JERICHO Technical report 09

Preliminary

Assessment of Reliability of Altimeter Wave Period Data

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Introduction

In this report we assess the reliability of an altimeter estimate of zero upcrossing wave period data, as relevant to the purposes of the JERICHO programme. We consider three situations: the deep water and open ocean to the west of the British Isles, the more enclosed seas of the North Sea, and the shallower waters and enclosed sea of the English Channel.

Wave Periods Estimates From the Altimeter

The wave period estimate is derived from a semi empirical algorithm, developed and tested at Southampton Oceanography Centre [*Davies et al., 1998*]. The algorithm is a (non-linear) function of altimeter significant wave height and normal incidence sea surface radar backscatter ($\sigma 0$). [*Cotton, 1998*] compared altimeter wave period estimates (from Geosat, ERS-1, ERS-2, TOPEX and Poseidon) with measurements from US NDBC (the National Data Buoy Center) buoys, and generated altimeter specific calibration coefficients for this algorithm. These calibrations have been applied to all altimeter data analysed in this report..

UK Meteorological Office Open Ocean Buoy Data

ERS-1, ERS-2 and TOPEX/Poseidon wave period data were co-located (< 50km, and < 30 minutes) with data from 7 UKMO Open Ocean buoys, K1, K2, K3, K4, K5, K16 and K17. The buoy data were taken only for the periods during which the data were found to be reliable (see JERICHO Tech. Report: Cotton, July 1998). Wave period estimates derived from individual 1 Hz altimeter records were compared, using principle components regression, to the buoy data. The results are presented in Table 1 and Figure 1.

Buoy	*Lat (°N)*	*Long (°E)*	*N*	*r.r.m.s. (m)*	*Gradient*	*95% C.I.*	*Intercept*	*95% C.I.*
K1	48.7	-12.4	212	0.7434	1.2586	0.0767	-2.1223	0.5765
K2	51.0	-13.3	126	0.6307	1.0659	0.0793	-0.8614	0.6099
K3	53.6	-15.3	100	0.7837	1.2047	0.1262	-1.7753	0.9719
K4	55.5	-13.0	288	0.8325	1.2790	0.0944	-2.4408	0.7266
K5	59.3	-9.9	151	0.8575	1.3388	0.1442	-2.6832	1.0830
K16	57.0	0.0	62	0.6114	1.2295	0.1791	-1.5469	1.0669
K17	55.3	2.3	174	0.5654	1.2184	0.1166	-1.3464	0.6568
All buoys			1115	0.7904	1.1690	0.0355	-1.4496	0.2579

Table 1. Results of Principal Components Regression Between Altimeter and Buoy Wave Period for UKMO buoy data.

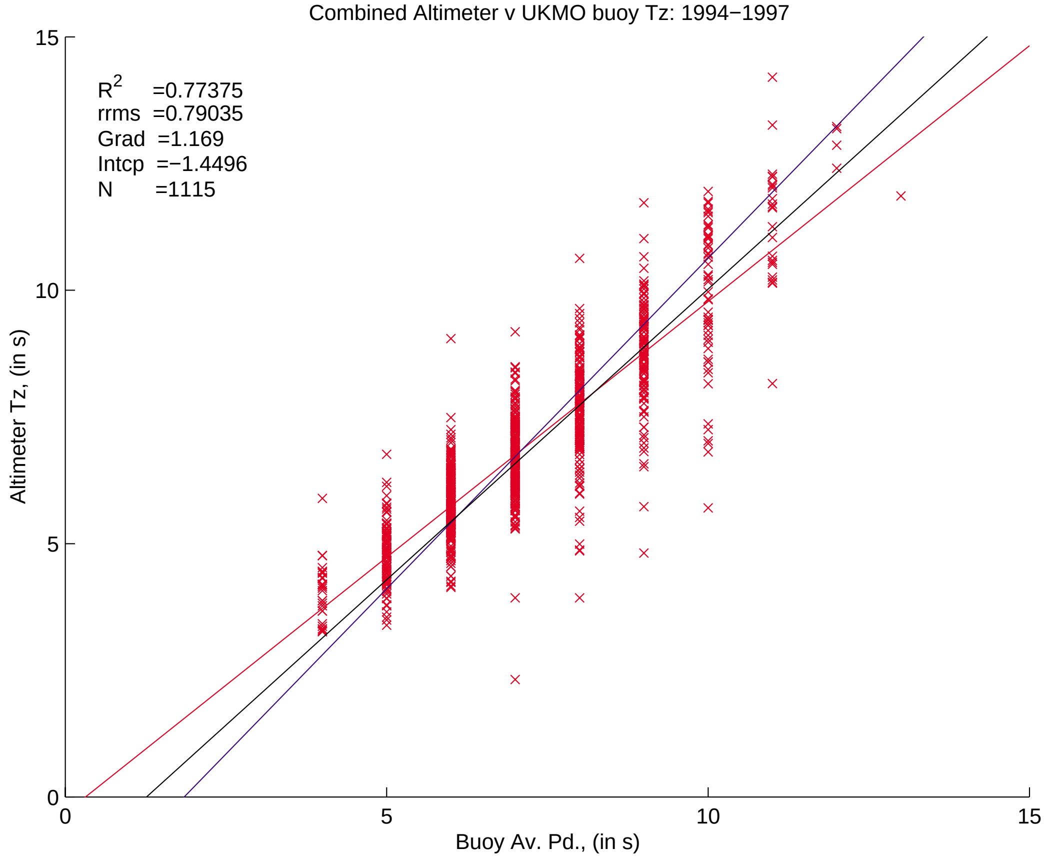

Figure 1. Scatter plot of co-located altimeter and buoy wave period data. The two linear regression lines, plus the principal component, are indicated.

Table 1 indicates that the co-located wave period data from buoys K16 and K17 (located in the North Sea) exhibit least scatter (r.r.m.s. <= 0.6 s), whilst data at K4 and K5 (the Northernmost buoys to the west of the British Isles) show the most scatter (r.r.m.s. > 0.8 s). The gradient of the principal component line is greater than 1.0 for data from each of the buoys, and significantly so in all but one case (K2). The intercepts of regressions from all 7 buoys are all (significantly) negative.

The gradient estimated for K2 data is significantly less than that for K1 and K5 data. The intercept for K2 data is also significantly different (closer to zero) from that for K1, K4 and K5. The K2 buoy is located out in the open North-Eastern Atlantic Ocean, in the South Western approaches to the English Channel and so should not experience any particularly unusual set of wave conditions. It seem unlikely therefore that this anomalous set of wave period regression parameters is due to environmental effects, but is more probably due to the presence of outliers in the data, or to instrumental (buoy) problems

When the combined altimeter/buoy wave period data were analysed, a gradient of 1.1690 (standard error of 0.0355) and intercept of -1.4496 (standard error of 0.2579) were calculated. This again indicates that the UKMO co-located wave period data are significantly from those from the combined NDBC co-located data. However, from *Cotton [1998]* the regional analysis of co-located altimeter and NDBC wave period data again showed a range of regression parameters (in gradient 0.75 to 1.21, in intercept -1.30 to 1.65) which spanned the values from the UKMO buoys.

The r.r.m.s. variances from the NDBC wave period data ranged between 0.53 to 0.76 s, with an overall average value of 0.6848 s, indicating a slightly higher accuracy than the UKMO data (r.r.m.s = 0.7904 s). A test on the effect of reduced precision on the NDBC data (1 s in the UKMO data, limiting the number of measurable values to 10 in the range 4-13 seconds), gave a reduction in accuracy of the NDBC comparisons to 0.7373 s. This suggests that the altimeter/ UKMO buoy wave period comparisons could provide accuracies close to those from the US NDBC measurements, if higher precision data were available.

North Sea Measurements

See JTR-19

English Channel Measurements

See JTR-19

Testing for Environmental Dependencies of Wave Period

The environmental dependencies of wave period errors were investigated in [*Cotton 1998*], by looking for dependency of normalised altimeter error (altimeter estimate minus buoy measurement, divided by buoy measurement) upon various environmental measurements available from the US NDBC buoys, see figure 2. No evidence was found of any significant dependence on temperature of boundary layer stability (air temperature minus sea temperature). However some dependence was seen on buoy wave age (increasingly positive error as wave age reduces below 2).. An opposite dependent tendency of wave period on wave height and wind speed was found, with an increasingly negative error with reducing wind speed/ wave height). These observations suggest that the wave period algorithm still does not fully account for wave age dependence.

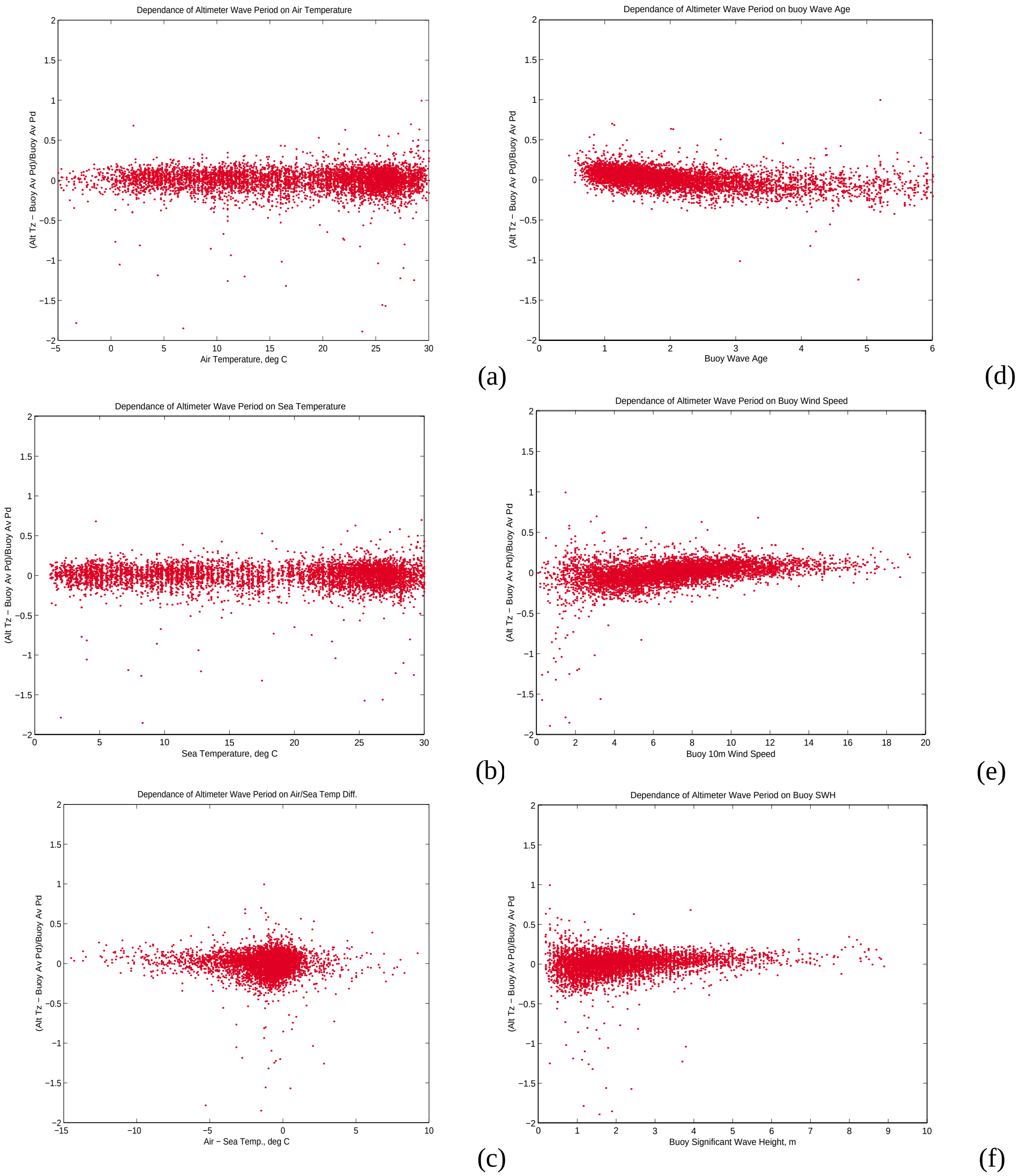

Figure 2. Dependence of error in altimeter Tz on: buoy measurements of Ta (2a), Ts (2b), dTas (2c), bwa (2d), U10 (2e), and Hs (2f).

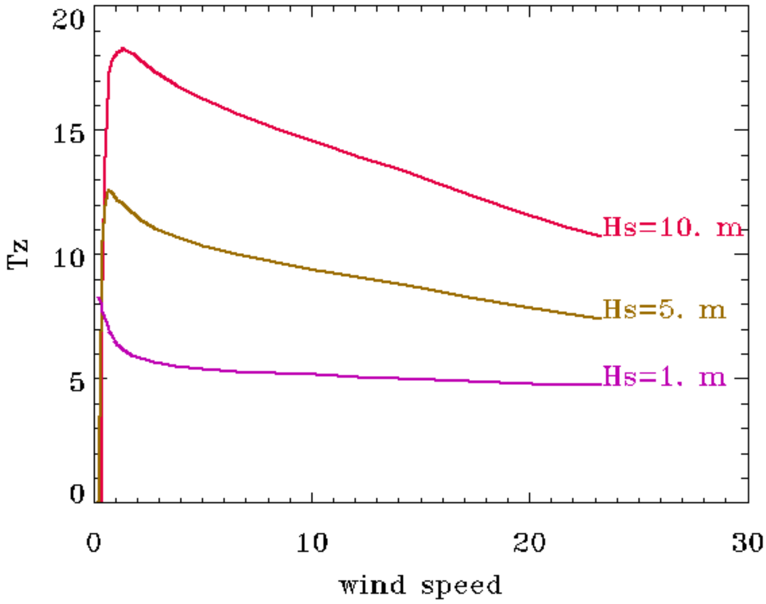

Figure 3. Dependence altimeter Tz on altimeter wind speed and significant wave height (Hs)

Algorithm Characteristics

The sensitivity of the altimeter wave period algorithm to changes in altimeter significant wave height and wind speed are illustrated in figure 3. Remember that the algorithm is a function of significant wave height and radar backscatter, we have converted the later to equivalent wind speed for ease of interpretation. It is apparent from figure 3 (and also figure 1), that the algorithm is not capable of retrieving wave periods less than about 4 seconds. Whilst this represents a significant failure of the algorithm for short wavelength seas, it is an inevitable consequence of relying on an *in situ* data set (ships/buoys) which itself does not resolve higher frequency waves. It is not yet clear whether the algorithm, when fitted to suitable *in situ* data which is capable of recording higher frequencies, can retrieve shorter periods or whether this cut-off is a fundamental characteristic of the algorithm and high frequency limitations of the altimeter itself.

Another clear feature of figure 3 is the lack of sensitivity of derived wave period to changes in altimeter wind speed (and hence radar backscatter) at low wave heights.

One can also investigate the characteristics of the altimeter wave period by considering how they perform in terms of derived parameters. Significant steepness is a wave parameter important for a number of considerations, and can be easily calculated from the significant wave height and wave period through the deep water dispersion relation (equation 1)

$$\text{Significant Steepness} = 2\pi / g\, Tz^2 \qquad (1)$$

In Figures 4 and 5, altimeter measured significant wave heights and wave periods are plotted against each other, and lines of constant significant steepness are drawn. The two figures represent the situation in the open ocean waves and enclosed seas respectively, and illustrate a number of characteristics of the altimeter wave period. Firstly, one would expect the “cloud” of data to lie roughly parallel to lines of constant significant steepness, with the bulk of the data between 1/40 and 1/20. Whilst this is the case for longer, higher waves, it seems that the wave period does not decrease in proportion to significant wave height below about 7 seconds. This is another manifestation of the altimeter wave period cut off at 4-5 seconds. In Figure 4, representing data in the open ocean, one might also expect to see some data representing low wave height, but long period, swell. These data points would have low significant steepness and would lie to the right of the 1/40 line. The altimeter measurements do not appear to have identified any such occurrences.

In figure 5, contours from Light Vessel data are also indicated. These seem to confirm the above observation than the altimeter algorithm calculates wave periods that are too long for lower wave heights. There is also a suggestion that the spread of altimeter data on the Hs/Tz plot is too narrow.

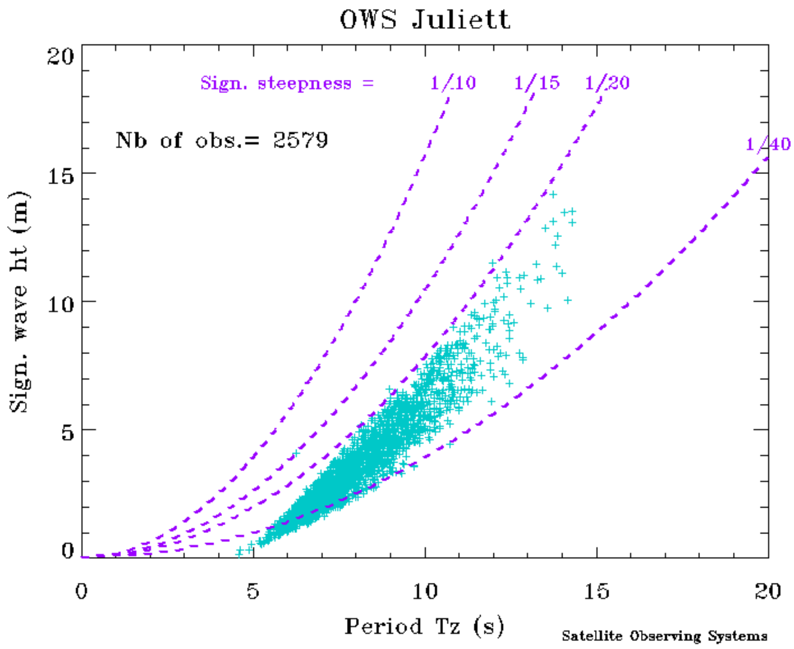

Figure 4. Altimeter measured significant wave height against wave period, and lines of constant significant steepness. Altimeter measurements within 100km of Ocean Weather Station Juliett

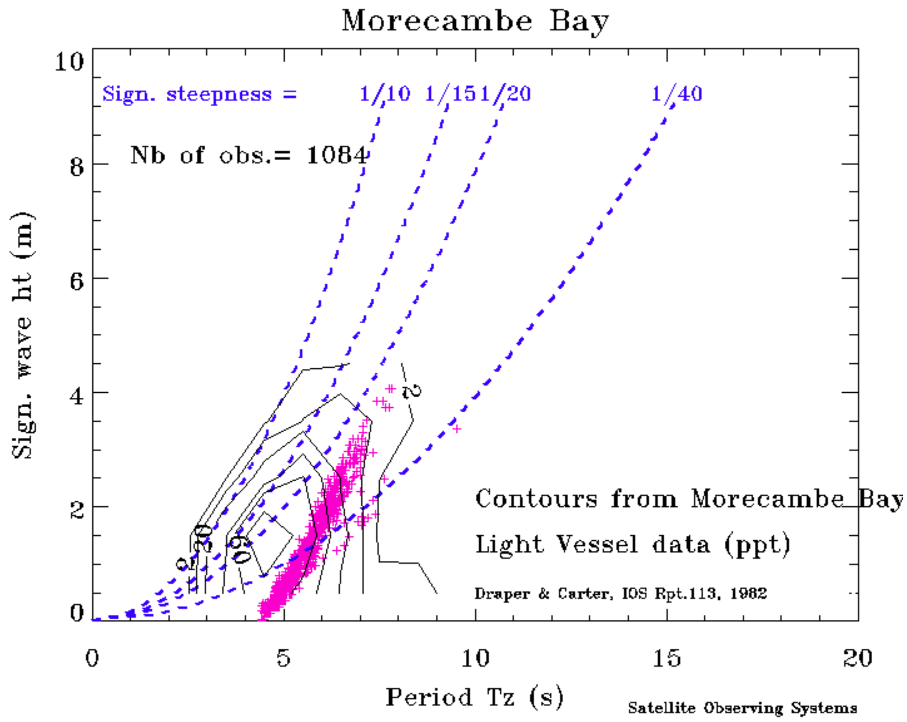

Figure 5. Altimeter measured significant wave height against wave period, and lines of constant significant steepness. Altimeter measurements within 100km of Morecambe Bay Light Vessel. Density contours from light vessel data are also shown.

Conclusions

The regressions of altimeter wave period against open ocean measurements indicate that the altimeter data are accurate to better than 1 second rrms. This provides a wave period estimate which has practical value, and would provide the first ever global scale measurements of this parameter. This accuracy also compares with that of other *in situ* data sources. However, a more detailed analysis of the characteristics of the altimeter algorithm suggests that it may have limitations at short periods, and in less developed seas. This may be a consequence of the nature of the *in situ* data sets which have been used to tune the altimeter algorithm, or a more significant restriction of the ability of the altimeter to resolve shorter waves.

References:

P.D. Cotton, 1998,'A Feasibility Study for a global satellite buoy intercalibration experiment', SOC research and consultancy report no. 26.

Davies, C.G., P.G. Challenor, and P. D. Cotton, 1997, Measurements of wave period from radar altimeters, in 'Ocean wave measurement and analysis', proceedings of the third international symposium, WAVES '97, Eds, B.L. Edge and J. M. Hemsley, ASCE, Virginia, USA.