The ITRF97 Reference Frame and its Effect on Sea Level Change Studies

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Abstract

Sea level change over the past century is studied almost exclusively using tide gauge records, but they suffer from the unknown effects of land motion and poor spatial distribution. With satellite altimetry, some of these limitations are overcome in that the measurements are global and are tied to the Earth's center-of-mass in a precise reference frame. However, uncertainties still arise with regard to the long-term performance of the instruments and the maintenance of the reference frame from one altimeter mission to the next. Care must be taken to maintain the reference frame across multiple geodetic techniques and multiple decades if climate change signals are to be reliably determined. To gain some insight into the sensitivity of the reference frame choices, we investigate the effect on the orbits and on the observed sea level change due to switching the TOPEX/POSEIDON orbit processing to the newly released ITRF97 coordinates.

Effect of Reference System on Orbits and Determination of Mean Sea Level

With the long time series of sea level that TOPEX/POSEIDON (T/P) and Jason-1 will provide, attention has turned to the influence of the reference system used for the precision orbit determination (POD). To understand the manner in which the choice of reference system affects the orbit, and consequently sea level, a series of experiments were previously conducted (Ries et al., 1998):

Case 1: 30 mm random errors in every station coordinate
Case 2: systematic 10 mm/yr error for every station
Case 3: reduce all station velocities to zero
Case 4: switch from nominal SLR/DORIS coordinates to ITRF96

The results, summarized in Table 1, indicate that the orbit is unaffected by small reference system errors or changes that result in a miscentering in the equatorial plane (the X and Y axes). The parameters typically estimated for most orbit determination methods are unable to accommodate a miscentering or other motion of the reference system in these directions because the Earth rotates in inertial space once per day. (This would likely not be true for very short arcs or if a large number of subarc acceleration parameters per day were estimated.) It is clear, however, that the orbit responds quite strongly, almost one for one, with a reference system motion in Z. The adjustment of the initial conditions easily accommodates this signal, creating an erroneous Z motion in the orbit relative to the true orbit.

As a consequence, if the reference system happened to have a drift in Z of 10 mm/y, due to a systematic error in the station velocities for example, the orbit would follow that drift at about the same level. If this drift in Z is mapped into global mean sea level, we find that because the Earth is largely covered by ocean, only ten percent of the signal, or 1 mm/yr, shows up (Nerem et al., 1998). However, the hemispherical signal would be larger, with up to 4–5 mm/yr showing up in the extreme latitudes of the northern and southern hemispheres.

Note that the difference between the nominal system used for the NASA and CSR orbits (based on the CSR95L01 and CSR95D02 station solutions) and the ITRF96 reference system results in a drift of approximately 1 mm/y in Z. This reflects the lumped effect of the different station velocities between the two systems. As seen above, this would be 0.1 mm/yr error in the global mean sea level observation, and a maximum antisymmetric drift of 0.4–0.5 mm/yr. The velocities for the DORIS stations in CSR95D02 were based only on 3 years of DORIS data, and thus are not sufficiently accurate to be used indefinitely. Consequently, a new reference system is required. Because the ITRF reference system attempts to combine the SLR, DORIS and GPS networks into a common reference system, it is a reasonable choice. This is especially important for Jason-1, since GPS tracking data will also be used. However, we can expect this reference system to be updated periodically, and the challenge is to prevent these changes from affecting the T/P and Jason-1 results.

Table 1. Effect of reference system changes on T/P orbit

Case 1: 30 mm random errors in every station coordinate
Case 2: systematic 10 mm/year error for every station
Case 3: reduce all station velocities to zero
Case 4: switch from nominal SLR/DORIS coordinates to ITRF96

	Case	1	2	3	4
T/P orbit	X	0	0	0	0
effect	Y	0	0	0	0
(mm/yr)	Z	2	9	12	1
RMS radial orbit difference (mm)		9	28	52	5

(comparison is with nominal SLR/DORIS orbit over 5 years)

CSR95L01/CSR95D02 Compared to ITRF97

A test similar to that conducted for ITRF96 was conducted using the ITRF97 coordinates for the SLR and DORIS tracking stations, but using every tenth repeat cycle for seven years. To be consistent, the IERS polar motion series was used with ITRF97. Failure to use consistent polar motion has a measurable effect on the data fits and radial orbit accuracy. Tables 2 and 3 indicate the 7-parameter transformation between the two systems and the level of agreement after the transformation.

Table 2: (a) Transformation between CSR95L01 and ITRF97 positions for the SLR stations at epoch 1997.0. The 15 best stations were used for these comparisons, but the results are similar if 28 stations are used. Also given are the rotation rates of the CSR95L01 system relative to ITRF97.

	X	Y	Z
Translation (cm)	0.3	0.3	2.3
Rotation (mas, mas/yr)	0.8, 0.2	1.3, 0.1	0.4, 0.03
Scale (ppb)	3.7		

(b) RMS of differences between CSR95L01 and ITRF97 positions for SLR at epoch 1997.0

	ΔX	ΔY	ΔZ
Before Transformation (cm)	3.2	2.6	2.9
After Transformation (cm)	1.3	0.6	0.7

Table 3: (a) Transformation between CSR95D02 and ITRF97 positions for the DORIS stations at epoch 1997.0. 50 stations were used for these comparisons.

	X	Y	Z
Translation (cm)	0.6	-1.6	-1.2
Rotation (mas)	0.5	0.2	1.2
Scale (ppb)	2.3		

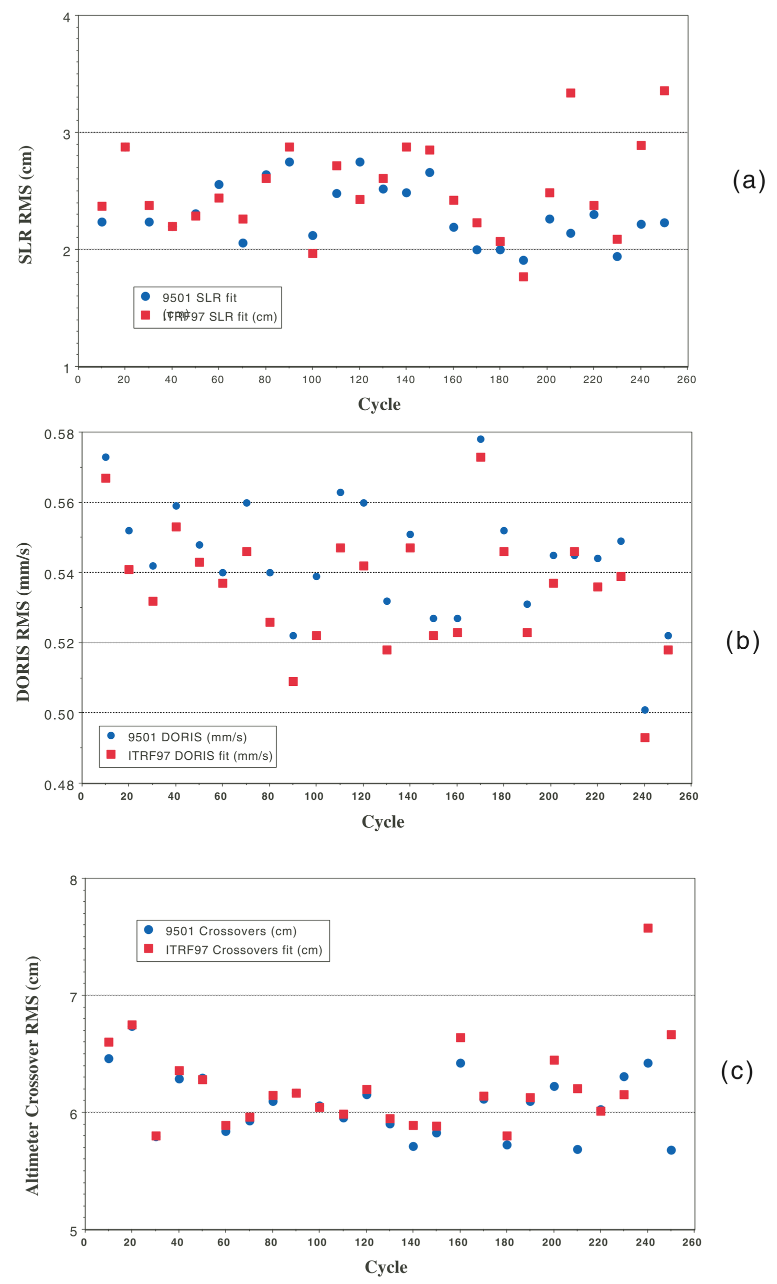
(b) RMS of differences between CSR95L01 and ITRF97 positions for the DORIS stations at epoch 1997.0

	ΔX	ΔY	ΔZ
Before Transformation (cm)	4.7	4.7	4.6
After Transformation (cm)	4.1	3.9	4.2

Orbit Results

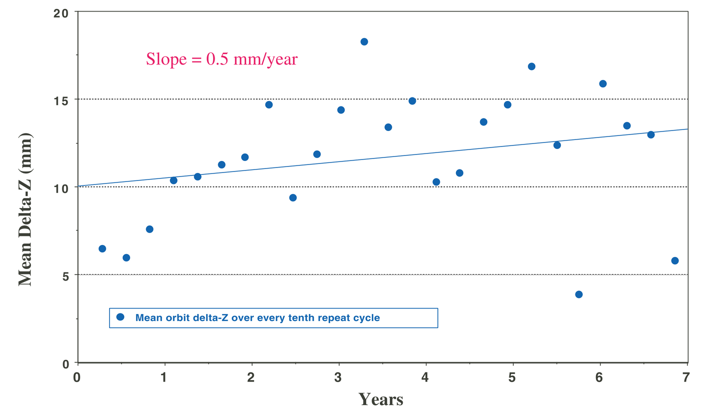
The RMS of the SLR and DORIS tracking data residuals for the 25 cycles tested are plotted in Figure 1a and 1b. It is clear that the DORIS fits are dramatically improved, whereas the SLR results are poor near the end of the test span (roughly late-1998 to 1999). During this period, several new sites come on-line, and it appears that not all of the eccentricities and biases were correctly incorporated. As a result, the altimeter crossover RMS, shown in Figure 1c, also degrades during that period. This does not necessarily reflect on the quality of the ITRF97 solution; it merely illustrates the difficulty in implementing all the details of this very precise and complex coordinate system.

Figure 1: Data RMS using CSR95 and ITRF97 for (a) SLR, (b) DORIS and (c) altimeter crossovers



More work is required to eliminate the discrepancies before ITRF97 can be adopted for the CSR and NASA orbit production. However, the fits are sufficient to evaluate the effect of the reference frame on the orbit centering. As noted earlier, the principal concern is any drift in the Z direction. No radial drift can occur due to the reference frame choice; this is entirely determined by the dynamic model. Figure 2 compares the mean Z difference for every tenth cycle over the 7 year T/P mission. The relative drift appears to be a modest 0.5 mm/yr, which would translate to only 0.05 mm/yr in global mean sea level rate.

Figure 2: Mean Z difference between orbits computed at CSR using the CSR95 and ITRF97 reference frames



The comparison in Figure 2 is a test of the Z-drift inherent in the CSR95 and ITRF97 reference frames, but it does not test the actual POE orbits. Figure 3 shows the mean Z difference between the distributed NASA orbits and the same 25 cycles computed at CSR with the ITRF97 frame. In this case, the magnitude of the drift is larger, at 1.8 mm/year.

Figure 3: Mean Z difference between the NASA POE orbits using the CSR95 reference frame and the ITRF97 orbits computed at CSR

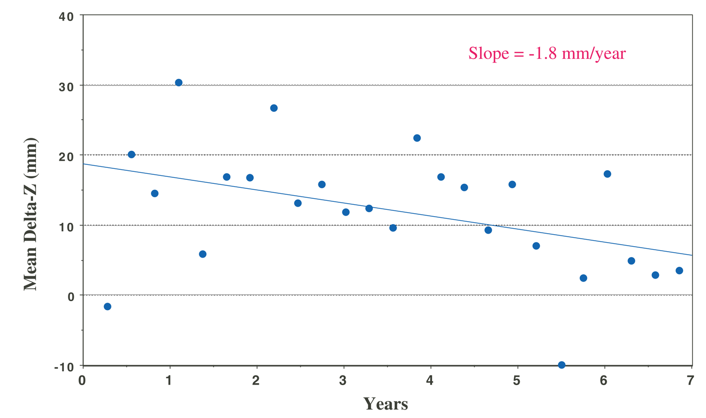
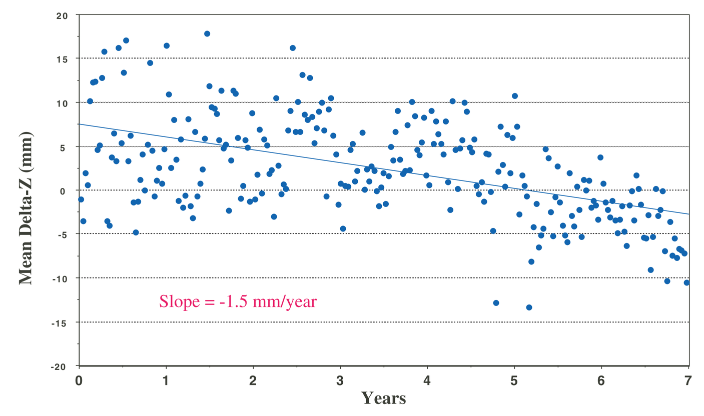


Figure 4, where the NASA/CSR comparison of every cycle of the T/P mission is shown, appears to indicate that this larger slope is reflecting some minor reference frame model changes that have occurred over the course of the mission, rather than a systematic drift. Recall also that even this slope would cause less than 0.2 mm/yr in the altimeter measurement of global mean sea level rise.

Figure 4: Mean Z difference between the NASA POE orbits and the CSR verification orbits, both using the CSR95 reference frame



The reduction in the scatter of the Z-shifts after Cycle 92 reflects the higher weight given to SLR when the JGM-3 models were adopted. There is a preliminary indication that the slightly positive mean for most of the mission represents a station bias modeled at CSR but not NASA. This indicates the strength of the SLR data in centering the orbit, as well as the level of detail that must be observed to obtain the maximum benefit of this very accurate data type. At about the fifth year, this bias was corrected at the station, and the two orbits moved closer together. The trend during the last year, however, is a concern, and this is being investigated. We intend to identify the source of the discrepancy and remove this Z-shift trend from the orbit differences.

Conclusions

It has been shown that the reference frame choice can affect the determination of sea level from the altimeter data. A common reference frame model for the U.S. and French POD efforts will help to assure a greater level of consistency between the two sets of orbits and the resulting sea level time series. This reference frame will also provide the link between the T/P and Jason-1 missions. The ITRF97 reference frame has been proposed as this common reference frame.

The analysis here indicates that the current CSR95L01/CSR95D02 frame has a rotational drift of ~0.2 mas/yr with respect to ITRF97. The Z-drift relative to ITRF97, as reflected in the T/P orbits over 7 years, appears to be ~0.4 mm/yr, smaller than the drift previously observed with ITRF96 (~1 mm/yr) based on only 5 years of orbits. It is difficult to test the absolute drift of a reference frame with respect to the Earth's center of mass, but if various reference frames exhibit consistency at the mm/yr level or better, the effect on mean sea level can be expected to be very small.

It is not obvious from these results that adopting a reference system consistent with ITRF97 will make a significant difference to mean sea level studies based on the NASA orbits. The recent trend observed in the NASA POE orbits relative to the CSR verification orbits requires further attention, but the effect is still only ~0.15 mm/yr in global mean sea level rate.

The DORIS coordinates in ITRF97 are a clear improvement over CSR95D02, as exhibited by the better fits to the tracking data. The SLR coordinates may also be improved as well, but some inconsistencies in the site eccentricities and biases are obscuring this. Further effort is needed to sort out the remaining discrepancies and implement the ITRF97 frame completely correctly.

Since it is unlikely that a set of station coordinates determined at this time can span the entire life of the combined T/P and Jason-1 missions, a method to switch to updated reference systems without introducing discontinuities or trends into the orbits is essential. This can be accomplished by agreeing that future reference frame models adopted for the orbits are constructed to have no significant offset or drift (in rotation and translation) with respect to the previously employed frame.

References:

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