WindSat SDR and EDR On Orbit Calibration and Validation

Sandra Lindström[1] and Christopher Ruf[2]

1. Luleå University of Technology, Kiruna, Sweden
sandra_lindstrom@hotmail.com (E)
2. University of Michigan, Ann Arbor, MI 48109 USA
734-764-6561 (V), 734-764-5137 (F), cruf@umich.edu (E)

Abstract - **The Coriolus spacecraft was successfully launched on 6 January 2003. Its primary payload is the WindSat fully polarimetric radiometer. WindSat is a first-of-its-kind instrument that will remotely sense the speed and direction of near surface winds over the ocean by measuring the partial correlation between orthogonally polarized components of natural thermal emission radiated by the ocean surface at microwave frequencies. The ability of WindSat to successfully retrieve wind vector depends critically on two issues, hardware calibration of the four Stokes brightness temperatures and the relationship between those TBs and the ocean surface wind vector. An approach is described to detecting and estimating possible errors in both the hardware calibration and forward model based on a new type of statistical analysis of the on-orbit radiometer measurements.**

I. Introduction

WindSat calibration is attempted by a method which essentially relies on stationary statistical properties of the prevailing trade winds over the ocean to provide a reliable baseline against which to compare critical parameters of the radiometer performance. This approach is similar to one developed earlier for NSCATT cal/val by Ebuchi [1999]. It has been tested using a numerical simulation based on a large ensemble of NDBC buoy data. The ensemble permits globally distributed radiometer measurements to be simulated with realistic statistical distributions. Hardware calibration and forward model inaccuracies can be introduced into the simulation under controlled conditions. Histograms of the 3rd and 4th Stokes brightness temperatures are derived both with and without a proper accounting being made of the errors. The differences between the correctly and incorrectly accounted histograms are found to be sensitive to, and to be able to differentiate between, potential calibration problems. There are two major results produced by this method. A quantitative characterization of the behavior of WindSat calibration and wind vector retrieval errors is produced with respect to the nominal statistical distributions of data products that would be produced by an ideal (or, equivalently, an ideally calibrated) instrument. This characterization is then inverted to provide quantitative estimates of errors in specific coefficients used by the hardware calibration algorithm and ocean surface emission forward model.

II. Simulation of WindSat Calibration Method

A 10 year archive of NDBC buoy data covering 1991-2000 was assembled and characterized with regard to the stationarity of a number of its wind direction statistics. In this way, several sites were identified that had extremely repeatable statistics which are particularly well suited to this study. In particular, histograms were compiled for every buoy partitioned by month and year. That is, for one buoy there are twelve histograms showing January, February and so on with each showing the wind direction frequency (for more information see Lindström [2002]). In order to find out if the statistics are stationary the histograms between years but for the same month are compared. One way to do that is to look at the mean of the wind direction for every year for one month and then take the standard deviation of those mean values. This gives a measure of how stable the mean is through ten years of data for that particular month. Another way to compare the histograms is to look at the maximum value of the histograms for every year during one month and then take the standard deviation of those maximum values. This will indicate how stable the wind direction is from 1991 until 2000 for one month. Another approach is to look at the standard deviation of the standard deviations and that will indicate how stable the changes in the wind direction are during ten years for the same month. As a result of this analysis, buoys with particularly stationary statistics have been located nearby the Hawaiian Islands (NDBC buoys 51001 and 51002).

III. Monte Carlo Data Simulation

A large ensemble of simulated WindSat data was generated with wind vector statistics consistent with the NDBC data base. Fully polarimetric brightness temperature vectors were generated using an ocean model based on the work of Stogryn [1997] and Yueh et al. [1997, 1999]. These "true" TBs were propagated through a pre-launch WindSat instrument model based on Gaiser [1998]. The instrument model includes known non-ideal characteristics such as polarization mixing as well as additive NEΔT noise. The true TBs were then estimated from the measurements by inverting the instrument model. Perturbations were then added to the forward instrument model, representing unknown differences between the actual instrument behavior and its pre-launch model, while the inversion process remained based on the pre-launch model. This corresponds to the case where one model is assumed by the WindSat calibration algorithm while a slightly different one is in fact the case. A comparison was then made of the histograms of TB after instrument calibration both with and without the perturbations added to the forward model. Difference between these two histograms that are significantly different than natural variability in the histograms would, in principle, be identifiable as calibration errors.

In our Monte Carlo simulation, 50,000 values of fully polarimetric brightness temperature were generated both wioth and without unknown behavior and their histograms were compared. One example of the difference in their histograms (in units of percent occurrence) is shown in figures 1 and 2 for the case of 18.7 GHz, 3rd and 4th Stokes parameter. To be able to separate different errors, in each individual plot there is only one error applied to the model. In the plots, the solid line is the difference between modeled and estimated histograms and the two dashed lines represent +/- one standard deviation of the climatological variability of each statistic over the ten year buoy data base. In other words, perturbations in the solid line that significantly exceed the dashed lines are statistically significant and represent detectable errors in either the wind model function or the sensor calibration.

IV. Interpretation of Numerical Results

Figure 1 shows perturbation histograms for T_3 at 18.7 GHz for the case of 0 deg radiometer look angle and 45 deg cross polarization angle. Beginning with the bottom row in the figure, the perturbations due to a 3% change in NEΔT are much smaller than the climatological variability. This indicates that perturbations in the histogram due to variations in hardware noise level are not significant. A 1 deg error in the assumed cross polarization angle (second row of plots from bottom) can be seen to introduce a much more significant perturbation in the histogram. Other simulations (not shown here) indicate that this effect grows monotonically with increasing phase error. A 0.2 dB error in the assumed level of cross polarization isolation (third row of plots from bottom) also introduces a significant, detectable perturbation. This effect also grows with increasing error. Note that a positive error in the level of cross polarization has a roughly comparable effect as that of a negative error in the phase of the cross polarization, and vice versa. 10% errors in either the T31 or T32 wind model coefficients (the top two rows of plots) do not appreciably perturb the histograms. This indicates that hardware calibration errors should be readily distinguishable from errors in the wind model.

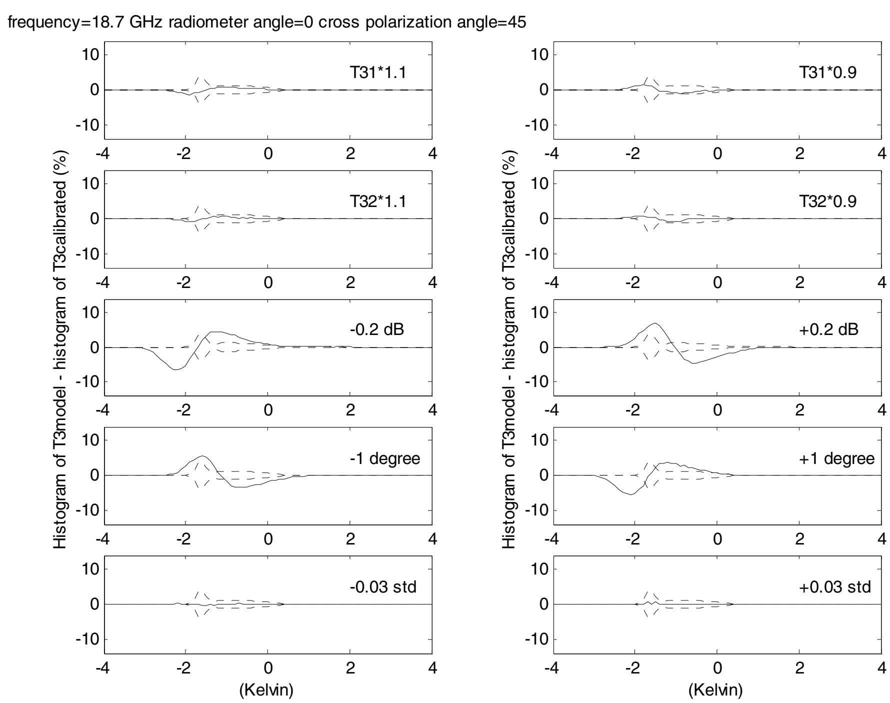

Figure 1. The difference between the statistics of the 3rd Stokes parameter for ten different errors introduced into the model (solid line). Dashed lines represent +/- one standard deviation of the climatology.

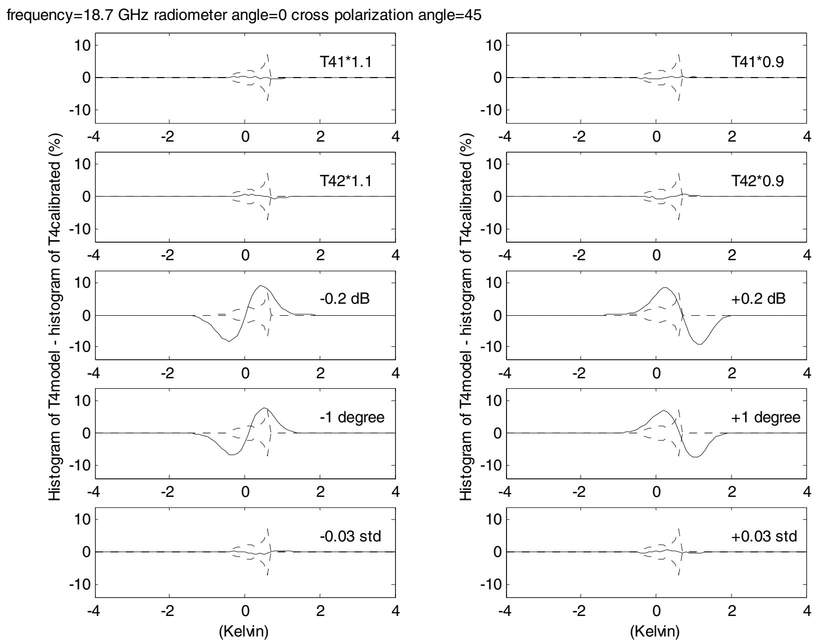

Figure 2. Similar to Figure 1 but for the 4th Stokes parameter.

Figure 2 shows similar histograms for T_4 at 18.7 GHz. It is very noteworthy that, in the T_4 case, positive errors in the level of cross polarization are roughly in shape to positive errors in the phase of cross polarization. This is the exact opposite of the case for T_3 and suggests that there is great promise of being able to separate apart, characterize, quantify, and, ultimately, correct for these two sources of error in practice.

V. FUTURE PLANS

We intend to apply this WindSat histogram analysis method to actual flight data in a variety of different ways.

1) Filter WindSat measurements with respect to region and time of year as per the NDBC statistical records and climatology. Compare WindSat histograms to NDBC predicted climatology. This approach is limited in its sensitivity to detection and characterization of calibration problems by the inherent stationarity of the climatological statistics

2) Filter WindSat measurements in time and space corresponding to the assembly of concurrent NDBC buoy data. Derive wind vector and TB histograms from buoy data, together with atmospheric ephemeris. Compare WindSat histograms to these co-located ones. This approach will better track the wind's statistical variability by using concurrent buoy data.

3) Assemble daily or subdaily (to isolate diurnal wind patterns) WindSat histograms over selected regions of statistically stable winds (as in approach 1). Derive wind vector and TB histograms from Numerical Weather Prediction fields for the same times as the s/c overpasses. This approach may hold the most promise of resolving small calibration errors. Large regions can be used with many WindSat/NWP "hits" that will produce large ensembles from which to derive the histograms.

4) Filter the results of the WindSat sensor characterization with respect to a number of instrument parameters that could impact the calibration accuracy and stability. These parameters include orbit parameters such as the beta angle of the orbit plane and the relative attitude of the sun and spacecraft, the azimuth scan angle of the WindSat antenna mainbeam, overall spacecraft attitude, and instrument temperature. This phase will need to wait until a significant sampling of different sensor conditions has been amassed.

REFERENCES

N. Ebuchi. (1999). Relationship between directional distribution of scatterometer-derived winds and errors in geophysical model functions. J. Adv. Mar. Sci. Technolo. Soc., 5(1,2), 19-30.

P. Gaiser. (Program Manager). (1998). WindSat Critical Design Review, Remote Sensing Division, Naval Research Laboratory, Washington, DC.

S. Lindström. (2002). Development and testing of a numerical method designed for evaluating the performance of a polarimetric microwave radiometer. M.S. Thesis (*while on leave at Univ. of Michigan*), Dept. of Space Engin., Luleå University of Technology, Kiruna, Sweden, 68 pp.

A. Stogryn. (1997). Equations for the permittivity of sea water. Prepared for Naval Research Laboratory, Code 7223, under Purchase Order No. 570122.

S.H. Yueh, W.J. Wilson, S.J. Dinardo, F.K. Li. (1999). Polarimetric microwave brightness signatures of ocean wind directions. IEEE transactions on geosciences and remote sensing, 37(2), 949-959.

S.H Yueh. (1997). Modeling of wind direction signals in polarimetric sea surface brightness temperatures. IEEE transactions on geosciences and remote sensing, 35(6), 1400-1418.