Air-Sea Exchange in Strong Winds

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Slippery when windy?
Motivation

• Hypotheses
Air-sea exchange in strong winds:
  – Is NOT a simple extrapolation of more moderate conditions, but is genuinely extraordinary
  – Represents a large fraction of exchange averaged seasonally, regionally and globally
  – Can be realistically studied by a range of in situ, remote sensing and (laboratory and numerical) modelling methods

• Conclusion
The topic is:
  – Distinct
  – Important
  – Tractable
When winds are strong (12 – 25 m/s)
Model Relationships of Whitecapping to Wind Speed

"ZTX"

\[ W = 4.02 \times 10^{-7} R_H^{0.96} \]

\[ R_H = \frac{u_* H}{v_a} \]

\[ H = \min(0.0246 U^2, 0.0163 X^{0.5} U) \]
Air-sea gas exchange in a bubbly ocean

Net Flux = $K (\alpha C_a - C_w)$

1) Flux IS NOT proportional to air-water concentration difference!

$$K = a U_{10N}^b \text{Sc}^{-1/2}$$

2) Transfer velocity doesn’t depend simply on wind speed

3) The dependence on molecular properties involves more than Schmidt Number
Modification of gas transfer velocities due to collective effects

Simple model is modified to include finite plume size. Here void fraction is assumed to be 25%
Belcher et al., 2012; deepening of OSBL
Belcher et al., 2012; deepening of OSBL

Regime diagram for relative contribution of directly wind-forced, wave-forced and convective forcing to turbulent dissipation.

White contours are the joint pdf for Southern Ocean winter (JJA).
When winds are too strong (> 25 m/s)
Regime change at high mixing?

→ Regular Distribution of bubbles results from a "gravitational sieve". Partial dissolution is typical

Critical point
Most of volume flux is in large bubbles, all with similar terminal rise velocity ~0.25m/s

Injection →
If critical point is exceeded even large bubbles may be submerged to large depths and total solution is typical
Effect of heavy particles on turbulence?  
Kudryatsev, 2006

N.B. Spume drops **not** bubble droplets
Aerodynamically Smooth?
Holthuijsen, Powell and Pietrzak, 2012
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Azimuthal hurricane sectors
right-front (following swell)
left-front (cross swell)
rear (opposing swell)

Drag coefficient $C_d$ ($\times 10^3$)

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

$\sigma_\theta \leq 30^\circ$
$\sigma_\theta \geq 80^\circ$
$\sigma_\theta = 50^\circ$
$\sigma_\theta \leq 45^\circ$
$\sigma_\theta \geq 55^\circ$

90% confidence

this study
left-front
rear
right-front
Aerodynamically Smooth?
Holthuijsen, Powell and Pietrzak, 2012
Let us talk