N95-14283

I. RADAR ALTIMETER CALIBRATION USING SLR

107869

S.M. Klosko

Accurate absolute calibration of radar altimeters is essential to separate possible hardware drift from long-period phenomena in the measured ocean topography. Monitoring sub-centimeter global sea level changes is one of the major goals of these missions.

OVERVIEW

Historically, all NASA altimeter missions have flown a laser retroreflector array. The most accurate space-based measurement of absolute distance is now achieved with SLR. In principle a calibration experiment is designed to enable a direct, orbit-independent comparison of the laser ranges, with their sub-centimeter accuracy, to the radar altimeter, in order to independently assess the range bias and drift within the radar system at the noise level of the closure of these measurements. The accurate calibration of radar altimeters is increasingly more critical to the overall success of these altimeter missions. Constant offsets in the radar range measurements are troublesome, but are less troubling than bias drift, which differentially affects ocean topography measurements. These differential changes, if undetected, obscure the monitoring of long period and secular changes in global sea level.

ALTIMETER CALIBRATION EXPERIMENTAL DESIGN

Given the unprecedented accuracy being achieved by the TOPEX/Poseidon mission for the altimetric mapping of the ocean surface, it is clearly feasible that these data can provide a direct and unambiguous measure of global sea level change which is directly referenced to the Earth's geocenter. An altimeter-based measurement of global sea level change avoids many of the problems associated with attempts at determining the same effect using historical tide gauge data. From tide gauges, one measures the relative height of sea level with respect to a fixed point on the Earth's crust. However, the height and secular motion of the gauges themselves are uncertain at levels comparable to the global sea level signal due to post-glacial rebound.. Post-glacial rebound predominates over regions which provide the most dense tide gauge networks (e.g. Europe and North America) and have required rebound models of uncertain accuracy to separate crustal from sea level trends.

In all likelihood, TOPEX/Poseidon is the first of a series of high class altimeter missions which will provide altimetric mapping of the Earth's ocean topography on a continuous basis from this time onward. Therefore, experimental and resource considerations for a direct calibration of these instruments need to be addressed, and will remain of concern for an extensive period of time.

It is a significant requirement to calibrate altimeter instrument performance continuously over their active lifetimes. This is facilitated by the availability of a complementary, absolute ranging system. The most accurate space-based measurement of absolute distance is now achieved with SLR. In principal, the ideal altimeter calibration experiment is designed to enable a "direct" (orbit-independent) comparison of the laser ranges, with their sub-cm accuracy, to that of the radar altimeter, in order to independently assess the range bias and drift within this radar system.

Constant offsets in the altimeter instrument are inherently less troubling than bias drift, which differentially affects ocean topography measurements and can mask sea level secular trends. Careful consideration of each element of altimeter calibration is required to limit absolute errors. Time-dependent biases must be resolved by regular repetition of rigorous calibration tests. A primary challenge in the design of a good altimeter calibration experiment is the ability to make sufficiently precise observations to permit frequent and accurate determinations of altimeter bias and drift parameters. This allows an absolute comparison of altimeter-based ocean topographies separated by large intervals of time and across altimeter missions.

TOPEX/Poseidon

The TOPEX/Poseidon (T/P) mission is ongoing and producing a synoptic mapping of the ocean's topography comparable in accuracy with that achieved using standard tide gauge instruments. This is an unprecedented improvement in satellite altimetric performance which has been achieved through:

- Dramatic improvement in the precision orbit determination, with T/P now benefitting from orbit knowledge radially at the 3 cm level. This is an order of magnitude better orbit knowledge than has previously been seen; and

- Improved environmental corrections for the altimeter range measurement made possible through the dual-frequency measurements acquired by the NASA altimeter system, and the excellent performance of the T/P radiometer to measure the integrated water vapor content in the sub-satellite atmospheric column.

The ongoing calibration of the TOPEX altimeter is not benefitting from a direct overflight of an SLR site and is producing results at the 2-3 cm RMS level (see Figure 1 from Christensen et al., 1994). A direct overflight experiment, on the other hand, is likely the only means to produce an orbit-independent instrument calibration which achieves the accuracy needed to support global sea level monitoring.

Extended calibration of the TOPEX altimeter is presently taking place using the Harvest Platform (oil tower) off the coast of California, near Vandenburg Air Force Base (see Figure 2). T/P overflies the tower approximately every ten days, at which time the following data is taken on the tower:

- o Tide height measured by an underwater pressure gauge operated by the University of Colorado;
- o Vertically integrated water vapor measurements using a microwave radiometer operated by JPL; and
- o Meteorological data (pressure, temperature and humidity) recorded and retrieved remotely by NOAA.

During the early calibration stage, JPL also operated a GPS receiver on the platform in order to monitor its position relative to the Quincy laser site and to deduce integrated electron content to compute Ku-band altimeter ionospheric corrections. However, the platform showed no periodic or long-term motion and a sufficiently precise tie between Harvest and Quincy was obtained.

A second calibration site in the Mediterranean Sea on Lampedusa Island was also supported early in the mission but has been suspended since this time. Calibration activities at this site may recommence at those times when the Lampedusa laser site is reoccupied by a TLRS or MLRS mobile laser tracking system.

The calibration procedure consists of accomplishing a "closure" measurement. The direct measurement to the sea surface is made by the altimeter, although this observation must be corrected for the effects of wet and dry tropospheric propagation, ionospheric propagation, and EM-bias. Errors due to imperfect altimeter performance from variable sea state and off-nadir pointing must also be accommodated, as well as antenna offset at the satellite center of mass. The sea state in the vicinity of the Harvest Platform has been a persistent problem causing tide guages to disagree with one another at the 2 cm level and have caused altimeter range corrections from this source which have significant uncertainties.

The indirect measurement of the distance between the satellite and the sea surface is based on the following:

- o A satellite orbit based on either a short arc of laser data from at least two or three co-observing sites, a SLR/DORIS "long arc orbit", or on GPS data including observations from a receiver on the tower. In the case of the laser short arc orbit, the reference point is at one of the laser sites, while the GPS technique provided a reference point on the tower. Of note, the Harvest experiment requires a 3-D orbit determination.

- 0 A geometric tie between the laser site and the tower, which for Harvest has been made using a GPS receiver at Quincy and one at the tower.

- 0 A survey tie on the tower between the GPS receiver reference point and the tide guage reference point.

- 0 A tide guage measurement of the water surface relative to the reference point. At Harvest, there were originally two NOAA tide guages as well as the one provided by the University of Colorado, which was subsequently decided to be more reliable.

The uncertainty in the altimeter measurement due to noise in the Ku-band measurement is typically in excess of 10 cm at a data rate of 20 pps. The altimeter telemeters down filtered data, which although it has correlated errors, has a noise level close to 2 or 3 cm when averaged over a second for very low sea states. High sea state is common at Harvest and the data noise is usually substantially higher.

The calibration task requires the estimation of orbits, followed by the collection of data for making the required corrections and computing bias estimates. Nevertheless, reconciliation of all the segments of the closure experiment is the key issue, and reduction of errors in each segment reduces the overall error in the absolute accuracy of the calibration itself. Yet, given the complexity and environmental setting of the Harvest Experiment, inadequate calibration accuracy is being achieved. While +/- 2-3 cm knowledge (from 10-day samples) of the TOPEX range bias is quite good, it is not sufficient to detect mm/year trends in instrument performance.

SUMMARY

Clearly a calibration of the TOPEX altimeter (and future TOPEX-class altimeters) which is more accurate and better meets the demands of global sea level trend monitoring is warranted. T/P is well into its second year of data acquisition; if it survives or surpasses its two to five year projected baseline, an unprecedented opportunity for monitoring global sea level trends at mm/y levels will have been lost due to insufficient accuracy in its altimeter calibration. It is therefore paramount to revisit the design of the T/P calibration experiment and implement a more direct approach which better utilizes the accuracy of SLR to perform this needed bias assessment.

References

Christensen, E.J. and 14 others, *Calibration of TOPEX/Poseidon at Platform Harvest,* J.Geophys.Res., special TOPEX/Poseidon Issue, in preparation, 1994.

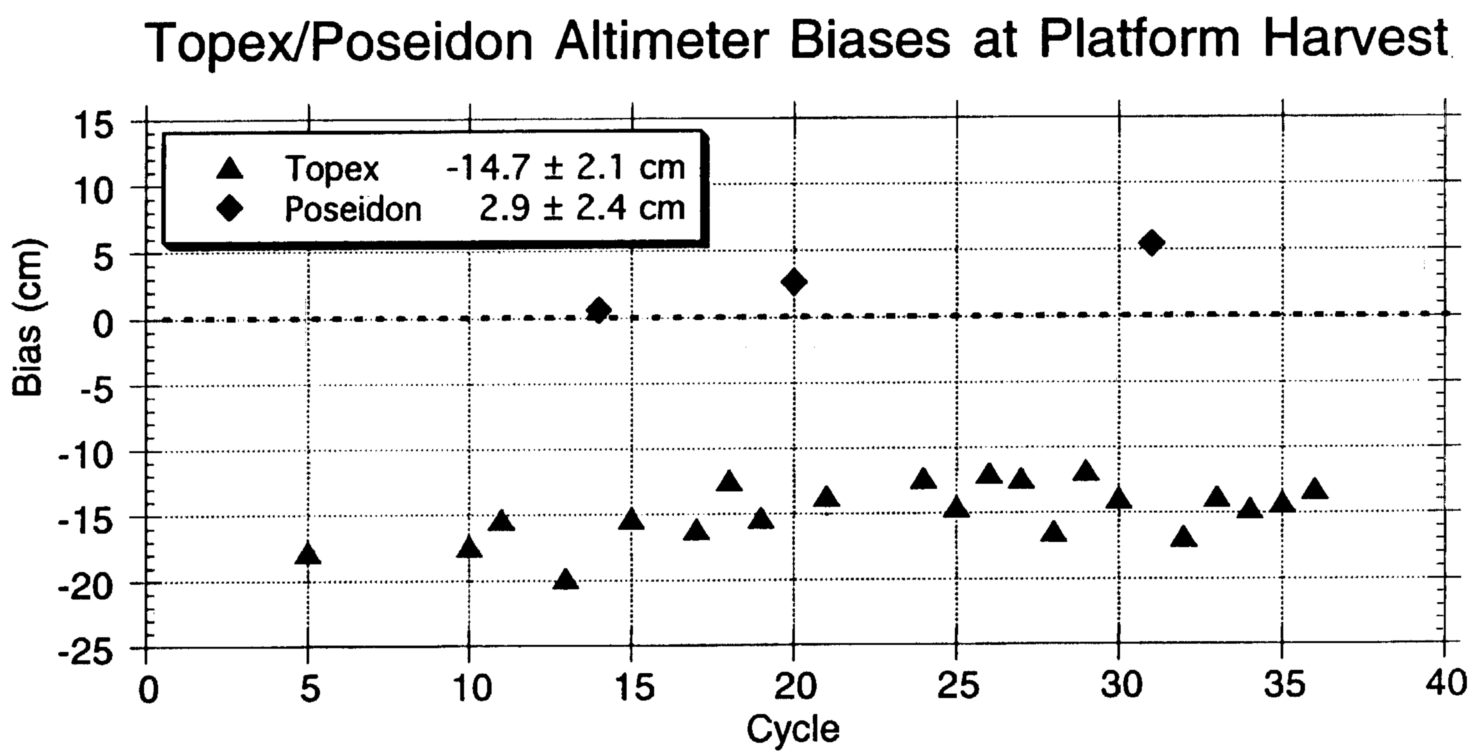
Topex/Poseidon Altimeter Biases at Platform Harvest
Topex -14.7 ± 2.1 cm
Poseidon 2.9 ± 2.4 cm
Bias (cm)
15
10
5
0
-5
-10
-15
-20
-25
0
5
10
15
20
25
30
35
40
Cycle

Figure 1.

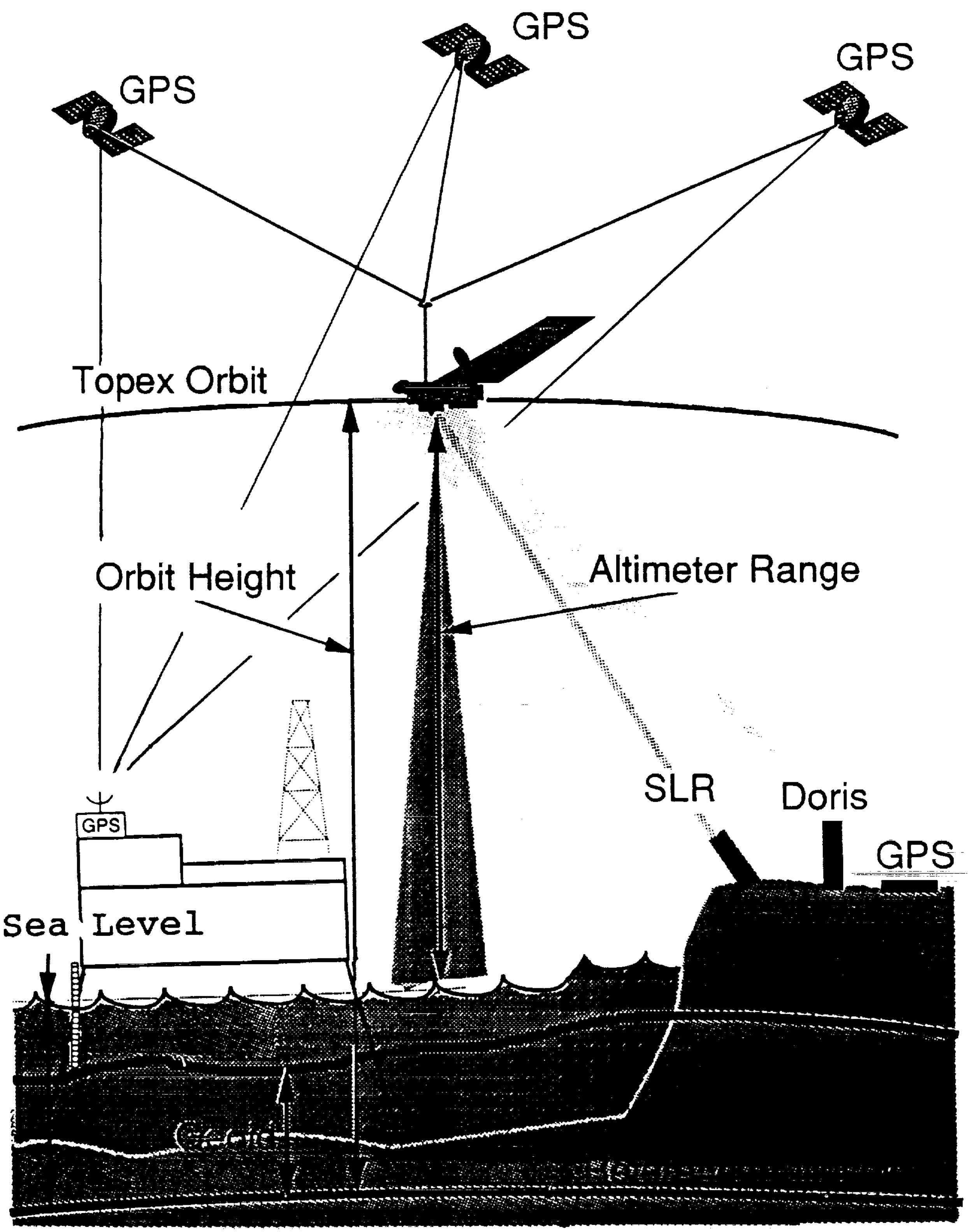
GPS
GPS
GPS
Topex Orbit
Orbit Height
Altimeter Range
GPS
SLR
Doris
GPS
Sea Level

Figure 2.