American Meteorological Society
20th Symposium on Boundary Layers and Turbulence/18th Conference on Air-Sea Interaction

Whitecap Fraction of Actively Breaking Waves: Toward a Database Applicable for Dynamic Processes in the Upper Ocean

Magdalena D. Anguelova and Paul A. Hwang

Remote Sensing Division
Naval Research Lab, Washington, DC 20375

Air-Sea Processes

Mass
- Sea spray flux
- Gas flux

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

Energy
- Momentum flux
- Dissipation rate

- Ambient noise

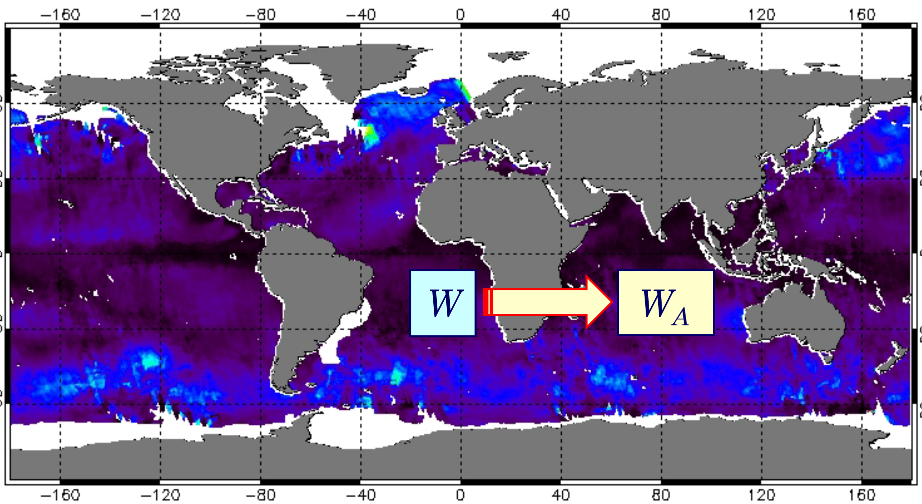
Air-Sea Processes and Whitecaps

	Process	W	W_A
Mass	Sea spray flux	W	W_A
Mass	Gas flux		W_A
Heat	Sensible heat flux	W	
Heat	Latent heat flux	W	
Heat	Enthalpy flux	W	W_A
Energy	Momentum flux		W_A
Energy	Dissipation rate		W_A
	Ambient noise		W_A

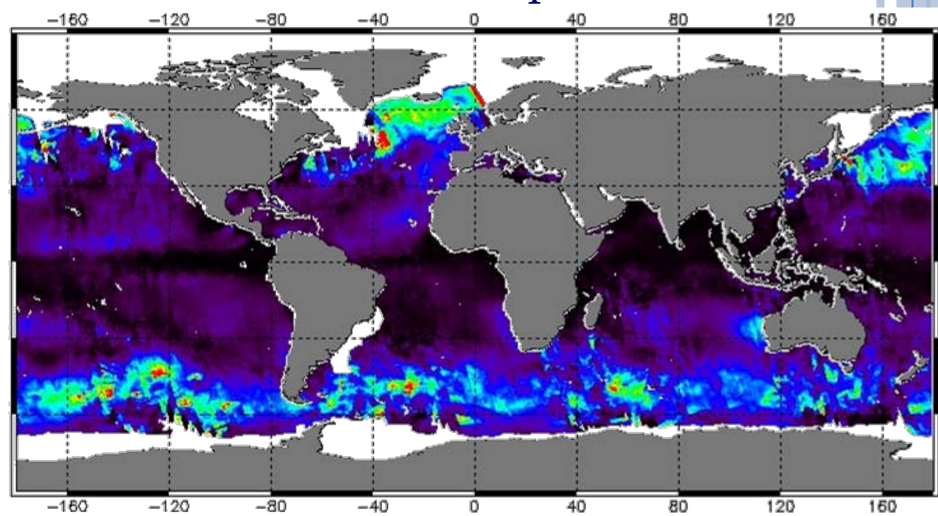
- Whitecap fraction W
  - The fraction of ocean surface covered with foam
  - Includes all stages of whitecap lifetime
- Active whitecap fraction W_A
  - Foam associated with breaking wave crests
  - Only the initial stages of whitecap lifetime
  - The foam moves along with the wave

SATELLITE-BASED WHITECAP FRACTION *W*

W from WindSat data



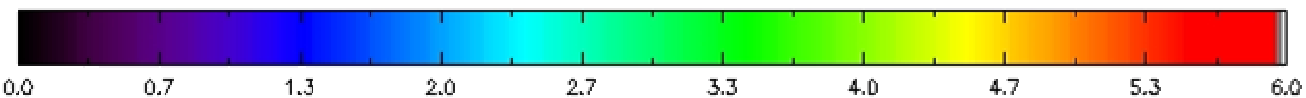
W from wind-speed formula



Anguelova et al., 2009

Whitecap fraction, *W* (%)

March 2007, map grid 0.5°×0.5°



- Features:
  - Similar spatial distributions
  - Different magnitudes

Our advantage:
Objective method
Global data
Variability

- Wind speed formula:
  - Conventional $W(U_{10})$ model*:

$$W = 3.84\times10^{-6}U_{10}^{3.41}$$

  - U_{10} from QuikSCAT or GDAS;

* Monahan and O'Muircheartaigh (1980)

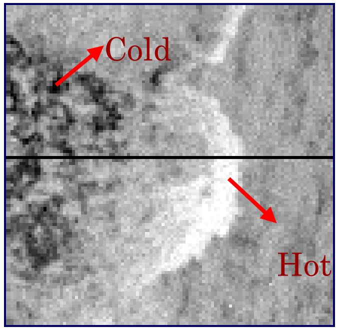
Separate Active Part from the Total

Theoretical approach

- Physical basis
  - Phillips concept
  - Expression $W_A(\varepsilon)$
- Realization
  - Regionally
    - Buoy data
  - Globally
    - WindSat data

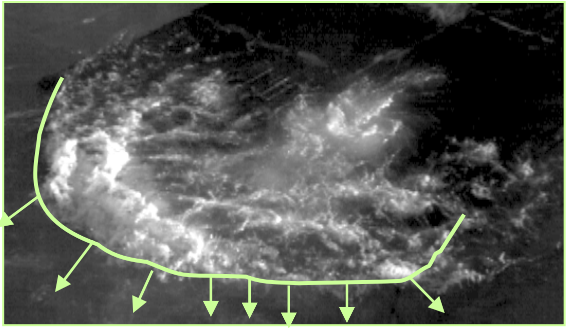
Experimental approach

- Physical basis
  - Foam IR signature
  - Cold and Hot foam
- Realization
  - Field campaign
  - Many instruments
- Poster #63
  - St. George



Phillips concept

$\vec{c}$ is breaking fronts velocity



- Breaking crest length distribution:

$$\Lambda(\vec{c}),\ \Lambda(\vec{c})d\vec{c} \quad \vec{c}, \vec{c}+d\vec{c}$$

- Active whitecap fraction:

$$W_A = \int_c Tc\Lambda(\vec{c})\,d\vec{c}$$

- Energy dissipation:

$$\varepsilon(\vec{c})\,d\vec{c} = bg^{-1}c^5\Lambda(\vec{c})\,d\vec{c}$$

- $W_A(\varepsilon)$ relationship:

$$W_A(\varepsilon) = gTb^{-1}\int_c c^{-4}\varepsilon(\vec{c})\,d\vec{c}$$

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

- Integrate over c and obtain:

$$W_A(\varepsilon) = \frac{gT}{4b\rho_w c_{\min}^4 \ln\left(c_{\max}/c_{\min}\right)}\langle\varepsilon\rangle$$

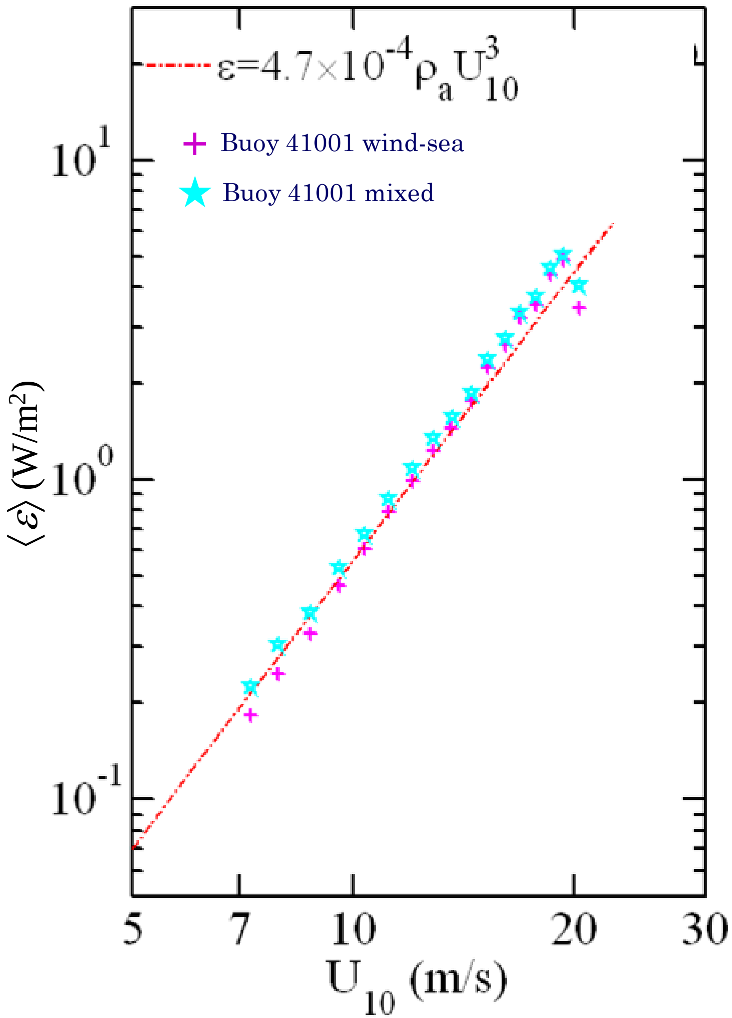
- Need $\langle\varepsilon\rangle$, T, b, c_{min} , and c_{max}

TOTAL DISSIPATION RATE $\langle \varepsilon \rangle$

- Parametric approach
  - Hwang and Sletten (2008)

$$\langle \varepsilon \rangle = \alpha \rho_a U^3, \quad \alpha = 0.2 \omega_*^{3.3} \eta_*$$

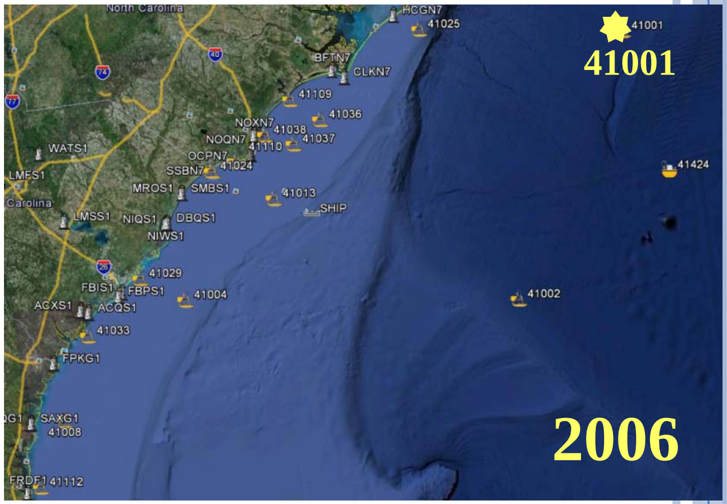
    - ✓ Wind speed U,
    - ✓ Wave parameter α
    - ✓ ω_* , η_* non-dimensional frequency and surface elevation
    - ✓ Air density ρ_a
  - Wave spectra data from buoys
    - ✓ Wave period T_p and
    - ✓ Significant wave height H_s
- Separate swell (Hwang et al., 2012, JPO)



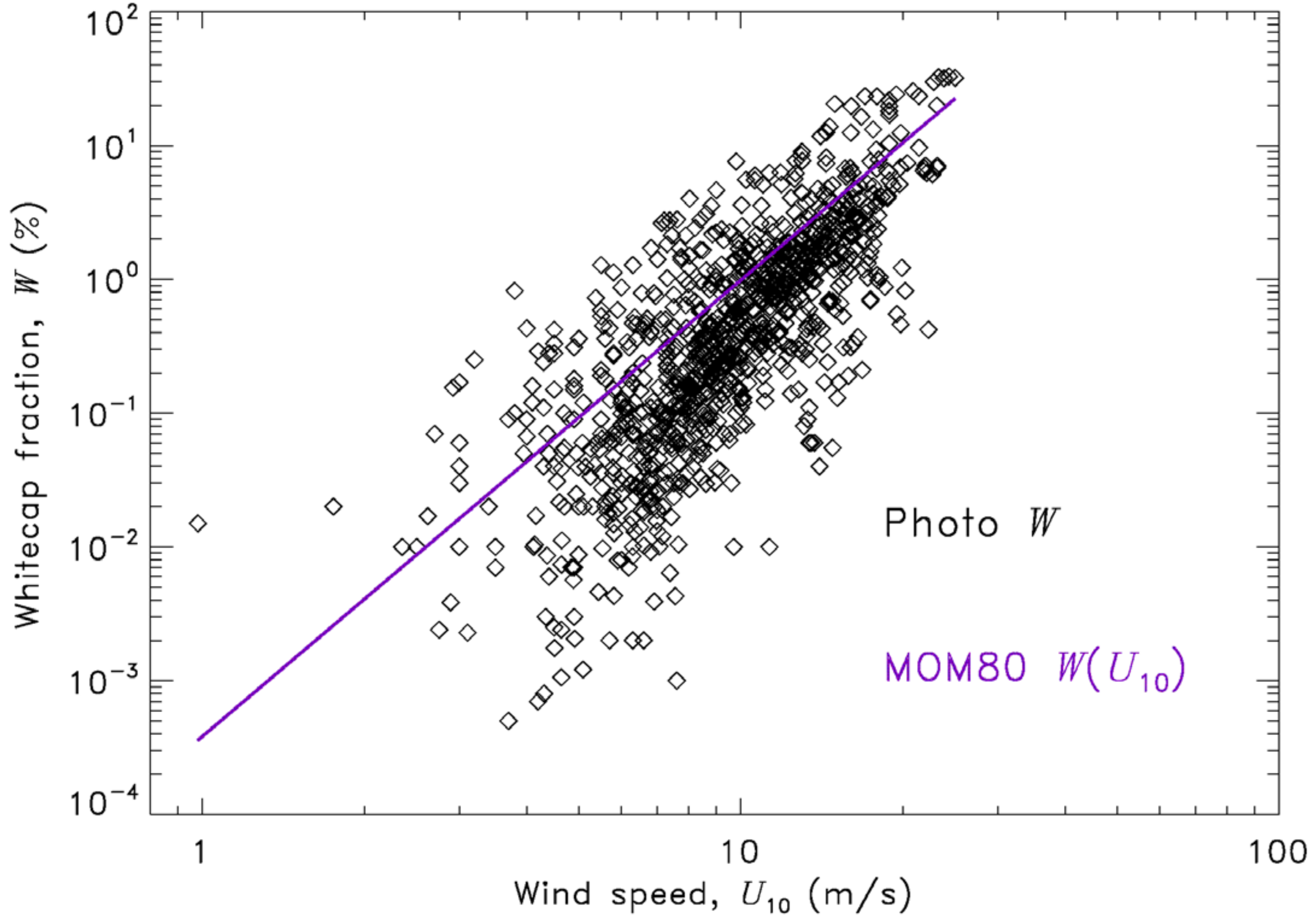
Parameter values

$$W_A(\varepsilon) = \frac{gT}{4b\rho_w c_{min}^4 \ln(c_{max}/c_{min})}\langle\varepsilon\rangle$$

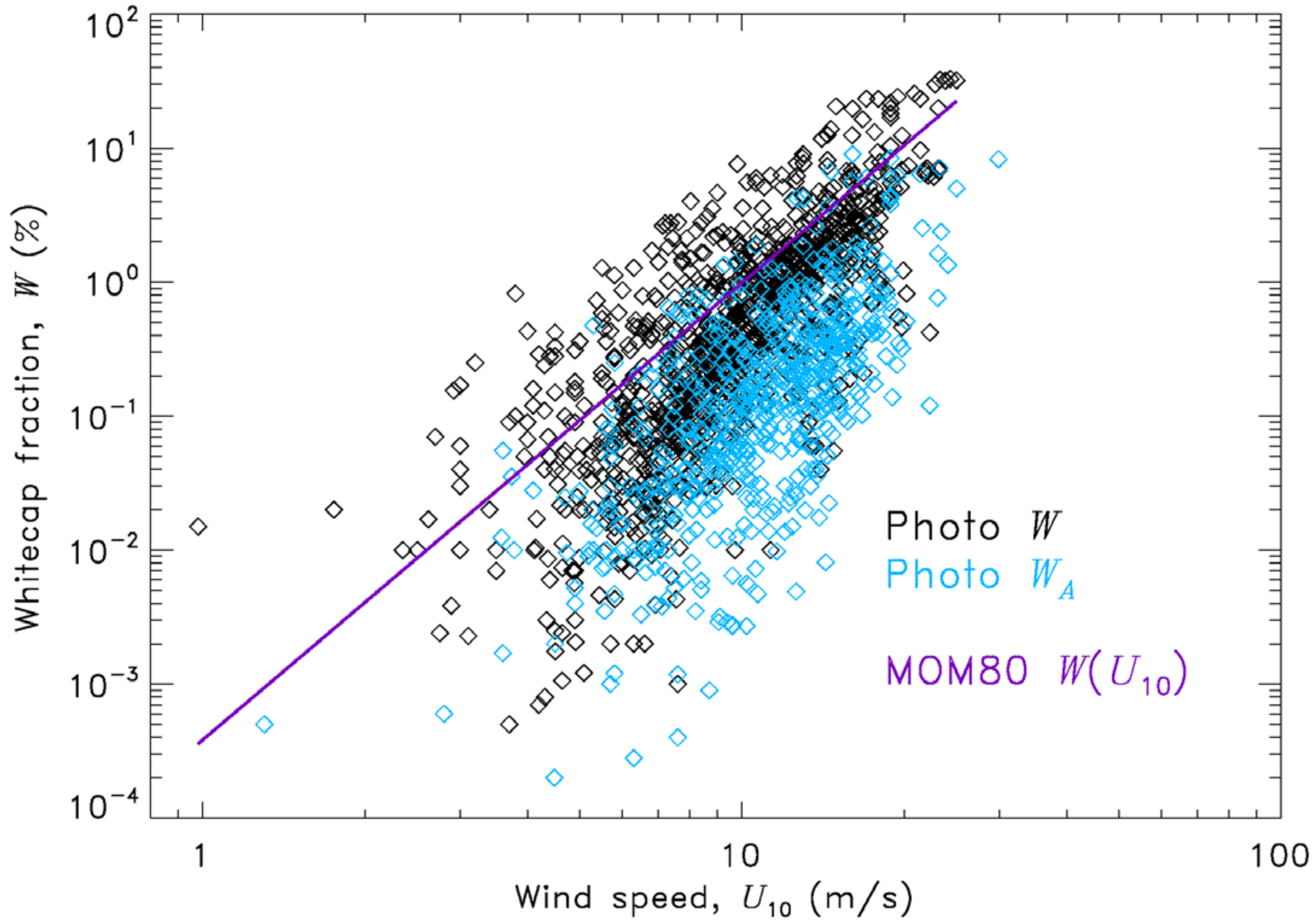
- T, b, c_{min} , and c_{max}
- Breaking parameter $b = 0.0153$
- Bubbles persistence $T = 2$ s
  - Callaghan et al. (2012)
  - T influence by the wave field (limited)
  - Other factors: salinity, SST, surfactants
- Breaker speed $c_{min} = \alpha_c c_{pw}$, $c_{pw} = \dfrac{gT_{pw}}{2\pi}$
  - $\alpha_c = 0.3$
    - Gemmrich et al., 2008; fully developed sea
    - Others suggest $\alpha_c \geq 0.8$
  - $c_{min} \in (1.8$ to $5.6)$ m s^{-1}
- $c_{max}/c_{min} = 10$



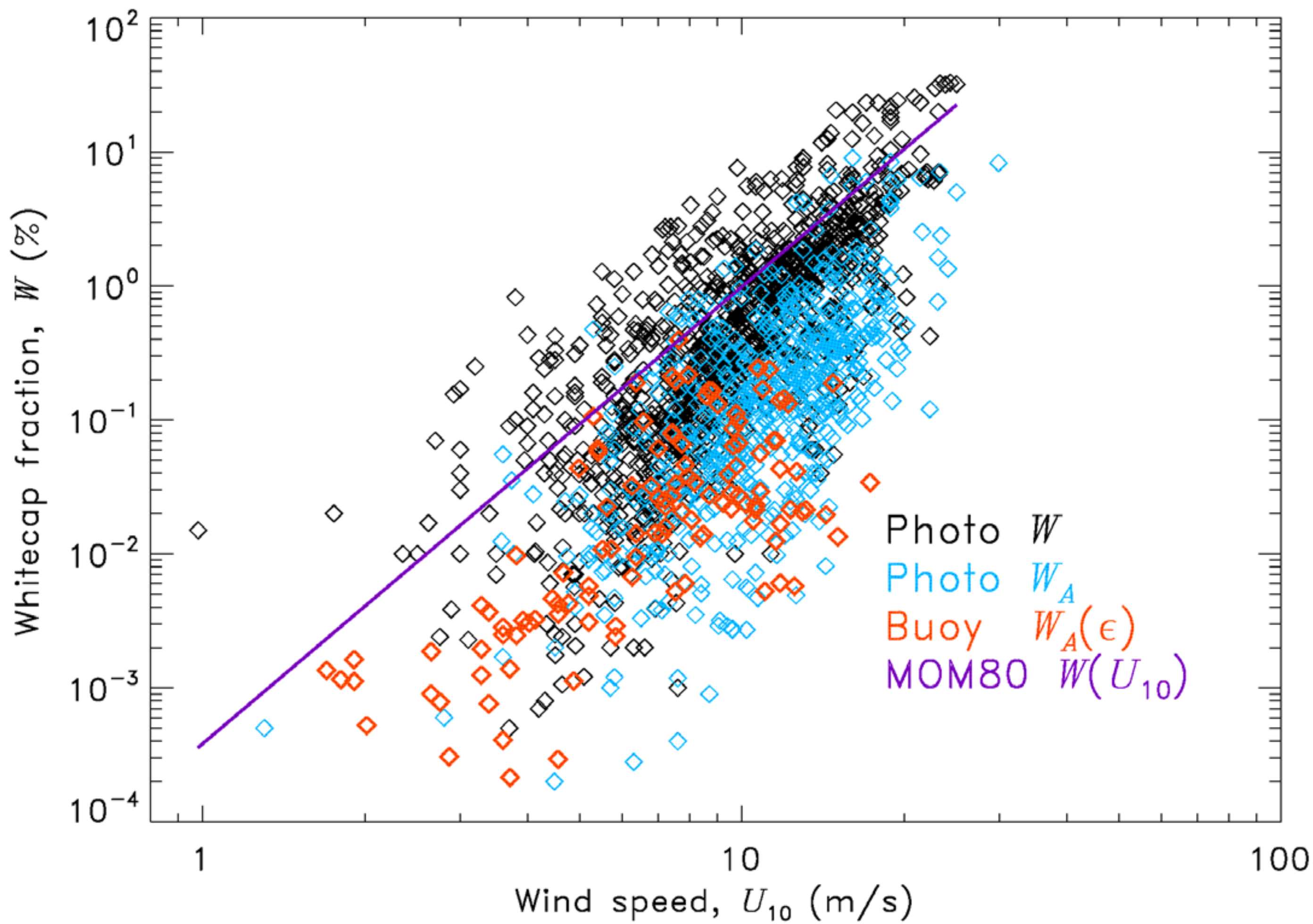
ACTIVE WHITECAP FRACTION PHILLIPS-BUOY



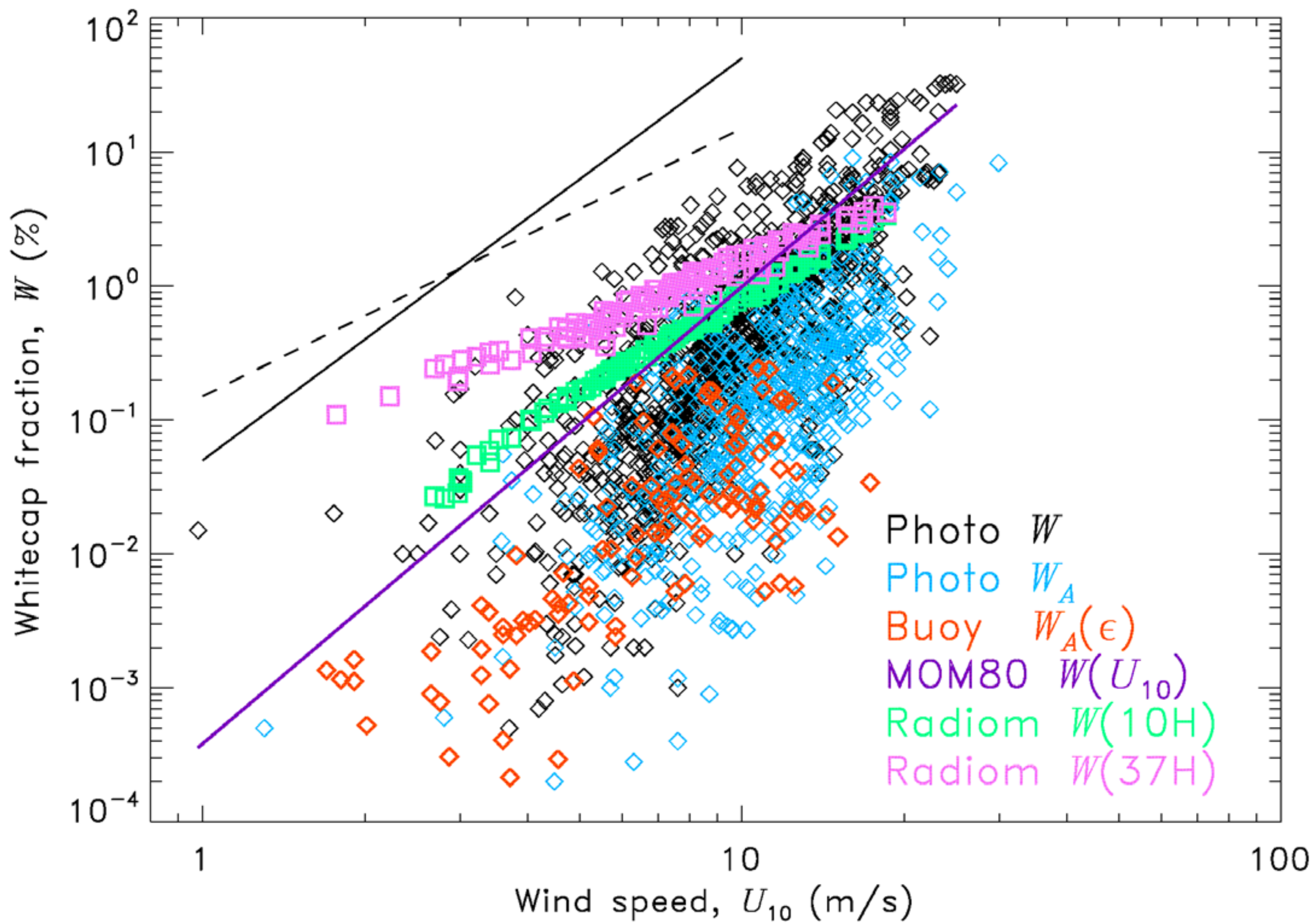
ACTIVE WHITECAP FRACTION PHILLIPS-BUOY



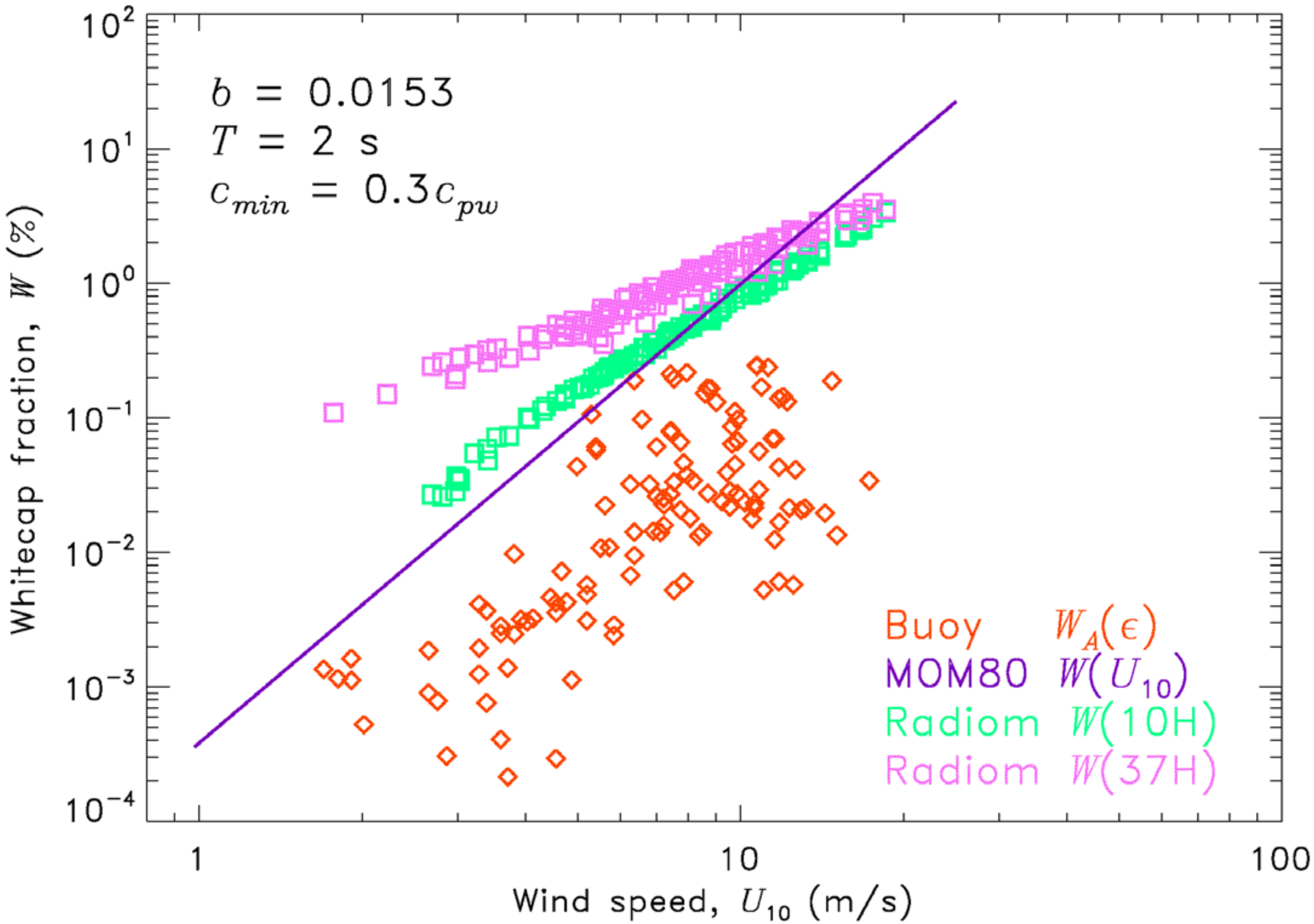
Active whitecap fraction Phillips-Buoy



Active whitecap fraction Phillips-Buoy

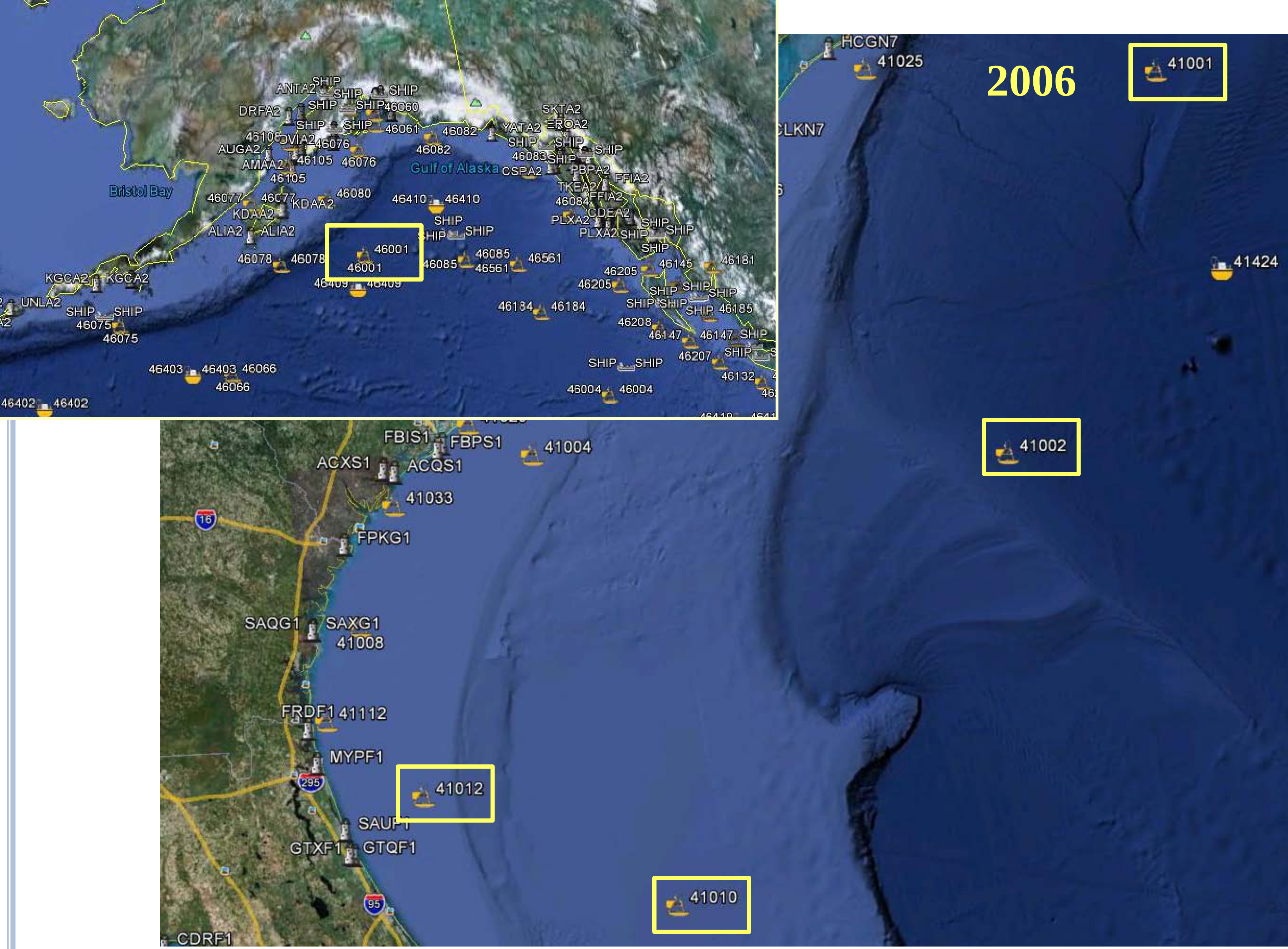


Active whitecap fraction Phillips-Buoy



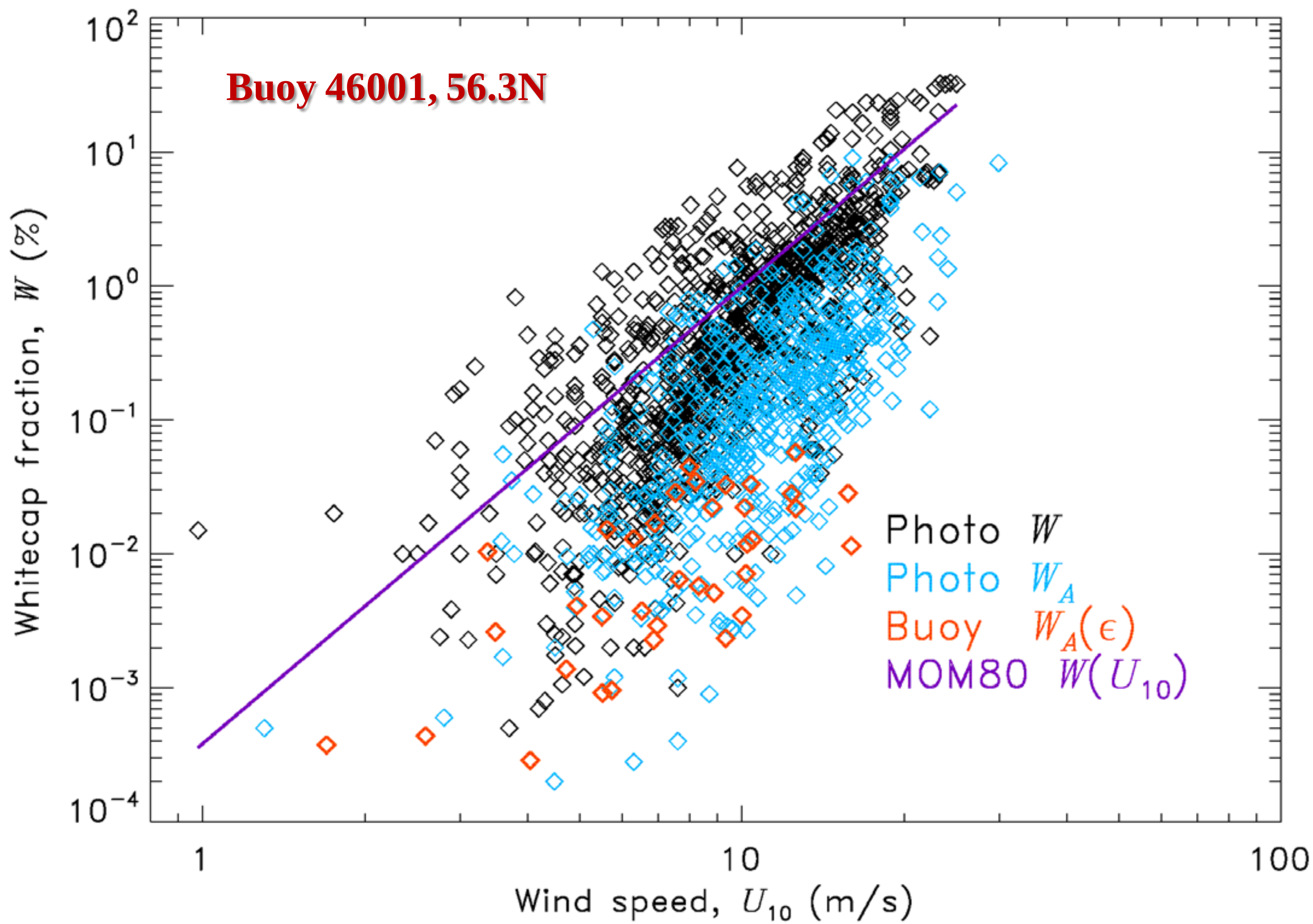
Active from total whitecap fraction

- Having $W_A(\varepsilon)$ from buoy data
- Make match-ups with W from WindSat
  - $0.5^o \times 0.5^o$ 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

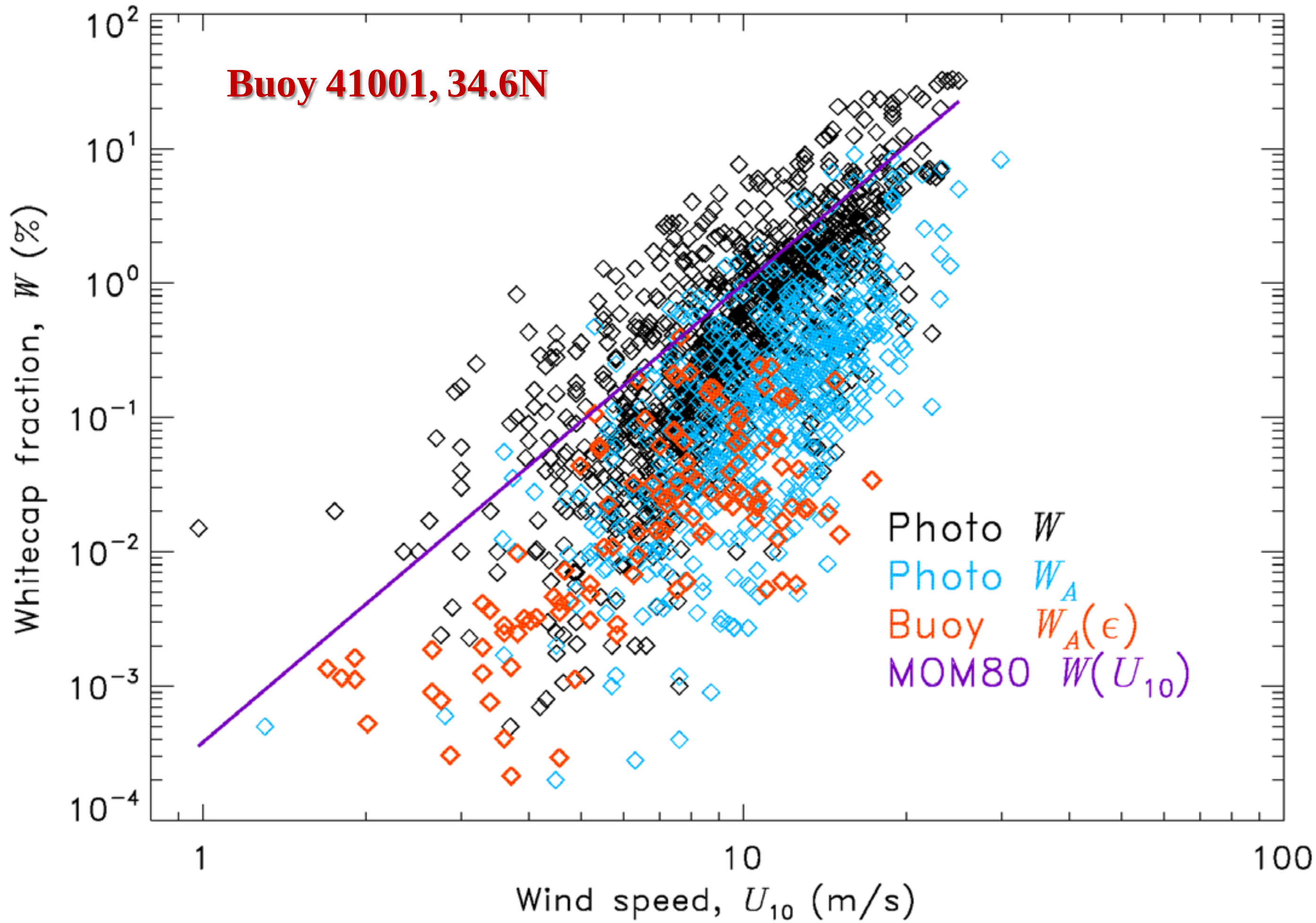


2006
41001
41002
41012
41010
46001
41025
HCGN7
41424
41004
FBIS1
FBPS1
ACXS1
ACQS1
41033
FPKG1
SAQG1
SAXG1
41008
FRDF1
41112
MYPF1
SAUF1
GTXF1
GTQF1
CDRF1
Gulf of Alaska
Bristol Bay
46410
46085
46561
46184
46004
46403
46066
46402
46075
46080
46078
46077
46205
46208
46147
46207
46132
46145
46181
46185

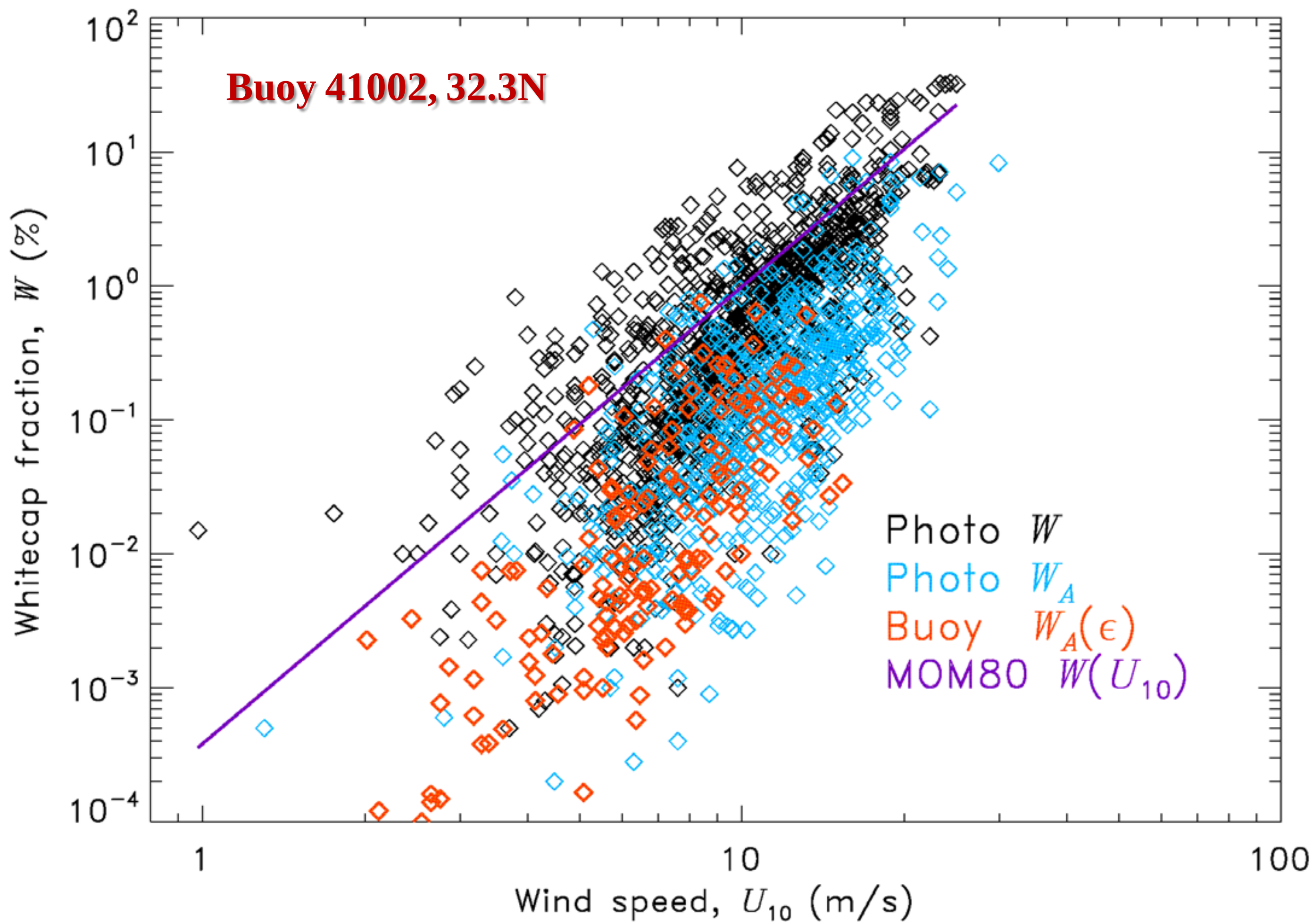
ACTIVE WHITECAP FRACTION PHILLIPS-BUOY



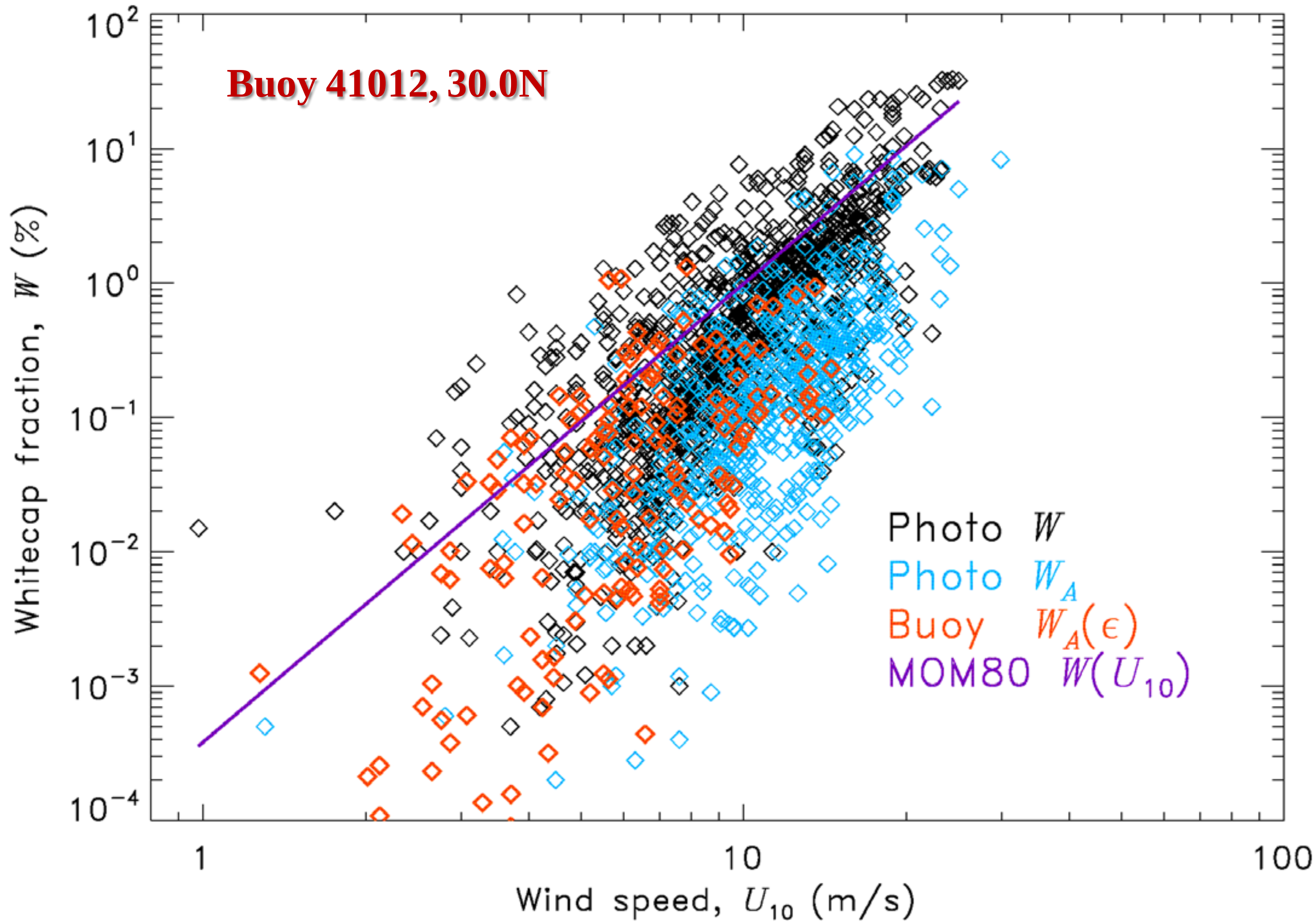
Active whitecap fraction Phillips-Buoy



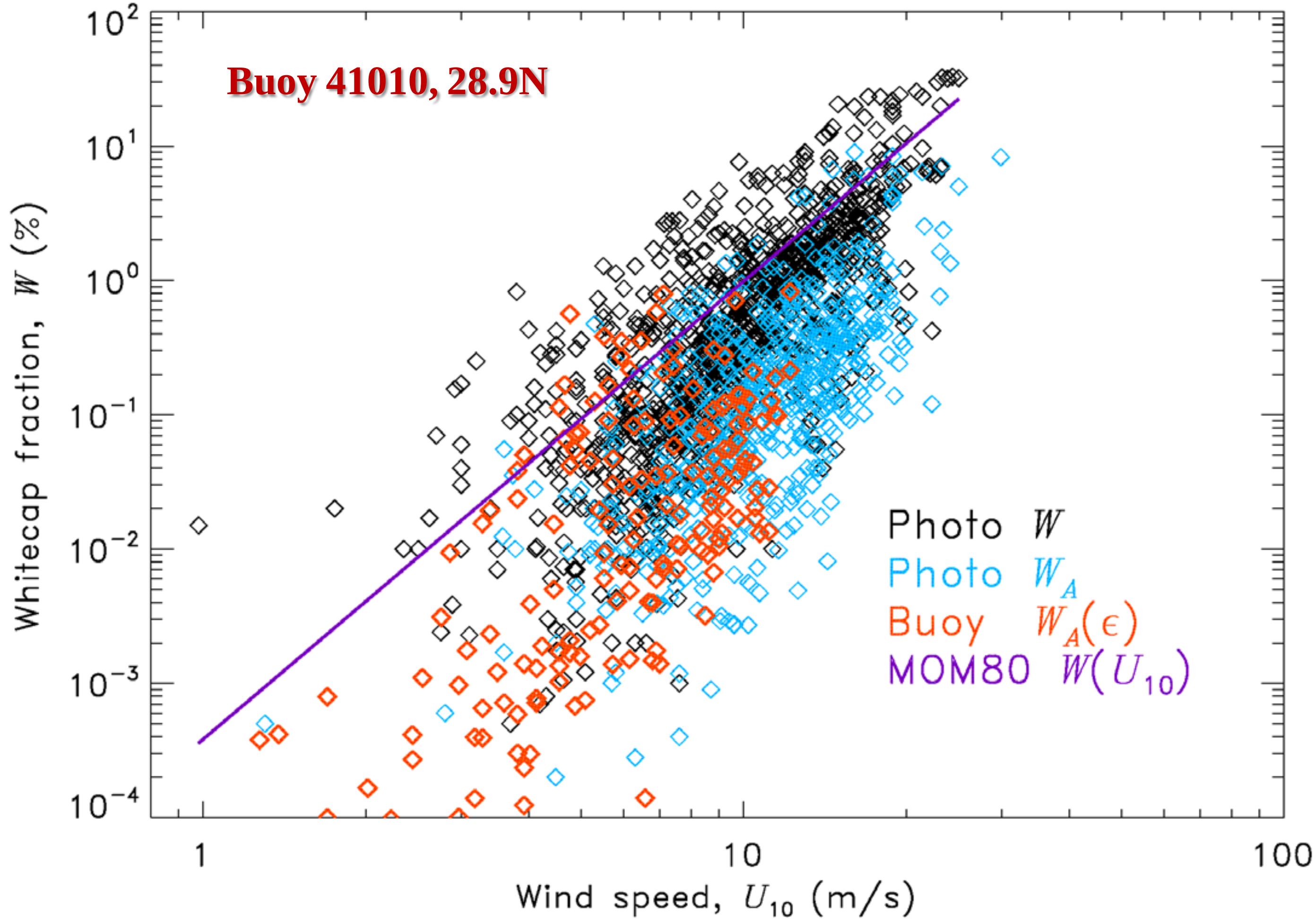
Active whitecap fraction Phillips-Buoy

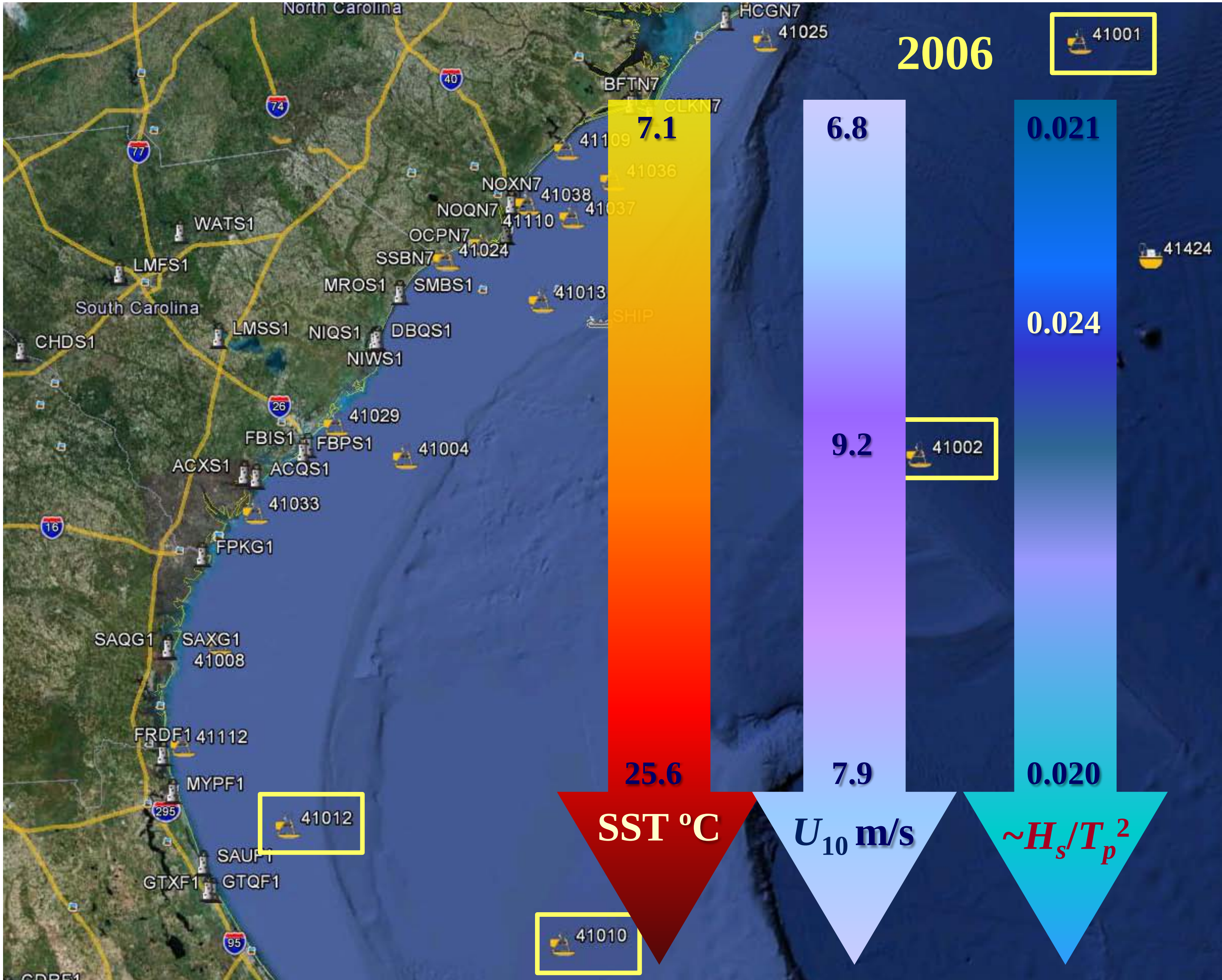


Active whitecap fraction Phillips-Buoy



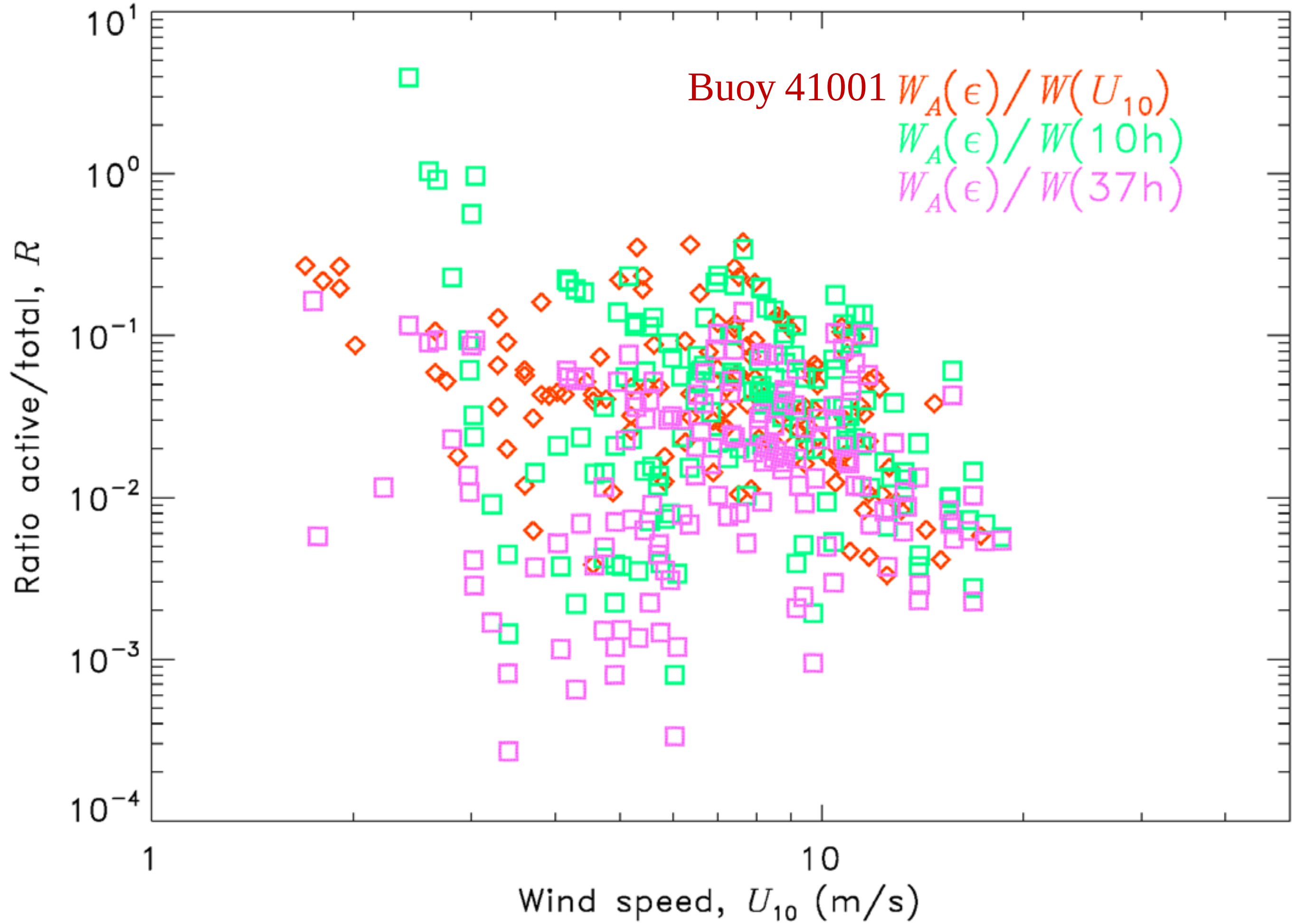
ACTIVE WHITECAP FRACTION PHILLIPS-BUOY



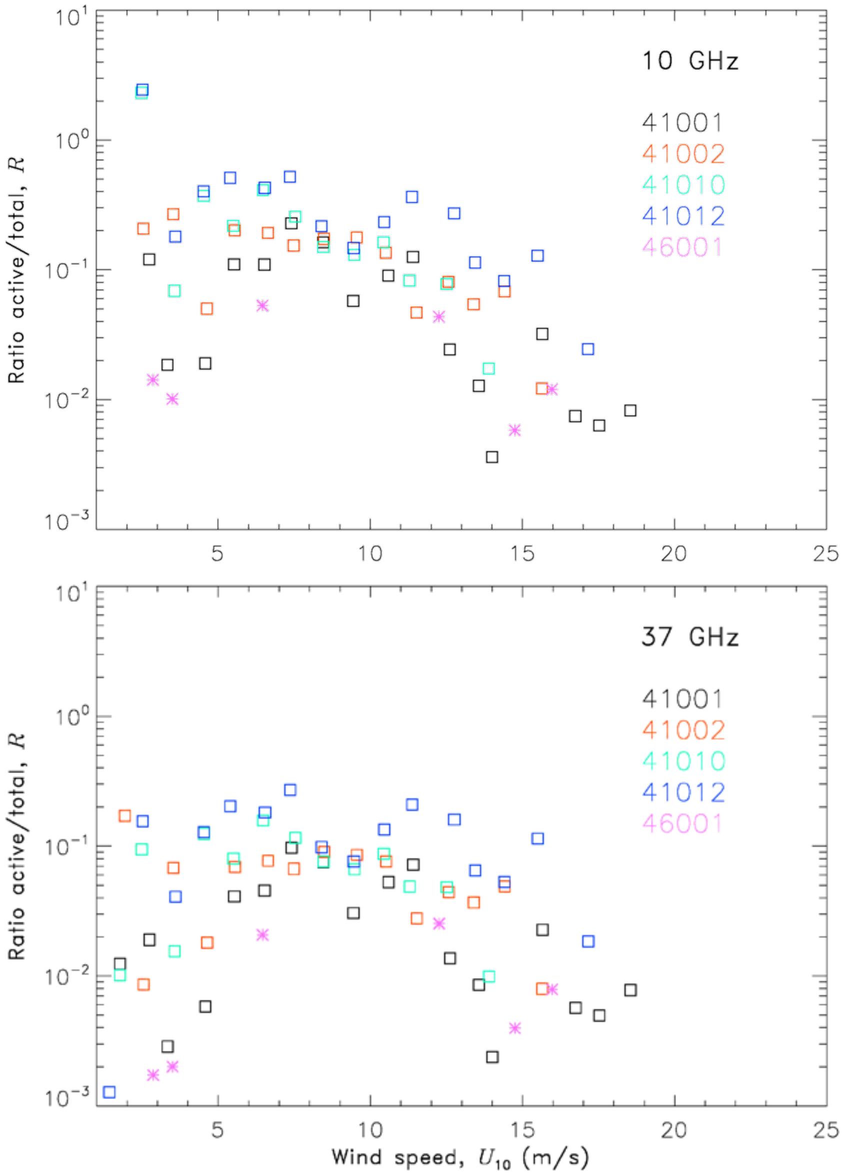


2006
North Carolina
South Carolina
HCGN7
41025
41001
BFTN7
CLKN7
41109
41036
NOXN7
41038
NOQN7
41037
41110
OCPN7
SSBN7
41024
WATS1
LMFS1
MROS1
SMBS1
41013
SHIP
41424
CHDS1
LMSS1
NIQS1
DBQS1
NIWS1
41029
FBIS1
FBPS1
41004
41002
ACXS1
ACQS1
41033
FPKG1
SAQG1
SAXG1
41008
FRDF1
41112
MYPF1
41012
SAUF1
GTXF1
GTQF1
41010
CDRF1
7.1
25.6
SST °C
6.8
9.2
7.9
U_{10} m/s
0.021
0.024
0.020
$\sim H_s/T_p^2$

Scaling Factor W_A/W



Spatial variations



Summary

- Obtain W_A from W on a global scale using satellite data
- Phillips concept to obtain W_A from dissipation rate ε
- 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

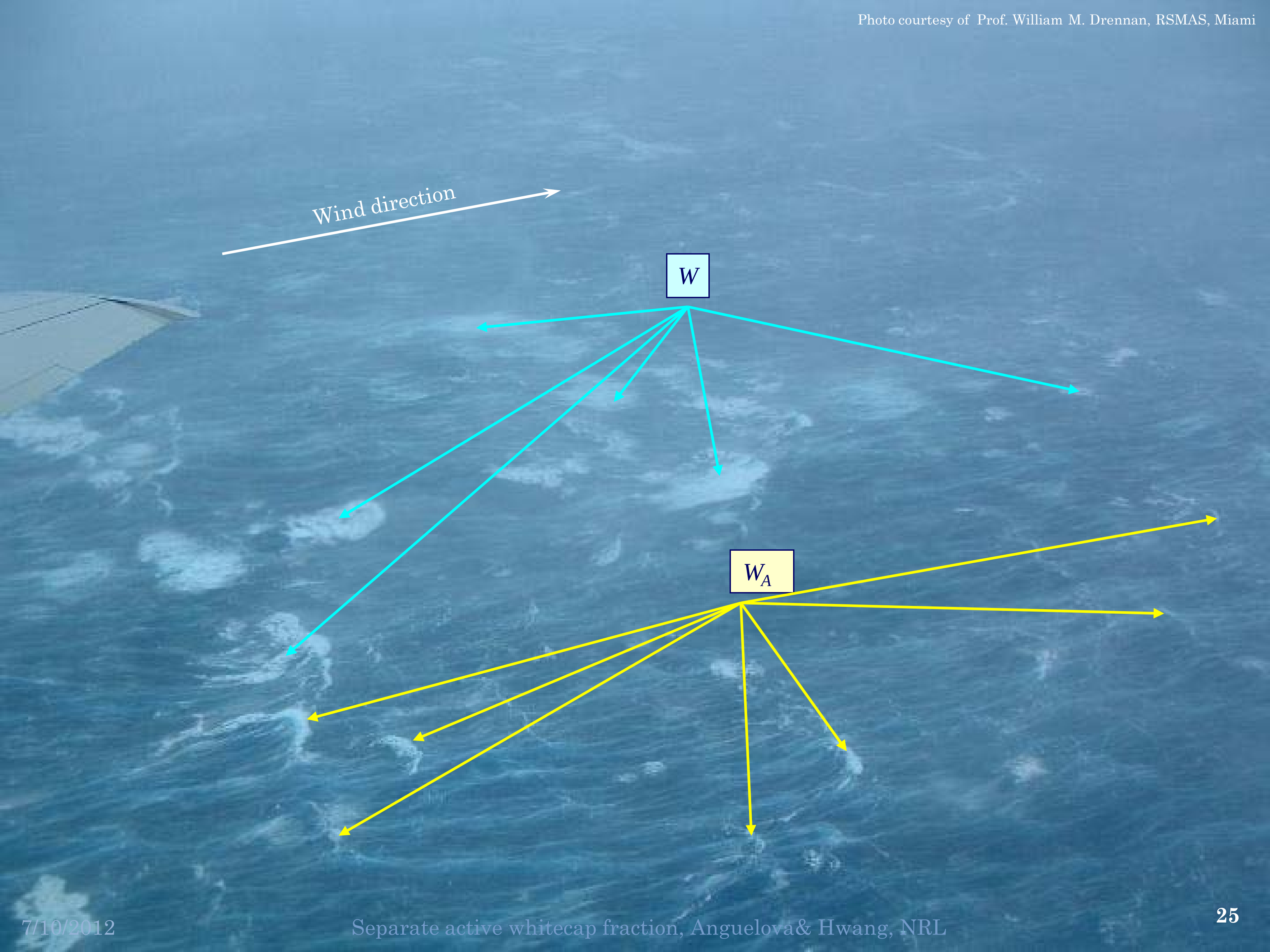


Photo courtesy of Prof. William M. Drennan, RSMAS, Miami