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Analysis of Altimeter Wave Period Estimates in the North Sea

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Introduction

This report presents an analysis of altimeter wave period data in enclosed seas. To this end we have considered data from the TOPEX altimeter at two sites in the North Sea, one in the north (61° N) and one in the south (53° N), see Table 1. These sites were chosen because reliable *in situ* data were also available. This report should complement the analysis of altimeter estimates in the open ocean, reported in an earlier JERICHO technical report.

Name	Lat (°N)	Lon (°E)	Instrument (waves)	owner/source
K13	53.2	3.2	WAVEC buoy	Rijkwaterstaat
N North Sea	61.2	1.1	various,combined	Shell/Seadata

Table 1: Locations of North Sea sites for the analysis of altimeter wave period estimates

The report starts with a review of the development of the altimeter wave period algorithm, and an assessment of the characteristics of that algorithm. We then compare altimeter wave period estimates with *in situ* data, finally drawing some conclusions and making recommendations for the use of altimeter derived wave period estimates.

The Altimeter Wave Period Algorithm

Development and Testing at SOC

A new algorithm to derive altimeter estimates of zero upcrossing wave period has been developed and tested at Southampton Oceanography Centre [Davies et al., 1997]. A theoretical algorithm was developed, based upon the theory of wave statistics and the relationship of the moments of the wave spectra to the wave parameters that can be measured by a radar altimeter (significant wave height and radar backscatter).

This theoretical algorithm was then tested with a data set of collocated *in situ* and ERS-1 altimeter data, and a significant dependence on wave age was identified. The algorithm was then modified to include an empirically determined dependence upon “pseudo wave age” (a wave age like parameter that can be derived from the altimeter, see Fu and Glazman, 1991). The final algorithm is a two stage function, the first stage calculates an “altimeter period” as function of significant wave height and radar backscatter, the second stage is a quadratic function of this altimeter period and altimeter derived pseudo wave age (a function of significant wave height and wind speed). Early tests suggested that the altimeter could provide a wave period estimate which was accurate to approximately 0.7s.

Cotton [1998] then tested the altimeter wave period for other altimeters (Geosat, TOPEX/Poseidon, and ERS-2, against a larger set of buoy data. This confirmed that the altimeter could provide a useful estimate of wave period (to an accuracy of 0.7s), over a range 4-12 s in the open ocean. This work also indicated that linear calibrations should be applied to the data to provide a more accurate wave period estimate. Equation (1) shows how pseudo wave age is calculated (Fu and Glazman, 1991), (2) gives the calibration correction derived by Cotton [1998]for TOPEX wave period data.

$$\text{Pseudo wave age, } \xi = 2.56.\,(H_s^2.g^2/U_{10}^4)^{0.3} \quad (1)$$

$$Tz_{\text{adjusted}} = 1.494 * Tz_{\text{TOPEX}} + 0.880 \quad (2)$$

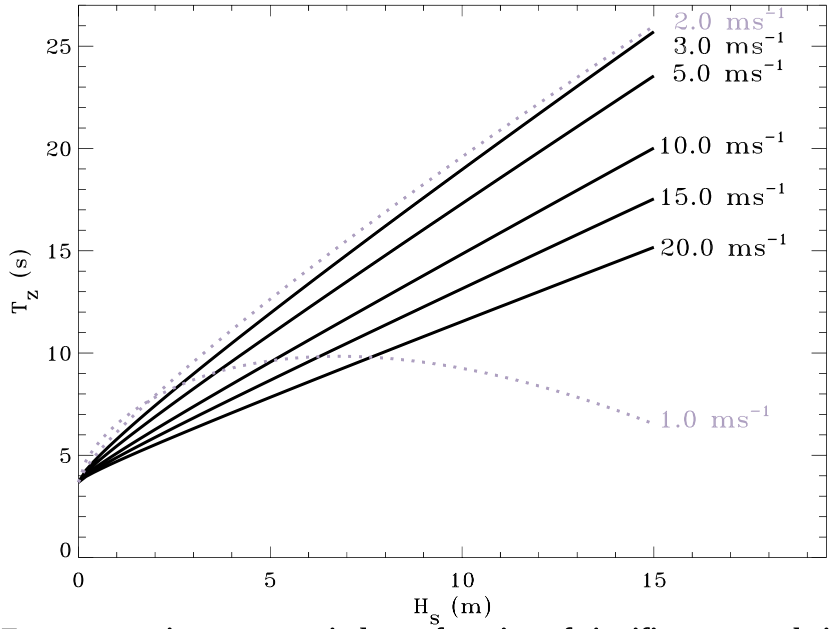


Figure 1: Altimeter Zero upcrossing wave period as a function of significant wave height, for a range of (altimeter) wind speeds.

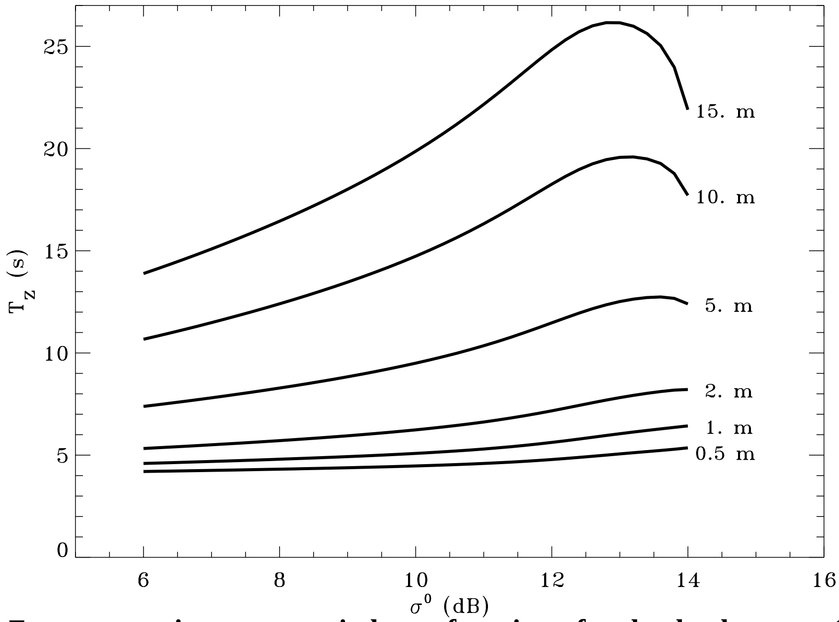


Figure 2: Altimeter Zero upcrossing wave period as a function of radar backscatter (σ0), for a range of significant wave heights.

Characteristics of the Altimeter Wave Period Algorithm

The characteristics of the wave period algorithm can be assessed by generating altimeter wave period for a range of input parameters. Figures 1 and 2 illustrate altimeter derived Tz as function of significant wave height and radar backscatter (σ0). One can see that for low wave heights the algorithm has little sensitivity to wind speeds and hence radar backscatter , and also that for wave heights greater than 2.0m and wind speeds less than 2.0 ms^{-1} (σ0 > 14 dB) the altimeter algorithm will provide anomalously low estimates for wave period. It is also clear that the algorithm will not return values of wave period less than 4 seconds, a consequence of the fact that the algorithm was empirically fitted to an *in situ* data set which contained no values less than 4 s.

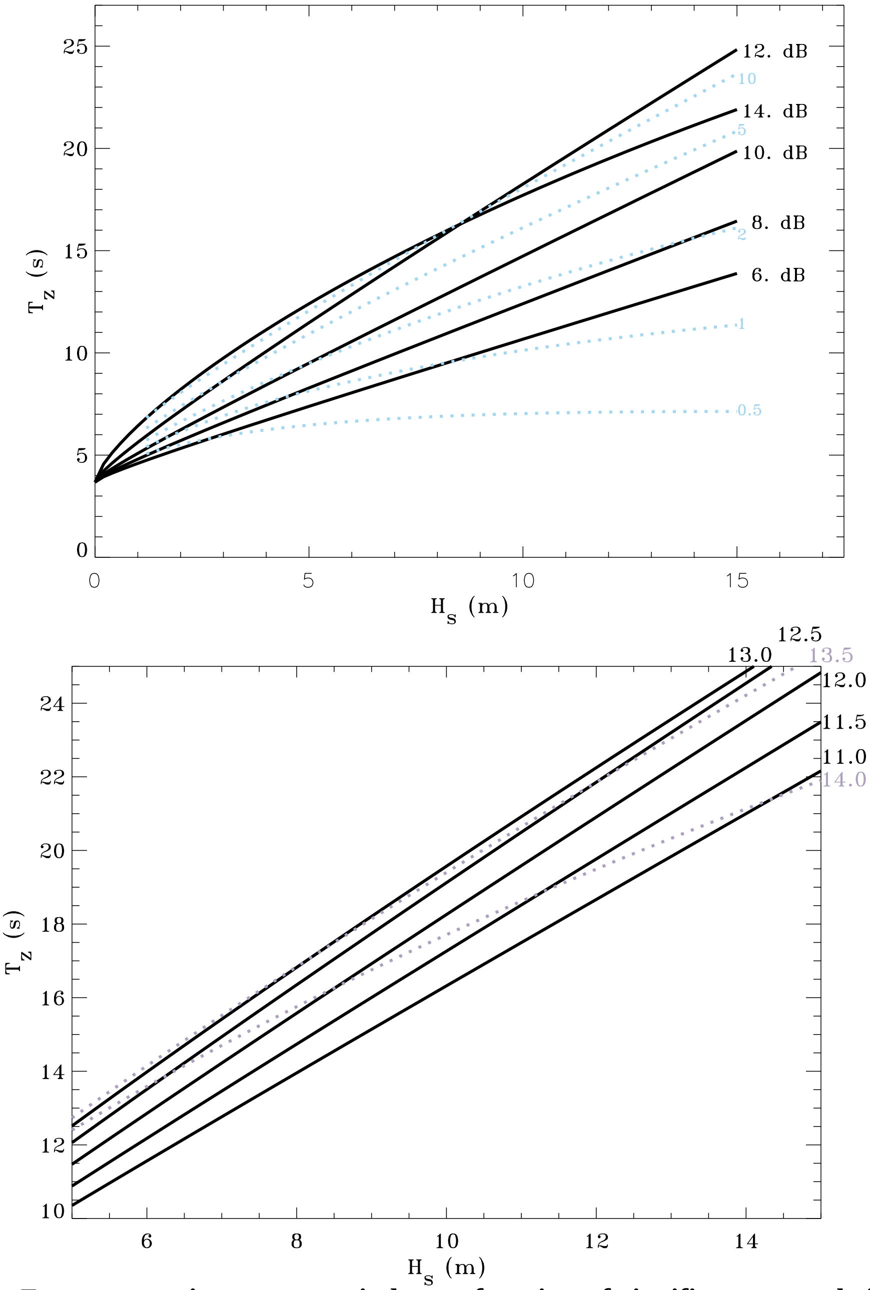


Figure 3: Altimeter Zero upcrossing wave period as a function of significant wave height for a range of values for radar backscatter (σ0), and wave age (top panel only, dashed lines). The bottom panel considers a reduced range of wave period and wave height, and only presents Tz for different values of radar backscatter.

Figure 3 demonstrates how the algorithm behaves as a function of Hs for different values of $\sigma 0$, and (for the top panel only- dashed lines), wave age. The bottom panel provides a magnified view over a limited range. It is again clear that the algorithm generates erroneous values for $\sigma 0$ > 13 dB (low wind speeds) when the significant wave height is greater than 5.0 m.

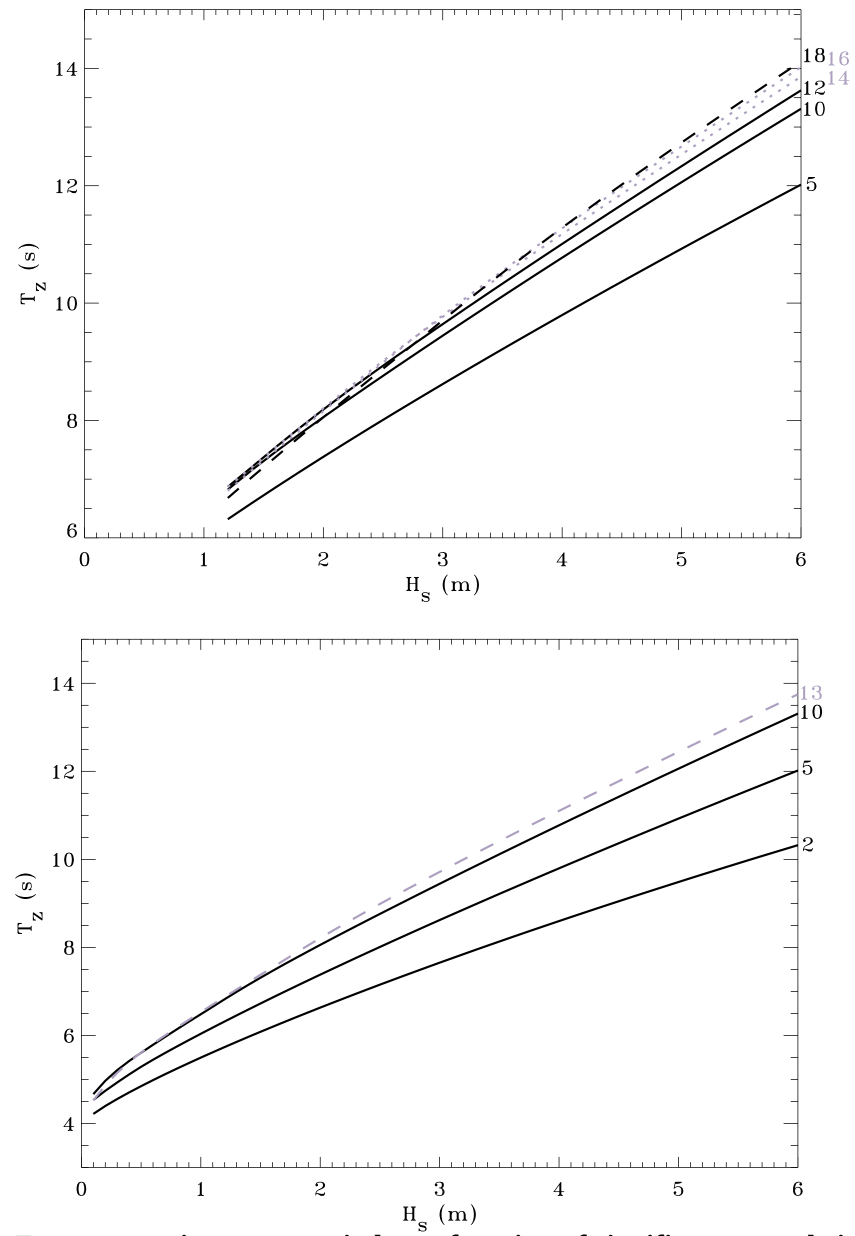


Figure 4: Altimeter Zero upcrossing wave period as a function of significant wave height for a range of wave ages. The bottom panel considers a subset of wave ages.

Finally, in figure 4, we consider how the algorithm behaves as a function of *Hs* and pseudo wave age. The bottom panel provides a magnified view over a limited range. It is apparent that once the pseudo wave age increase beyond 13, the algorithm begins to generate wave periods of decreasing magnitude for low *Hs*. As the pseudo wave age increases further, to 14, 16 and 18 (top panel) then the algorithm generates decreasing values of *Tz* over a larger range of *Hs*. We thus identify a pseudo wave age of 13 as a limit for the use of the altimeter algorithm.

Summary

The altimeter wave period algorithm consists of two separate functions, and the combined effect of these two functions is to produce a wave period that increases with significant wave height and radar backscatter ($\sigma 0$), but which is not sensitive to changes in $\sigma 0$ for Hs < 2 m. The algorithms show unphysical tendencies where low wind speeds (< 2 ms^{-1}) and moderate wave heights (> 2 m) occur together, which can be translated together into a pseudo wave age of greater than 13.
It is thus recommended that the algorithm is not used to estimate wave periods when the pseudo wave age is greater than 13, or when the wind speed is less than 2 ms^{-1}.

Validation in the North Sea

Data Processing

Significant wave height, wind speed and $\sigma 0$ data from the TOPEX altimeter were extracted for the distance of closest approach to K13 and NNS (Table 1), at least within 50 km. These data were calibrated (Hs also corrected for drift - Challenor and Cotton, 1998) and used to calculate wave periods according to the Davies et al. [1997] algorithm, which were then further adjusted according to the linear calibration suggested by Cotton [1998], see equations 2-4. These extracted data were then merged with the buoy data collected on the nearest hour (hence a maximum time separation of 30 minutes). For the purposes of extraction it was assumed that in situ measurements were made on the hour.

$$Hs_{(adjusted)} = Hs_{TOPEX} * 1.089 - 0.187 + 4.0e^{-4} * D_{drift} \quad (3)$$

$$D_{drift} = \text{No. days since 25 April 1997}$$

$$U10_{(adjusted)} = U10_{TOPEX} * 0.875 + 0.680 \quad (4)$$

Regression Analysis

An orthogonal distance regression was then carried out on the collocated wave height and wave period data, Figures 5 and 6 and Table 2.

data set	gradient	std. error	intercept	std. error	r.r.m.s
K13 Tz (s)	0.9419	0.0550	0.3504	0.2651	0.3562
NNS Tz (s)	1.2098	0.0517	-1.2966	0.3346	0.4068
K13 Hs (m)	1.0423	0.0194	-0.0922	0.0304	0.1221
NNS Hs (m)	0.9758	0.0172	0.1286	0.0566	0.2228

Table 2 - Results of orthogonal distance regression on collocated in situ and TOPEX altimeter data (r.r.m.s - residual root mean square). The 95% confidence intervals on the estimates for gradient and intercept may be calculated by adding (subtracting) two times the standard error.

Thus, at the 95% level of confidence, the gradient for the collocated NNS Tz data (1.21) is significantly greater than 1.0 and the intercept (-1.30) is significantly less than zero, whereas the K13 buoy and altimeter data are not distinguishable (at the 95% level). This indicates that the estimates of wave period from the TOPEX data at K13 need no adjustment, but that at NNS they are biased low by just over 1 second and are over sensitive to changes in period by about 21%.

These regressions also indicate that the TOPEX significant wave height measurements at NNS are biased high (but only by 0.1m - the gradient is not significantly different from 1.0). At K13 the indication is that the significant wave heights are biased low (by less than 0.1 m), whilst the gradient (1.04) is significantly larger than 1.0.

Joint Distribution Analysis

A further assessment of the altimeter wave period data can be gained through analysis of distribution functions. In figures 7 and 8 distributions of wave period against significant wave height are plotted, for *in situ* data (top panels), and calibrated altimeter estimates (bottom panels). It is clear from both figures that the *in situ* data are spread over a wider range of significant steepness than the altimeter data, also that the uncalibrated data are biased toward lower significant steepness at low wave heights. The application of the calibration correction improves the latter, but cannot address the former problem. It appears that the altimeter (or the algorithm) is not able to retrieve wave periods over as large a range as expected, particularly at low wave heights.

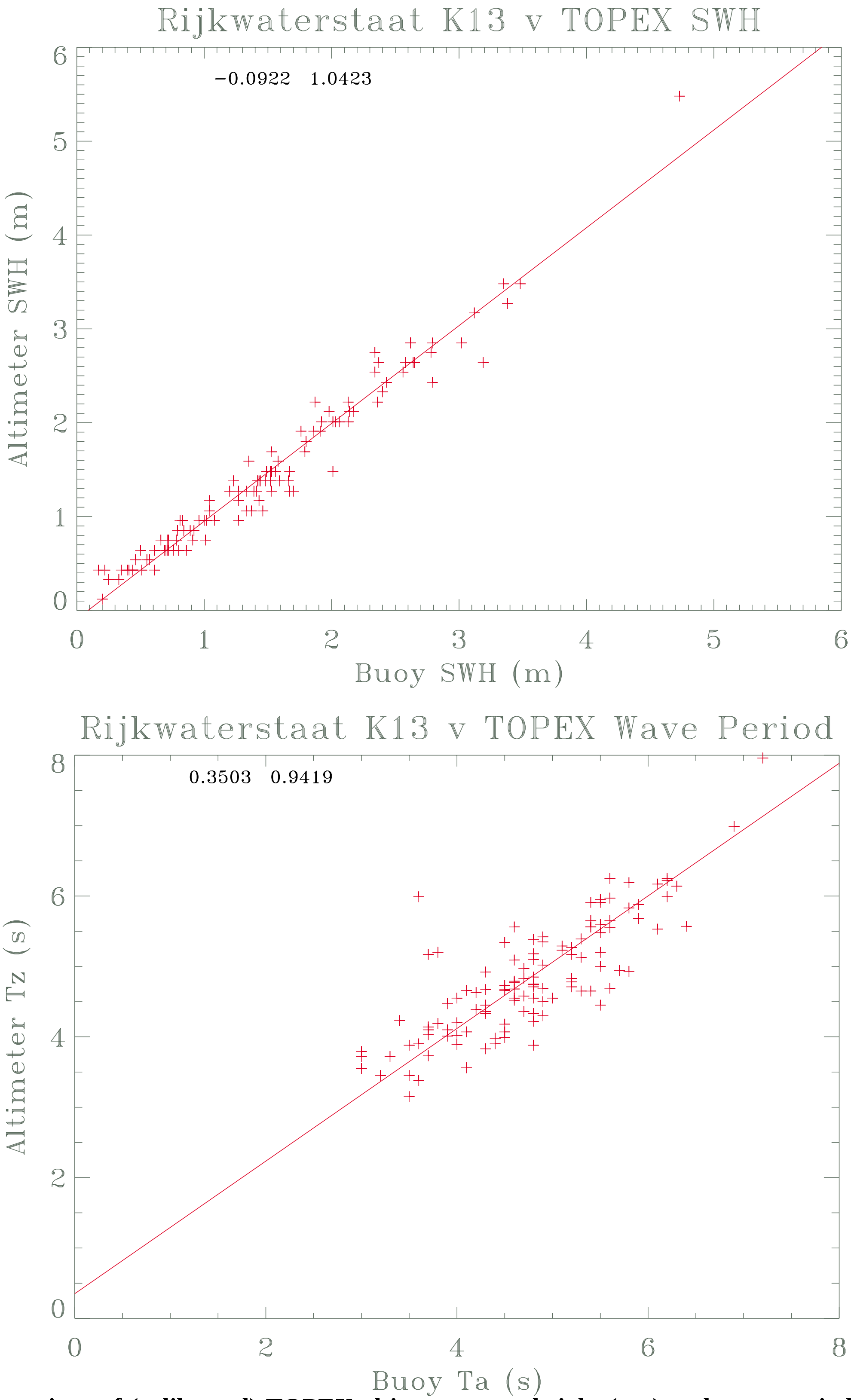
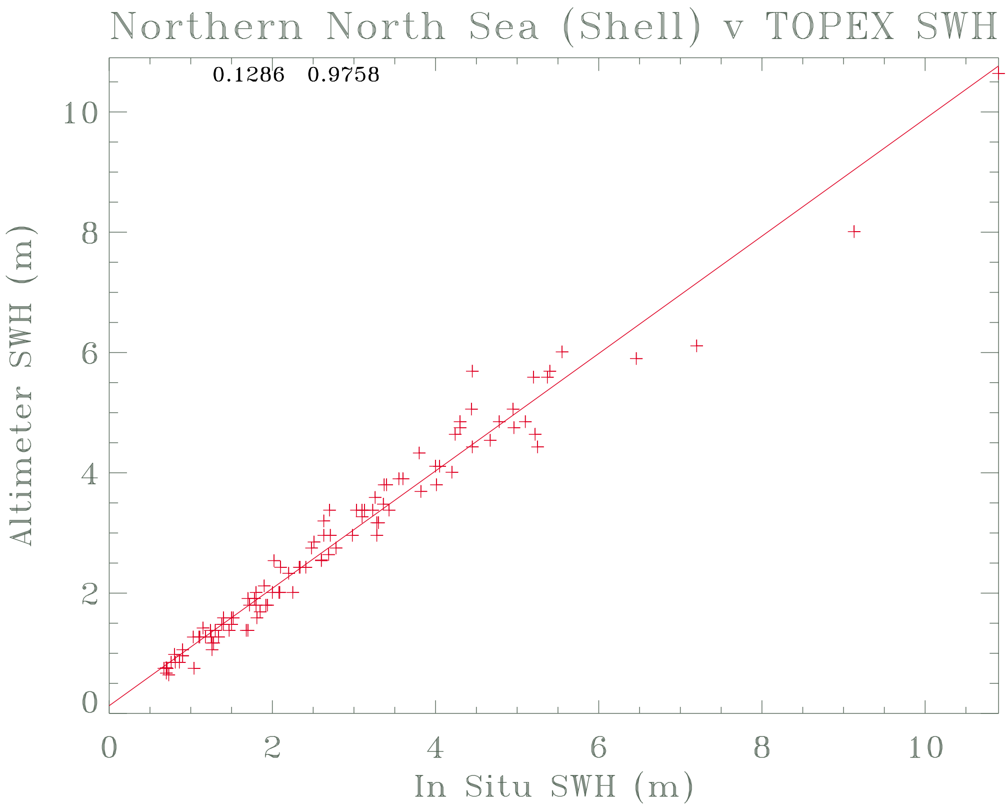


Figure 5: Comparison of (calibrated) TOPEX altimeter wave height (top) and wave period (bottom) against collocated values from buoy K13. The parameters (gradient then intercept) and line derived from an orthogonal distance regression are indicated.



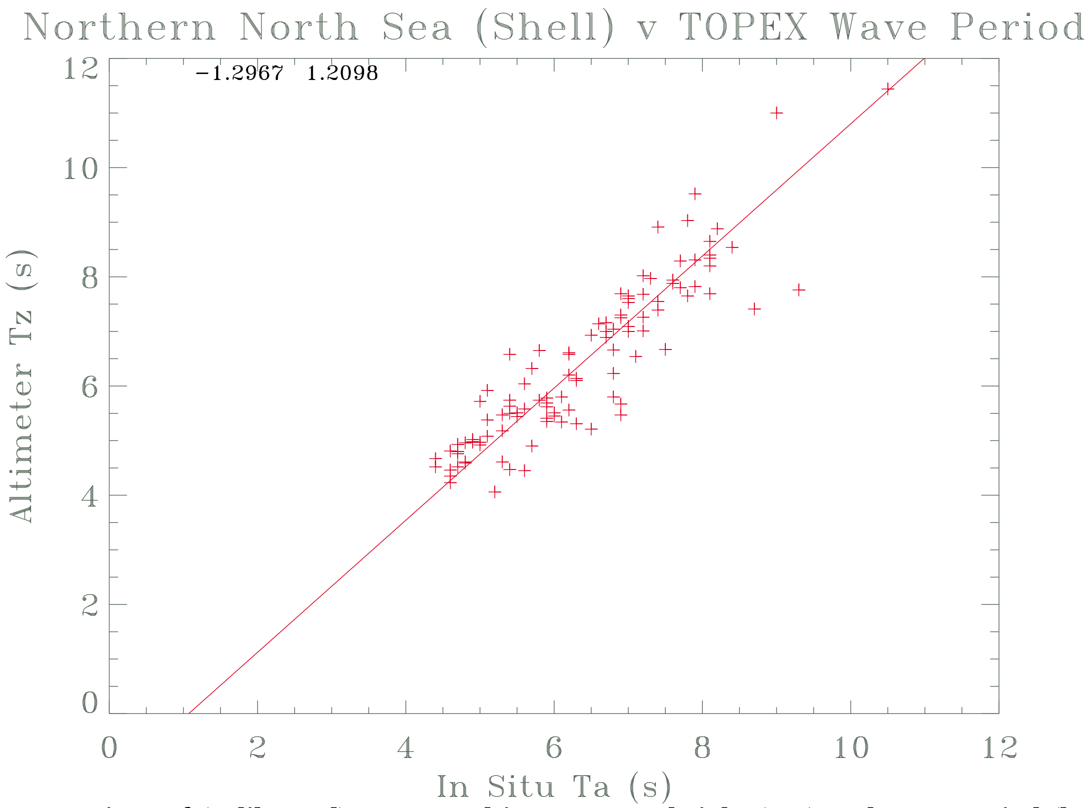


Figure 6: Comparison of (calibrated) TOPEX altimeter wave height (top) and wave period (bottom) against collocated values from the Shell/Seadata NNS data set. The parameters (gradient then intercept) and line derived from an orthogonal distance regression are indicated.

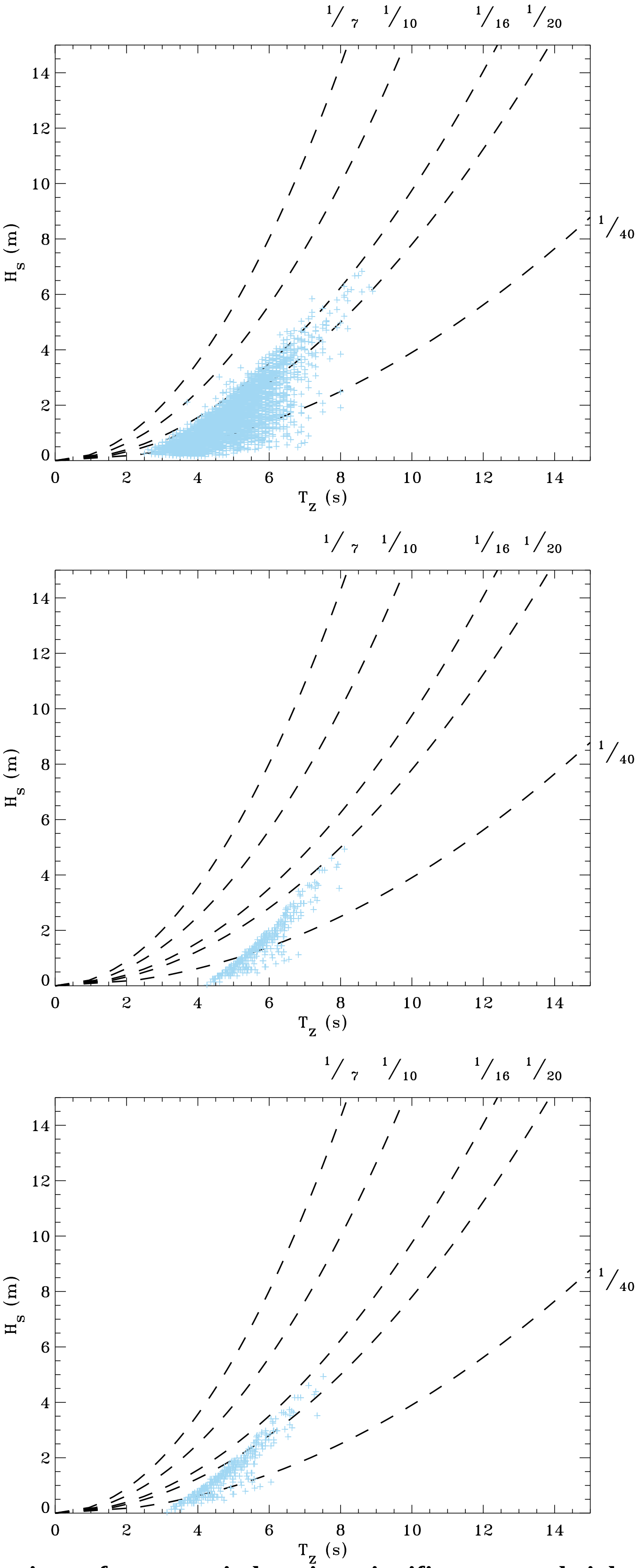


Figure 7: Recorded distributions of wave period against significant wave height at the location of buoy K13, contours of significant steepness are indicated. The top panel displays in situ measurements, the middle panel uncalibrated TOPEX altimeter estimates, and the bottom panel TOPEX estimates calibrated according to equation 2.

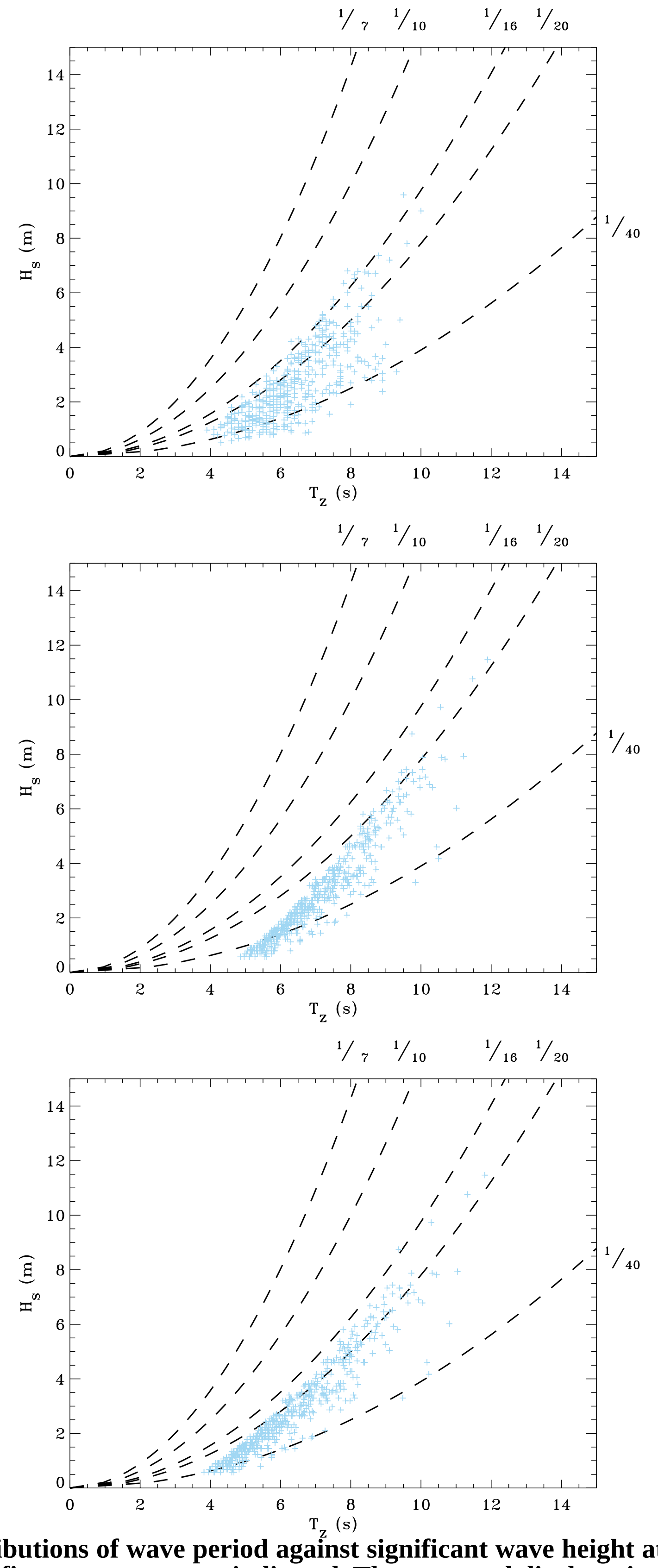


Figure 8: Recorded distributions of wave period against significant wave height at the location of the NNS data set, contours of significant steepness are indicated. The top panel displays in situ measurements, the middle panel uncalibrated TOPEX altimeter estimates, and the bottom panel TOPEX estimates calibrated according to equation 2.

Conclusions

After a comparison with *in situ* data we conclude that the TOPEX altimeter can provide estimates of wave period with an accuracy of better than 0.5 s in the North Sea. There is an indication that, in addition to those indicated in the text, further slight adjustments may be necessary for data in the northern North Sea in order to bring them into best agreement with *in situ* data.

The wave period algorithm should not be used to provide altimeter estimates of wave period in conditions where low wind speeds and moderate to high significant wave heights occur together. Useful limitations are wind speeds below 2 ms^{-1}, and pseudo wave ages above 13.

Altimeter derived periods do not appear to cover as wide a range of *Tz* for given *Hs* as do *in situ* data, This is particularly the case for low wave heights.

References

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