Improving Sea Surface Microwave Emissivity Model for Radiance Assimilation

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2nd Workshop on Remote Sensing and Modeling of Surface Properties

9-11 June 2009, Toulouse, France

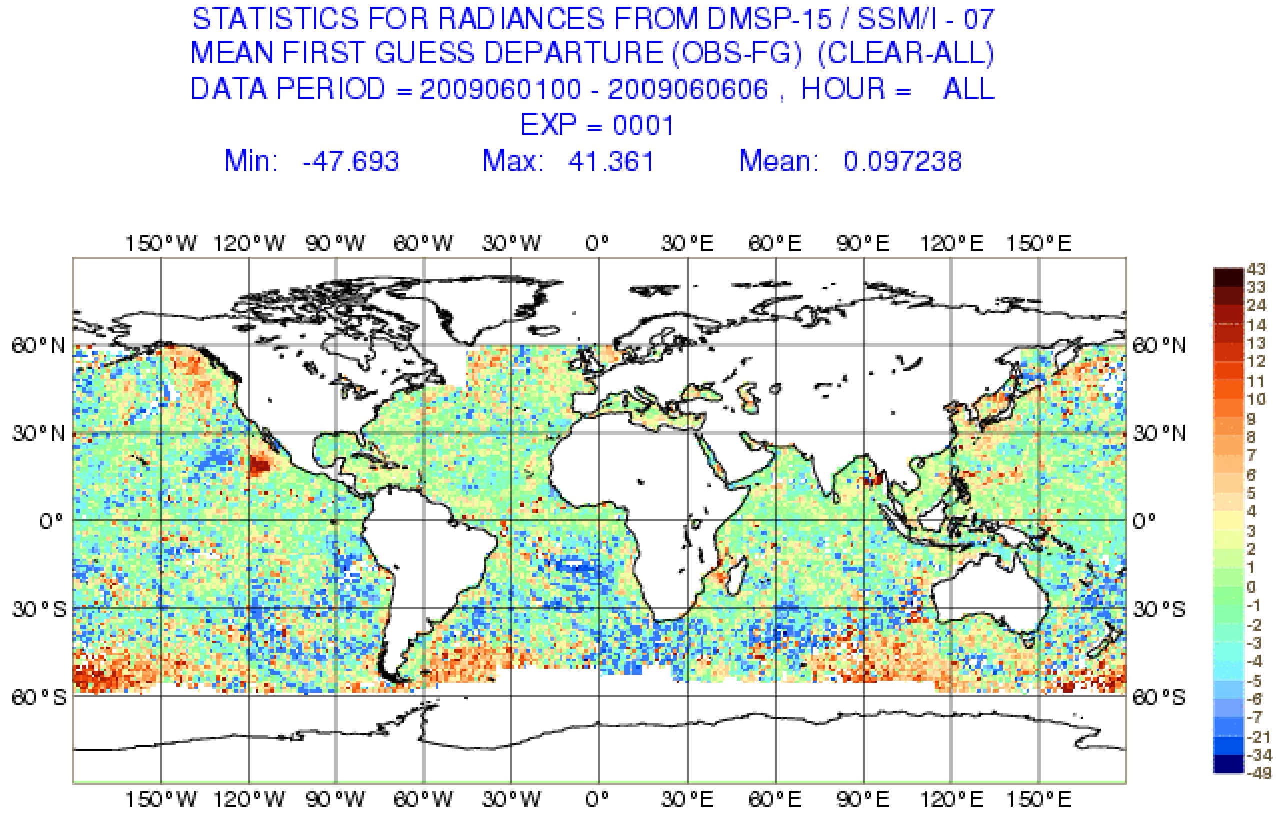
OUTLINE

- Overview
- Errors in Fastem model
- Improved model (permittivity and roughness)
- SUMMARY and Future Work

Overview

- Microwave emissivity model uncertainty and inadequate cloud detection leads to poor use of microwave window channel radiances in data assimilation
- Fastem model is widely used but has large errors:
  - Biases at high frequency
  - Inadequate treatment of roughness for lower frequency observations
  - Does not allow for salinity variation
- Mark Liu visited NWPSAF (Met Office, Exeter) in 2008 to address these issues.

ECMWF SSMI F15 Ob-FG



Permittivity Models

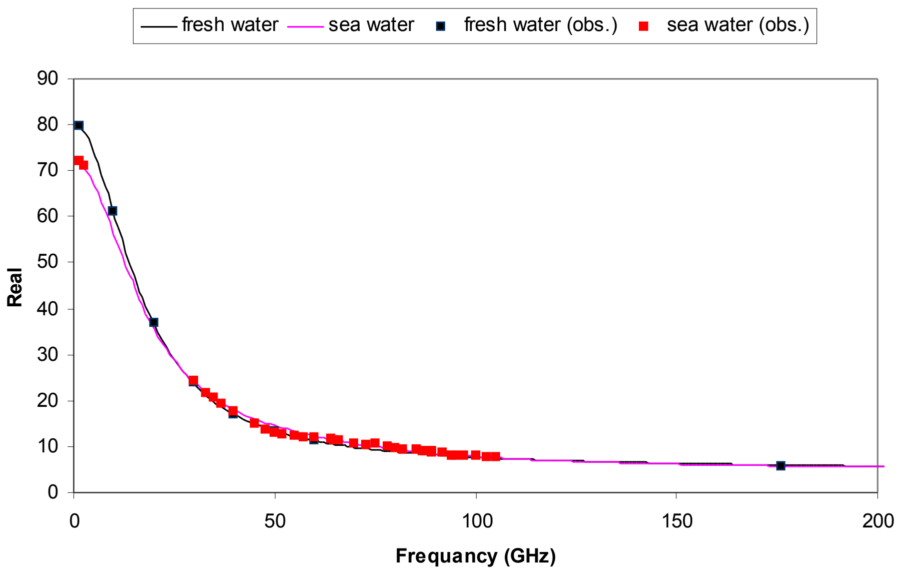
- Permittivity models are either single or double Debye's formula due to polarization.
- Single Debye's model: Stogryn, 1971; Klein and Swift, 1977; Ellison et al., 1998; Guillou et al., 1998.
- Double Debye's model: Ellison et al., 2003; Meissner and Wentz, 2004; Romaraju and Trumpf, 2006.
- For a low frequency (< 20 GHz), permittivity depends on salinity.
- Permittivity model of Ellison et al. (2003) is used in the FASTEM emissivity model that are applied in RTTOV and Community Radiative Transfer Model (CRTM).

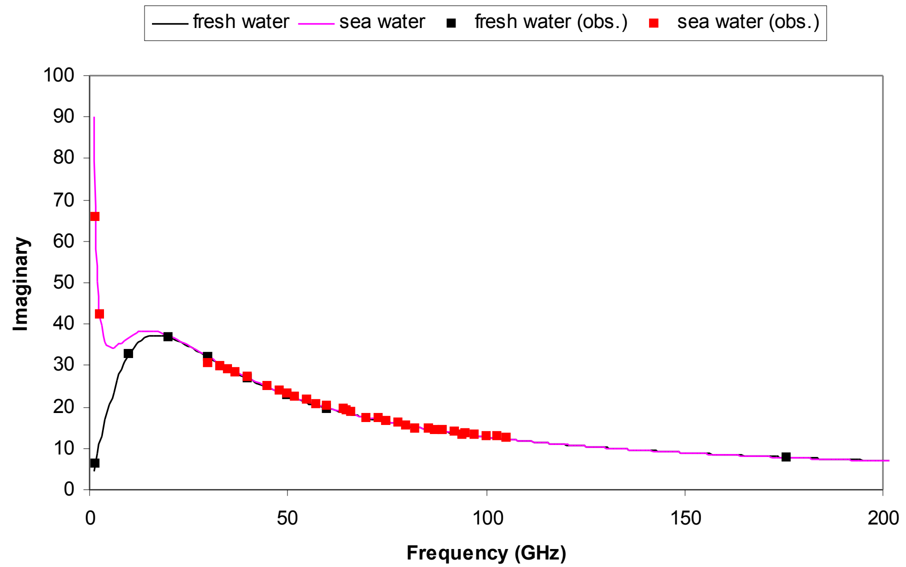
Permittivity comparisons, model vs measurement

The permittivity model of Ellison (2003) is for a fixed salinity of 35‰.
The permittivity model of Somaraju and Trumpf (2006) has a simple expression, but its empirical coefficients were not derived from measurements.
The model of Meissner and Wentz (2004) can be used for frequencies up to 500 GHz. The model fits measurements well, generally. But, its permittivity at an infinitive frequency depends on salinity, conflict with physics.
We (this model) remove the salinity dependency and revise fitting coefficients.

	Sea water				Pure water			
	real		imaginary		real		imaginary	
	bias	rms	bias	rms	bias	rms	bias	rms
This model	0.02	0.71	0.03	0.52	-0.02	0.34	0.00	0.35
Meissner and Wentz, 2003	1.18	1.34	0.14	0.58	-0.02	0.34	0.00	0.35
Guillou et al., 1998	0.32	1.06	-1.34	1.50	-0.23	2.05	-0.40	2.30
Klein and Swift, 1977	1.44	1.63	-0.45	0.95	0.02	0.44	-0.09	0.58
Ellison et al. (2003), S=35‰	0.09	0.98	0.63	4.46				

Permittivity





The results using this modified model are given in black line for fresh water) and red line for sea water. The symbol squares are measurements for fresh water (black) and sea water (red).

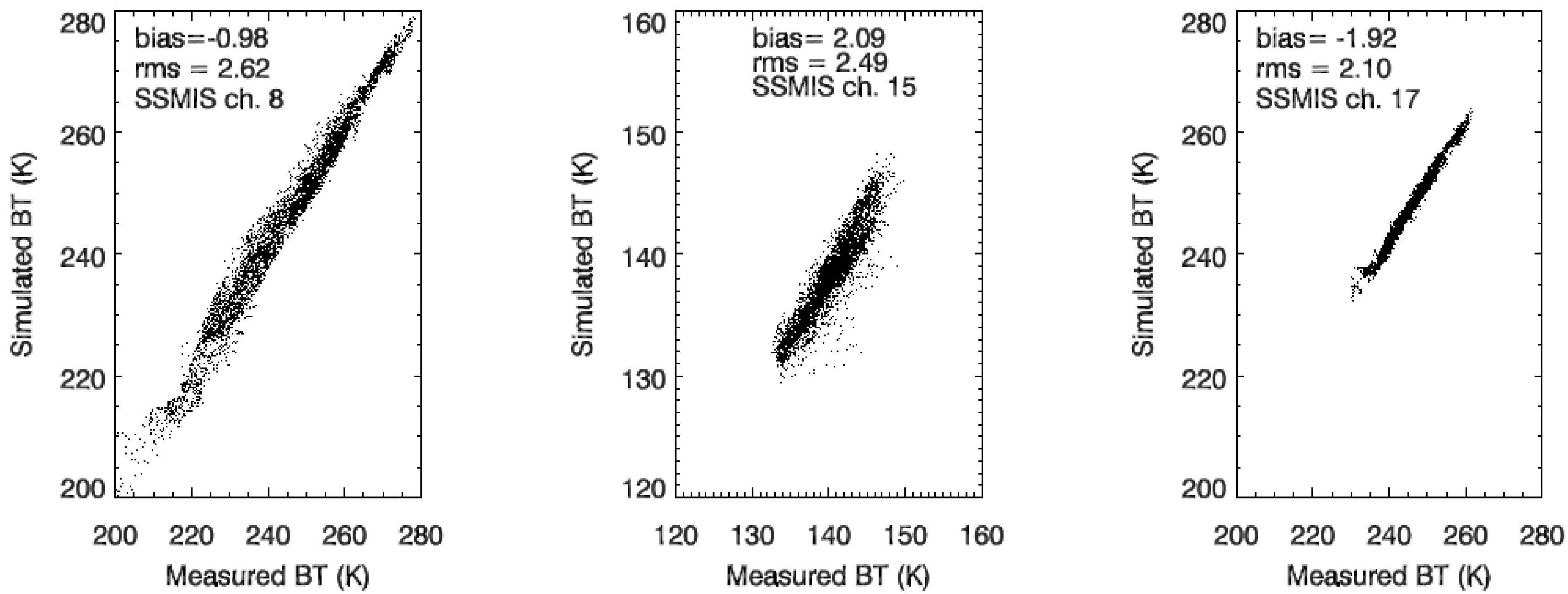
Roughness spectrum

- Coupled short, intermediate, and long-waves.
- Gaussian distribution with Cox and Munk (1954) slope variance.
- Bjerkaas and Riedel (1979) is a composite model without a wave age dependency.
- Donelan and Pierson (1987), disagree with Cox and Munk
- Apel's (1994), disagree with Cox and Munk.

Two-Scale Emissivity Model

- The theory is primarily based on several literatures by Yueh (1997) and Yueh et al. (1995) and Gasiewski and Kunkee (1994).
- Bjerkaas and Riedel (1979).
- The cut-off wavelength is optimally and automatically selected.
- Monte-Carlo two-scale emissivity model (Liu et al., 1998)
- Large differences from geometric optics model used for generating Fastem coefficients.

window channel (FASTEM3, 5263 points)



Using NWP cloud water path, and polarization, and ch. 18 to screen out cloudy pixel.

Fastem-4?

- Include new permittivity model, including salinity.
- Treatment of roughness identical to Fastem-3 but coefficients calculated from new 2 scale model.
- Substantially reduces biases versus SSMIS and AMSR-E measurements.
- Will be incorporated as part of RTTOV-10.

SUMMARY and Future Work

- Cloud identification is very important for microwave window channels, in particular horizontally polarized channels.
- Improvement of quality control scheme in our NWP radiance assimilation is required.
- Further comparisons for conical and cross-scan microwave sensors.
- Finalizing fitting coefficients for FASTEM3 for all frequencies and salinity.

Extra slides

Double Debye's Model

Double Debye's model fits measurements better, in particular at high frequencies.

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_1}{1 + j2\pi f\tau_1} + \frac{\varepsilon_1 - \varepsilon_\infty}{1 + j2\pi f\tau_2} + j\frac{\sigma}{2\pi f\varepsilon_0}$$

Where f the frequency, ε_∞ ε_1 ε_s are the permittivity at infinitive

and intermediate frequencies, and static.

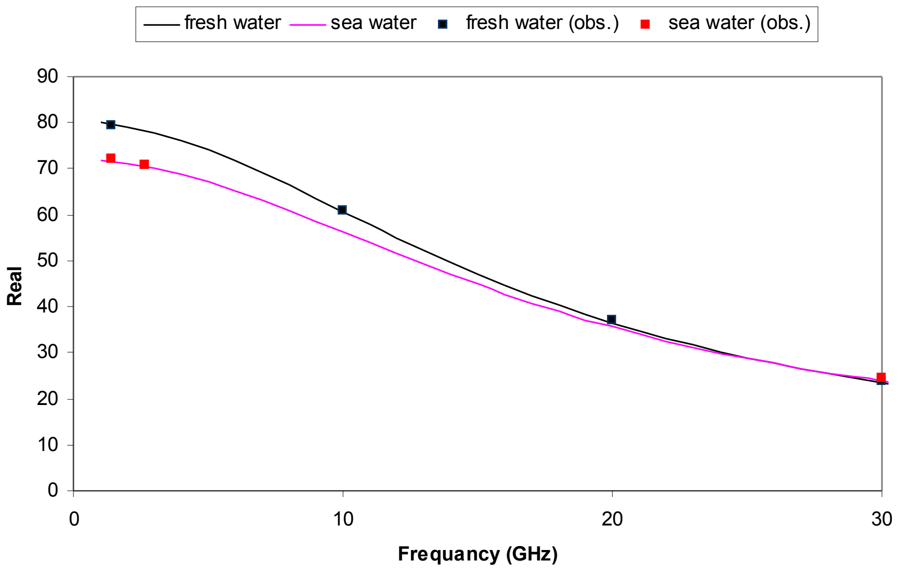
τ_1 τ_2 are relaxation times, σ the ionic conductivity of the dissolved salt.

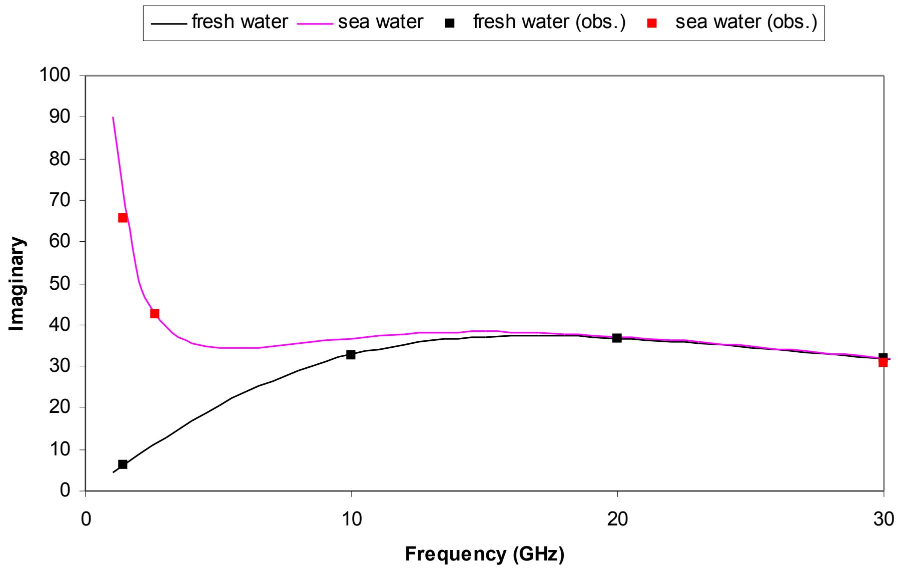
The dielectric constant at an infinitive frequency is a function of water temperature. Other Debye's parameters are a function of water temperature and salinity.

These functions are often empirical, and empirical coefficients are fitted with limited measurements.

$\varepsilon_0 = 8.8429 \times 10 F / m$ the permittivity of free space.

Permittivity for low frequency





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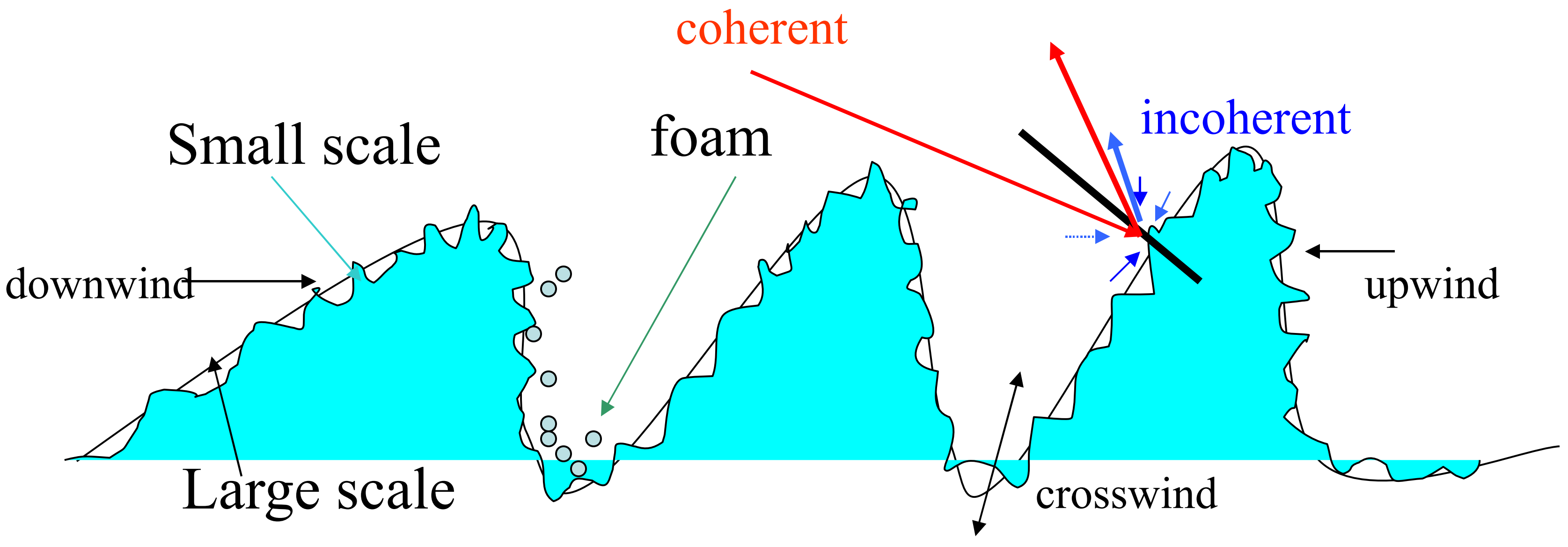
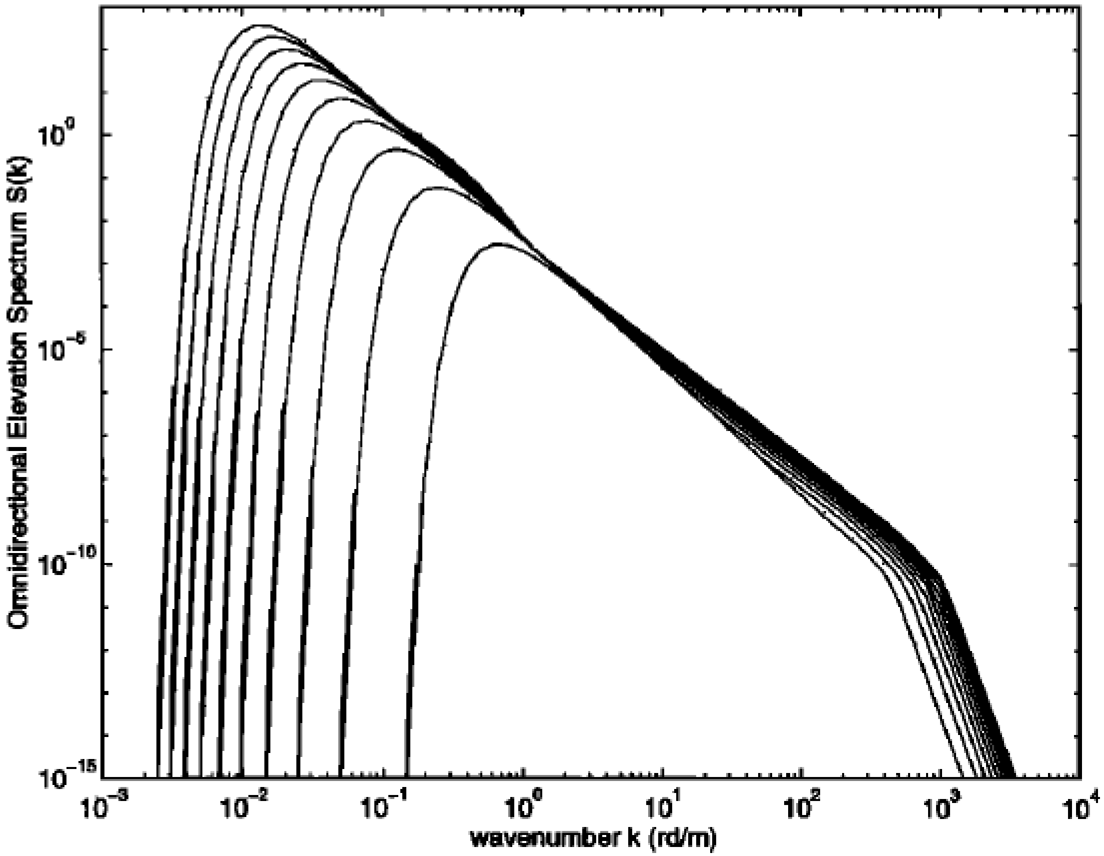
Surface Roughness Model

The large-scale roughness is dependent on the gravity waves and whereas the small irregularities is affected by capillary waves. There are coherent reflection and incoherent scattering associated with the waves in both scales



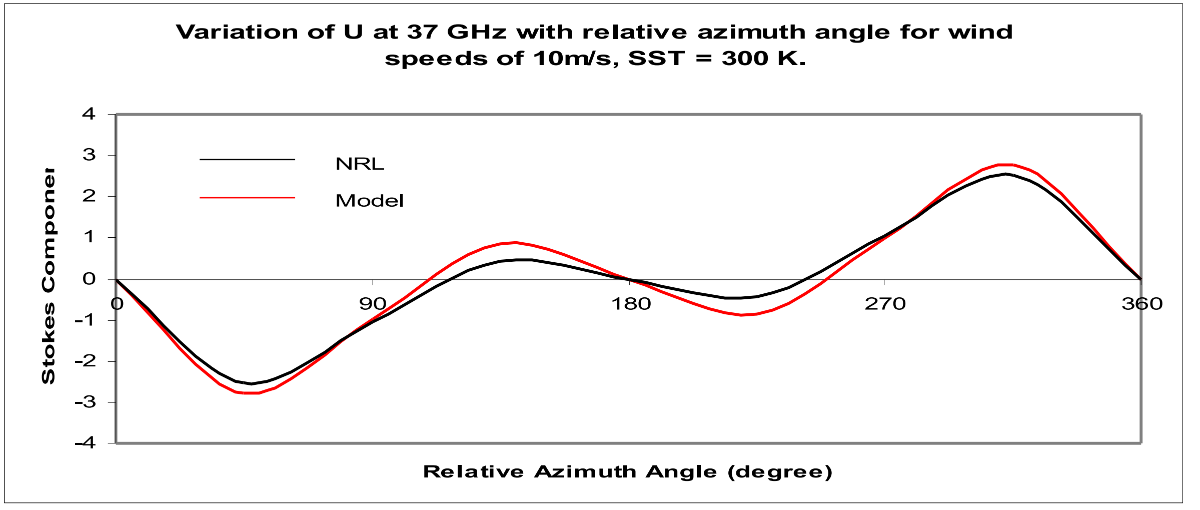
Bjerkaas and Riedel (BR) spectrum

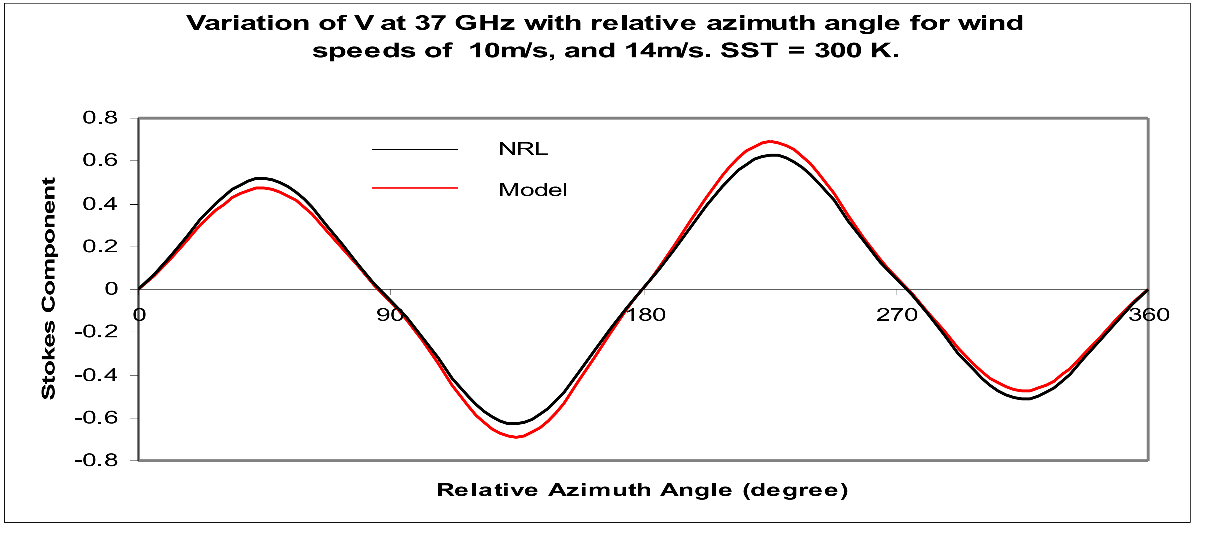
We use BR spectrum in this study.



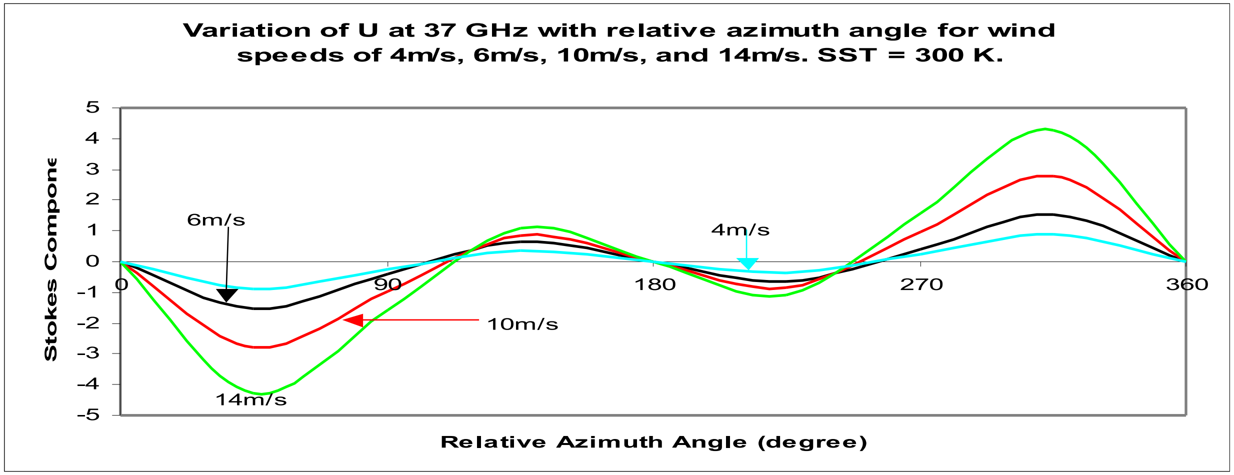
Sea surface roughness spectrum for various wind speeds (Elfouhaily et al., 1997).

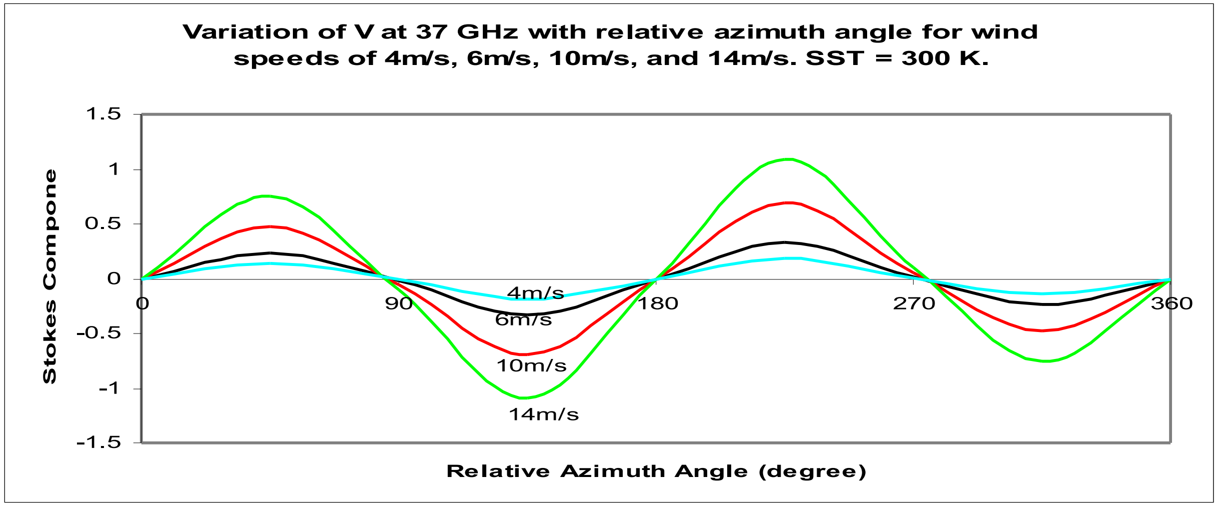
Model vs. NRL measurements



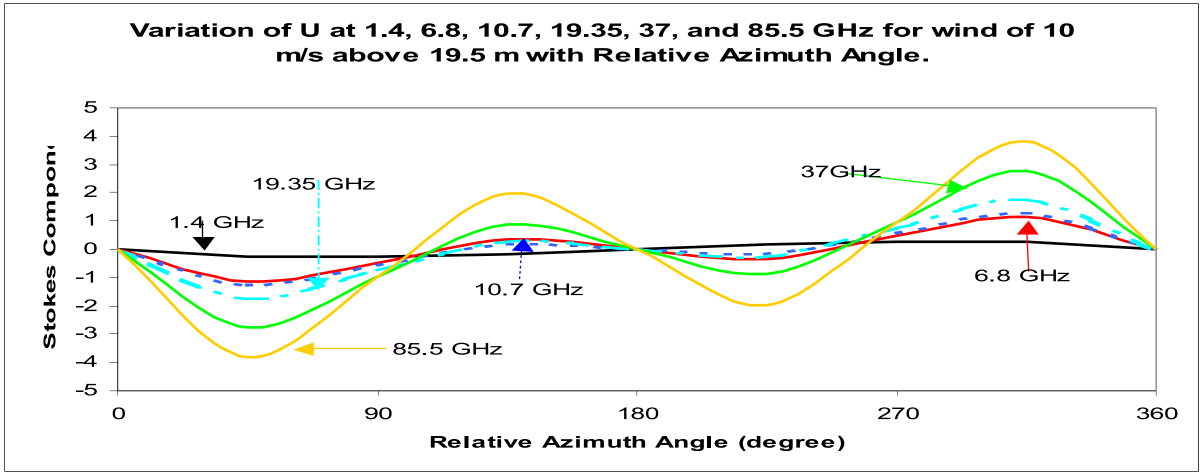


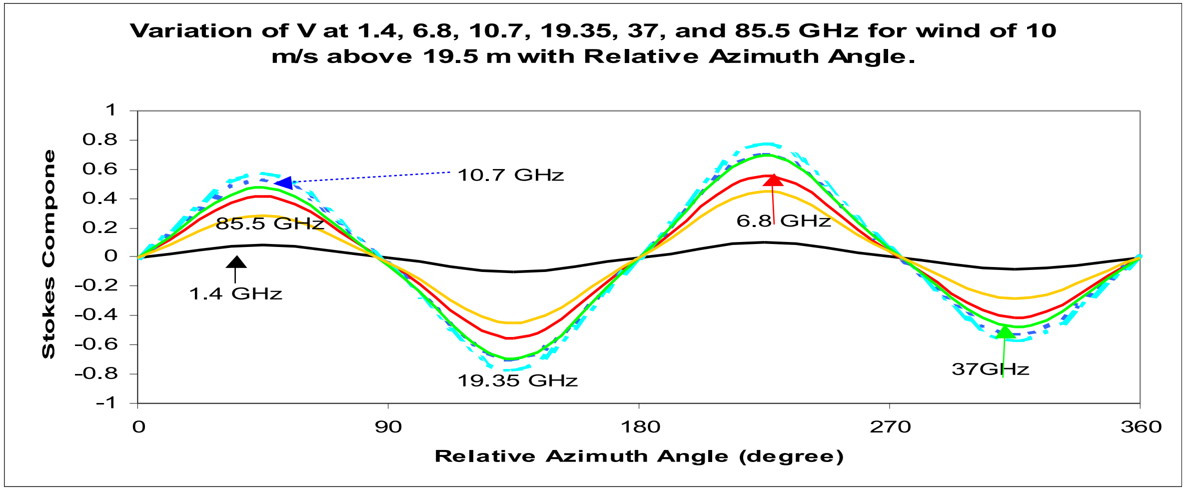
Variation of emissivity to azimuth angles for different wind speeds





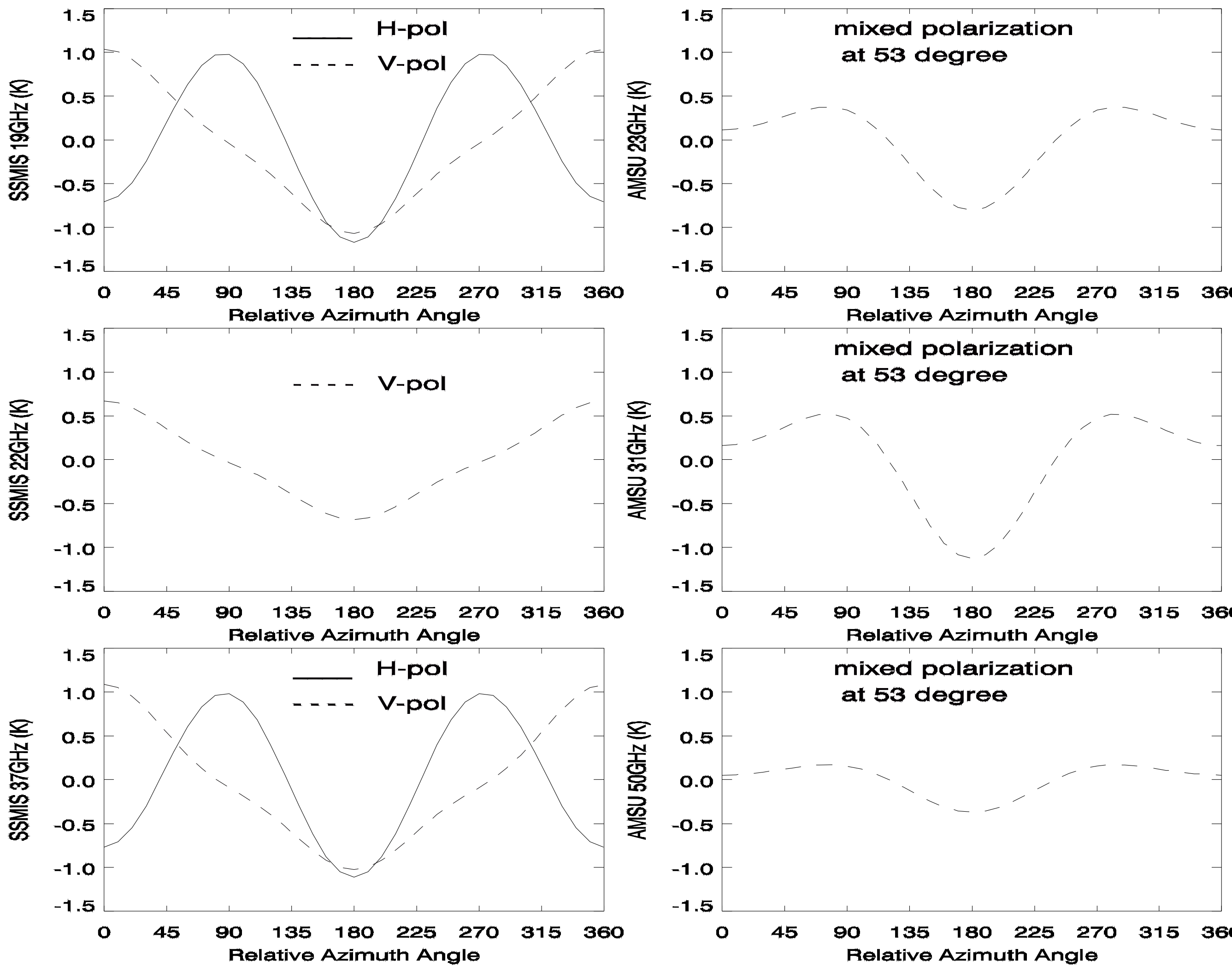
Variation of emissivity to azimuth angles for different frequencies





Surface emissivity/reflectivity model (2)
Polarimetric ocean surface model

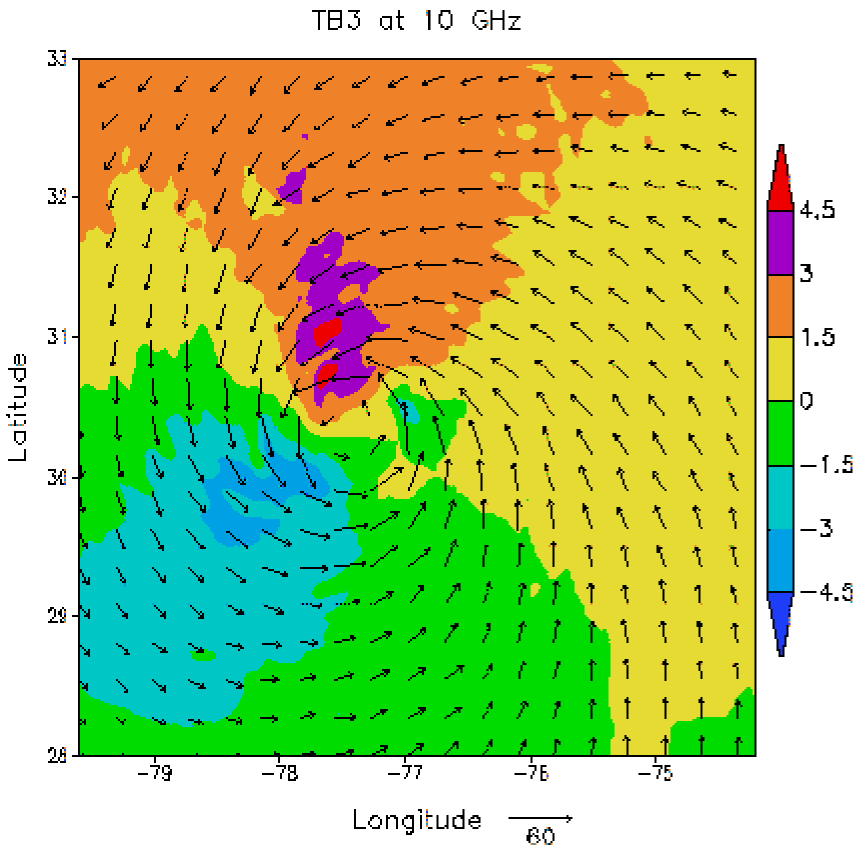
Microwave polarimetric emissivity model has been preliminarily implemented in CRTM. The model allows users not only simulate polarimetric sensor WINDSAT, but also the wind-directional variation for SSMIS and AMSU.



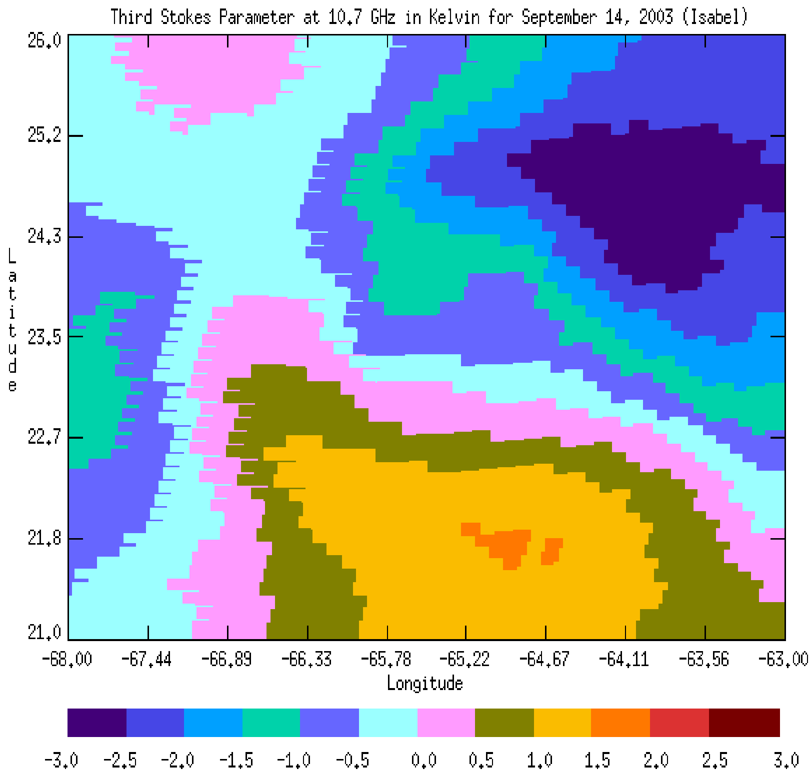
New signatures from Hurricane Isabel

The third Stokes parameter from Windsat observations of 3rd Stokes parameter clearly reveals the vortex structure of surface wind.

Simulations for Bonnie



Windsat observation for Isabel



Fast Emissivity Model

RTTOV and CRTM models adopt the FASTEM microwave sea surface emissivity model (English, 1998).

Large bias and rms error between measurements and simulations have been reported.

This study found that current cloud screen method is insufficient,
in particular the single channel quality control technique.

This study compares modeling and measurements using two cloud screening:

a. NWP cloud water content (< 10/m2)
b. NWP cloud water content, polarization, and ch. 18.

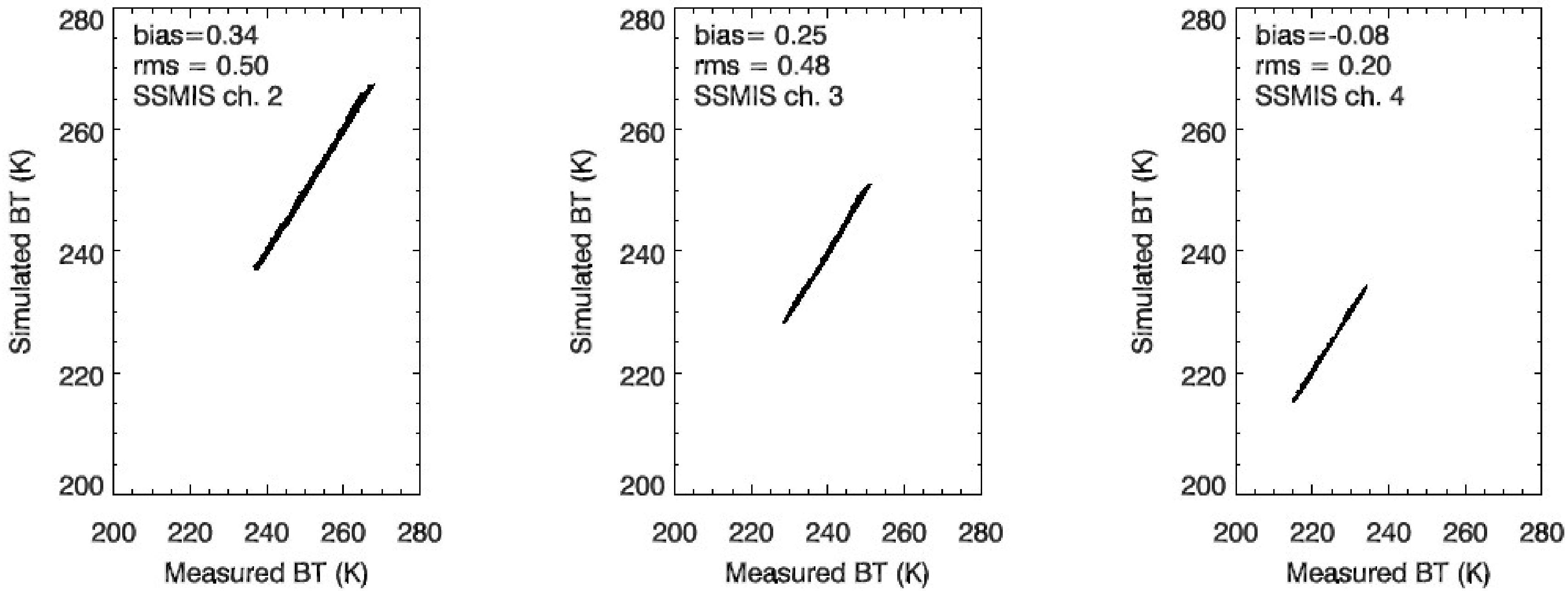
One day (Jan. 21, 2009) SSMIS data and UK NWP analysis data are applied.

SSMIS sensor

Table 1. SSMIS Nominal Parameters

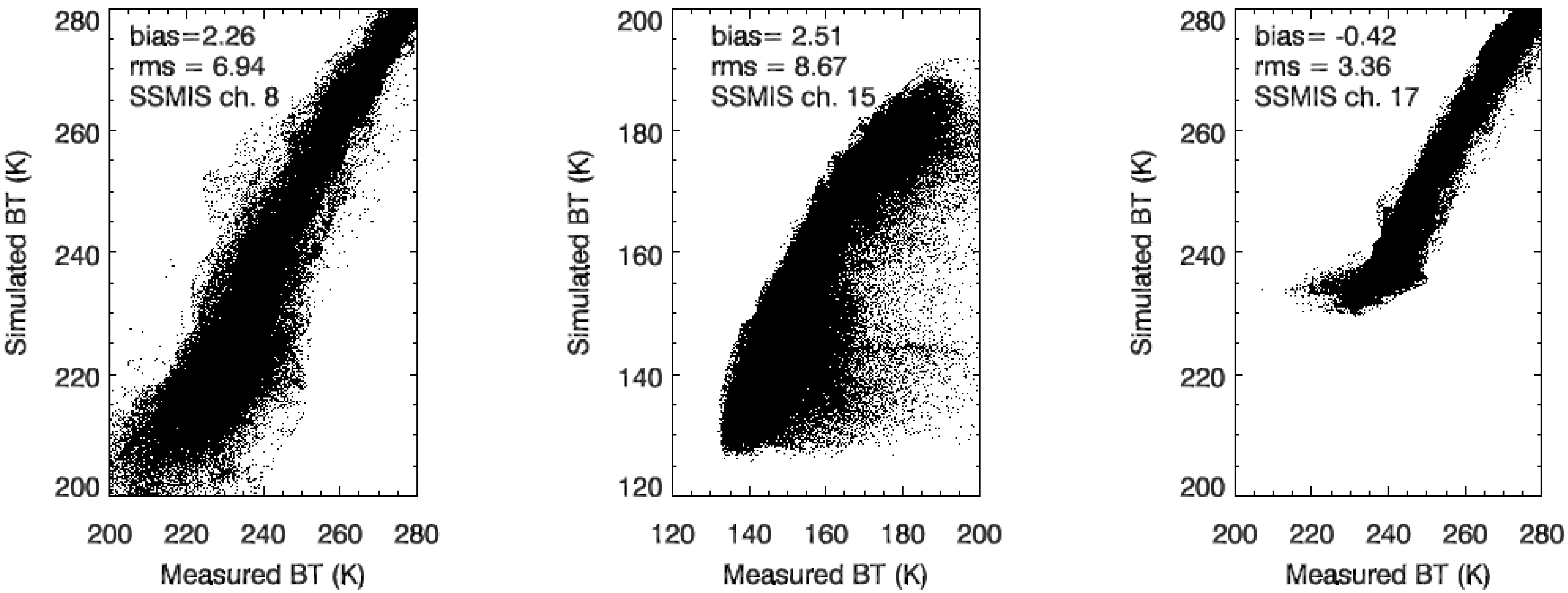
Channel Number	Frequency, GHz	1st IF, MHz	2nd IF, MHz	Band Width, MHz	Polarization	Resolution, Cross × Down, km
1	50.300	0	0	400	V	37.7 × 38.8
2	52.800	0	0	400	V	37.7 × 38.8
3	53.596	0	0	400	V	37.7 × 38.8
4	54.400	0	0	400	V	37.7 × 38.8
5	55.500	0	0	400	V	37.7 × 38.8
6	57.290	0	0	350	RC	37.7 × 38.8
7	59.400	0	0	250	RC	37.7 × 38.8
8	150.000	1250	0	1500	H	13.2 × 15.5
9	183.310 ± 6.6	6600	0	1500	H	13.2 × 15.5
10	183.310 ± 3	3000	0	1000	H	13.2 × 15.5
11	183.310 ± 1	1000	0	500	H	13.2 × 15.5
12	19.350	0	0	400	H	46.5 × 73.6
13	19.350	0	0	400	V	46.5 × 73.6
14	22.235	0	0	450	V	46.5 × 73.6
15	37.000	0	0	1500	H	31.2 × 45.0
16	37.000	0	0	1500	V	31.2 × 45.0
17	91.655	900	0	1500	V	13.2 × 15.5
18	91.655	900	0	1500	H	13.2 × 15.5
19	63.283248	285.271	0	1.5	RC	75.2 × 75.0
20	60.792668	357.892	0	1.5	RC	75.2 × 75.0
21	60.792668	357.892	2.0	3.0	RC	75.2 × 75.0
22	60.792668	357.892	5.5	6.0	RC	75.2 × 75.0
23	60.792668	357.892	16	16.0	RC	75.2 × 75.0
24	60.792668	357.892	50	60.0	RC	37.7 × 38.8

Sounding channel comparison



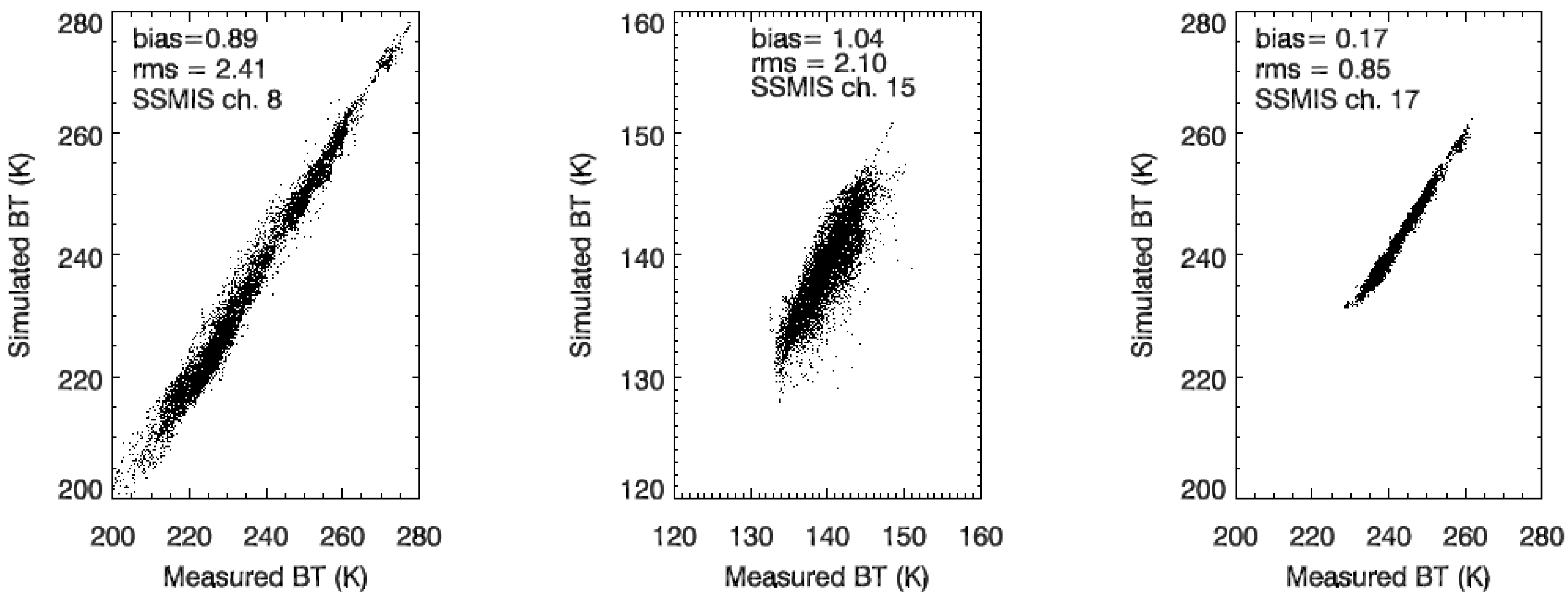
Using NWP cloud water path to screen out cloudy pixel.

window channel comparison



Using NWP cloud water path to screen out cloudy pixel.

window channel (8018 points, Fastem3 with new fitting coefficients)



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