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 (Brum 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 seaward 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 up to 850 hPa (Kiehl et al., 2008).
- UMWM wave model implemented in GEOS-5 simulates wave energy spectrum, E(k,θ) for 36 wave numbers (k) and 37 directions (θ). 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 force (see poster please see poster #0931E-1857 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$_{GOCART}$), WC GEOS based on friction velocity from the wave model (WC$_{UMWM}$), and WC based on Deike et al., 2017 and Anguelova et al., 2012 are compared with the satellite database for WC (WC$_{sat}$). We focus on total WC (WC维尔 + decay).

$$\begin{align*}
WC_{MAX} & = \left( U_{10}^{2.4} \right) \\
WC_{GOCART} & = \left( U_{10}^{2.4} \right) \\
WC_{UMWM} & = 1 + \left( U_{10}^{2.4} \right)
\end{align*}$$

GEOS-AGCM

Wind at first model level

UMWM

GoCART SeaSat Emission

$U_{10}$, Mean wave height (SWH), wave phase velocity, and other wave field properties

3. Results: Global WC patterns and seasonal changes

Monahan, GEOS, Deike, WindSat 37 GHz

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

3.1 Observation and model comparison statistics

Monahan, GEOS, Deike

Fig. 3. Seasonal variation in WC Normalized Mean Difference (top) JJA, (bottom) April-May. NMO = 100 in (WC observed – WC predicted)/WindSat.

- WC$_{GOCART}$ has a high bias overall up to 150%. WC$_{UMWM}$ and WC$_{Deike}$ have low bias up to 50% over Equator and mid-latitudes and up to 100% 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 April-May and WC increases during the monsoon in JJA months.

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$_{GOCART}$ 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 April-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 model wave.

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 supercomputer.