A Two-Parameter Wind Speed Algorithm for Ku-Band Altimeters

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ABSTRACT

Globally distributed crossovers of altimeter and scatterometer observations clearly demonstrate that ocean altimeter backscatter correlates with both the near-surface wind speed and the sea state. Satellite data from TOPEX/Poseidon and NSCAT are used to develop an empirical altimeter wind speed model that attenuates the sea-state signature and improves upon the present operational altimeter wind model. The inversion is defined using a multilayer perceptron neural network with altimeter-derived backscatter and significant wave height as inputs. Comparisons between this new model and past single input routines indicates that the rms wind error is reduced by 10%–15% in tandem with the lowering of wind error residuals dependent on the sea state. Both model intercomparison and validation of the new routine are detailed, including the use of large independent data compilations that include the SeaWinds and ERS scatterometers, ECMWF wind fields, and buoy measurements. The model provides consistent improvement against these varied sources with a wind-independent bias below 0.3 m s^{-1}. The continuous form of the defined function, along with the global data used in its derivation, suggest an algorithm suitable for operational application to Ku-band altimeters. Further model improvement through wave height inclusion is limited due to an inherent multivaluedness between any single realization of the altimeter measurement pair [σ^o, H_S] and observed near-surface winds. This ambiguity indicates that H_S is a limited proxy for variable gravity wave properties that impact upon altimeter backscatter.

1. Introduction

Empirical models have been devised to improve satellite altimeter ocean wind speed retrieval using many differing numerical approaches and datasets (Brown et al. 1981; Dobson et al. 1987; Chelton and McCabe 1985; Witter and Chelton 1991; Glazman and Greysukh 1993; Young 1993; Lefèvre et al. 1994; Freilich and Challenor 1994). The global altimeter ocean wind product is mostly limited to validation and climatological usage (e.g., Young 1999) because the altimeter's nadir-pointing geometry only permits estimates of surface wind speed along a narrow (≃2 km) swath and precludes wind direction detection. However, accurate wind speed estimates are also important because they are used in the point-by-point correction of an altimeter's estimate of mean sea surface height via the electromagnetic bias algorithm. Freilich and Challenor (1994) and Glazman and Greysukh (1993) expand on these points and suggest that objective model improvement metrics should include the minimization of wind speed biases and root-mean-square error, removal of nonwind geophysical impacts such as sea state, and functional continuity (finite first derivative) such that the wind speed histogram is not distorted.

The operational altimeter wind speed product for TOPEX is derived from interpolation over the look up table known as the modified Chelton–Wentz algorithm (MCW) of Witter and Chelton (1991). This model directly maps measured Ku-band altimeter backscatter (σ^o) to the wind speed 10 m above the ocean (U_{10}). The overall bias, $\langle U_{err}\rangle$, for this algorithm is suggested to be 0.48 m s^{-1} ($U_{err} = U_{altim} - U_{insitu}$) and the root-mean-square (rms) error lies between 1.5 and 2.0 m s^{-1} (e.g., Witter and Chelton 1991; Gower 1996; Freilich and Challenor 1994; Wu 1999). Numerous studies have suggested that the form for this single parameter algorithm could be improved upon (e.g., Freilich and Challenor 1994). However, the limited amount of validation data combined with the generally small level of improvement in algorithm performance leaves MCW as the current choice for new altimeters such as the GEOSAT Follow-On (GFO) and *Jason-1*.

A goal that remains of interest for altimeter wind retrieval is the detection and correction of wind speed errors associated with longer ocean waves that are not necessarily closely coupled to the local wind field. Evidence for a sea-state effect on altimeter-derived wind has been addressed in several studies (Monaldo and

Dobson 1989; Glazman and Pilorz 1990; Glazman and Greysukh 1993; Lefèvre et al. 1994; Freilich and Challenor 1994; Hwang et al. 1998). Reported results range from substantial impacts to no impact (cf. Wu 1999). The central and unique factor here is an altimeter's coincident and accurate measure of significant wave height, H_S.

Motivation for the present study follows from compilation of a large number of TOPEX altimeter observations made coincident with National Aeronautics and Space Administration (NASA) scatterometer (NSCAT) surface wind estimates. The global coverage, fidelity, and volume of this dataset leads to a much clearer picture of H_S variation impacts upon altimeter backscatter and wind inversion over a range of wind speeds from 1 to 20 m s^{-1}. We develop two models, a forward and an inverse solution, using neural network methods to map between altimeter and scatterometer observations and incorporating a globally derived correction for sea-state impacts using the altimeter-derived H_S estimate. Numerous independent datasets containing collocation between altimeter and ancillary wind estimates are then used to evaluate a best-choice routine and its applicability for operational usage. This paper is derived from an earlier report by Gourrion et al. (2000). That effort includes wind speed models for the C-band altimeter aboard TOPEX, but the present effort concentrates solely on Ku-band model definition.

7. Summary

This study defines and validates a two-input altimeter wind speed algorithm applicable for operational use, where a Ku-band altimeter's coincident σ^o and H_S estimates are utilized in the point-to-point inversion. An analytical formulation (termed f_1) is prescribed with nine coefficients as detailed in section 4. Motivation comes from the new capability to assemble large, globally distributed and high fidelity model training sets composed of coincident satellite altimeter and scatterometer crossovers. The dataset chosen for model training and subsequent validation is a 96 000 sample compilation of TOPEX and NSCAT crossings. Limiting NSCAT usage to only higher incidence angle retrievals strengthens our assumption that the scatterometer wind product is itself free of sea-state impacts. Subsequent validations using buoy and ECMWF winds provide further support.

The empirical development is focused to define an improved and robust wind inversion that incorporates H_S into the solution. This routine should be applicable for all Ku-band altimeters such as those aboard the ERS, ENVISAT, GFO, and *Jason-1* platforms. f_1 intercomparison to past altimeter models and numerous independent validations demonstrates modest, but measurable, success in improving upon the current operational MCW model. These independent data sources include an extensive buoy compilation, the ERS scatterometer, the SeaWinds scatterometer, and the ECMWF model. The f_1 inversion ($[\sigma^o, H_S] \rightarrow [U_{10N}]$) delivers an overall rms improvement of 10–15%, 0.1 to 0.2 m s^{-1} in absolute terms. The domain for model application covers all values of H_S and wind speeds ranging from 1 to 20 m s^{-1}. Error statistics were evaluated over the range of 1–17 m s^{-1}. Wind speed bias is below 0.3 m s^{-1} throughout this range. Improvement in rms error is significant up to winds of about 12 m s^{-1} and equivalent to MCW above this point. The weighting of H_S within the model becomes negligible at these high wind levels. While wind speeds above 20 m s^{-1} are infrequent, a slight modification of f_1 that aligns the altimeter inversion with that predicted by the *QSCAT-1* model function is proposed in appendix B. Statistically, the GG2 algorithm provides similar improvement, but we recall that this classification scheme leads to point-to-point estimate discontinuities and a bi-modal wind speed distribution. TOPEX wind speed histograms, derived using f_1, provide marked improvement over the MCW result in comparison to either buoy, model or scatterometer results. This affirms the continuous nature of the network solution and its applicability for operational use. The TOPEX-generated model is also shown to work well when applied to *ERS-2* altimeter data. The model is adjusted for differing altimeters using a constant σ^o bias and is also relatively insensitive to H_S estimate errors.

Physically, one expects that H_S is a limited proxy for actual gravity wave slope variations that affect the nominal relation between the observed radar cross section and wind speed. Observations and model functions depict measurable correlations amongst the three variables $[\sigma^o, H_S, U_{\mathrm{NSCAT}}]$ but they also exhibit a multivaluedness that inhibits further wind estimate improvement in the absence of additional surface roughness information. This ambiguity leads to an increased altimeter wind speed noise if one attempts to use the forward (f_2) model for U_{10} inversion. This effect occurs even though f_2 is the most effective at removing residual error associated with H_S. Another repercussion is the inability of the f_1 model to correct altimeter wind underestimation during fetch-limited events. These events are rare within the global data set and the neural network minimization solution gives little weight (by design) to this mapping within the domain of possible outcomes.

These points emphasize that present empirical and global-mean model functions do not fully capture the scattering physics. Their application to specific case study will not dramatically improve upon results derived using the MCW model. It is clear, however, that the f_1 algorithm is a measurable improvement that can directly replace the single parameter routine. As importantly, the documented correlation between σ^o and H_S at any chosen wind speed needs to be considered within the empirical modeling of the altimeter sea state bias correction (cf. Chapron et al. 2001). Future work combining the altimeter's unique coincident measure of H_S with multifrequency σ^o (e.g., at S-, C-, Ka- and/or Ku-band) signatures is certain to bring further refinement to these geophysical inversions on both global and local scales.