# *Developing Accuracy Constraints for Climate Quality Observations*


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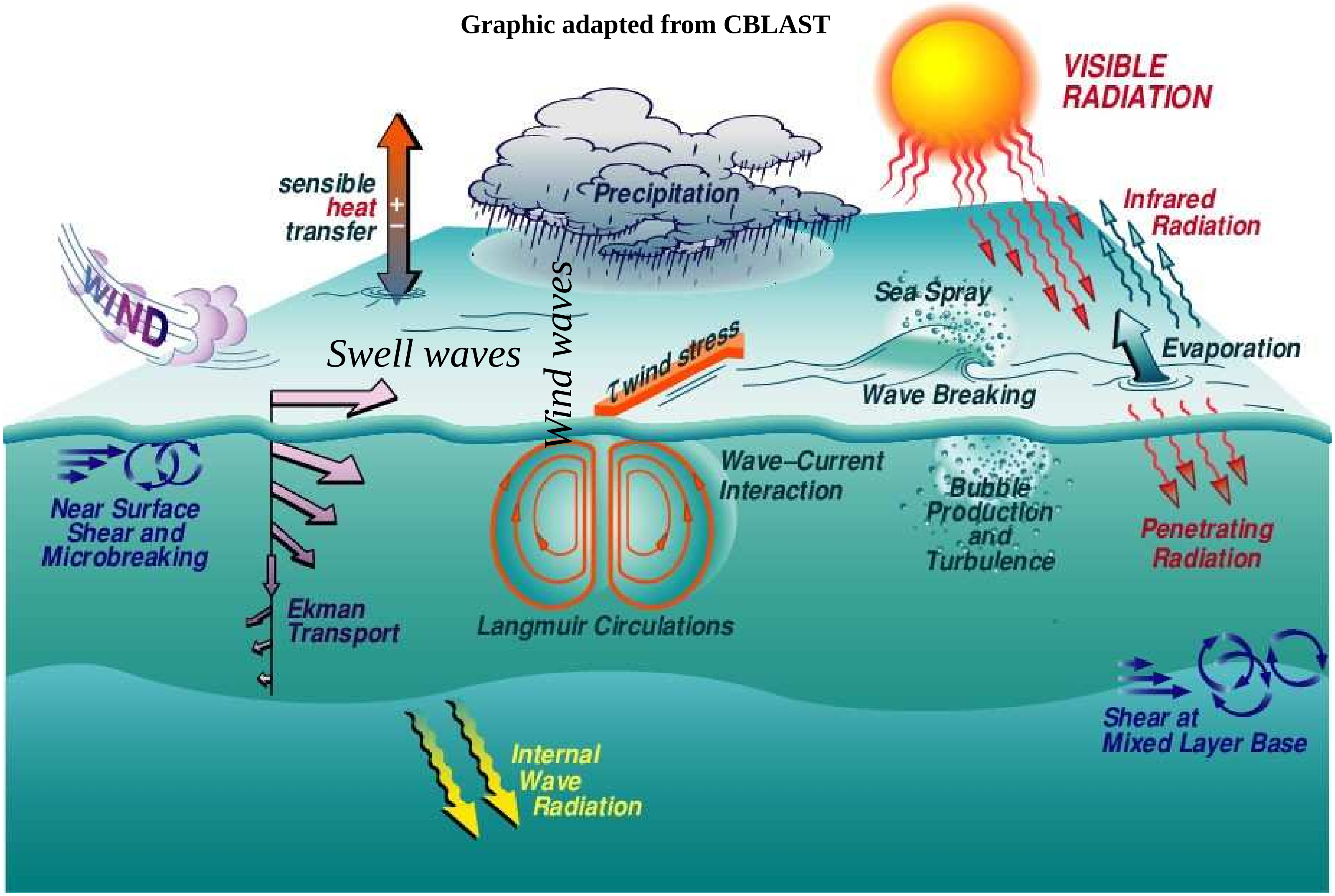
# Many Air/Sea Interaction Processes

## - Most are strongly influenced by wind (or stress) -

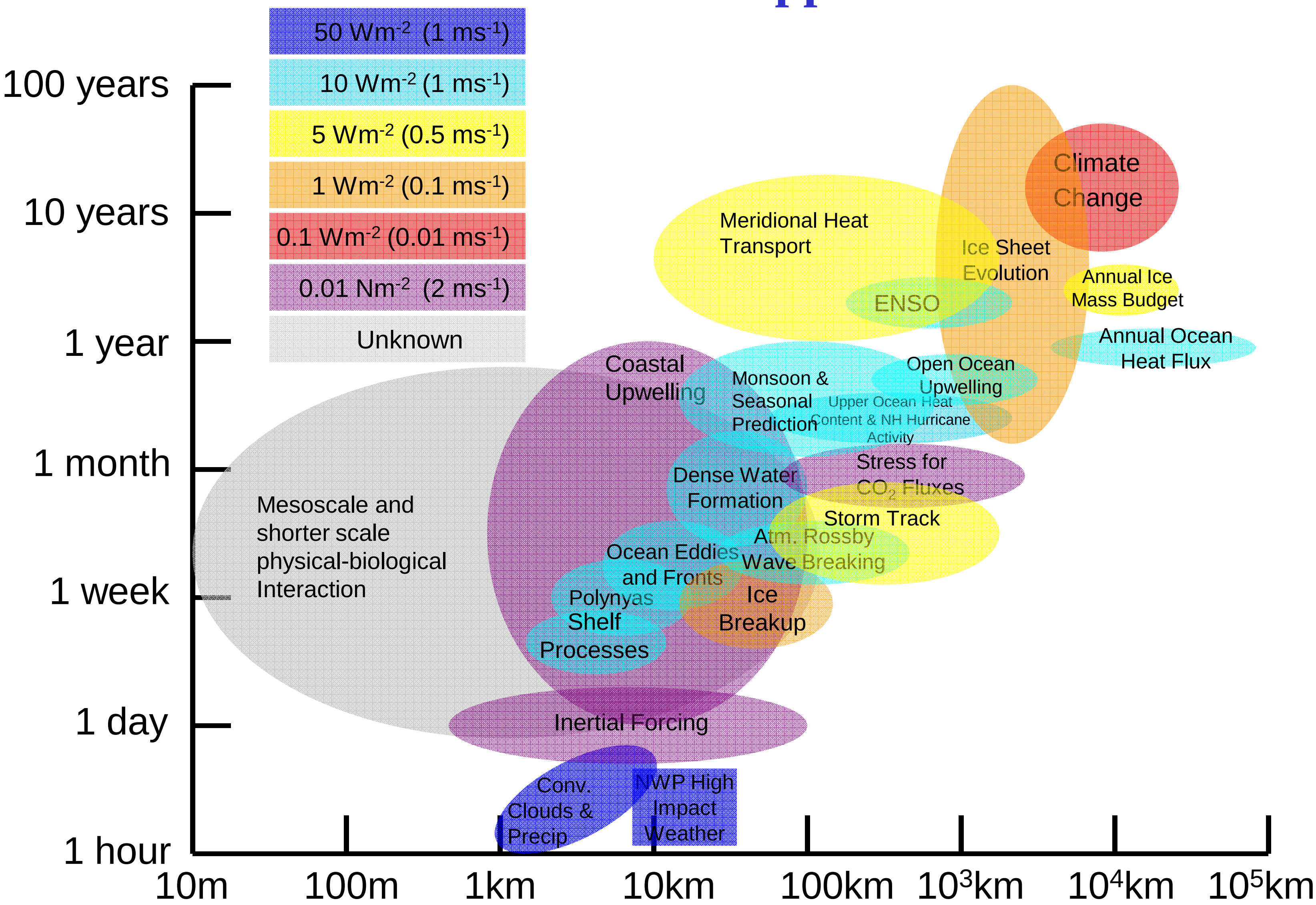
**Graphic adapted from CBLAST**



# Coupling Fluxes at the Air/Sea Interface

- How accurately do we have to know the various fluxes through the air sea interface?
  - Stress – vertical transport of horizontal momentum ($Nm^{-2}$)
    - Magnitude proportional to wind speed squared or cubed
  - Latent heat – heat transferred through phase change from water to water vapor ($Js^{-1}m^{-2} = Wm^{-2}$)
    - Proportional to wind speed & air/sea moisture difference
  - Sensible heat – heat transferred without phase change from water to air ($Js^{-1}m^{-2} = Wm^{-2}$)
    - Proportional to wind speed & air/sea temperature difference
  - Evaporation – proportional to latent heat flux ($kgs^{-1}m^{-2}$)
    - Proportional to wind speed & air/sea moisture difference
  - Precipitation – rain of snow falling and reaching the surface
- The curl of the stress is very important for vertical motion and deep circulation.

# Flux and Wind Accuracies Desired for Various Applications



# Observational Errors

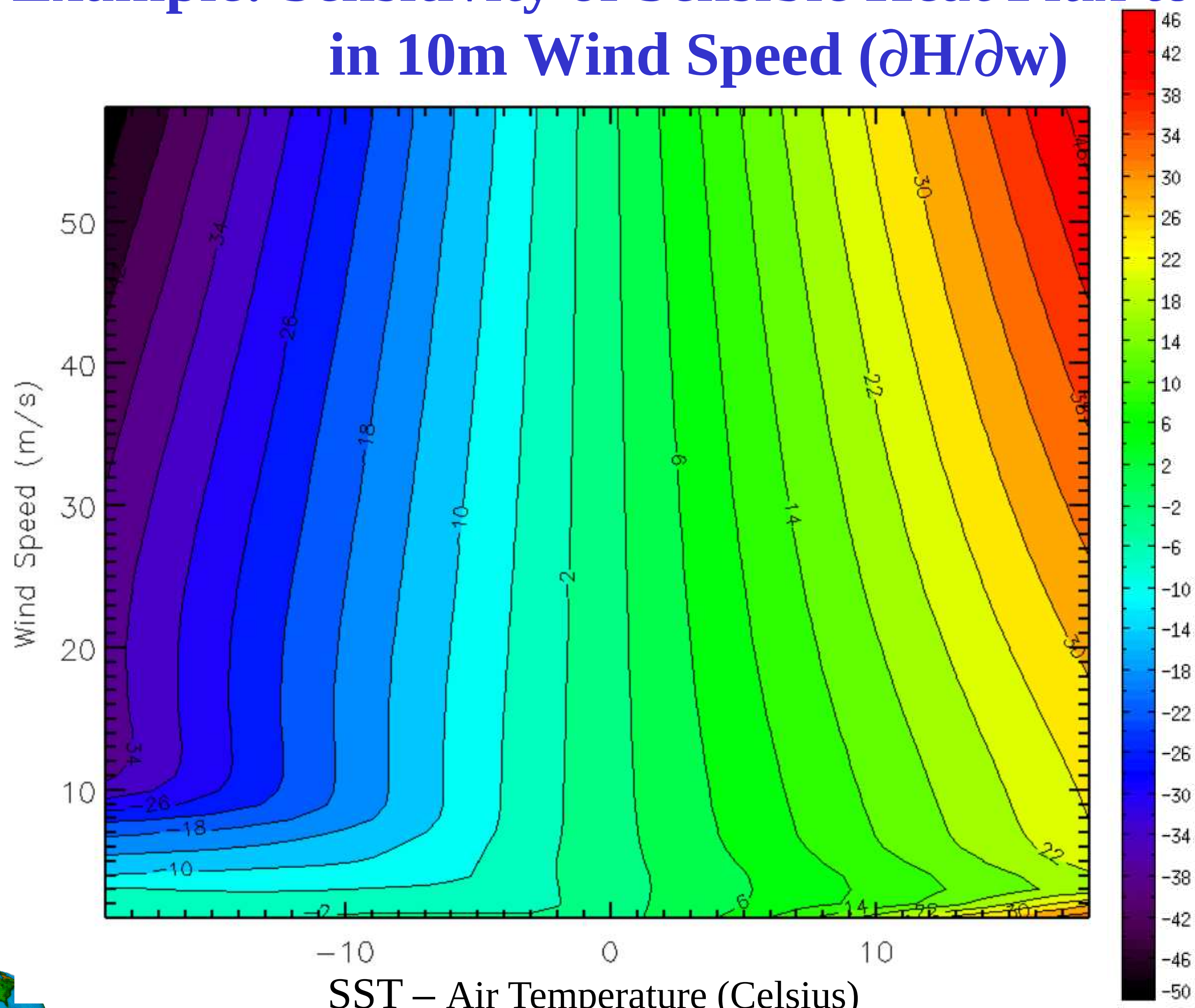
- Errors can be described as composed of
  - A bias (this bias could be a function of environmental conditions),
  - Random uncertainty, and
  - More complicated systematic errors

- We are primarily interested in how biases in observations of wind speed (w)
  - sea surface temperature (SST), near surface air temperature ($T_{air}$), and near surface humidity ($q_{air}$) translate to biases in calculated fluxes.
  - Turbulent fluxes: sensible heat (H), latent heat (L), and stress ($\tau$).
- In general, the bias in one of these observations can be related to the bias in a flux through a Sensitivity (S).
- Symmetrically distributed random errors in data that are used linearly will cause only small error if there is a large enough sample.
  - Non-linear processes can result in biases due to random errors.

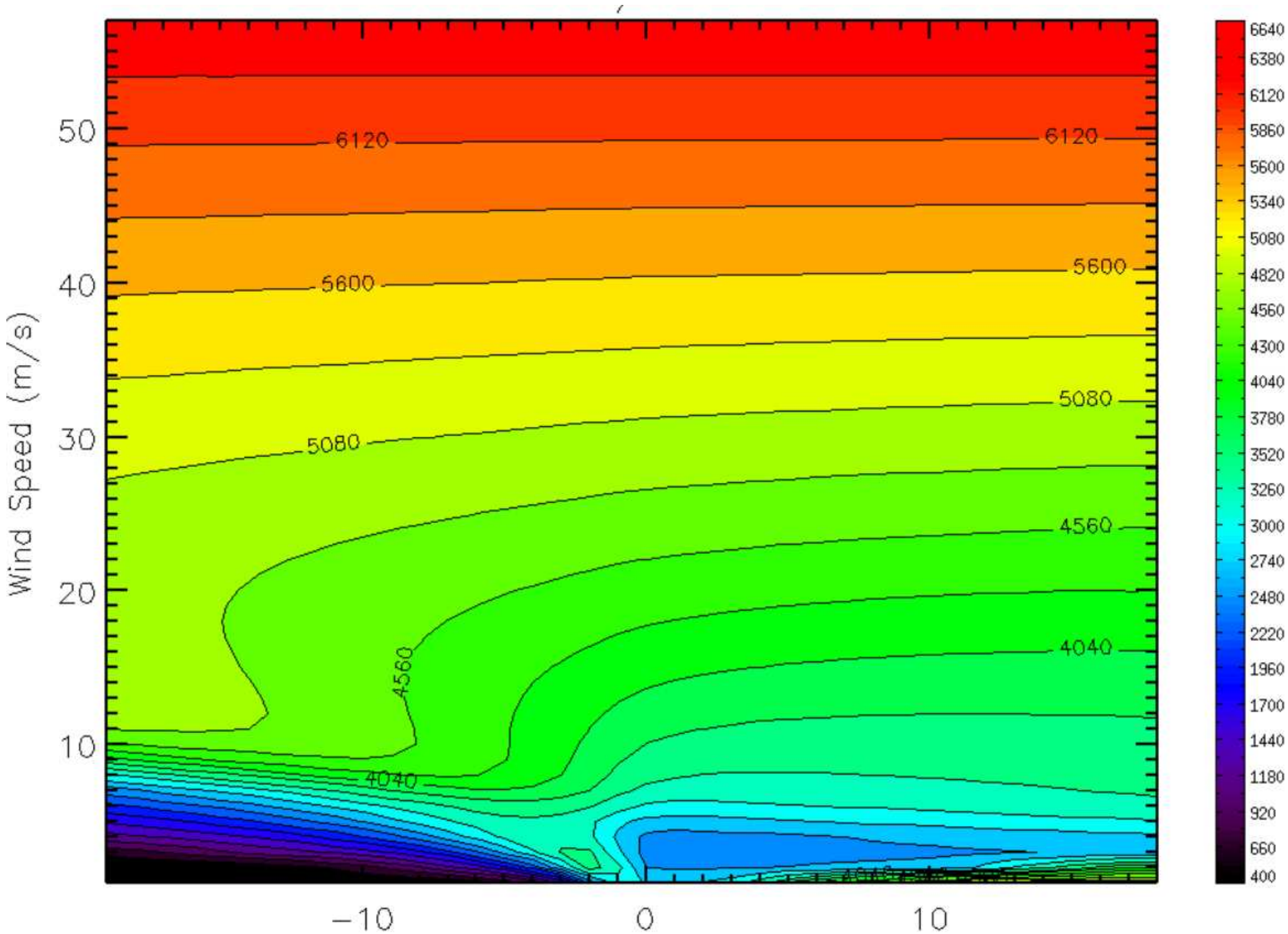
# Biases – For Specific Conditions

- Example: How much does a bias in speed ($\Delta w$) contribute to a bias in the latent heat flux ($\Delta L$)?
  - $\Delta L = S_{L,w}\, \Delta w$
  - If $S_{L,w}$ is very large, then even a small bias in w can result in a large bias in L.
  - If the sensitivity is very small, then the calculated variable is insensitive to errors in the observation.
- The maximum allowable bias in an observation (e.g., $|\Delta w|$) can be estimated from the maximum specified error in the calculated variable (e.g., $|\Delta L|_{max}$), and the sensitivity (e.g., $S_{L,w}$)
  - $|\Delta w|_{max} = |\Delta L|_{max} / |S_{L,w}|$
- The sensitivity is the partial derivative of the output quantity (e.g., the flux) with respect to the input observation (e.g., wind speed).
  - $S_{L,w} = \partial L / \partial w$

# Example: Sensitivity of Sensible Heat Flux to Errors in 10m Wind Speed (∂H/∂w)



# Example: Sensitivity of Latent Heat Flux to Errors in Wind Speed: ∂(E/Δq)/∂w



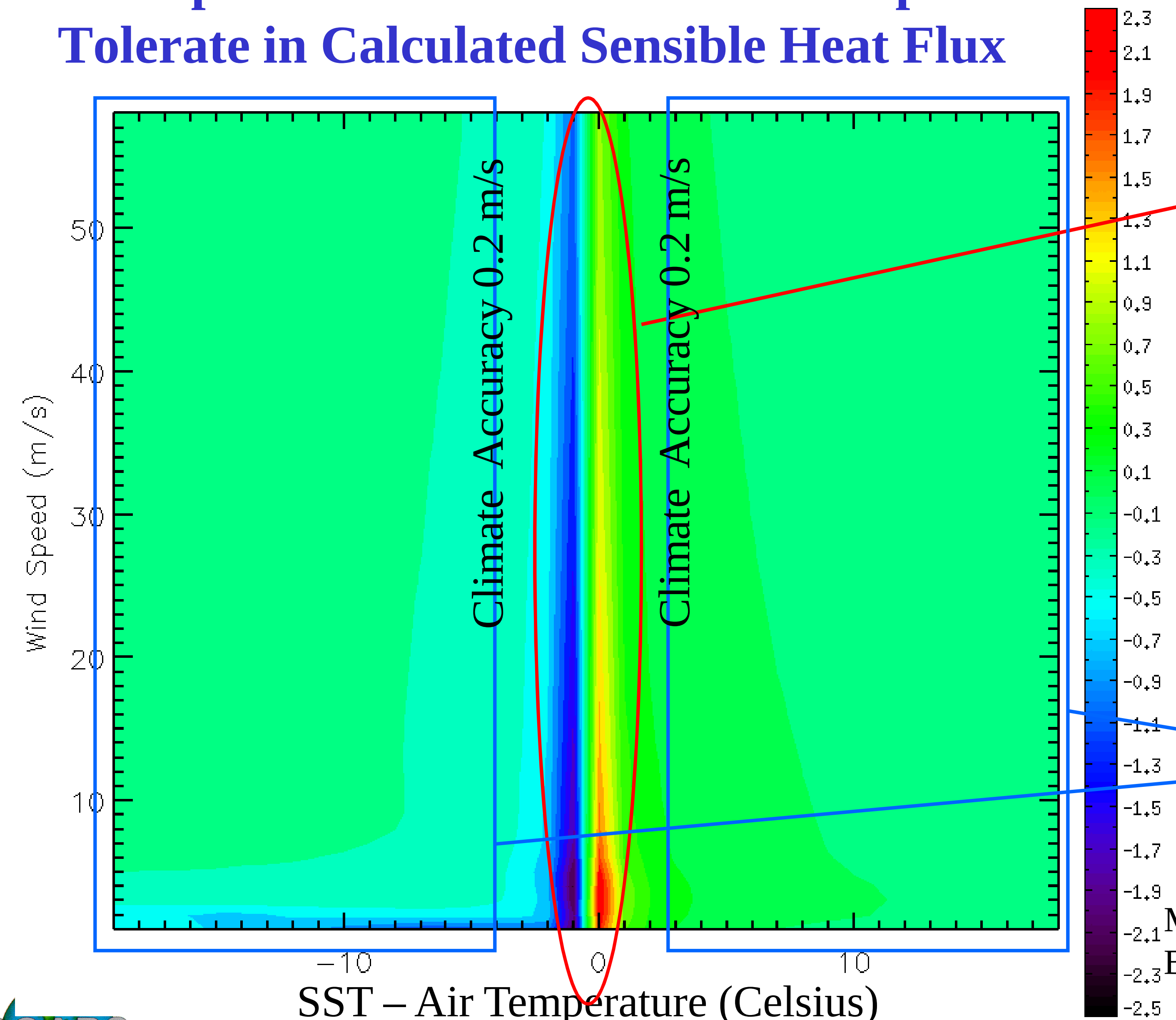

SST – Air Temperature (Celsius)

- Air/sea humidity differences are also important.
- A third dimension is awkward to work with. Therefore sensitivity, per kg/kg is given.
- Humidity differences are typically on the order of 1g/kg.

# Error Limits for Observation Errors

- For this talk, we will ignore random errors, assuming that they will be small given enough samples.
  - This is a common assumption, but will not be true for all applications!
- The maximum allowable bias in an observation (e.g., $|\Delta w|$) can be estimated from the maximum specified error in the calculated variable (e.g., $|\Delta E|$), and the sensitivity (e.g., $S_{E,w}$)
  - $|\Delta w|_{max} = |\Delta E|_{max} / |S_{E,w}|$

# Example: How Much Bias in Wind Speed Can We Tolerate in Calculated Sensible Heat Flux

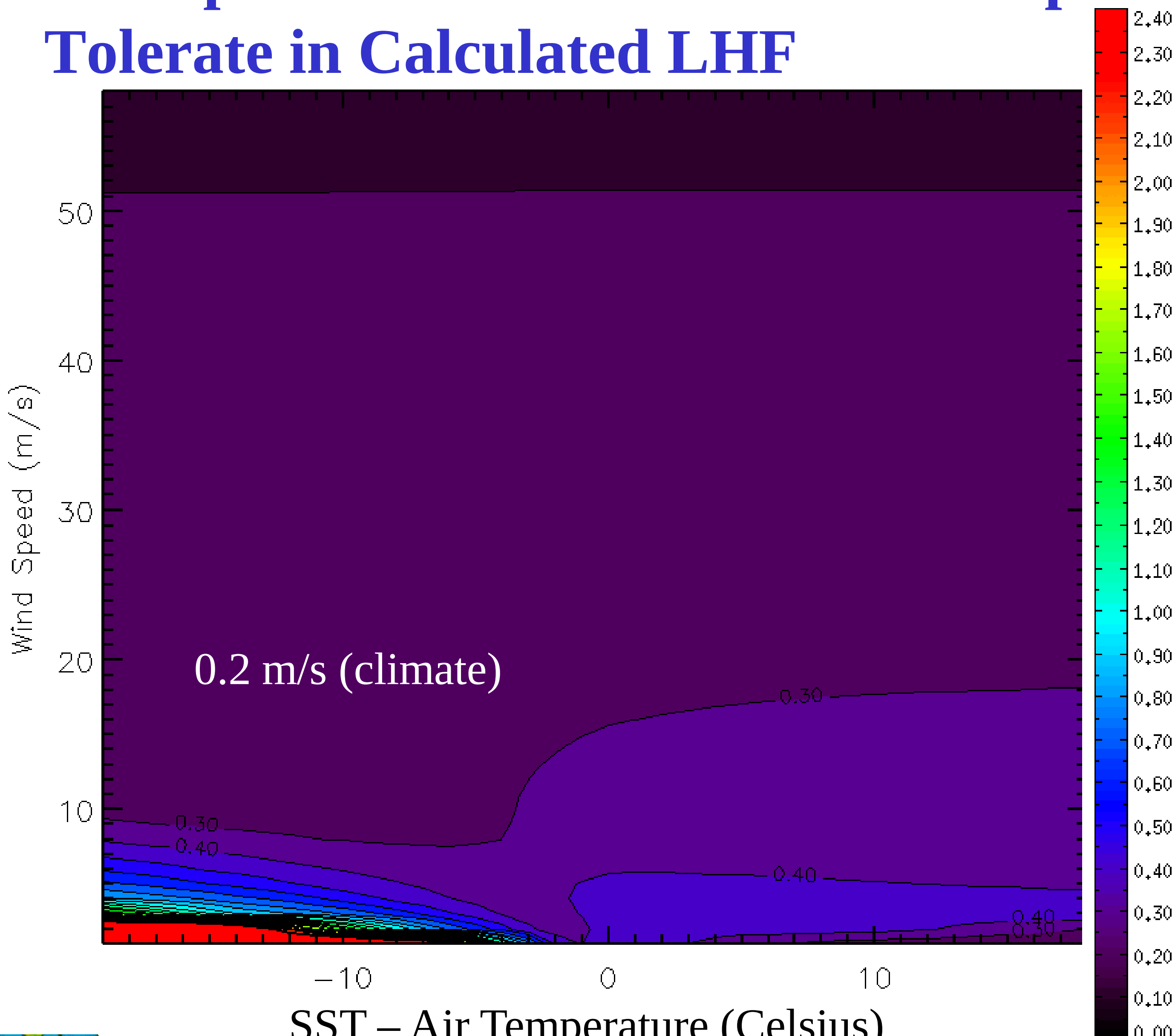



- We can be relatively sloppy.

Assume a bias in SHF of <1.25 $Wm^{-2}$ is OK.

- We must be relatively accurate.

# Example: How Much Bias in Wind Speed Can We Tolerate in Calculated LHF




- Fortunately, high winds are usually associated with unstable stratification ($SST - T_{air} > 0$).
- In strong storms, we will not meet our accuracy requirement.

# Conclusions

- Speed constraints
  - For *average* open ocean conditions, accuracy requirements for turbulent heat fluxes are easily achieved: ~1ms$^{-1}$ bias is OK.
    - Might be OK for tropics for annual applications
    - Insufficient for mid-latitudes
  - For harsh mid-latitude conditions, speed biases of ≤0.2ms$^{-1}$ are needed
  - For multi-decadal applications slightly finer accuracy is needed.
- Direction
  - While direction is very important for physical processes, the bias constraints for direction (or vector component error) are not known.
  - Slightly finer accuracy might be needed for Sverdrup flow?
- There are applications that are non-linearly dependent on wind speed (or stress) for which the impacts of random errors should be investigated.
- Sampling of the synoptic and diurnal variability could also cause biases.

# *Surface Turbulent Fluxes and Scatterometry*

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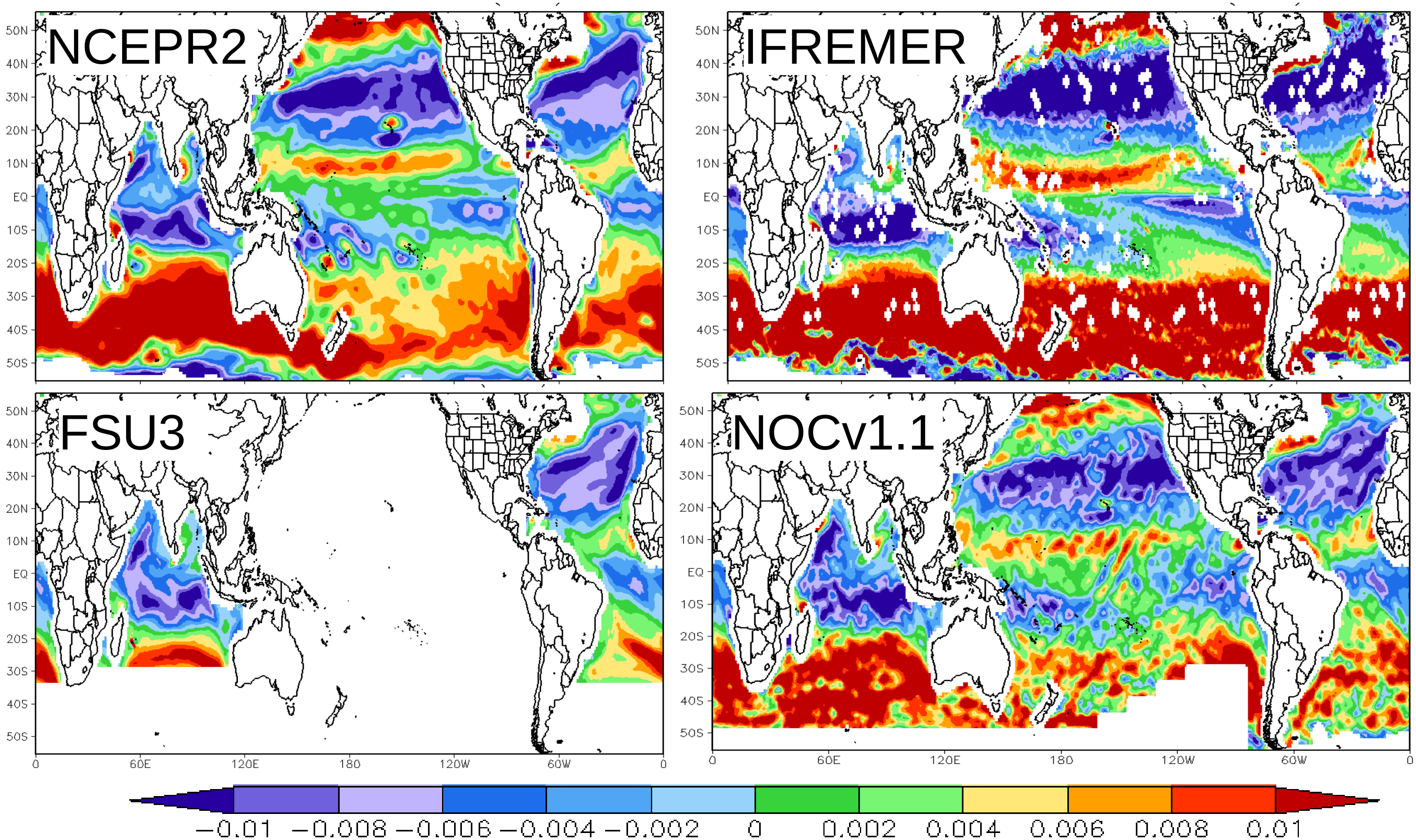
# Suggested Measurement Accuracy For Research Vessels

Table 1: Accuracy, precision and random error targets for SAMOS. Accuracy estimates are currently based on time scales for climate studies (i.e., ±10 W/m$^2$ for $Q_{net}$ on monthly to seasonal timescales). Several targets are still to be determined.

| Parameter | Accuracy of Mean (bias) | Data Precision | Random Error (uncertainty) |
|---|---|---|---|
| Latitude and Longitude | 0.001° | 0.001° | |
| Heading | 2° | 0.1° | |
| Course over ground | 2° | 0.1° | |
| Speed over ground | Larger of 2% or 0.2 m/s | 0.1 m/s | Greater of 10% or 0.5 m/s |
| Speed over water | Larger of 2% or 0.2 m/s | 0.1 m/s | Greater of 10% or 0.5 m/s |
| Wind direction | 3° | 1° | |
| Wind speed | Larger of 2% or 0.2 m/s | 0.1 m/s | Greater of 10% or 0.5 m/s |
| Atmospheric Pressure | 0.1 hPa (mb) | 0.01 hPa (mb) | |
| Air Temperature | 0.2 °C | 0.05 °C | |
| Dewpoint Temperature | 0.2 °C | 0.1 °C | |
| Wet-bulb Temperature | 0.2 °C | 0.1 °C | |
| Relative Humidity | 2% | 0.5 % | |
| Specific Humidity | 0.3 g/kg | 0.1 g/kg | |
| Precipitation | ~0.4 mm/day | 0.25 mm | |
| Radiation (SW in, LW in) | 5 W/m$^2$ | 1 W/m$^2$ | |
| Sea Temperature | 0.1 °C | 0.05 °C | |
| Salinity | | | |
| Surface Current | 0.1 m/s | 0.05 m/s | |

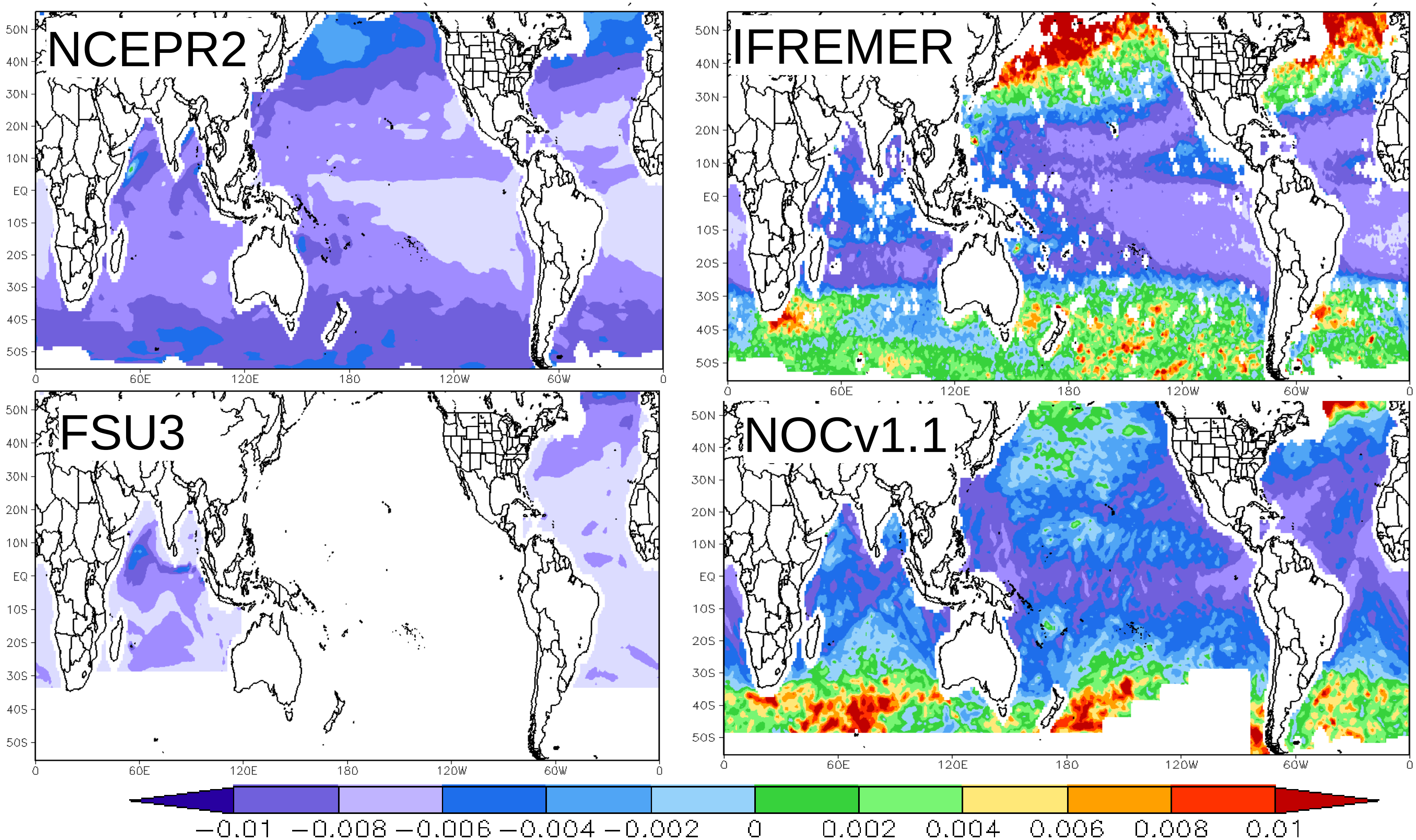
- I will assume that a 5Wm$^{-2}$ is the limit for biases in radiative fluxes.
- Then 5Wm$^{-2}$ is the limit for biases in surface turbulent heat fluxes.

# Curl of the Stress



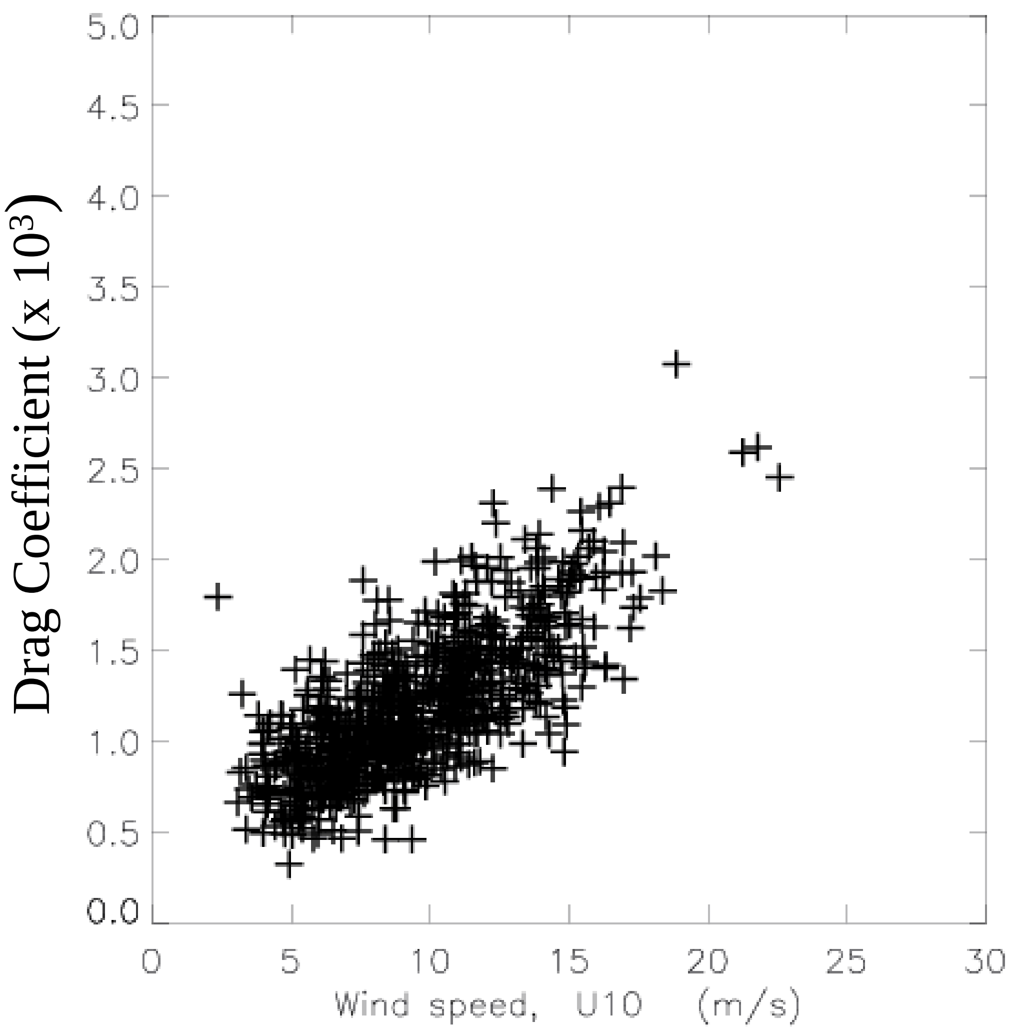

- Ship tracks are apparent in many products, as are TAO buoys

# Standard Deviation of the Curl of the Stress




- Ship tracks are apparent in many products, as are TAO buoys

# 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.
- Spread is much bigger than expected from observational errors

# How Do Waves Enter The Picture?

- The surface turbulent stress and LHF are usually parameterized as

$$\tau = \rho C_D U_{10}^2 \qquad\qquad L = \rho L_v C_E (q_{10} - q_{sfc}) U_{10}$$

- This form can be more accurately written as

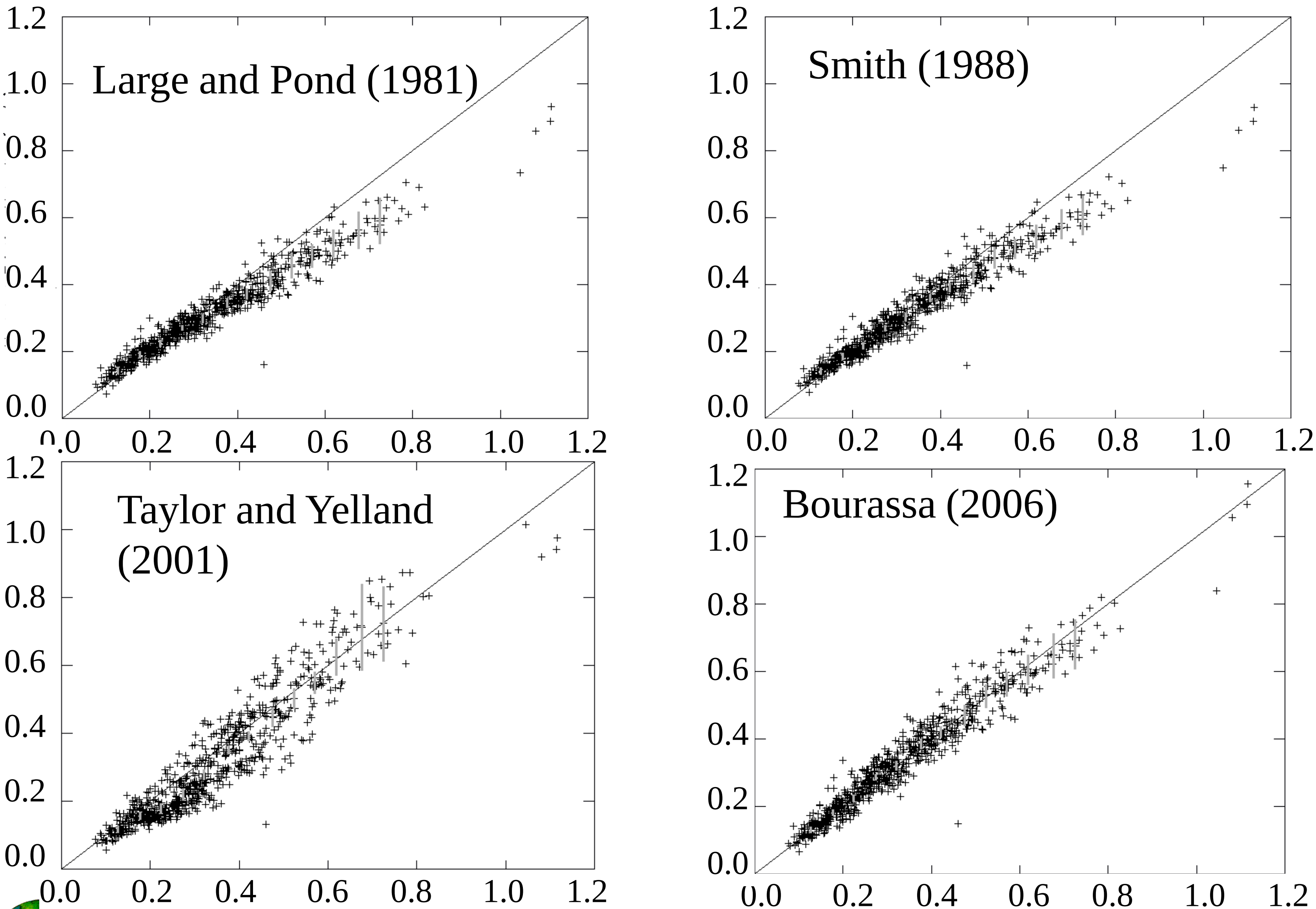
$$\boldsymbol{\tau} = \rho C_D \left|\mathbf{U}_{10}\right| \mathbf{U}_{10} \qquad\qquad L = \rho L_v C_E (q_{10} - q_{sfc}) \left|\mathbf{U}_{10}\right|$$

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

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

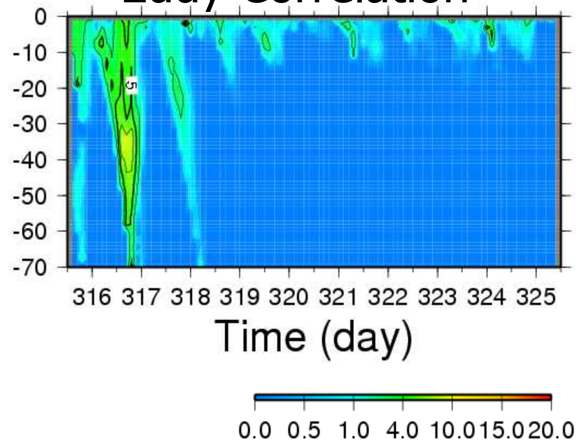
- Does a scatterometer respond to $\mathbf{U}_{10}$ or to $\mathbf{U}_{10} - \mathbf{U}_{sfc}$?
  - *Cornillon and Park* (2001, *GRL)*, *Kelly et al.* (2001, *GRL*), and *Chelton et al.* (2004, *Science*) showed that scatterometer winds were relative to surface currents.
  - *Bentamy et al.* (2001, *JTech*) indicate there is also a dependence on wave characteristics.
  - *Bourassa* (2006, *WIT Press*) showed that wave dependency can be parameterized as a change in $\mathbf{U}_{sfc}$.

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

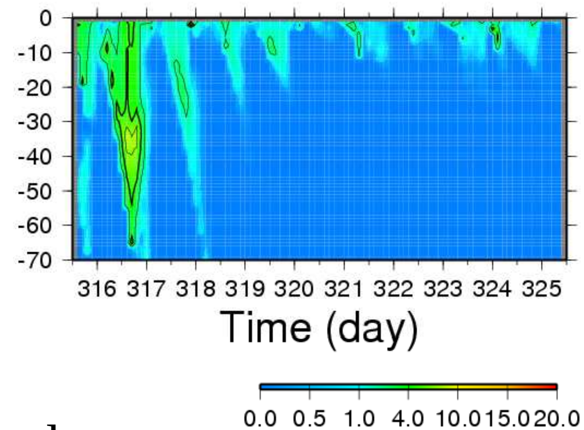


# Ocean's TKE Based on Observed Surface Fluxes

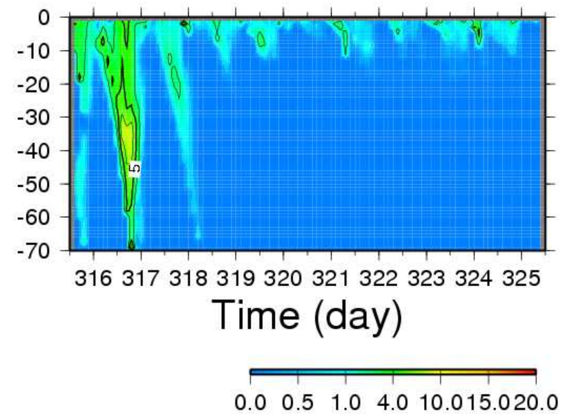
Eddy Correlation




Inertial Dissipation




Bulk Method




Calculations by Derrick Weitlich

Clayson & Kantha model