AN UPDATED GEOPHYSICAL MODEL FOR WINDSAT OBSERVATIONS

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ABSTRACT

An accurate geophysical model is required to support calibration of a microwave imaging radiometer and retrieval of geophysical parameters. WindSat is a passive microwave imaging radiometer aboard the Coriolis satellite which was launched in January 2003. WindSat observations include dual-polarized antenna temperatures in two frequency bands (6.8 GHz and 23.8 GHz) and fully polarimetric antenna temperatures in three frequency bands (10.7 GHz, 18.7 GHz and 37.0 GHz). We have updated the Naval Research Laboratory (NRL) geophysical model for WindSat using an improved atmospheric model and by accounting for the frequency passband characteristics of the individual receivers. We have developed a parameterized version of the model which is used for both WindSat calibration and retrievals.

Index Terms— radiative transfer, microwave, polarimetric, WindSat, radiometer, geophysical, model

1. INTRODUCTION

WindSat ocean vector wind retrievals are retrieved in near-real-time using the Naval Research Laboratory (NRL) retrieval algorithm and operationally assimilated into numerical weather prediction global models. The retrieval algorithm utilizes a parameterized geophysical model for the modified Stokes components at the frequencies of the measured WindSat brightness temperatures. The algorithm simultaneously retrieves the ocean surface vector wind, sea surface temperature (SST), precipitable water vapor (PWV) and columnar cloud liquid water (CLW). The model must be accurate to on the order of 0.1 K to support wind vector retrievals due to the small magnitude of the the wind direction signal. An accurate geophysical model is also required to support instrument calibration.

We previously reported on the initial version of the NRL geophysical model and retrieval algorithm [1]. We have updated that initial model by including the wind direction dependence of the sea surface emissivity for the vertical and horizontal polarizations and basing the model on a different one dimensional atmopsheric radiative transfer model. We have also modeled all of the WindSat channels instead of only the modeling the modified Stokes parameters. The updated model also accounts for differences in the frequency passbands of the individual WindSat receivers [2, 3].

Table 1. WindSat Instrument Parameters

Freq. (GHz)	Polarizations	BW (MHz)	EIA (deg)	IFOV (km)
6.8	V, H	125	54.0	39 x 71
10.7	V, H, P, M, L, R	300	50.3	25 x 38
18.7	V, H, P, M, L, R	750	55.9	16 x 27
23.8	V, H	500	53.5	20 x 30
37.0	V, H, P, M, L, R	2000	53.5	8 x 13

2. WINDSAT DATA DESCRIPTION

WindSat is a 22-channel conical-scanning radiometer which measures the vertical and horizontal polarizations at nominal center frequencies of 6.8 and 23.8 GHz and six polarizations (vertical (V), horizontal (H), $+45^\circ$ linear (P), -45° linear (M), left circular (L) and right circular (R)) at nominal center frequencies of 10.7, 18.7 and 37 GHz. WindSat was designed to provide observations in both the forward and aft viewing directions. The usable scan angle range of the aft viewing observations is smaller than for the forward viewing direction due to the location of the calibrations loads on WindSat. The earth incidence angle (EIA) is different for each frequency band due to the arrangement of the feedhorns on the WindSat feedbench. The EIA varies about 0.6° over the WindSat scan due to an apparent on-orbit tilt of the spacecraft axis [4]. The nominal WindSat center frequencies, EIA for the forward-viewing portion of the scan, nominal frequency passbands and instantaneous field of view for the WindSat frequency bands are given in Table 1. A more complete description of the WindSat sensor is provided in [5].

The WindSat data processing produces antenna temperature measurements for all 22 WindSat channels. The antenna temperatures are adjusted to account for Faraday rotation due to propagation through the ionosphere [6], polarization rotation, antenna cross-polarization and spillover and along-scan biases. The measurements are then resampled and averaged to provide collocated brightness temperatures (T_bs) at three different common resolutions for the sensor data records (SDRs). The NRL WindSat SDRs are currently produced at elliptical effective fields of view (EFOV) of approximately 25 km by 35 km, 35 km by 53 km and 50 km by 71 km. The SDRs contain T_bs for 16 channels which include the full modified Stokes parameters at 10.7, 18.7 and 37 GHz and the vertical and horizontal polarizations at 6.8 and 23.8 GHz.

3. MODEL DESCRIPTION

We have updated the parameterized model we described in [1]. The T_bs measured by the satellite are the sum of the upwelling atmospheric radiation, the reflected downwelling atmospheric and cosmic background radiation and the direct emission of the sea surface. The reflected downwelling radiation and the direct emission are attenuated by the atmosphere. The modeled T_bs at each WindSat frequency can be expressed as

$$T_{bp} = T_{bp0} + \tilde{T}_{bp} \quad (1)$$

$$T_{bp0} = T_{\mathrm{up}} + \tau(T_S - r_p T_{Rp}) \quad (2)$$

where p refers to polarization, T_{bp0} refers to the direction independent part of the T_b and $\tilde{T}_{bp}$ the wind direction dependent part. The sea surface emissivity for polarization p is e_p and the corresponding reflectivity is $r_p = 1 - e_p$. The parameter T_{Rp}, which is used here to simplify the expressions, can be considered an effective temperature of the surface. We also define T_{R0} which equals T_{Rp} in the limit of specular reflectivity

$$T_{R0} = (T_S - T_C) - [T_{\mathrm{down}} - T_C(1-\tau)]$$
$$T_{Rp} = T_{R0} - [T_{\mathrm{down}} - T_C(1-\tau)]\Omega_p$$

T_{up} is the upwelling atmospheric brightness temperature at the top of the atmosphere, T_{down} is the downwelling atmospheric brightness temperature at the surface and τ is the atmospheric transmissivity. T_C is the cosmic background radiation temperature which is approximately 2.7 K. The Ω_p term is a correction factor to account for non-specular reflection of the atmospheric downwelling radiation from the rough sea surface [7].

Consistent with our earlier model the wind direction dependence is modeled as

$$\tilde{T}_{bp} = -\tau r_{hp} T_{R0}$$

where for vertical or horizontal polarizations

$$r_{hp} = c_{1p}\cos(\phi_w) + c_{2p}\cos(2\phi_w),$$

for the third or fourth Stokes parameters

$$r_{hp} = c_{1p}\sin(\phi_w) + c_{2p}\sin(2\phi_w)$$

and ϕ_w is the wind direction relative to look direction of the antenna. Note that the T_{bp0} term is zero for the third and fourth Stokes parameters. The differences between the frequency passbands for receivers in a frequency band can be significant for radiative transfer. This is primarily due to differences in the water vapor absorption in the atmosphere for the channels in the 18.7 and 23.8 GHz bands. Therefore, we calculate all four modified Stokes parameters for each of the 22 WindSat channels and combine them to obtain the appropriate polarization for each channel [8]. The modeled frequencies for each channel are based on an analysis of the receiver frequency passbands [2].

The atmospheric parameters τ, T_{up} and T_{down} are calculated assuming a one-layer isotropic atmosphere approximation because the WindSat frequency band set does not provide the information necessary to estimate atmospheric profiles. The parameters are calculated using regression to a database of results from radiative transfer model runs using atmospheric profiles [9]. We use the monochromatic radiative tranfer model MonoRTM [10], version 5.2, developed by Atmospheric and Environmental Research, Inc. The regressions are functions of SST, PWV, CLW and earth incidence angle and are derived separately for each frequency.

The sea surface emissivity model is an update to the model described in [1] which is based on a two-scale ocean surface roughness model [7] with empirical corrections. The emperical corrections to the emissivity have been rederived using WindSat SDRs collocated to wind vector values from QuikSCAT retrievals [11] and ECMWF analyses [9]. The frequency dependence of the excess emissivity due to ocean surface roughness and sea foam is small. We have completed two scale model simulations to show that the frequency differences between frequency passbands for the receivers in a WindSat frequency band do not have a significant effect on the excess emissivity due to roughness. We have completed a similar analysis for foam emissivity using the model in [12]. The effect of the frequency differences on the specular emissivity is included in the model.

4. CONCLUSION

The NRL WindSat geophysical model has been updated to improve the modeling of atmospheric propagation, sea surface emissivity and receiver frequency passband effects. Work is ongoing to utilize the updated model in calibration analyses and an updated retrieval algorithm. This work will include and analysis to verify that the receiver frequency passband effects shown in the model are consistent with the WindSat measurements.

5. REFERENCES

[1] M. H. Bettenhausen, C. K. Smith, R. M. Bevilacqua, N.-Y. Wang, P. W. Gaiser, and S. Cox, “A nonlinear optimization algorithm for WindSat wind vector retrievals,”

IEEE Trans. on Geosci. Remote Sens., vol. 44, no. 3, pp. 597–610, Mar. 2006.

[2] M. H. Bettenhausen and P. W. Gaiser, "Analysis of the WindSat Receiver Frequency Passbands," Naval Research Laboratory, Remote Sensing Division, Washington, DC 20375-5320, Tech. Rep. NRL/MR/7220–14-9558, 12 Sep. 2014.

[3] M. H. Bettenhausen and I. S. Adams, "The impact of passband characteristics on imaging microwave radiometer brightness temperatures over the ocean," *Radio Science*, vol. 48, no. 3, pp. 352–357, 2013. [Online]. Available: http://dx.doi.org/10.1002/rds.20041

[4] W. E. Purdy, P. W. Gaiser, G. A. Poe, E. A. Uliana, T. Meissner, and F. J. Wentz, "Geolocation and pointing accuracy analysis for the windsat sensor," *IEEE Trans. on Geosci. and Remote Sens.*, vol. 44, no. 3, pp. 496–505, March 2006.

[5] P. W. Gaiser, K. M. St. Germain, E. M. Twarog, G. A. Poe, W. Purdy, D. Richardson, W. Grossman, W. L. Jones, D. Spencer, G. Golba, J. Cleveland, L. Choy, R. M. Bevilacqua, and P. S. Chang, "The WindSat spaceborne polarimetric microwave radiometer: Sensor description and early orbit performance," *IEEE Trans. Geosci. Remote Sens.*, vol. 42, no. 11, pp. 2347–2361, Nov. 2004.

[6] M. Singh and M. H. Bettenhausen, "An accurate and efficient algorithm for Faraday rotation corrections for spaceborne microwave radiometers," *Radio Sci.*, vol. 46, no. 4, pp. RS4008–, Aug. 2011. [Online]. Available: http://dx.doi.org/10.1029/2010RS004509

[7] J. T. Johnson, "An efficient two-scale model for the computation of thermal emission and atmospheric reflection from the sea surface," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 3, pp. 560–568, 2006.

[8] J. R. Piepmeier, D. G. Long, and E. G. Njoku, "Stokes antenna temperatures," *IEEE Trans. on Geosci. and Remote Sens.*, vol. 46, no. 2, pp. 516–527, Feb 2008.

[9] European Centre for Medium-Range Weather Forecasts, "ERA-Interim Project," Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory, 2009.

[10] V. Payne, E. Mlawer, K. Cady-Pereira, and J. Moncet, "Water vapor continuum absorption in the microwave," *IEEE Trans on Geosci. and Remote Sens.*, vol. 49, no. 6, pp. 2194 –2208, 2011.

[11] SeaPAC. 2013, "QuikSCAT Level 2B Ocean Wind Vectors in 12.5km Slice Composites Version 3. Ver. 3," PO.DAAC, CA, USA, dataset accessed 2013-12-23 at http://dx.doi.org/10.5067/QSX12-L2B01.

[12] M. D. Anguelova and P. W. Gaiser, "Microwave emissivity of sea foam layers with vertically inhomogeneous dielectric properties," *Remote Sensing of Environment*, vol. 139, pp. 81 – 96, 2013.