Relevance Of The Modified Model For The Microwave Brightness Temperature To The TOPEX/Poseidon Satellite Altimetry Mission.

Sandra Cruz-Pol, PhD, University of Puerto Rico at Mayaguez

Abstract An improved model for the microwave brightness temperature seen from space over calm ocean is presented and its relevance to the TOPEX/Poseidon Altimetry mission. This model can be divided into two sub-models, the atmospheric absorption model and the ocean surface emissivity model. An improved model for the absorption of the atmosphere near the 22 GHz water vapor line is described in the first part of this work. The Van-Vleck-Weisskopf line shape is used with a simple parameterized version of the model from Liebe for the water vapor absorption spectra and a scaling of the model from Rosenkranz for the 20-32 GHz oxygen absorption. Radiometric brightness temperature measurements from two sites of contrasting climatological properties — San Diego, CA and West Palm Beach, FL — are used as ground truth for comparison with *in situ* radiosonde derived brightness temperatures. Estimation of the new model's four parameters, related to water vapor line strength, line width and continuum absorption, and far-wing oxygen absorption, are performed using the Newton inversion method. Improvements to the water vapor line strength and line width parameters are found to be statistically significant. The accuracy of brightness temperatures computed using the improved model is 1.3-2% near 22 GHz.

In the second part of this work, a modified ocean emissivity model is explained. The brightness temperature measured above the sea surface depends, among other things, on the ocean's specular emissivity. We investigate the contribution to the brightness temperature from the specular ocean emission. For this purpose, satellite-based radiometric measurements from the TOPEX/Poseidon project are employed together with near-coincident radiosonde profiles from fifteen (15) stations around the world's oceans and TOPEX altimeter measurements for filtering of low wind conditions. The radiosonde profiles are used to compute the upwelling and downwelling emission and the opacity of the atmosphere. The radiative transfer equation is applied to the radiosonde profiles, using the atmospheric model developed in the first part of this work, in order to account for atmospheric effects in the modeled brightness temperature. The dielectric properties of sea water are found from the modified Debye equation using salinity and sea surface temperature data from NODC ocean depth-profiles. The ocean complex permittivity model developed by Klein and Swift and, more recently, by Ellison is tested and revised. The average error in the modified emissivity model, over the range 18-40 GHz, is found to be 0.0037, which in terms of brightness temperatures, translates to a model error of approximately 1K.

1. Introduction

Knowledge of the state of the ocean plays a vital role in weather and ocean wave forecasting models [*Wilheit*, 1979a] as well as in ocean-circulation models [*Dobson* et al., 1987]. One approach to measuring the state of the ocean is by remote sensing of the ocean's surface emission. Microwave radiometers on satellites can completely cover the earth's oceans. Satellite radiometry offers numerous advantages over ship and buoy data. Some of these advantages include the vast coverage of global seas, including locations where radiosonde or buoys cannot be afforded, relatively low power consumption, no maintenance and continuous operation under a wide range of weather conditions.

Measurements of the microwave brightness seen from the sea are used in the retrieval of physical parameters such as wind speed, cloud liquid water and path delay. A suitable model for these measurements includes contributions from atmospheric emission, mainly water vapor and oxygen, and from ocean emission.

In 1992 the TOPEX/POSEIDON satellite was launched as a joint venture between NASA and Centre National d'Etudes Spatiale (CNES) to provide high-accuracy global sea level measurements. Data from TOPEX/Poseidon is used to map ocean circulation patterns, help understand how the oceans interact with the atmosphere, and improve our ability to predict the global climate [*Stewart*, 1986]. It includes a three channel nadir viewing microwave radiometer (TMR) at 18, 21 and 37 GHz designed to measure the water vapor along the path viewed by the altimeter to correct the altimeter data for pulse delay due to water vapor. It has a claimed accuracy of 1.2 cm [*Keihm* et al., 1995].

The need to improve the calibration of existing models for atmospheric and ocean emission is motivated by several current and upcoming satellite remote sensing missions. In the case of TMR, an improved atmospheric model would enhance the inversion algorithm used to retrieve path delay information. Another case is the JASON satellite, a joint NASA/CNES radiometer and altimeter scheduled to be launched in 2000 [*JPL*, 1998]. For JASON, absolute calibration is performed by occasionally looking at calm water. This type of calibration reduces the cost in hardware, complexity, size and power. However, the quality of the calibration depends strongly on the accuracy of a model for the calm water emission. In contrast, for the TMR an absolute calibration is performed using hot and cold references carried by the satellite [*Ruf* et al., 1995].

Errors in the modeling of microwave brightness temperature, T_B, seen from orbit over the sea include errors in the models for vapor and oxygen absorption and sea surface emissivity. Conversely, errors in the measurement of the microwave T_B include errors in the antenna temperature calibration, and beam pattern correction. Currently, the dominant error source when modeling the ocean brightness temperature is the vapor absorption model. In the case of the TOPEX/POSEIDON microwave radiometer, this uncertainty is approximately 35% higher than the radiometer's T_B measurement error [*Keihm* et al., 1995]. Precise microwave radiometry equipment such as this demands more accurate models for the retrieval of the ocean's parameters. The accuracy of these models must be consistent with the level of the errors introduced by the microwave sensor; otherwise the model uncertainties dominate the error budget. The improvement and revision of two models needed to achieve a higher accuracy in the ocean T_B modeling are addressed in this work. The first model accounts for atmospheric absorption. The second accounts for the sea surface emissivity.

In this paper, a section is devoted to each of these models. In Part I, the development of an improved microwave atmospheric absorption model is presented. Part II is dedicated to ocean microwave emission. In both cases, a model is developed and interactively adjusted to fit a carefully calibrated set of measurements. Part III presents the relevance and improvements made in the final error budget of this particular mission.

For the atmospheric absorption model, ground-based radiometric experiments were conducted at two locations of contrasting humidity conditions; San Diego, CA and West Palm Beach, FL. In addition, radiosonde profile data at each site were collected for comparison purposes in the retrieval of the atmospheric model parameters. Advantages over previous such experiments include the use of three independent radiometers for absolute calibration verification, sampling at eight distinct frequencies across the 22 GHz absorption line, and filtering of the raob data to minimize the effects of errors in the relative humidity readings.

Uncertainties in the improved model for atmospheric emission are significantly improved over previous published models. The line-strength and width parameters' uncertainties are reduced to 1% and 1.6%, respectively. The overall uncertainty in the new absorption model is conservatively estimated to be 3% in the vicinity of 22GHz and approaching 8% at 32 GHz. The RMS difference between modeled and measured thermal emission by the atmosphere, in terms of the brightness temperature, is reduced by 23%, from 1.36 K to 1.05 K, compared to one of the most currently used atmospheric models.

For the ocean emission study, satellite-based radiometric measurements from the TOPEX/Poseidon project are employed. In addition, altimeter (active remote sensor) data from the same satellite is utilized for the purpose of wind speed estimation and specular emissivity corroboration. We investigate the contribution from the specular ocean emission by employing the altimeter to pinpoint the exact times when the wind is calm, in order to relax the dependence of the correction to the specular model on the accuracy of the wind model.

The modified ocean dielectric models exhibit significant improvements in the estimate of T_B. Of the two, the modified *Ellison* et al.[1977] model exhibits superior overall performance, including the lowest bias at both frequencies, which is a very important attribute indicative of the accuracy of the model. Its frequency dependence was decreased to 0.30K, which will allow for more reliable extrapolation to higher frequencies. In addition, this modified model has the lowest dependence on sea surface temperature and the lowest RMS difference for both 18GHz and 37GHz. Consequently, this is the model that we recommend for future remote sensing applications involving microwave emissions from the ocean emissivity of the ocean. The average error in the modified emissivity model, over the range 18-40 GHz, is found to be 0.37%, which in terms of brightness temperatures, translates into a model error of approximately 1K.

We first develop the necessary background theory in Section 2. Section 3 deals with the model theory, experiments and data analysis related to the atmospheric absorption model. The forth section presents the relevance of these calibrated models to the total error budget of the TOPEX/Poseidon altimetry mission. Conclusions are presented in section 5.

2. Microwave Atmospheric Absorption Model

The brightness temperature measured by a downward looking spaceborne microwave radiometer has two components. The radiometer measures the emission by the surface and from the atmosphere, both, the upwelling emission, and the downwelling emission reflected at the surface. The total brightness temperature in the zenith direction is given by [*e.g. Ulaby et al*., 1981]

$$T_a = T_{UP} + \in_s T_s e^{-\tau(0,H)\sec\theta}$$
$$+ (1-\in_s)(T_{DN} + T_C e^{-\tau(0,\infty)\sec\theta})e^{-\tau(0,H)\sec\theta}$$
(1)

where T_s is the thermodynamic temperature of the surface in Kelvin, $\in_s$ is the emissivity of the surface, $(1-\in_s)$ is the reflectivity of the surface, H is the satellite height in km, T_C is the cosmic radiation and T_{DN} is given by

$$T_{DN} = \sec\theta \int_0^\infty T(z)\alpha(f,z)e^{-\tau(0,z)\sec\theta}dz$$
(2)

The upwelling brightness temperature in the zenith direction is given by

$$T_{UP} = \int_0^H T(z)\alpha(f,z)e^{-\tau(z,H)}dz \qquad (3)$$

where θ is the incidence angle of the radiation which is measured with respect to the normal to the surface, $\alpha(f, z)$ is the atmospheric attenuation in Nepers/km at frequency f and height z, $\tau(0,z)$ is the opacity of the atmosphere between altitude 0 and z , and $T(z)$ is the air temperature at height z. The opacity measures the total amount of extinction suffered through the path and is given by

$$\tau(0,z) = \int_0^z \alpha(f,z')dz' \qquad (4)$$

where the absorption coefficient, $\alpha(f, z)$, accounts for both water vapor and oxygen absorption (assuming a non-scattering, clear atmosphere).

In equation (1), T_C is the cosmic background radiation incident on the atmosphere from the top. The cosmic radiation at microwave frequencies varies with frequency as

$$T_C = 2.69 + 0.003625f \qquad (5)$$

which has an average of 2.78 K for the 20-32 GHz range. The frequency dependence accounts for the variable inaccuracy of the Rayleigh-Jeans approximation [*Janssen,* 1993].

Equation (1) contains all the quantities needed to compute the response of a satellite-based microwave radiometer to changes in atmospheric and surface variables. In order to test models for surface emissivity against observations of T_B, we will need to estimate each of the other components of the model, using ancillary data sources.

The atmospheric absorption model described in *Cruz Pol et al.* [1998] (henceforth referred to as modL) is a modification to L93 that is based on a refined set of observations of atmospheric downwelling brightness temperature by a radiometer/spectrometer operating in the near vicinity of the 22 GHz water vapor line. A 1.3% increase in the line strength, together with a 6.6% increase in the line width, of the 22 GHz absorption line are determined to be statistically significant corrections to the L93 model within the range of 18-37 GHz.

3. SEA SURFACE EMISSIVITY

The brightness temperature measured from the sea surface depends on the specular ocean emission and the excess emissivity induced by the wind. In this part of the work, we adjust a model for observed T_B from a satellite-based radiometer over the ocean, by comparing it to the TOPEX/Poseidon Microwave Radiometer (TMR) data over a four- year period (1992-1997). In order to fully model the T_B, we need to know the sea surface temperature and salinity, the upwelling and downwelling brightness temperatures, the atmosphere transmissivity and the wind speed. For this purpose, near-coincident radiosonde profiles from fifteen (15) stations around the world's oceans are used to find the upwelling, downwelling and transmissivity of the atmosphere. The dielectric properties of sea water are found from the modified Debye equation using salinity and sea surface temperature data from NODC ocean depth-profiles. The wind speed is estimated from the TOPEX/Poseidon dual-frequency altimeter. Adjustment to the model is accomplished by means of the Newton-Raphson method.

3.1 Current models and their limitations

A satellite-based radiometer looks down at the ocean surface and hence its brightness temperature depends upon the ocean emissivity. The ocean emissivity can be decomposed into a contribution from the specular emission of the sea surface and emissivity induced by the wind.

Recent work to determine the sea water dielectric coefficient was based on laboratory measurements of sea water samples from different parts of the ocean. Although these measurements should render good understanding of the emission from a calm ocean surface, their accuracy in providing values of the ocean still needed to be examined. Our present investigation of the specular sea emission seen from space provides field verification of the sea water specular emissivity over broader regions of the oceans. In this work, we investigate and adjust two ocean dielectric models using well calibrated radiometer data from the TOPEX/Poseidon satellite mission, paying particular attention to reducing the frequency dependence of the model and the overall bias of the estimated brightness. In addition, we evaluate the performance of several models for their dependence on salinity and sea temperature.

The modified models exhibit significant improvements in the estimate of T_B. Of the two modified models, ModE exhibits superior overall performance. It has the lowest bias at both frequencies (0.16 and 0.14K, respectively), which is indicative of the accuracy of the model. Its frequency dependence was decreased from -2.3 to 0.30K, which is half of that exhibited by ModKS, and which will allow for more reliable extrapolation to higher frequencies. In addition, ModE has the lowest dependence on sea surface temperature and the lowest RMS difference of 2.58K and 3.52K for 18GHz and 37GHz, respectively. For these reasons, we recommend this model[1] for future remote sensing applications involving microwave emissions from the ocean.

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[1] See Appendix E for a FORTRAN program listing of the modified ocean surface specular emissivity model

4. Relevance of this work to the TOPEX/Poseidon altimetry mission

The atmospheric and sea surface emissivity models are the two primary components of a total model for the brightness temperature seen from a satellite. Many other factors, both from theoretical models and instrumental errors, contribute to the error budget that determines the overall accuracy of a satellite's measurements.

Table 1 places the water vapor attenuation and sea surface emissivity model uncertainties into the context of the total error budget for the retrieved path delay algorithm used by the TOPEX Microwave Radiometer. The individual components of the error are described by *Keihm* et al. [1995] and paraphrased here:

Inherent - This error is due to the fact that the relationship between T_B and *PD* is not a one-to-one correspondence. Instead, there are a multiple number of possible water vapor profiles which yield the same brightness temperature but different path delays.

Vapor Absorption Model - This refers to the uncertainty in the water vapor absorption model which can produce both offset and scale errors in the path delay retrieval.

Oxygen absorption model - The effect of the uncertainty in the oxygen absorption model was assessed by considering a simplified global average version of the path delay retrieval algorithm.

Liquid absorption model - This is the uncertainty in the model for the cloud liquid water content.

Specular sea surface emissivity model - This is the path delay retrieval error due to the uncertainty in the sea surface emissivity model.

Emissivity vs. Wind speed model - This is the uncertainty introduced by the wind speed retrieval model used by TMR. The path delay retrieval varies with the estimate of wind speed. Biases in the wind speed estimate will bias the path delay.

The first column in Table 1 is the pre-launch error budget for the TMR path delay algorithm as presented by *Keihm* et al. [1995]. In the second column, we present the errors using our improved models for the water vapor and sea surface emissivity. The shadowed area indicate changes. An improvement of 37% is attained in the overall *PD* error budget when the results from this work are applied.

Table 1. Error Budget for the Path Delay Algorithm

Error Source	PD error [cm]	
	Nominal	New
Inherent	0.37	0.37
Vapor abs. Model	*0.80*	*0.40*
Oxy. Abs. Model	0.05	0.05
Liq. Abs. Model	0.03	0.03
Specular sea surface emis. model	*0.20*	*0.02*
Emissivity vs. wind speed model	0.21	0.21
RSS algorithm Error	0.93	0.59

In addition to the error in the path delay algorithm, the overall error budget for the wet troposphere correction includes other uncertainties [*Keihm* et al., 1995]:

Antenna Temperature Calibration and Beam Pattern correction - This takes into account the accuracy of the TMR brightness temperature measurements including stochastic noise, pre-launch calibration residuals, and the antenna pattern correction error.

Decorrelation between TMR and Altimeter main beams - This takes into account the difference in the beamwidth of the TMR channels (tens of kilometers) and the assumed equivalence of the path delay in the smaller footprint of the altimeter (~3 km).

Beam Size Differences for 3 TMR Channels - This takes into account the difference in the beamwidths of the individual TMR frequency channels (43.4 km at 18 GHz; 36.4 km at 21 GHz, and 22.9 km at 37 GHz)

Path Delay Retrieval Algorithm Error - This is the error in the path delay retrieval algorithm presented in Table 1.

These error sources are presented in Table 2.

Table 2. Total Error Budget for TOPEX Microwave Radiometer (TMR) Wet Troposphere Range Correction. [*Keihm* et al., 1995]

Error Source	PD error (cm)
Antenna Temperature Calibration and Beam Pattern correction	0.69
Decorrelation Between TMR and Altimeter Main Beams	0.30
Beam Size Differences for 3 TMR Channels	0.11
Path Delay Retrieval Algorithm Error	0.93
RSS Total Error	*1.20*

In the case of the TOPEX/Poseidon altimeter, we are interested in the reliability and accuracy of its sea surface height measurements, since it is used primarily for the global monitoring of the ocean topography. Factors such as the precise orbit determination, gravitational and ocean tidal forces, solar radiation effects, atmospheric drag, altimeter noise, etc. have to be accounted for when determining the accuracy of such measurements. A complete error covariance model of the data for the sea surface topography is presented by *Tsaoussi and Koblinsky* [1994] and briefly summarized here.

The altimeter measures the distance between the satellite and the sea surface to obtain a detailed map of the global topography. The sea surface height is obtained by subtracting the altimeter range measurements from the altitude of the satellite above a reference ellipsoid. The uncertainty in this sea surface height measurement is therefore dependent on the accuracies of the altimeter and the precise knowledge of the position of the satellite in space. The position of the satellite is determined by three different systems: Satellite Laser Ranging (SLR); Doppler Orbitography and Radiopositioning Integrated by Spacecraft (DORIS); and Global Positioning System (GPS). SLR uses laser beams sent from the ground and reflected from a laser reflector array to determine the exact position of the spacecraft. DORIS uses a radio tracking system developed by CNES. The satellite also carries a GPS receiver on board which tracks signals sent by an array of 21 satellites that orbit the earth to pinpoint the precise position of TOPEX/Poseidon in space. These systems provide the spacecraft's radial position with an accuracy of better than 3 cm.

Table 3 presents a list of errors encountered in the retrieval of the sea surface height for the model, pre-launch, post-launch and post-verification phases [*Nerem* et al., 1994; *Tsaoussi and Koblinsky,* 1994; *Fu* et al.., 1994; *Keihm* et al., 1995]. Sources of error include;

Table 3. RMS Errors of Individual Sea Surface Topography Error (units in centimeters [*Tsaoussi* and *Koblinsky,* 1994; *Fu* et al., 1994]

Error Source	Model	Pre-launch	Post-launch	Post-verification
Altimeter Noise	0.2	2.0	1.2	1.7
EM Bias	0.7	2.0	2.0	2.0
Ionosphere	0.8	2.2	0.7	0.5
Dry troposphere	1.0	0.7	0.7	0.7
Wet troposphere	*1.8*	*1.2*	*1.5*	*1.1*
Atmospheric Load	1.1	2.8	2.8	n/a
Ocean Tides	1.7	n/a	n/a	n/a
Solid Earth tides	0.3	n/a	n/a	n/a
Radial orbit height	2.3	12.8	8.0	3.5
Gravity field	10.9	n/a	n/a	n/a
High-frequency geoid	4.8	n/a	n/a	n/a
Total Error[2]	11.5	n/a	n/a	n/a
Total time dependent Error	3.5	13.4	8.6	4.7

Altimeter noise- This include white noise in the instrument components and mispointing and skewness effects. These combined altimeter errors are found to be less than 1 cm [*Fu* et al., 1994].

EM bias- Another error in the sea surface height measurement is the electromagnetic (EM) bias. The EM bias refers to the fact that the radar backscatter cross section is larger at wave troughs than at wave crests [*Walsh* et al, 1989]. For a typical 2-m SWH (significant wave height) the residual EM bias is about 2 cm.

Ionosphere - The range delay caused by the ionospheric free electrons is retrieved by the dual-frequency altimeter (see Section 1-1.2.1). Error in the retrieval of the ionospheric range delay is about 0.5 cm [*Imel*, 1994].

Wet Troposphere - The water vapor in the atmosphere is responsible for the wet propagation delay of the radar signal. The TMR is used to determine this wet path delay. Comparisons of TMR observations with ground based water vapor radiometers and radiosondes yield an estimated accuracy of 1.2 cm [*Ruf* et al.,1994].

Dry Troposphere - The dry troposphere delay in the altimeter signal is caused by the dry air mass of the troposphere. This delay is corrected by using the sea level pressure estimates from ECMWF. The RMS accuracy of this correction is estimated to be 0.7 cm.

Atmospheric Drag - The acceleration of the spacecraft caused by its interaction with the Earth's atmosphere causes a drag on the satellite's orbit. This atmospheric drag is easily modeled at the relatively low atmospheric density at the corresponding high altitude (1336 km). Errors in the modeled atmospheric load account for 2.8 cm or less [*Tsaoussi and Koblinsky*, 1994].

Ocean Tides - The natural rise and fall of sea level due to the pull of gravity among the Moon, Earth and Sun change the orbit of artificial satellites such as TOPEX. The error in this model has been estimated to be approximately 1.7 cm [*Casotto*,1989].

Solid Earth Tides - Another force acting on the satellite is generated by the inhomogeneous mass distribution on and within the Earth. Errors in the modeled solid earth tides are estimated at 0.3 cm [*Rosborough*, 1986]

[2] includes the gravity field (geoid error)

Radial orbit height - The uncertainty in the radial component of the satellite orbit is the largest error source in satellite altimetry. The post launch gravity improvement activities, which include comprehensive tracking of the satellite by SLR and DORIS and improvements in the force modeling and reference systems and numerical methods, have resulted in an RMS accuracy of approximately 3.5 cm [*Tapley* et al., 1994].

Gravity field - This uncertainty refers to the error in the model for the gravity field effect. It is estimated at about 11 cm [*Lerch* et al., 1994]. Most of this error is random and can be reduced by time averaging [*Fu* et al., 1994].

High-frequency geoid - This error relates to the exact size and shape of the Earth and the determination of the exact satellite position with respect to the geoid[3] [*Tapley* et al., 1994].

The total RSS error and the total time-dependent error for each phase are presented in the bottom two rows of Table 3. Post-launch tuning of all the physical models mentioned allows the non-conservatives forces acting on TOPEX to be modeled to the required accuracy. Consequently, some of the errors at pre-launch show considerable improvement in the post launch and verification phases. As seen in Table 3, the gravity field (geoid) error dominates the error budget on the sea surface topography. However, this error cancels out when performing time-averaging for the data. For the post-verification phase, the total time-dependent error reduces to 4.7 cm, of which 1.1cm is due to the wet troposphere uncertainty. Comparisons of the TOPEX measured sea level variation to the Tropical Ocean and Global Atmosphere data set yield an average RMS difference of 4.6 cm after smoothing the tide gauge data for temporal averaging [*Nerem* et al., 1994]. These results corroborate the level of the error presented in Table 3's post- verification stage of 4.7 cm. At a first glance, a wet tropospheric path delay of 1.2 cm looks insignificant compared to a total (pre-launch) error of 13.4 cm. However, as seen in the post-launch and model columns of Table 3, the significance increases compared to a total error budget of 3 to 4.7 cm. Improvements in the accuracy of the wet troposphere propagation path delay render more accurate measurements from the TOPEX altimeter mission.

5. Conclusions and future work

The contributions of this work are the improved models for the atmospheric water vapor absorption and the sea surface emissivity. The improved model for the absorption of the clear atmosphere near the 22 GHz line is presented in section 2. The Van-Vleck-Weisskopf line shape is used with a simplified version of the model by *Liebe* [1987] for the water vapor absorption spectra and the model by *Rosenkranz* [1993] for the oxygen absorption. Radiometric brightness temperature measurements from two sites of contrasting climatological properties, San Diego, CA and West Palm Beach, FL, were used as ground truth for comparison with *in situ* radiosonde derived brightness temperatures. Retrieval of the new model's four parameters, water vapor line strength, line width, and continuum absorption, and far-wing oxygen, was performed using the Newton-Raphson inversion method. The RMS difference between modeled and measured T_B was reduced by 23%, from 1.36 K to 1.05 K, with the new parameters. Sensitivity analysis shows that the standard deviations in the C_L, C_W, C_X parameters are 5% or less, and 8% for C_C, assuming 0.5K RMS errors in the T_B data. The extra frequencies over the 20-32 GHz range constrain the shape and level of the absorption model simultaneously, producing the highest agreement with the radiometric temperatures.

In order to reduce the correlation in the retrieved atmospheric parameter for the continuum and the oxygen cluster parameters, C_C and C_X, future experiments should include more variation in the air pressure within the data set. In addition, to avoid the painstaking process of selecting the raob data less affected by the relative humidity problem, more accurate raob balloons should be launched close to the radiometer sites.

[3] Average sea level of an ocean at rest.

In section 3, an analysis is presented to examine and adjust two ocean dielectric models using well calibrated radiometer data from the TOPEX/Poseidon satellite mission together with NODC salinity and sea surface temperature depth-profiles, and atmospheric profiles from 15 raob stations around the world. Particular attention was paid to reducing the frequency dependence of the model and the overall bias of the estimated brightness. In addition, we evaluated the performance of several models for their dependence on salinity and sea temperature.

The modified models, ModE and ModKS, exhibit significant improvements in the estimate of T_B. Of the two modified models, ModE exhibits superior overall performance, including the lowest bias at both frequencies, which is a very important attribute indicative of the accuracy of the model. Its frequency dependence was decreased to 0.30K, which will allow for more reliable extrapolation to higher frequencies. In addition, ModE has the lowest dependence on sea surface temperature and the lowest RMS difference for both 18GHz and 37GHz. Consequently, this is the model that we recommend for future remote sensing applications involving microwave emissions from the ocean emissivity of the ocean. The average error in the modified emissivity model, over the range 18-40 GHz, is found to be 0.0037, compared to 0.003 for E96, which in terms of brightness temperatures, translates into a model error of approximately 1K.

We found that the dominant source of errors in determining the modified ocean dielectric models were the uncertainty in the salinity and sea surface temperature data from NODC. For this reason, a future experiment should provide more accurate readings of sea surface salinity and temperature.

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