Empirical Model for Sea Spray Production

Michael H. Bettenhausen[1], Sarah J. Norris[2], Ian M. Brooks[2], Ivan B. Savelyev[1], John Prytherch[2], Magdalena D. Anguelova[1], Margaret J. Yelland[3], Robin W. Pascal[3], Dominic J. Salisbury[2]
[1]Remote Sensing Division, Naval Research Laboratory, [2]School of Earth & Environment, University of Leeds, Leeds, UK, [3]National Oceanography Centre, Southampton, UK

Project Description

Goal: Develop a reliable sea spray source term for global aerosol modeling using satellite microwave radiometers. Method:

- Collocate in situ sea spray production flux measurements with satellite microwave radiometer observations.
- Derive the microwave brightness temperature contribution from ocean surface emission for the collocated observations.
- Develop a parameterization for the sea spray production flux based on the ocean surface brightness temperatures.

Sea Spray Measurements

The Waves, Aerosol and Gas Exchange Study (WAGES) [2] collected 18 months of near-continuous and autonomous turbulent air-sea flux estimates from the research vessel RRS James Clark Ross. Supporting meteorological and sea-state measurements were also made. We use the following measurements from WAGES:

- size-segregated sea spray aerosol concentration,
- wind vector (adjusted to neutral stability at 10 m height),
- sea surface temperature (SST).

The sea spray aerosol concentration was obtained using the Compact Lightweight Aerosol Spectral Probe (CLASP)[1]. After quality control we begin with a set of 785 measurements taken between 2010-10-05 and 2013-06-06.

WindSat Description

- WindSat is a polarimetric satellite-based microwave imager
- Jointly Sponsored by US Navy and the NPOESS Integrated Program Office; Designed and build by the Naval Research Laboratory (NRL)
- We use only the vertical and horizontally polarized channels for this work.

Freq. (GHz)	Channels	BW (MHz)	EIA (deg)	IFOV (km)
6.8	v, h	125	54.0	39 x 71
10.7	v, h, +/- 45, lc, rc	300	50.3	25 x 38
18.7	v, h, +/- 45, lc, rc	750	55.9	16 x 27
23.8	v, h	500	53.5	20 x 30
37.0	v, h, +/- 45, lc, rc	2000	53.5	8 x 13

FLIP Experiment 2012

Unique simultaneous in-situ measurements of:

- sea spray production
- microwave brightness temperature
- surface foam
- metocean data

Quantitative evidence of relationship between sea spray production and the 10.7 GHz microwave brightness temperatures in the form of ΔT_b [3] where

$$\Delta T_b = \delta T_{bH} - \delta T_{bV}$$
$$\delta T_{bp} = T_{bp} - T_{bp0}$$

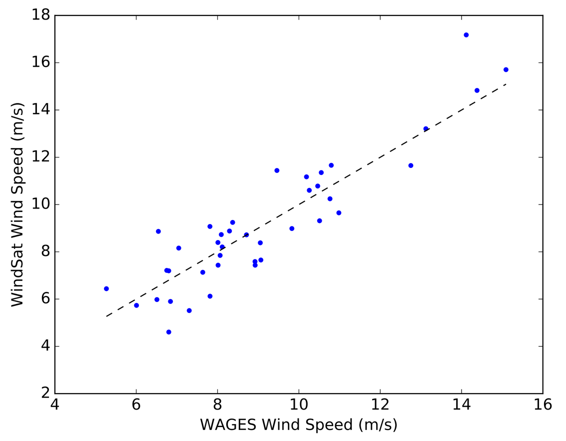
where T_{bp0} is the microwave brightness temperature at polarization p for a flat ocean surface.

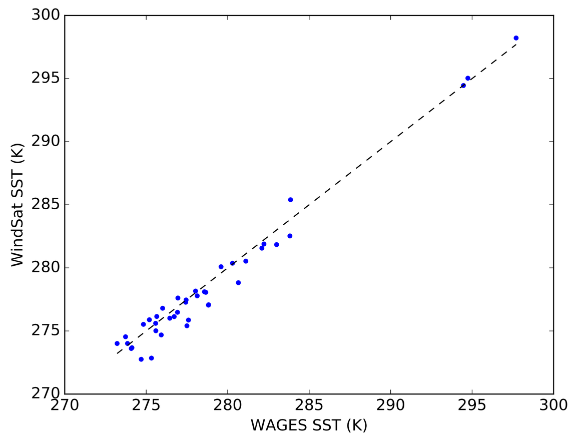
Sea spray production flux parameterized as a function of ΔT_b

$$F = a(\Delta T_b)^m$$

Data Collocation

- We collocate WAGES measurements to WindSat observations within one hour and 50 km.
- One-to-one matchup is obtained by choosing the WAGES measurement closest in time to a WindSat observation.
- We use sea spray production flux measurements with collocated WindSat observations available within one hour and 50 km.
- Total of 30 collocated observations.
- Good agreement between WindSat retrieved wind speed and SST and the in situ measurements from WAGES. RMS differences of 1.1 m/s for wind speed and 1.1 K for SST.





Parameterized Model for WindSat Brightness Temperatures

$$T_{bp} = T_{up} + \tau(T_S - R_p T_{Rp})$$

where

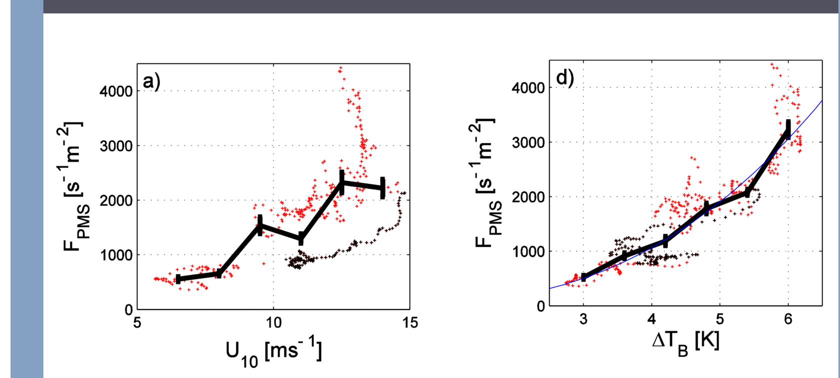
- T_{bp}: brightness temperature for p polarization (vertical or horizontal)
- $T_{R0} = (T_S - T_C) - [T_{down} - T_C(1-\tau)]$
- $T_{Rp} = T_{R0} - [T_{down} - T_C(1-\tau)]\Omega_p$
- T_{up}, T_{down}: upwelling and downwelling temperatures
- R_p: isotropic sea surface reflectivity
- T_S: sea surface temperature
- T_C: cosmic background temperature ($\approx$ 2.7 K)
- Ω: correction for non-specular reflection
- τ: atmospheric transmissivity

- To obtain T_bs corresponding to those measured during the FLIP experiment we need to remove the atmospheric contribution.
- The NRL WindSat ocean retrieval algorithm [4] retrieves SST, wind vector, precipitable water vapor (PWV) and cloud liquid water (CLW).
- WindSat retrieved PWV and CLW are used to calculate T_{down}, T_{up} and τ.
- We solve for the R_p using

$$R_p = (T_S - (T_{bp} - T_{up})/\tau)/T_{Rp}$$

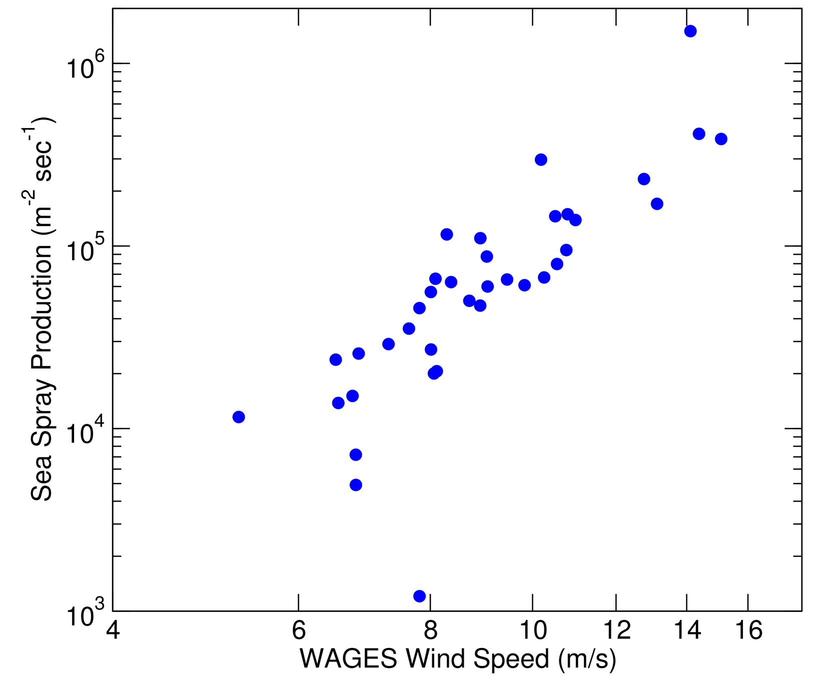
then taking R_{0p} as the reflectivity of a flat ocean surface

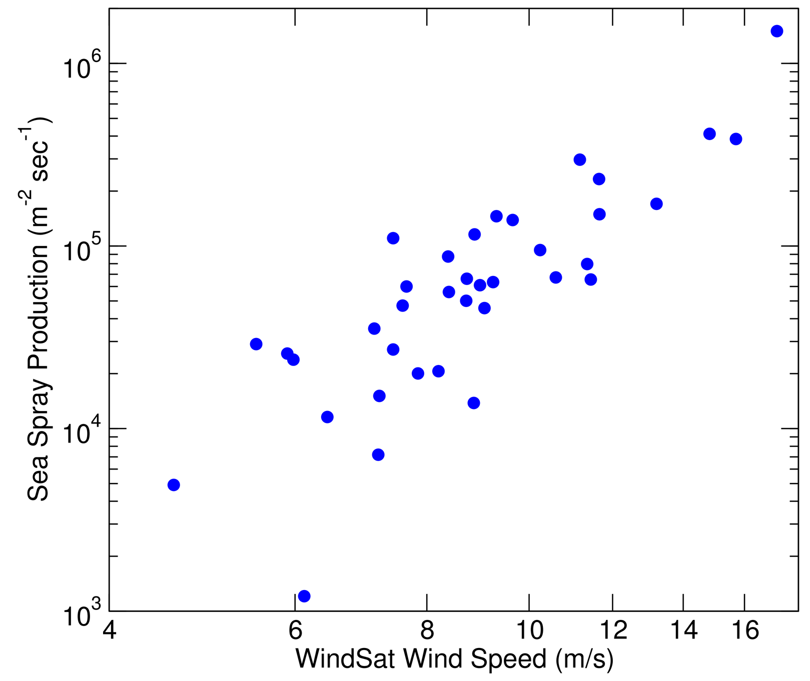
$$\delta T_{bp} = (R_{0p} - R_p)T_S$$



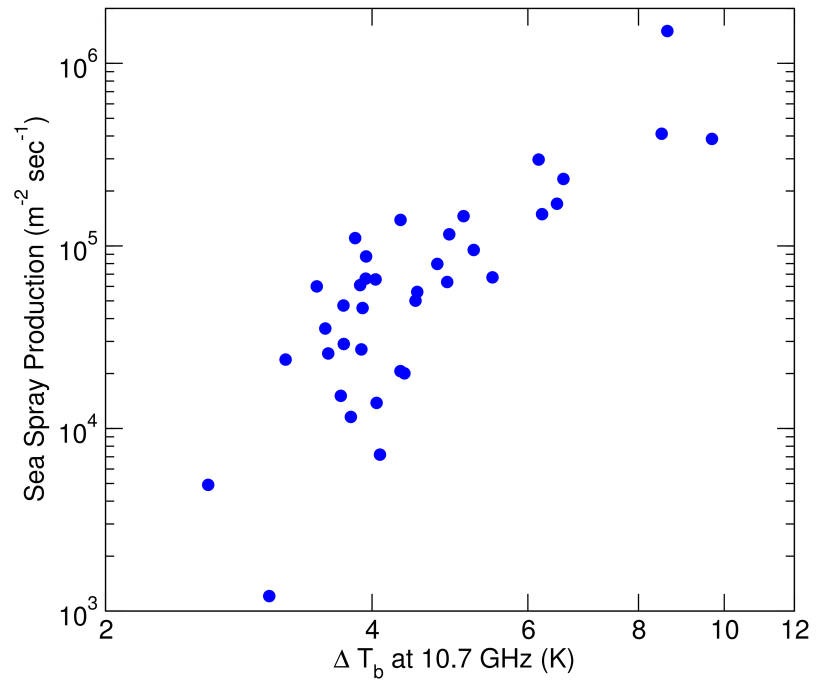
Initial Results

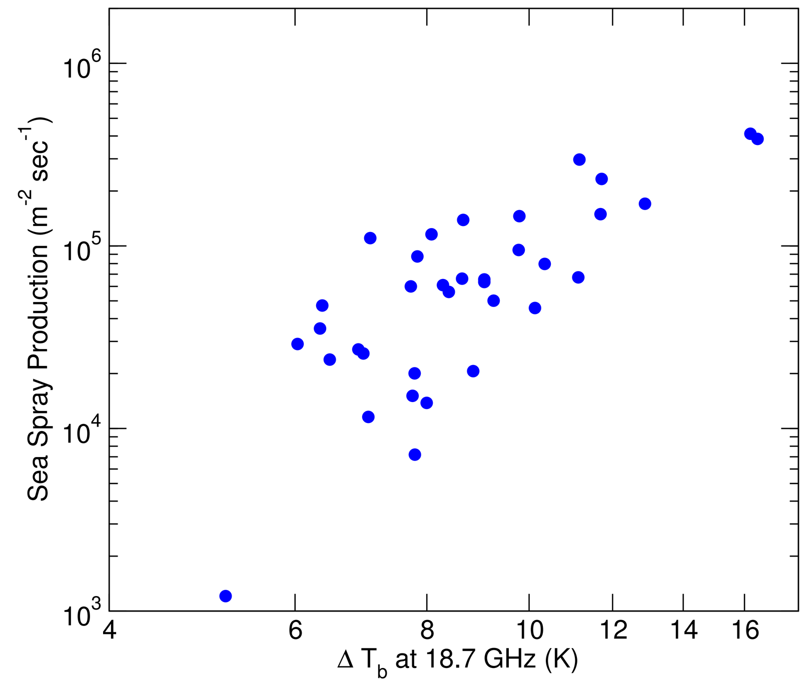
Total sea spray production flux versus wind speed.





Total sea spray production flux versus ΔT_b.





Sources of Uncertainty

- Spatial and temporal mismatch between the WAGES and WindSat measurements.
  - WindSat T_b resolution used here is 25 km x 35 km
  - Sea spray production can vary significantly with collocation limits of 50 km and one hour.
- Measurement noise in the WindSat T_bs.
- Errors in the WindSat parameterized model function.
- Measurement errors in the sea spray production flux.

Conclusions

- Good correspondence between WAGES measured and WindSat retrieved wind speed and SST
- Indication of potential for accurate parameterization of sea spray production flux in terms of microwave brightness temperature from a satellite-based radiometer
  - Satellite measurements would then provide global sea spray source term

Future Work

- Calculate sea spray production as mass flux by accounting for particle size distribution.
- Investigate using microwave observations from the AMSR-E and AMSR2 instruments to increase the number of data points.
- Parameterize mass production flux as a function of ΔT_b.
- Complete an error analysis.

References

1. M.K. Hill, B.J. Brooks, S.J. Norris, M.H. Smith, I.M. Brooks, G. de Leeuw, "A compact lightweight aerosol spectral probe (CLASP)," J. Atmos. Oceanic Technol., 2008, v.25, 1996-2006, doi:10.1175/2008JTECHA1051.1.
2. J. Prytherch, M.J. Yelland, I.M. Brooks, D.J. Tupman, R.W. Pascal, B.I. Moat, S.J. Norris, "Motion-correlated flow distortion and wave-induced biases in air-sea flux measurements from ships," Atmos. Chem. Phys. 2015, v.15, 10619-10629, doi:10.5194/acp-15-10619-2015.
3. I.B. Savelyev, M.D. Anguelova, G.M. Frick, D.J. Dowgiallo, P.A. Hwang, P.F. Caffrey, and J.P. Bobak, "On direct passive microwave remote sensing of sea spray aerosol production," Atmos. Chem. Phys. 2014, v.14, 11611-11631, doi:10.5194/acp-14-11611-2014.
4. M.H. Bettenhausen, C.K. Smith, R.M. Bevilacqua, N.Y. Wang, P.W. Gaiser, S. Cox, "A nonlinear optimization algorithm for WindSat wind vector retrievals," IEEE Trans. Geosci. Remote Sens., 2006, v.44, 597-610, doi:10.1109/TGRS.2005.862504.

Mail: bettenhausen@nrl.navy.mil
WWW: http://www.nrl.navy.mil/windsat