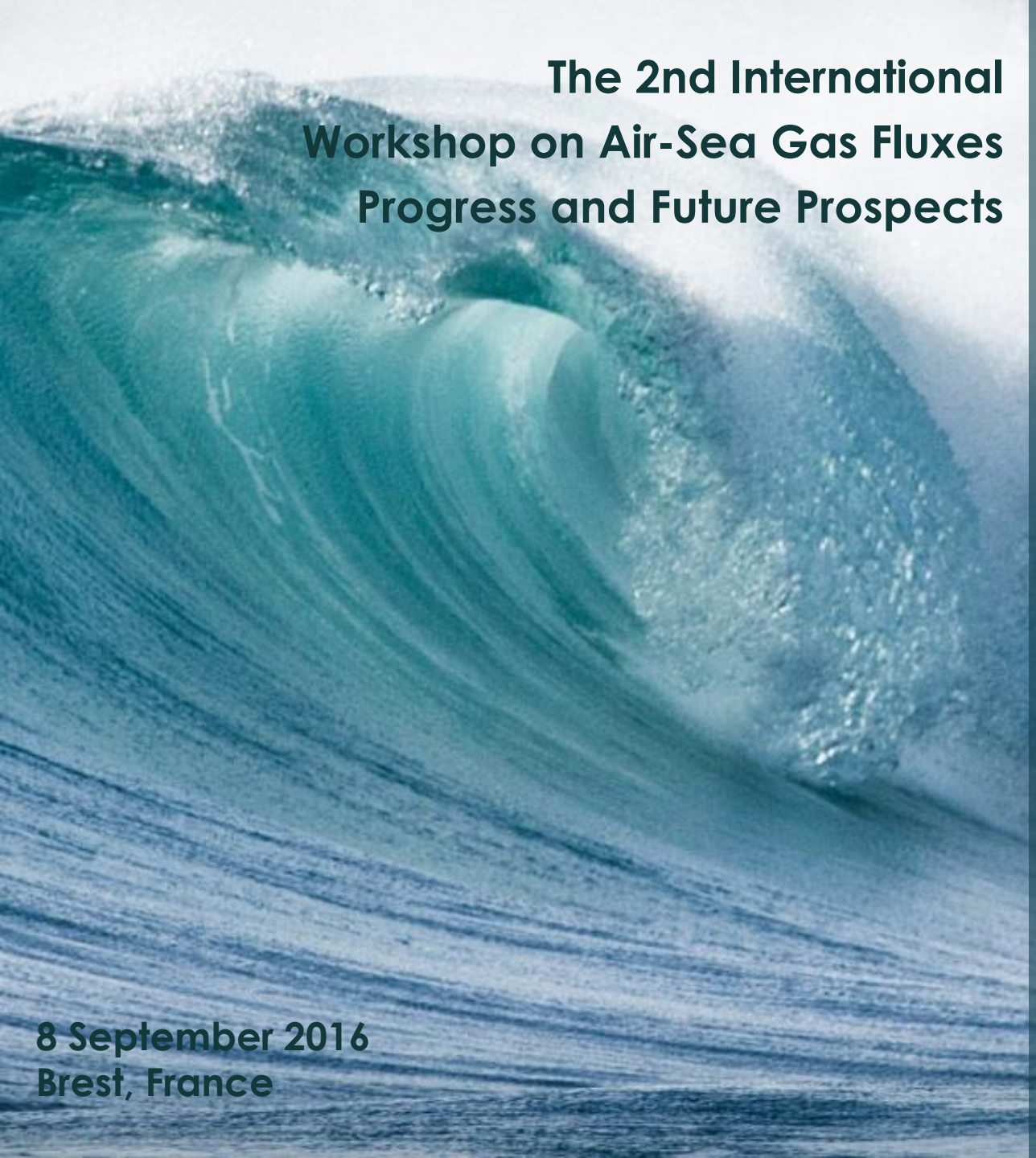

The 2nd International Workshop on Air-Sea Gas Fluxes Progress and Future Prospects

8 September 2016
Brest, France

U.S. NAVAL RESEARCH LABORATORY

Parameterizations of Whitecap Fraction: Status Update

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Outline

Gas exchange and whitecaps

- Motivation

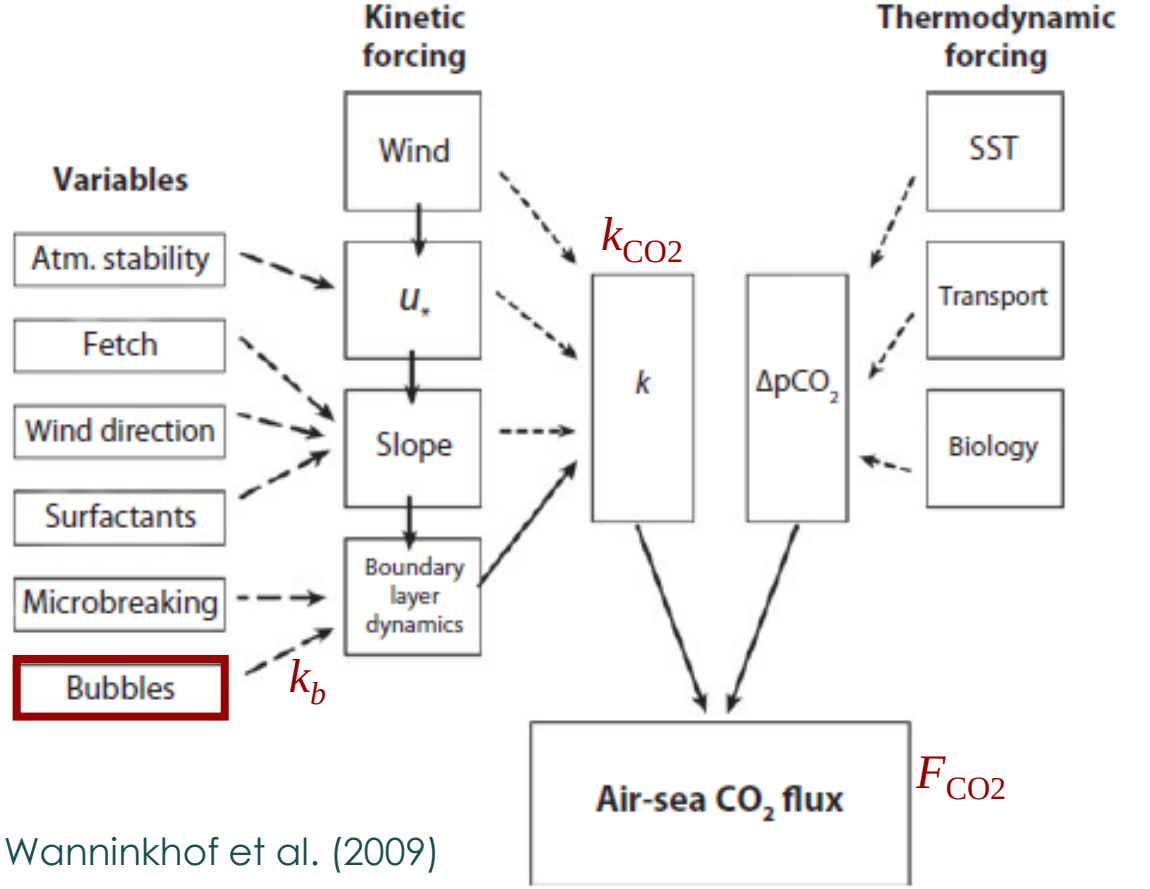
Whitecap fraction modeling

- New state-of-the-art status

New trends

- New measuring techniques
- New parameterization goals

Gas transfer velocity

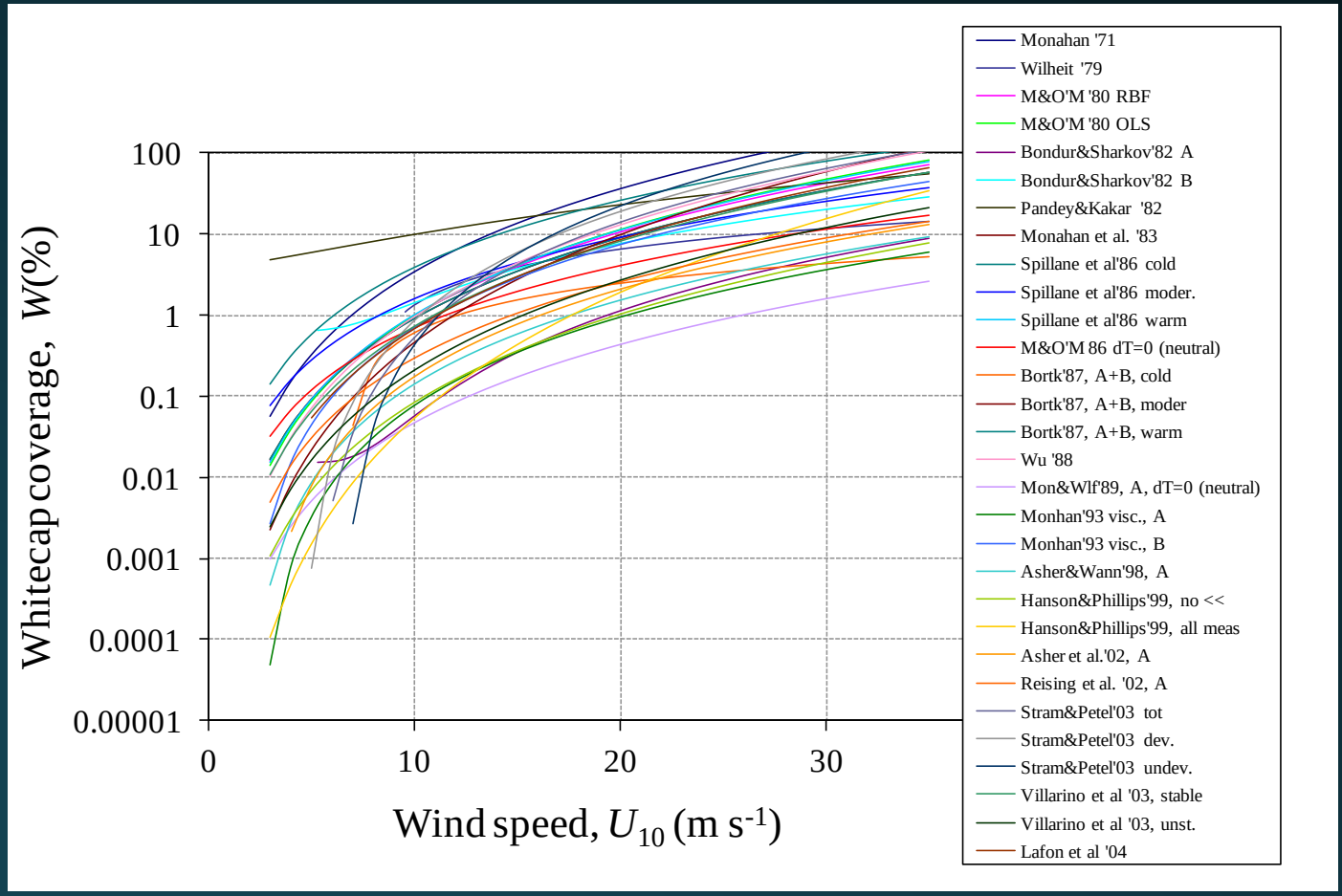


Wanninkhof et al. (2009)

- Whitecap fraction W
  - Measure for bubble population
  - Enhanced gas exchange
  - Sea spray production
- COAREG 3.1 formulation
  - $k_b \sim W$
    - Woolf, 1997
  - $W = 3.85\times10^{-6}\ U^{3.41}$
    - Monahan and O'Muichaertaigh (1980) MO'M80
- W affects estimates of k_b, k_{CO2}, and F_{CO2}
  - Parameterizations $W(U_{10})$
  - W data

Whitecap fraction parameterizations

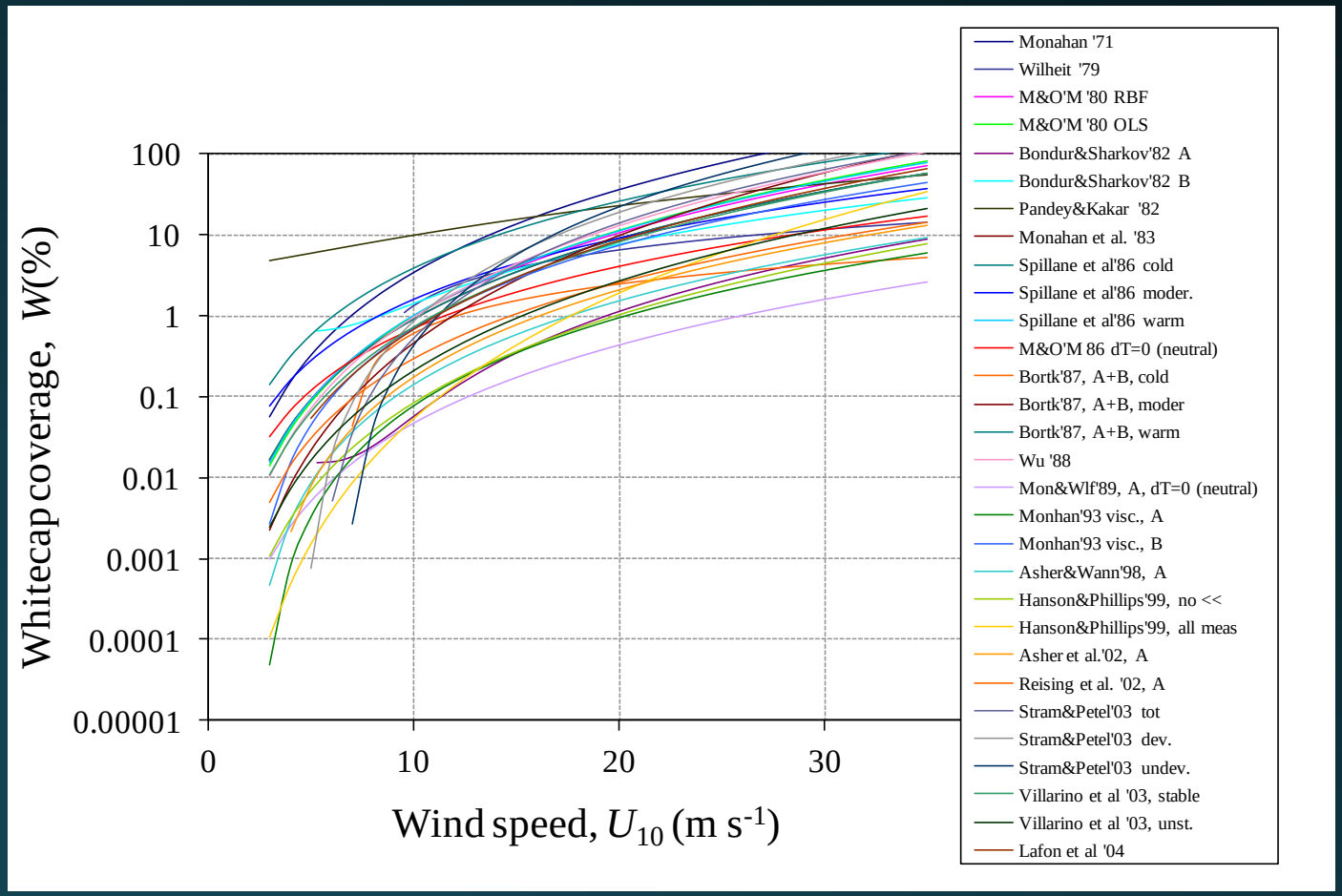
262 $W(U_{10})$ Monahan and O'Muichaertaigh (2012)



Anguelova and Webster (2006)

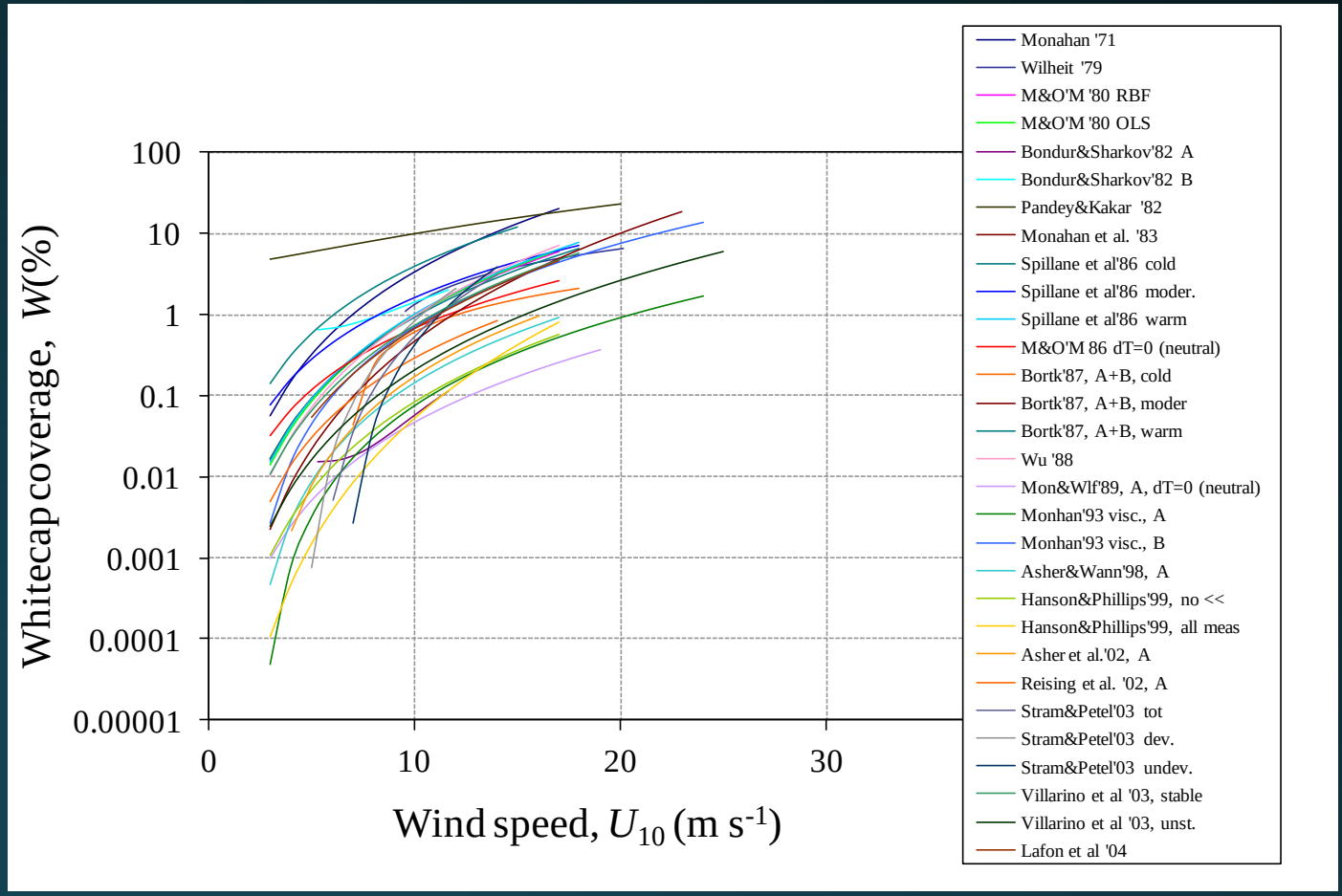
State of the art in 2005

- Use of this graph:
  - Large spread:
    - Measuring difficulties
    - Natural variability
  - Need for improvements in
    - Collecting data
    - Processing images
    - Parameterizations
- Issues:
  - "Misleading" for the range of applicability
    - Brumer et al., OcSci, 2016
  - Spread is in "stark contrast" with new expressions
    - Schwendeman and Thomson, JGR, 2015



Anguelova and Webster (2006)

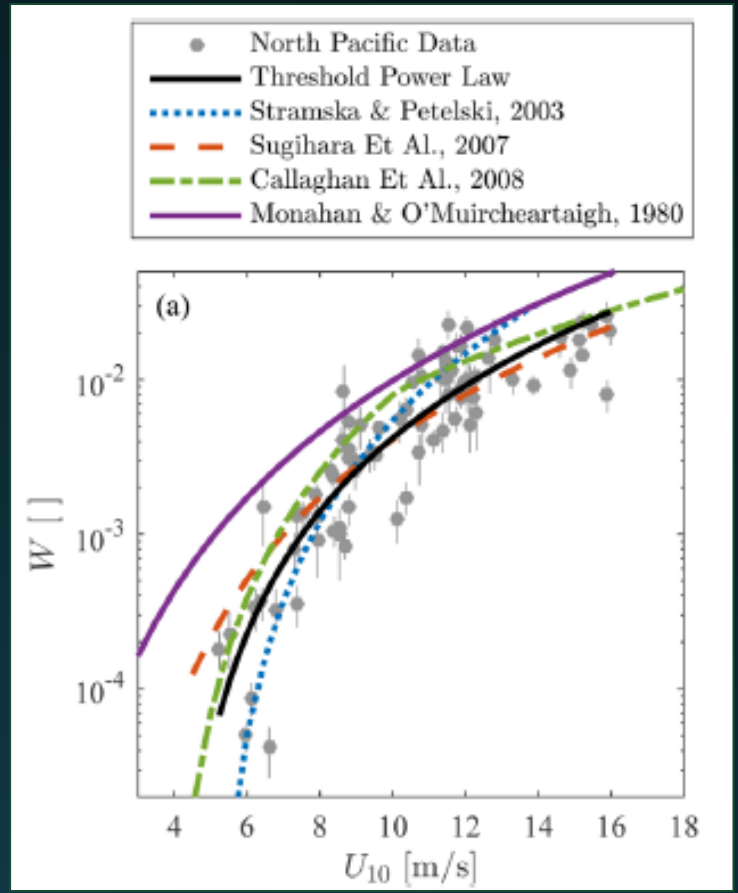
Range of applicability



Anguelova and Webster (2006)

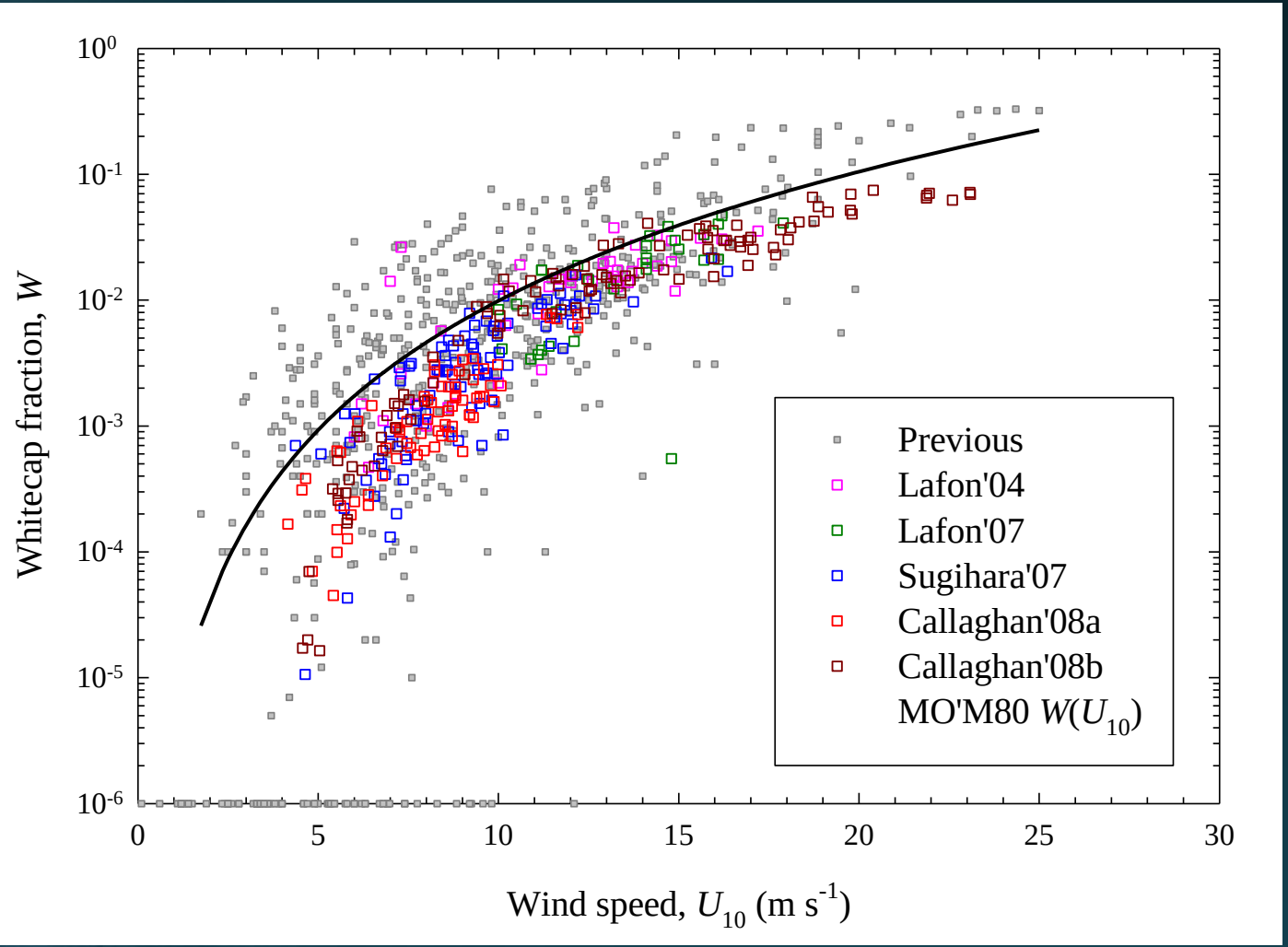
New expressions

Schwendeman & Thomson, 2015

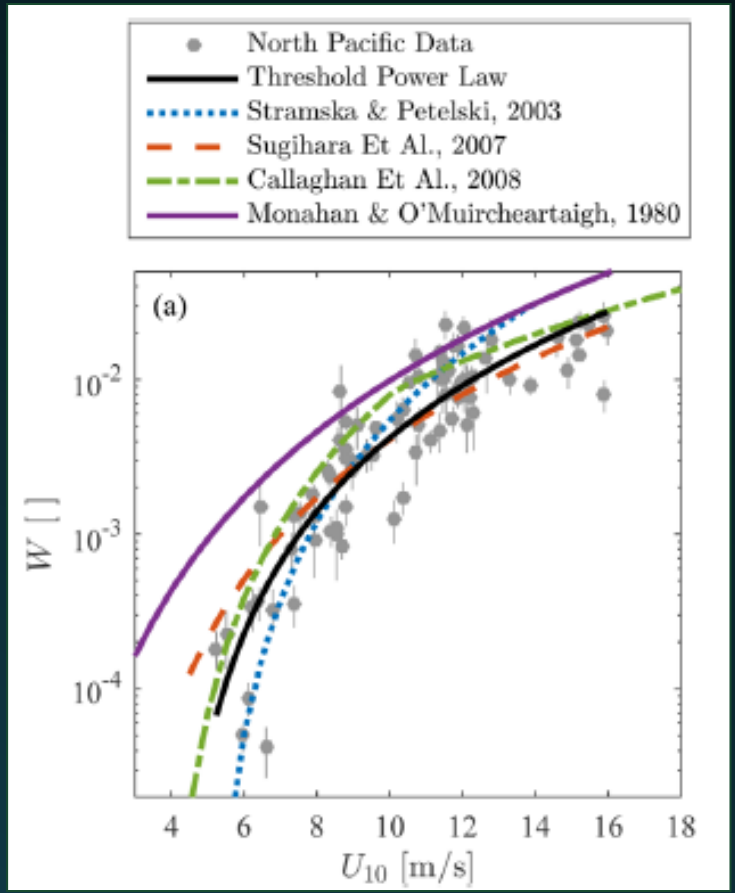


Recent data

de Leeuw et al., 2011

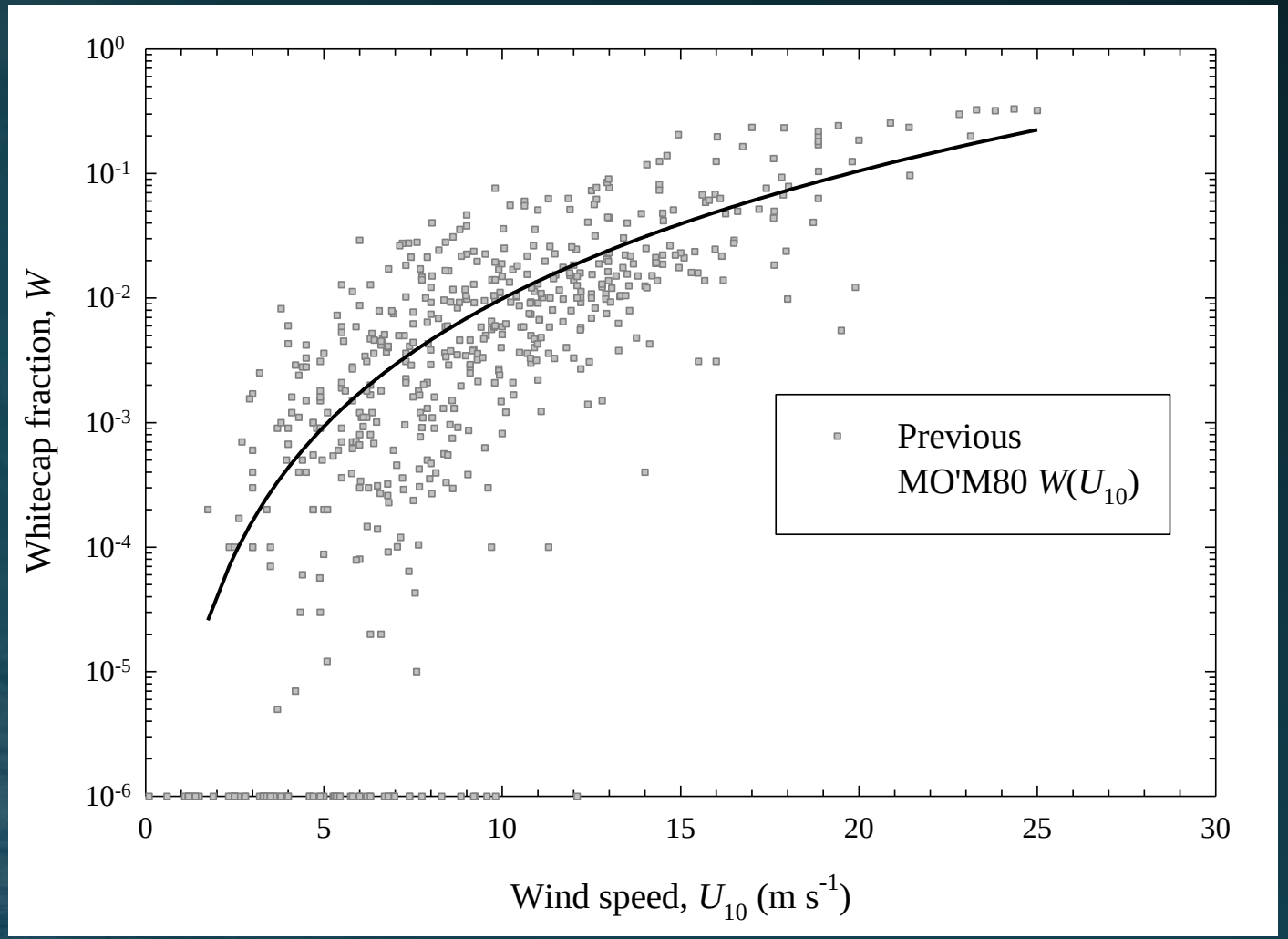


Schwendeman & Thomson, 2015



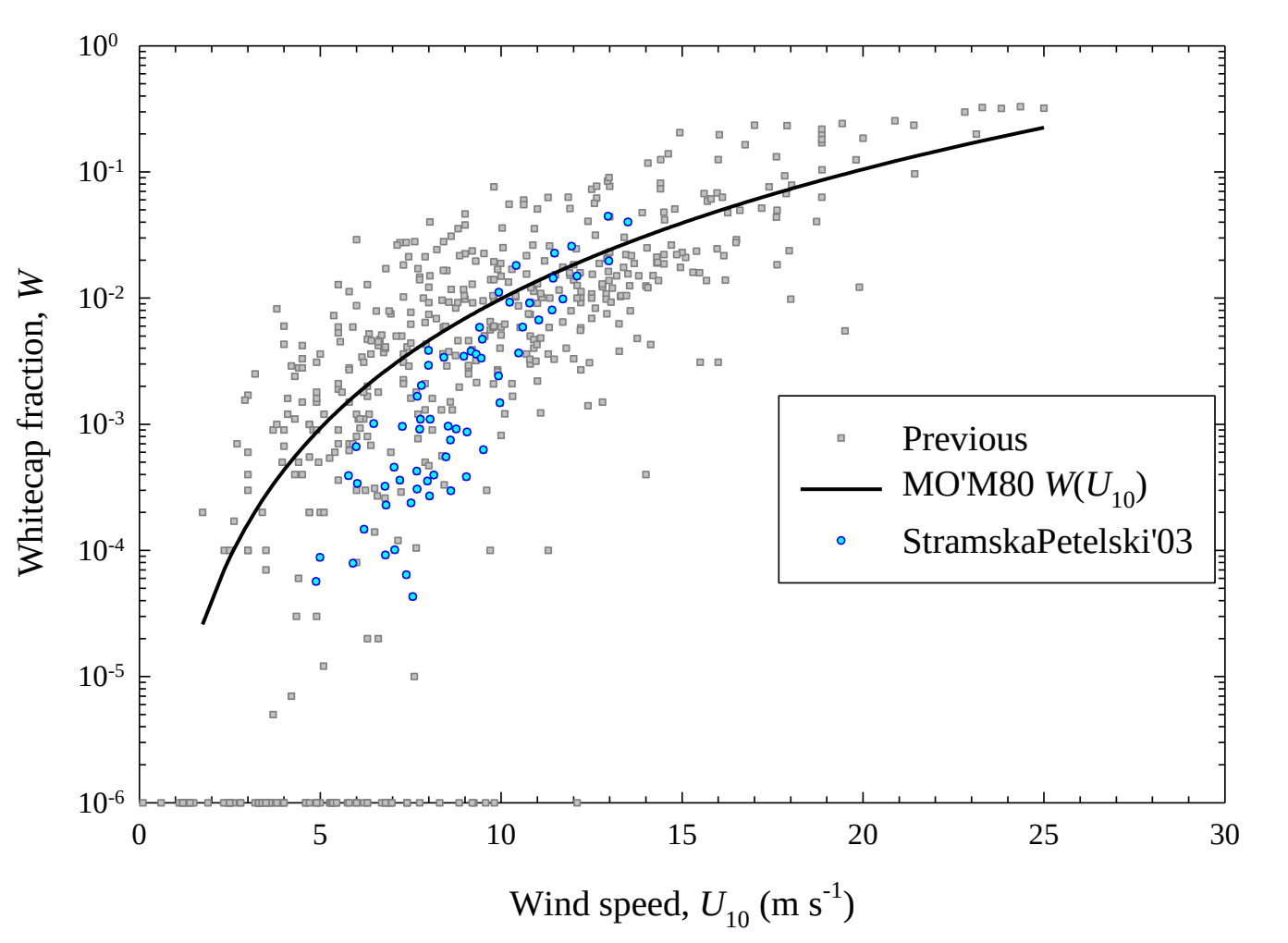
- Improvements
  - Collecting data
  - Processing images

Data for that graph



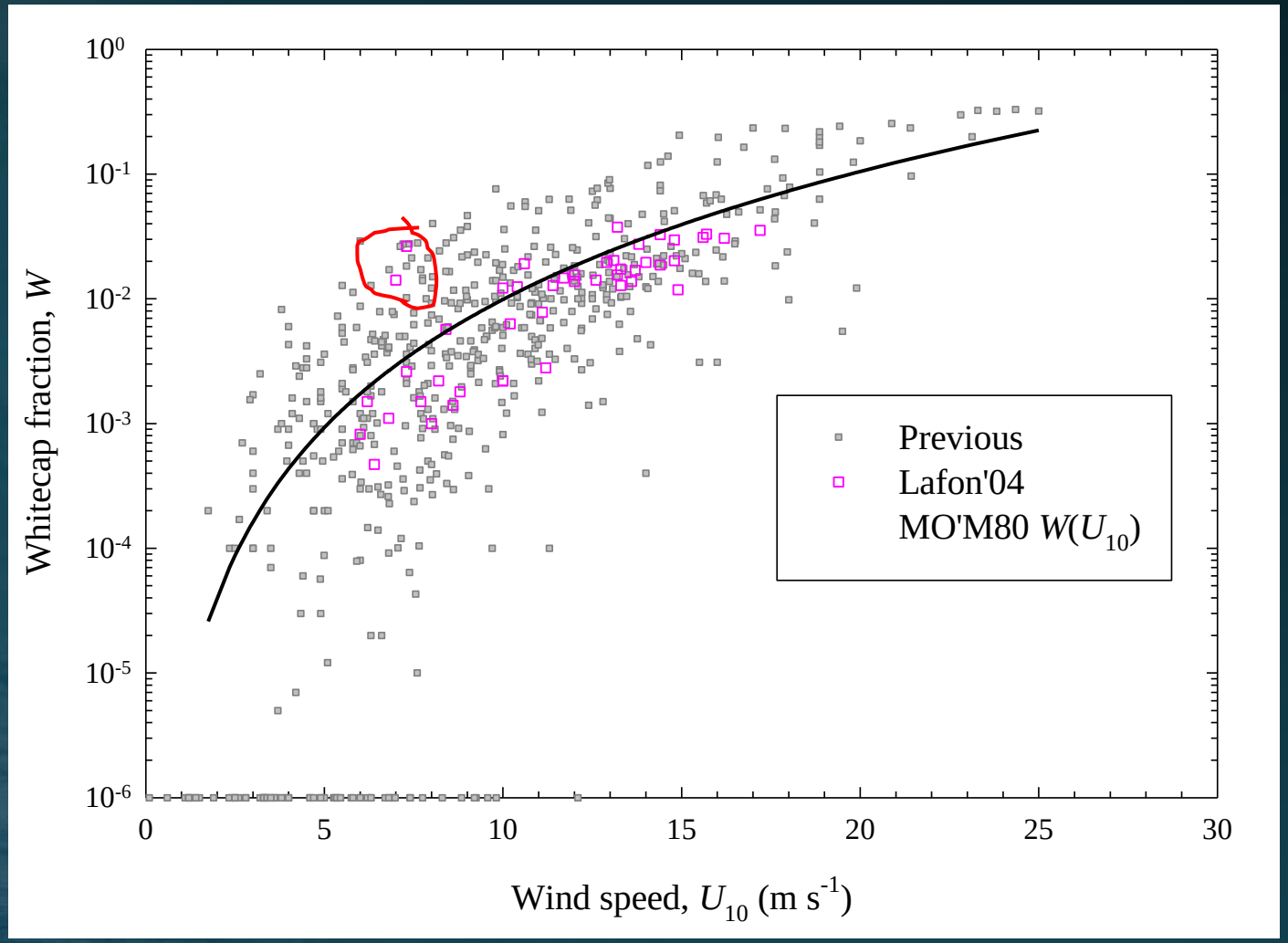
- 18 data sets
  - Table 2
    - Anguelova and Webster (2006)
- Collected 1952-2000
  - Published 1963-2004
- Photographic method
  - Usually 1-20 photos for one *W* data point

First digital data



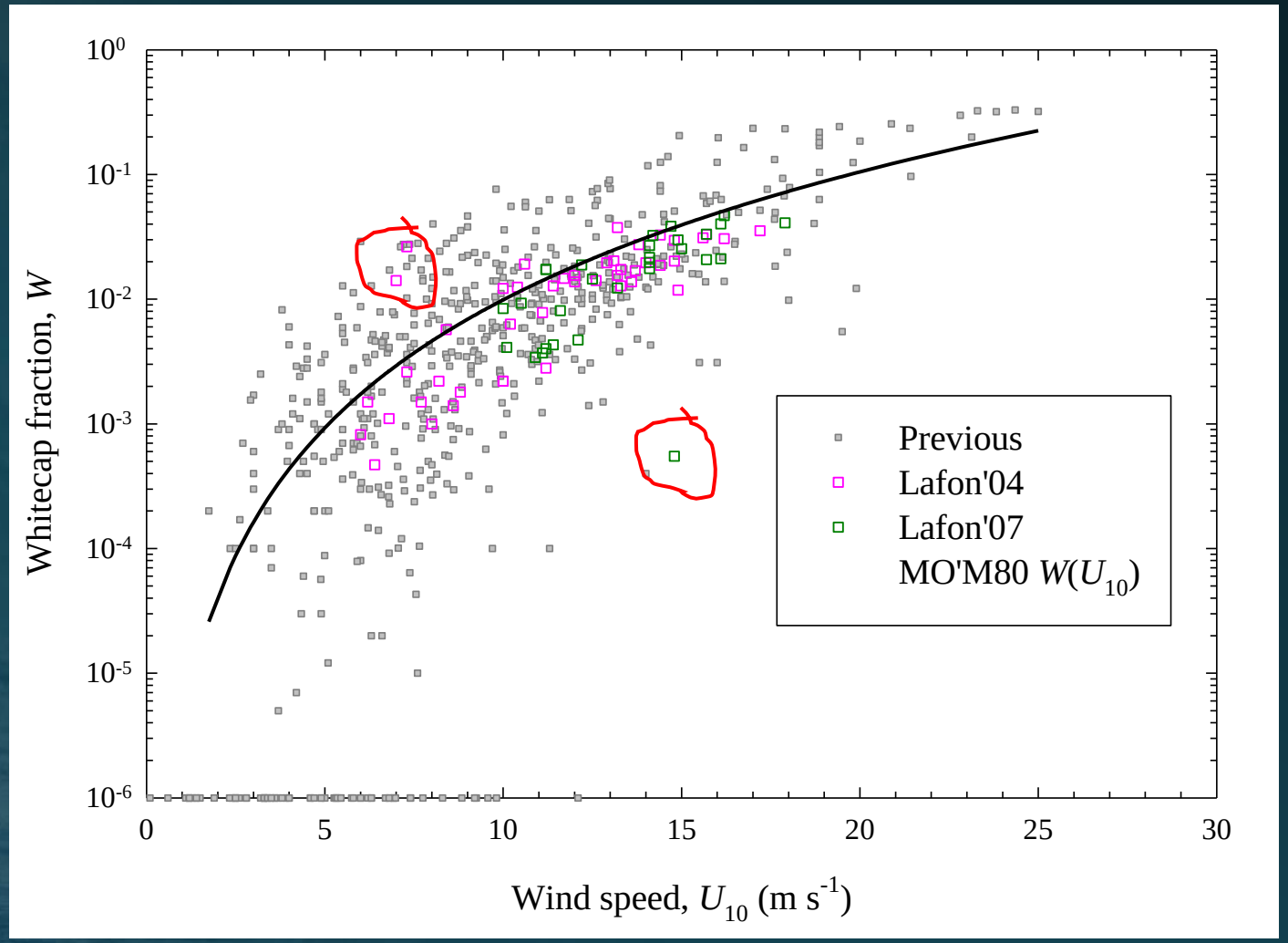
- Stramska and Petelski (2003)
- Due to memory ⇒ 10-20 photographs per station
- Presumably, 10-20 photos ⇒ one *W* data point

Averaging images



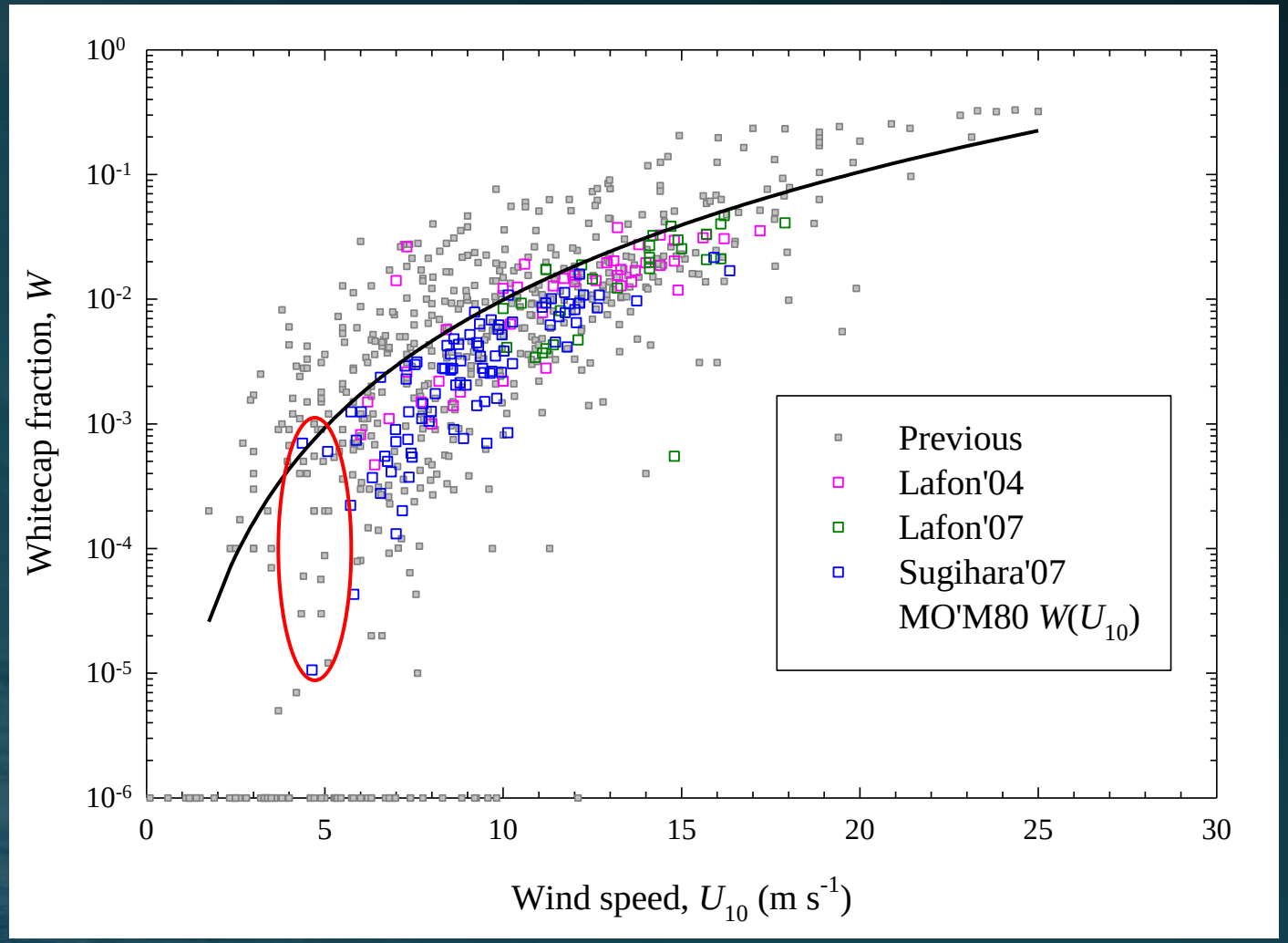
- Lafon et al. (2004)
- Film (35 mm) camera
- 10-25 photographs ⇒ one *W* data point

Averaging images



- Lafon et al. (2004)
- Film (35 mm) camera
- 10-25 photographs ⇒ one *W* data point
- Lafon et al. (2007)

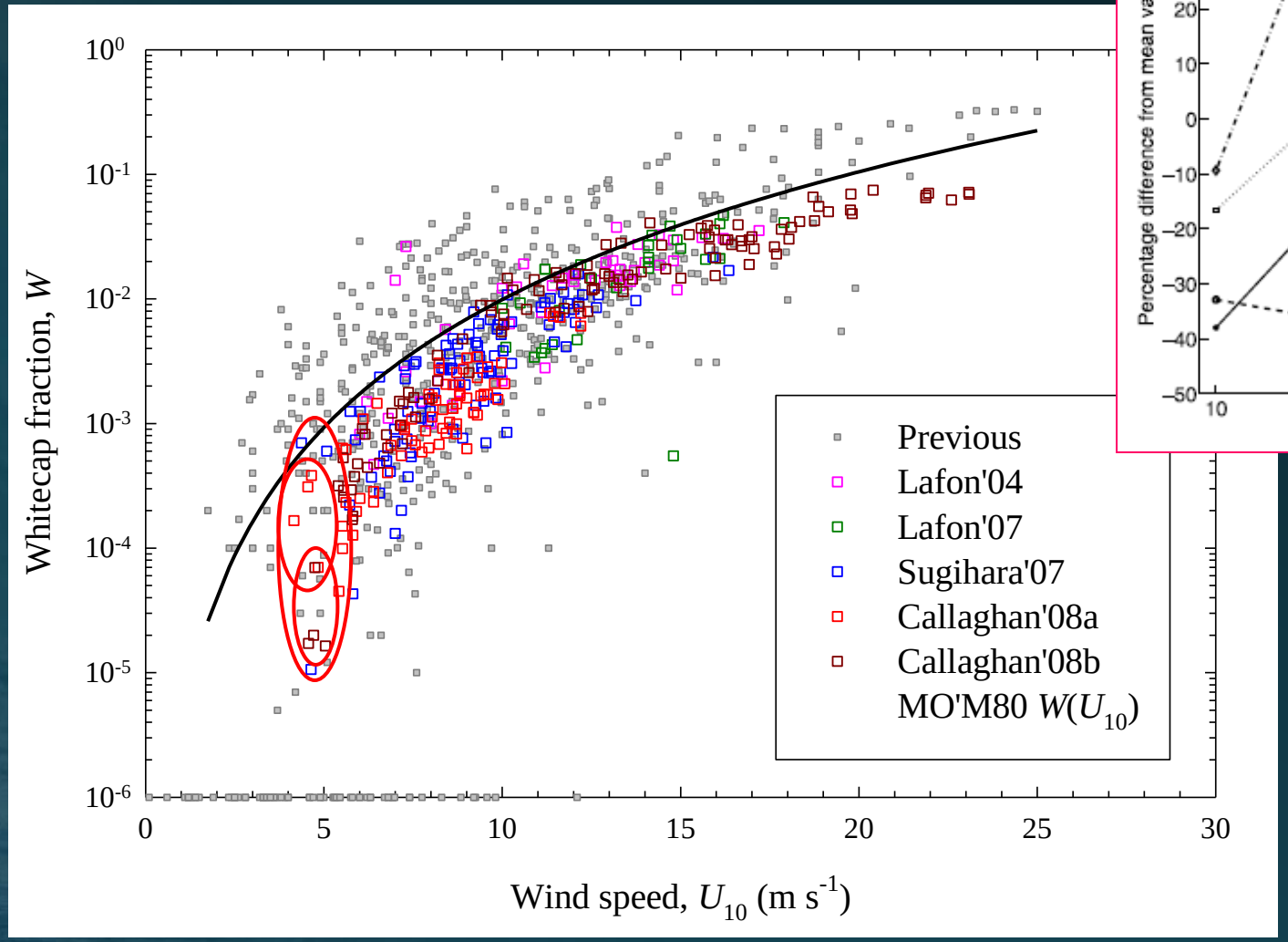
Digital camera *and* Averaging images



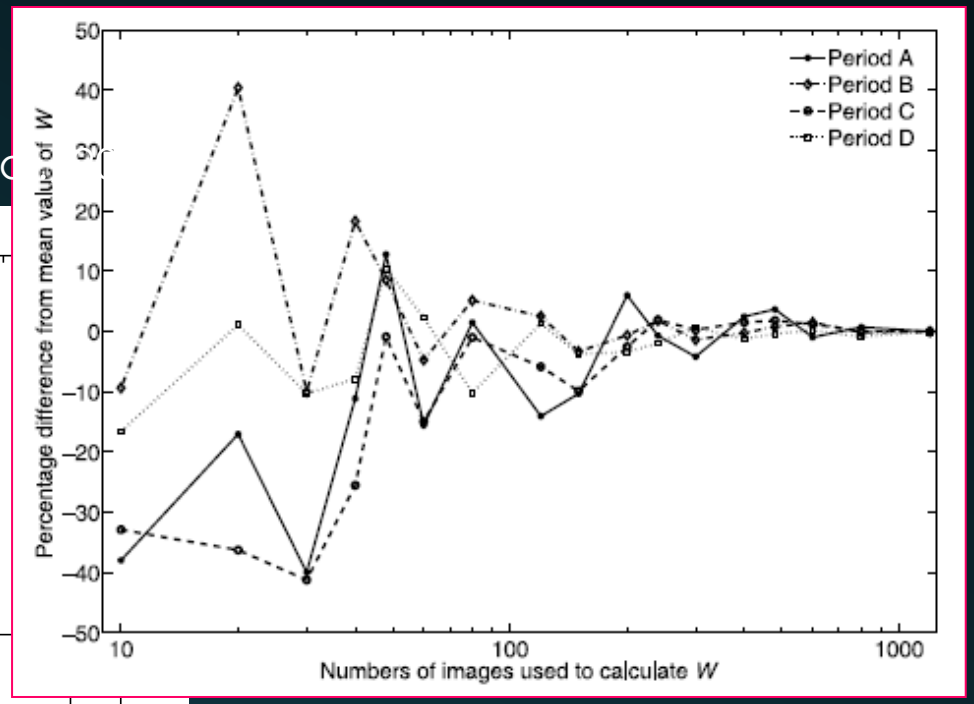
- Sugihara et al. (2007)
  - Digital camera
  - Sampling rate 1 s
  - Averaged 600 images to get one *W* data
    - 10-min averages

Recent data

de Leeuw et a

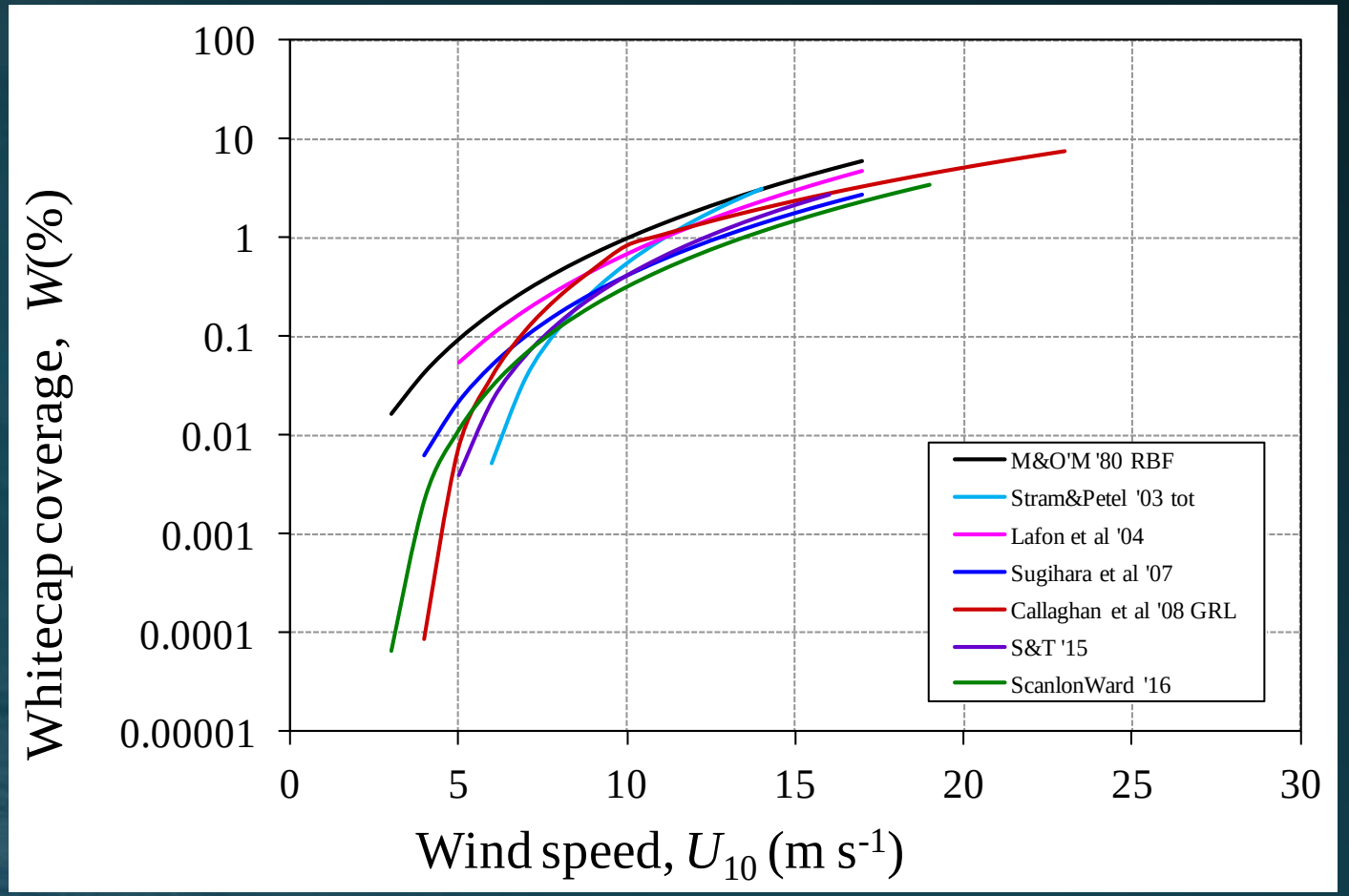


Callaghan et al., JGR, (2008)

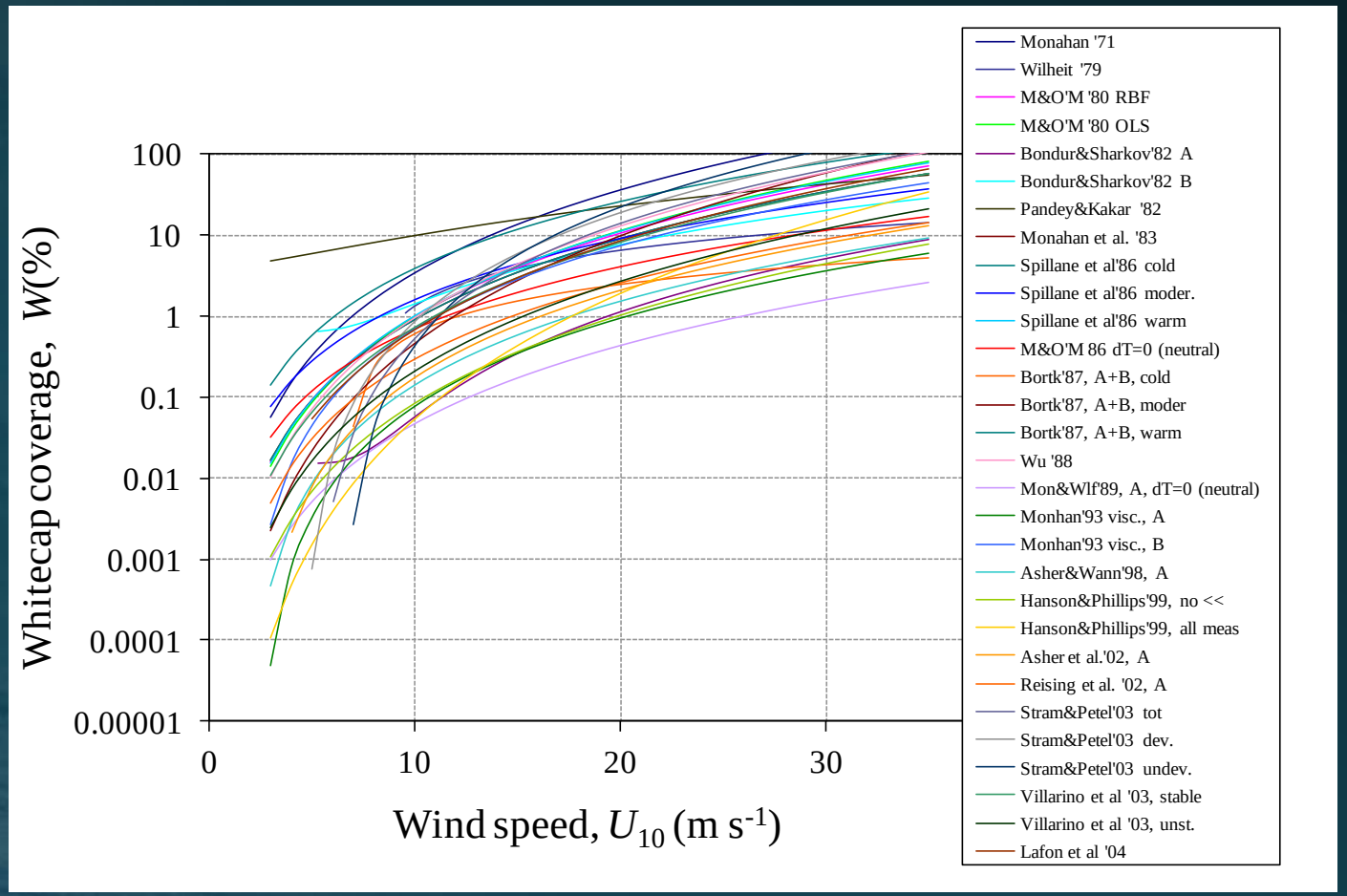


- Data sets
  - MVCO, 2002
  - Atlantic, 2006

New state-of-the art



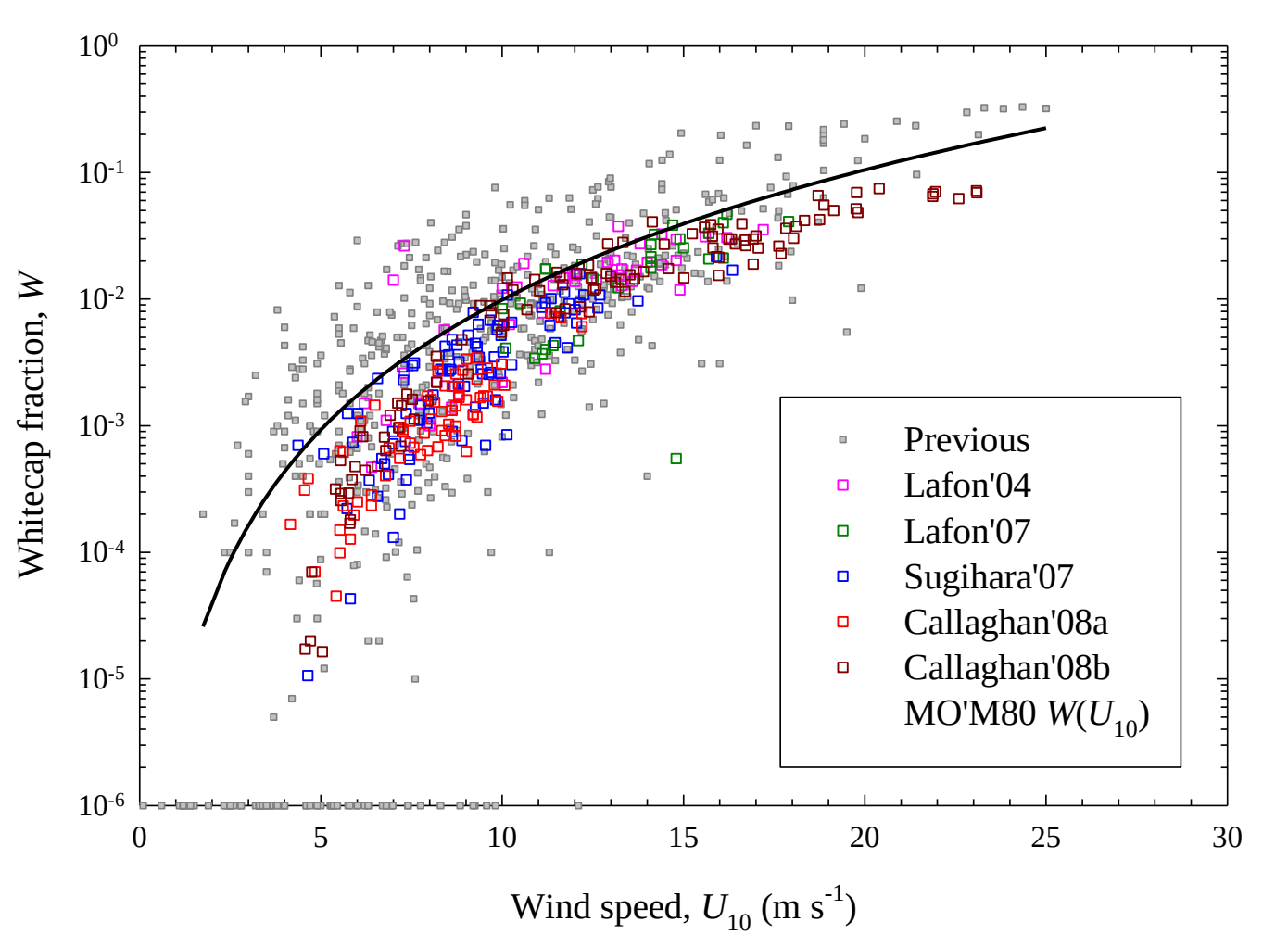
Retire this graph



Anguelova and Webster (2006)

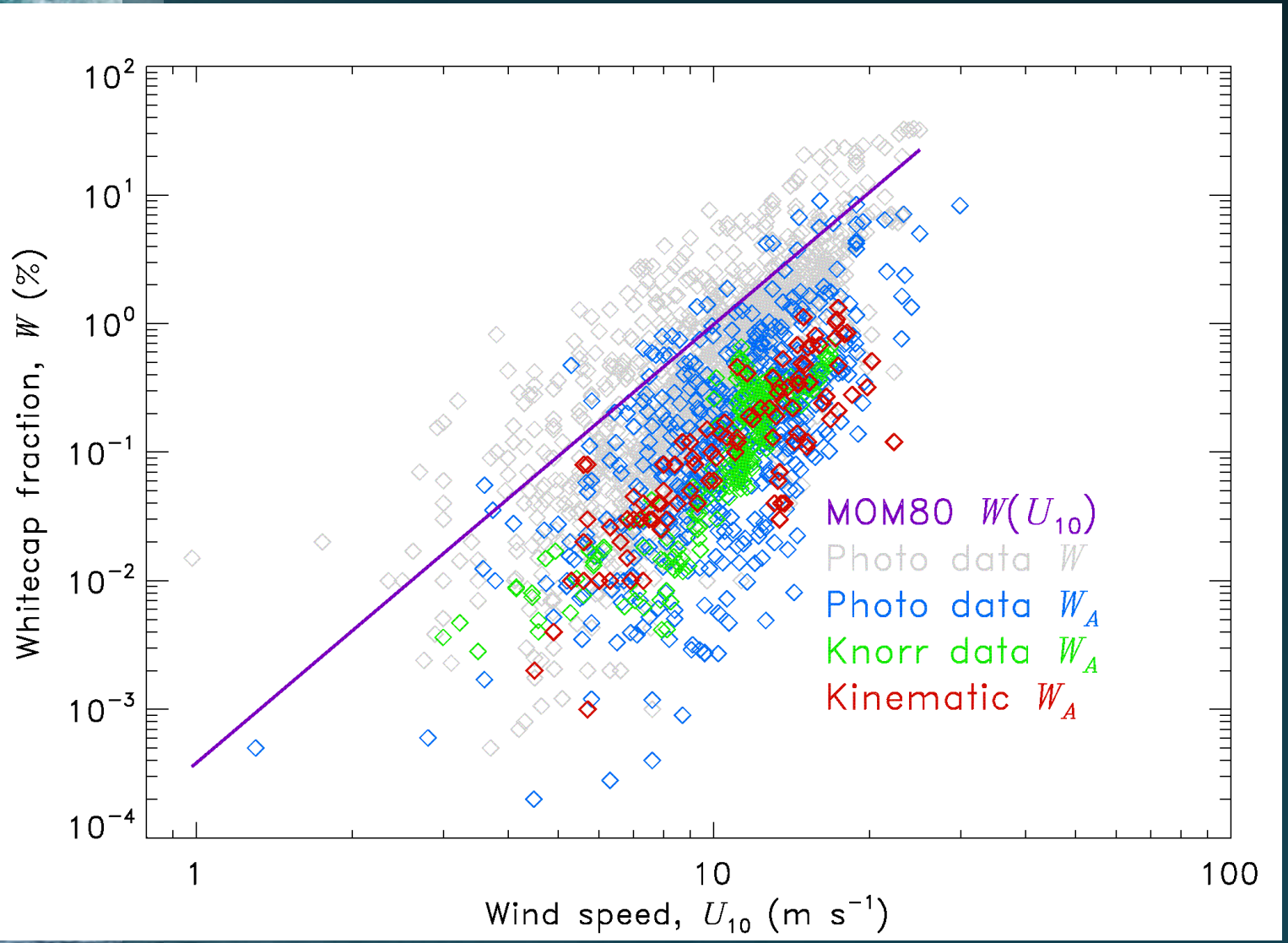
New *W* data caveats

de Leeuw et al., 2011



- Heavy averaging
  - Missing useful information
  - Decaying foam

New W data caveats



- Heavy averaging
  - Missing useful information
  - Decaying foam
- Active whitecap fraction still unconstrained
- Further improvements
  - Image processing
  - New measuring techniques

New measuring methods

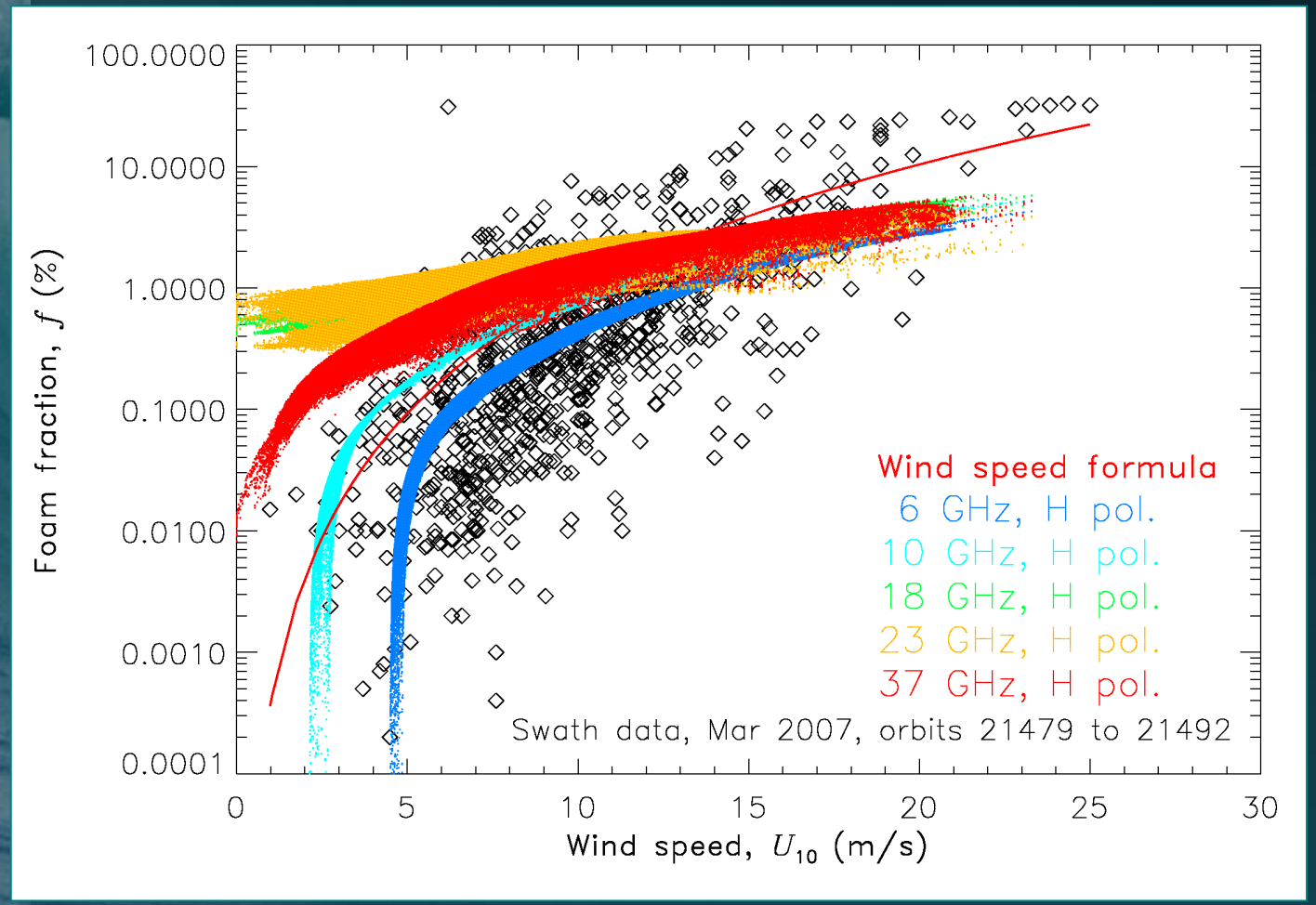
Measured quantity

- Energy dissipation
  - Buoys
    - Hanson and Phillips, 1999
    - Anguelova and Hwang, 2016
  - Models
    - Kraan et al., 1996
    - Scanlon et al., 2016
  - Direct measurements
    - Schwendeman & Thomson, 2015
- Breaking crest length Λ
    - Ken Melville group
    - Gemmrich et al., 2008

Electro-magnetic spectrum

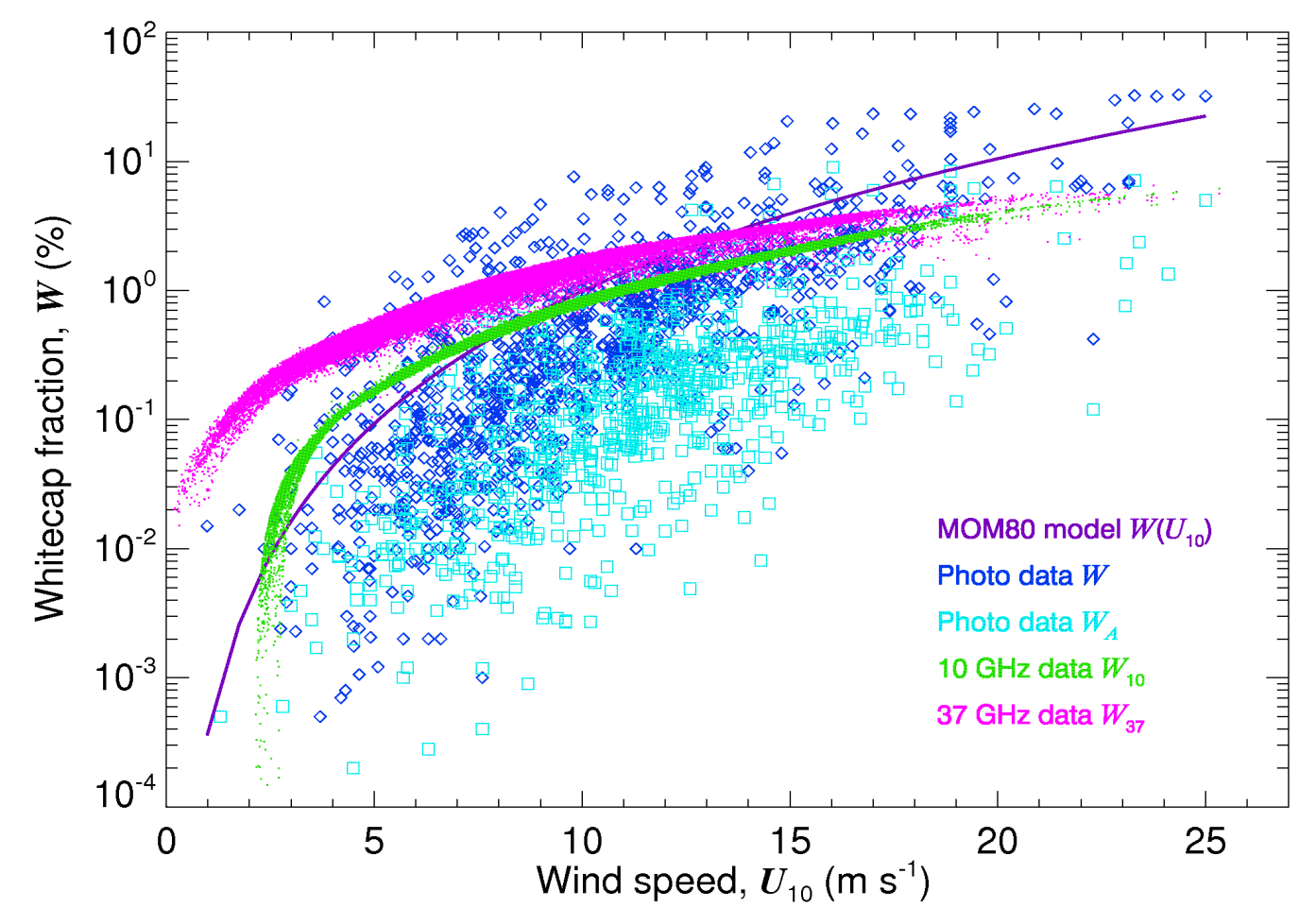
- Radiometry
  - Microwave
    - NRL WindSat data
  - Visible
    - Randolf et al., 2016 (OcSci)
- IR images
    - Sutherland and Melville (2013; 2015)
    - Potter et al. (2015)

Microwave radiometry



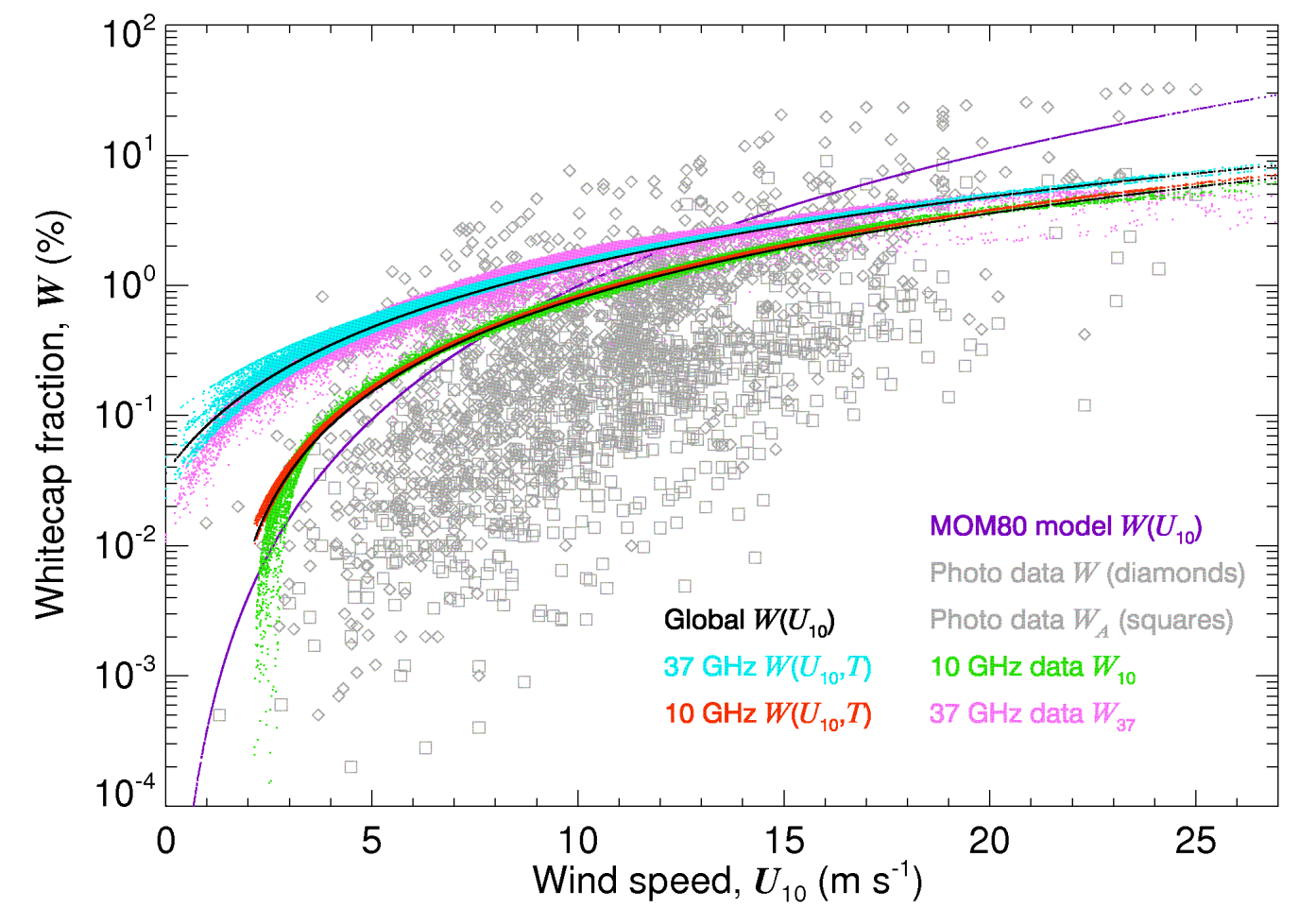
- Different platforms
  - Satellite
  - Air plane
  - Ship
- Different frequencies
  - 6-40 GHz
    - Database
  - 40-200 GHz
    - High spatial resolution
  - 1– 2 GHz
    - High temporal resolution

Whitecap database

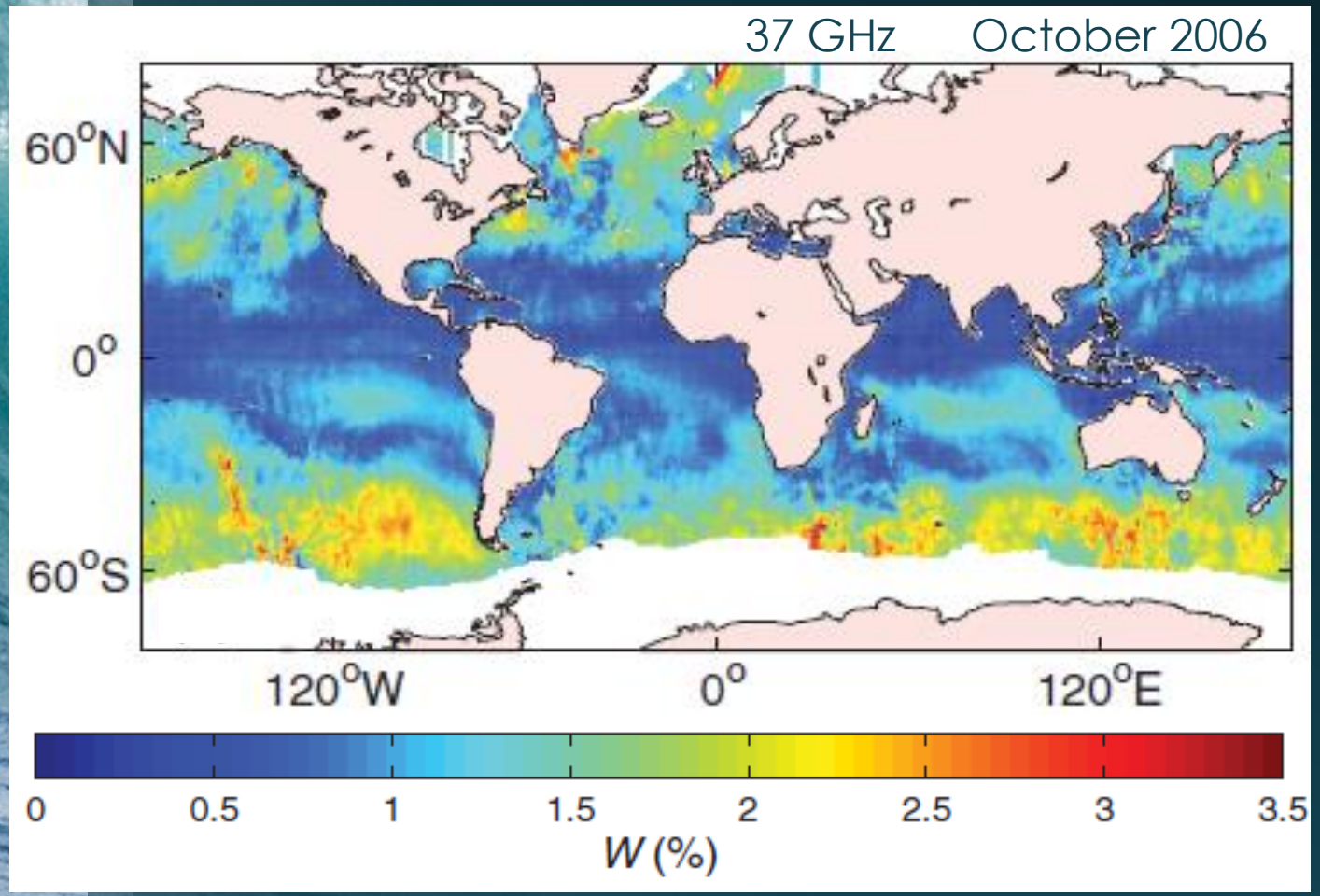


- Gridded data
- Two frequencies
  - Sensitivity to foam thickness
- Matched-up met-oc data
  - U_{10}, U_{dir}, SST, T_a, H_s, T_p

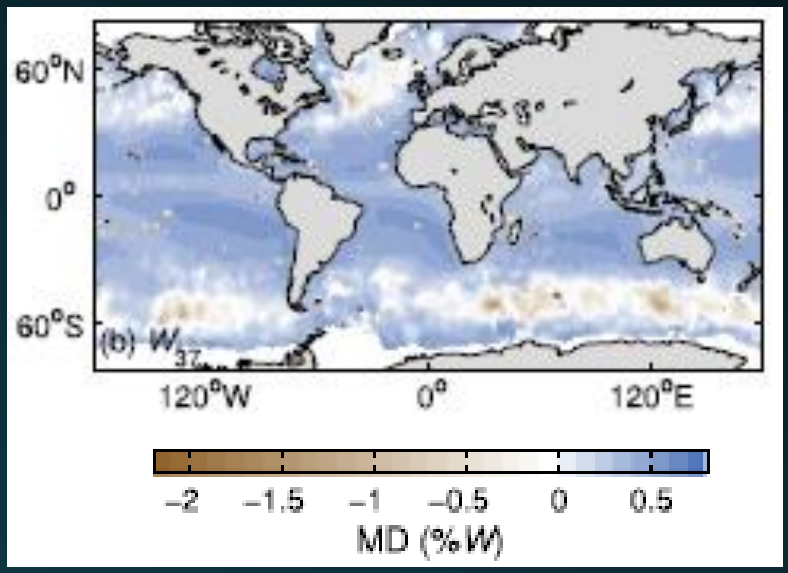
Parameterizing additional variables



Satellite-based measurements



Salisbury et al., 2013



Salisbury et al., 2014

- Annual mean difference

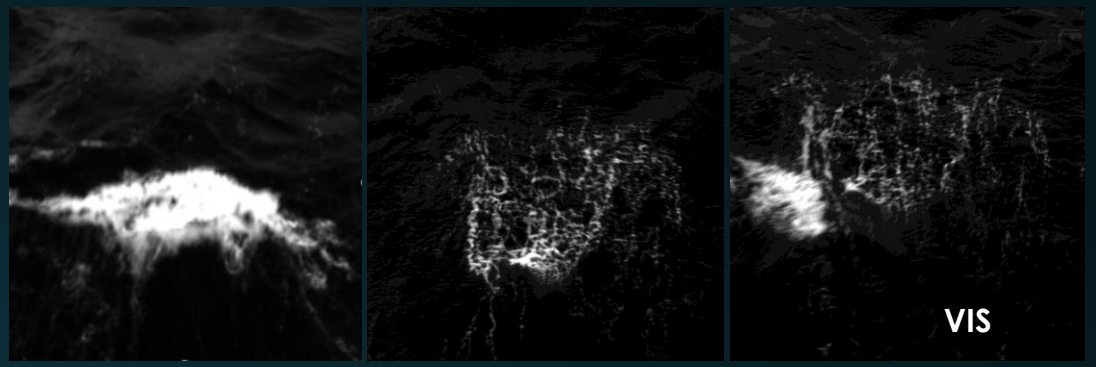
$$\Delta W = \overline{W_{TB}} - \overline{W_U}$$

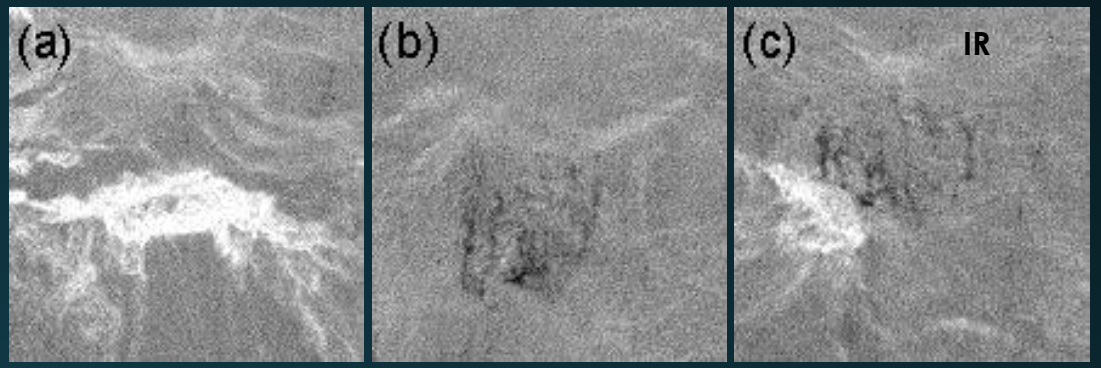
- Difference from MOM80

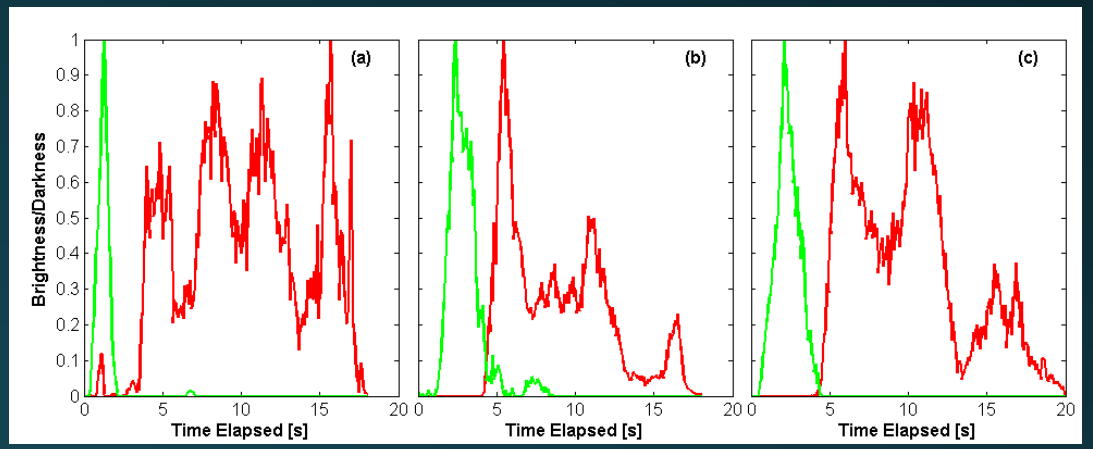
$$W_U \propto U_{10}^{3.41}$$

IR observations

- Lifetime separation
- Independent measuring method







Potter et al., 2015

Conclusions

Improvements

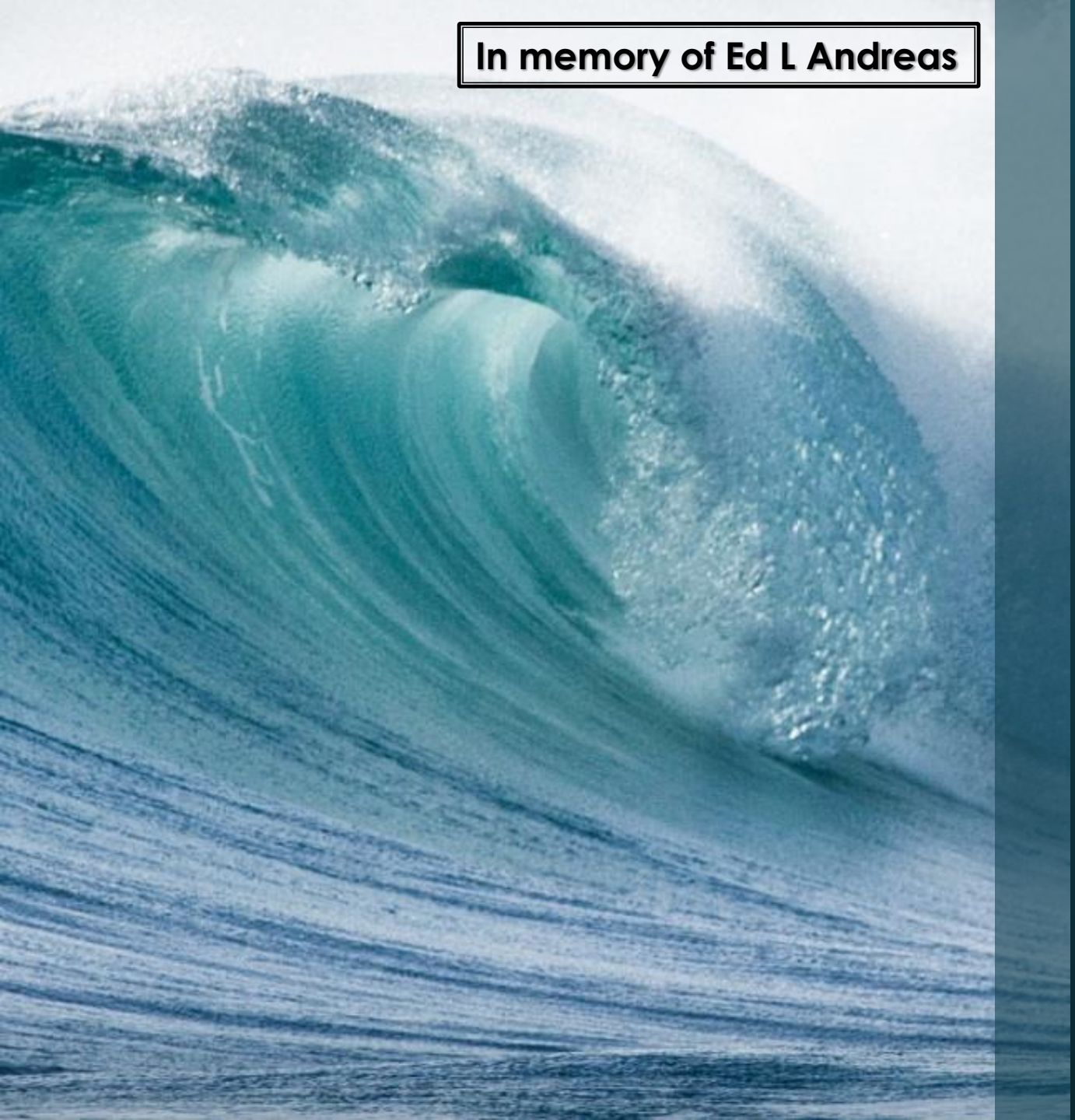
- Digital photography
- Processing algorithms

New state-of-the-art status

- Less noisy data
- Closely clustered parameterizations

New trends

- New measuring techniques
- New parameterizations—include more variables



In memory of Ed L Andreas

?

Thank you!

First *W* data

- Unpublished photographs
  - U.S. Weather Squadron Two (1952)
  - Aerial observations of sea state
- Standard K-20 aircraft camera
  - altitude of 400 to 600 ft
  - deep waters of the Caribbean area
  - during June-October
- Instantaneous *W* values
  - One photo ⇒
    one *W* data point

Blanchard, 1963

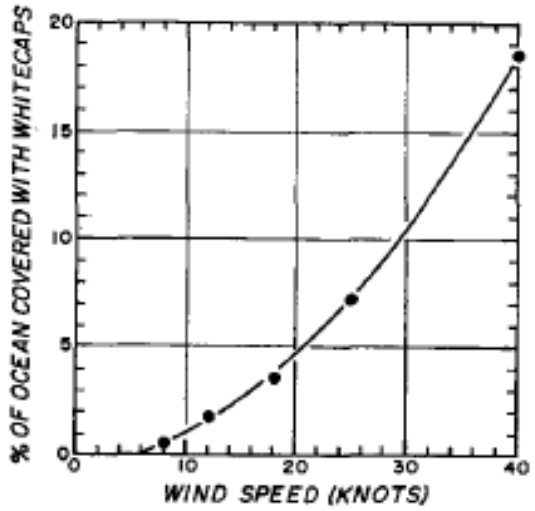


FIG. 31. The oceanic whitecap coverage as a function of wind speed.

K-20 Aerial Camera . . . a light weight, compact, hand-held camera designed especially for rapid-action observation spotting. A highly efficient camera for obtaining a series of aerial photographs in rapid succession from low altitudes. Equipped with lens of 6⅜" focal length. ...gral roll-film magazine with self-con-...d vacuum back provides up to 50 ...sures size 4"x 5".

Systematic collection of *W* data

- Ed Monahan, late 60s
- Widely used formula (MO'M80):

$$W = 3.85 \times 10^{-6} U_{10}^{3.41}$$

- Two data sets combined:
  - BOMEX (Monahan, 1971)
  - East China sea (Toba and Chaen, 1973)
- Parameterization approach
  - Different wind speed exponent

Monahan and Ó'Muircheartaigh, 1980