Related Improvements in Surface Turbulent Heat Fluxes – A DFS Application

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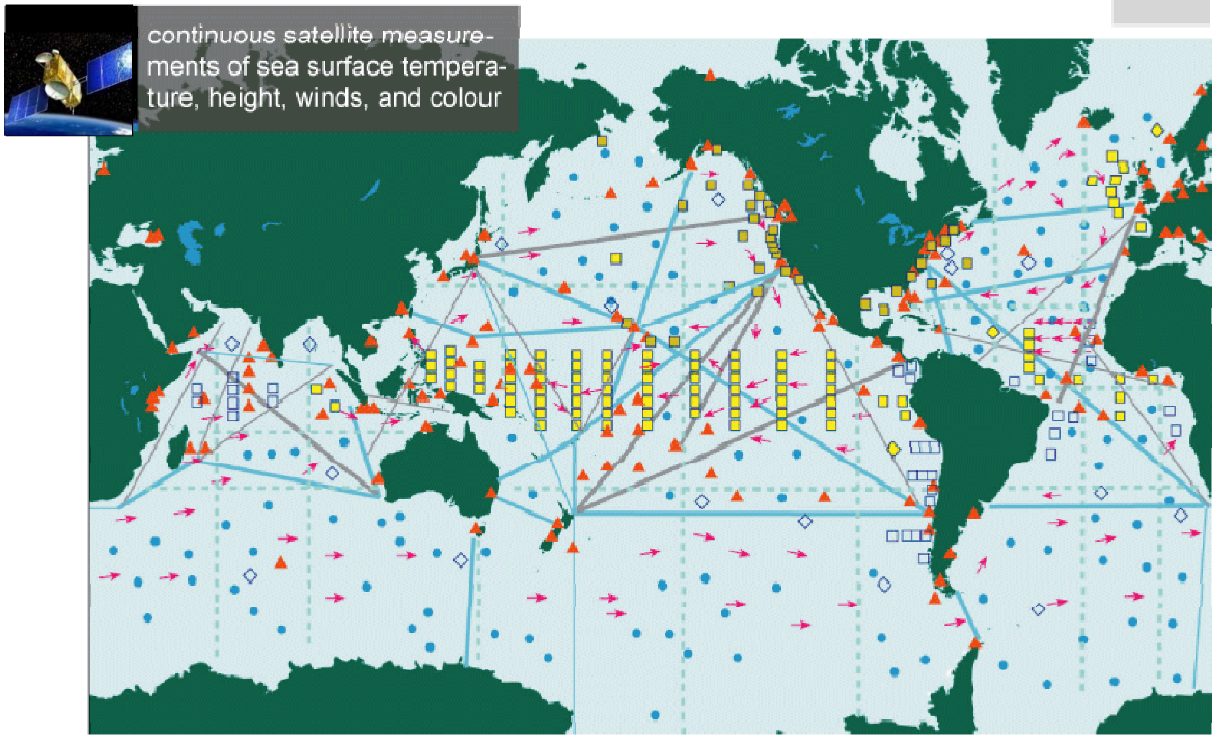
•Initial Global Ocean Observing System for Climate

Status against the GCOS Implementation Plan and JCOMM targets

•Total *in situ* networks **•62%** •January 2010



•100% **Surface measurements** from volunteer ships (VOSclim)

200 ships in pilot project

•100% Global **drifting surface buoy** array

5° resolution array: 1250 floats

•59% **Tide gauge** network (GCOS subset of GLOSS core network)

170 real-time reporting gauges

•80% **XBT** sub-surface temperature section network

51 lines occupied

•100% **Profiling float** network (Argo)

3° resolution array: 3000 floats

•62% **Repeat hydrography and carbon inventory**

Full ocean survey in 10 years

Reference time series •48%

58 sites

•34% Global **reference mooring** network

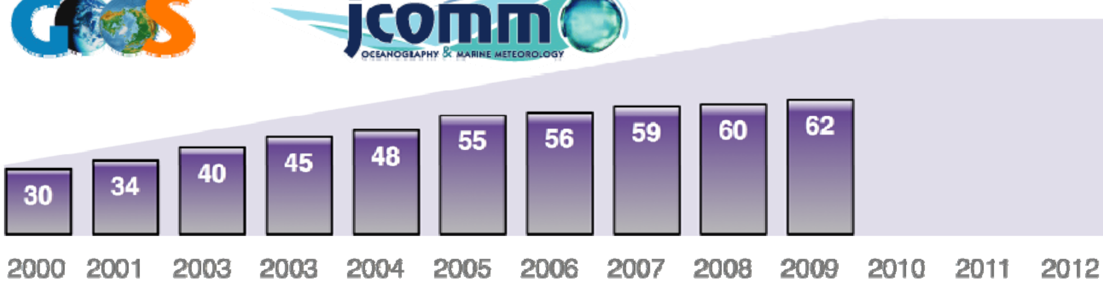
29 moorings planned

•73% Global **tropical moored buoy** network

119 moorings planned

GCOS GOOS jcomm

•System % complete

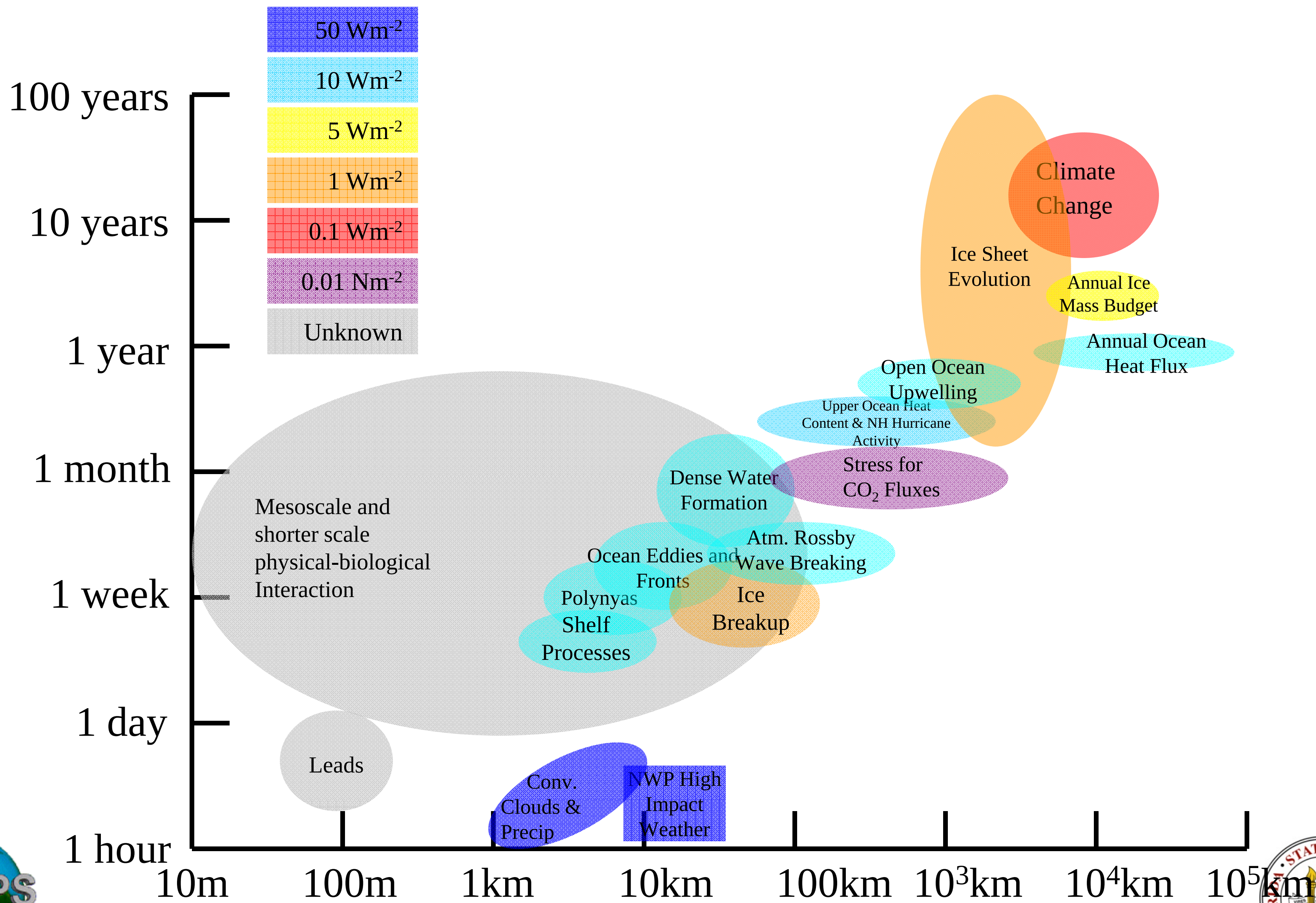


•Original goal: 100% implementation in 2010

Motivation

- Surface turbulent fluxes from space will have much better spatial sampling that the in situ observing system
  - Better temporal sampling over most of the global oceans
- Mid-level (85kPa to 70kPa) water vapor plays an important role in hurricane and mid-latitude storm evolution
  - In many cases, surface fluxes are non-negligible, but
  - Surface fluxes are often more important for the conditioning of the environment about the storm
- Surface vector winds (or stress) and air/sea temperature differences are important players in getting the moisture out of the boundary-layer and into the lower portion of the free atmosphere.
- I will show how surface turbulent fluxes of energy (sensible and latent heat) and moisture (evaporation) can be calculated from satellite observations similar to those expected to be on GCOM-W2

Flux Accuracies and Applications



Flux Parameterizations

$$\tau = \rho\, \mathbf{u_*}\, |\mathbf{u_*}| \approx \rho\, C_D (\mathbf{U_{10}} - \mathbf{U_s})\, |(\mathbf{U_{10}} - \mathbf{U_s})| \quad \text{Stress}$$

$$H = -\rho\, C_p\, \theta_*\, |\mathbf{u_*}| \approx \rho\, C_p\, C_H (T_s - T_{10})\, |(\mathbf{U_{10}} - \mathbf{U_s})| \quad \text{Sensible Heat Flux}$$

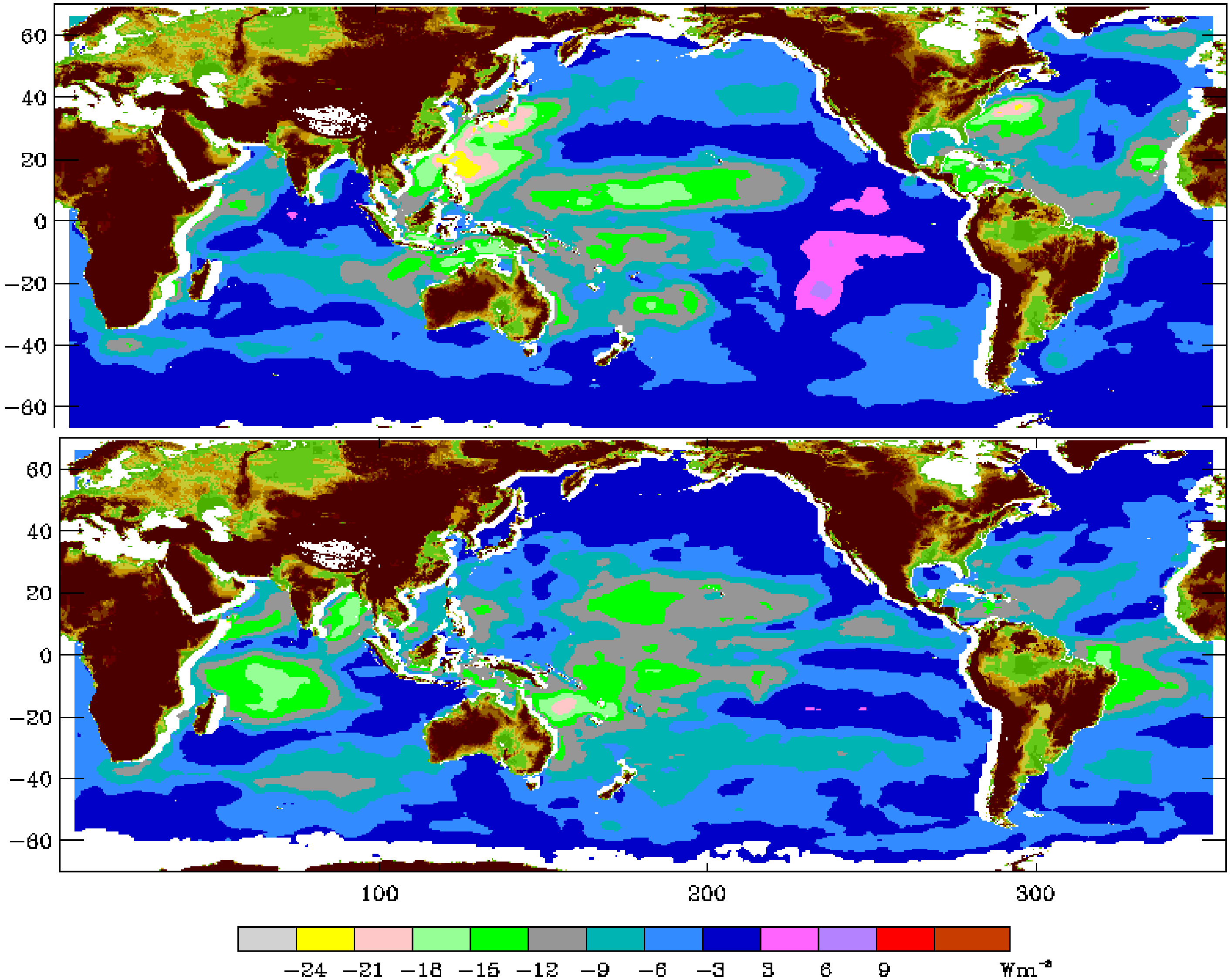
$$E = -\rho\, q_*\, |\mathbf{u_*}| \approx \rho\, C_E (q_s - q_{10})\, |(\mathbf{U_{10}} - \mathbf{U_s})| \quad \text{Evaporation}$$

$$Q = -\rho\, L_v\, q_*\, |\mathbf{u_*}| \approx L_v\, E \quad \text{Latent Heat Flux}$$

ρ	air density	$\mathbf{u_*}$	friction velocity
C_D	drag coefficient	θ_*	temperature scale factor
C_H	heat transfer coefficient		(analogous to friction velocity)
C_E	moisture transfer coefficient	q_*	moisture scale factor
U_s	mean surface motion	T	mean air temperature
U_{10}	Wind speed at height of 10m	q	mean specific humidity
L_v	latent heat of vaporization	C_p	heat capacity

Traditionally, scatterometer winds are tuned to equivalent neutral winds (Ross et al. 1985), which are directly translatable to friction velocity – not stress

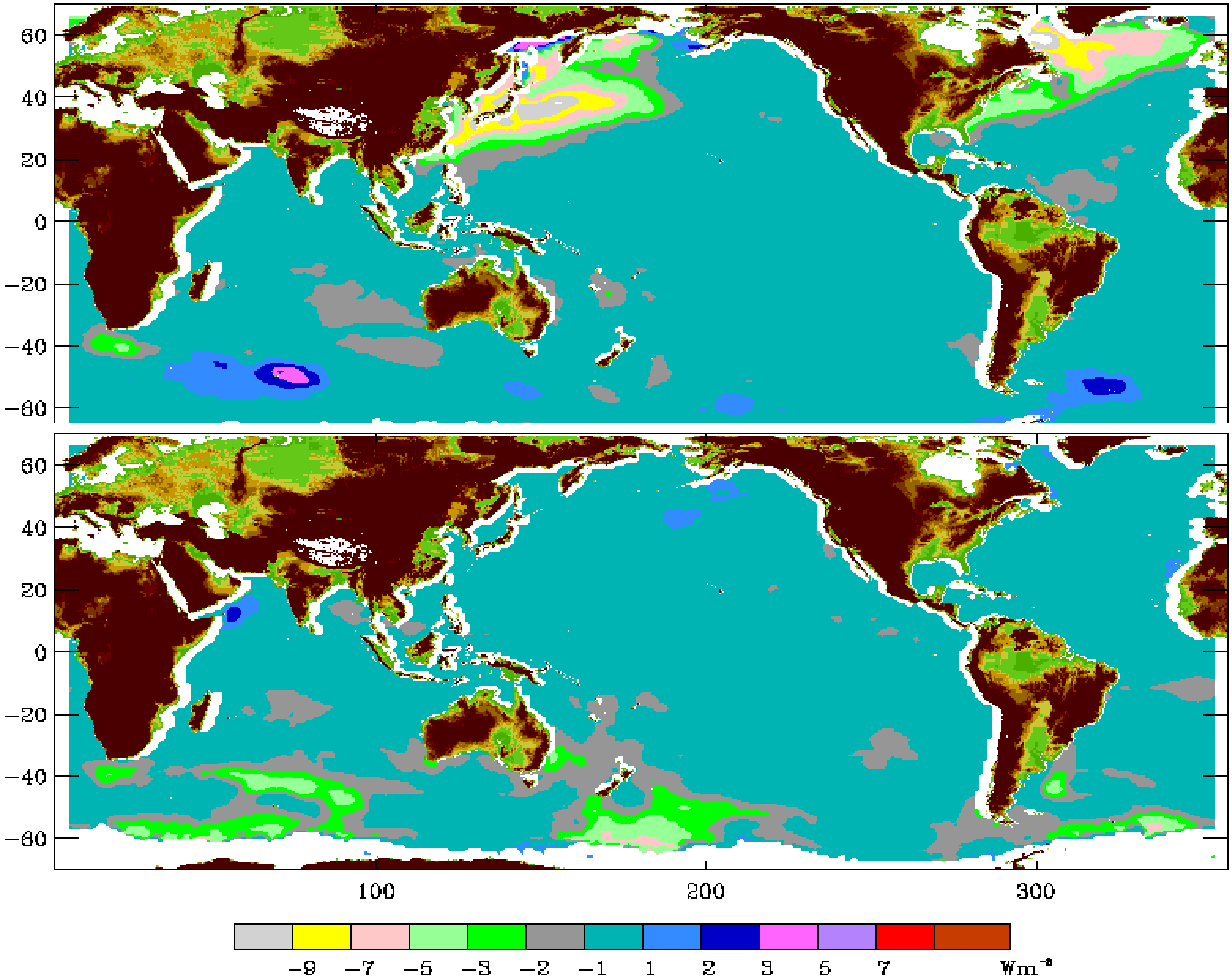
Monthly LHF Differences Due to Wave-Induced Shear



February
1999

August
1999

Monthly SHF Differences Due to Wave-Induced Shear



February 2000

August 1999

Flux Parameterizations – Further Complications

$$C_H = c_h\, c_d, \quad \text{where } c_d^{1/2} = C_D$$

$$C_E = c_e\, c_d$$

- All wave related variability can be included in C_D and $\mathbf{U_s}$
- c_h and c_e depend only on boundary-layer stratification

$$\boldsymbol{\tau} = \rho\, \mathbf{u}_* |\mathbf{u}_*| \approx \rho\, C_{DN} (\mathbf{U_{10EN}} - \mathbf{U_s})\, |(\mathbf{U_{10EN}} - \mathbf{U_s})| \qquad \text{Stress}$$

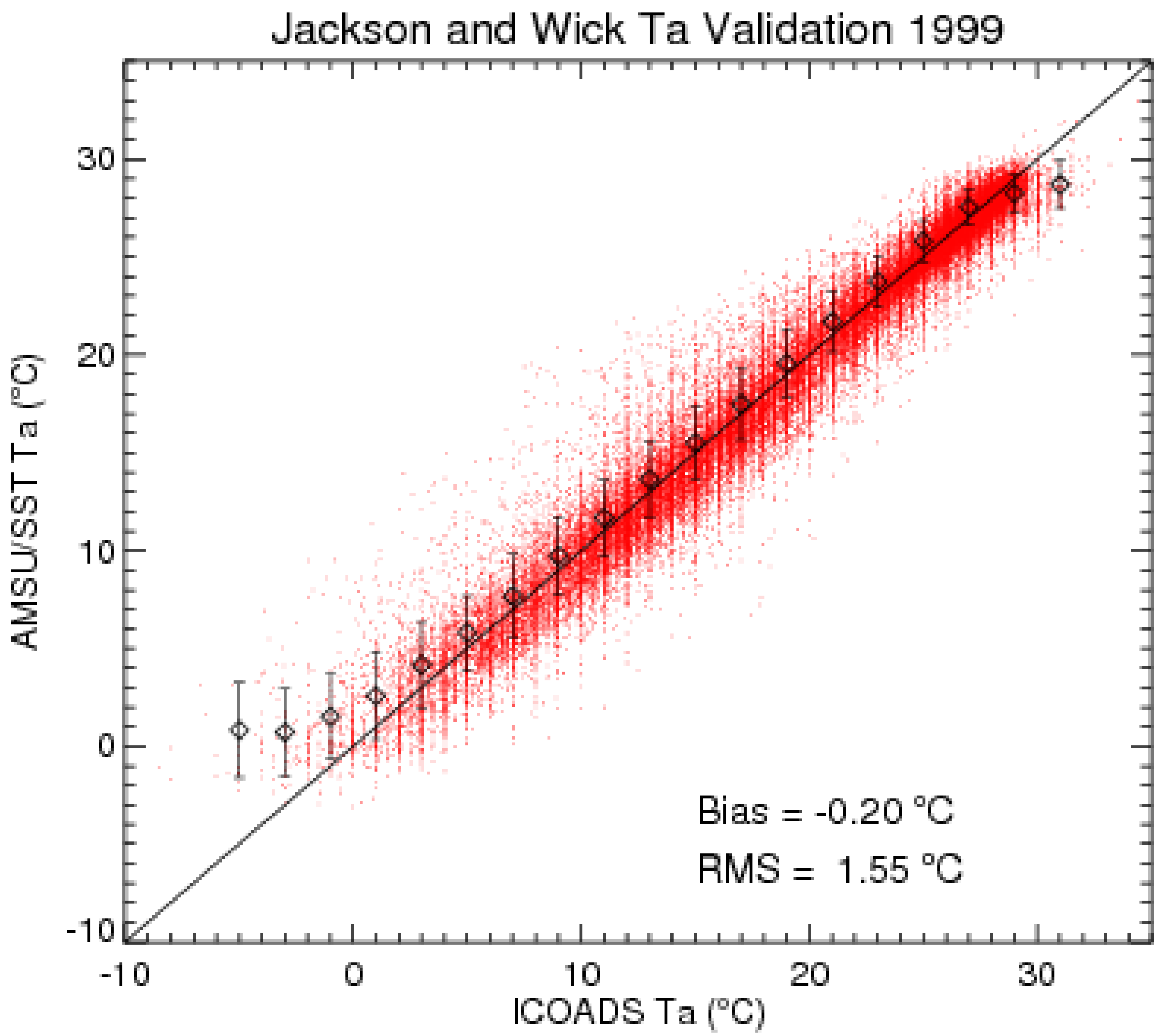
$$H = -\rho\, C_p\, \theta_* |\mathbf{u}_*| \approx \rho\, C_p \boxed{c_h} c_d \boxed{(T_{10} - T_s)}\, |(\mathbf{U_{10}} - \mathbf{U_s})| \qquad \text{Sensible}$$

$$E = -\rho\, q_* |\mathbf{u}_*| \approx \rho \boxed{c_e} c_d \boxed{(q_{10} - q_s)}\, |(\mathbf{U_{10}} - \mathbf{U_s})| \qquad \text{Evaporation}$$

$$Q = -\rho\, L_v\, q_* |\mathbf{u}_*| \approx L_v\, E \qquad \text{Latent}$$

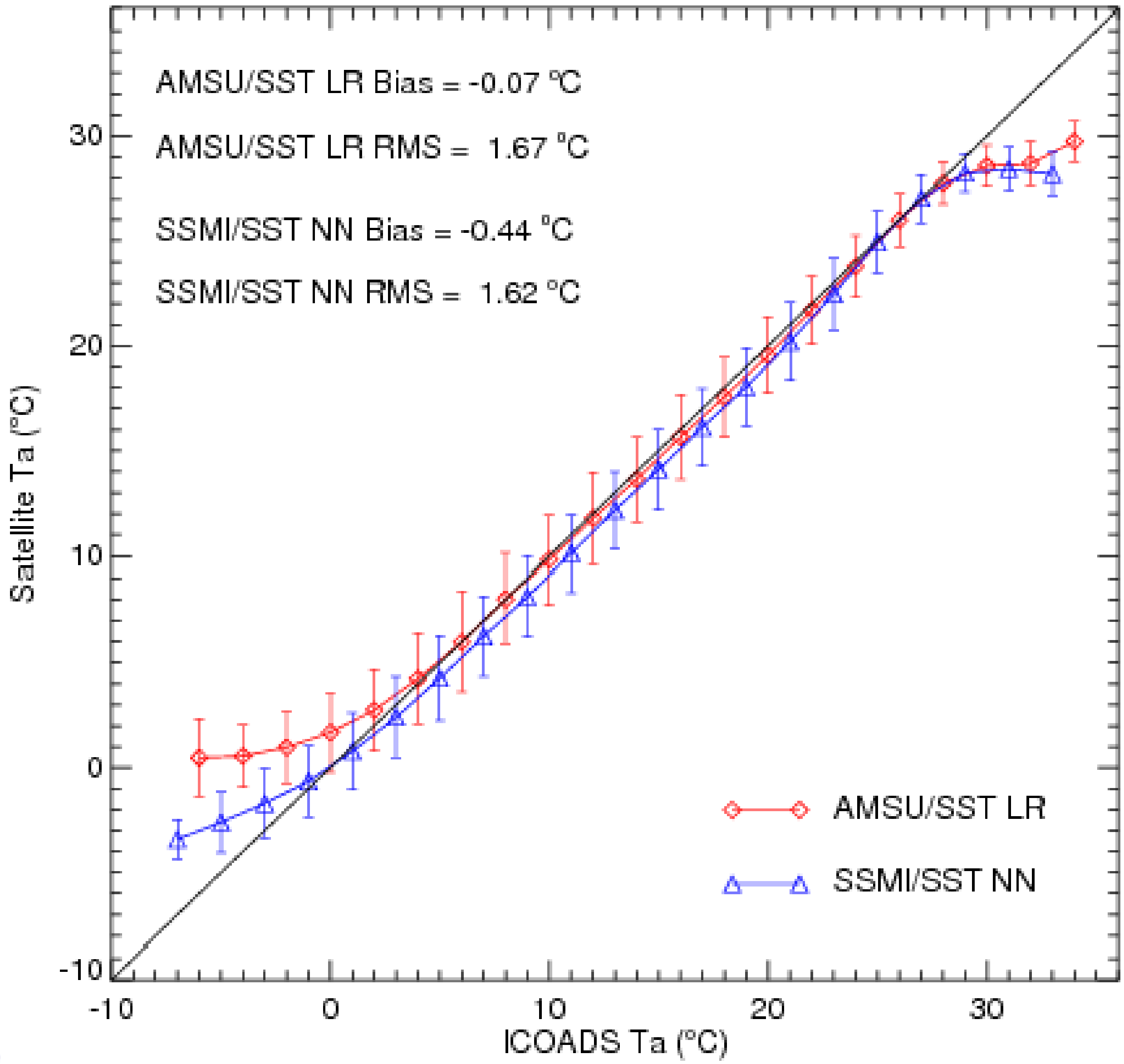
- So we want to be able to accurately estimate
  - $T_{10} - T_s$
  - $q_{10} - q_s$

Example Retrievals of 10m Air Temperature



- Multiple linear Regression technique
- Pretty good for most conditions
- Issues for very low temperature and very high temperatures

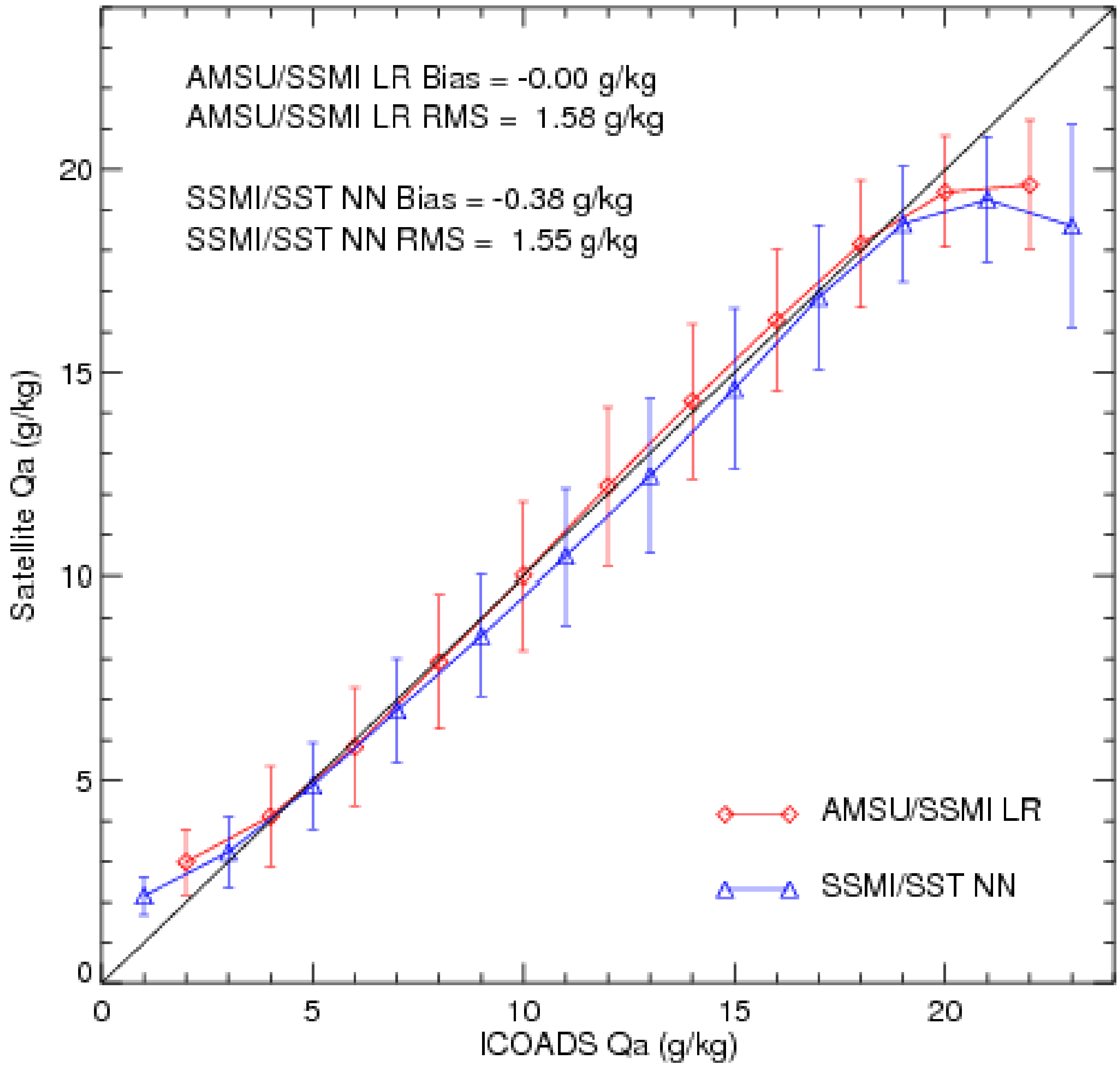
Comparison With The Latest Technique



Jackson and Wick

Roberts et al.

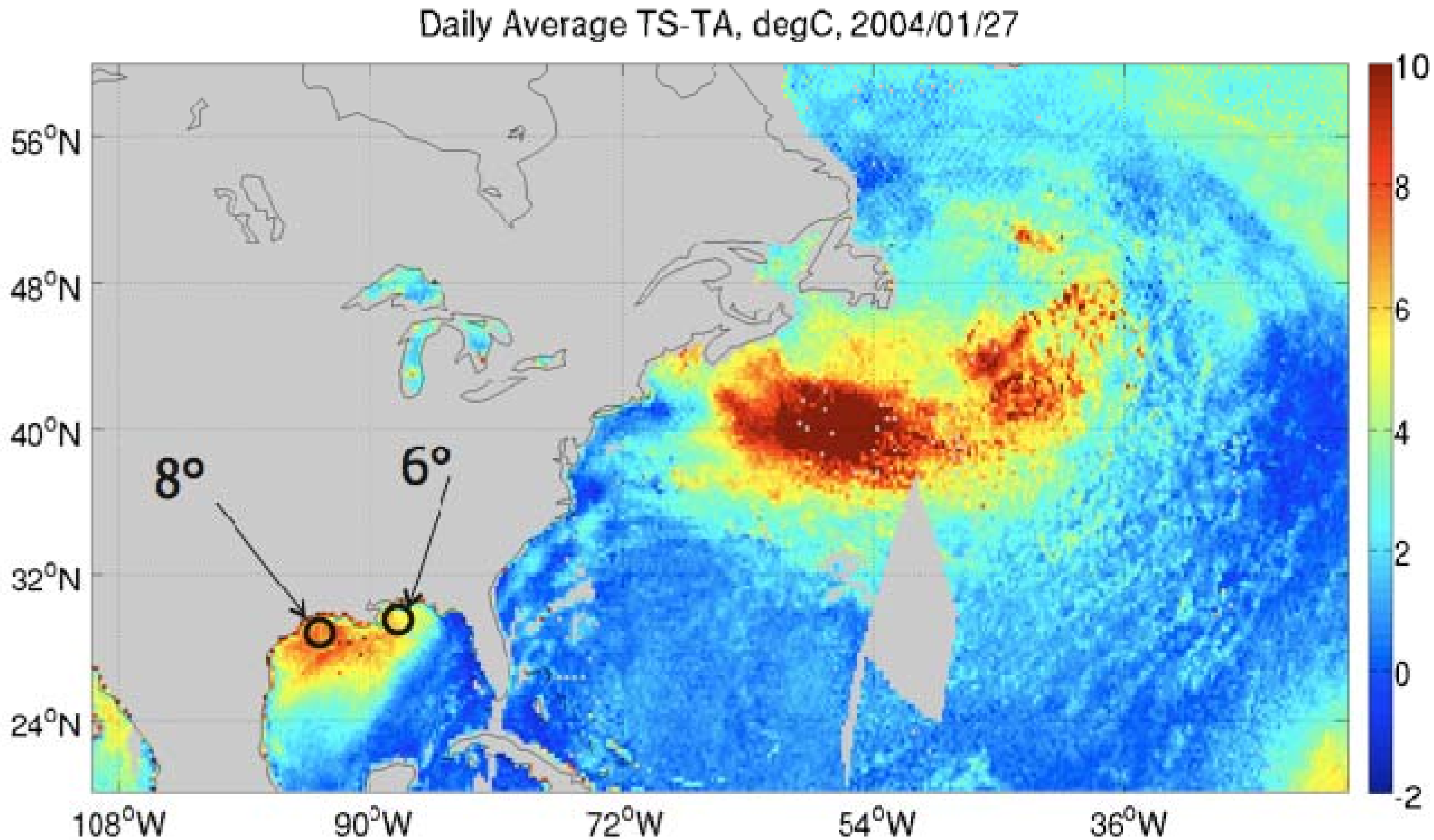
Comparison With The Latest Technique



Jackson and Wick

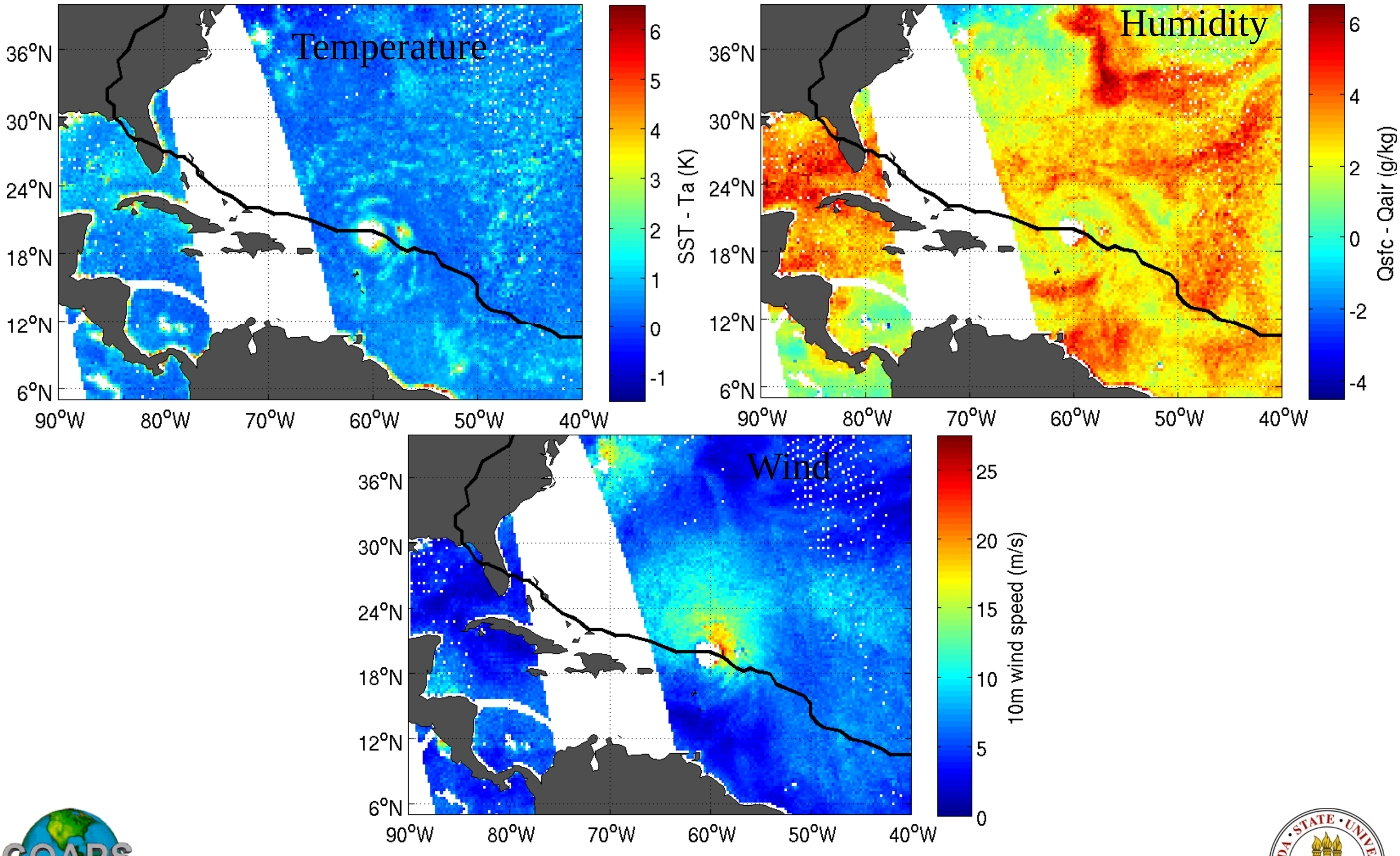
Roberts et al.

Validation of Air/Sea Temperature Differences



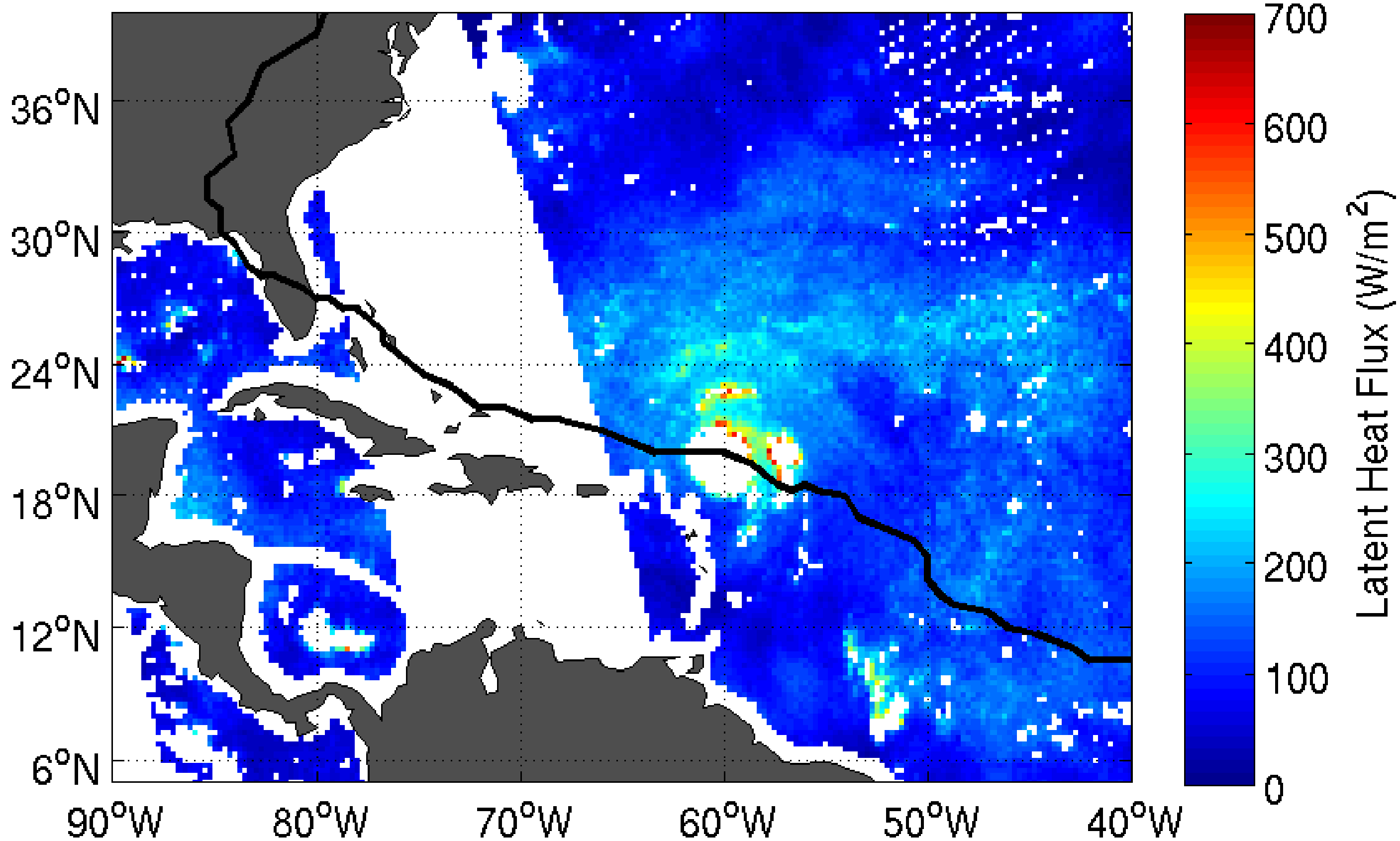
- Roberts et al. (2010) retrieval technique for T_{10} and q_{10}.
- Comparison to buoy observations (circles in the Gulf of Mexico)

Hurricane Francis Air/Sea Differences 30 Aug 2004 21 Z



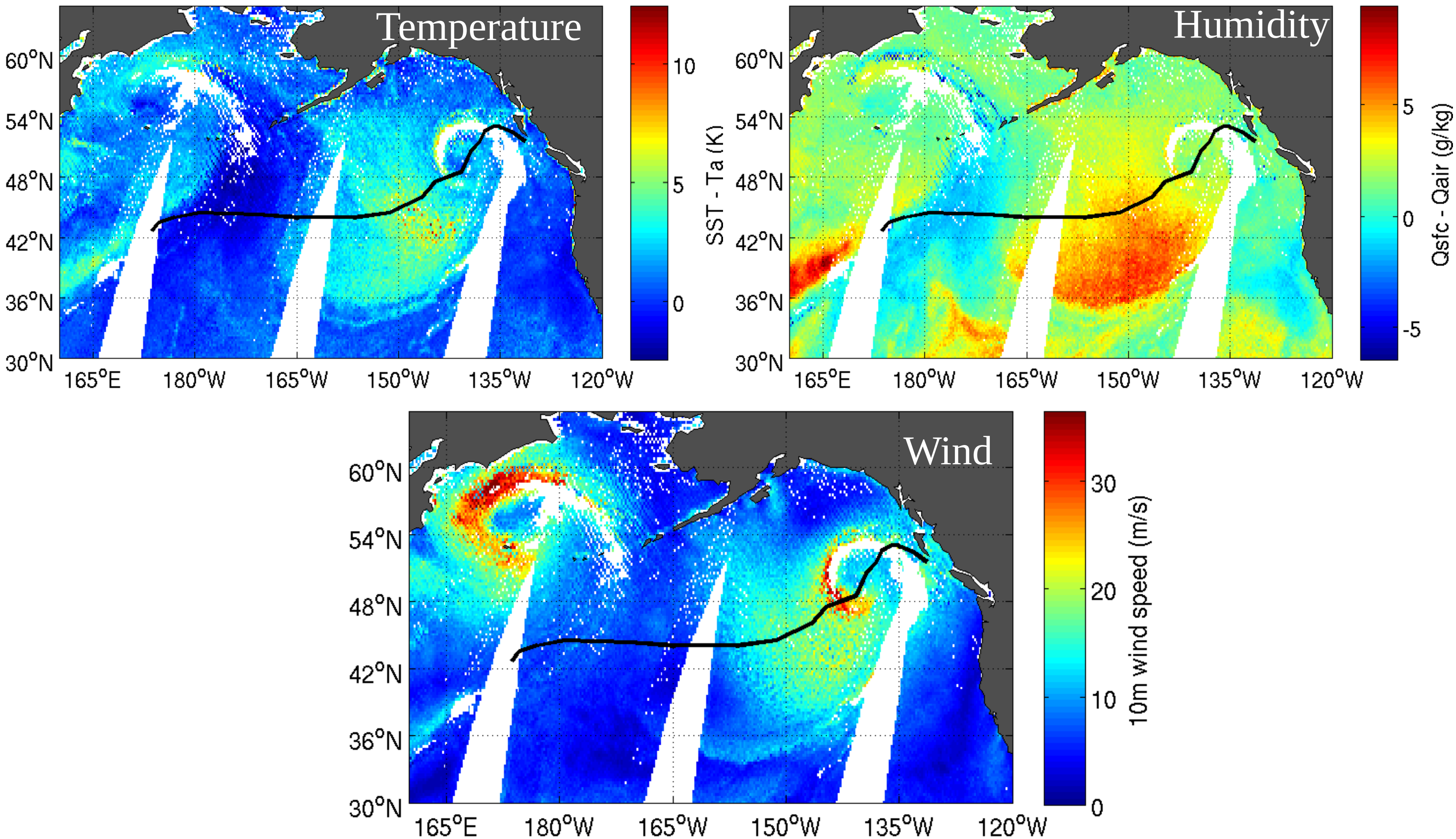
COAPS

Hurricane Francis LHF 30 Aug 2004 21 Z



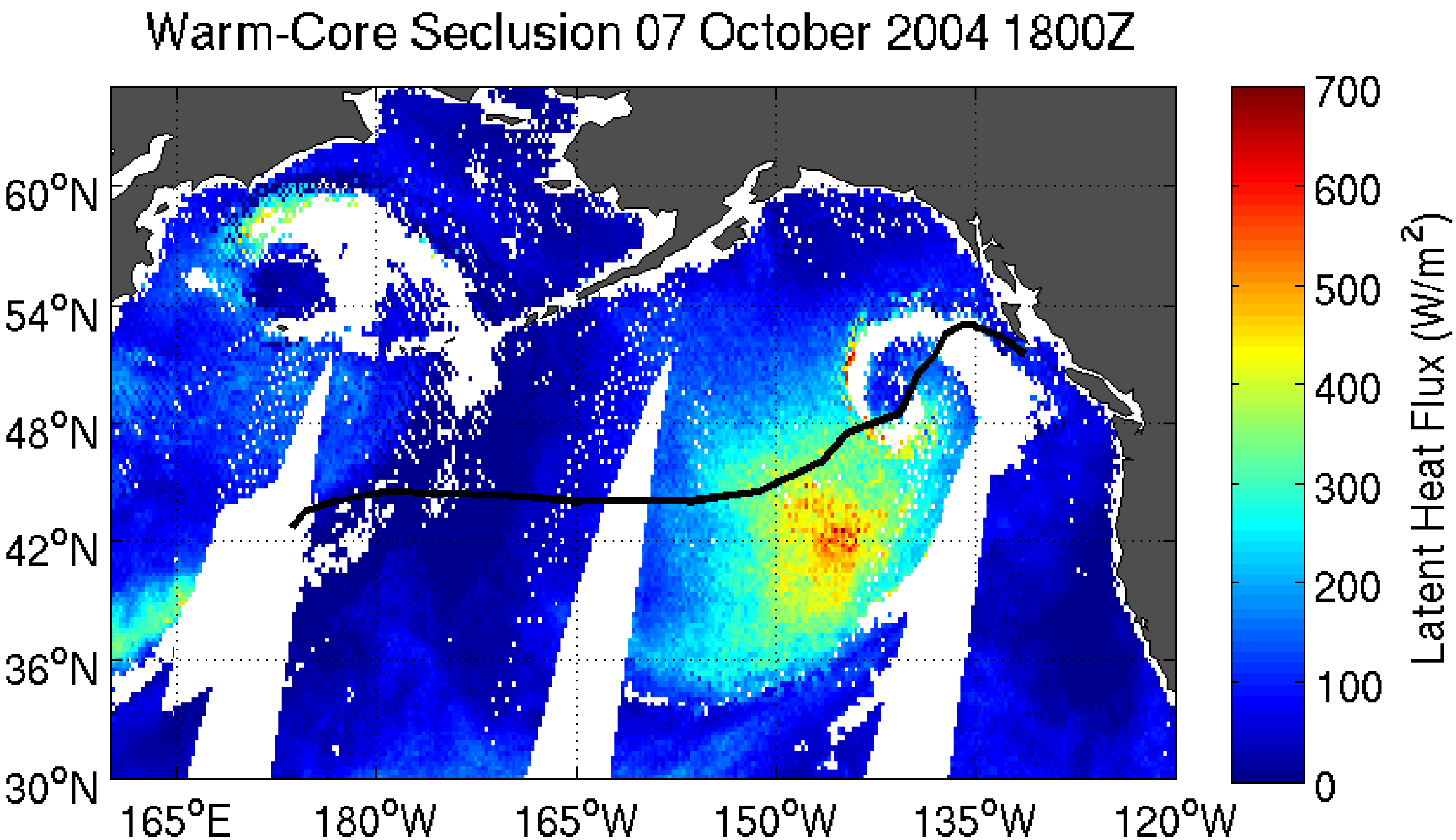
- T_{10} and q_{10} from Roberts et al.
- Wind speed interpolated from RSS

Warm Core Seclusion Air/Sea Differences



Example LHF Retrieval: Warm Core Seclusion

- Black line is the track from Ryan Maue's data set
- Lack of retrieval in areas with too much rain



Conclusions

- Preliminary results are quite impressive
- Concerns
  - Need for more careful calibration & intercalibration
    - Further reduction of biases
      - Non-linear processes converting random errors to biases??
    - Particularly for low temperatures and high winds
  - Sampling – missing some of the really big events
  - Accuracy of winds (or stress) for high wind speeds
  - Quality assessment flags
- Preliminary results are quite impressive
- Retrieval of stress from an active instrument should improve retrievals of temperature and humidity.
- High resolution surface winds should be helpful in modeling exchange between the boundary-layer and the lower free atmosphere

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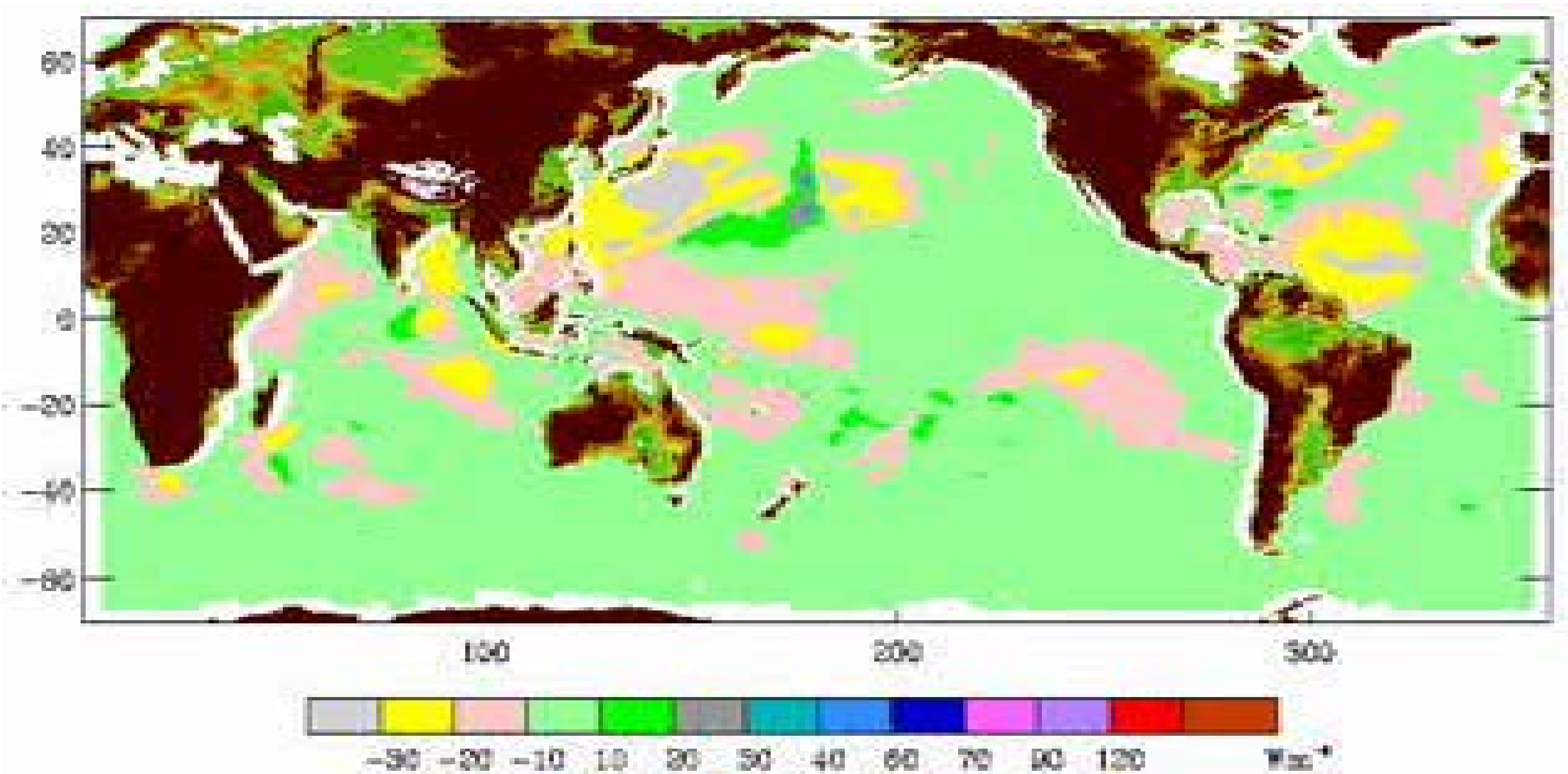
LHF Differences Due to Wave-Induced Shear



- Animation of 6 hourly change in fluxes:
  - Case with waves minus case with $U_{orb} = 0$
  - 6 hour time step

Submonthly Contribution to Average LHF

- L is determined through a bulk formula.

  $$L \approx \boxed{\bar{\rho} L_v C_E \bar{U} (\bar{q}_{sfc} - \bar{q})}$$

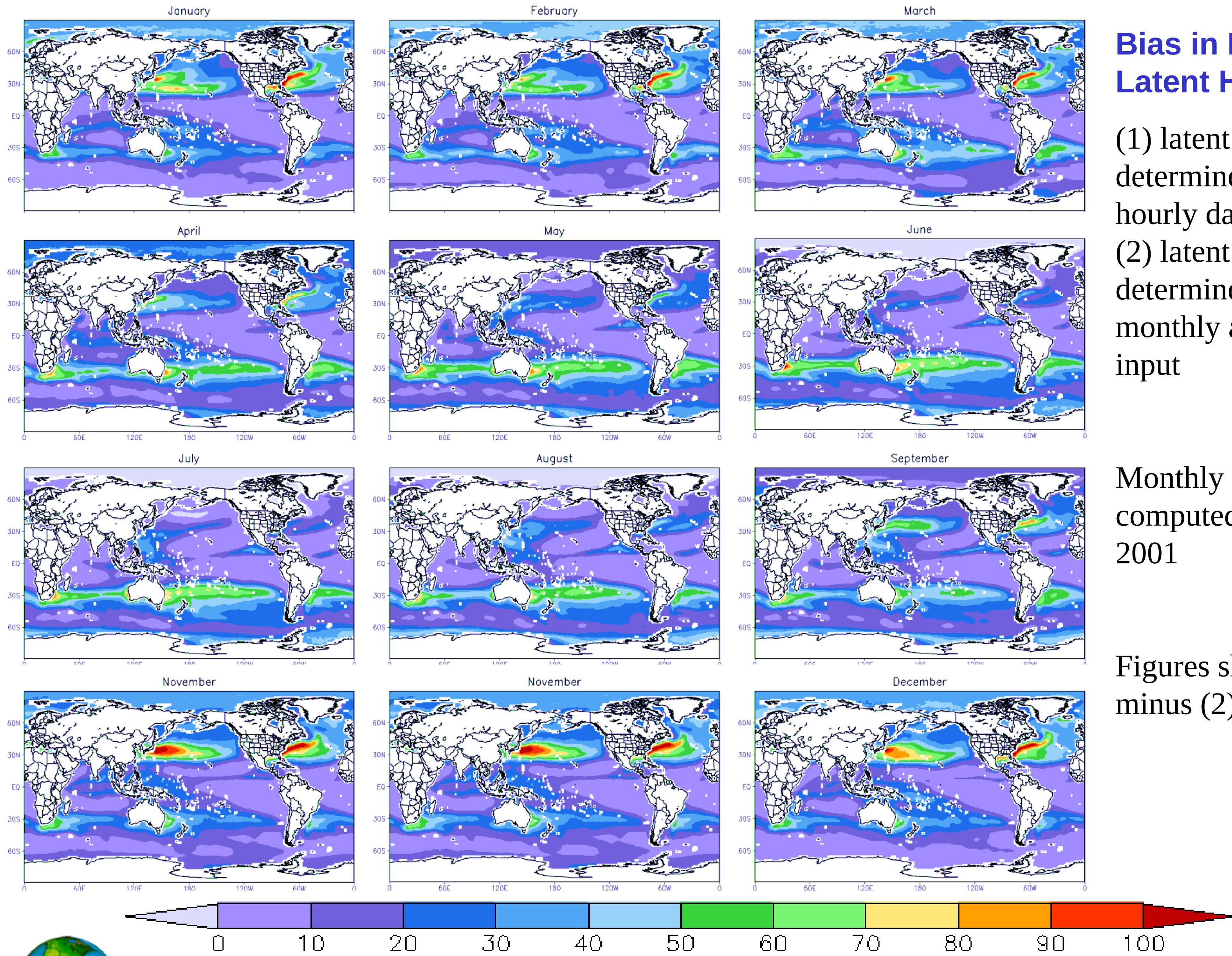
  - Where the overbar indicates a monthly average
  - There is considerable controversy about that accuracy of this averaging
- A more accurate approach is to calculate the flux at each time step then average these fluxes: $L \approx \overline{\rho L_v C_E U (q_{sfc} - q)}$
- If we apply Reynolds averaging this equation becomes

  $$L = \bar{\rho} L_v \overline{\left(C_E + C'_E\right)\left(U + U'\right)(q_{sfc} - q'_{sfc} - q + q')}$$

- If we assume density variations are not important, this equation becomes

  $$L = \boxed{\bar{\rho} L_v \overline{C_E}\, \bar{U} (\bar{q}_{sfc} - \bar{q})} + \bar{\rho} L_v \left(\overline{C_E}\; \overline{U'(q' - q'_{sfc})} + \bar{U}\; \overline{C'_E (q' - q'_{sfc})} + \overline{(q' - q'_{sfc})}\; \overline{C'_E U'} \right)$$

- Following examples of monthly biases are based on ECMWF reanalysis.
  - Plots bias from using monthly averaged flux input data
  - They do not include wave information



Bias in Latent Heat Flux (Wm^{-2})

Thanks to Paul Hughes and Ryan Maue

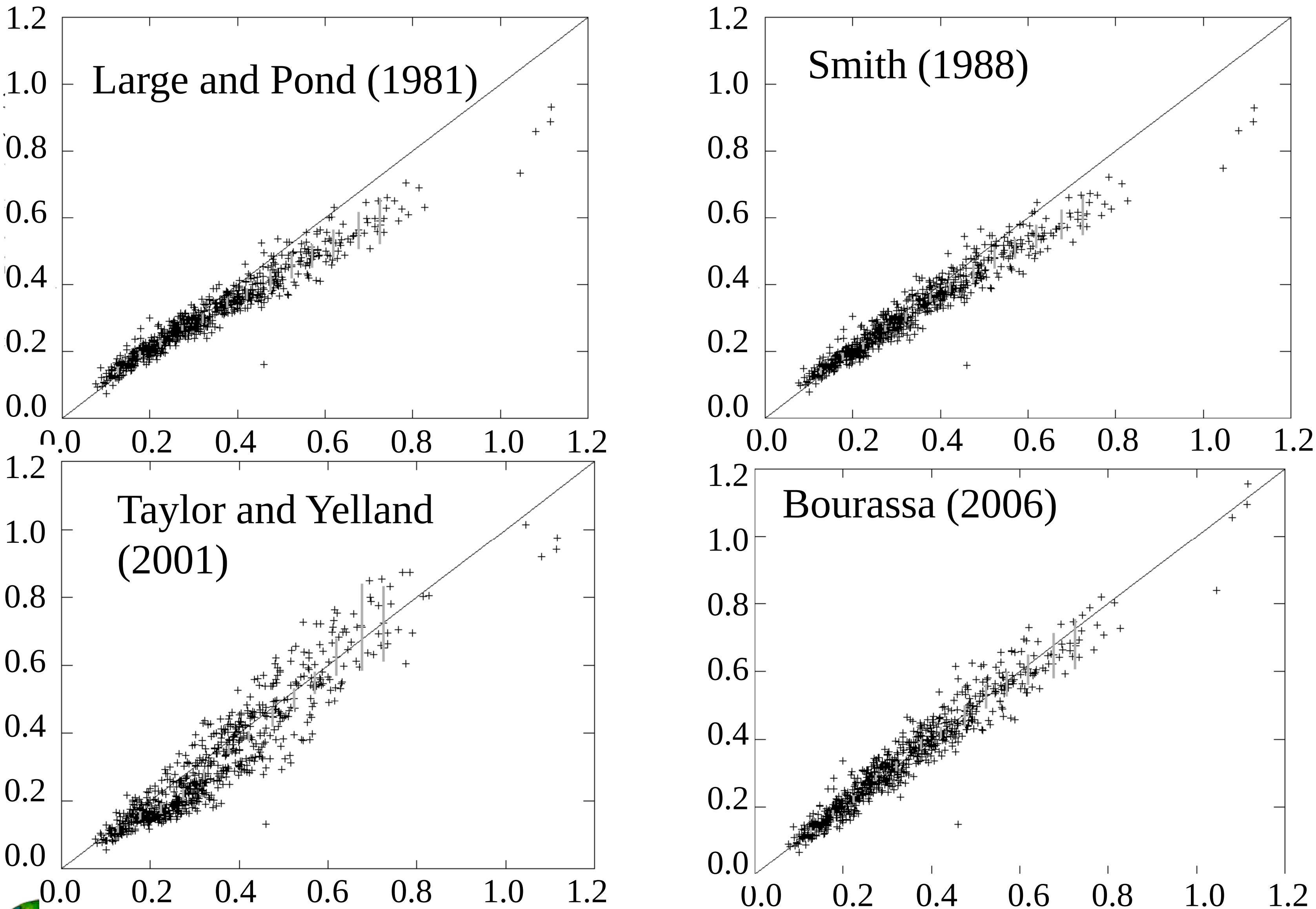
Bias in Monthly Latent Heat Flux

(1) latent heat flux determined from 6 hourly data and
(2) latent heat flux determined from monthly averaged input

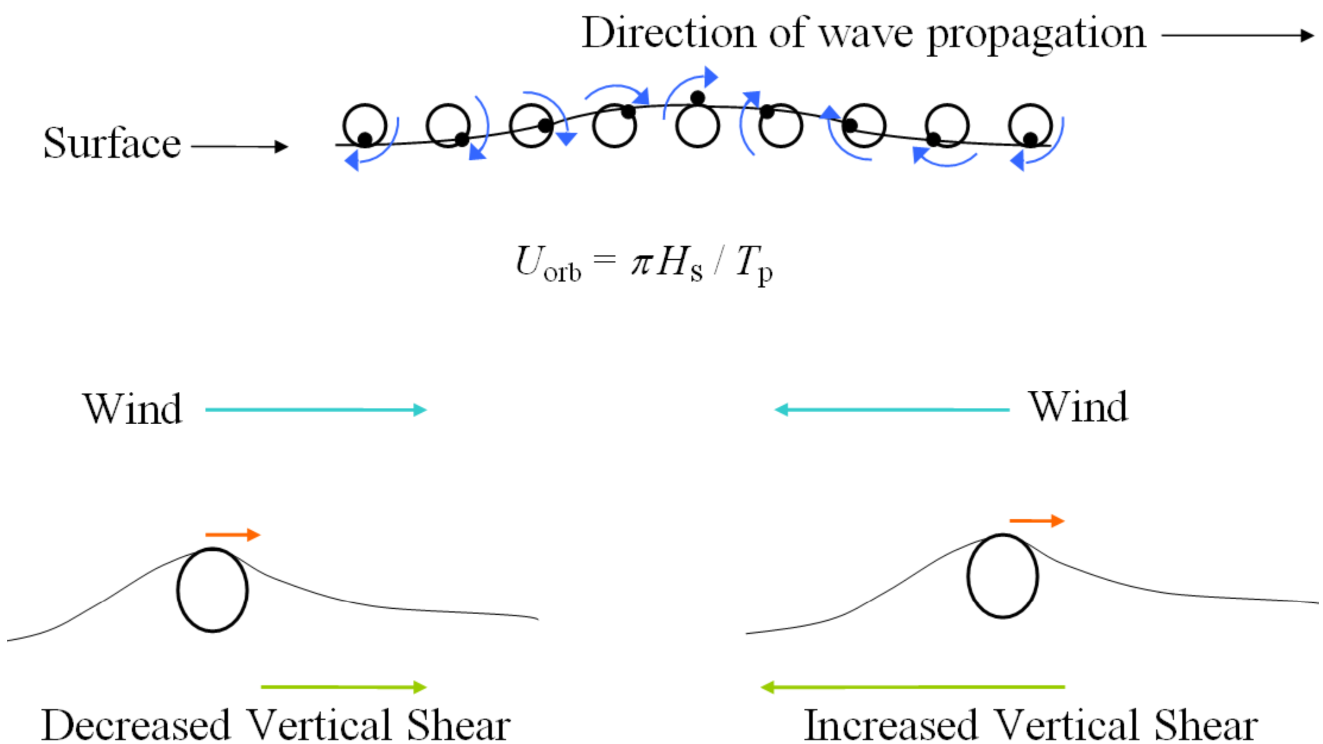
Monthly climatology computed for 1978-2001

Figures show: (1) minus (2)

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

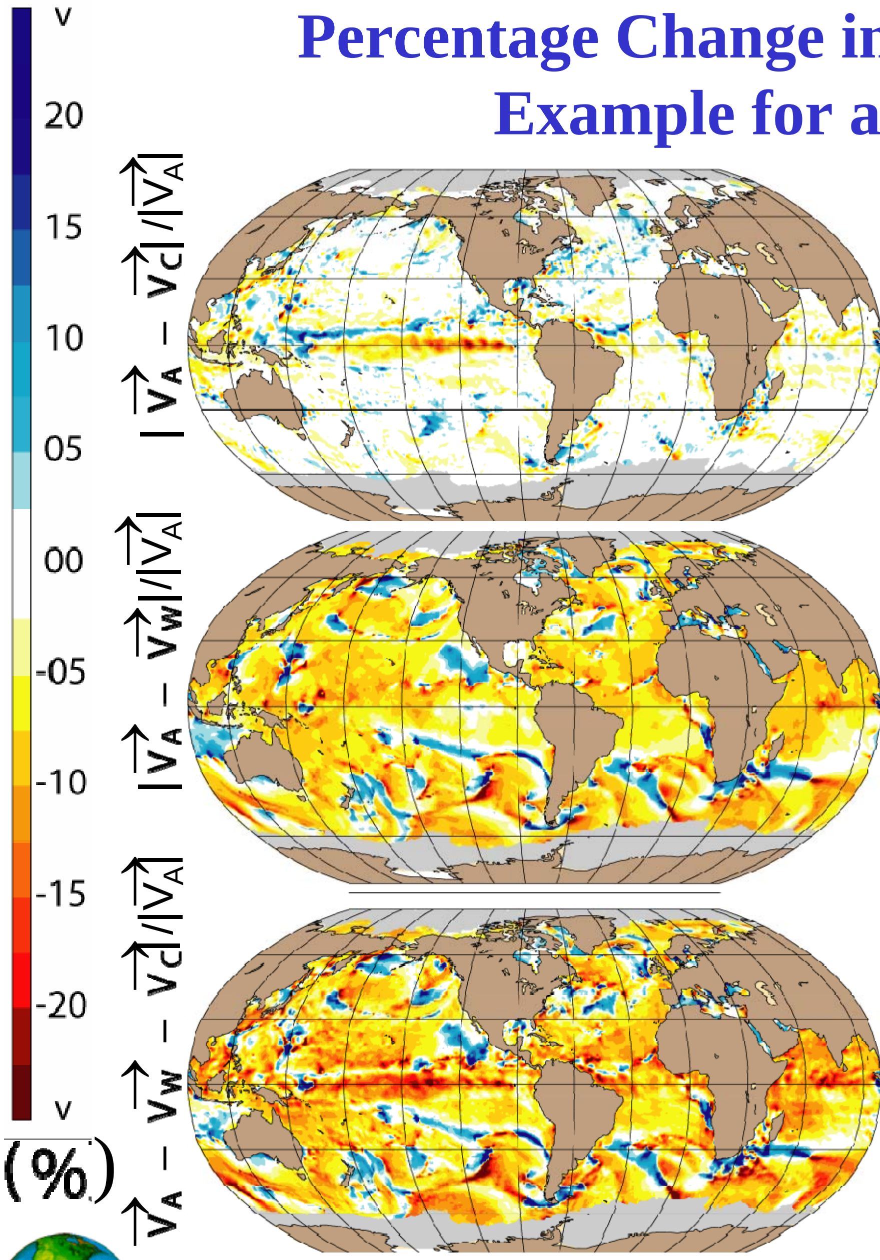


Wave Motions Modify U_{sfc} and Hence change the Wind Shear



- For wind driven waves and common wave ages
  - this is qualitatively similar to the HEXOS results, and
  - qualtitatively similar to Taylor and Yelland (2001)

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



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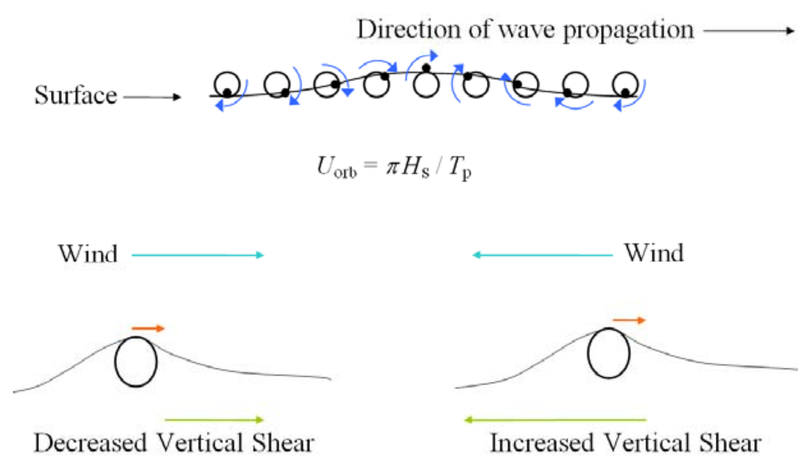
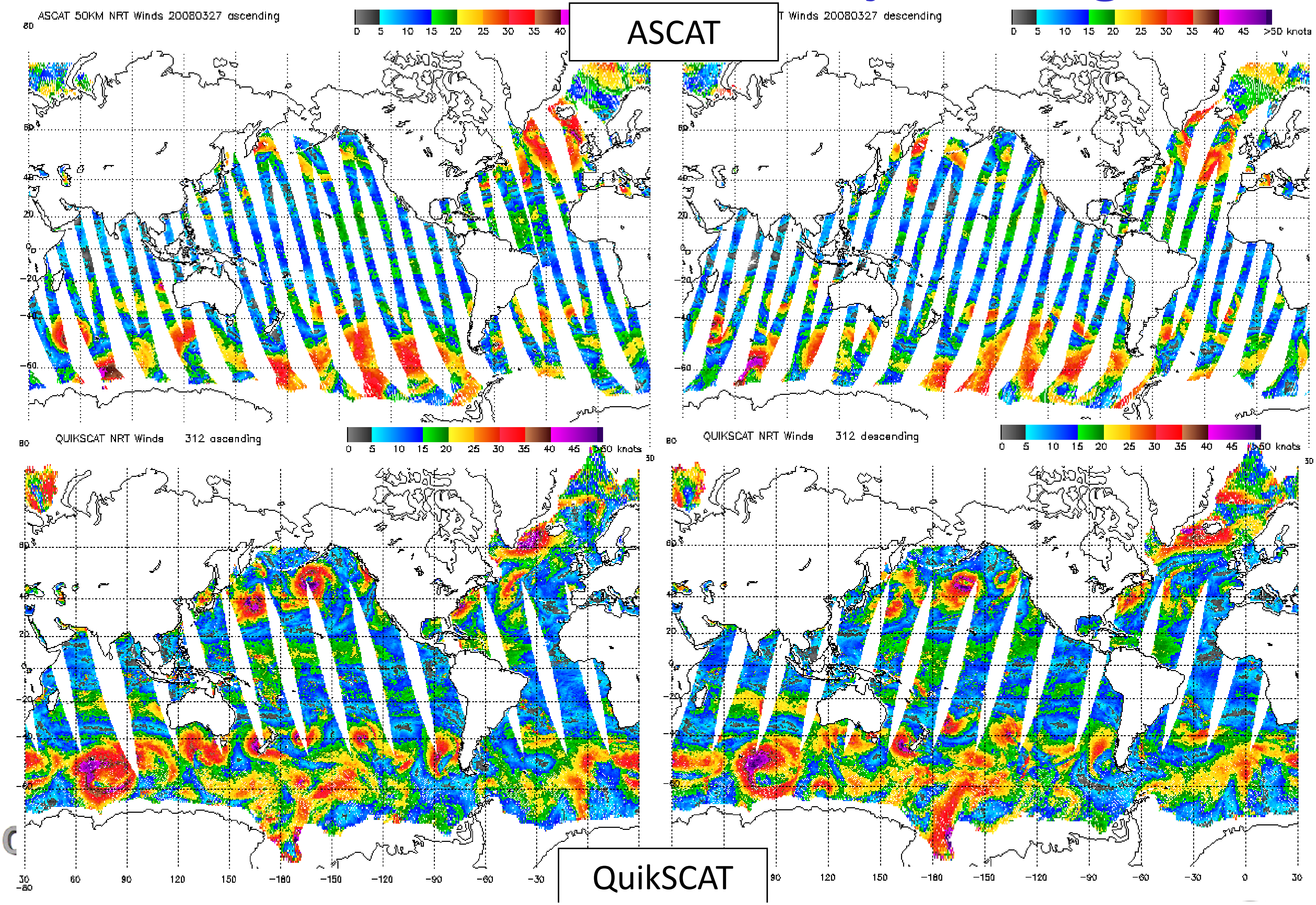
- The percentage change in surface relative winds is roughly proportional to the change in energy fluxes.
- The percentage change squared is roughly proportional to changes in stress.
- The drag coefficient also changes by about half this percentage.



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

ASCAT vs. QuikSCAT Daily Coverage



To What Does a Scatterometer Respond?

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

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

- Does a scatterometer respond to $\mathbf{U}_{10}$ or to $\mathbf{U}_{10} - \mathbf{U}_{sfc}$ or stress?
  - *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.
  - The drag coefficient can be modeled as depending on waves
  - *Bourassa* (2006, *WIT Press*) showed that wave dependency can be parameterized as a change in $\mathbf{U}_{sfc}$. This greatly simplifies the drag coefficient
    - Considering waves reduces the residual between scatterometer equivalent neutral winds and equivalent neutral winds calculated from buoy observations
- A $\rho^{-0.5}$ dependency is found in the residual between scatterometer equivalent neutral winds and equivalent neutral winds calculated from buoy observations