

# A reference model for ocean surface emissivity and backscatter from the microwave to the infrared

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## ABSTRACT

It is not possible to sound the lower troposphere from space without accurate knowledge of the radiative contribution from the earth's surface. The simplest assumption to make is that the surface emits from a thin skin with a characteristic emissivity and temperature. Skin temperature can be estimated from flux balance at the surface in a Numerical Weather Prediction system. Emissivity can either be modelled or estimated from observations. Recent work has shown that uncertainties in surface emissivity models are not well known. These studies identified a need to develop a model of reference quality, spanning the full frequency range from microwave to infrared, and including visible albedo. The term reference model means a model where the uncertainty is known, because components of the model have had their uncertainty traced to an established reference. This short paper outlines the critical components of such a model and how a reference model could be developed, if resources can be found.

## 1. Introduction

A fast model like Fastem [1] is only as good as the reference model it attempts to replicate. Unlike atmospheric transmission we lack a state of the art reference model for surface emissivity. JCSDA are developing CSEM [2]. This incorporates emissivity models, from visible to microwave, over both land and ocean. TESSEM2 [3] is similar to Fastem. The RSS model [4] is based on observations from instruments on the DMSP and Coriolis satellites. None provide a reference model.

An ocean emissivity model has three main components:

1. **The dielectric model** A double Debye form is often used. Given the dielectric properties the Fresnel equation tells us the polarised reflection and refraction at the water surface. However even in this most basic component there is uncertainty. See Lawrence *et al.* (ITSC-21) for more detail.

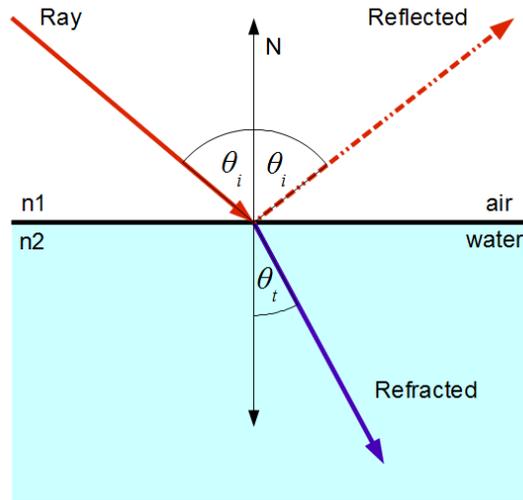


Figure 1: Reflection and refraction at ocean:water boundary for a flat surface. Even in this idealised scenario uncertainty is not fully characterised.

2. **The roughness model** Ocean roughness arises both from wind induced ocean roughness and large scale ocean swell. Geometric optics can be applied to large scales. Smaller scales need a scattering model. A two scale model can be applied, but as the scale separation is arbitrary they have limitations. A more general solution is highly desirable for a model applicable to a wide range of wavelengths. Ideally the large scale swell should be estimated from a wave model, not the local wind speed.

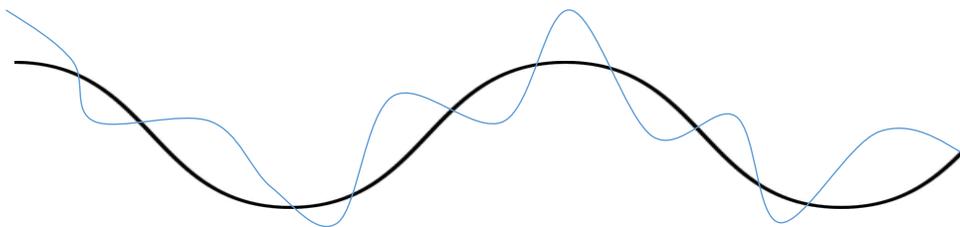


Figure 2: Ocean waves have a large scale swell component with smaller waves driven by the local wind superimposed, as depicted above in stylised form and in a photograph.

3. **The foam model** Most models parameterise ocean foam coverage ( $F$ ) as a function of the instantaneous wind ( $U$ ),  $F=aU^3$  and then assume an emissivity model or assume foam is a blackbody. Efforts have begun to model foam from a wave model [5] as shown to the left which could allow full foam radiative transfer rather than artificial separation of coverage and emissivity. This could take into account foam asymmetry using a 3D wave slope model.

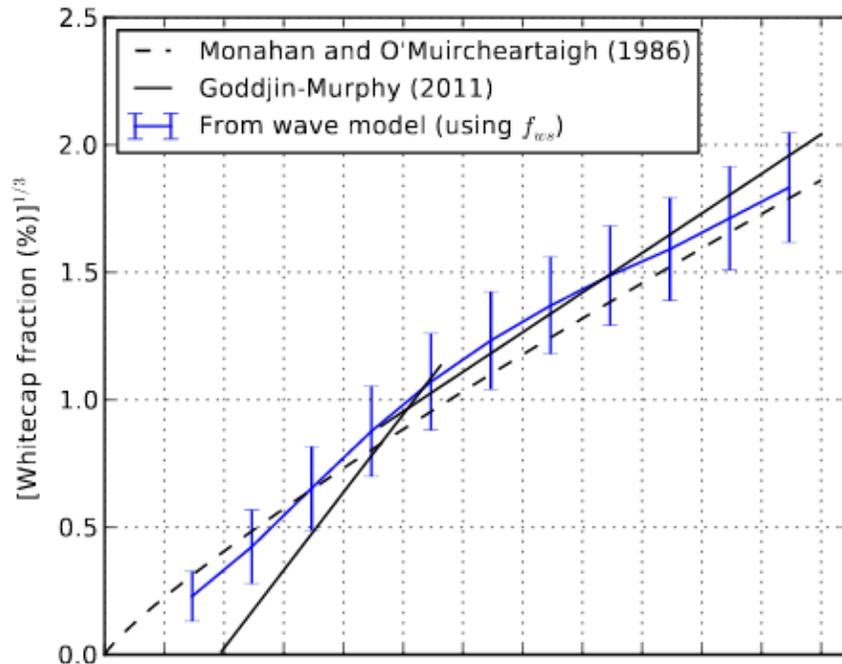


Figure 3: Comparison of foam coverage derived from wave model [5] with wind speed models.

The development of the Fastem model from version 1 to 6 has shown very large differences from model version to model version, as shown in Figure 4. Unfortunately as the uncertainty is not known it is not possible to say if there is any real skill difference. However Figure 4 shows lowest errors with respect to the GMI radiometer occur with most recent versions, and considering all channels version 6 achieves agreement to better than 1K across the spectral range.

## 2. Elements of a reference model

### a. Dielectric model

Lawrence (ITSC-21) undertook a careful analysis of the uncertainty of the dielectric model, going back to the uncertainty estimates on the original laboratory measurements.

### b. Wave and foam model

Ocean waves have different physical processes depending on length scale. The large scale ocean swell can propagate from one region to another. It should therefore be modelled from a wave model, however typically it is parameterized as a function of instantaneous local wind speed. A reference model should be as close to the physics as possible, so should base large scale waves on

wave model output. Shorter scales (ripples) are driven by the instantaneous wind speed. These also have been parameterized as a function of instantaneous wind speed, but clearly assumptions about the statistical

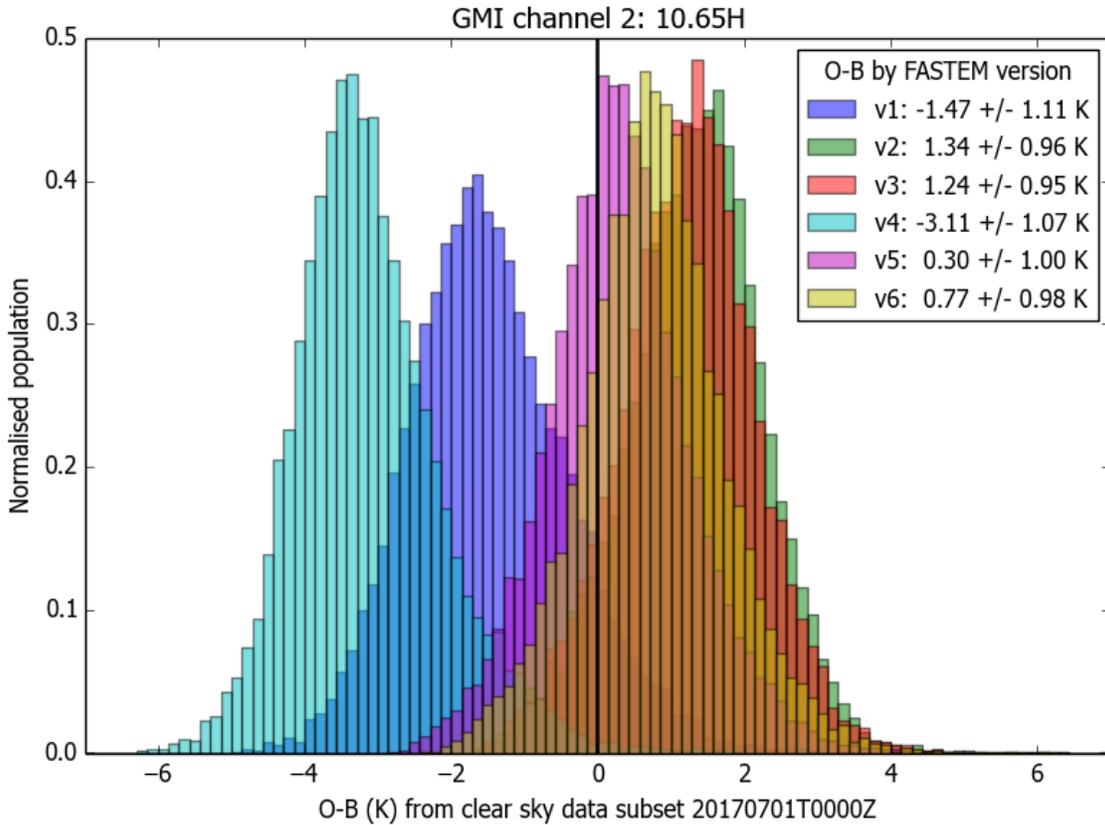


Figure 4: The fit of the Fastem model from version 1 to version 6 against the GMI 10.65 GHz horizontal polarisation, whose radiometric uncertainty is considered to be known to be a few tenths of a Kelvin.

properties of these ripples have to be made. In both scales, and both mechanisms, effort is needed to trace the uncertainty in the wave spectrum, and to understand what this uncertainty looks like in observation space, at different wavelengths. Whicapping and foam streaks are driven by breaking waves, and are therefore related to the dissipative wave energy, which can be analysed from a wave model (following [5]). However as with large scale swell the foam coverage has typically been parameterized as a function of instantaneous windspeed. The uncertainty arising in radiative calculations assuming wave model output to be available, or relying solely on instantaneous wind speed estimates, needs to be established.

*c. Radiative solver*

Once the dielectric and wave spectrum uncertainty are known the radiative solver needs to be selected. Fastem versions 1 and 2 were based on a Geometric Optics model, which assumes all length scales for waves are long compared to the wavelength of observation, and can therefore be treated as a set of angled facets. However at very long observation wavelengths this assumption breaks down, and Fastem versions 3 to 6 were based on a two scale model, where large scales are solved using the same titled facets geometric optics approach, but shorter scales (with respect to the wavelength of observation) are solved as a surface scattering problem, and applied as a modulation to the emissivity. In each case the effect of foam is added as an ad hoc correction to

the emissivity. No account is taken of the asymmetry of foam coverage on waves. The two scale models suffer from the arbitrary nature of the division of large and short scales. In a reference model a ray-tracing full EM solver should be employed to reduce the uncertainty arising from the actual solver to a very low level. Such models have been developed for the land surface problem (e.g. for SMOS at L-band) and could be applied to the ocean case, given suitable inputs from the wave spectrum model.

### 3. Conclusions

The priorities for the reference model are that it should be,

1. Maintained and supported;
2. Have traceable uncertainty estimation at each step;
3. Be documented code freely available to research community;
4. Have new science [7], [8], for IR to MW with BRDF capability (Rec from ECMWF-JCSDA workshop, Dec 2015);
5. Support passive and active applications.

It is our view that the development of such a reference model is urgently needed to ensure effective use of both microwave and infrared sounding observations near the ocean surface. Without it the future scientific development of fast models will be limited, and the use of near surface channels will be hampered by lack of confidence in the overall uncertainty assessment.

#### *Acknowledgments.*

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