WHITECAP FRACTION OF ACTIVELY BREAKING WAVES: TOWARD A DATABASE APPLICABLE FOR DYNAMIC PROCESSES IN THE UPPER OCEAN

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Air-Sea Processes

- Sea spray flux
- Gas flux
- Sensible heat flux
- Latent heat flux
- Enthalpy flux
- Momentum flux
- Dissipation rate
- Ambient noise

Separate active whitecap fraction, Anguelova & Hwang, NRL
**Air-Sea Processes and Whitecaps**

- **Mass**
  - Sea spray flux
  - Gas flux

- **Heat**
  - Sensible heat flux
  - Latent heat flux
  - Enthalpy flux

- **Energy**
  - Momentum flux
  - Dissipation rate

- **Whitecap fraction \( W \)**
  - The fraction of ocean surface covered with foam
  - Includes all stages of whitecap lifetime

- **Active whitecap fraction \( W_A \)**
  - Foam associated with breaking wave crests
  - Only the initial stages of whitecap lifetime
  - The foam moves along with the wave

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**Features:**
- Similar spatial distributions
- Different magnitudes

**Our advantage:**
- Objective method
- Global data
- Variability

**Wind speed formula:**
- Conventional $W(U_{10})$ model*:
  $W = 3.84 \times 10^{-6} U_{10}^{3.41}$
- $U_{10}$ from QuikSCAT or GDAS

* Monahan and O’Muircheartaigh (1980)
### Theoretical approach

- **Physical basis**
  - Phillips concept
  - Expression $W_A(\varepsilon)$

- **Realization**
  - Regionally
    - Buoy data
  - Globally
    - WindSat data

### Experimental approach

- **Physical basis**
  - Foam IR signature
  - Cold and Hot foam

- **Realization**
  - Field campaign
  - Many instruments

- **Poster #63**
  - St. George
**PHILLIPS CONCEPT**

- **Breaking crest length distribution:**
  \[ \Lambda(\bar{c}), \Lambda(\bar{c})d\bar{c} \quad \bar{c}, \bar{c} + d\bar{c} \]

- **Active whitecap fraction:**
  \[ W_A = \int_c Tc \Lambda(\bar{c}) \, d\bar{c} \]

- **Energy dissipation:**
  \[ \varepsilon(\bar{c}) \, d\bar{c} = bg^{-1} c^5 \Lambda(\bar{c}) \, d\bar{c} \]

- **\( W_A(\varepsilon) \) relationship:**
  \[ W_A(\varepsilon) = gTb^{-1} \int_c c^{-4} \varepsilon(\bar{c}) \, d\bar{c} \]

- **Expression for \( \varepsilon(\bar{c}) \, d\bar{c} \) from the wave spectrum**

- **Integrate over \( c \) and obtain:**
  \[ W_A(\varepsilon) = \frac{gT}{4b\rho_w c_{min}^4 \ln(c_{max}/c_{min})} \langle \varepsilon \rangle \]

- **Need \( \langle \varepsilon \rangle, T, b, c_{min}, \) and \( c_{max} \)**

\( \bar{c} \) is breaking fronts velocity

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**Total Dissipation Rate \( \langle \varepsilon \rangle \)**

- **Parametric approach**
  - Hwang and Sletten (2008)

\[
\langle \varepsilon \rangle = \alpha \rho_a U^3, \quad \alpha = 0.2 \omega_*^3 \eta_*
\]

- Wind speed \( U \),
- Wave parameter \( \alpha \)
- \( \omega_* \), \( \eta_* \) non-dimensional frequency and surface elevation
- Air density \( \rho_a \)

- Wave spectra data from buoys
  - Wave period \( T_p \) and
  - Significant wave height \( H_s \)

- **Separate swell** (Hwang et al., 2012, JPO)

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PARAMETER VALUES

- $T$, $b$, $c_{\text{min}}$, and $c_{\text{max}}$

- Breaking parameter $b = 0.0153$

- Bubbles persistence $T = 2$ s
  - Callaghan et al. (2012)
  - $T$ influence by the wave field (limited)
  - Other factors: salinity, SST, surfactants

- Breaker speed $c_{\text{min}} = \alpha c_{pw}$, $c_{pw} = \frac{gT_{pw}}{2\pi}$
  - $\alpha_c = 0.3$
    - Gemmrich et al., 2008; fully developed sea
    - Others suggest $\alpha_c \geq 0.8$
  - $c_{\text{min}} \in (1.8 \text{ to } 5.6)$ m s$^{-1}$

- $c_{\text{max}}/c_{\text{min}} = 10$

\[
W_A(\varepsilon) = \frac{gT}{4b\rho_w c_{\text{min}}^4 \ln (c_{\text{max}}/c_{\text{min}})} \langle \varepsilon \rangle
\]
ACTIVE WHITECAP FRACTION PHILLIPS-BUOY

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Active whitecap fraction Phillips-Buoy

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**Active Whitecap Fraction Phillips-Buoy**

\[ b = 0.0153 \]
\[ T = 2 \text{ s} \]
\[ c_{min} = 0.3 c_{pw} \]

![Graph showing active whitecap fraction with data points and lines representing different models: Buoy $W_A(\epsilon)$, MOM80 $W(U_{10})$, Radiom $W(10H)$, Radiom $W(37H)$](image)
ACTIVE FROM TOTAL WHITECAP FRACTION

- Having $W_A(\varepsilon)$ from buoy data
- Make match-ups with $W$ from WindSat
  - $0.5^\circ \times 0.5^\circ$ around buoy position
- Find scaling factor $R = W_A/W$
- Buoy-satellite match-ups at different latitudes
- Parameterize $R$ in terms of
  - Wind speed or
  - Geography (lat, lon)
- Use $W$ database from satellites and $R$ to build $W_A$ database
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ACTIVE WHITECAP FRACTION PHILLIPS-BUOY

Buoy 46001, 56.3N

Wind speed, $U_{10}$ (m/s)

Whitecap fraction, $W$ (%)
Active whitecap fraction Phillips-Buoy

Buoy 41001, 34.6N

Whitecap fraction, $W$ (%) vs. Wind speed, $U_{10}$ (m/s)

Photo $W$
Photo $W_A$
Buoy $W_A(\epsilon)$
MOM80 $W(U_{10})$
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Active whitecap fraction Phillips-Buoy

Buoy 41012, 30.0N

Wind speed, $U_{10}$ (m/s)

Whitecap fraction, $W$ (%)
ACTIVE WHITECAP FRACTION PHILLIPS-BUOY

Buoy 41010, 28.9N

Whitecap fraction, $W$ (%) vs. Wind speed, $U_{10}$ (m/s)

- Photo $W$
- Photo $W_A$
- Buoy $W_A(\epsilon)$
- MOM80 $W(U_{10})$

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Scaling Factor $W_A/W$
Spatial Variations

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SUMMARY

- Obtain $W_A$ from $W$ on a global scale using satellite data
- Phillips concept to obtain $W_A$ from dissipation rate $\varepsilon$
- Buoy data for wave spectrum
  - Remove swell
  - Parametric approach to obtain $\langle \varepsilon \rangle$
  - Choose values for coefficient of proportionality
  - Calculate $W_A(\varepsilon)$
- Obtain scaling factor $R = W_A/W$ in various regions

Future work:
- Validate $\langle \varepsilon \rangle$ with independent measurements, previous and new
- Refine choices for $T$, $b$, $c_{min}$, and $c_{max}$
- Parameterize $R$

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Wind direction

$W$

$W_A$

Photo courtesy of Prof. William M. Drennan, RSMAS, Miami

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