Sea-state based estimation of white cap fraction : Implications for primary marine aerosol fluxes

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Global Modeling & Assimilation Office

A11G-2285

1. Introduction

- Wave breaking is a ubiquitous surface phenomena across the global oceans. Energy dissipated during wave breaking has important consequences for air-sea interactions, heat and momentum transfer, aerosol and gas exchange, and operational wave modeling.
- Air entrainment from breaking waves generate bubbles that rise to the surface resulting in oceanic whitecaps (WC). WC is the most direct way to parameterize bubble mediated marine aerosol and gas emissions from the oceans.
- WC fraction is commonly parameterized using wind speed at 10m (U_{10}). However, WC values are not uniquely linked to U_{10} and therefore should include explicit wind and wave field properties in the parameterizations (Brumer et al., 2017).
- UMWM-2.0 (University of Miami wave model) was implemented in GEOS-5 (GEOS-UMWM) and physically motivated WC parameterizations based on wind and wave field properties were incorporated in the seasalt aerosol emission modules in GEOS.
- The goal of this study is to assess the spatial and seasonal variability of total WC fraction and compare results from the new physically motivated parameterization to previous predictions of WC based on U_{10} and friction velocity. We also compare model results with satellite retrievals of WC from Anguelova et al. (NRL)

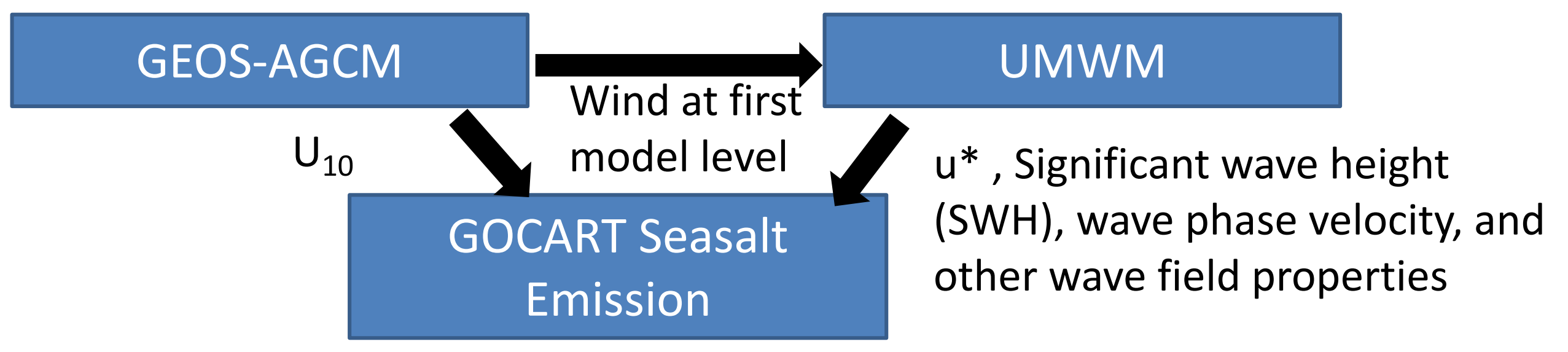
2. Implementing physically motivated WC in GEOS-UMWM

- The GEOS-5 AGCM is a robust weather and climate-capable model used for meteorological analysis, weather and composition forecasting, coupled and uncoupled climate predictions at 2° - 0.25° horizontal resolution, with 72 vertical layers upto 0.01 hPa (Rienecker et al., 2008).
- UMWM wave model implemented in GEOS-5 simulates wave energy spectrum, E(k,Φ) for 36 wave numbers (k) and 37 directions (Φ). There is a feedback of GEOS-5 winds to UMWM in the current setup.
- Sources and sinks for waves include : 1) Wind Input , 2) Non-linear Interaction , 3) Wave breaking and dissipation, 4) Dissipation due to turbulence and viscous forces (see poster please see poster # OS31E-1837 for details on implementation in GEOS)
- Aerosols in GEOS-AGCM are simulated using the online Goddard Chemistry, Aerosol, Radiation, and Transport model (GOCART) . WC parameterizations based on Monahan et al., 1971 (WC_{Mon}), WC GEOS based on friction velocity from the wave model (WC_{GEOS}), and WC based on Deike et al., 2017 and Anguelova et al., 2012 are compared with the satellite database for WC (WC_{D17A}). We focus on total WC (WC active + decay).

$$\mathbf{WC_{Mon}}\ \alpha\ \left(\mathbf{U_{10}^{3.41}}\right)$$

$$\mathbf{WC_{GEOS}}\ \alpha\ \left(\mathbf{u_*^{2.41}}\right)$$

$$\mathbf{WC_{D17A}}\ \alpha\left(\frac{1}{R}\right) * c_p * \left(\frac{u_*}{g * SWH}\right)^{2.0}$$



GEOS-AGCM

Wind at first model level

UMWM

U_{10}

u* , Significant wave height (SWH), wave phase velocity, and other wave field properties

GOCART Seasalt Emission

Fig 1. Schematic of GEOS-UMWM and GOCART Seasalt Emission module

3. Results: Global WC patterns and seasonal changes

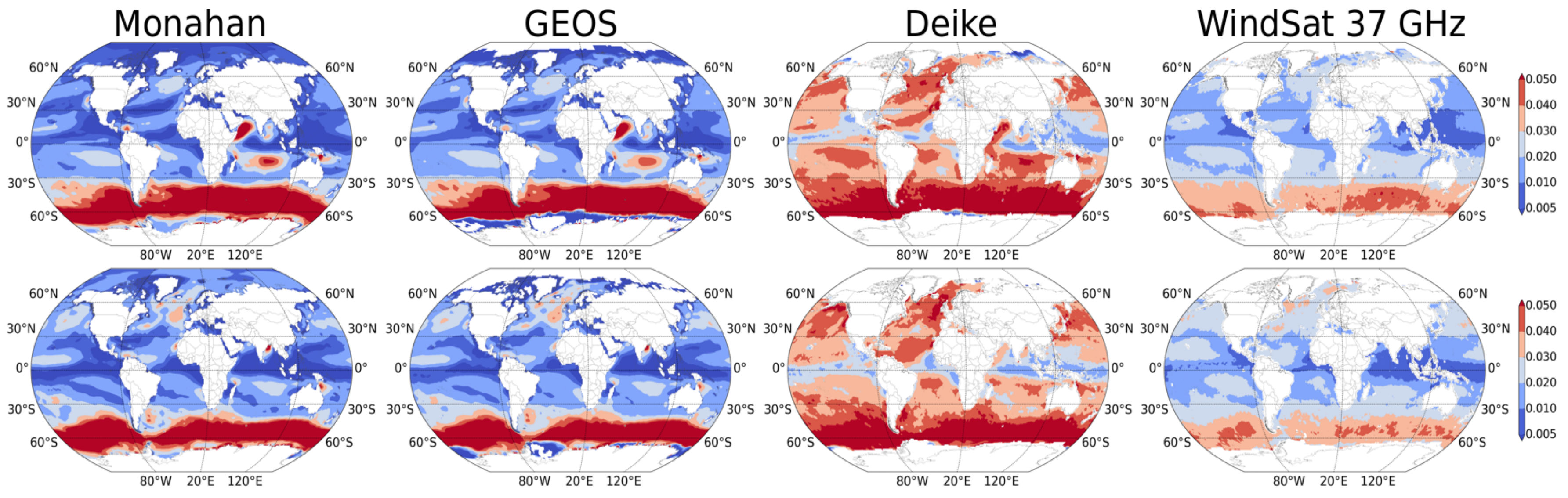


Fig 2. Seasonal means WC fraction June-August(top), April-May (bottom)

3.1 Observation and model comparison statistics

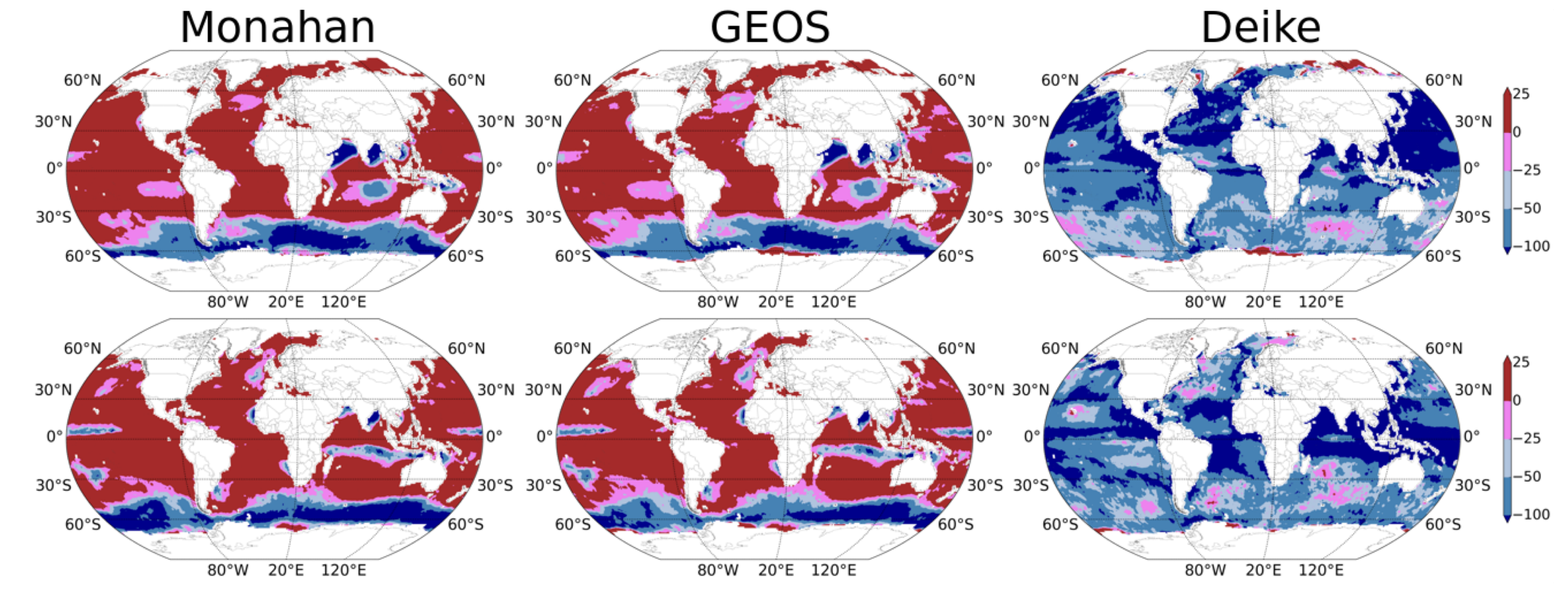
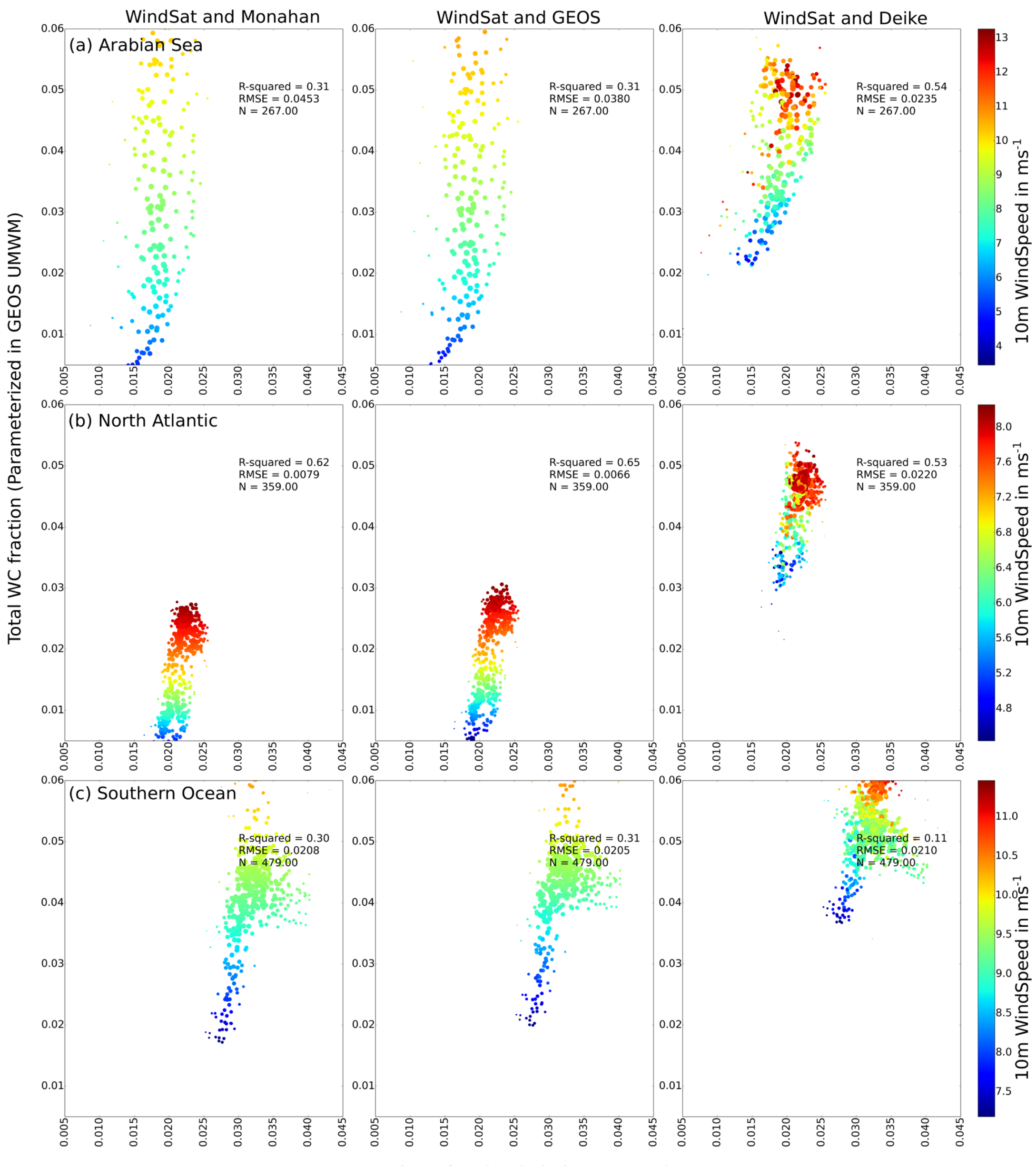


Fig3. Seasonal variation in WC Normalized Mean Difference (top) JJA, (bottom) April-May.
NMD = 100 x ((WC observed – WC predicted)/WindSat).

- WC_{D17A} has a high bias overall upto 150%. WC_{GEOS} and WC_{Mon} have low bias upto 50% over Equator and Mid-latitudes and high bias upto -150% near the poles .
- Seasonal variation is strongest in the Northern Hemisphere. In particular, Indian Ocean, Arabian Sea, and Bay of Bengal show reduction in WC before the monsoon in Apr-May and WC increases during the monsoon in JJA months.

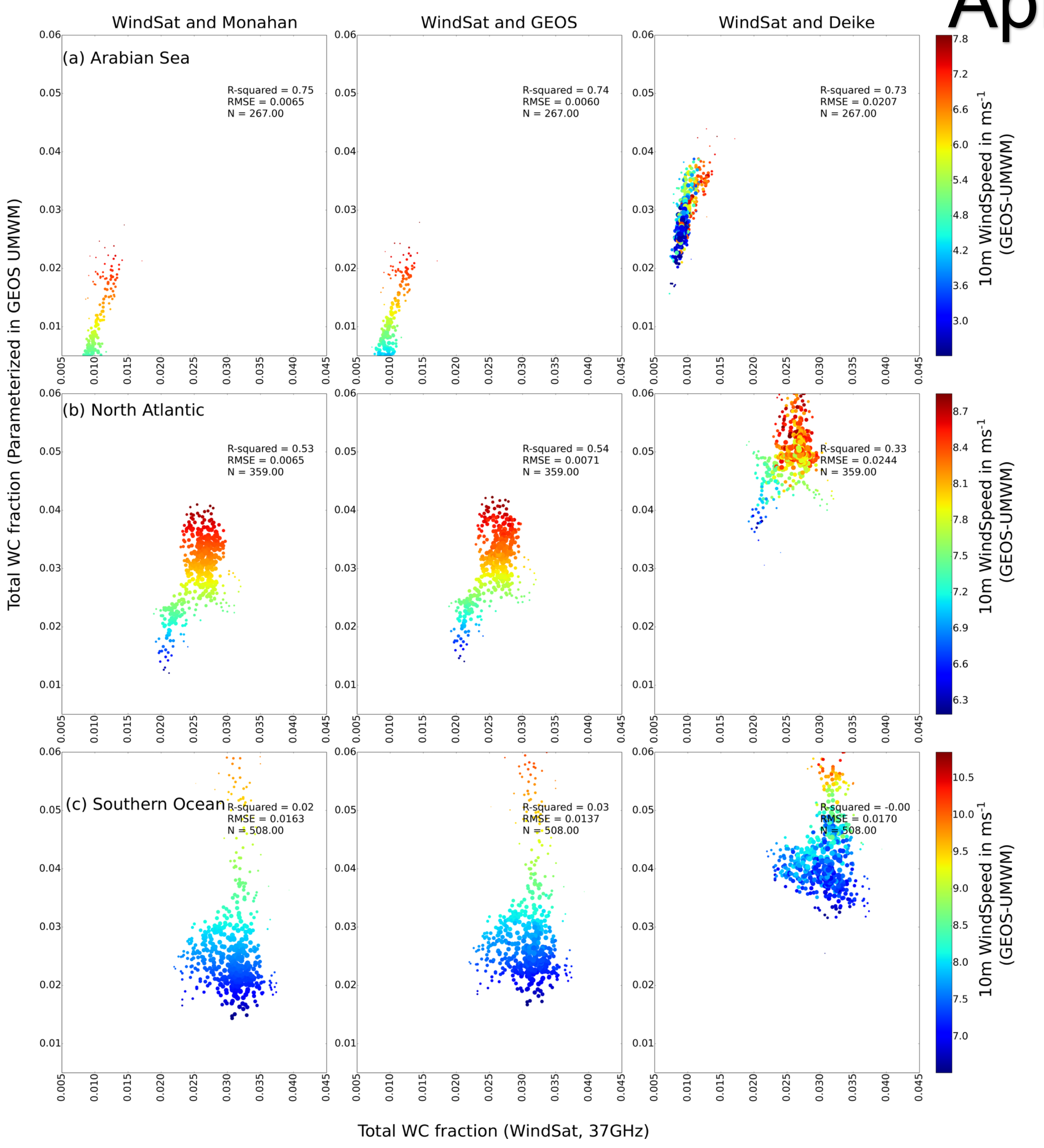
3.2. Regional relationship between WC, windspeed, and wave slope



JJA

Fig 4. Density scatter plots for collocated WindSat (abscissa) and parameterized (ordinate) WC fraction for (top) Arabian Sea (5°N - 25°N; 55°E - 70°E), (middle) SEASAW and DOGEE field campaign region (36°N – 60°N; 25°W – 10°W), and SO GasEx campaign (60°S – 30°S ; 47°W – 30°W). (Left) The probability density was calculated using a Gaussian kernel and values are colored by the wind speed. Different sizes of the circles correspond to the values of the joint probability density between the model and WindSat.

WC_{D17A} has the highest correlation over Arabian Sea. WC_{GEOS} and WC_{Mon} have highest correlation with WindSat for the Mid-Atlantic. All models correlate poorly with the data for the Southern Ocean.



Apr-May

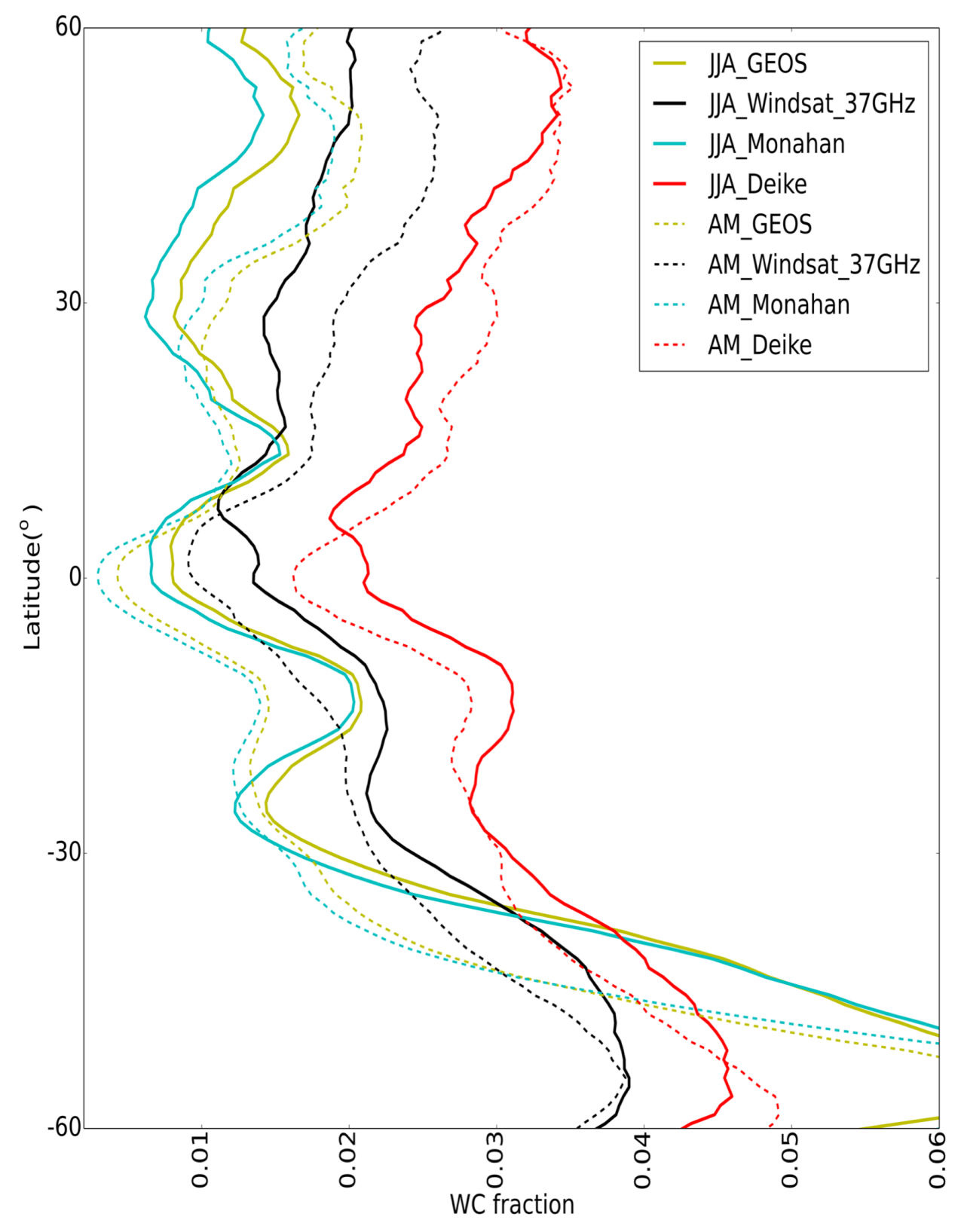


Fig 5. Latitudinal variation in WC values from WindSat and parameterized models for JJA and Apr-May.

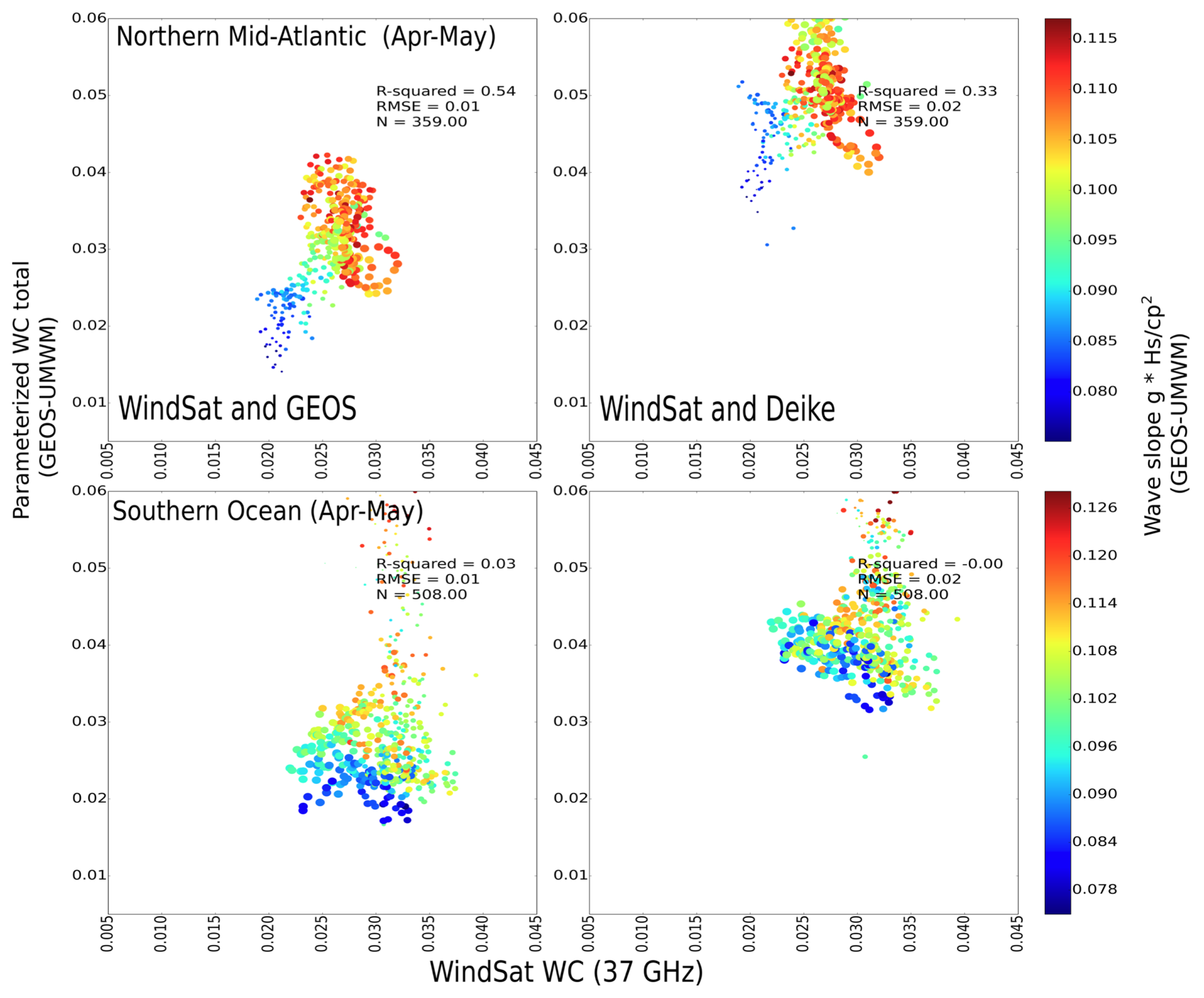


Fig 6. Density scatter plots for collocated WindSat (abscissa) and parameterized (ordinate) WC fraction. Joint probability density circles for WindSat and parameterized WC colored by wave slope. Sizes of the circle reflect the values of probability density.

WC fraction shows a distinct difference based on wave slope in the Mid-Atlantic. For higher wave slopes, WC decreases in the parameterized models whereas WindSat WC values are not affected by the wave slope.

In the Southern Ocean, the gradient in WC values based on wave slope is very low and the decreasing trend in WC is not clear. However, for higher wave slope, the spread in WC is higher.

4. Key Points and Further Work

- The parameterized models show similar geographical patterns in WC variability as WindSat. Wave field based WC parameterization using the property, volume of air entrained during wave breaking certainly improves the low bias in Tropics and Mid-Atlantic regions by more than 50%. However, WC_{D17A} overshoots the WindSat retrievals.
- It is interesting to note the distinct variability in WC trend based on wave slope in the Mid-Atlantic and Southern Ocean. Such variability is not seen from WindSat. Looking at other wave properties in addition wind speed gives more information about WC.
- Longitudinal mean in WC shows that in the Northern Hemisphere, WC is higher in Apr-May compared to JJA whereas this trend reverses close to the Equator and in the Southern Hemisphere with higher WC values in JJA. The Indian monsoon also shows some interesting patterns in WC with higher WC and stronger gradient between Arabian Sea and Bay of Bengal during JJA months. Future study will explore the relationship between WC and other wave properties, ocean currents and the impact of a two-way coupled wave model.

5. Acknowledgements : This study is funded by NASA-MAP proposal in response to NNH16ZDA001N-MAP. The WindSat satellite retrieval product was obtained from M.D. Anguelova, NRL. The study was carried out at NASA GSFC GMAO and the GEOS-UMWM model simulations were run in NASA DISCOVER super computer.

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