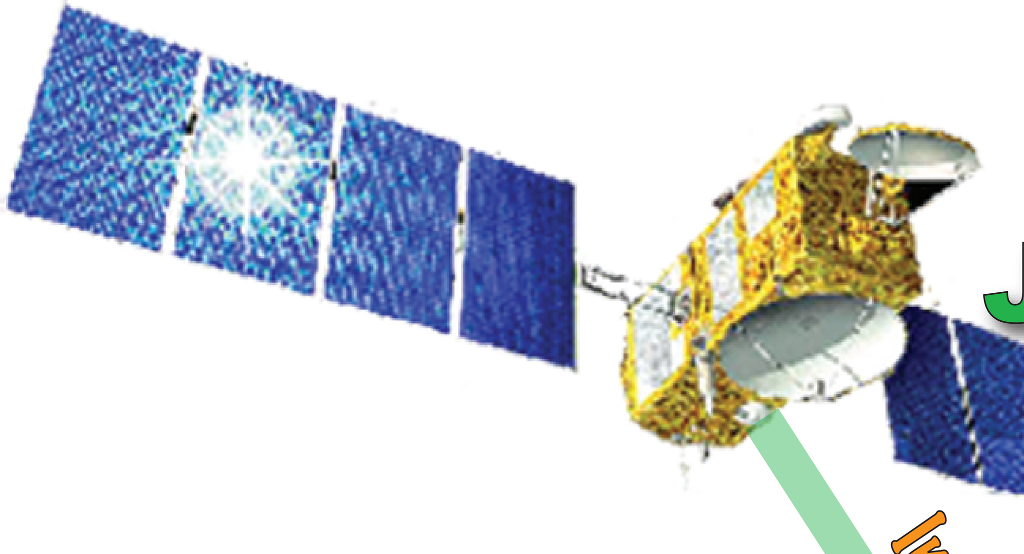

P. Bonnefond, P. Exertier, O. Laurain, P. Berio OCA/GEMINI, Grasse, France
D. Coulot (IGN), Marne la Vallée, France

Validation Activities for Jason-1 and TOPEX/Poseidon Precise Orbits

ABSTRACT

Considering the 1 cm challenge to be reach for the global determination of the orbit of altimeter satellites using DORIS and/or GPS measurements, we plan to evaluate the accuracy of the Jason-1 and TOPEX/Poseidon (T/P) precise orbits using Satellite Laser Ranging (SLR) data. Above the Europe area and, as a consequence, above the Mediterranean sea where several calibration/validation sites have been or will be installed in the next future, the fact that the orbit of both altimeters is largely covered by SLR is a very interesting aspect for altimetry.
Obviously, other SLR sites around the world (US, south Pacific, mainly) largely contribute to the tracking of the tandem mission, thanks notably to the role of the International Laser Ranging Service (ILRS) through its recommendations, its data storage and distribution, and its monitoring of the up-to-date activity (qualitative and quantitative monitoring). Thus, this permits to enlarge the possibilities of CAL-VAL activities.
We have developed a short-arc orbit technique for the validation of altimeter satellite precise orbits. It is based on SLR data, and on rigorous geometrical adjustment criterions. These developments and capacities have been installed on a dedicated Internet site: http://grasse.obs-azur.fr/cerga/gmc/calval/pod/. The goal is to permit the quasi-immediate validation of Jason-1 and T/P orbits. Since the beginning of the Jason-1 mission, it is possible to use this site to evaluate a given orbit cycle or results of the overall missions; orbit and/or SLR residuals (eventually per station) are presented "permanently".
The proper error budget of the method, being at the level of less than 1 cm, this has allowed us to study the radial orbit error, which appears above a given site. Thanks to a selective choice of SLR measurements, taking into account their intrinsic precision/accuracy, and the precision of the station coordinates of the SLR network, the error budget of the orbit validation has been reduced to 1 cm.
In the frame of the Jason-1 GDR-B products, orbit validation of the CNES and GSFC precise orbit strategy has been performed and analyzed. Impact of the new standards (IERS 2003 convention, ITRF 2005-rescaled, …) on the calibration process is also evaluated.

OVERVIEW

We have developed a short-arc orbit technique [Bonnefond et al., 1995] for the validation of altimeter satellite precise orbits. It is based on SLR data, and on rigorous geometrical adjustment criterions. These developments and capacities have been installed on a dedicated Internet site: http://grasse.obs-azur.fr/cerga/gmc/calval/pod/. The goal is to permit the quasi-immediate validation of Jason-1 and T/P orbits. Since the beginning of the Jason-1 mission, it is possible to use this site to evaluate a given orbit cycle or results of the overall missions; orbit and/or SLR residuals (eventually per station) are presented "permanently".
The proper error budget of the method, being at the level of less than 1 cm, this has allowed us to study the radial orbit error, which appears above a given site. Thanks to a selective choice of SLR measurements, taking into account their intrinsic precision/accuracy, and the precision of the station coordinates of the SLR network, the error budget of the orbit validation has been reduced to 1 cm.
For the whole Short-arc validations presented in this poster, we used ITRF2005-rescaled as reference frame for the SLR network.
The orbits used in this study are:
Jason-1
- The new CNES POE (provided in GDR-B, SLR, DORIS and GPS data, GGM02C gravity field, ITRF 2000)
- The new NASA POE (SLR, DORIS, GGM02C gravity field, SAA anomaly model)
TOPEX/Poseidon
- The old NASA POE (M-GDR, JGM3 gravity field, CSR95 up to cycle 360 and ITRF 2000 after)
- The new NASA POE (provided in Retracked GDR, GGM02C gravity field, ITRF 2000)

Bonnefond, P., P. Exertier, P. Schaeffer, S. Bruinsma and F. Barlier, Satellite Altimetry From a Short-Arc Orbit Technique: Application to the Mediterranean, J. Geophys. Res., 100 (C12), 25365-25382, 1995.

Impact of Reference frame on Orbit Precision and Stability

Precise Orbit Analysis Through Short-Arc Technique

SHORT-ARC ANALYSIS FOR TOPEX/POSEIDON

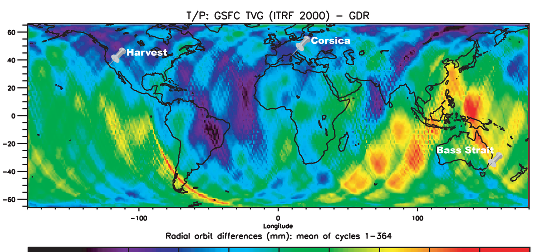

Plate 1. Radial orbit differences (mm) between TOPEX/Poseidon GSFC TVG ITRF 2000 and GSFC GDR orbits.

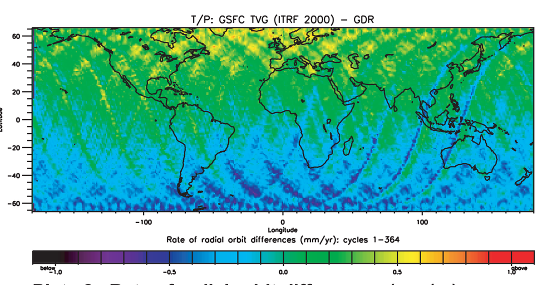

Plate 2. Rate of radial orbit differences (mm/yr) between TOPEX/Poseidon GSFC TVG ITRF 2000 and GSFC GDR orbits.

Plate 1 shows the radial orbit differences between the new NASA POE (TVG ITRF2000) and the old one (GDR). In order to better understand these differences, Short-arc analysis has been performed separetly on each orbit:
- Radial orbit correction (Table 1), notably over Europe (Mediterranean area), is contaminated by the remaining T/P LRA mismodelling. However, the Standard Deviation that reflects the "precision stability" (cycle by cycle) is improved by 7 mm and 11 mm (Root Sum Square differences) over respectively Europe and USA. However, the mean is increased for new NASA POE orbits by 8 mm and 4 mm over respectively Europe and USA (sign is the opposite of differences shown in Plate 1 as Short-Arc corrections are added to the orbits).
- The Standard deviation of SLR residuals (Table 2) is improved by 20 mm and 23 mm (Root Sum Square differences) over respectively Europe and USA. For me this is mainly due to the dramatic improvement of the Along-track component (but also Across-track): 29 mm and 32 mm (Root Sum Square differences) over respectively Europe and USA. This improvement removes the big drop in the standard deviations between cycle 200 and 300 which can be seen in Figures 1b and 2b.

Plate 2 shows the rate of radial orbit differences between the new NASA POE (TVG ITRF2000) and the old one (GDR). A detailed analysis will be given in the "impact for altimeter calibration section".

Table 1. Mean of Radial Short-Arc Corrections for TOPEX/Poseidon (cm)

Area (Orbit)	Raw		Filtered		Cycles	
	Mean	StD*	Mean	StD*	Begin	End
Med Area (TVG I00)	2.6	2.2	2.6	0.9	1	364
Med Area (GDR)	1.8	2.3	1.8	0.9	1	364
USA Area (TVG I00)	1.5	2.0	1.5	0.7	1	364
USA Area (GDR)	1.1	2.3	1.1	0.8	1	364

*Standard Deviation of the time series

Table2. Standard deviation of Global Residuals for TOPEX/Poseidon (cm)

Area (Orbit)	Raw		Filtered		Cycles	
	Mean	StD*	Mean	StD*	Begin	End
Med Area (TVG I00)	2.5	1.2	2.6	1.0	1	364
Med Area (GDR)	3.2	1.2	3.3	1.0	1	364
USA Area (TVG I00)	1.9	1.0	2.0	0.8	1	364
USA Area (GDR)	3.0	1.3	3.1	1.0	1	364

*Standard Deviation of the time series

Mediterranean Area

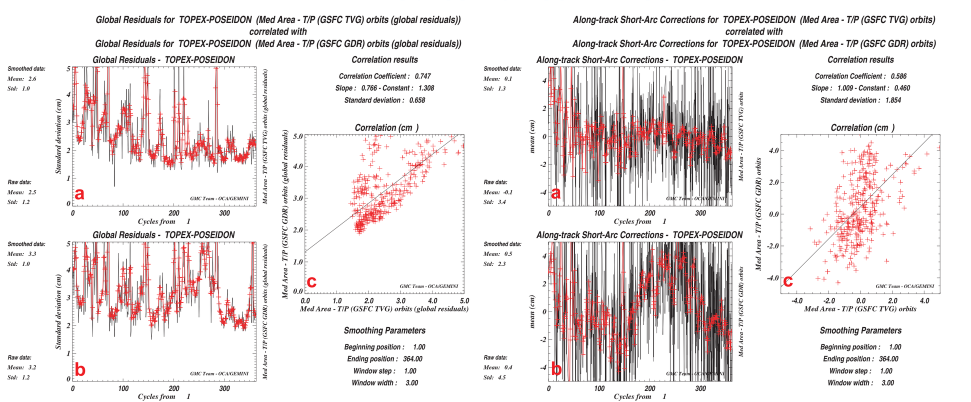

Figure 1. Mediterranean area: at left, standard deviation of SLR residuals for TOPEX/Poseidon GSFC TVG ITRF 2000 (a) and GSFC GDR orbits (b) and their correlation (c). At right, along-track short-arc corrections for TOPEX/Poseidon GSFC TVG ITRF 2000 (a) and GSFC GDR orbits (b) and their correlation (c).

USA Area

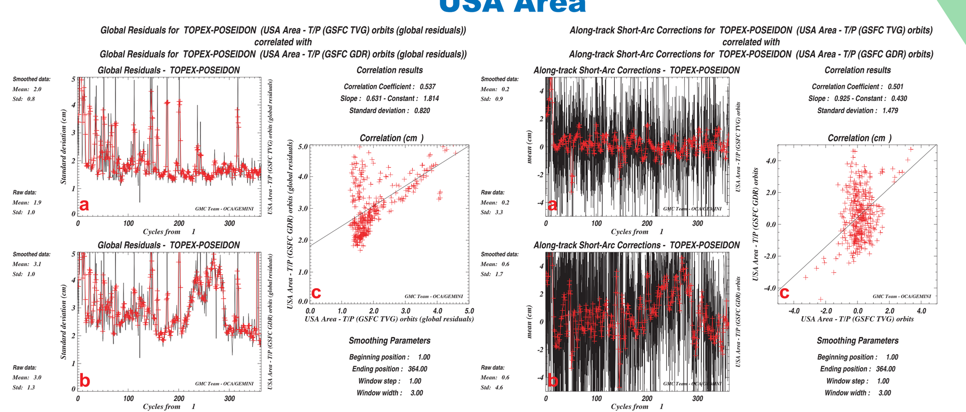

Figure 2. USA area: at left, standard deviation of SLR residuals for TOPEX/Poseidon GSFC TVG ITRF 2000 (a) and GSFC GDR orbits (b) and their correlation (c). At right, along-track short-arc corrections for TOPEX/Poseidon GSFC TVG ITRF 2000 (a) and GSFC GDR orbits (b) and their correlation (c).

SHORT-ARC ANALYSIS FOR JASON-1

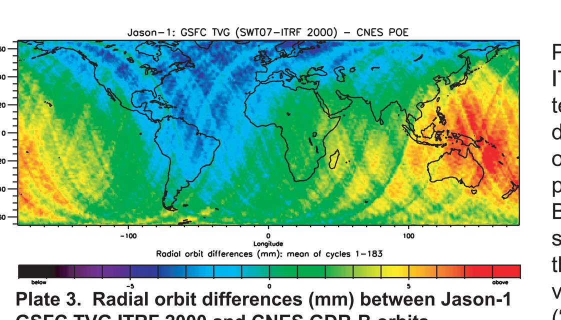

Plate 3. Radial orbit differences (mm) between Jason-1 GSFC TVG ITRF 2000 and CNES GDR-B orbits.

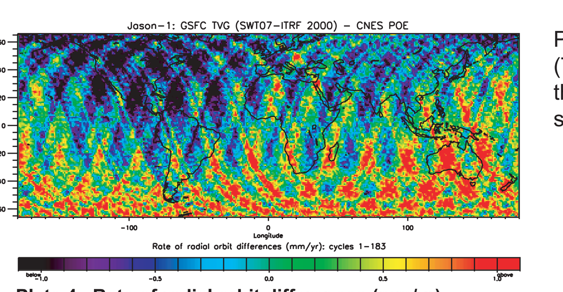

Plate 4. Rate of radial orbit differences (mm/yr) between Jason-1 GSFC TVG ITRF 2000 and GSFC GDR-B orbits.

Plate 3 shows the radial orbit differences between the new NASA POE (TVG ITRF2000) and the new CNES POE (GDR-B). Please note that even if patterns are similar to those of Plate 1, the range of radial orbit differences is divided by 2.5 (-8mm to +8mm for Jason-1 and -20mm to +20mm for T/P). In order to better understand these differences, Short-arc analysis has been performed separetly on each orbit.
Both orbits are really close for the radial component (Table 1) because the studied area are unfortunatly not located in the areas where the signals are the strongest (Plate 3). The new NASA POE (GSFC TVG-SWT orbits however show an important improvement for the Along-track component ("precision stability") at the level of 13 mm and 29 mm (Root Sum Square differences) over respectively Europe and USA (Table 2 and Figures 3&4).

Plate 4 shows the rate of radial orbit differences between the new NASA POE (TVG ITRF2000) and the new CNES POE (GDR-B). Signals are far stronger than those observed for T/P (Plate 2), see the "impact for altimeter calibration section" for more details.

Table 3. Mean of Radial Short-Arc Corrections for JASON-1 (cm)

Area (ITRF)	Raw		Filtered		Cycles	
	Mean	StD*	Mean	StD*	Begin	End
Med Area (GSFC TVG-SWT)	0.5	1.5	0.6	0.6	1	183
Med Area (CNES POE)	0.4	1.4	0.4	0.6	1	183
USA Area (GSFC TVG-SWT)	0.6	1.3	0.6	0.5	1	183
USA Area (CNES POE)	0.5	1.3	0.6	0.6	1	183

*Standard Deviation of the time series

Table 4. Standard deviation of Global Residuals for Jason-1 (cm)

Area (ITRF)	Raw		Filtered		Cycles	
	Mean	StD*	Mean	StD*	Begin	End
Med Area (GSFC TVG-SWT)	1.5	0.4	1.5	0.2	1	183
Med Area (CNES POE)	1.5	0.7	1.6	0.4	1	183
USA Area (GSFC TVG-SWT)	1.6	0.5	1.7	0.3	1	183
USA Area (CNES POE)	1.7	0.6	1.8	0.4	1	183

*Standard Deviation of the time series

Mediterranean Area

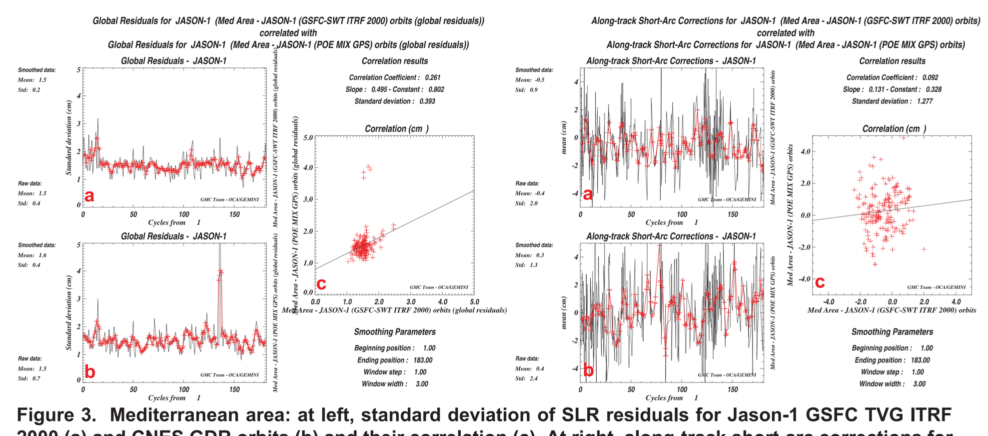

Figure 3. Mediterranean area: at left, standard deviation of SLR residuals for Jason-1 GSFC TVG ITRF 2000 (a) and CNES GDR orbits (b) and their correlation (c). At right, along-track short-arc corrections for Jason-1 GSFC TVG ITRF 2000 (a) and CNES GDR orbits (b) and their correlation (c).

USA Area

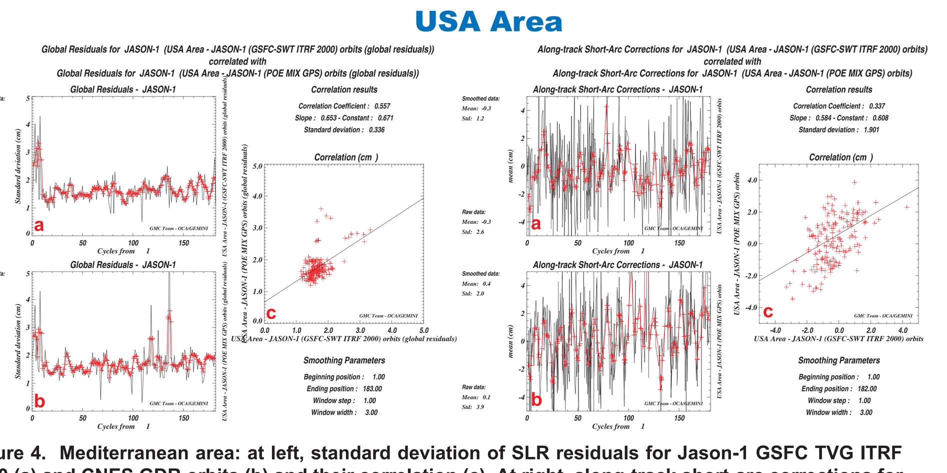

Figure 4. Mediterranean area: at left, standard deviation of SLR residuals for Jason-1 GSFC TVG ITRF 2000 (a) and CNES GDR orbits (b) and their correlation (c). At right, along-track short-arc corrections for Jason-1 GSFC TVG ITRF 2000 (a) and CNES GDR orbits (b) and their correlation (c).

OVERVIEW

In the frame of ITRF 2005 release and the problem discovered for the scale factor of the SLR network, we have conducted a study on the impact of the reference frame change in the POD for TOPEX/Poseiidon and Jason-1. Among all the existing space-geodetic techniques, Satellite Laser Ranging (SLR) plays a major role for the International Terrestrial Reference System (ITRS) materialization. Indeed, except for the last realization, ITRF2005, SLR has always provided the origin and the scale (together with VLBI) of the various International Terrestrial Reference Frame (ITRF) versions since the ITRF94 computation. For the first time in the ITRF history, the ITRF Product Center (ITRF PC) has considered time series of station positions and Earth Orientation Parameters (EOPs) provided by the four services of the International Association of Geodesy (IAG) as input for the ITRF2005 solution. As the International Laser Ranging Service (ILRS) SLR scale derived wrt ITRF2000 from the official time series during the ITRF2005 analysis exhibited a piece-wise behaviour, only the VLBI technique has provided the scale (and its rate) of this last ITRF version; the other reason of this choice is the 1 ppb relative scale bias between SLR and VLBI wrt ITRF2005. But nevertheless, the SLR technique is the satellite technique which produces the most accurate gravitational constant GM estimations and the ITRF scale is directly linked to this fundamental constant.
In this study, we focus on the SLR biases and on their effects on Terrestrial Reference Frame (TRF) scale factors. We test two opposite strategies. In the first approach, range biases are not considered at all in the computations: this is close to the ILRS strategy where no SLR bias is estimated for the core SLR network. In the second approach, we apply an upgraded temporal decorrelation method to compute station biases per satellite. Then, these estimated biases are applied to correct the SLR measurements during data processing. Finally, the results of these two computation strategies regarding weekly TRFs are presented and discussed.

Coulot, D., P. Berio, D. Féraudy, O. Laurain, and P. Exertier, Different ways of considering biases for Satellite Laser Ranging data processing: consequences on Terrestrial Reference Frame scale factors, sumitted to Geophys. Res. Lett., 2007.

SATELLITE LASER RANGING DATA BIASES: CONSEQUENCES ON TERRESTRIAL REFERENCE FRAME

Figure 7 shows the weeky translation and scale factor time series resulting from the stacking of the TRFs computed with the first method (no range bias is estimated during the SLR data processing). Regarding the scale factor time series, Figure 7 (zoom at right) clearly shows a piece-wise behaviour: 1993.0-1996.0, 1996.0-2001.0, 2001.0-2006.0 and 2006.0-2006.9. Tab. 1 provides the mean values and the drifts of the time series over these four intervals. We can see that the time series provides a drift of -2.5 mm/yr between 2001.0 and 2006.0. Moreover, the RMS of the time series is 5.2 mm. From all these results, we can conclude that these time series is not regular at all.
Finally, the results provided by this first method are similar, regarding weekly parameters and station position residual time series, to those produced with the ILRS official combined solution during the ITRF2005 analyses.
Figure 8 shows the weeky translation and scale factor time series resulting from the stacking of the TRFs computed with the second strategy (SLR measurements are corrected from the range biases per satellite computed with the temporal de-correlation method during the data processing). We can see that the TZ drift is reduced (its value is 0.5 ± 0.04 mm/yr). It seems that range biases can influence not only the scale factors but also the third translations. Indeed, Figure 8 (zoom at right) only shows the corresponding scale factor time series and these time series are clearly more regular than the previous ones. This visual remark is confirmed by the results provided in Table 5 (the drift between 2001.0 and 2006.0 is divided by 3.6 and the drifts over other time intervals are also reduced and even no more significant).

Table 5. Mean values (mm) and drifts (mm/yr) of weekly scale factors provided by the two strategies over identified time intervals : Without Biases (WoB.) and With Biases (WB.) computed with the temporal decorrelation method

Time interval	WoB.	WB.
1993.0-1996.0	-2.9[a] -0.3 ± 0.3[b]	0.7 0.3 ± 0.3
1996.0-2001.0	0.4 1.0 ± 0.2	0.7 0.3 ± 0.2
2001.0-2006.0	-2.9 -2.5 ± 0.2	-1.1 -0.7 ± 0.2
2006.0-2006.9	-5.7 2.2 ± 1.8	-0.9 0.0 ± 1.6

[a] The first value corresponds to the mean value.
[b] The second values respectively correspond to the estimated drift and its standard deviation.

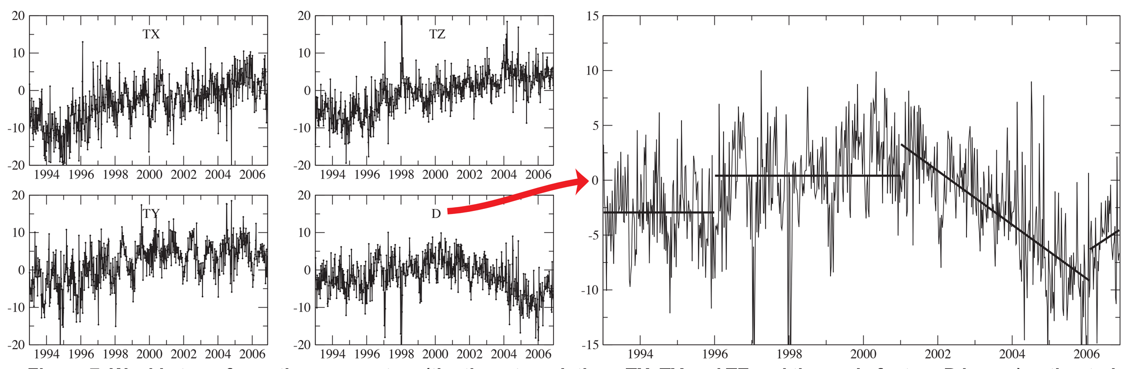

Figure 7. Weekly transformation parameters (the three translations TX, TY and TZ and the scale factors D in mm) estimated wrt ITRF2000. No range bias is estimated during the SLR data processing (very close to ILRS strategy for ITRF 2005).

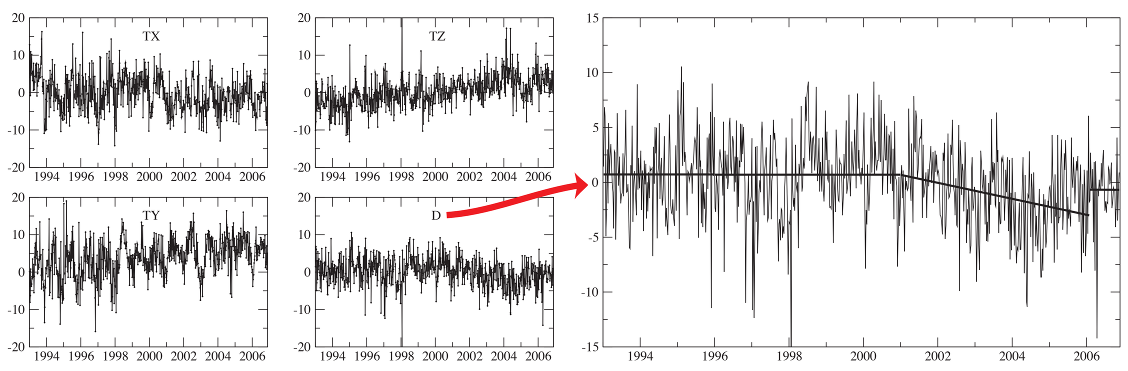

Figure 8. Weekly transformation parameters (the three translations TX, TY and TZ and the scale factors D in mm) estimated wrt ITRF2000. SLR measurements are corrected from the range biases per satellite computed with the temporal decorrelation method during the data processing.

From all the results of this study, we can firstly conclude that SLR biases really must be taken into account in any data reduction. Indeed, it seems that the piece-wise behaviour of the ILRS solution scale time series derived wrt ITRF2000 during the ITRF2005 analyses is mainly due to a wrong handling of these biases. Moreover, the temporal decorrelation method clealry provides regular scale factor time series. This method can still be improved. Indeed, it is obviously limited for stations for which ranging biases provide a poor stability. In this case, the time interval over which biases are estimated should probably be reduced. Moreover, a very small number of stations still provide position residuals which exhibit discontinuities. This discontinuities should be detected with the temporal decorrelation method applied on running variable time intervals.

IMPACT OF TERRESTRIAL REFERENCE FRAME ON TOPEX/POSEIDON AND JASON-1 ORBITS

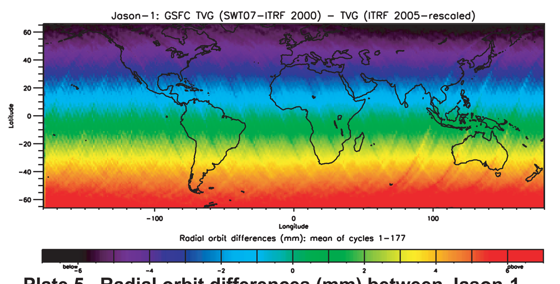

Plate 5. Radial orbit differences (mm) between Jason-1 GSFC TVG ITRF 2000 and GSFC TVG ITRF 2005-rescaled orbits.

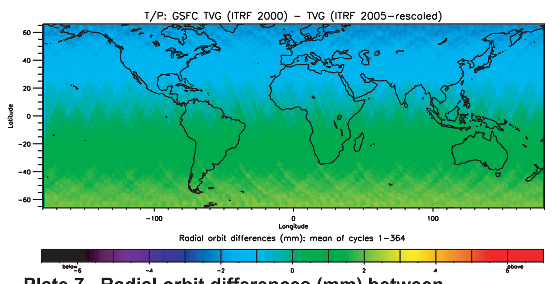

Plate 7. Radial orbit differences (mm) between TOPEX/Poseidon GSFC TVG ITRF 2000 and GSFC TVG ITRF 2005-rescaled orbits.

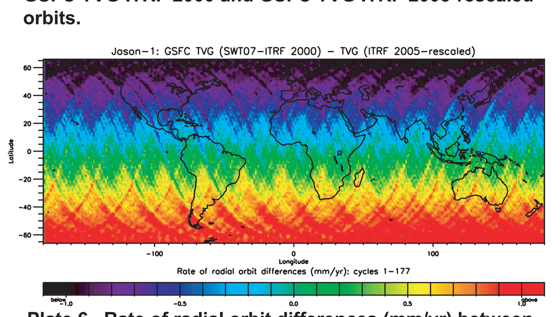

Plate 6. Rate of radial orbit differences (mm/yr) between Jason-1 GSFC TVG ITRF 2000 and GSFC TVG ITRF 2005-rescaled orbits.

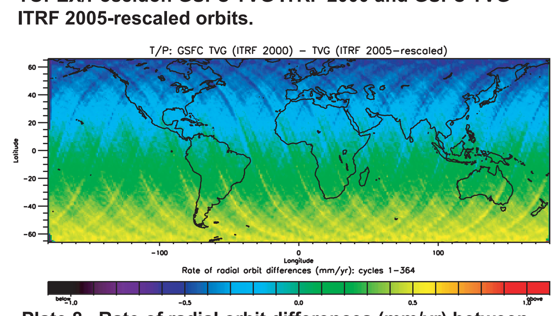

Plate 8. Rate of radial orbit differences (mm/yr) between TOPEX/Poseidon GSFC TVG ITRF 2000 and GSFC TVG ITRF 2005-rescaled orbits.

The orbit used for this study heve been provided by GSFC. The ones based on ITRF 2000 correspond to those analysed in the "Precise Orbit Analysis Through Short-Arc Technique" section. The ones based on ITRF2005-rescaled are based exactly on the same model, only the SLR reference frame changed. Plate 5 and 7 show the radial orbit differences between these two sets of orbits for respectively Jason-1 and TOPEX/Poseidon .Plate 6 and 8 show the rate of radial orbit differences between these two sets of orbits for respectively Jason-1 and TOPEX/Poseidon.
From these maps we clearly see that the effect of reference system is higher for Jason-1 (Plates 5 and 6) than for T/P (Plates 7 and 8) and this is linked to the fact that ITRF 2005 scale factor exhibits a strong trend after 2001 (begining of Jason-1 mission) while for T/P initial orbit period (ending in august 2002, cycle 365) the trend is lower (Figure 5, zoom at right). Indeed, even if ITRF 2005 has been rescaled, it has been done over the whole periode and do not take into account the piece-wise behaviour described in our study.
Sign and amplitudes of these signals have been confirmed in the altimeter calibration process in Corsica see Figure 5 and 6 in the "impact for altimeter calibration" section.

IMPACT FOR ALTIMETER CALIBRATION

TOPEX/Poseidon

The new NASA POE orbits (TVG-ITRF2000) have been used in replacement of the T/P GDR orbits in the altimeter process (ALT-B, cycle 237 to 364, Figure 5):
ALT-B bias (at epoch 2002.0) based on TVG orbits: -23.0 mm
ALT-B bias (at epoch 2002.0) based on GDR orbits: -11.7 mm
The 11.3 mm difference confirms the observed mean radial correction difference (8 mm, Table 1) over the Mediterranean Area suggesting that even it TVG orbits shows a dramatic improvement, they exhibit an increase of the GCE over Europe and probably 4 mm over USA.
Concerning the rate of radial orbit differences (Plate 2) we found in the altimeter process (ALT-B, cycle 237 to 364):
ALT-B bias based on TVG orbits: -0.9 mm/yr
ALT-B bias based on GDR orbits: +0.8 mm/yr
The differences linked to orbit differences is the -1.7 mm/yr which does not correspond to the value and the sign of the signals in Plate 2 in the Corsica area because it was determined on the whole T/P period (cycle 1 to 364). When studying the two altimeter periods are separetly the maps of radial orbit differences rate show opposite signal for ALT-A (Plate 2a) and ALT-B (Plate 2b). In this case, the difference of rate (-1.7mm/yr) found in the calibration process corresponds to the value and the sign of the signals in Plate 2b in the Corsica area. To avoid confusion in the patterns, results shown in Plate 2 have been mapped on the same color scale range than Plate 2a and 2b (see Plate 2c)

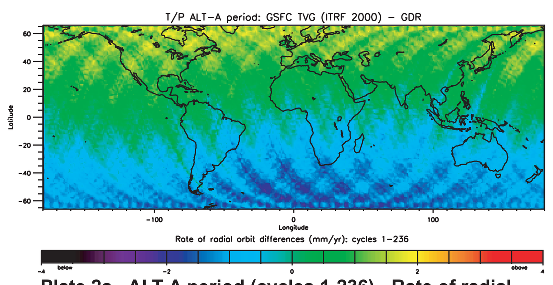

Plate 2a. ALT-A period (cycles 1-236) - Rate of radial orbit differences (mm/yr) between TOPEX/Poseidon GSFC TVG ITRF 2000 and GSFC GDR orbits.

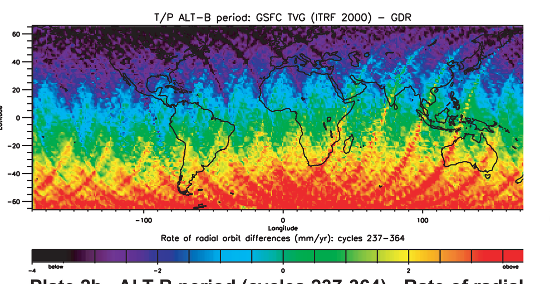

Plate 2b. ALT-B period (cycles 237-364) - Rate of radial orbit differences (mm/yr) between TOPEX/Poseidon GSFC TVG ITRF 2000 and GSFC GDR orbits.

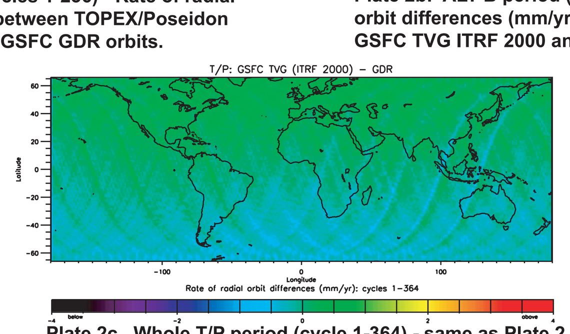

Plate 2c. Whole T/P period (cycle 1-364) - same as Plate 2 but with the color scale range of Plates 2a and 2b.

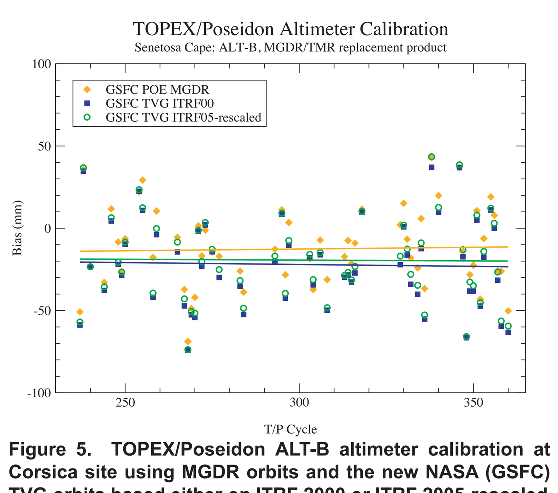

Figure 5. TOPEX/Poseidon ALT-B altimeter calibration at Corsica site using MGDR orbits and the new NASA (GSFC) TVG orbits based either on ITRF 2000 or ITRF 2005-rescaled.

Jason-1

Same exercice has been performed for Jason-1 where the new NASA POE orbits (TVG-ITRF2000) have been used in replacement of the CNES GDR-B orbits in the altimeter process (cycles 1-177, Figure 6):
POSEIDON-2 bias (at epoch 2002.0) based on TVG orbits: 81.8 mm
POSEIDON-2 bias (at epoch 2002.0) based on GDR-B orbits: 81.3 mm
The -0.5 mm difference is very close to the observed mean radial correction difference (1 mm, Table 3) over the Mediterranean Area.
Concerning the rate of radial orbit differences (Plate 4) we found in the altimeter process:
POSEIDON-2 bias based on TVG orbits: -0.9 mm/yr
POSEIDON-2 bias based on GDR-B orbits: +0.5 mm/yr
The differences linked to orbit differences is the -1.4 mm/yr which corresponds to the value and the sign of the signals in Plate 2 in the Corsica area.

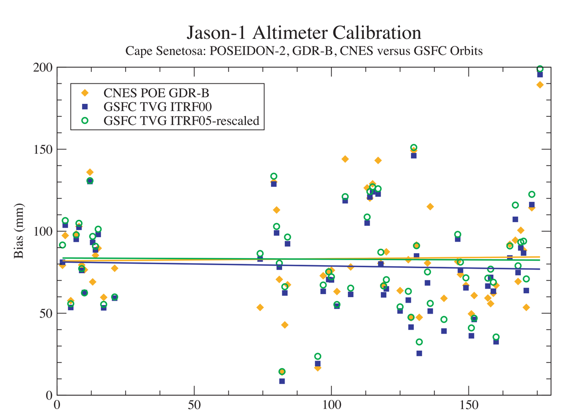

Figure 6. Jason-1 ALT-B altimeter calibration at Corsica site using CNES GDR-B orbits and the new NASA (GSFC) TVG orbits based either on ITRF 2000 or ITRF 2005-rescaled.