

Supplement 1

Algorithm Theoretical Basis Document for AMSR-E Ocean Algorithms

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1. Introduction

This document is a supplement to the Algorithm Theoretical Basis document (ATBD) for AMSR-E Ocean Algorithms [Wentz and Meissner, 2000]. This supplement focuses on the structure of the retrieval algorithm, which is somewhat different than described in *Wentz and Meissner* [2000].

The ocean algorithm is based on the physical Radiative Transfer Model (RTM) described in *Wentz and Meissner* [2000]. The RTM consists of an atmospheric absorption model for water vapor, oxygen and liquid cloud water and a sea surface emissivity model that parameterizes the emissivity as function of sea surface temperature, sea surface salinity, sea surface wind speed and direction. The details of the physical RTM have been described in *Wentz and Meissner* [2000]. Some components of the model have been updated. These are the dielectric constant of sea and cloud water [Meissner and Wentz, 2004], the isotropic wind induced sea surface emissivity [Meissner and Wentz, 2006] and the wind directional signal of the sea surface emissivity [Meissner and Wentz 2002, Meissner and Wentz 2006].

The RTM is used to Monte Carlo simulate ocean brightness temperatures (T_B) at the top of the atmosphere (TOA) over a large training data set of ocean-atmosphere scenes. The simulated T_B are then used to train multi-stage regressions.

This Supplement 1 to the ATBD describes and explains in detail the structure and training method of retrieval algorithms. The retrievals are done by a set of two-stage regression algorithms. The first-stage is a set of regressions trained with global data. The first-stage retrievals provide reasonably good estimates of SST, wind, vapor, and cloud. However, because of the non-linear relationships between brightness temperature and the geophysical parameters, the retrievals coming from the global regressions are not optimal. In the second stage, we use a set of regressions that have been specially trained for a localized range of environmental conditions in the neighborhood of the first-stage retrievals. A similar methodology is used for SST, wind, vapor, and cloud. Here we use the SST and wind speed algorithm as an example.

2. Basis of the SST and Wind Speed Algorithm

Between 4 and 11 GHz, the vertically polarized brightness temperature (T_B) of the sea-surface has an appreciable sensitivity to SST. For example, at the AMSR-E frequency of 6.9 GHz, the derivative of the v-pol T_B with respect to SST is about 0.5. It is this sensitivity that is the basis for microwave SST retrievals.

In addition to SST, T_B depends on the sea-surface roughness and on the atmospheric temperature and moisture profile. Note that sea-surface roughness, which is tightly correlated

with the local wind, is usually parameterized in terms of the near-surface wind speed and direction. Fortunately, the spectral and polarimetric signatures of the surface-roughness and the atmosphere are quite distinct from the SST signature, and the influence of these effects can be determined (and retrieved) given simultaneous observations at multiple frequencies and polarizations. For AMSR-E there are 10 channels corresponding to 5 frequencies (7, 11, 19, 24 and 37 GHz) and 2 polarizations (v-pol and h-pol). This channel set is more than sufficient to separate the SST, wind, and atmosphere signals (vapor, cloud, and rain).

3. Formulation of the Basic SST and Wind Algorithm

The AMSR-E SST retrieval algorithm is a physically based regression that expresses SST in terms of brightness temperature (T_B). The algorithm operates in two stages. In the first stage, initial estimates of SST and wind speed are obtained from the following expressions:

$$p_{1j} = a_{0j} + \sum_{i=1}^{10} a_{ij}t_i + b_{ij}t_i^2 \quad (1a)$$

$$t_i = T_{Bi} - 150 \quad \text{all channels except the 24 GHz channels} \quad (1b)$$

$$t_i = -\ln(290 - T_{Bi}) \quad \text{for the two 24 GHz channels} \quad (1c)$$

where subscript $j = 1$ or 2 denotes either SST (p_{11}) or wind speed (p_{12}). The leading subscript 1 denotes this is a first-stage retrieval. The summation is over the 10 AMSR-E channels, and T_{Bi} refers to the brightness temperature for the i^{th} channel. The terms a_{ij} and b_{ij} are regression coefficients that are determined from a radiative transfer model (RTM) as is discussed below.

Equation (1) provides a reasonably good initial estimate of SST and wind speed. However, the relationship of T_B versus SST and wind is non-linear, and the simple form given by (1) is not capable of fully representing these non-linearities. Hence, we add a second stage to the retrieval algorithm. For the second stage, a large set of localized retrieval algorithms are used. By 'localized', we mean the algorithm is trained to perform well over a relatively narrow range of SST and wind speeds. Localized algorithms are derived for 38 SST reference values ranging from -3 to 34 C and for 38 wind speed reference values ranging from 0 to 37 m/s. All SST/wind combinations are considered, thereby giving a total of 1444 localized algorithms. Each algorithm is trained to perform well over a SST/wind range of $\pm 1.5^\circ\text{C}$ and ± 2 m/s centered on the reference SST and wind value. The reason for using such a large number of algorithms is to ensure good continuity in the retrievals when moving from one set of reference SST/wind to the next. These localized algorithms take the form:

$$p_{jkl} = c_{0jkl} + \sum_{i=1}^{10} c_{ijkl}t_i \quad (2)$$

where the subscript k ranges from -3 to 34 and subscript l ranges from 0 to 37 and denote the reference SST and the reference wind speed, respectively. The second-stage retrieval is found from a linear interpolation of the localized algorithms that are in the neighborhood of the first-stage retrievals.

$$p_{2j} = \sum_{k=k_0}^{k_0+1} \sum_{l=l_0}^{l_0+1} w_{k-k_0, l-l_0} p_{jkl} \quad (3)$$

$$w_{00} = (1-x)(1-y) \quad (4a)$$

$$w_{10} = x(1-y) \quad (4b)$$

$$w_{01} = y(1-x) \quad (4c)$$

$$w_{11} = xy \quad (4d)$$

$$x = p_{11} - k_0 \quad (5a)$$

$$y = p_{12} - l_0 \quad (5b)$$

$$k_0 = \text{floor}(p_{11}) \quad (6a)$$

$$l_0 = \text{floor}(p_{12}) \quad (6b)$$

4. Training of the SST and Wind Algorithm

The algorithm regression coefficients are found by generating a large ensemble of simulated brightness temperatures computed from a microwave RTM for the ocean and intervening atmosphere [Wentz and Meissner, 2000]. The simulation is based on a set of 42,195 radiosonde soundings launched from weather ships and small islands around the globe [Wentz, 1997]. These radiosondes are used to specify the atmospheric part of the RTM. A cloud layer of various columnar liquid cloud water densities ranging from 0 mm to 0.3 mm and various cloud bottom and top heights between 500 m and 2500 m is superimposed over the radiosondes. For each radiosonde, a large range of the sea-surface conditions is considered. The sea-surface wind speed is varied from 0 to 40 m/s. The sea-surface temperature is varied $\pm 5.5^\circ\text{C}$ about the Reynolds SST for the island site. For each of these Earth scenes, the RTM computes the set of 10 AMSR-E T_B , and then noise is added to the T_B to replicated sensor noise.

The simulated T_B are substituted in equation (1), and the regression coefficients a_{ij} and b_{ij} are found via the standard least squares method, which minimizes the variance between the SST and wind value given by (1) and the true SST and wind value. Once the stage-1 algorithms are specified, training of the stage-2 algorithms can be performed. In this case, regression coefficients c_{ijkl} for 1444 separated algorithms are found, again using standard least squares. Each algorithm is trained using just a small subset of the Earth scenes that have a SST and wind value near the algorithm's reference SST/wind.

5. Correction for Wind Direction Signal

The surface emissivity and therefore also the T_B in each channel also depend on wind direction relative to the looking azimuth. The wind direction signal grows with wind speed and reaches up to 3 K peak to peak amplitude above 10 m/s. [Meissner and Wentz 2002, Meissner and Wentz 2006]. This leads to a significant error in the retrieved SST and wind and a crosstalk between the accuracy error of the SST and wind retrievals and relative wind direction. In order to correct for the wind direction signal, the algorithm training is performed separately for a discrete set of 19 values for relative wind directions between 0° and 360° in 20° steps. When doing the retrievals, the wind direction needs to be obtained from an auxiliary source. For

operational processing, we use the wind direction from the NCEP GFS forecast model. For the final processing the forecast is substituted by the NCEP GDAS analysis. The regression coefficients are linearly interpolated from the 19 reference values of the discrete wind directions to the actual NCEP wind direction.

6. Earth Incidence Variations

The surface emissivity also depends on the Earth Incidence Angle (EIA). Due to the oblateness of the Earth the EIA can deviate by about $\pm 0.5^\circ$ from the nominal EIA of 55° over the course of an AMSR-E orbit. The method to compensate for the variation in EIA is similar to the method to compensate for the wind direction effect described in the last section. The SST and wind algorithms are trained for 5 discrete values of EIA that are taken in 0.5° steps around the nominal EIA of 55° . In the retrievals, the regression coefficients are then linearly interpolated from the discrete set to the actual value of the EIA.

7. Salinity Correction

All regressions are trained using a reference ocean surface salinity S of 35 ppt when computing the ocean surface emissivity. In order to accommodate the variability of the ocean salinity, we could follow a procedure similar to that which we have done for the variations in relative wind direction and EIA. Because ocean salinity is a slowly varying function of time and location, it is somewhat simpler to correct the measured AMSR-E T_B to the reference salinity, before doing the retrieval. We precompute a T_B - correction climatology atlas, which consists of the ratio $[T_B(S) - T_B(35\text{ ppt})] / T_B(35\text{ ppt})$ for each channel at a discrete set of locations (latitude and longitude) and times (month of the year). For the calculation of this ratio we have used salinity values from the NODC World Ocean Atlas, SST values from the Reynolds climatology and typical values for the other geophysical parameters (wind speed, water vapor and liquid cloud water). In the retrievals, the T_B correction values are linearly interpolated in location and time to the actual values of the AMSR-E measurement.

8. Algorithm Flow Diagram

Figure 1 shows a schematic diagram of the SST algorithm training and retrievals. The schematic diagram for the wind algorithm is essentially the same.

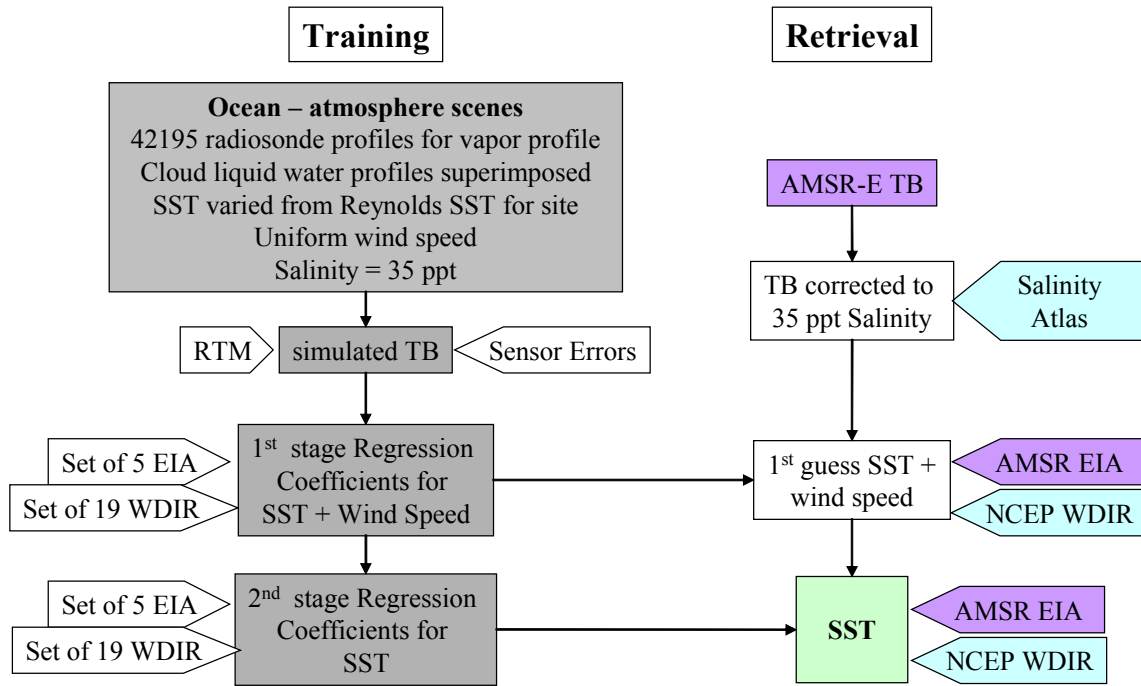


Figure 1. Schematic diagram of the SST algorithm training and retrievals

9. Algorithms for Other AMSR-E Ocean Products

The SST and wind speed algorithms, which are described above, are essentially the same. The only real difference is that the SST algorithm uses all 10 AMSR-E lower channels, while the wind algorithm does not use the 7 GHz channels. The reason is that 7 GHz is not significantly improving the wind retrievals and hence by not using it, we can obtain wind retrievals at a higher spatial resolution.

The columnar water vapor and columnar liquid cloud water algorithms also have a similar structure. These two algorithms only use the 19, 23, and 37 GHz channels.

10. References

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