specific DORIS software. It should investigate technical ways to compensate such and effect (by using a posteriori satellite or ground antenna offset).

Still concerning the Terrestrial Reference Frame, there is a problem that was raised several times [Willis et al., 2004d] but that was never carefully investigated. As shown in Figure 3, the weekly estimation of the TZ translation is affected by a very large bias for the SPOT-4 satellite during the first months of operations. Some of the annual variations are clearly artifact of computations and come from systematic errors in the current data analysis (SPOT4 in this case).

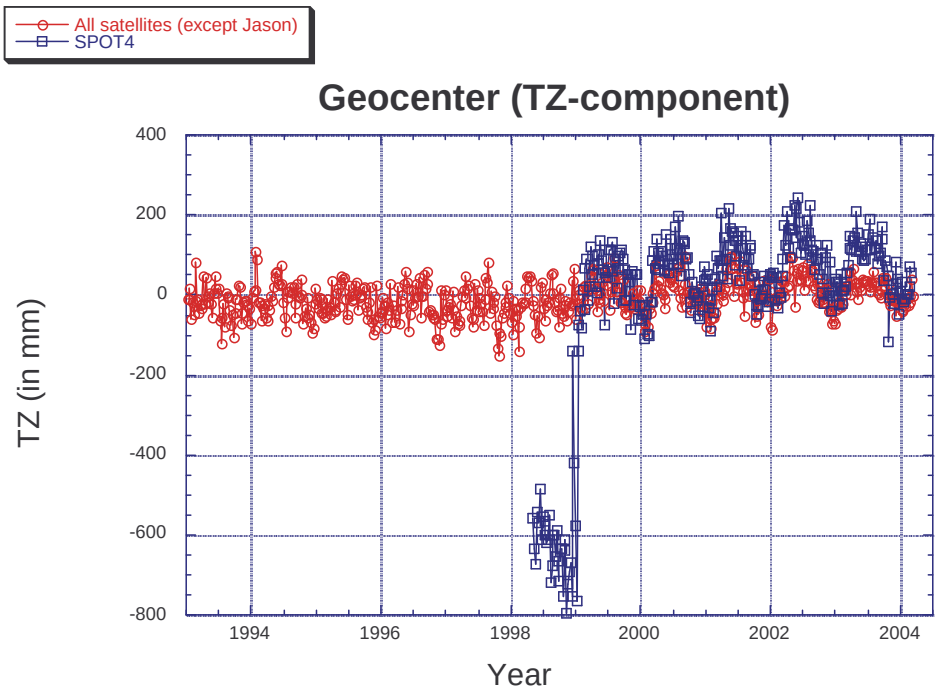

Figure 3: DORIS TZ translation. Weekly comparisons of IGN/JPL free-network solutions using only SPOT-4/DORIS data to ITRF2000 reference frame.

A erroneous translation of –60 cm (!!!) is estimated very consistently on a week by week basis from the very beginning of the SPOT4 data (May 1, 1998) to the start of cycle 32 (January 11, 1999). This effects maps in the multi-satellite solutions as a constant bias of –20 cm (= -60cm/3) over all this period of time. To solve this problem, recent solutions were performed using only 2 satellites (TOPEX and SPOT-2) and throwing away the first 8 months of DORIS data. Such a solution works but it is a pity to throw away so many data. The results are also less precise, as they are obtained using only 2 satellites.

To understand this problem correctly, we should have access to similar weekly solutions of SPOT-4 only data using different software packages. It could also be interesting to know if the problem remains when processing the raw DORIS data available in Toulouse, just to verify that there was no error in the preprocessing of the data. Such an investigation can only be conducted if several groups find it sufficiently interesting to generate this type of results.

> Recommendation 4.4: Different ACs should test if the estimated TZ translation (compared to ITRF2000) of their solutions using only SPOT4/DORIS data either from one of the IDS data center or directly from the raw measurements files available in Toulouse possess a significant bias from may 1998 to January 1999.

There are in fact several benefits that could be gained if the IDS ACs would start to do some type of intercomparisons, dicuss in details their data analysis strategies (models used and parameters estimation strategies) or would start to exchange problems that they see in their own data processing activity. As many different software are used, it is almost sure that some groups can handle better one type of correction or estimation parameters, while another group could handle better another type. Experience from all groups could be useful, not only for the newcomers but also for the present active groups. We should also benefit from the experience altimetry mission POD groups who participate or not in the IDS, and in return potentially propose ways to better handle Precise Orbit Determination with DORIS-only data or in combination with other techniques (Laser, GPS).

Just to demonstrate that there are still some systematic errors in DORIS data processing, we would like to show here a periodogram for a individual solution (TZ time series from IGN/JPL)..

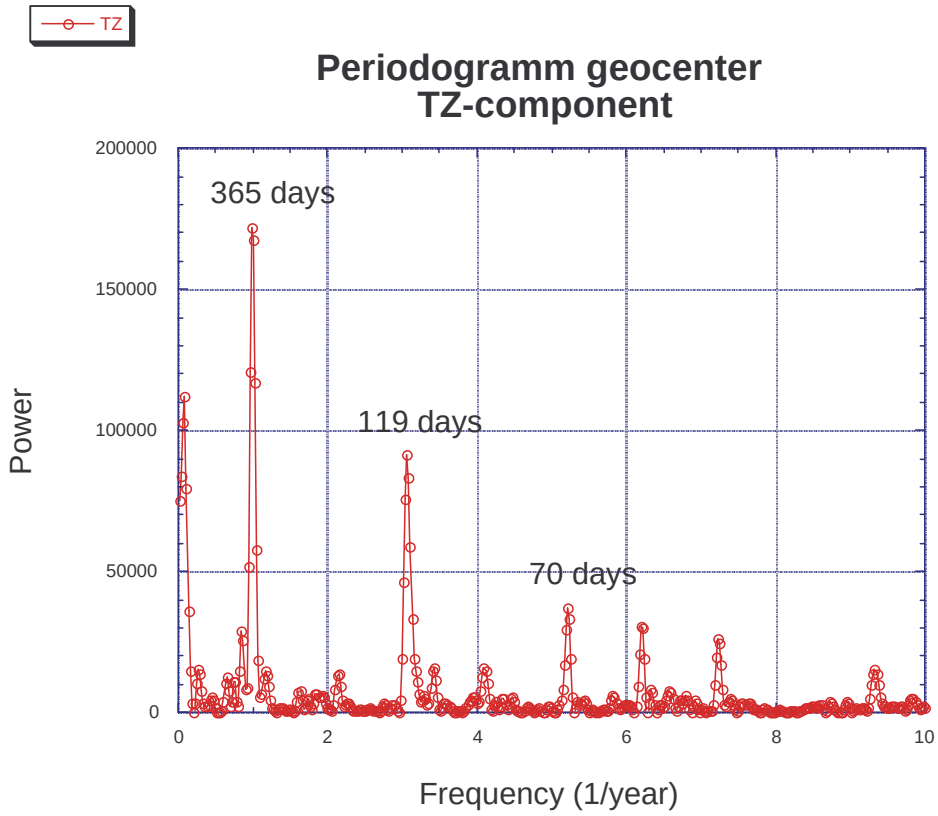

Figure 4: Periodogramm of the estimated TZ DORIS translation compared to ITRF2000 as reference (IGN/JPL solutions, all satellites used except Jason, 1993.0-2004.2).

Figure 4 shows that the TZ translations residuals are dominated by an annual signal as well as signal with a frequencies at 120 and 60 days [Willis et al., 2004c]. The last two signals are characteristic of mis-modeling errors in TOPEX/Poseidon data analysis

related to solar pressure modeling and/or estimating (beta prime period between sun and orbit plane for TOPEX/Poseidon). By doing such type of error analysis directly from the residuals and/or from the DORIS individual solutions and combined products, one could learn a lot about current systematic errors in DORIS data analysis from different groups.

5. Products validation

Presently, there is no real procedure for validating the individual solutions available at the IDS data center. In some cases (times series of coordinates, geocenter), some tests have been conducted by the Analysis Coordinator. We now need to better define how we should validate our products and set up a procedure to do that in an efficient and timely manner.

A specific presentation [Feissel-Vernier et al., 2004; Le Bail, 2004] will address some of these issues during the meeting and provide some proposals for validation processes that could be run operationally of needed.

> Recommendation 5.1: The Analysis Coordinator should propose validations procedures before accepting any IDS individual solutions and IDS product, either internal through combination or external using any type of information. These validations procedure should be an important part of the IDS product definition.

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