# Review of Equivalent Neutral Winds and Stress

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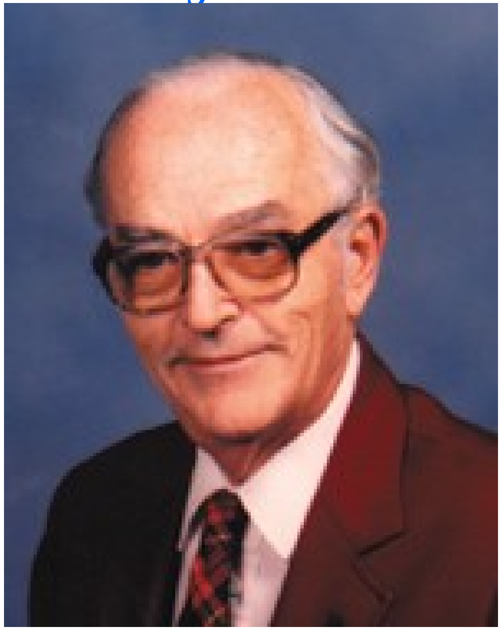
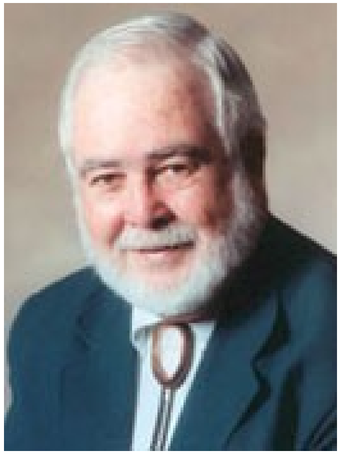
# Goal & Issues

- Goals: Define equivalent neutral winds and provide examples of some of the differences from traditional winds.

- Issues to be addresses:
  - Traditional definition of equivalent neutral winds
    - Recent modification
  - How does stress relate to equivalent neutral winds

# 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

# Qualitative Description of Earth-Relative Winds and Equivalent Neutral Winds

- **Earth relative winds** are wind speeds measured relative to the 'fixed' earth
  - **Earth relative winds** are the standard for almost all atmospheric applications:
    - Operational meteorology (forecasts and analyses)
    - Hurricane and marine cyclone analyses
  - Most meteorologists think in terms of **earth relative winds**
- **Equivalent neutral winds** are used to determine (as a proxy for) surface turbulent stress.
  - They have been designed for very simple conversion to stress.
  - The user communities are
    - Oceanographers (for surface forcing)
    - Warning: most flux models are tuned to **earth relative winds**

# Stress – Parameterization with a Drag Coefficient

- 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 $\mathbf{U}_{10} - \mathbf{U}_{sfc}$?
  - *Cornillon and Park* (2001, *GRL)*, *Kelly et al.* (2001, *GRL*), and *Chelton et al.* (2004, *Science*) 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 $\mathbf{U}_{sfc}$.

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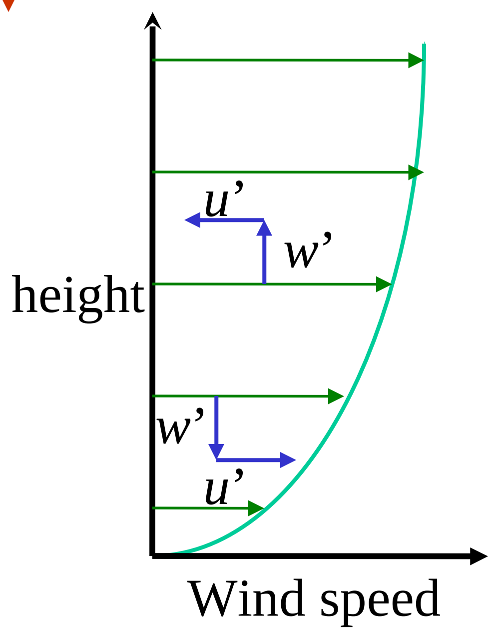
# Constant Stress Layer and the Log-Wind Profile

Input of horizontal momentum




Transfer of horizontal momentum to/from the surface
(positive downward)

- From the point of view of a point on the surface (land or ocean), horizontal momentum is transferred from the atmosphere to the surface.
- Where there is a non-zero vertical gradient of momentum, there is a non-zero stress.
  - Momentum = mass * velocity
- An upward (positive) perturbation in position requires a positive perturbation in vertical velocity (positive upwards).
- A parcel's upward change in position means that the parcel's horizontal velocity has a smaller velocity (a negative perturbation in this example.
- $\overline{u_i'u_3'}$ *is typically* $< 0 \qquad -\overline{u_i'u_3'} = |u_*|u_*$
- $\tau = -\rho|u_*|u_* \quad$ (positive downward)
- Stress is related to the wind shear

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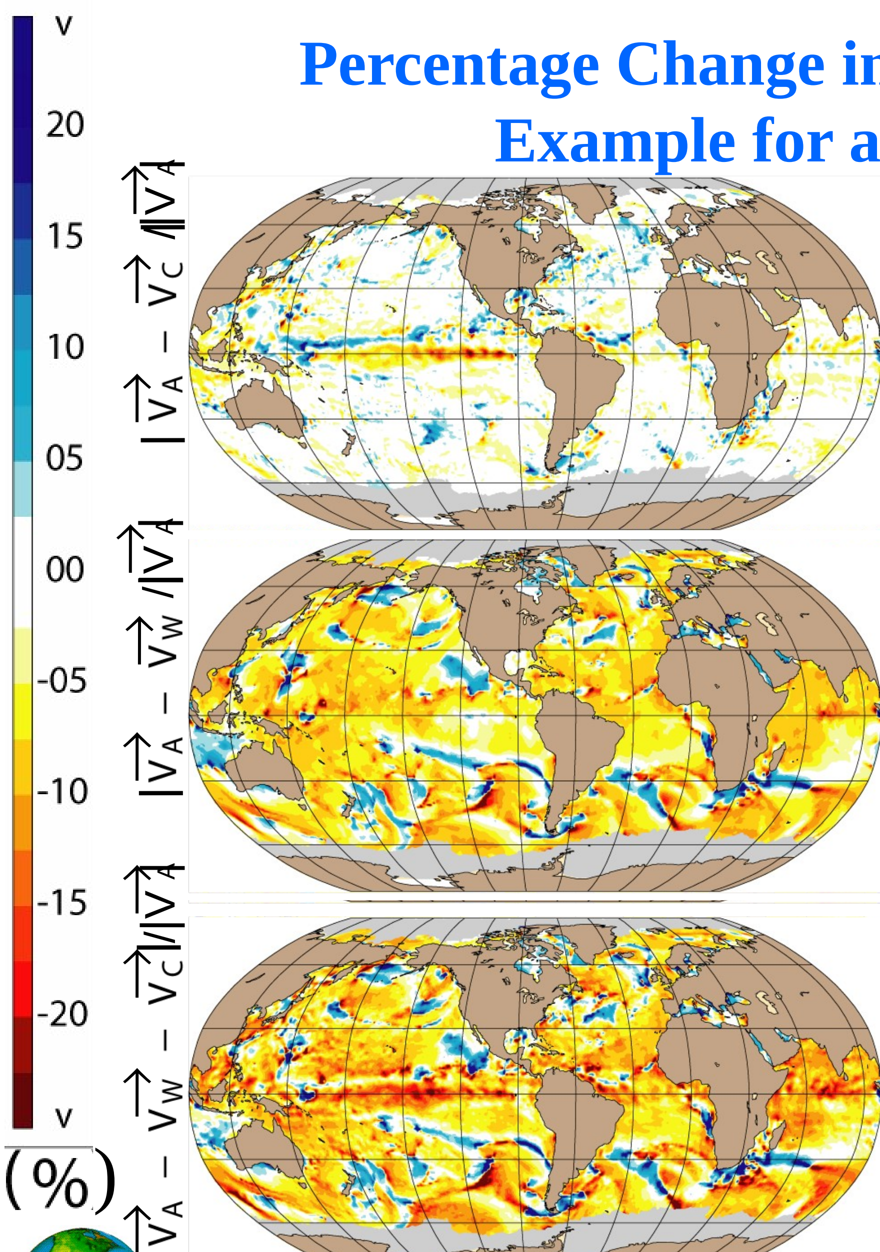
# Percentage Change in Surface Relative Winds Example for a 00Z Comparison




- 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
  - >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*)

# The Traditional Wind Profile, and Equivalent Neutral Winds

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

$$U(z) - U_{sfc} = \frac{u_*}{k} \ln\left( \frac{z}{z_o} + \phi\left(z, z_o, L\right) \right)$$

- The friction velocity ($u_*$) is the squareroot of the kinematic stress.
- The roughness length ($z_o$) governs the rate of curvature of the wind profile, and is a function of the shape and distribution of objects on the surface (roughness elements).
  - Over fluids, $z_o$ depends on stress (i.e., $u_*$).
- The $\phi$ term is a function of atmospheric stratification.
- The 10m **Equivalent Neutral wind** ($U_{10EN}$) is calculated by using the observed value of $u_*$, the corresponding value of $z_0$, and setting $\phi$ to zero.

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

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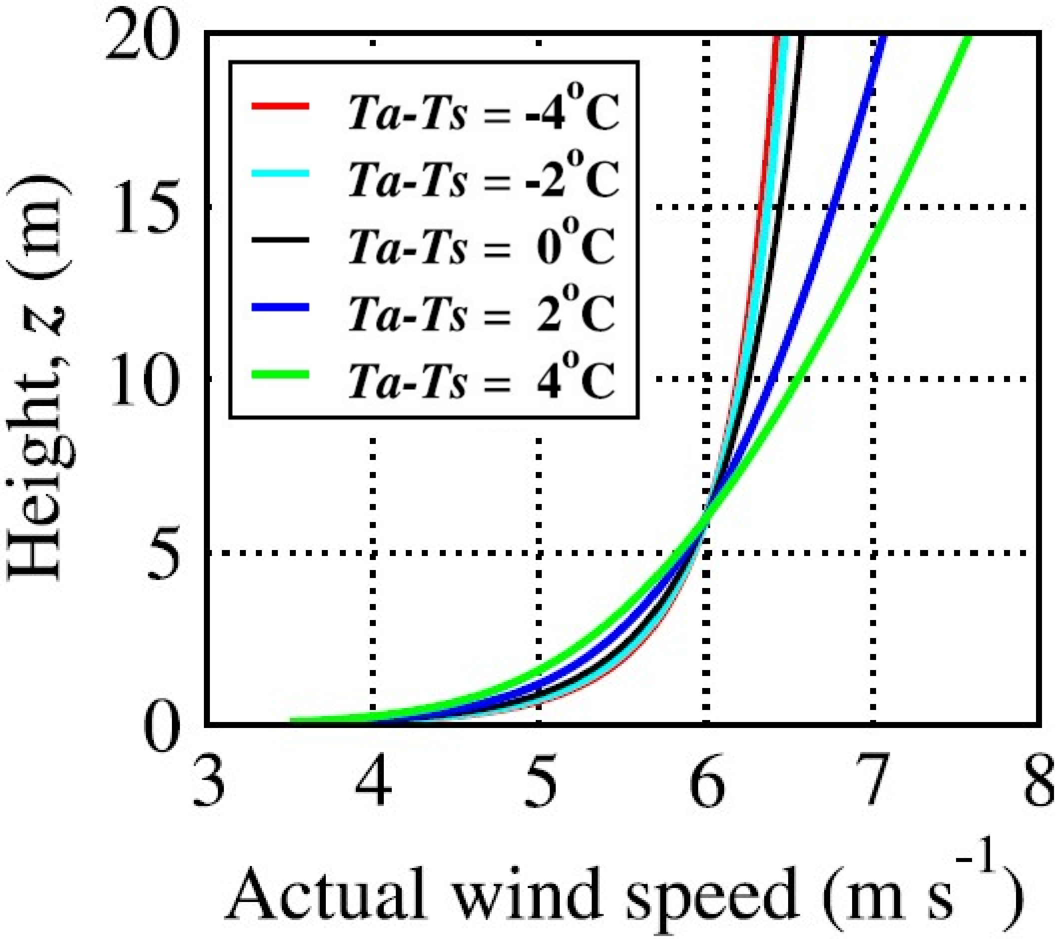
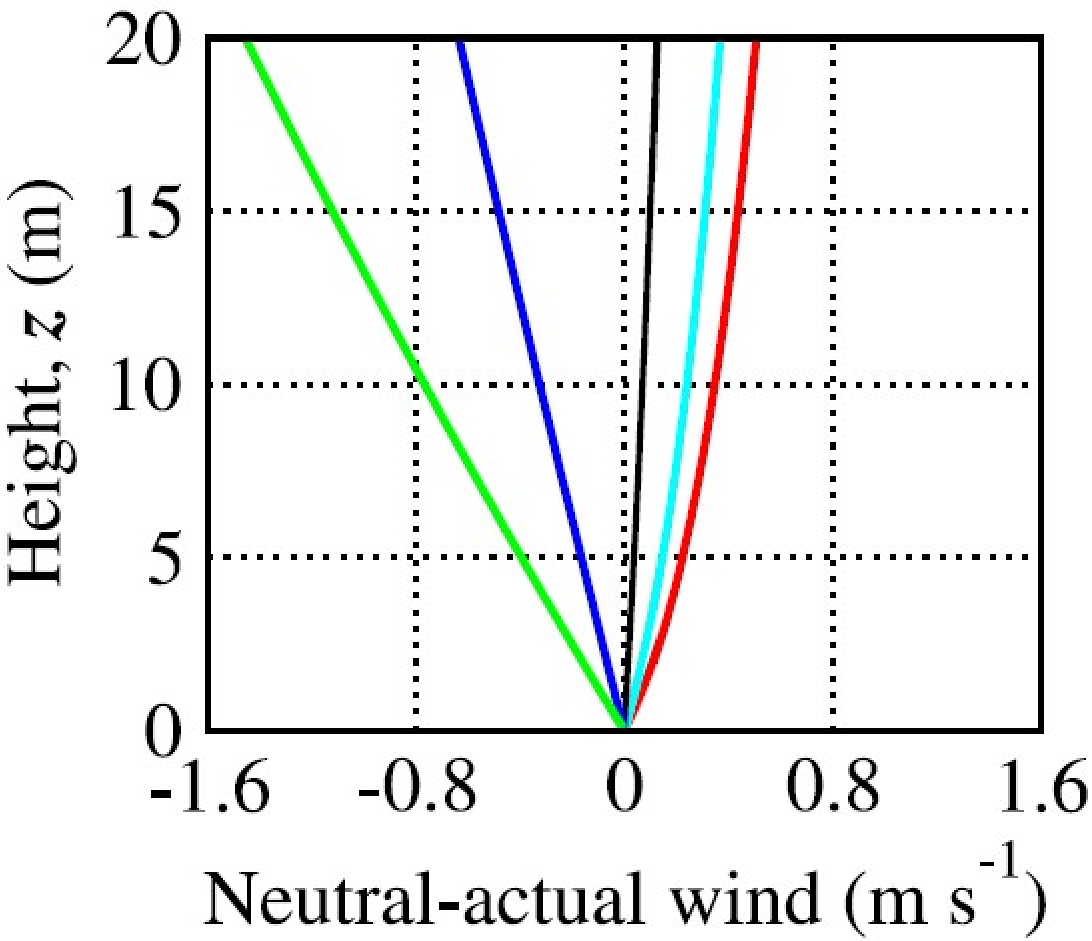
# Dependence of Earth Relative wind speed on Atmospheric Stratification

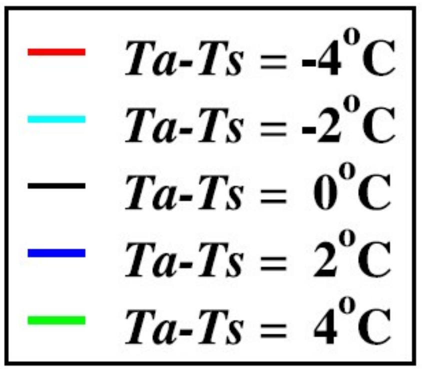



- The wind shear (and stress) depends on the atmospheric stratification
- Unstable air (red and light blue) result in greater vertical mixing and greater stress
  - Greater backscatter
- Stable air (dark blue and green) result in less vertical mixing and less stress
  - Lower backscatter
- Atmospheric stratification can cause **equivalent neutral winds** to differ from **earth relative winds**

# Equivalent Neutral wind speed minus Earth Relative wind speed




- For equal and opposite air/sea temperature differences, the change is greater for the stable



# Dependence on Parameterization of $z_o$

- The difference between **Equivalent Neutral wind** speed and **Earth Relative wind** speed is also dependent on the parameterization for roughness length ($z_0$)
  - If $z_0$ or the drag coefficient does not depend on roughness length, the differences can (more often than not) have the opposite sign of the stability dependent parameterizations!!!
- For example, roughness length is often parameterized in terms of friction velocity ($u_*$), which is dependent on atmospheric stratification

# What If Scatterometers Respond to Stress?

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

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

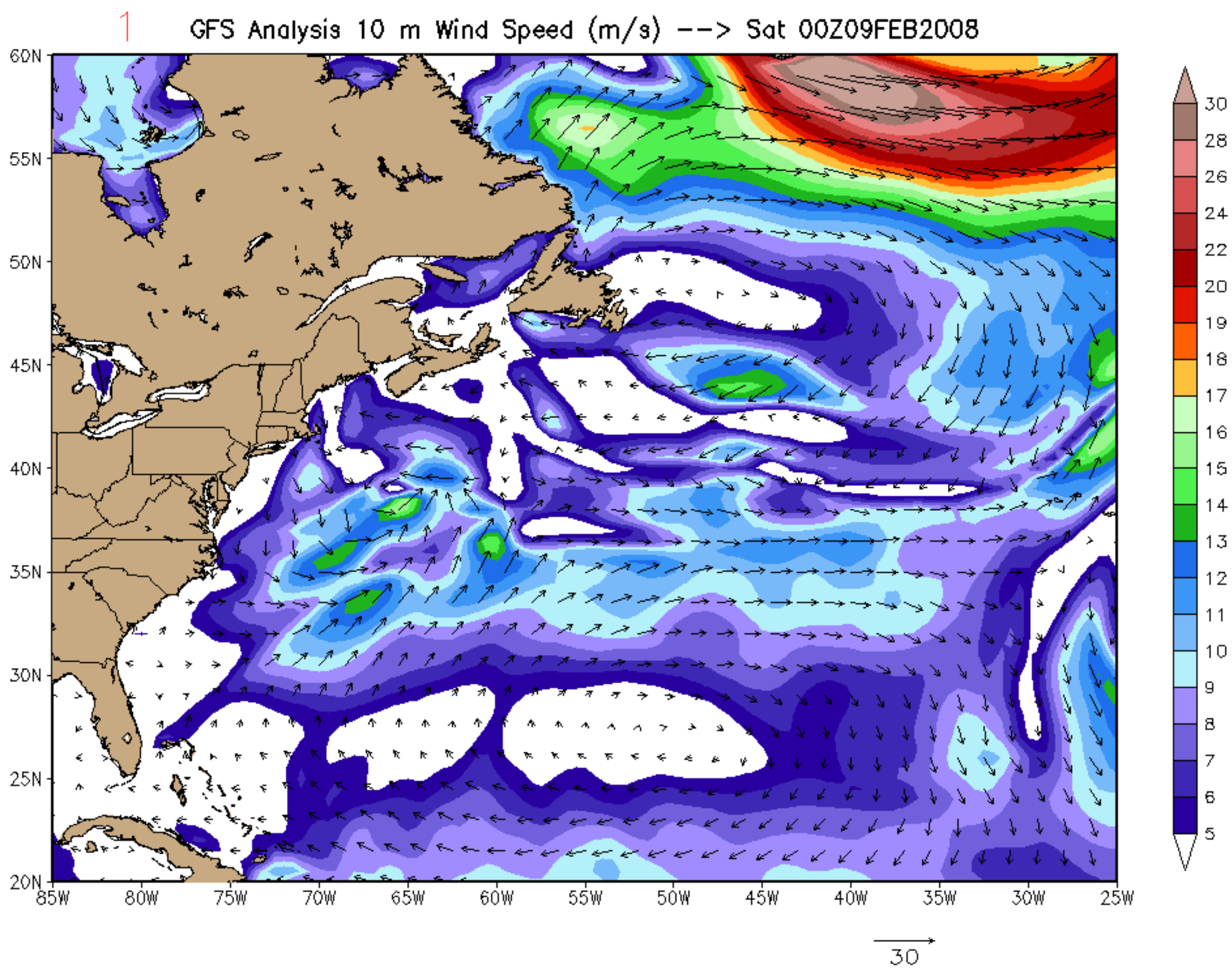
$$U_{10EN} = \frac{(\tau/\rho)^{0.5}}{k} \ln(10/z_o)$$

- $\tau = \rho_{air} u_*^2$
- Replace u* in the traditional definition of equivalent neutral winds – write in terms of $\tau$

- If scatterometers respond to stress, then it responds to changes in air density and change in friction velocity!
  - Our traditional definition of $U_{10EN}$ is tuned to friction velocity, or the assumption that $\rho_{air} = 1$
- If scatterometers respond to stress, then calibrations to this form of **equivalent neutral winds** will be off by a factor of $\rho^{0.5}$ – as has been observed

$$U_{10EN} = \frac{(\tau/\rho)^{0.5}}{k} \ln(10/z_o) * \text{(actual density / mean calibration density)}^{0.5}$$

# 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

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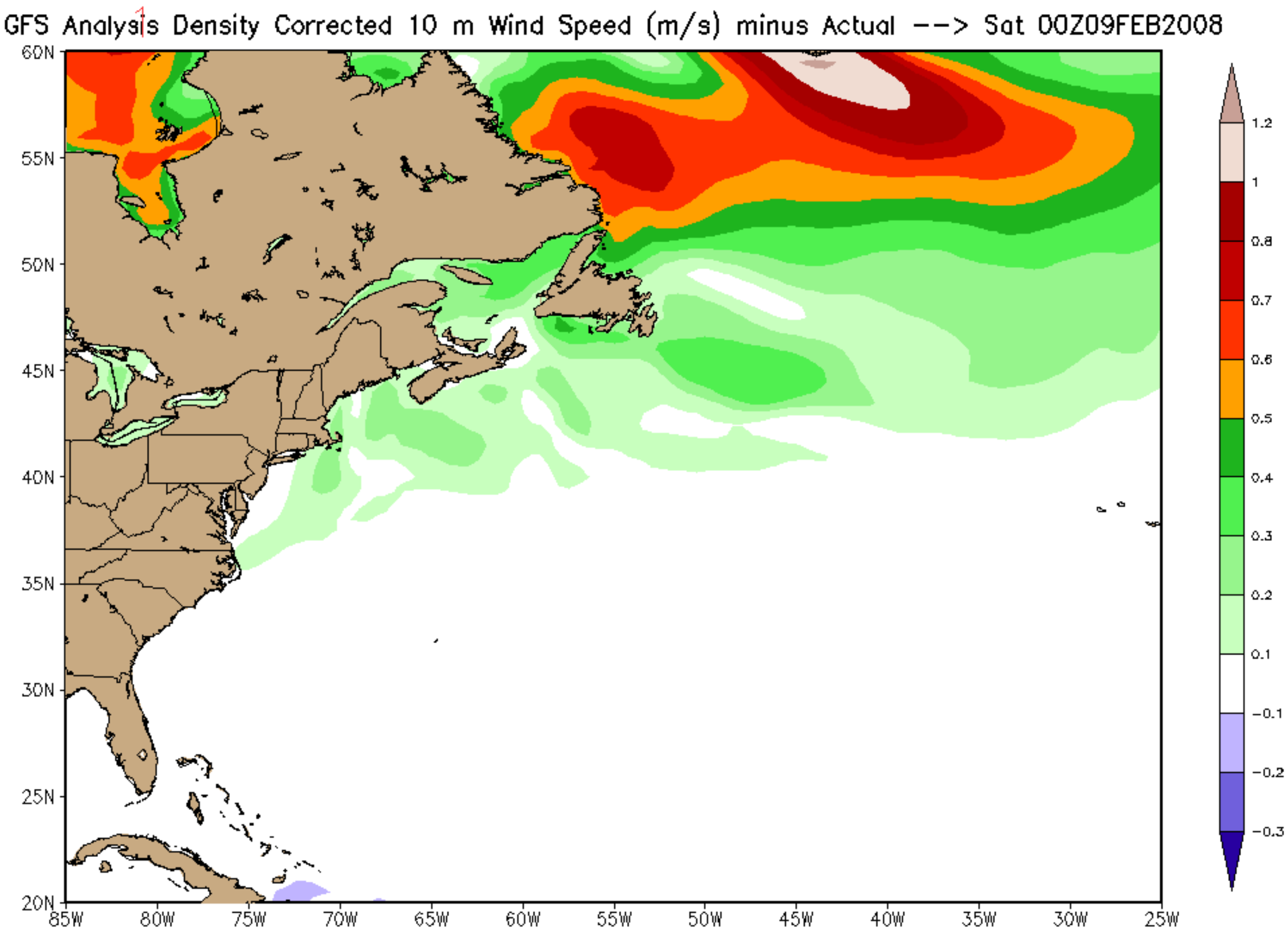
# Example: Density-Related Bias in Equiv. Neut. Winds




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

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# Summary

- The difference between **Equivalent Neutral winds** and **Earth Relative Winds** is dependent on
  - Surface currents
  - Waves (sea state)
  - Atmospheric Stratification
  - Air density
  - Perhaps other considerations (e.g., rain)
- Individually, these differences tend to be small (tenths of a m/s)
  - Global mean difference is roughly 0.2m/s
- Collectively, and in extreme cases, these differences can exceed 1m/s
- These differences can be important for calibration, merging of data sets, and many process studies that are dependent on wind speed
- They are also important for interpretation: scatterometers seem to respond more closely to stress than to wind and friction velocity

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