U.S. NAVAL RESEARCH LABORATORY


# Updated whitecap database from WindSat observations

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11th Symposium on Aerosol–Cloud–Climate Interactions

Session 4 Natural Aerosols: Deepening Our Understanding from Emissions through Impacts

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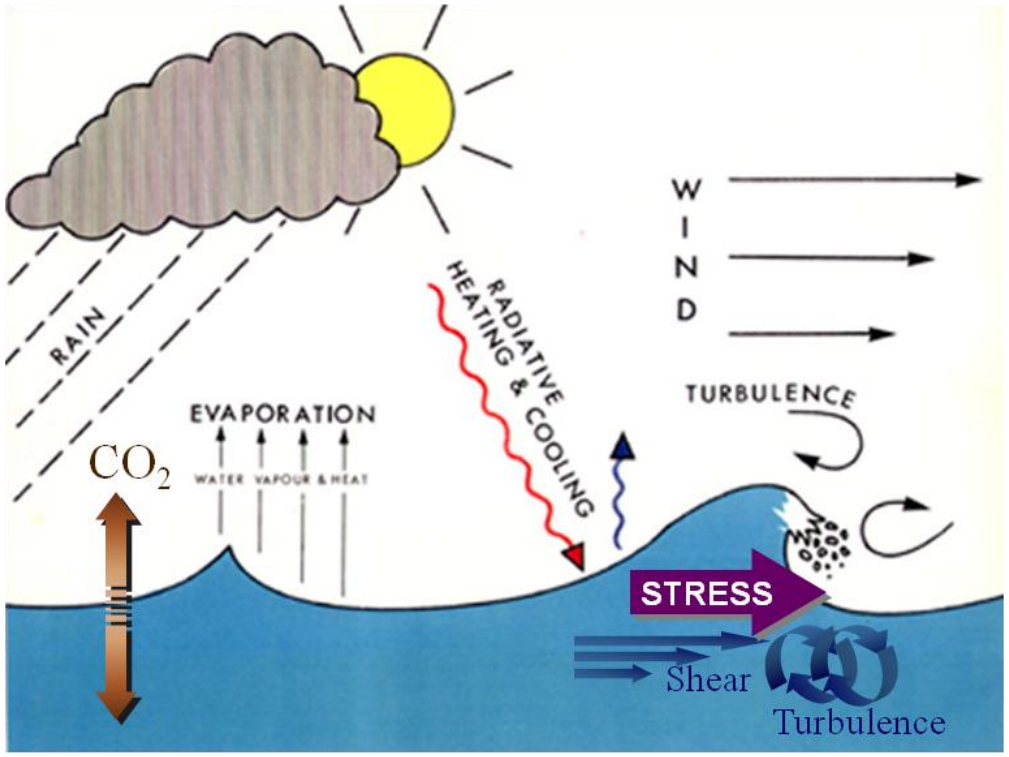
# Outline

- Need of whitecap database
- Whitecap fraction from satellite data
- First whitecap database
- Updated whitecap database
- Future work

# Air-sea processes and surface fluxes




**Mass**

- ❑ Gas flux
- ❑ Sea spray flux

**Heat**

- ❑ Sensible heat flux
- ❑ Latent heat flux

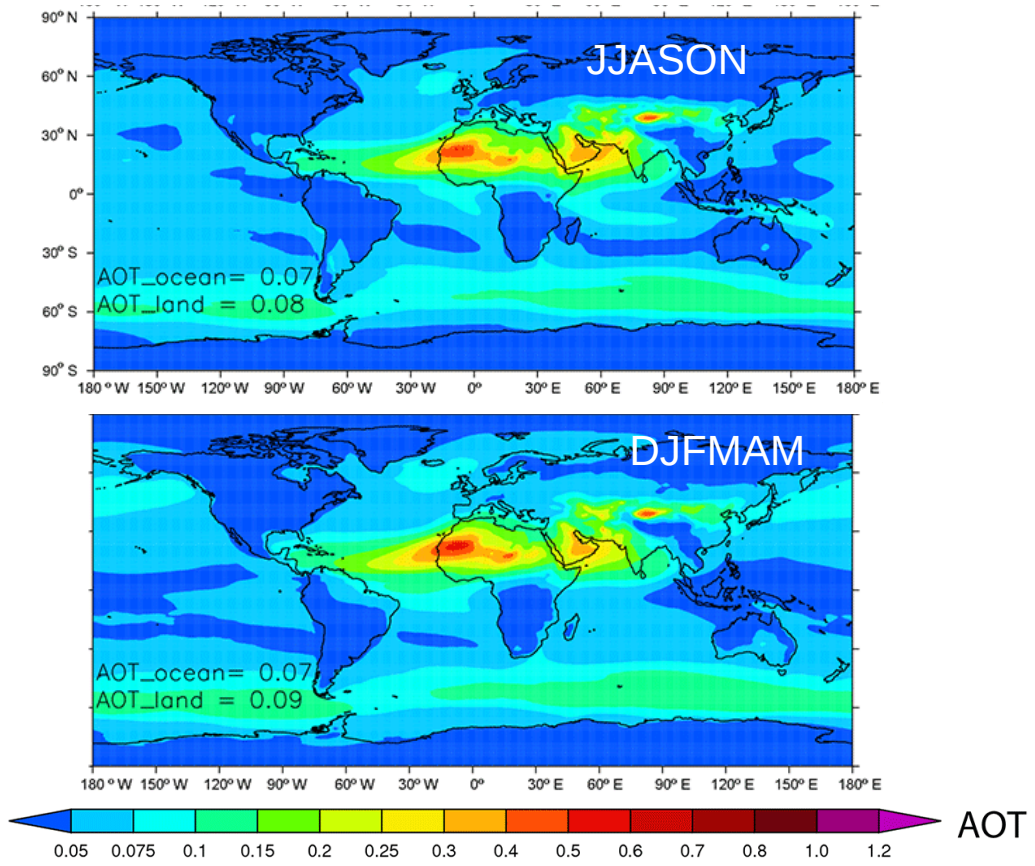
**Energy**

- ❑ Momentum flux
- ❑ Turbulent dissipation

# Surface fluxes and atmosphere-ocean coupling

- Surface fluxes used for
  - Modeling ocean-atmosphere coupling
  - Boundary conditions in models
  - Understanding ocean dynamics
  - Sea spray and CCN

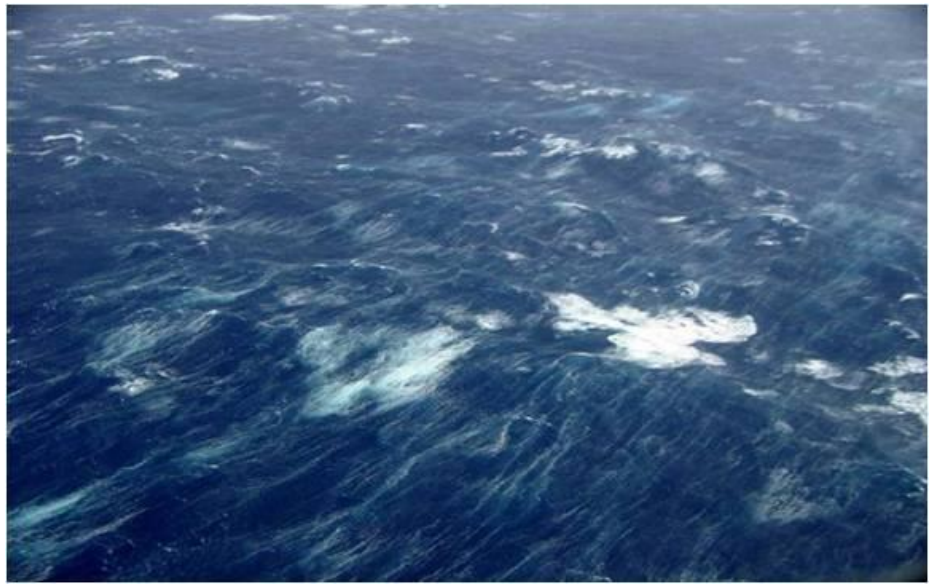
- Surface flux accuracy affects models for
  - Weather
  - Wave field
  - Visibility (from AOT)




Lynch et al. (2016)

# Surface fluxes and whitecaps

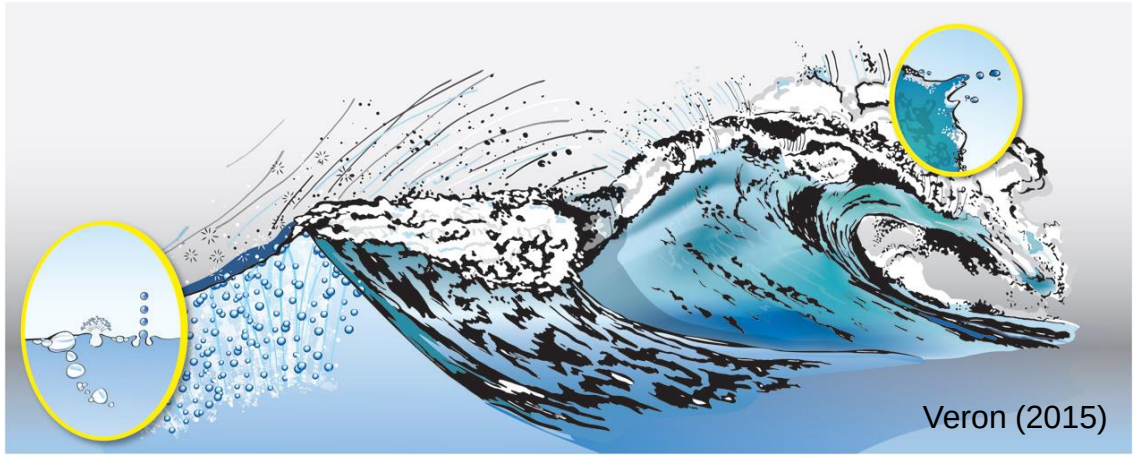
- Whitecap fraction $W$



- Sea spray source function

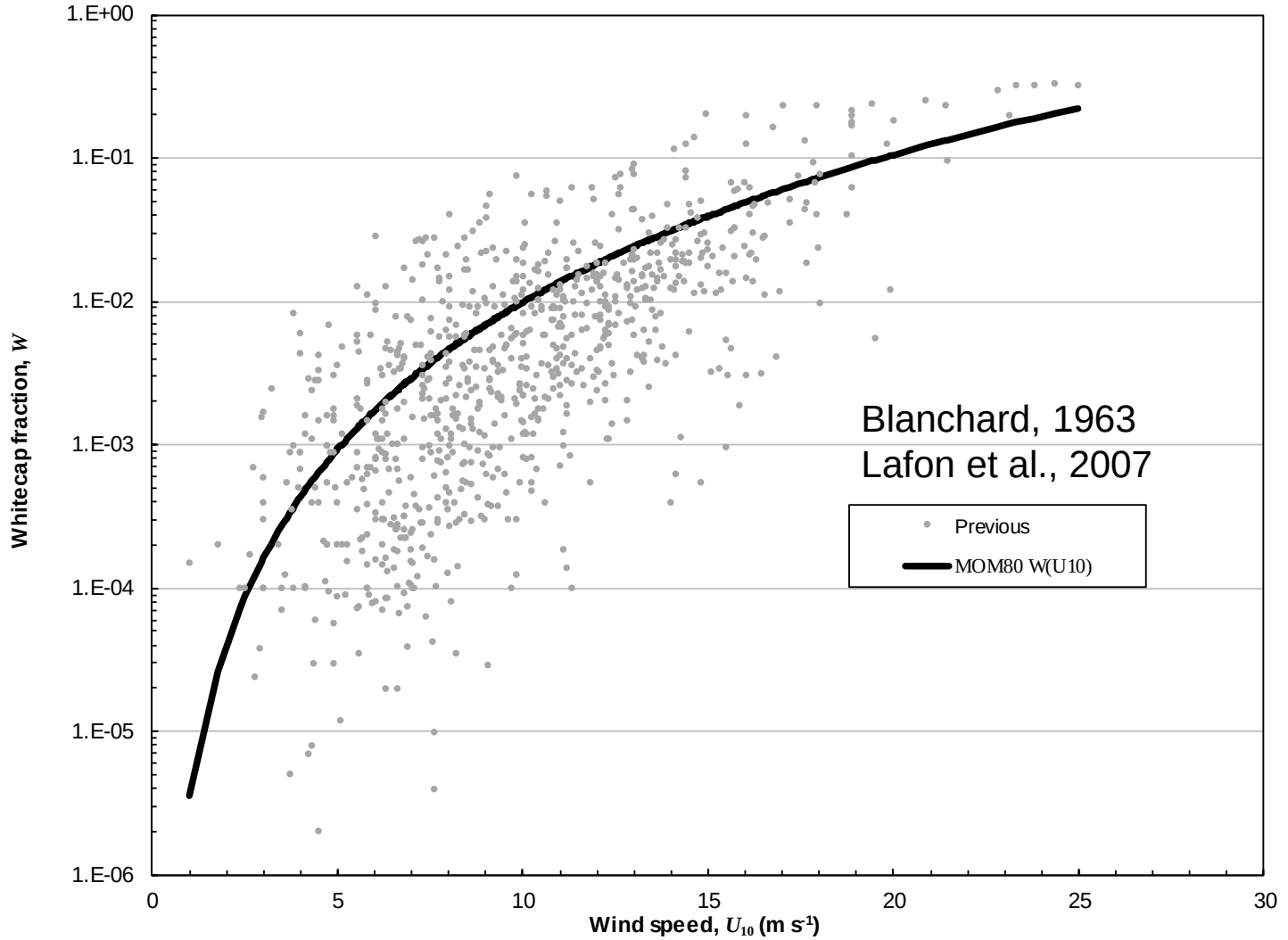
$$\frac{dF(r,U)}{dr} = f(r).f(U)$$

$$\frac{dF(r,U)}{dr} = f(r).W(U)$$



# In situ measurements of whitecap fraction

- Photographic measurements
  - Intensity threshold
  - Wide variations



# In situ measurements of whitecap fraction

- Photographic measurements
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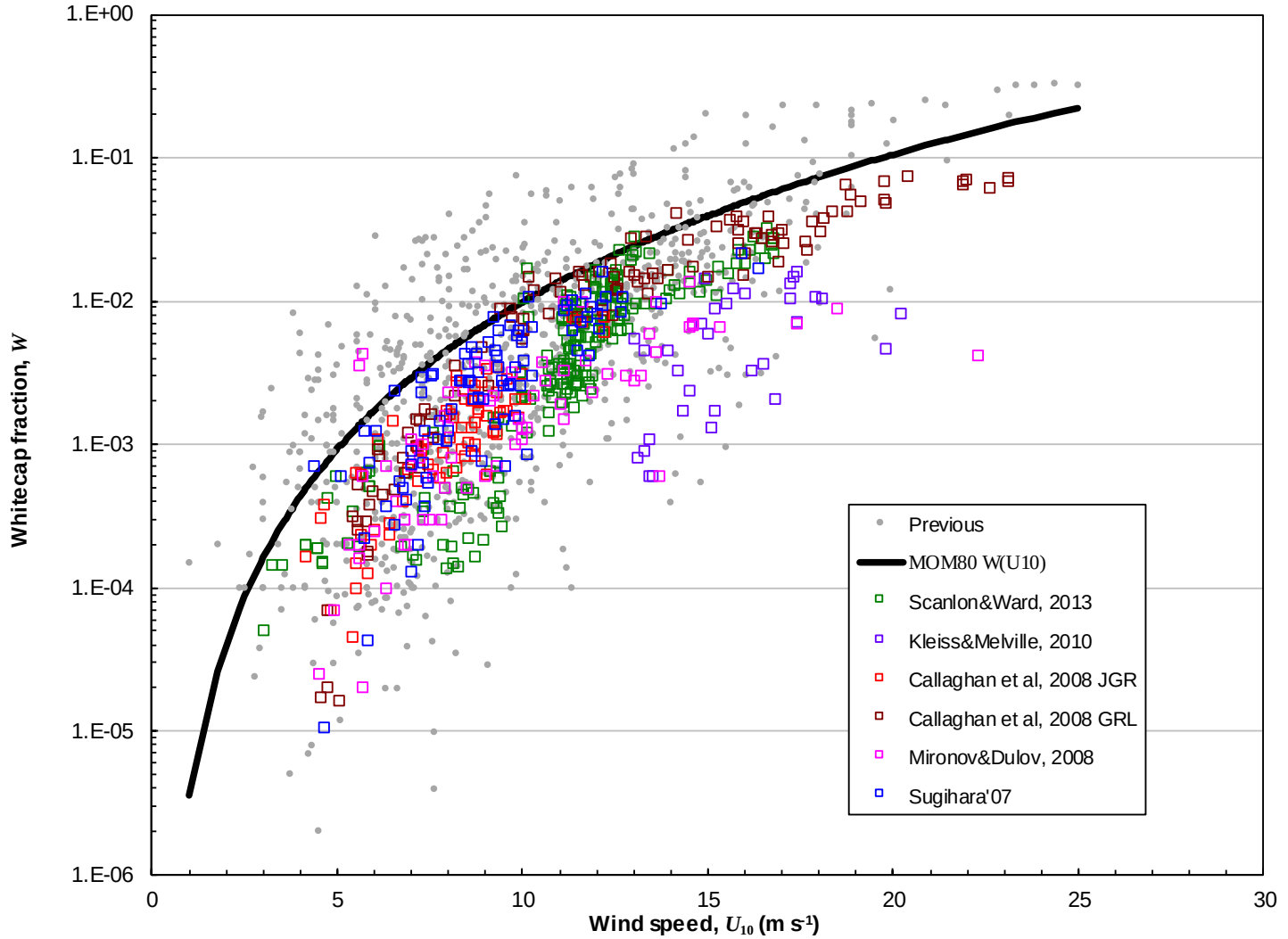
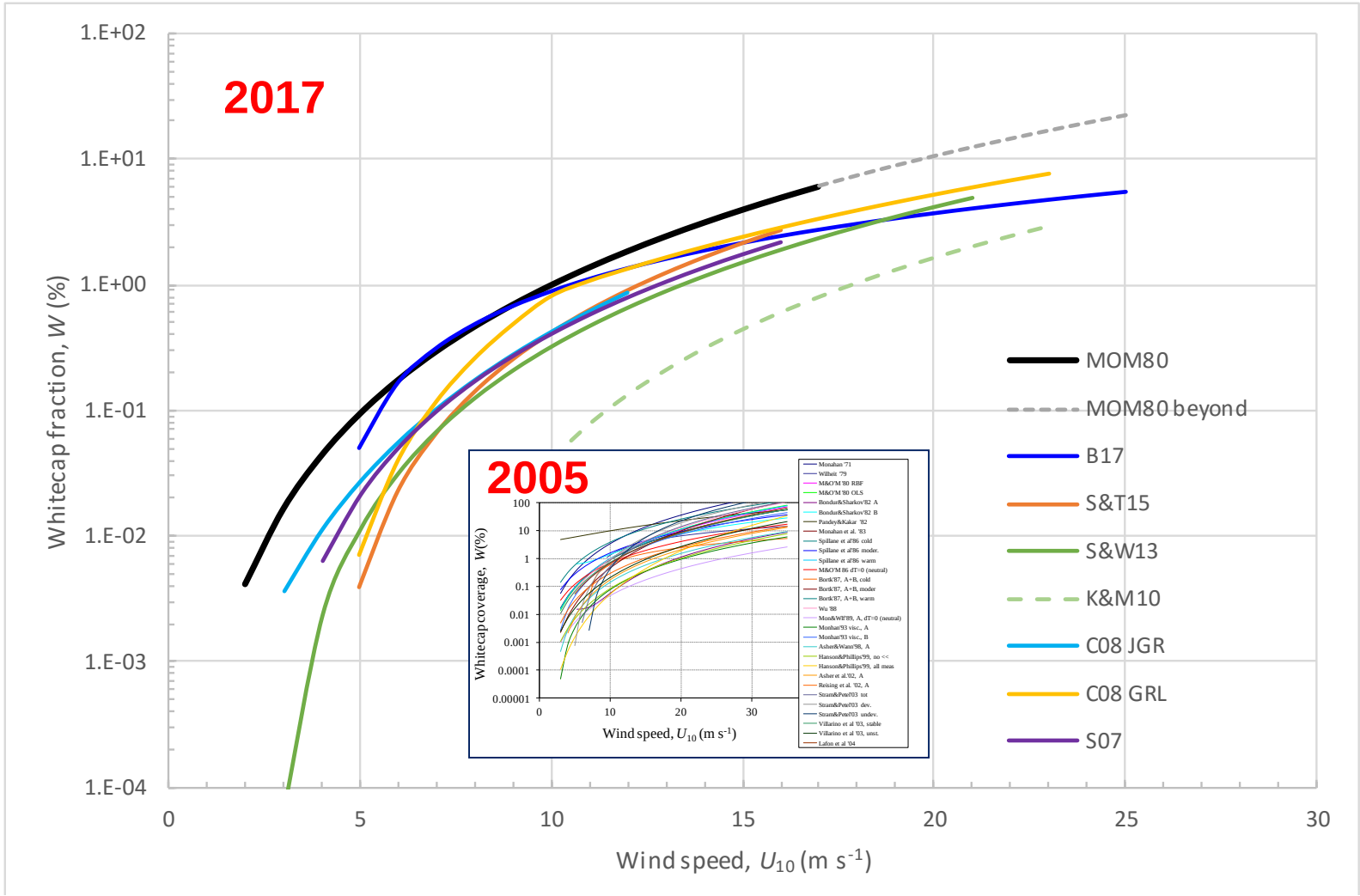
  - Wide variations
- Improvements
  - Digital photography
    - Data volume
  - Image processing algorithms
    - Consistency among groups



# In situ measurements of whitecap fraction

- Photographic measurements
  - Intensity threshold
  - Wide variations
- Improvements
  - Digital photography
    - Data volume
  - Image processing algorithms
    - Consistency among groups
- Order of magnitude variability

$$W(U, H_s, \Delta T, T_s, S, C)$$



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# Whitecap Fraction from Satellite Radiometric Observations

❑ Geophysical model for $W$

$$e = e_W + e_r = WE_f + (1-W)E_r$$

$$e_W \equiv WE_f = e - e_r$$

$$W = \frac{e_W}{E_f} = \frac{e-e_r}{E_f} = \frac{T_{B\mathrm{WS}}^{TOA} - T_{B\mathrm{rmod}}^{TOA}}{E_f A}$$

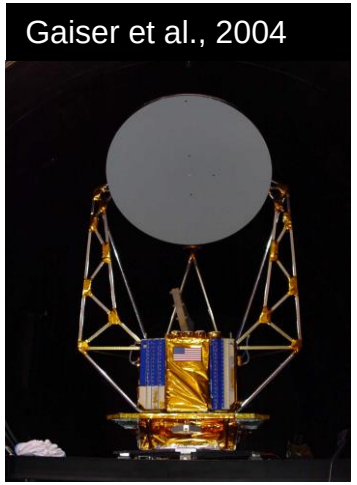
$$T_B = eT_s$$

The **emissivity** of a surface (or a material) is its effectiveness in emitting energy as thermal radiation

❑ Measure $T_B$

❖ WindSat

| Freq (GHz) |
|---|
| 6.8 |
| 10.7 |
| 18.7 |
| 23.8 |
| 37.0 |




❑ Model $T_B$ WindSat geophysical model

❖ Atmospheric model ($t$ etc.)

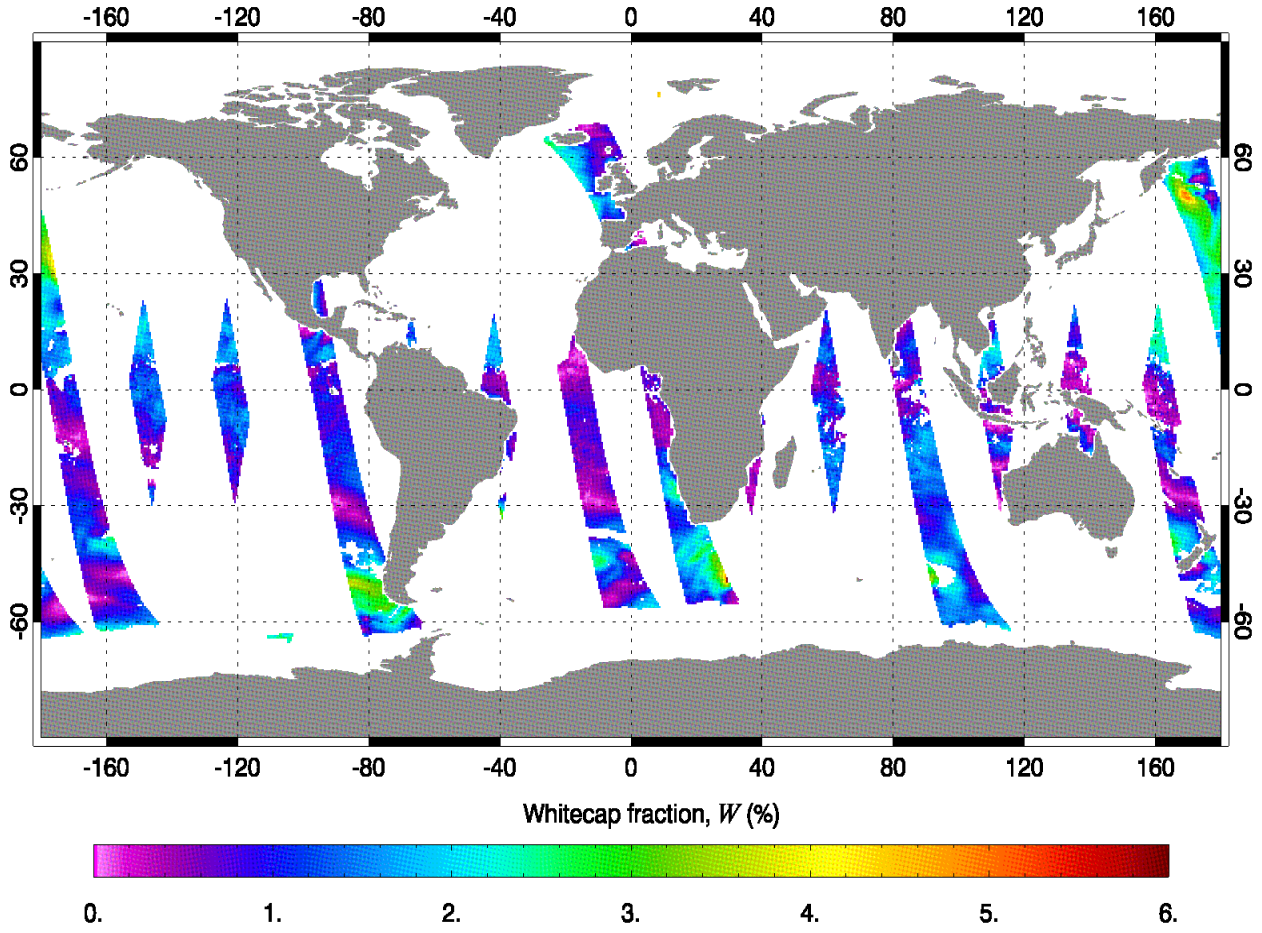
❖ Roughness model ($e_r$)

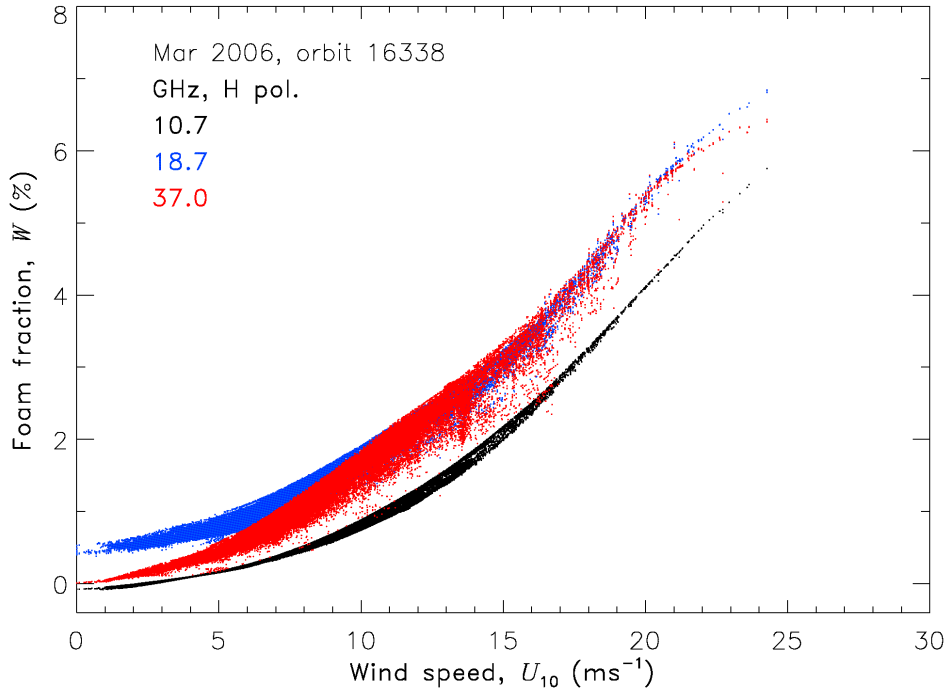
❖ Foam model ($E_f$)

# Early Version of the $W(T_B)$ Algorithm

- Use WindSat $T_B$ indirectly
  - At low resolution: 50 km $\times$ 71 km
- Use external data as model inputs
  - QuikSCAT: wind vector
  - GDAS: SST
  - SSM/I and/or TMI: Atmospheric variables
- Simple atmospheric correction

# Early Version of the $W(T_B)$ Algorithm



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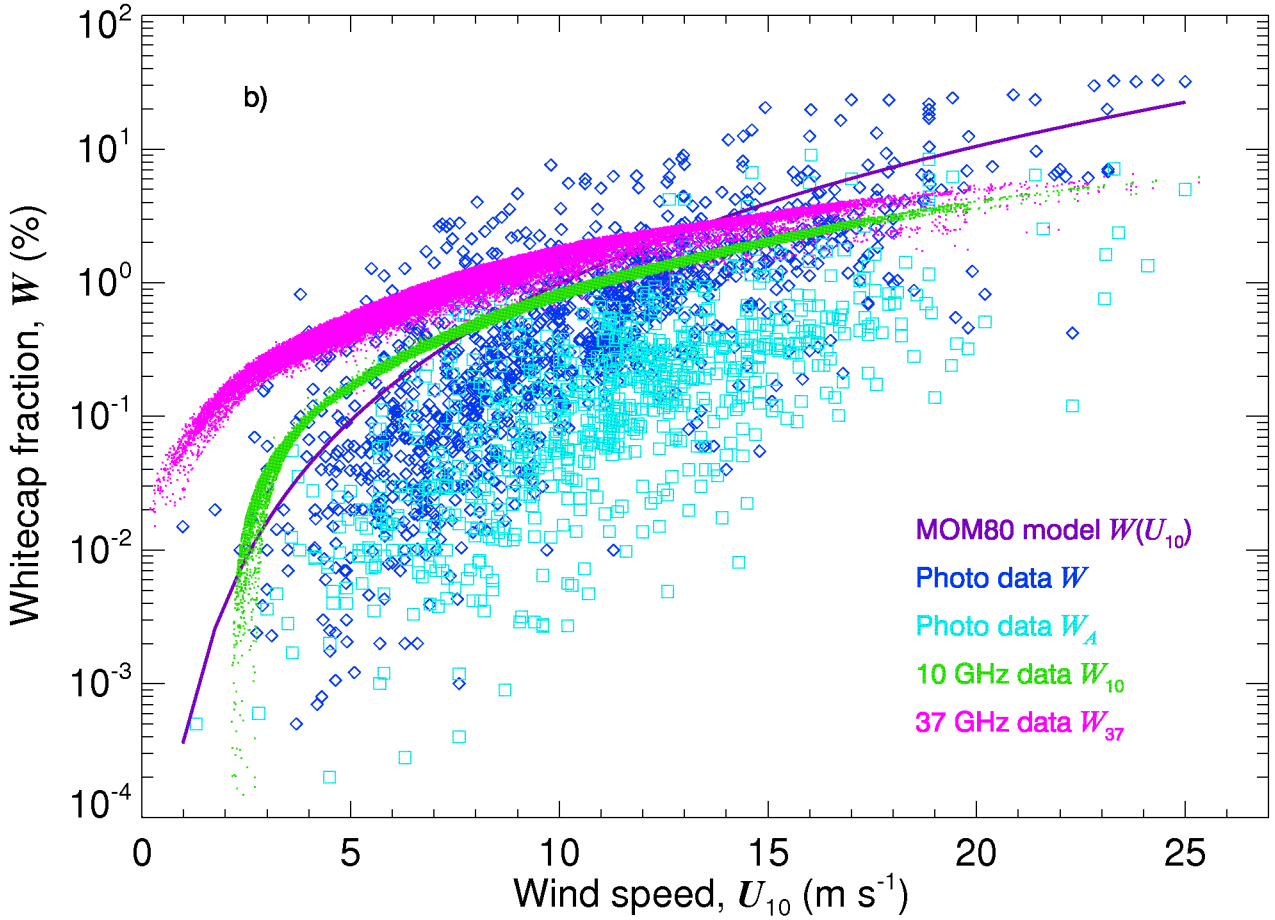
# First Whitecap Database

- Gridded data for 2006
  - 0.5° x 0.5°
- Two frequencies
  - 10 and 37 GHz
  - H polarization
  - Sensitivity to foam thickness
- Matched-up metoc data
  - QuikSCAT: $U_{10}$, $U_{\mathrm{dir}}$
  - GDAS: SST, air temperature
  - WW3: $H_s$, $T_p$ (total field)



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  - QuikSCAT: $U_{10}$, $U_{\mathrm{dir}}$
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  - WW3: $H_s$, $T_p$ (total field)
- Use
  - $W$ variability (Salisbury et al., 2013 JGR, 2014 GRL)
  - $W$ parameterization (Albert et al., 2016, ACP)

$$W(U, T_s)$$

  - Surface fluxes (Anguelova, 2016)
    - ✓ Sea spray
    - ✓ Gas transfer ($CO_2$)

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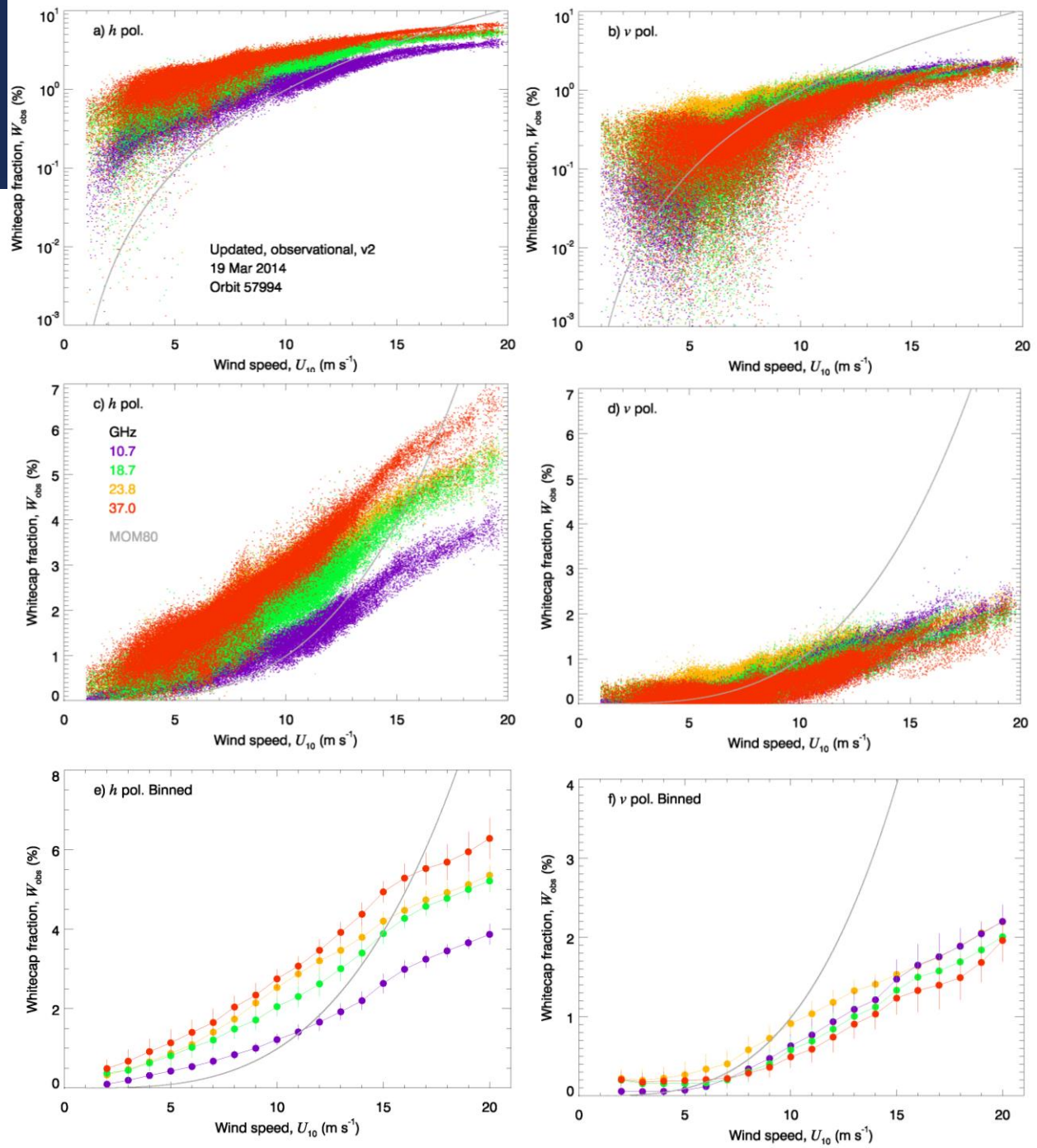
# Latest $W(T_B)$ algorithm

- Use WindSat $T_B$ directly
  - At high resolution: 25 km × 35 km
- WindSat retrievals as model input
  - $U_{10}$, $\phi$, $T_s$, $V$, $L$
- Full atmospheric correction
- Database entries
  - $W$ at 10H, 18HV, 37H



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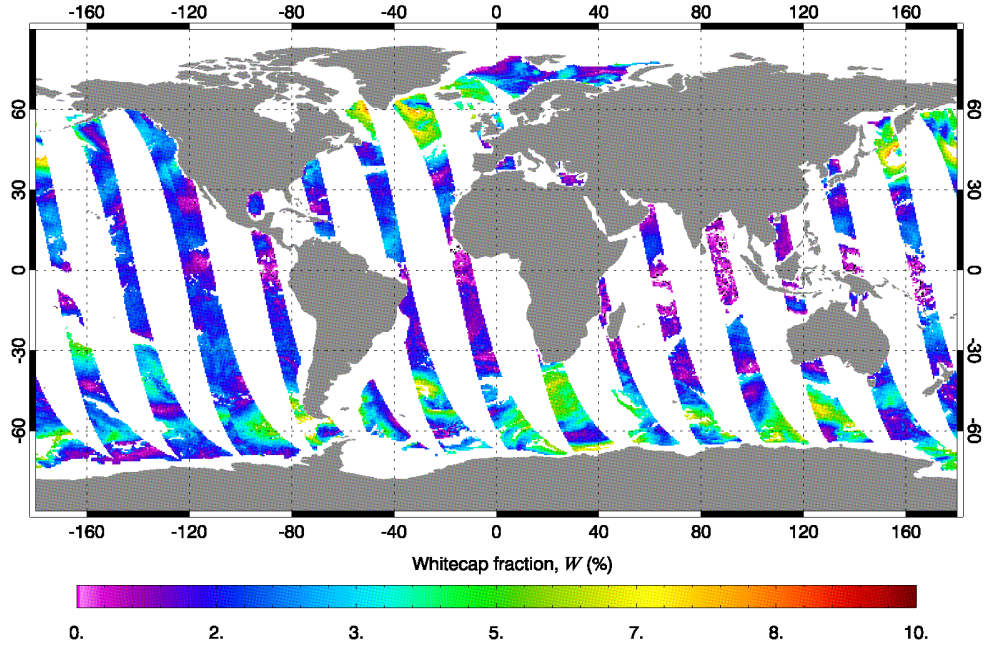
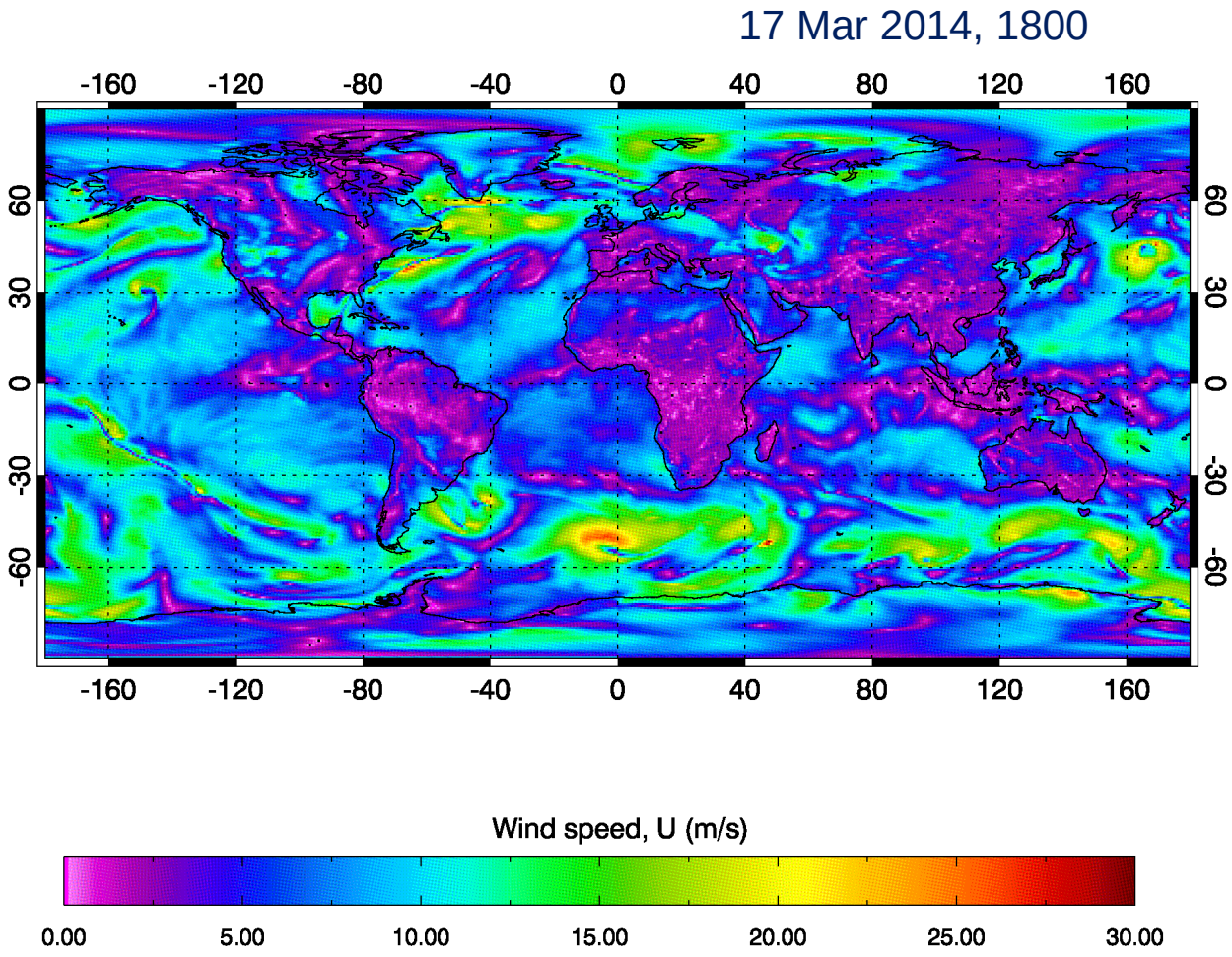


# Additional Data

- ECMWF 6-hr Re-analysis (ERA):
  - Data: $U_{10}$, $\phi$, $T_s$, air temperature
  - Grid $0.7° \times 0.7°$ ($512 \times 256$)



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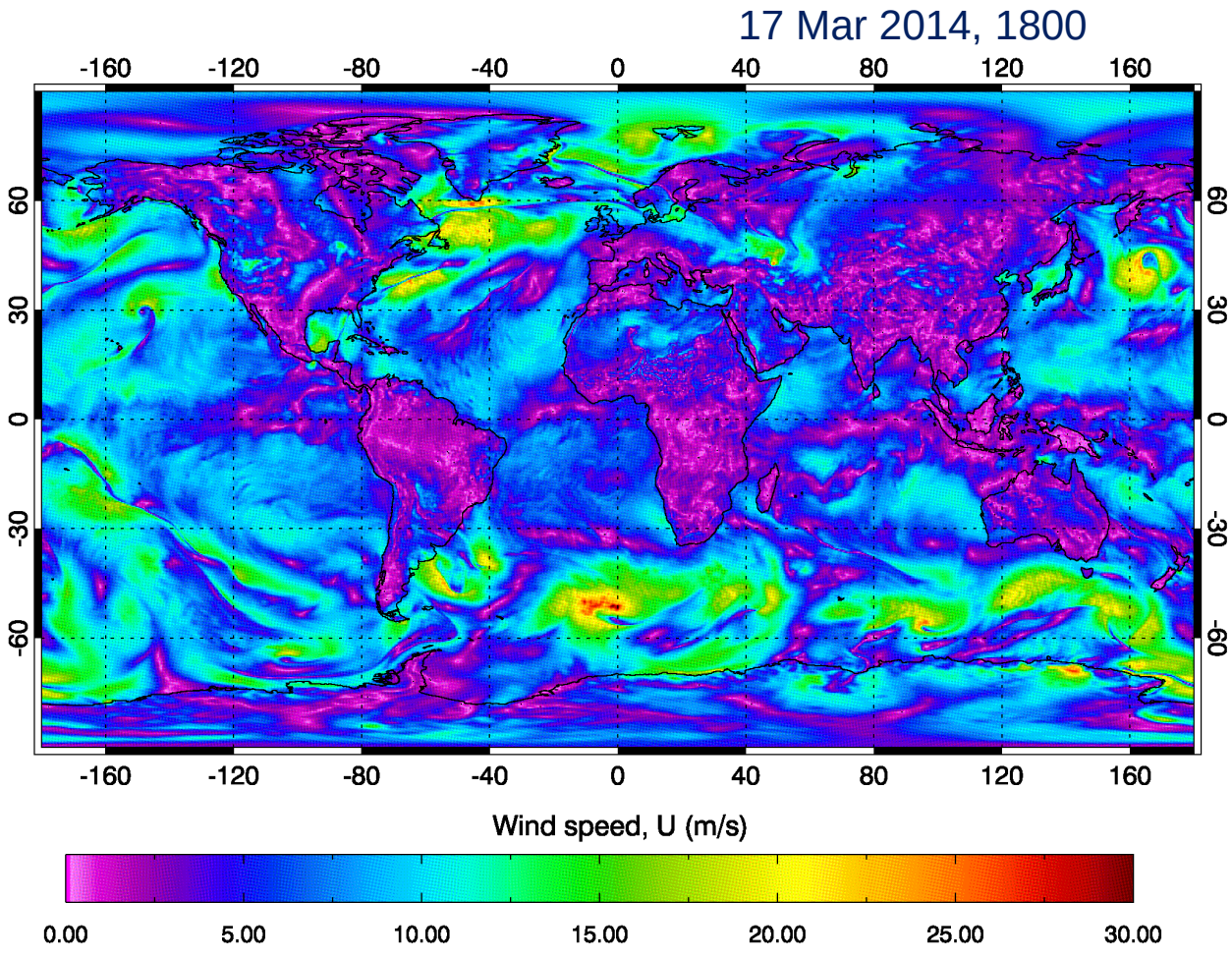
  - Data: $U_{10}$, $\phi$
  - Grid $1/3° \times 1/3°$ ($1080 \times 540$)



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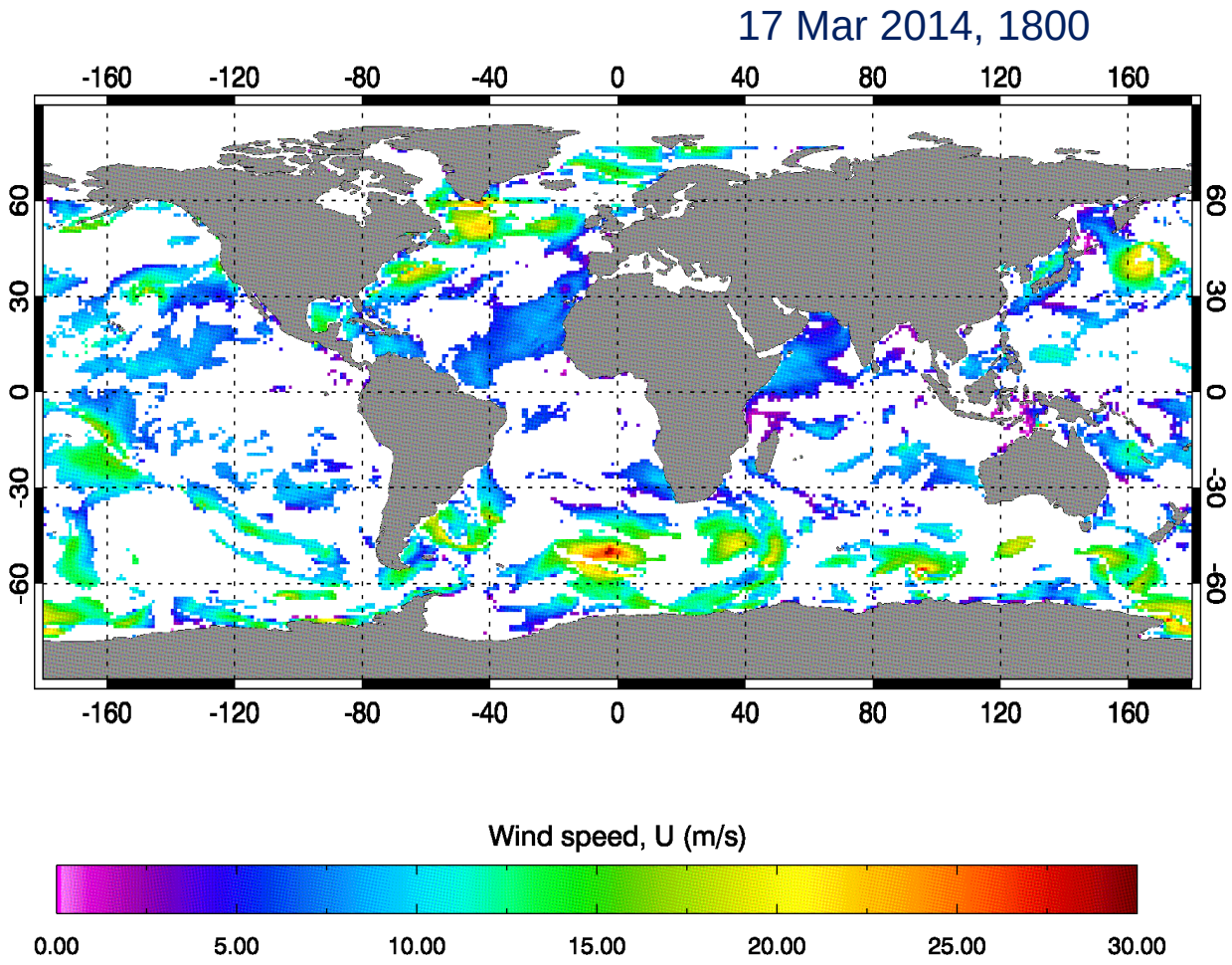
- NCEP Wave Watch III model (v. 3.14):
  - Data: $U_{10}$, $\phi$, $H_s$, $T_p$, $\theta_{wave}$
  - Grid 1° × 1° (360 × 180)



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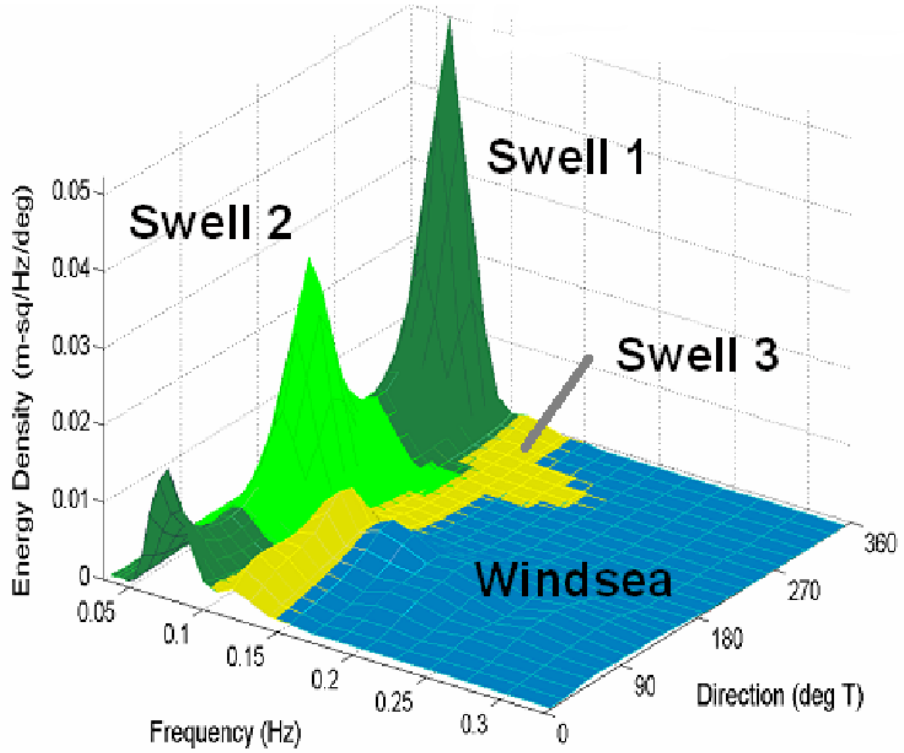
  - Windsea partition hourly



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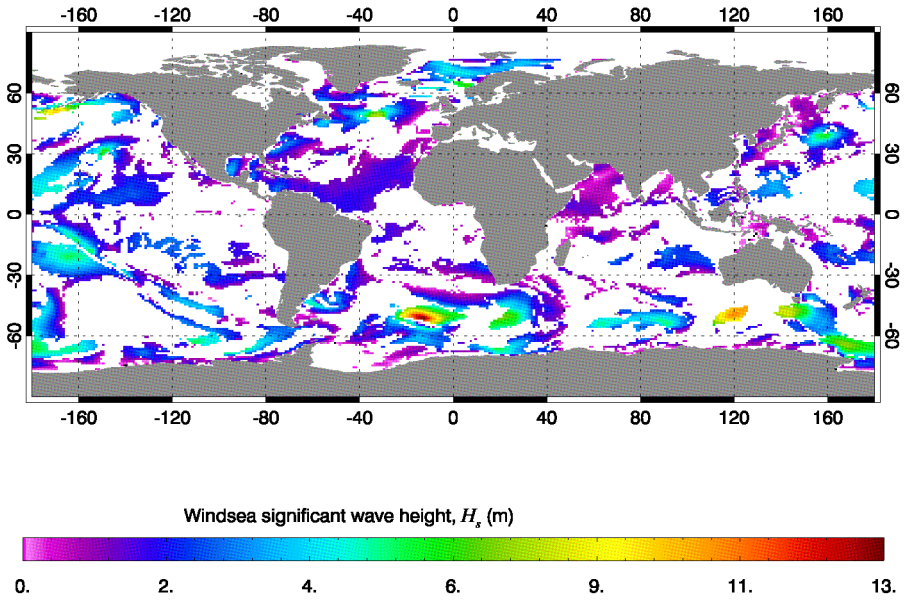
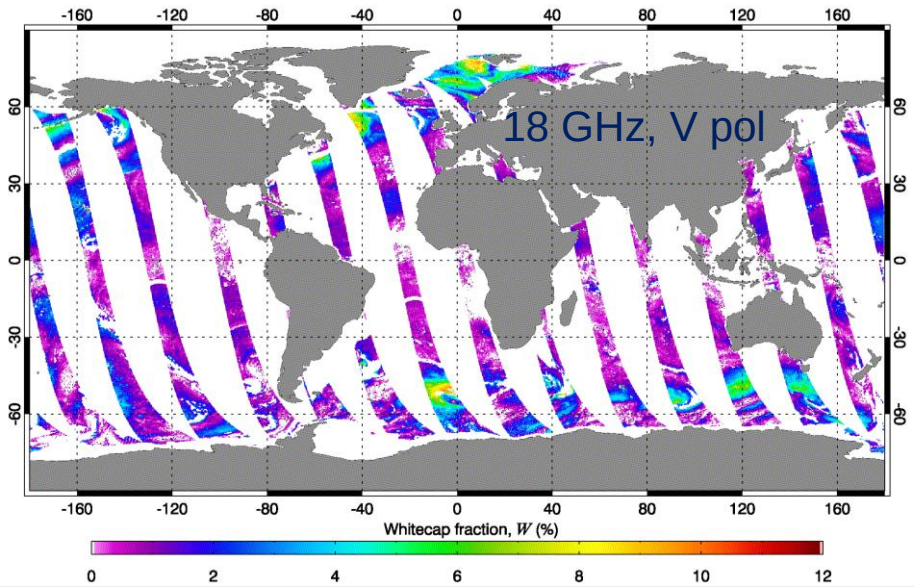
  - Grid 1° × 1° (360 × 180)
  - Windsea partition hourly
    - Above 75% of total wave field

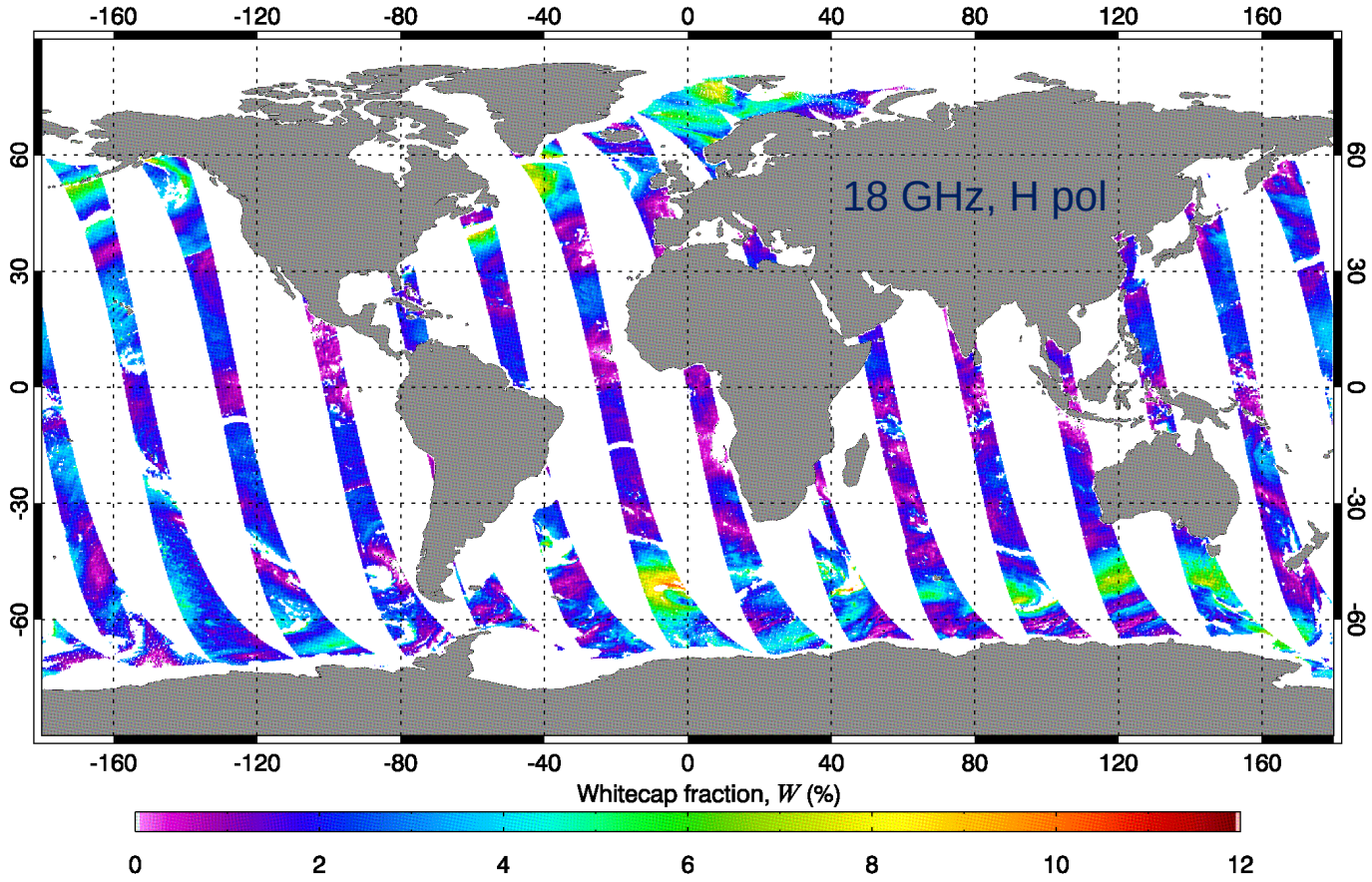


# Updated Whitecap Database

- All entries gridded at 0.25° × 0.25° (1440 × 720)
- Full 2014
- Daily maps
- NetCDF format

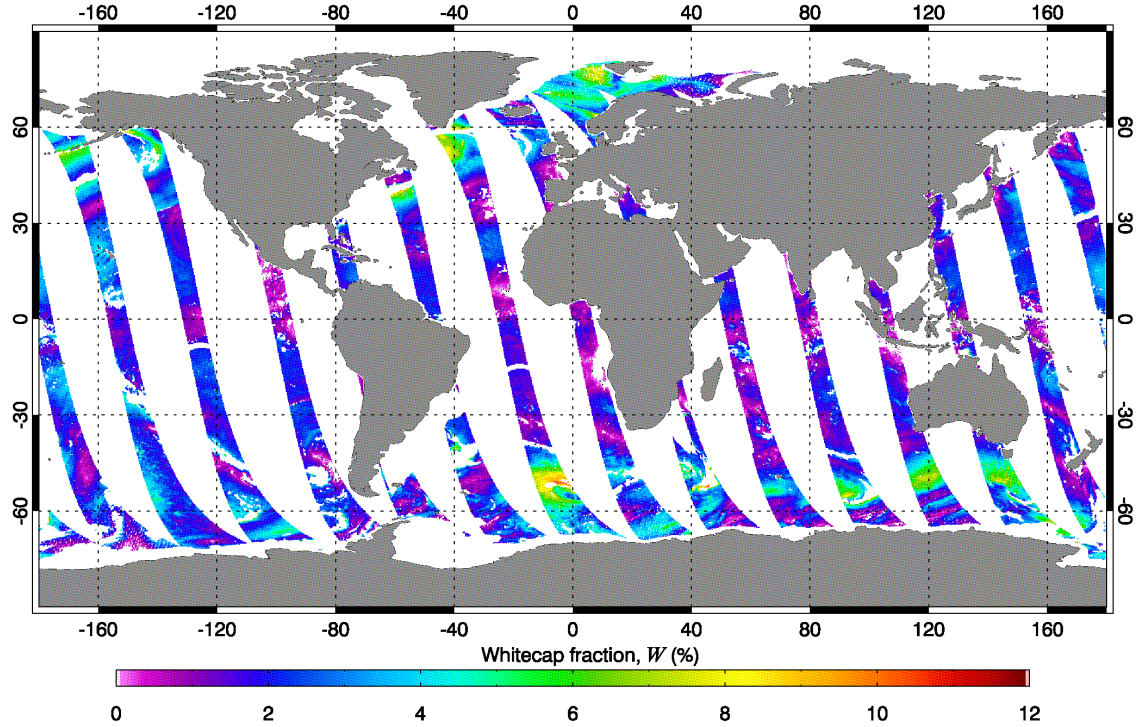
17 Mar 2014



# Conclusions

- Updated whitecap algorithm $W(T_B)$
  - Direct use of WindSat $T_B$ observations
  - WindSat retrievals are input to models
  - $W$ at high resolution
- Updated whitecap database
  - One year 2014
  - Gridded at 1/4° × 1/4°
  - 3 freq and 2 polarizations
  - Independent external data: NRA, ERA, WW3 (windsea)
  - Daily files in netCDF format



# Future work

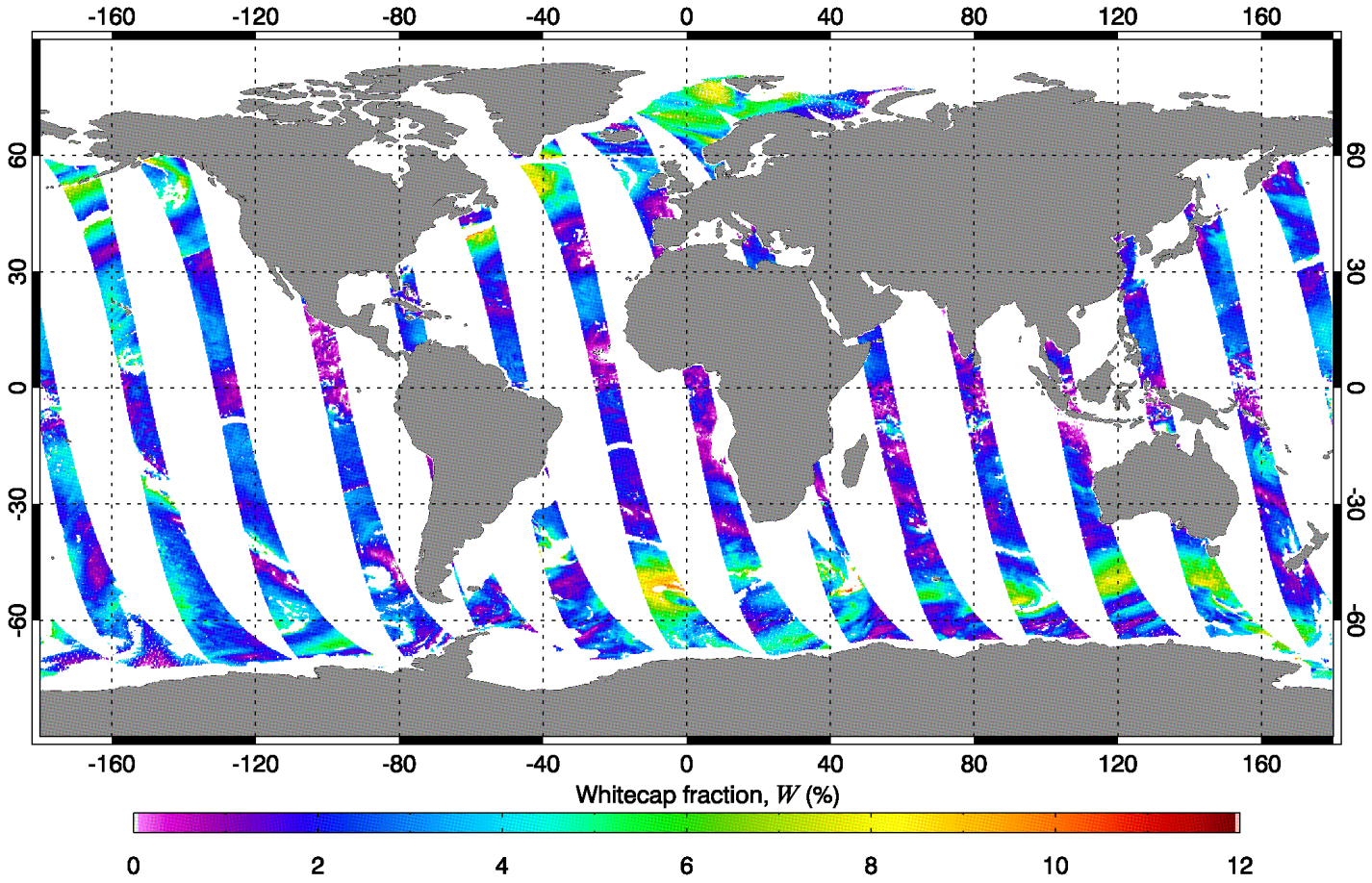
- Use the 2014 whitecap database
  - Study $W$ variability
  - New parameterizations $W(U_{10}, H_s, \Delta T, T_s, S, C)$
- Improve the $W(T_B)$ algorithm
  - Wind speed dependence in foam model
  - Tune wave spectrum in roughness model
  - Minimize H and V differences
  - Radiometric measurements at higher resolution

Poster 634: Bettenhausen and Anguelova

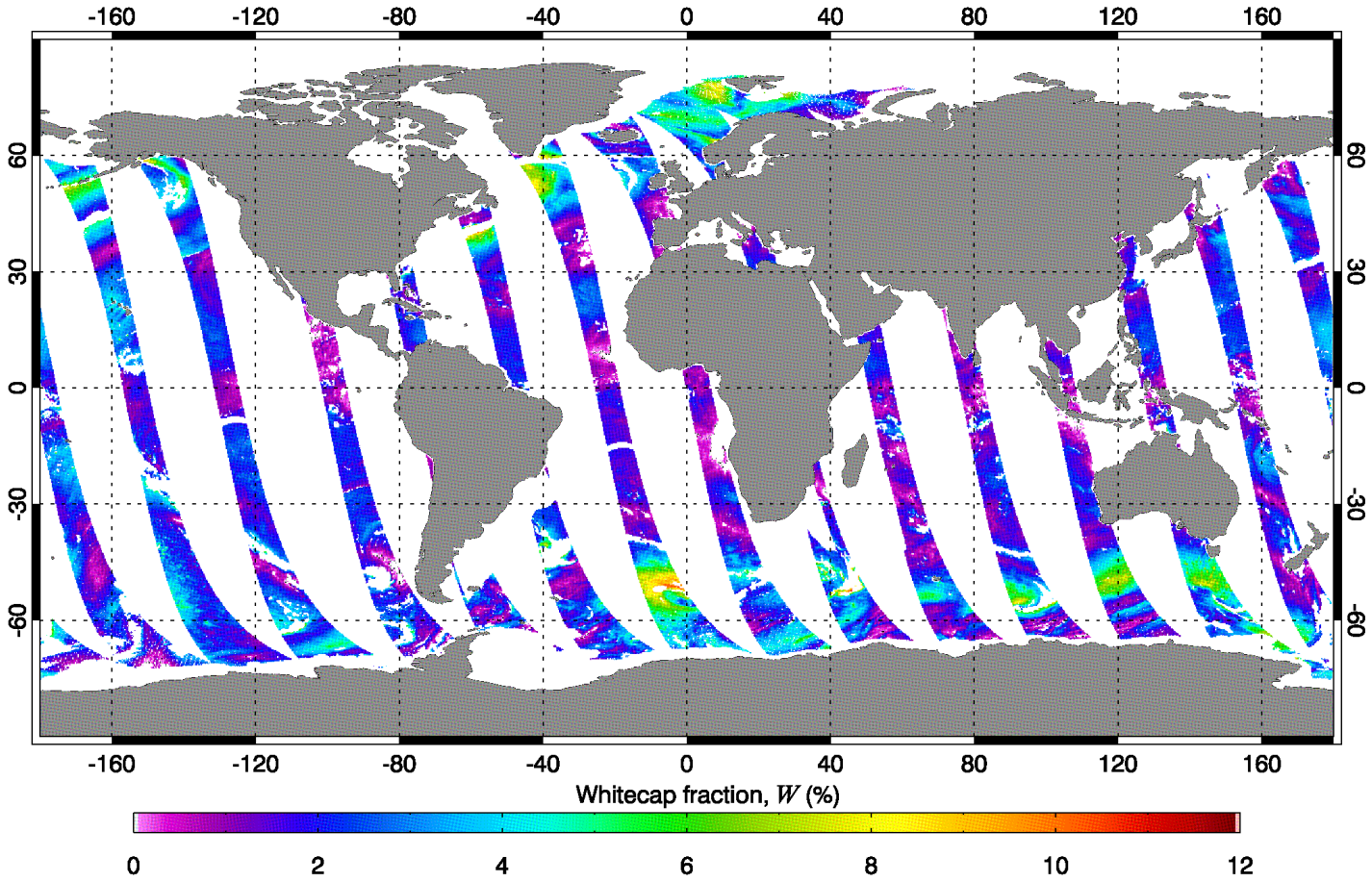
Thank you!

# Additional slides

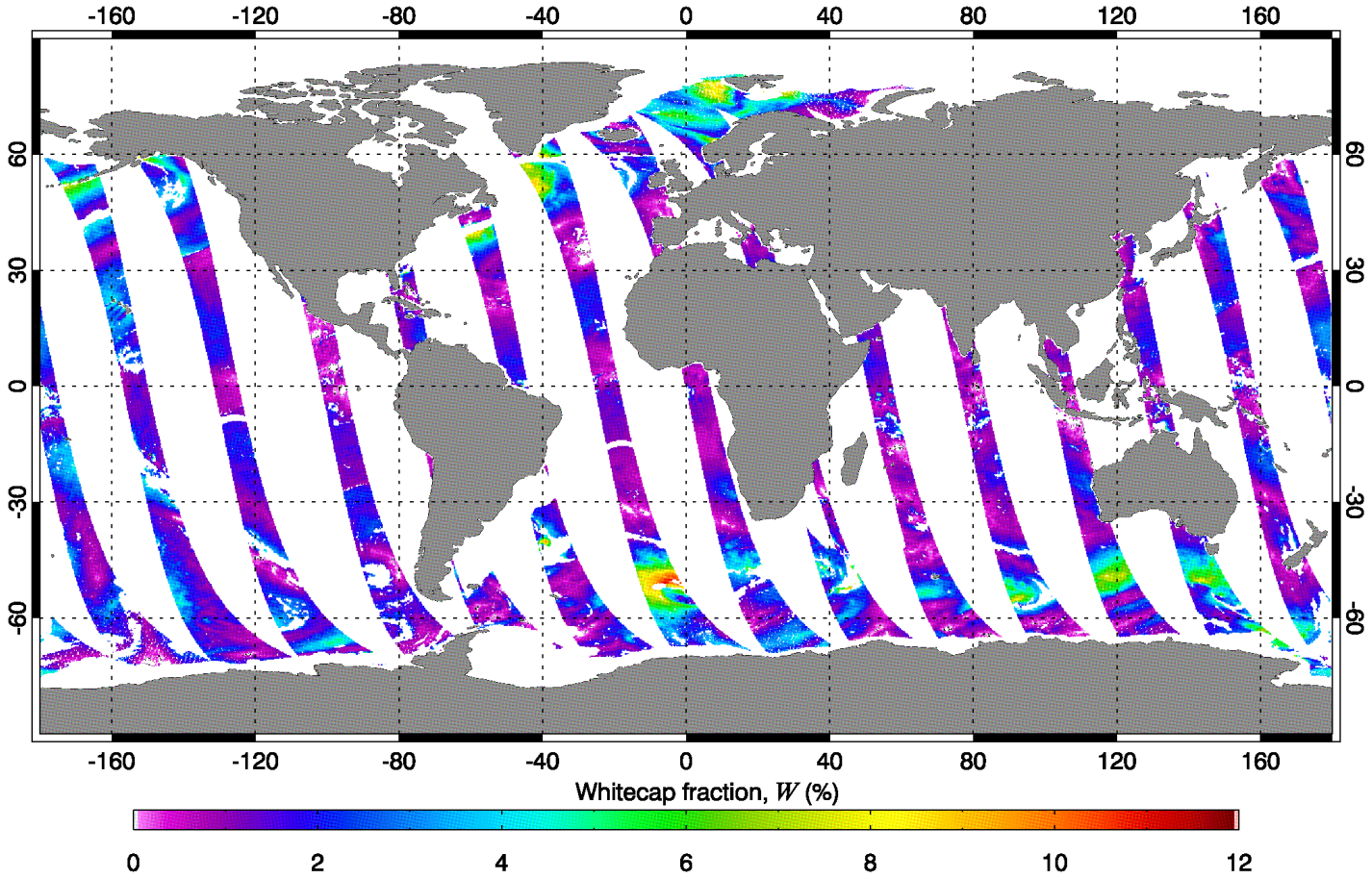
17 Mar 2014
37 GHz, H pol



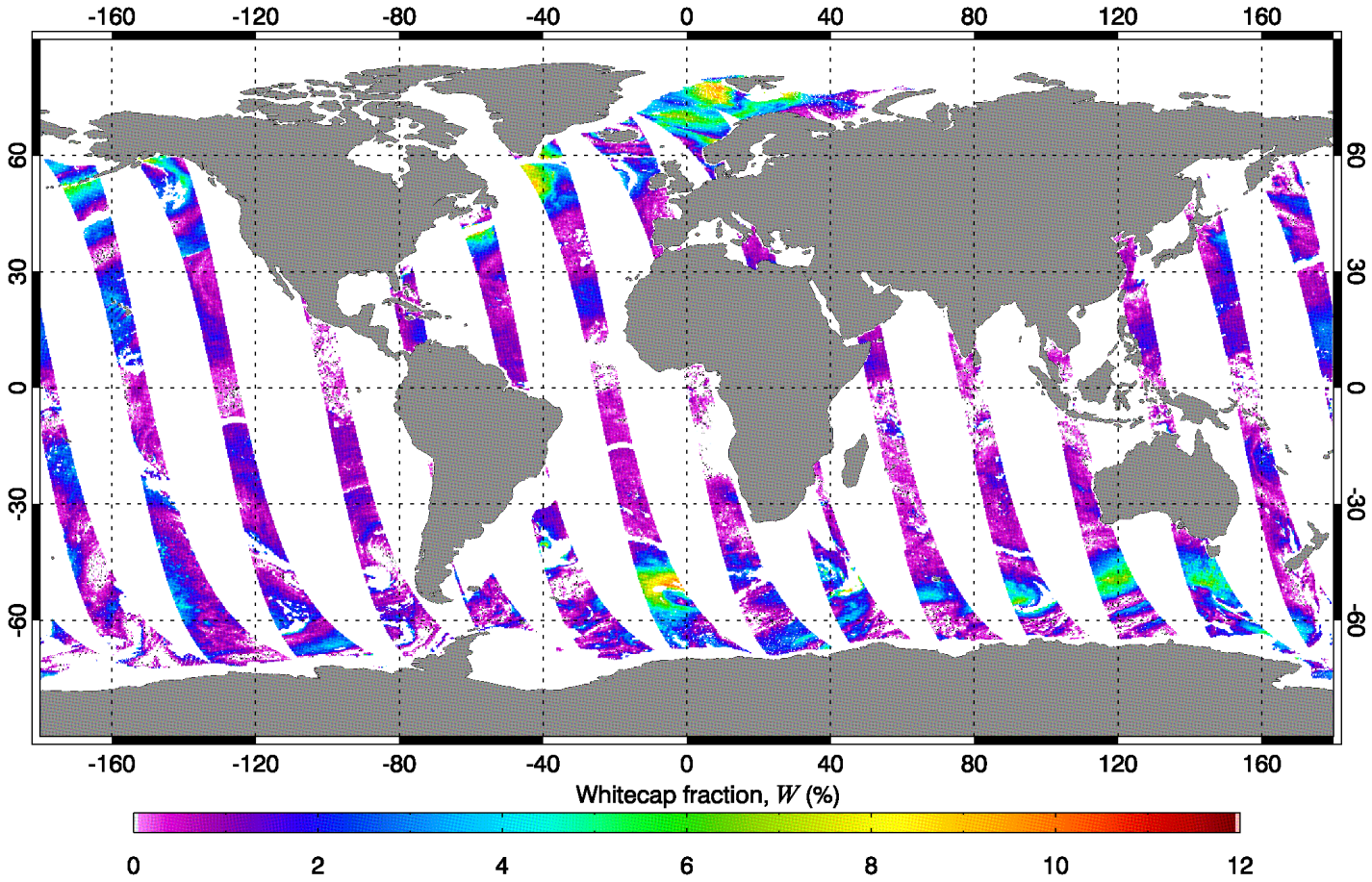
17 Mar 2014
18 GHz, H pol



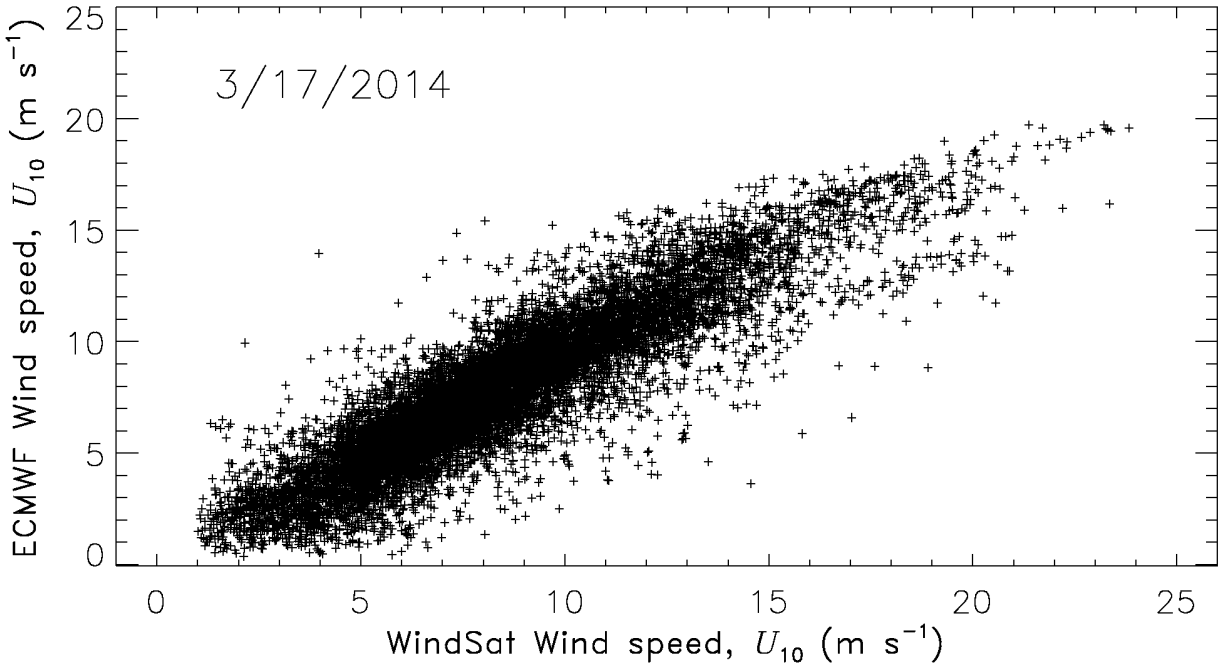
17 Mar 2014
10 GHz, H pol

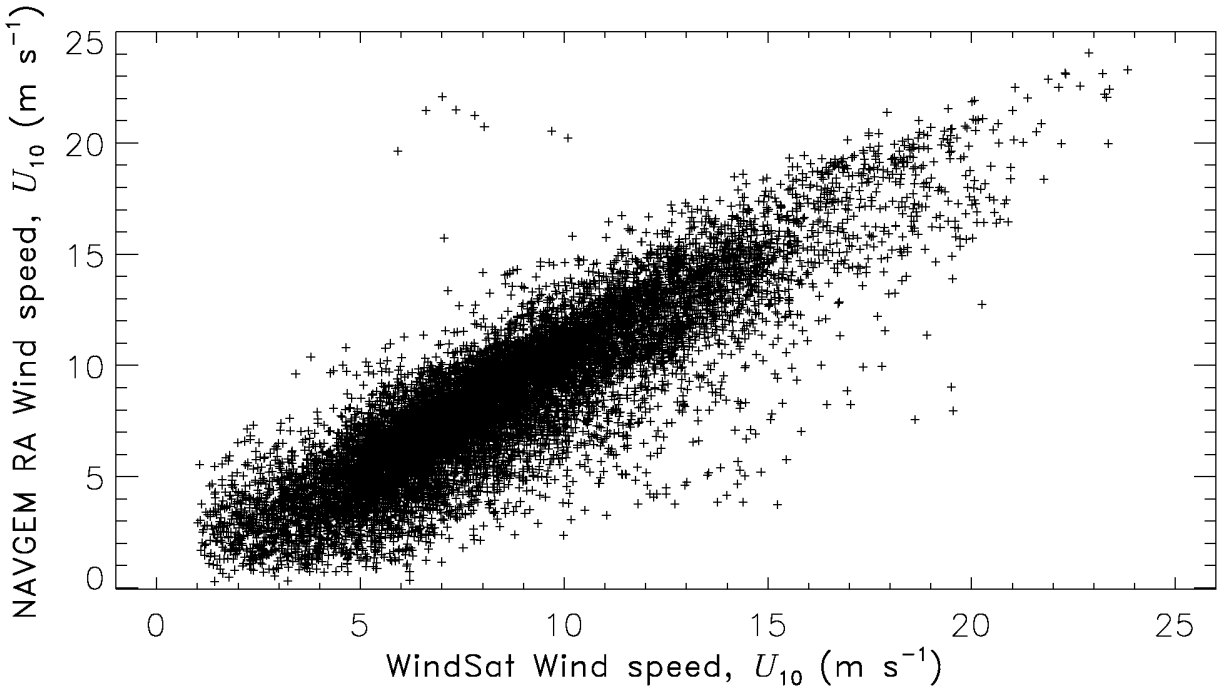


17 Mar 2014
18 GHz, V pol

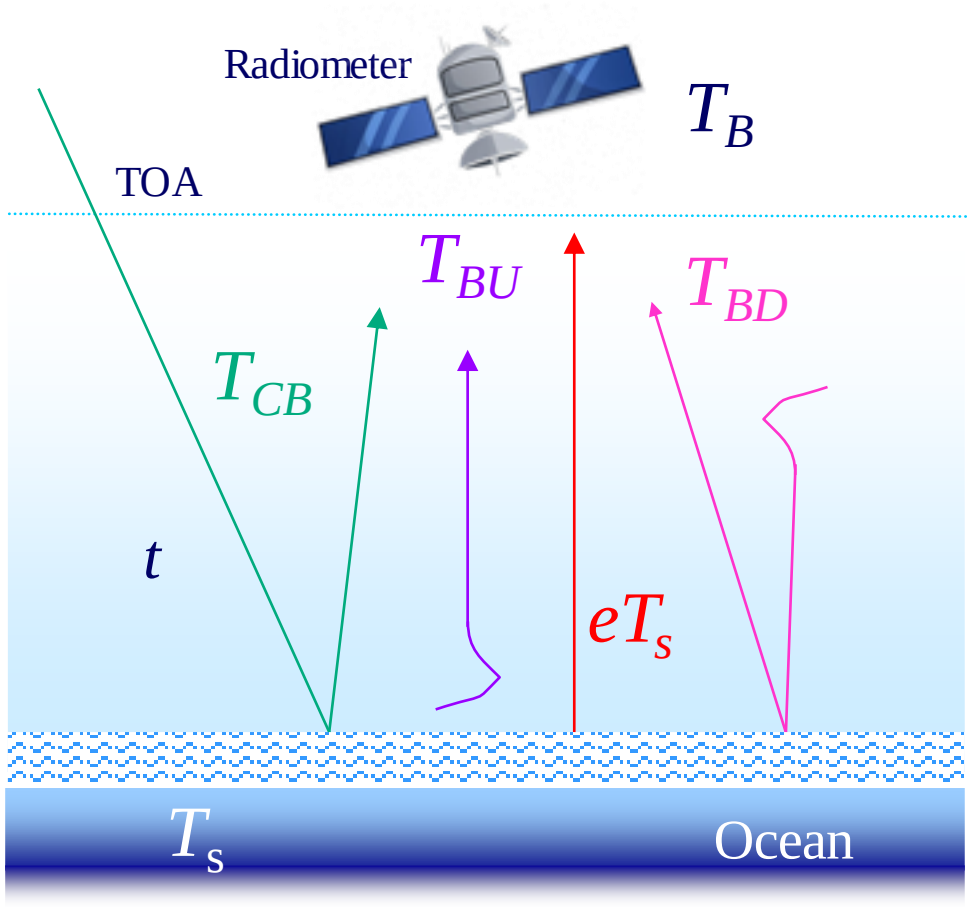


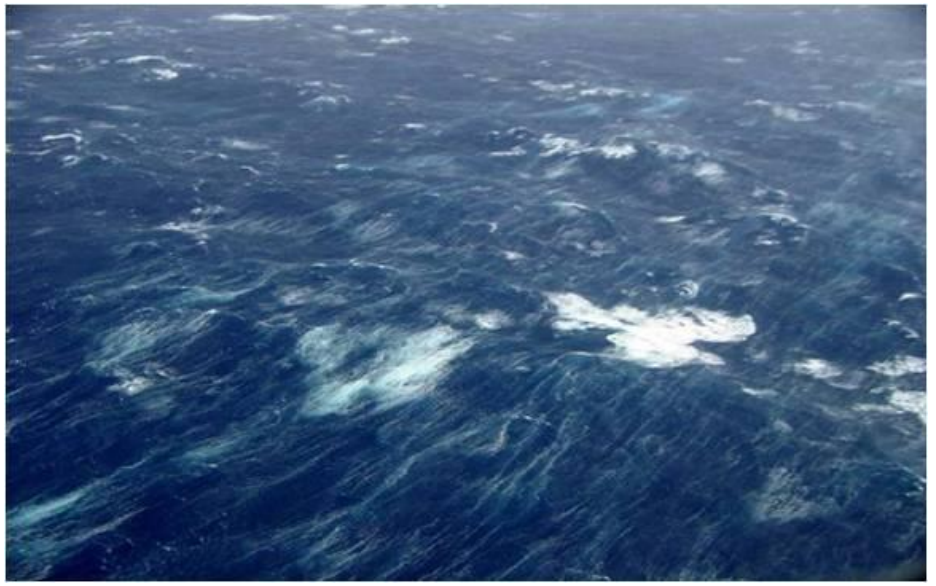
# Compare Wind Speeds



# Whitecaps observed with passive microwave radiometry



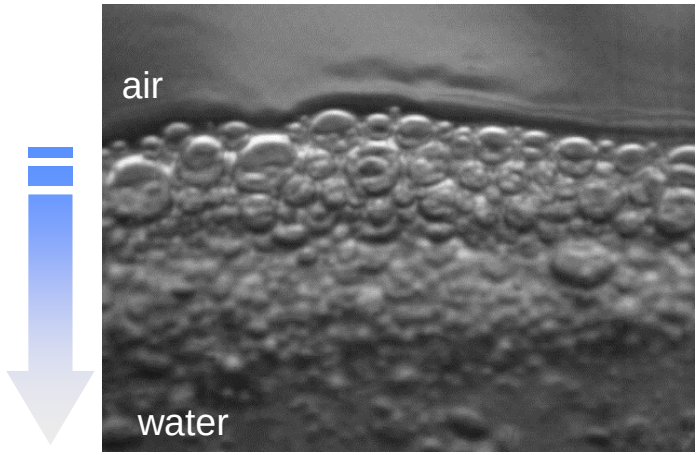
$$T_B = teT_s + T_{BU} + trT_{BD} + t^2 rT_{CB}$$

$$r = 1 - e$$

$$e = e_W + e_r = WE_f + (1 - W)E_r$$

# Sea Foam Emissivity

- Foam structure
  - Air-water mixture
  - Closely packed bubbles
  - Bubble sizes and shape varying
- Bubble diameters
  - << 1 mm
  - to a few mm
- Foam layer thicknesses
  - A few mm
  - To 20 cm and more
- Vertical profile
  - Void fraction
  - Bubble size distribution




$r \propto$ difference in media properties