Stress or Wind: Definitions and Biases

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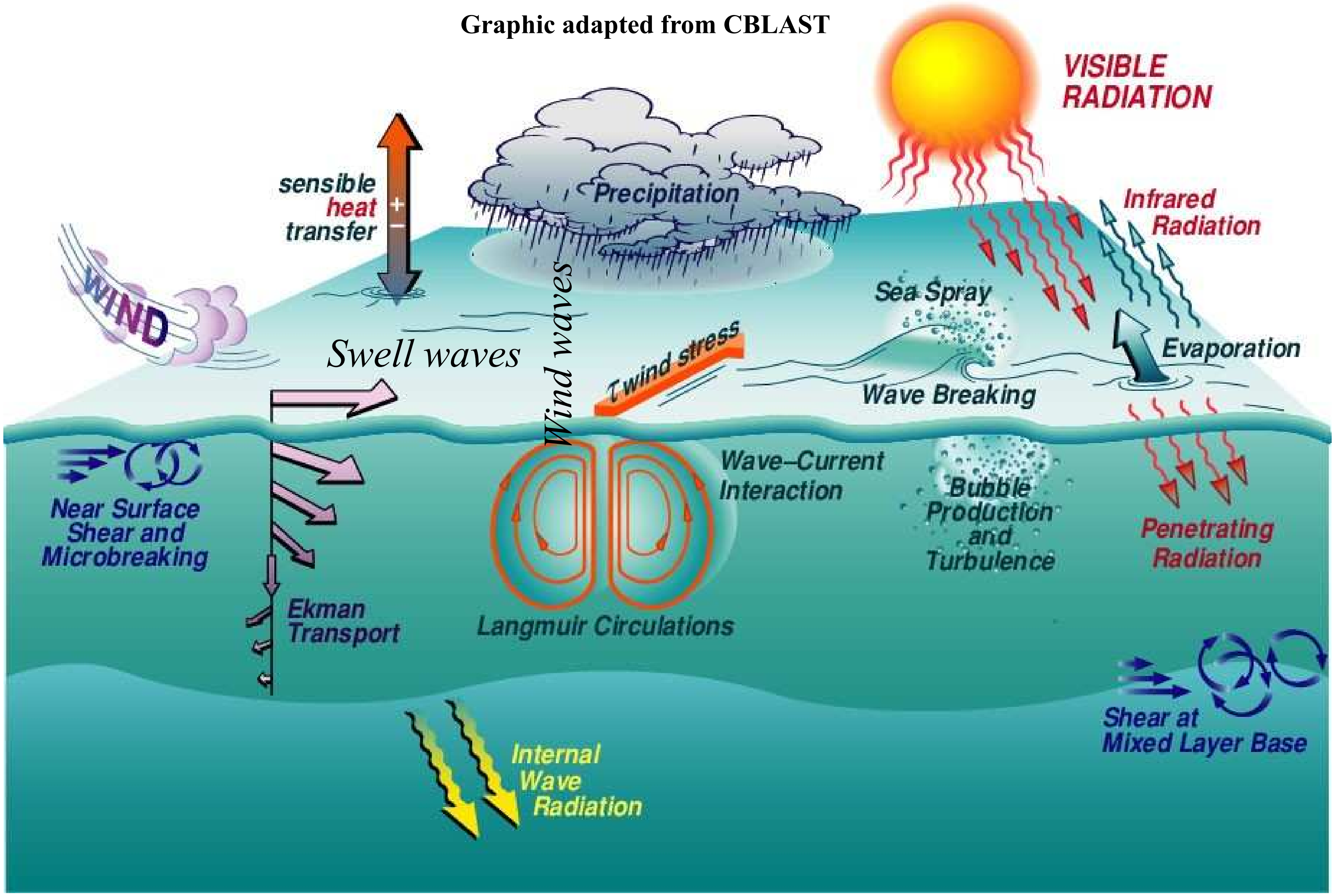
Many Air/Sea Interaction Processes

- Most are strongly influenced by stress -

Graphic adapted from CBLAST



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Goal & Issues

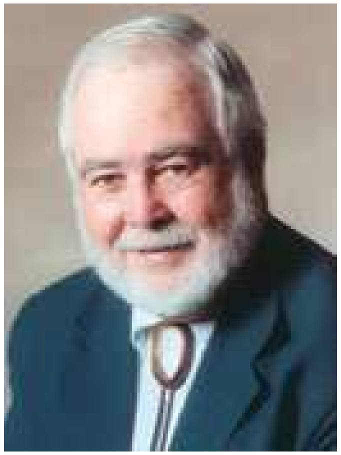
- Goal: determine if the scatterometer response is more wind-like (equivalent neutral winds) or more stress-like.

- Issues to be addresses:
  - Does a scatterometer respond to stress rather than other alternatives (e.g., wind or equivalent neutral wind)?
  - How to estimate stress from backscatter observations?

Outline

- Background
- Quick review of stress (momentum flux)
- Differences between scatterometer winds and earth-relative winds
- Evidence that scatterometers respond to stress
- Demonstration of the consequences
- A Stress model function

Why Calibrate to 'Winds' Rather than Stress



- Radar backscatter was observed to be dependent on wind speed and/or wave height in the 1950s.
- In 1963 Dick Moore had the idea that backscatter could be used to estimate oceanic variables.
- The NASA Sea Surface Stress (S^3) report indicated that scatterometers probably did respond to stress rather than wind.
- The number of stress observations available for calibration was approximately zero. Therefore it was desirable to calibrate to wind, for which the collocated observations would be plentiful.
- Willard Pierson, Vince Cardone and colleagues found that wind speed could be adjusted to be more consistent with surface stress.
  - Equivalent neutral wind

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Wind or Stress?

- The surface turbulent stress (momentum flux density) is usually parameterized as

$$\tau = \rho C_D U_{10}^2$$

- This form can be more accurately written as

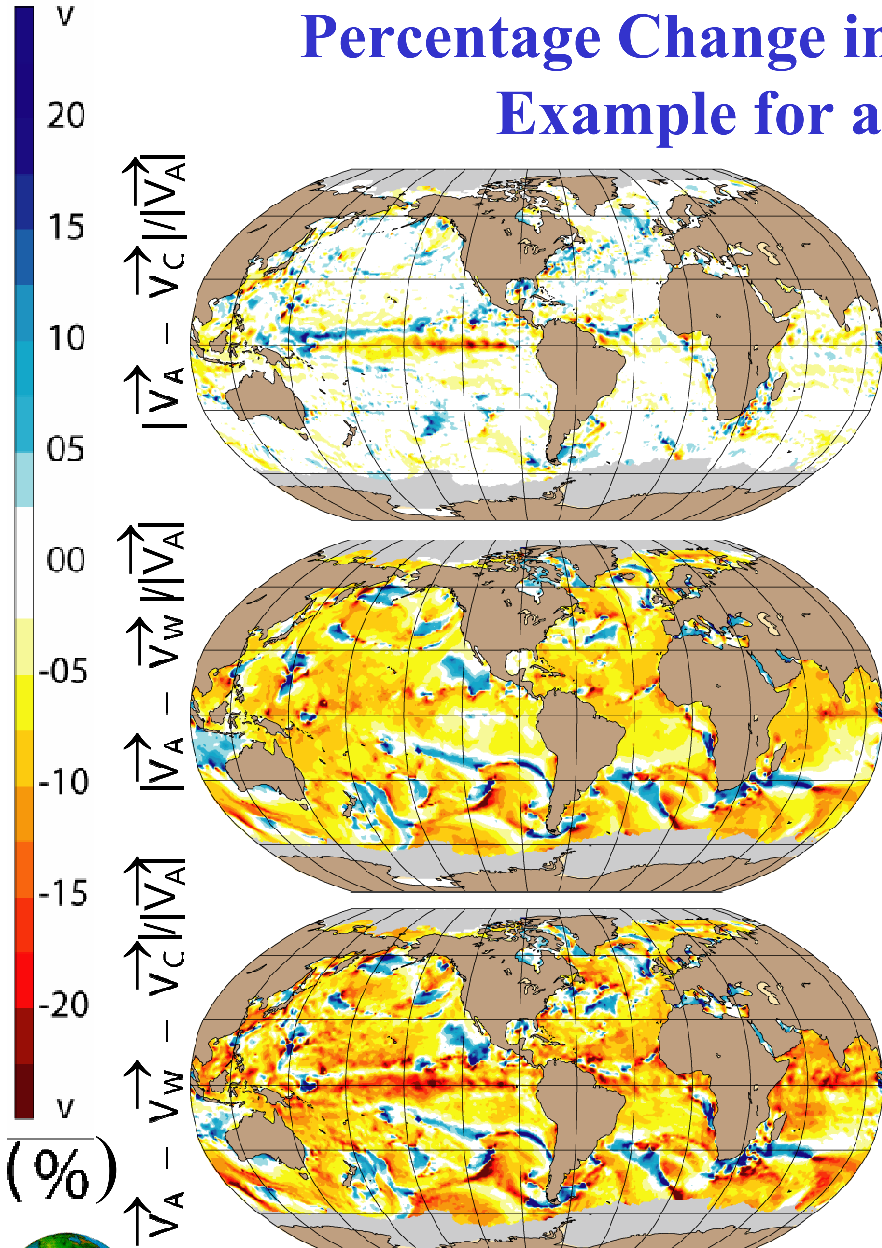
$$\boldsymbol{\tau} = \rho C_D \left|\mathbf{U}_{10}\right| \mathbf{U}_{10}$$

- It can be further improved in terms of surface relative wind vectors:

$$\boldsymbol{\tau} = \rho C_D \left|\mathbf{U}_{10} - \mathbf{U}_{sfc}\right| \left(\mathbf{U}_{10} - \mathbf{U}_{sfc}\right)$$

- Does a scatterometer respond to $\mathbf{U}_{10}$ or to $\mathbf{U}_{10} - \mathbf{U}_{\mathrm{sfc}}$?
  - *Cornillon and Park* (2001, *GRL)* and *Kelly et al.* (2001, *GRL*) showed that scatterometer winds were relative to surface currents.
  - *Bentamy et al.* (2001, *JTech*) indicate there is also a dependence on wave characteristics.
  - *Bourassa* (2006, *WIT Press*) showed that wave dependency can be parameterized as a change in $\mathbf{U}_{\mathrm{sfc}}$.

Percentage Change in Surface Relative Winds Example for a 00Z Comparison



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- The percentage change in surface relative winds is roughly proportional to the change in energy fluxes.
- The percentage change squared is roughly proportional to changes in stress.
- The drag coefficient also changes by about half this percentage.
  - >50% changes in stress associated with strong storms!
  - Can have opposite change nearby.
  - Huge change in the curl of the stress!
  - Caveat: models uncoupled!

From *Kara et al.* (2007, *GRL*)

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The Log-Wind Profile, and Equivalent Neutral Winds

The dependency of wind speed (U) on the height above the surface (z) is described by a log-wind profile

$$\mathbf{U} - \mathbf{U}_{sfc} = \frac{\mathbf{u}_*}{k}\left[\ln\left(\frac{z}{z_o}+1\right)+\phi\left(z, z_o, L\right)\right]$$

- The friction velocity (u_*) is the squareroot of the kinematic stress: $\tau = \rho u_*^2$
- The ϕ term is a function of atmospheric stratification.
- The 10m Equivalent Neutral wind (U_{10EN}) is calculated by using the value of u_* determined from buoy observations, the corresponding value of z_o, and setting ϕ to zero.

$$U_{10EN} = \frac{u_*}{k}\ln\left(\frac{10}{z_o}\right)$$

What If A Scatterometer Responds to Stress?

- If scatterometers respond in a manner consistent with equivalent neutral winds, then they respond to changes in friction velocity (u_*).

$$U_{10EN} = \frac{u_*}{k} \ln\left(\frac{10}{z_o}\right)$$

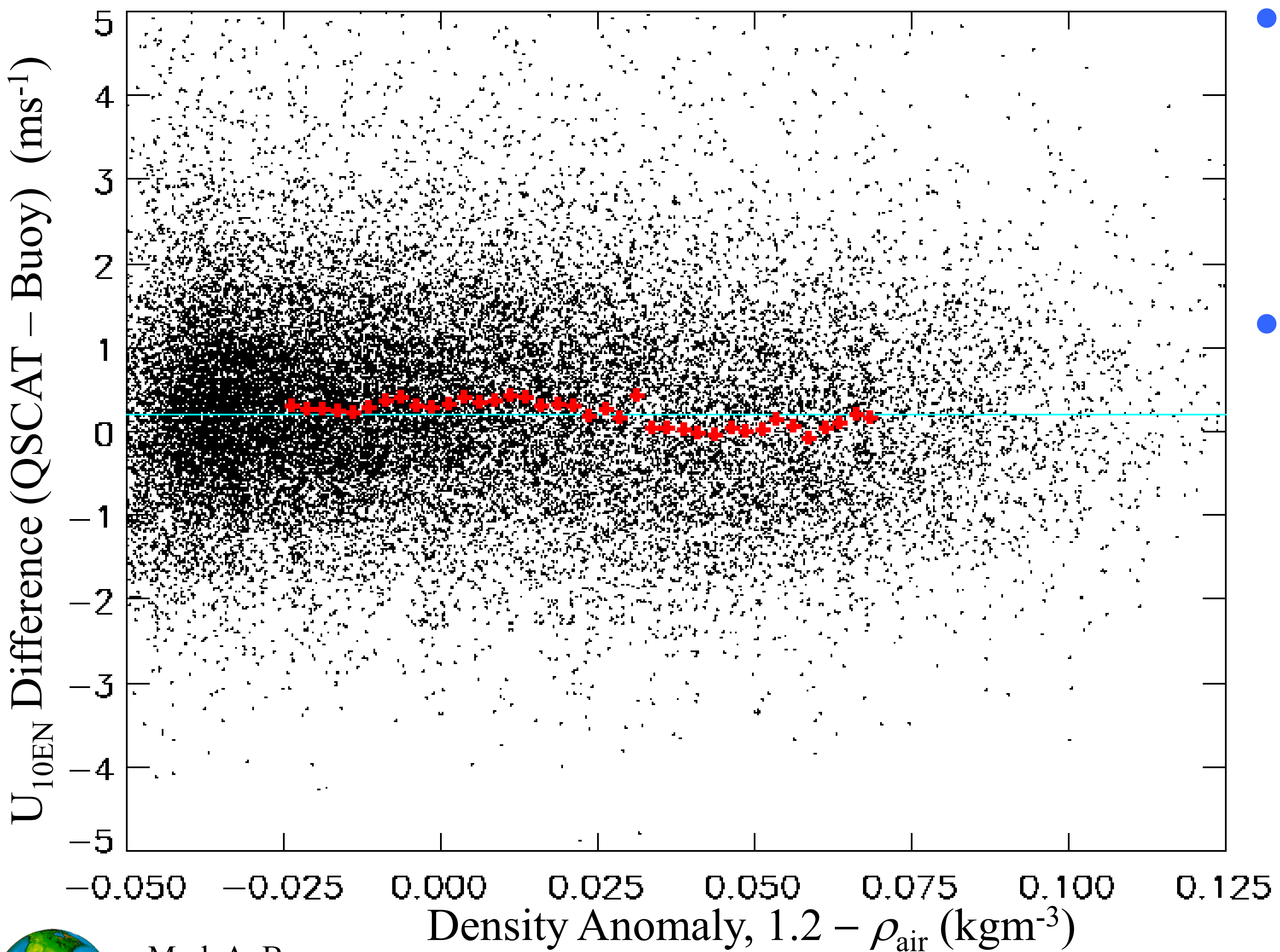
- If scatterometers respond to stress, then it responds to changes in air density and change in friction velocity!
  - The friction velocity (u_*) is the squareroot of the kinematic stress:

$$\tau = \rho_{air}\, u_*^{\,2}$$

$$U_{10EN} = \frac{(\tau / \rho)^{0.5}}{k} \ln(10 / z_o)$$

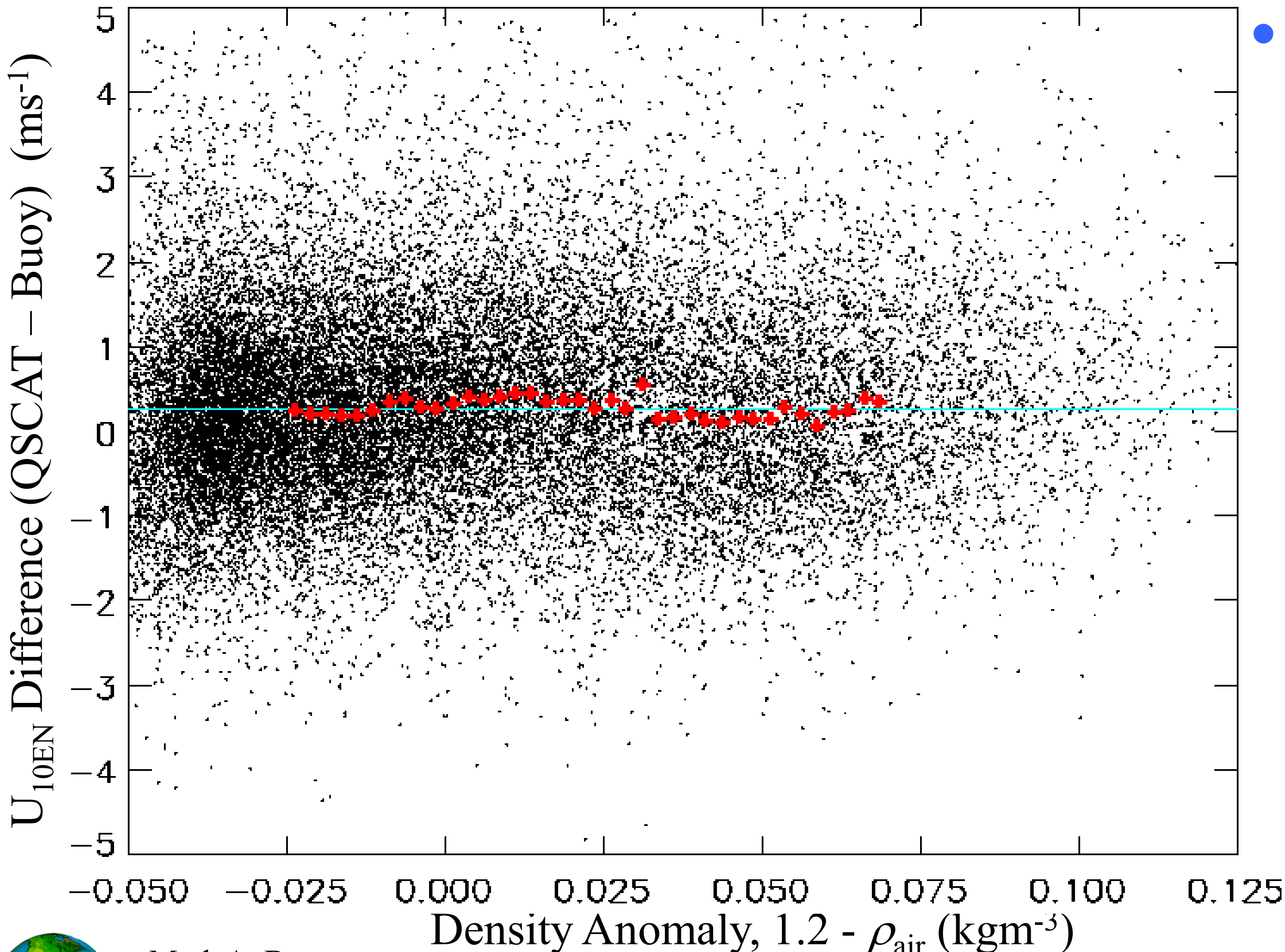
- If scatterometers respond to stress, then calibrations to this form of equivalent neutral winds will be off by a factor of $\rho^{0.5}$,
  - Or more accurately, in proportion to (actual density / mean calibration density $)^{0.5}$

Density Dependence – Seemingly So



- Thanks to Barry Vanhoff for provide the collocated QSCAT and buoy data!
- Only 5 means (analogous to red points) are less than 3 standard deviations from the zero line: the differences are statistically significant

Density Dependence Removed



- QSCAT U_{10EN} are adjusted by a factor of $(\rho/\overline{\rho})^{-0.5}$, removing the trend, and 20% of the rms difference between the median speed anomalies and the mean anomaly.

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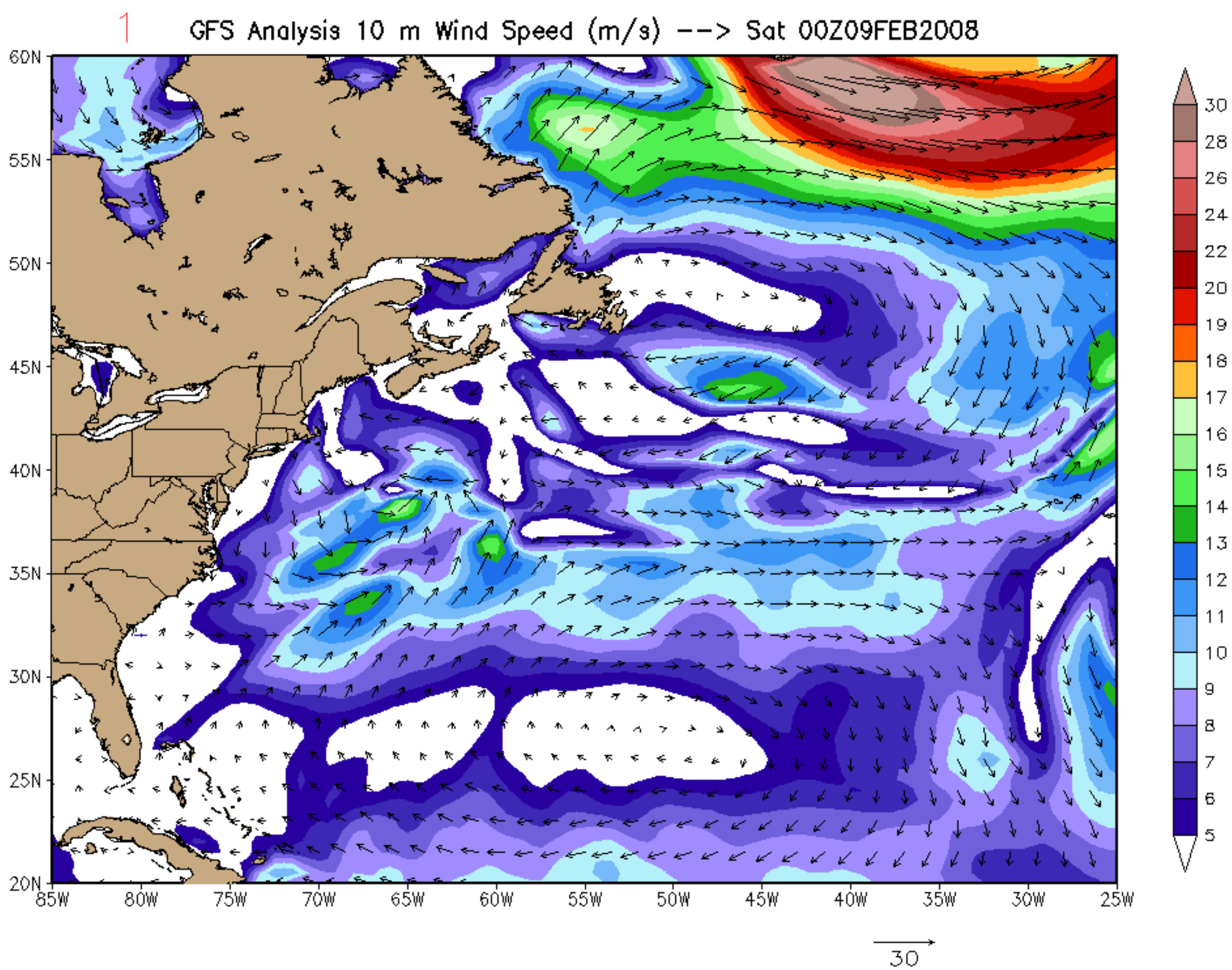
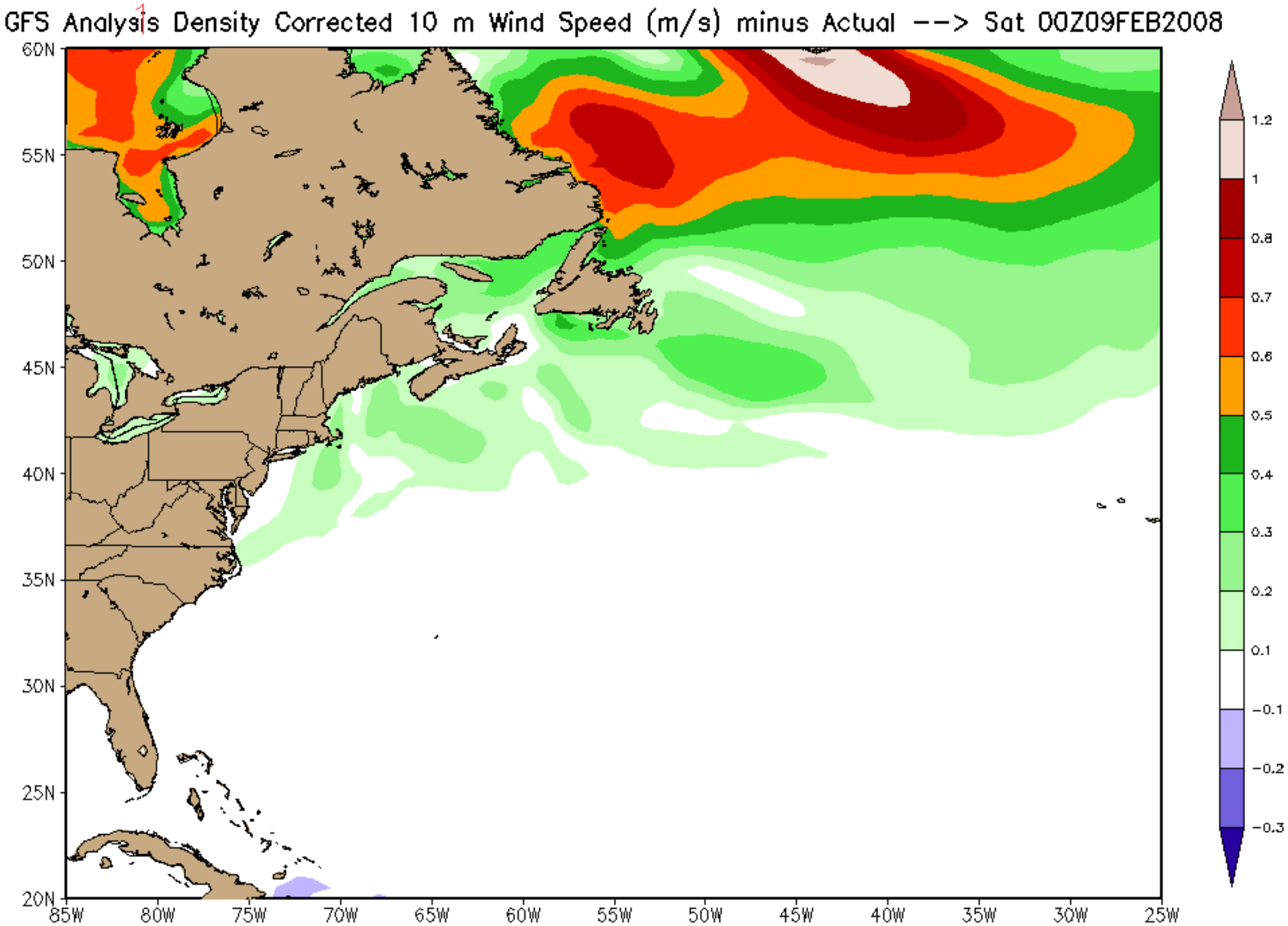
Example: A Cold Air Outbreak



- Example from NCEP's high resolution model, the GFS analysis.
- 0.5° (~40km) grid spacing
- 10 m wind
- Every 3rd vector

Example: Density-Related Bias in Equiv. Neut. Winds



- Shows overestimate of QSCAT winds.
- $U_{10} - U_{10}\,(\bar{\rho}/\rho)^{0.5}$
- Density is calculated from GFS 2m values.

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QuikSCAT Retrievals of Surface Turbulent Stress

- First Approximation:
  - We can use a more stress-consistent definition for equivalent neutral winds, to make better estimates of stress.
  - Concerns: Both the stress parameterization and the accuracy of the scatterometer model function for equivalent neutral winds are highly questionable for $U_{10} > 30\ \mathrm{ms}^{-1}$.

$$U_{10EN\_new} = \sqrt{\rho}\,\frac{\left|\vec{\mathbf{u}}_*\right|}{k}\ln\left(10/z_o\right)$$

- Converting the current calibration to stress includes two covariance terms. The last term is unknown and likely to be substantial.

$$\overline{\rho U_{10EN}^2} = \left[\overline{\sqrt{\rho}}\,\overline{U_{10EN}} + \mathrm{cov}\left(\sqrt{\rho}, U_{10EN}\right)\right]^2$$

$$+\,\mathrm{cov}\left(\sqrt{\rho}\,U_{10EN}, \sqrt{\rho}\,U_{10EN}\right)$$

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Summary

- Scatterometers do seem to respond to stress rather than kinematic stress (equivalent neutral winds) or earth-relative winds.
- The finding implies small regional biases related to the near-surface air density.
  - Improvement of the wind algorithm should be considered.
- Conversion of the existing geophysical model function for winds to a model function for stress requires considerations of non-linear terms in the tuning.
  - One of these terms is large and unknown.
- Therefore, we recommend estimation of stress from in situ observations for use in calibrating a stress model function.
  - Validation in comparison to in situ observations of stress

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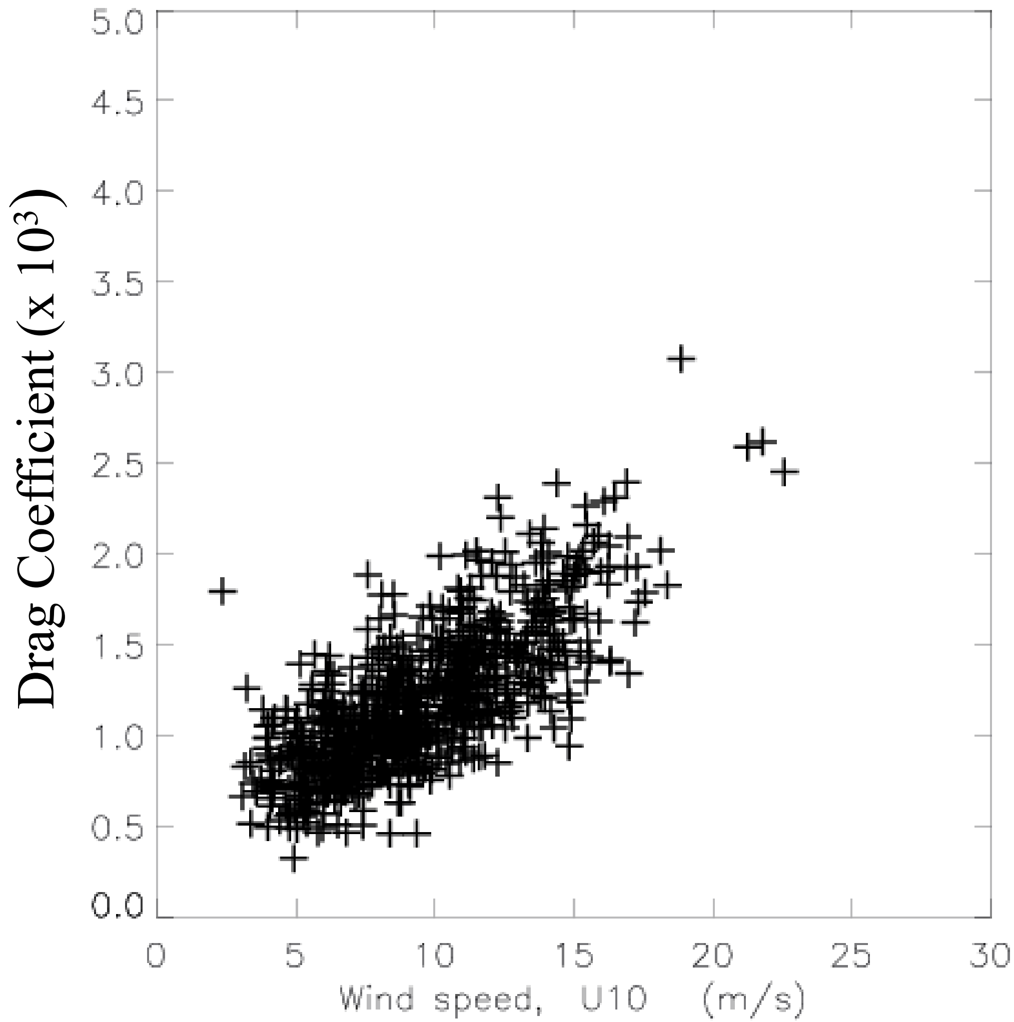
Drag Coefficient vs. Wind Speed



- Preliminary data form the SWS2 (Severe Wind Storms 2) experiment.
  - The drag coefficients for high wind speeds are large and plentiful.
  - The atypically large drag coefficients are associated with rising seas
- Many models underestimate these fluxes.

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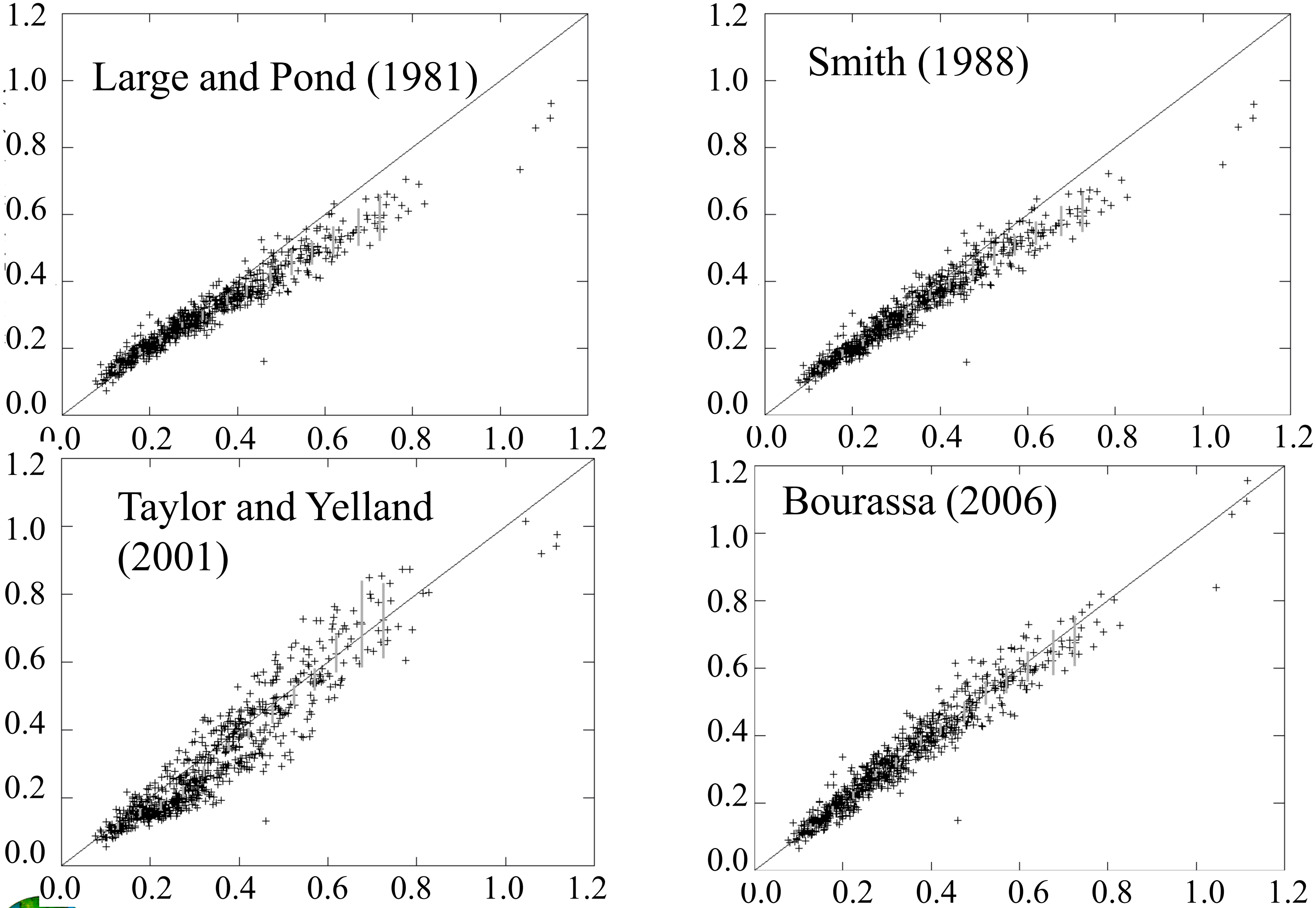
Observed (x) and Modeled (y) Friction Velocity (u_*)



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