An Example of Wind Observing System Change Influencing the Climate Record

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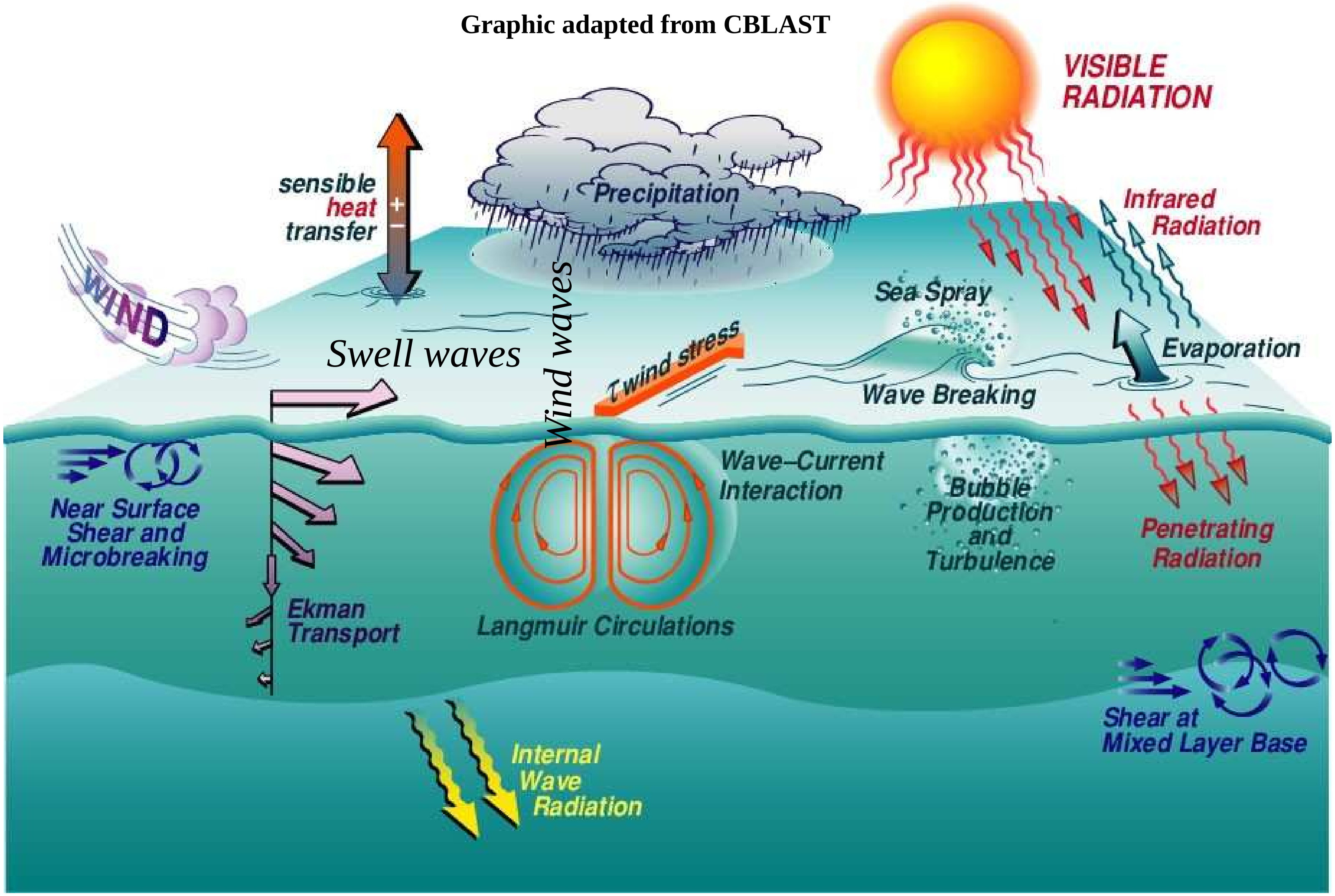
Goal & Issues

- Interest: How big are biases in fluxes associated with common assumptions?
  - On what time scales will these biases seriously alter assumptions
- Goal: Estimate the change in Pacific Ocean latent heat fluxes (LHF) due to the change from ship winds to satellite winds – assuming they are treated in the same manner
  - For NWP assimilation, both types of winds are treated as earth relative
  - I will focus on the difference due to waves (swell and wind waves).
- Goal: Assess the influence of synoptic or finer scale variability on LHF
  - That is, differences from fluxes based on monthly averaged inputs
  - Wave-related variability is ignored in this part of the study

Many Air/Sea Interaction Processes

- Most are strongly influenced by stress -

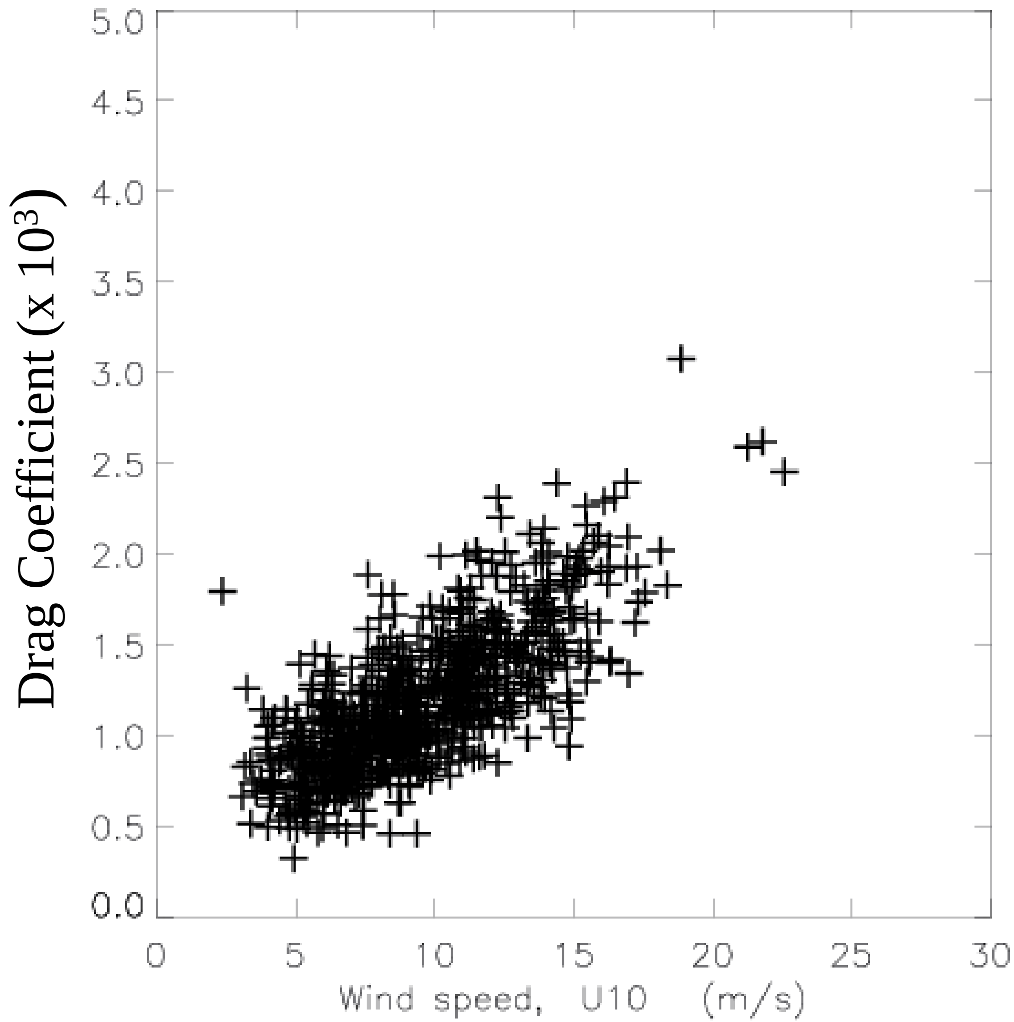
Graphic adapted from CBLAST



Caveats

- Wave portion of analysis is based on theory – observations and not sufficient
- The one thing flux modeler agree on is that they disagree on how to model wave influence
  - There is a wide range of proposed mechanisms for how waves modify surface fluxes.
- Flux models used to study waves
  - Model used herein is Bourassa (2006):
  - Bourassa, M. A., 2006, Satellite-based observations of surface turbulent stress during severe weather, Atmosphere - Ocean Interactions, Vol. 2., ed., W. Perrie, Wessex Institute of Technology Press, Southampton, UK, 35 – 52 pp.
  - Moisture roughness length based on surface renewal theory: Clayson-Fairall-Curry (1996) model.

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

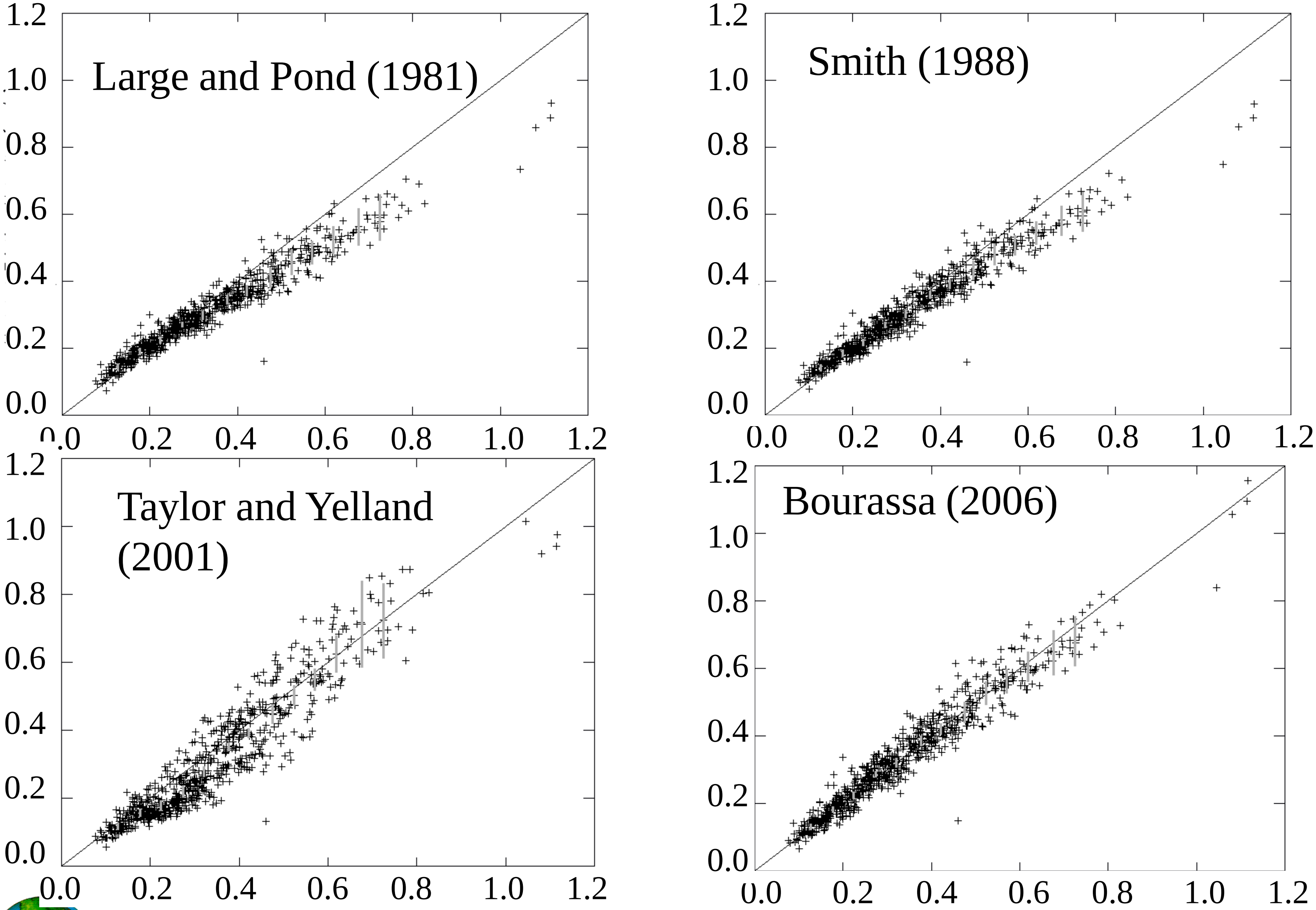
$$\boldsymbol{\tau} = \rho C_D \left|\mathbf{U}_{10}\right| \mathbf{U}_{10} \qquad\qquad L = \rho L_v C_E (q_{10} - q_{sfc}) \left|\mathbf{U}_{10}\right|$$

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

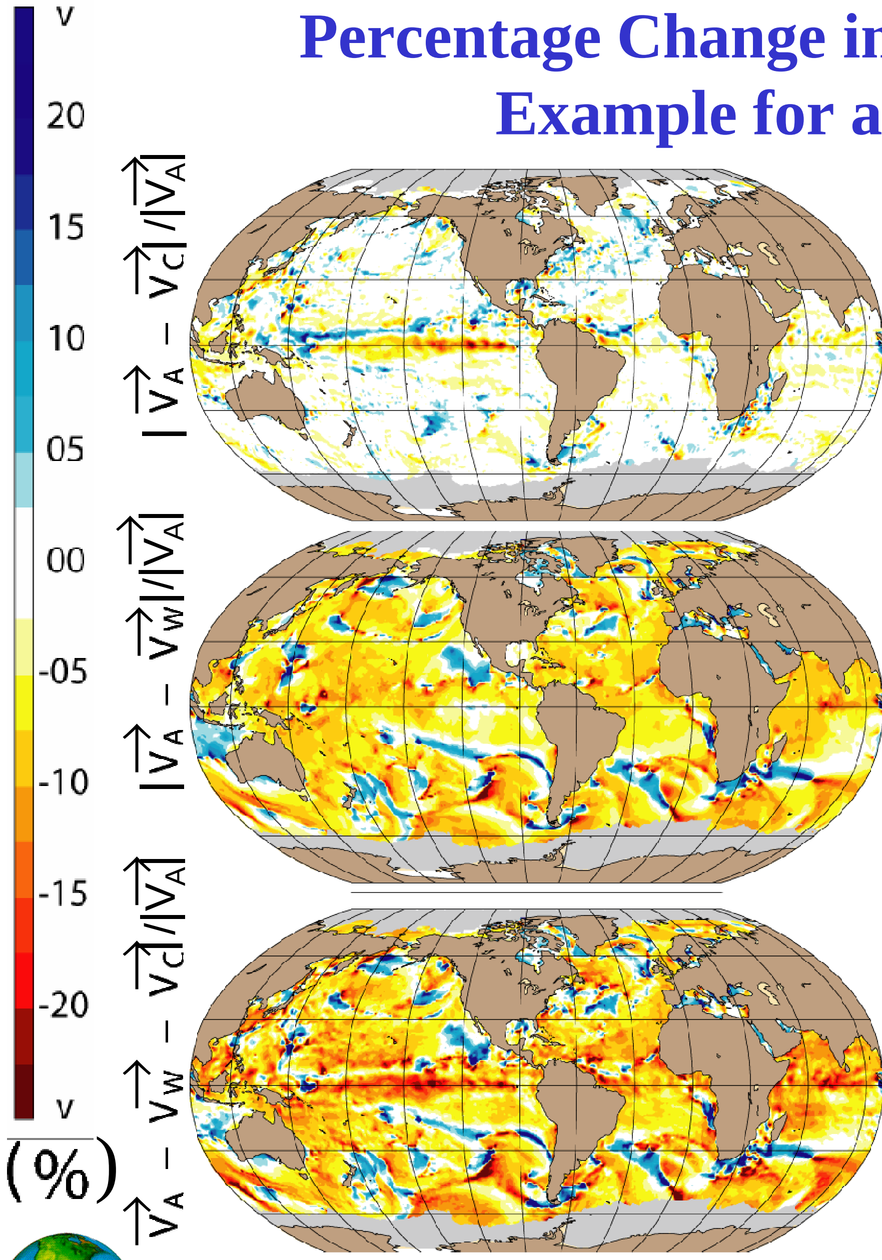
$$\boldsymbol{\tau} = \rho C_D \left|\mathbf{U}_{10} - \mathbf{U}_{sfc}\right| \left(\mathbf{U}_{10} - \mathbf{U}_{sfc}\right) \qquad\qquad L = \rho L_v C_E (q_{10} - q_{sfc}) \left|\mathbf{U}_{10} - \mathbf{U}_{sfc}\right|$$

- 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 $\mathbf{U}_{sfc}$.

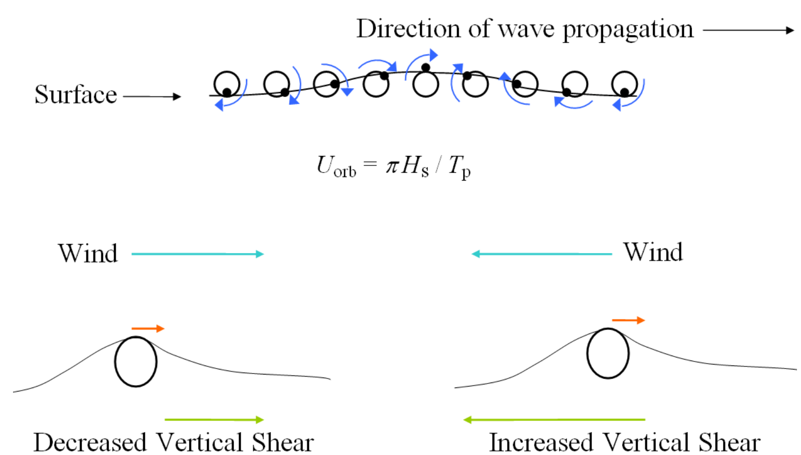
Observed (x) and Modeled (y) Friction Velocity (u_*)



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

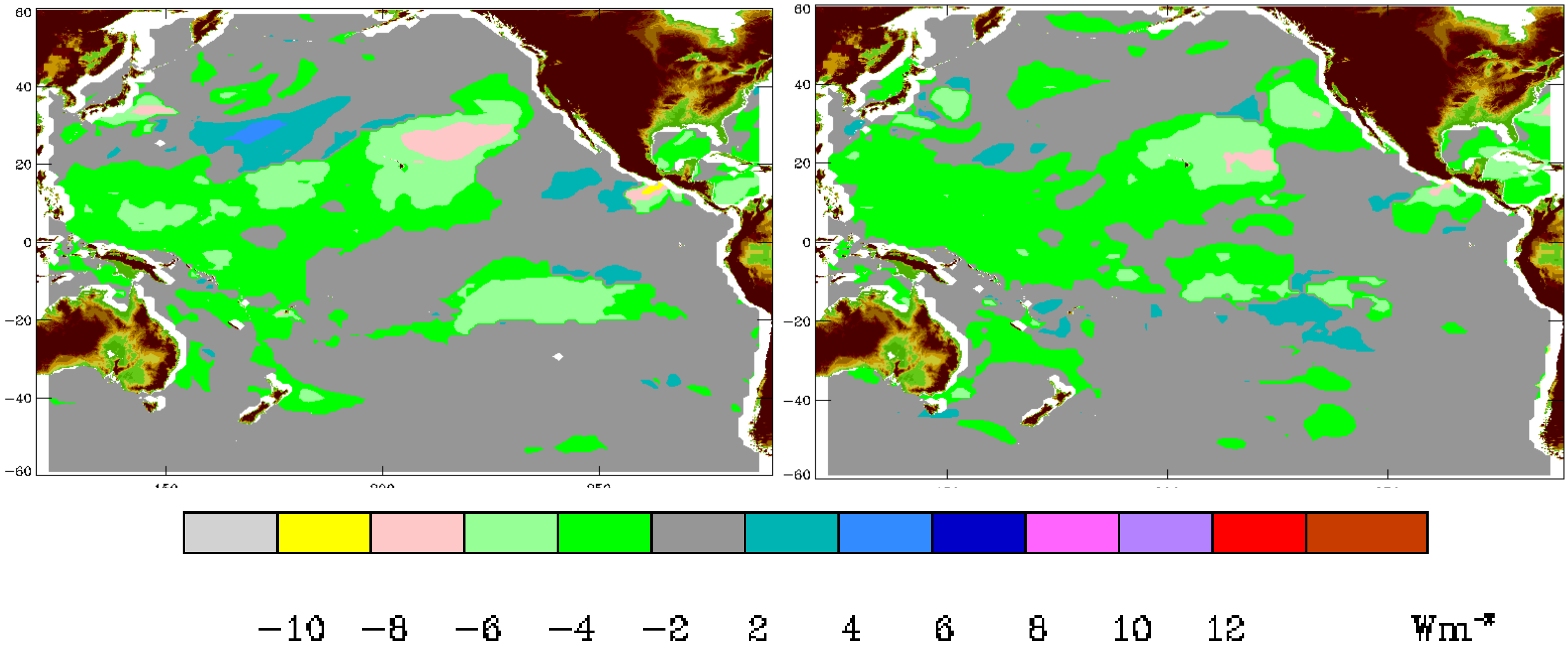


- The percentage change in surface relative winds is roughly proportional to the change in energy fluxes.
- The percentage change squared is roughly proportional to changes in stress.
- The drag coefficient also changes by about half this percentage.



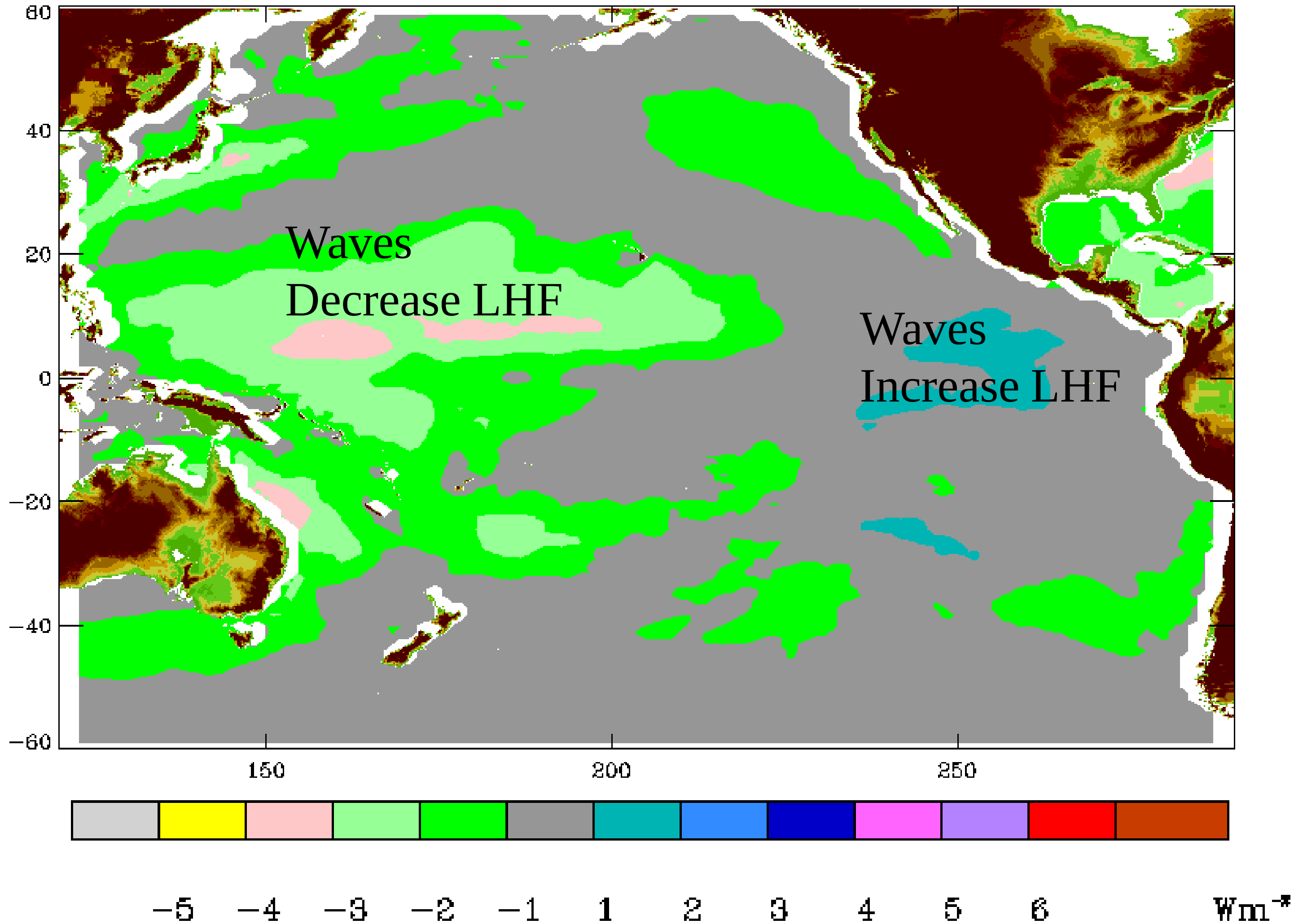
From *Kara et al.* (2007, *GRL*)

Wave Induced Changes in LHF



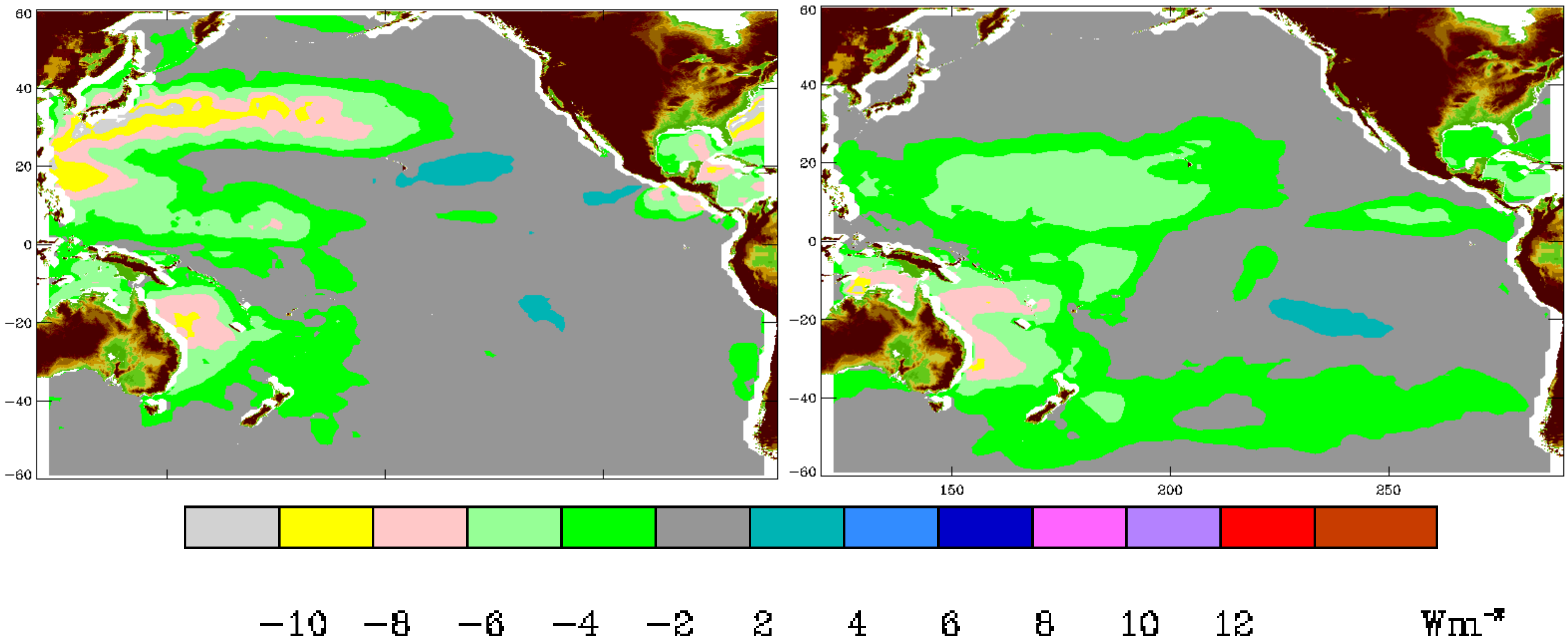
- Examples from snapshots (6 hourly time steps)
- Input data:
  - WaveWatch3 (WW3) winds and waves
  - ECWMF temperatures and humidities

Example of Results
Change in LHF Due to Waves: March 1999



Positive upward

Monthly Averaged Changes in LHF: Two Examples



- January 2003 (left) and June 1999 (right)
- One persistent feature is a reduction of heat transfer from the western Pacific warm pool to the atmosphere
- The roughly 5Wm^{-2} across basin difference is important for studies of decadal variability, and possibly for ENSO

Submonthly Contribution to Average LHF

- L is determined through a bulk formula.

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

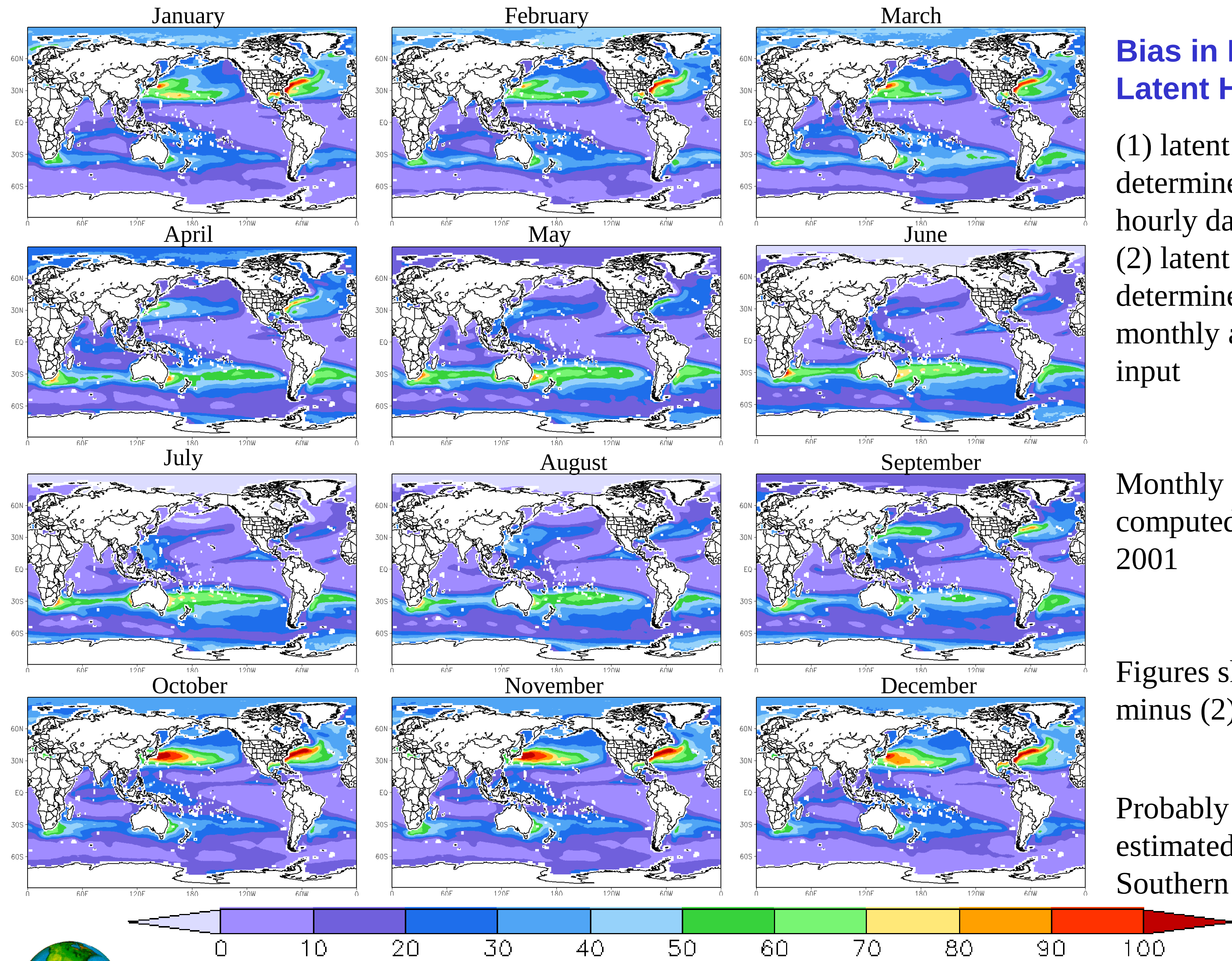
  - Where the overbar indicates a monthly average
  - There is considerable controversy about that accuracy of this averaging
- A more accurate approach is to calculate the flux at each time step then average these fluxes: $L \approx \overline{\rho L_v C_E U (q_{sfc} - q)}$
- If we apply Reynolds averaging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

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

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

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

- 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 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)

Probably under-estimated for the Southern Ocean

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

Thanks to Paul Hughes and Ryan Maue

Summary

- Synoptic scale variability in regional latent heat fluxes and flux related variables can be large (>50 Wm^{-2} in some regions).
  - Particularly down wind of continents and by western boundary currents.
  - Implies heat fluxes in the Southern Ocean will be underestimated
- In the tropics, sub-monthly variability - **ignoring waves** – can exceed 20Wm^{-2}; however, it is typically <10 Wm^{-2}.
- Monthly averaged tropical **wave related** variability is more wide spread:
  - Tends to reduce LHF by roughly 5Wm^{-2} in the Western tropical Pacific Ocean
  - Slightly increases LHF in the Eastern tropical Pacific Ocean
  - Could be of interest on ENSO time scales and longer.
- Similar magnitude and spatial distribution to what some people call the global warming signal.

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