Satellites and Satellite Observing in the Future

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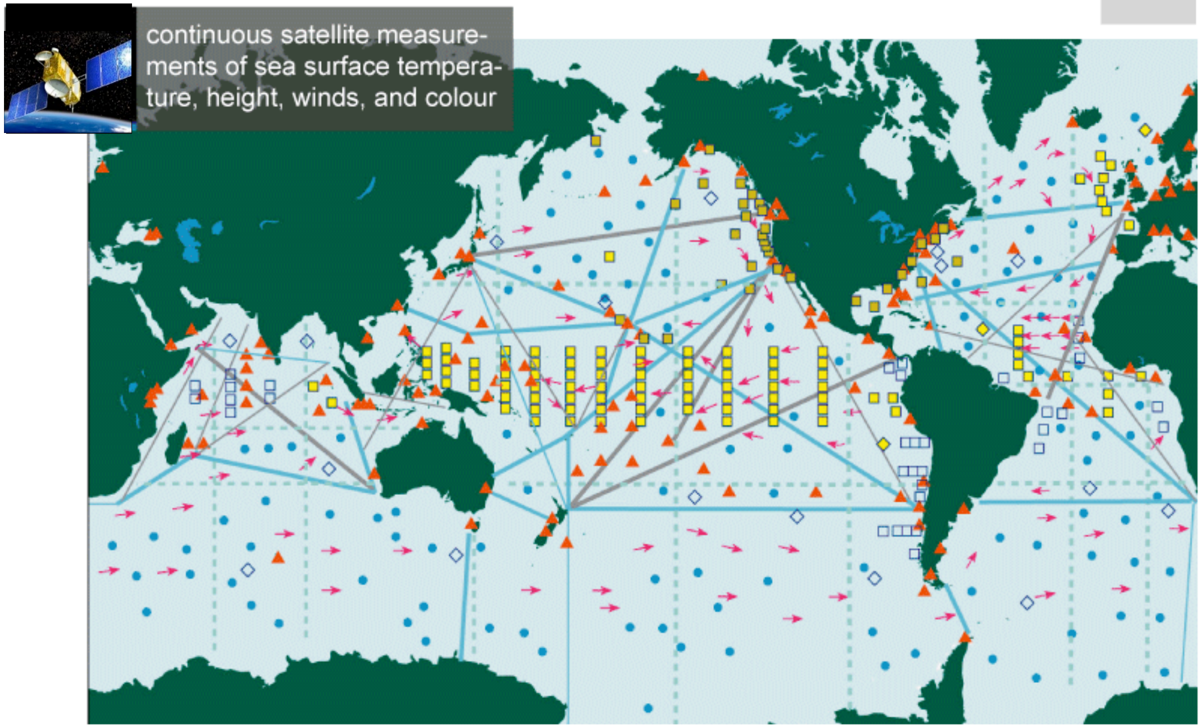
•Initial Global Ocean Observing System for Climate

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**

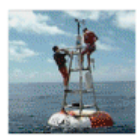
Full ocean survey in 10 years

Reference time series •48%

58 sites

•34% Global **reference mooring** network

29 moorings planned

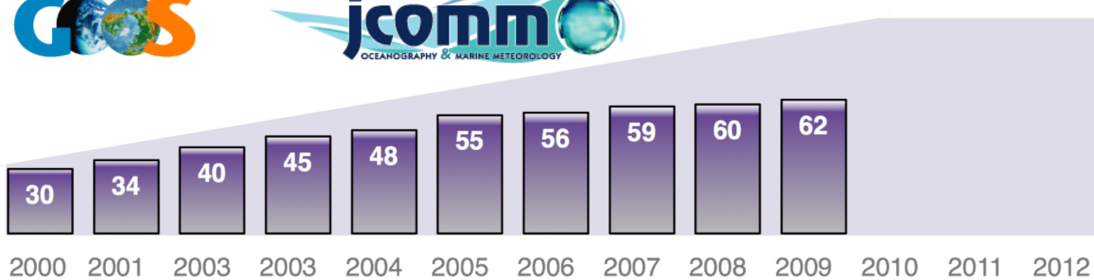


•73% Global tropical **moored buoy** network

119 moorings planned

GCOS GOOS jcomm

•System % complete

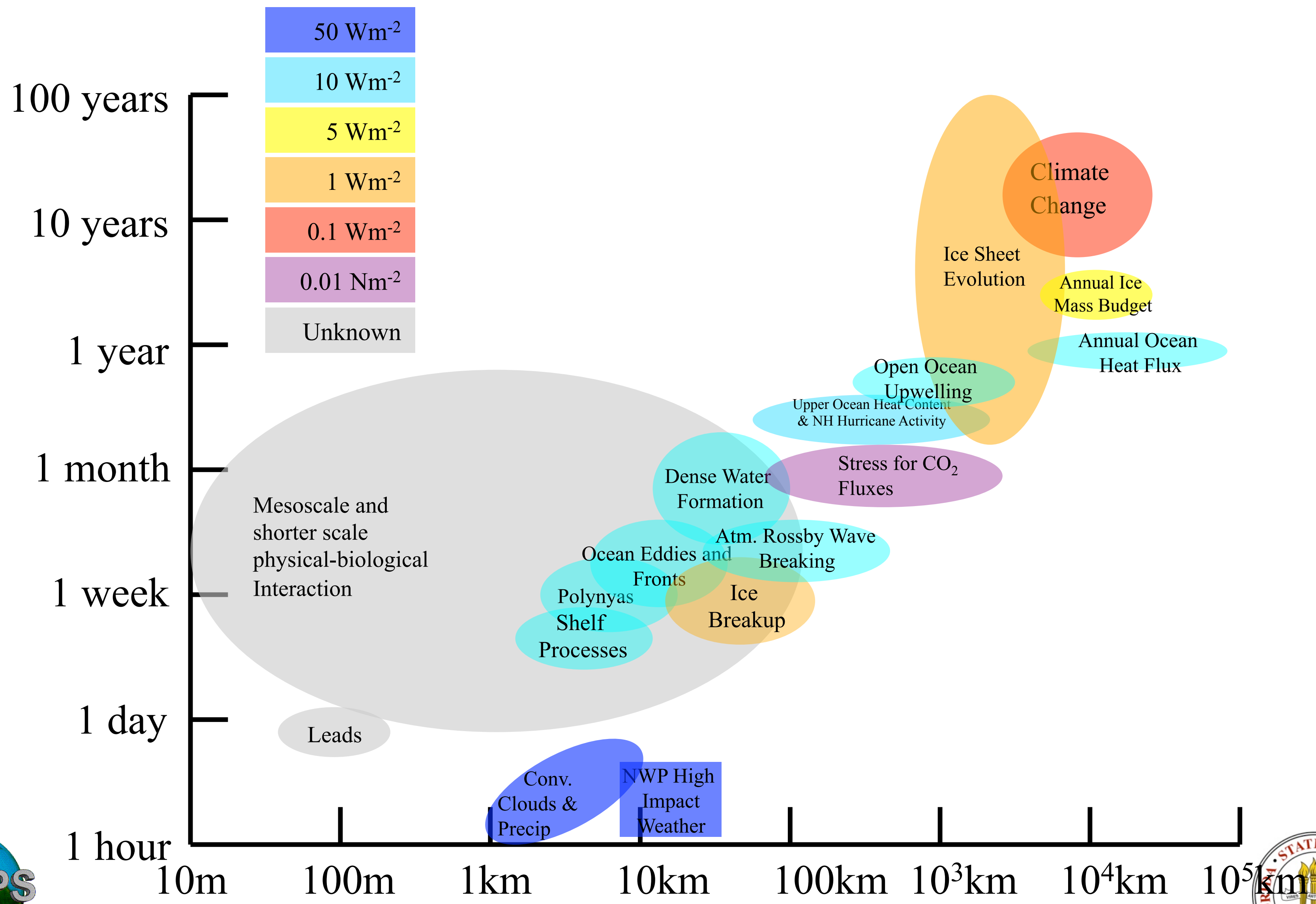


•Original goal: 100% implementation in 2010

Outline

- Setting the stage
  - Accuracy Desires
  - Sampling error – monthly averages
- Different Perspectives on Flux Product Creation
- Summary of Recent Results in
  - Turbulent Heat Fluxes
  - Radiation
  - Precipitation
  - Stress (momentum)
  - CO_2
- Upcoming and developing satellite missions

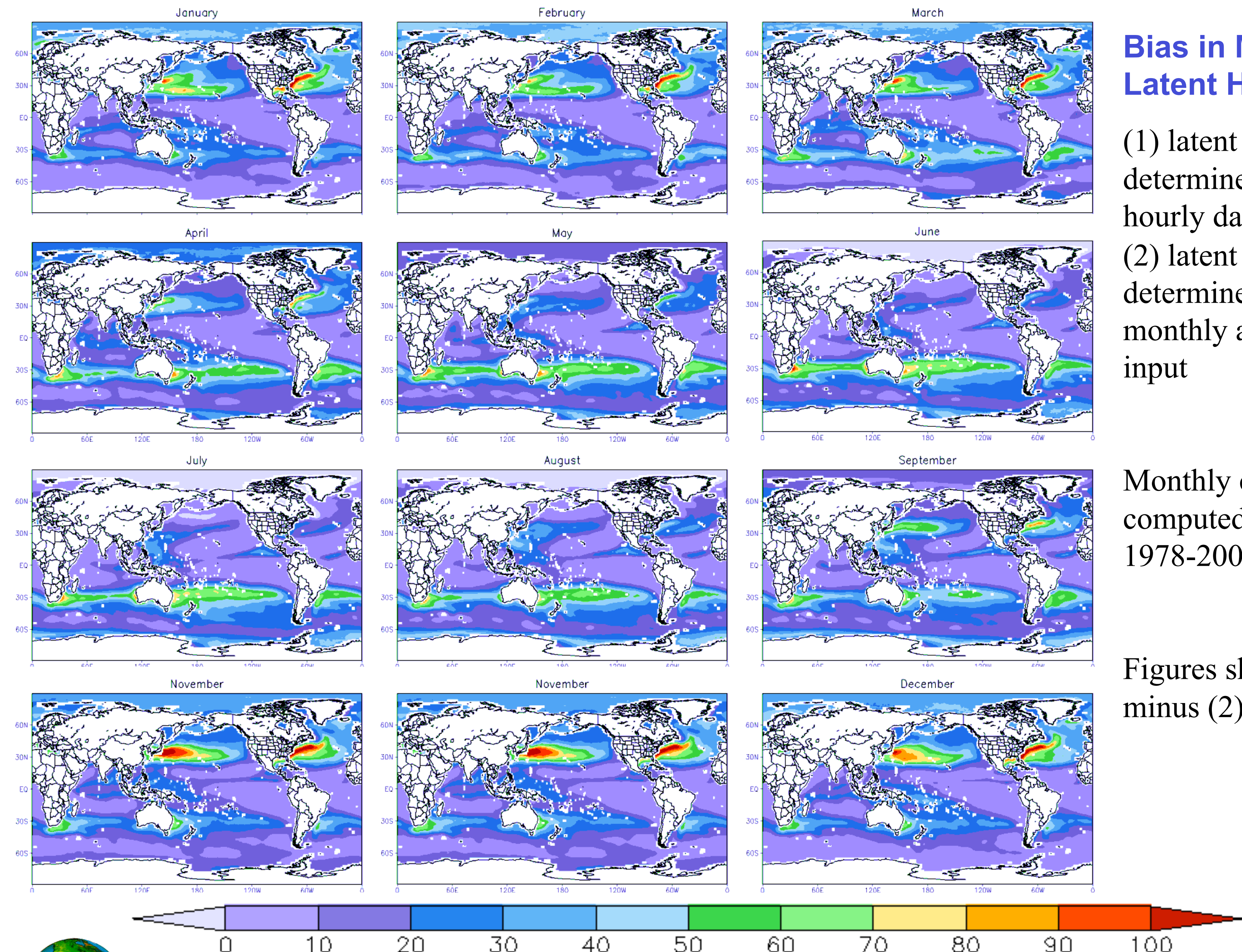
Flux Accuracies and Applications



COAPS

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
  $$L = \bar{\rho} L_v \overline{(C_E + C'_E)(U + U')(q_{sfc} - q'_{sfc} - q + q')}$$
- If we assume density variations are not important, this equation becomes
  $$L = \boxed{\bar{\rho} L_v \overline{C_E}\,\bar{U} (\bar{q}_{sfc} - \bar{q})} + \bar{\rho} L_v \left(\overline{C_E}\,\overline{U'(q' - q'_{sfc})} + \overline{U}\,\overline{C'_E (q' - q'_{sfc})} + \overline{(q' - q'_{sfc})}\,\overline{C'_E U'} \right)$$
- 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

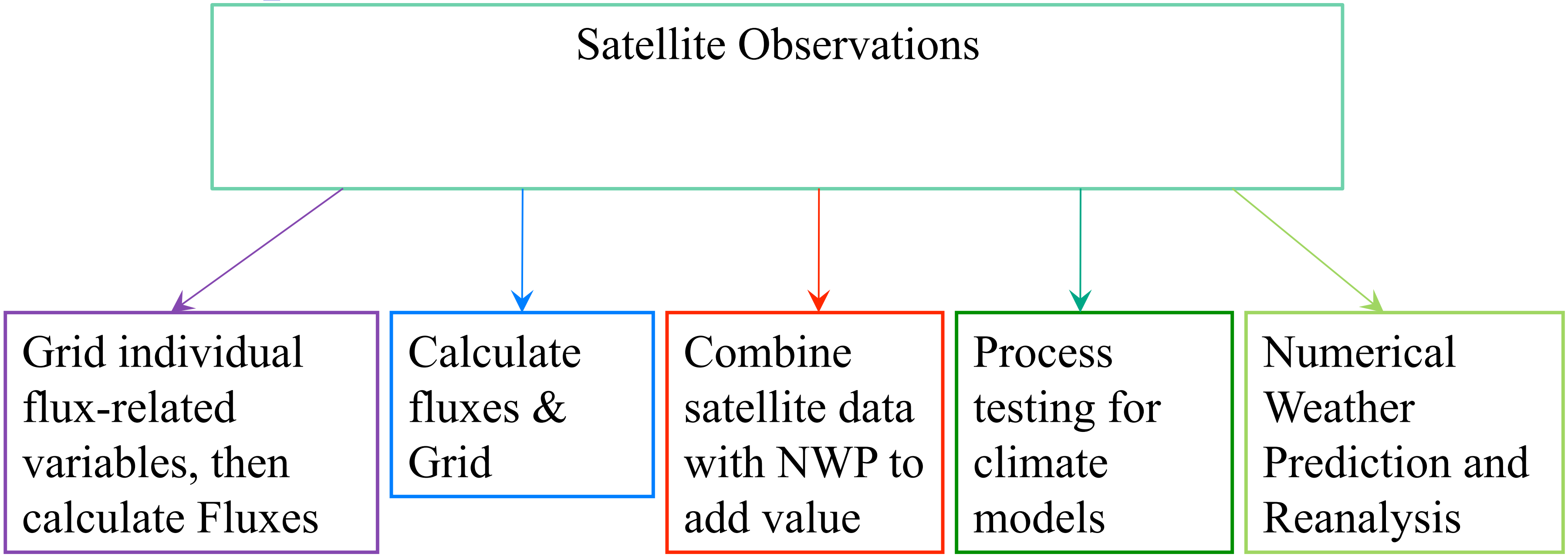
Monthly climatology computed for 1978-2001

Figures show: (1) minus (2)

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

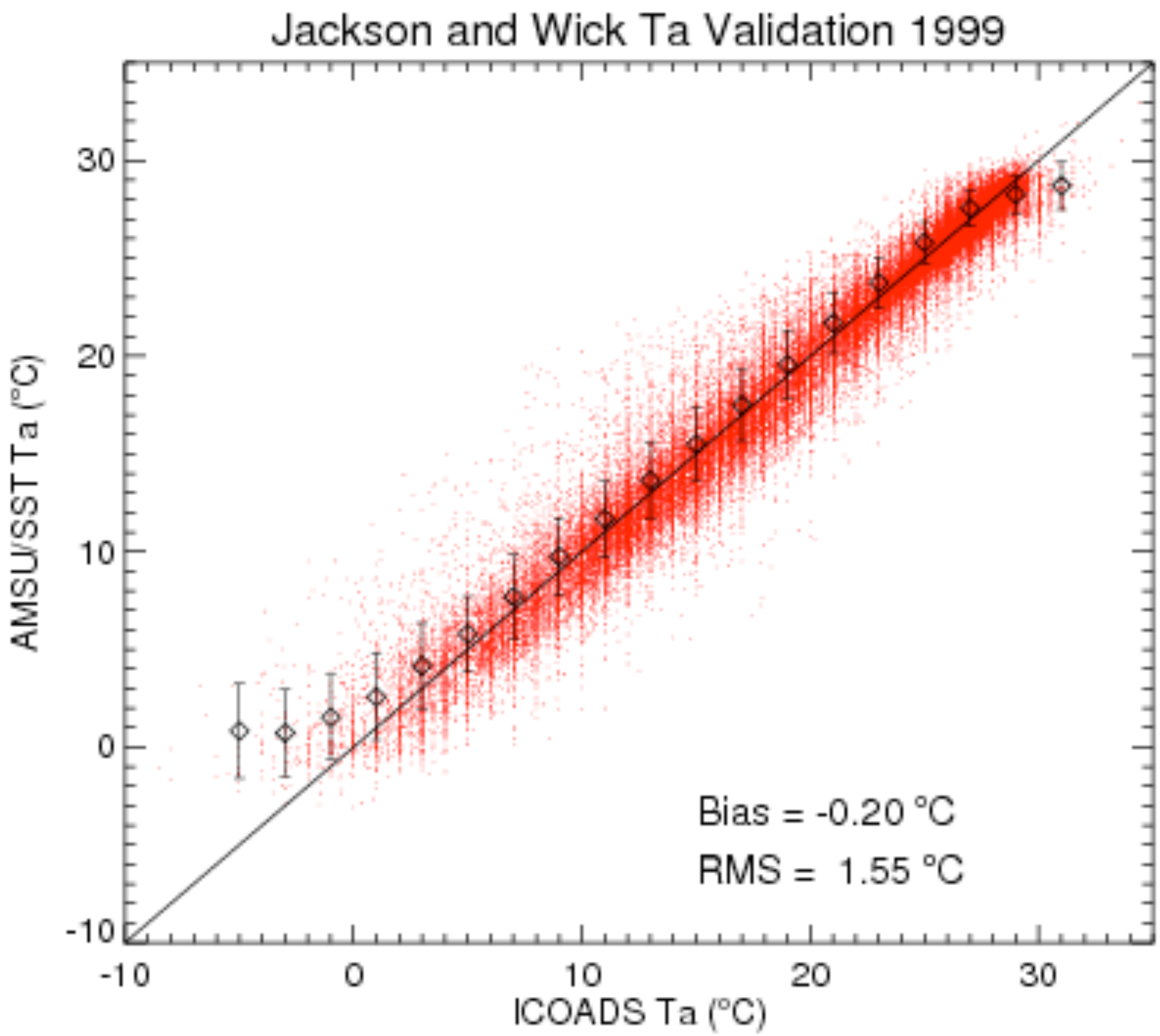
Thanks to Paul Hughes and Ryan Maue

Perspectives on the Use of Satellite Observations



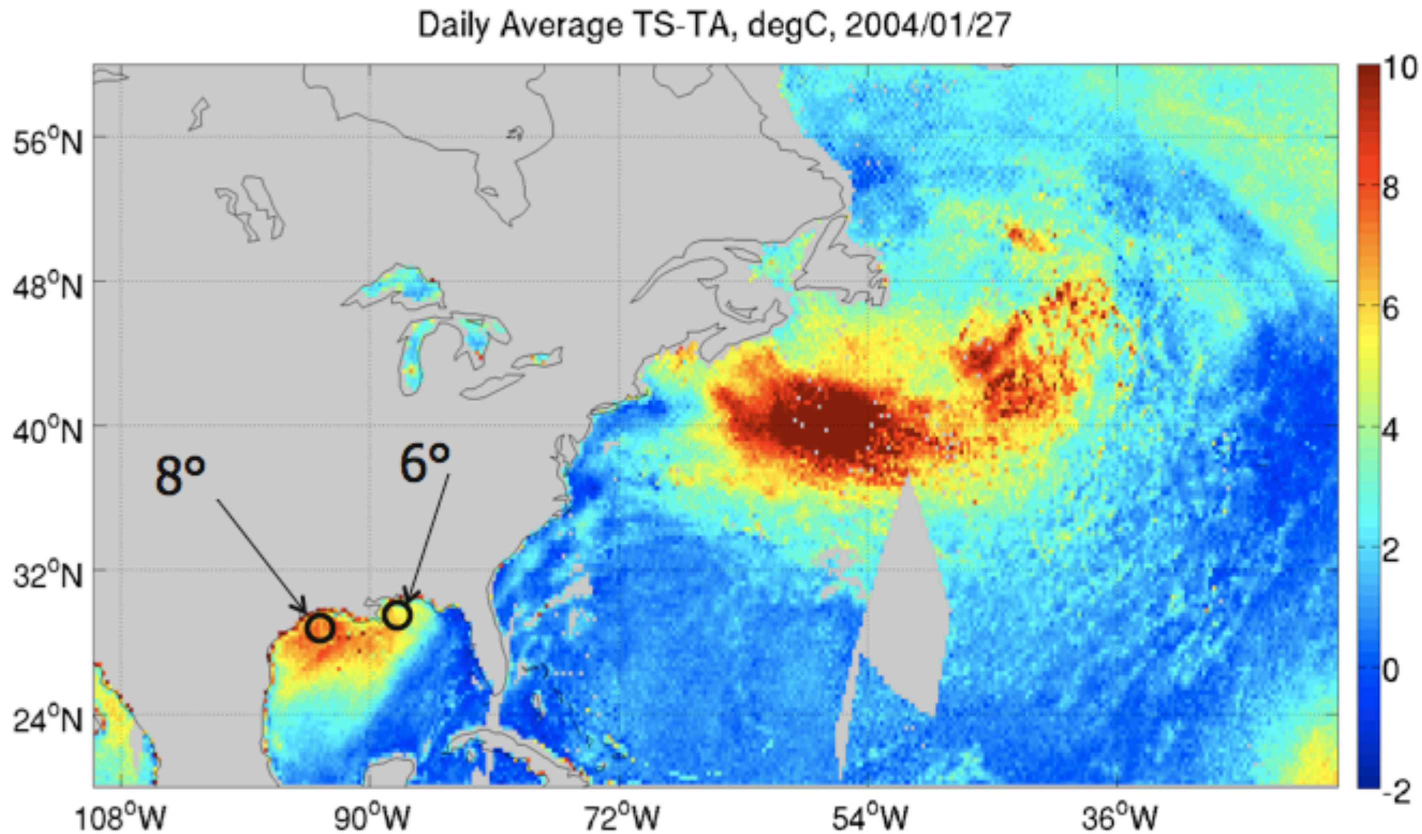
- Each of these approaches has its strengths and weakness, requirements for sampling, and approaches to blending the data
- Users of the resulting products have very different requirements depending on the application
  - One product does not fit all!
- Each of these approaches would benefit from more data, better calibration, and better understanding of the related physics

Example Retrievals of 10m Air Temperature



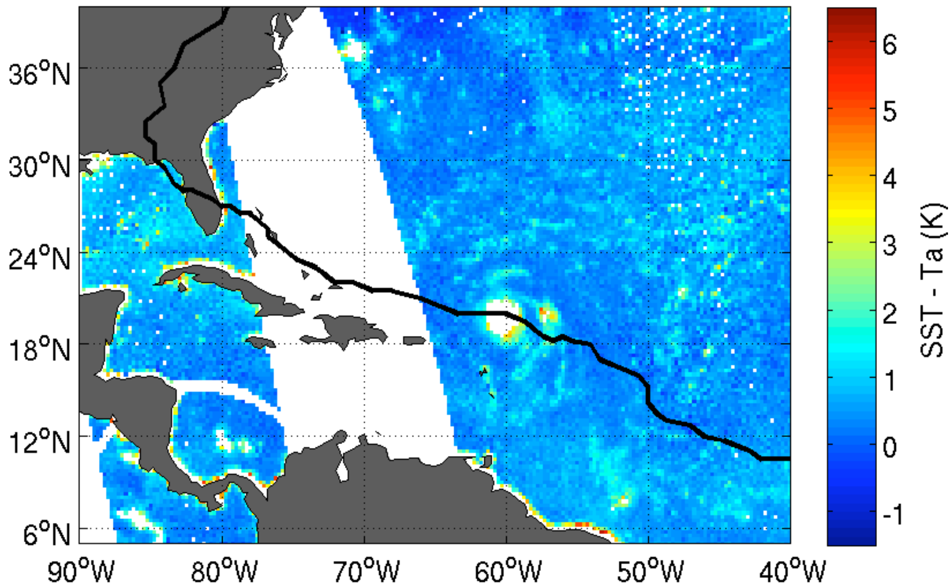
- Multiple linear Regression technique
- Pretty good for most conditions
- Issues for very low temperature and very high temperatures

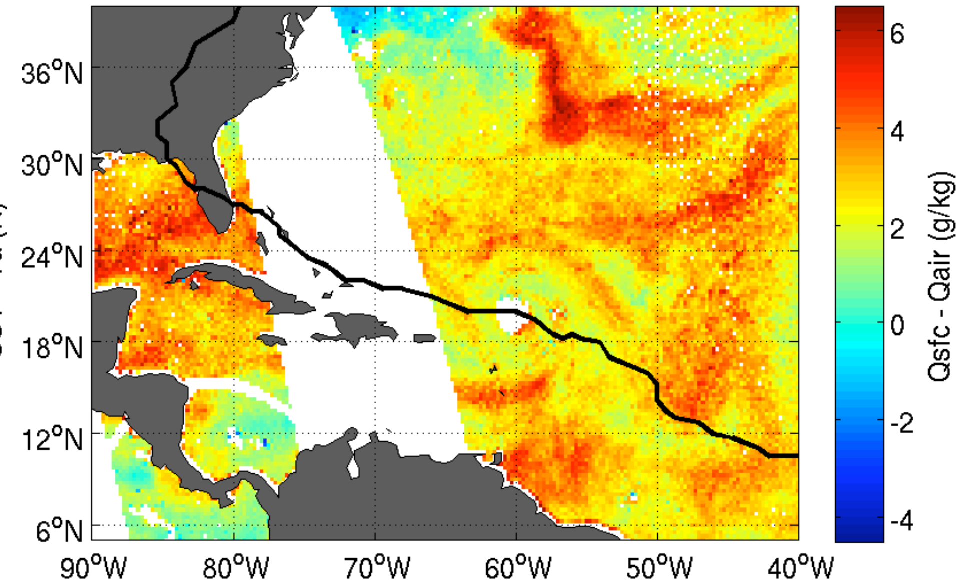
Validation of Air/Sea Temperature Differences

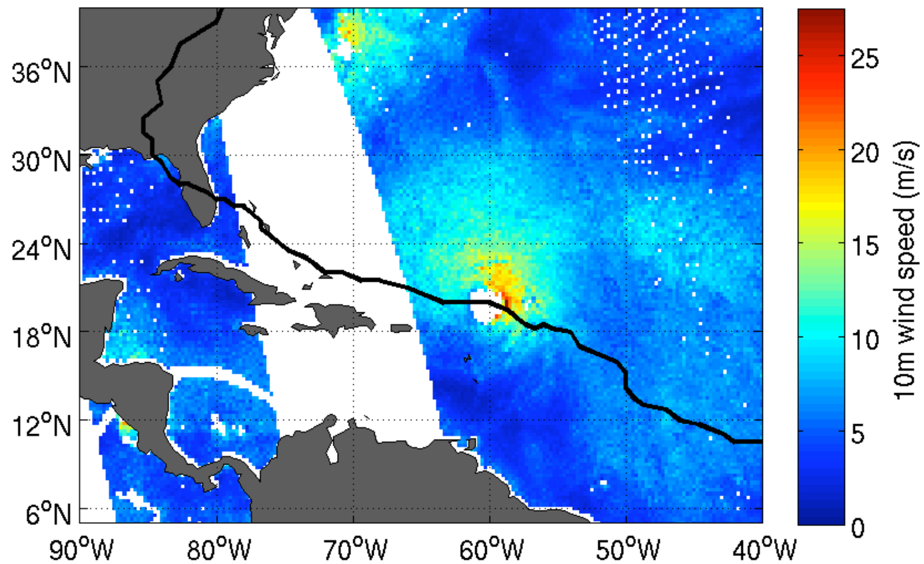


- Roberts et al. (2010) retrieval technique for T_{air} and q_{air}.
- Comparison to buoy observations (circles in the Gulf of Mexico)

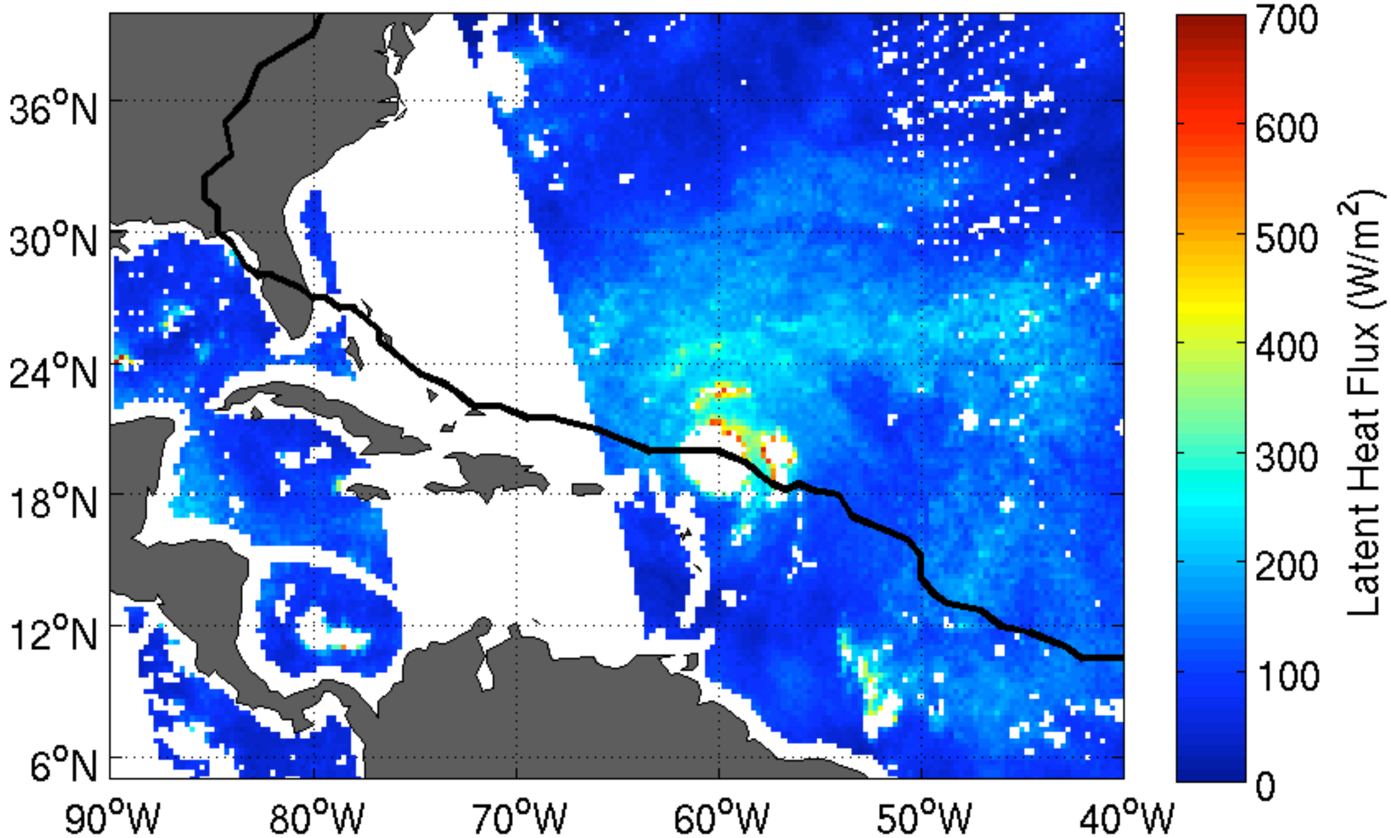
Hurricane Francis Air/Sea Differences 30 Aug 2004 21 Z







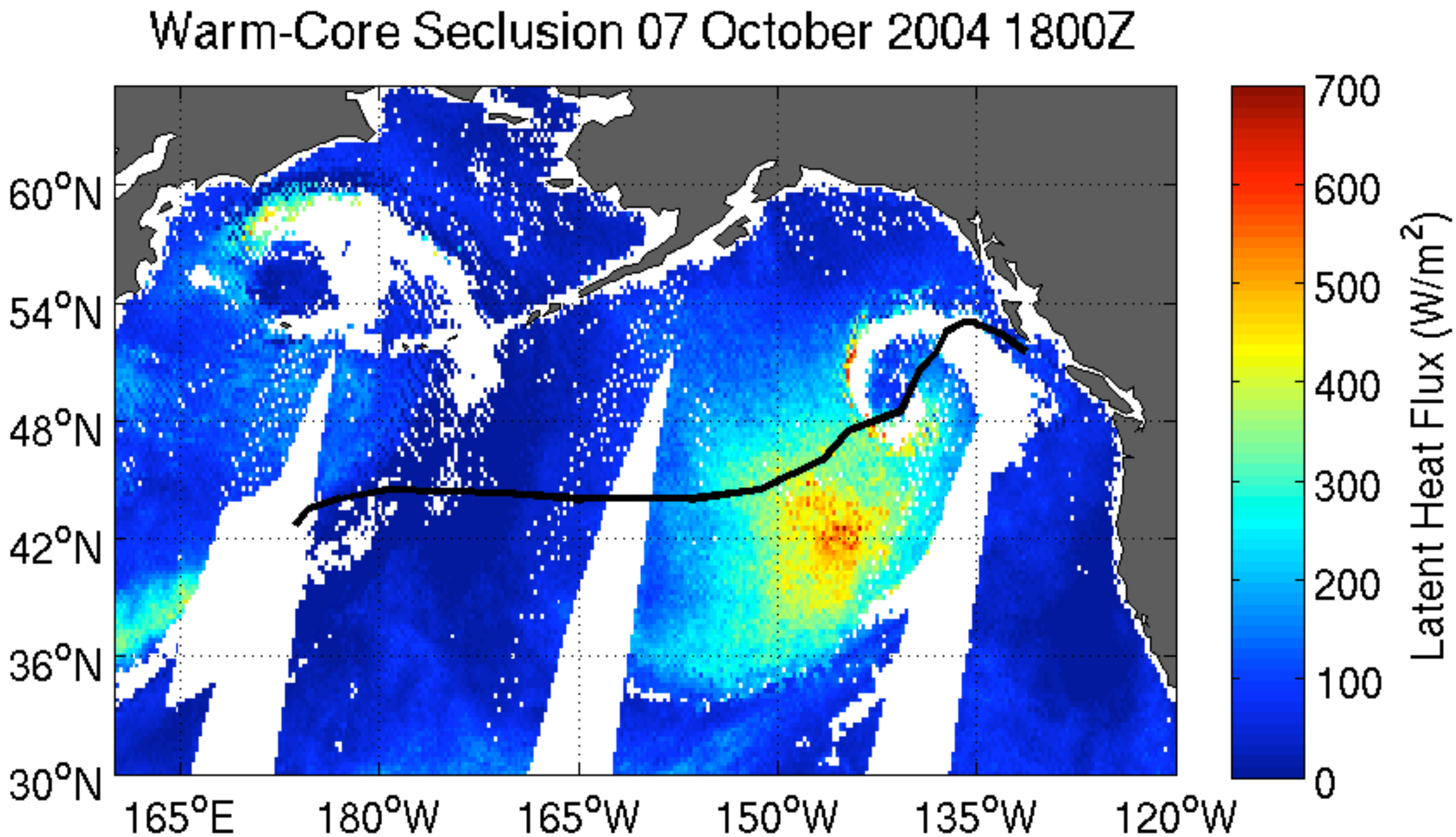
Hurricane Francis LHF 30 Aug 2004 21 Z



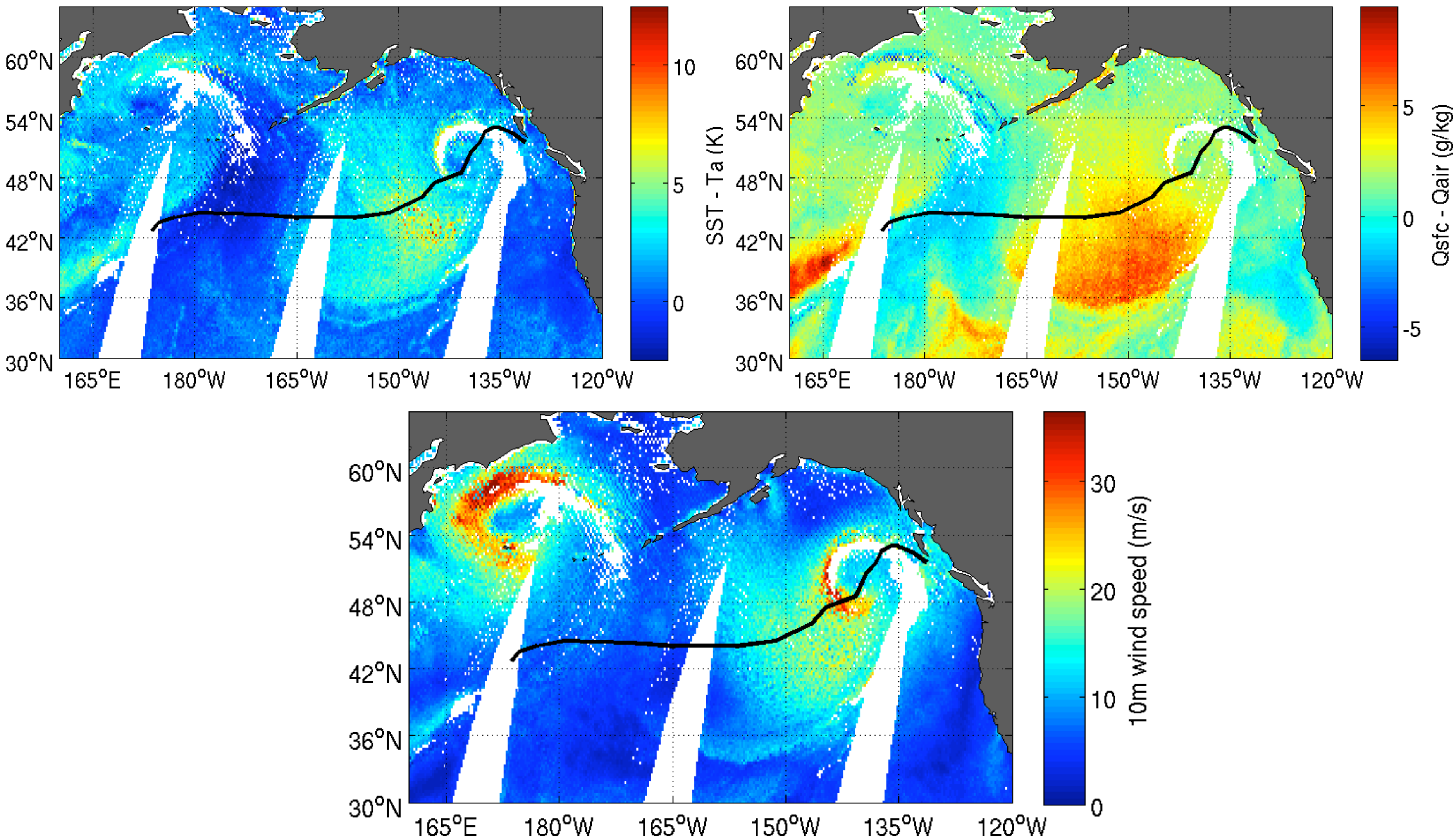
- T_{air} and q_{air} from Roberts et al.
- Wind speed interpolated from NCDC

Example LHF Retrieval: Warm Core Seclusion

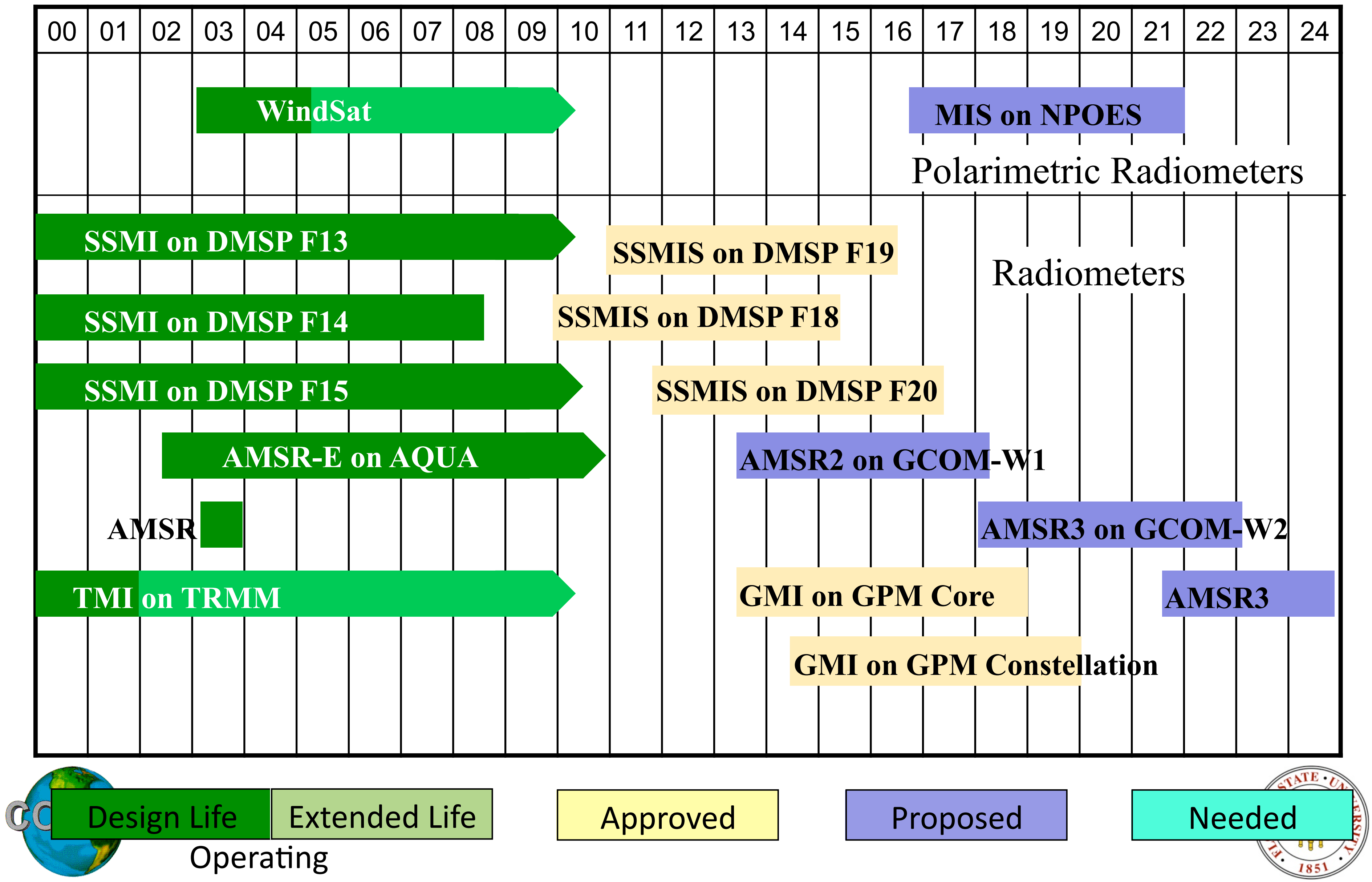
- Black line is the track from Ryan Maue's data set
- Lack of retrieval in areas with too much rain



Warm Core Seclusion Air/Sea Differences



Radiometers



Radiative Fluxes

- There is currently no satellite programmed aimed a dramatic improvements in radiative fluxes.
- Incremental progress can be made with better cloud and water vapor information, particularly in the boundary-layer.
  - The previous studies suggest that we can improve estimates of 10m humidity.
  - Improved estimates of latent heat fluxes would also help NWP estimates of humidity.
- We can anticipate modest improvements, particularly in the net long-wave flux.

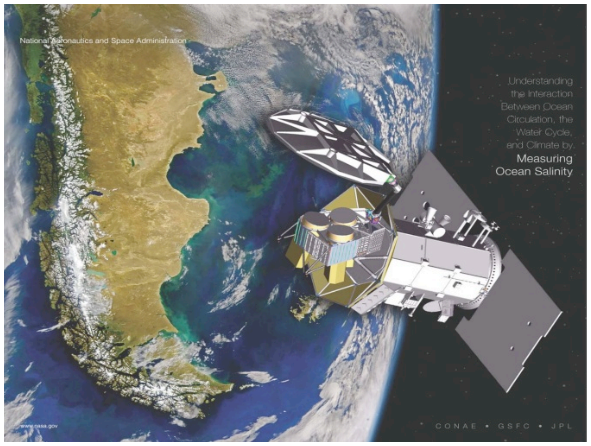
Precipitation

- There are numerous satellites that help with precipitation estimates:
  - Radiometers
  - Precipitation radar
  - Altimeters
  - Can also use scatterometers – not done at this time
- Future Instruments
  - Global Precipitation Mission (GPM)
  - Duo-Frequency Scatterometer (DFS)

•Aquarius/SAC-D

•*Goal:* Provide sea surface salinity observations

•Description



•Application

•***Primary Science Objective:*** Using a L-band radiometer and scatterometer, Aquarius will provide pioneering sea surface salinity observations of the global ice-free ocean at 150-kilometer resolution over a 3-year mission lifetime.

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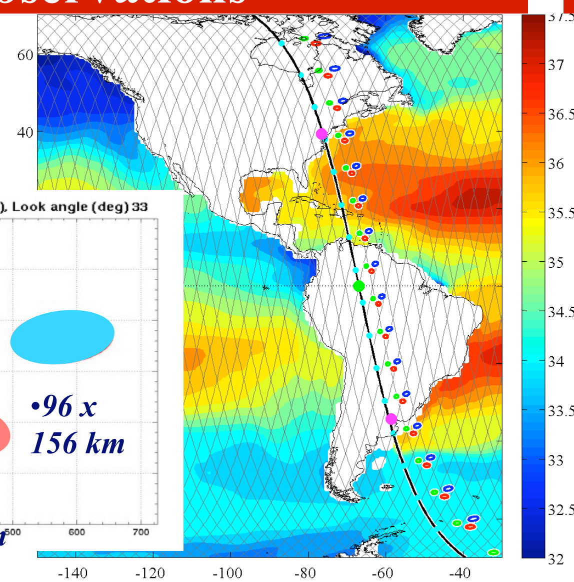
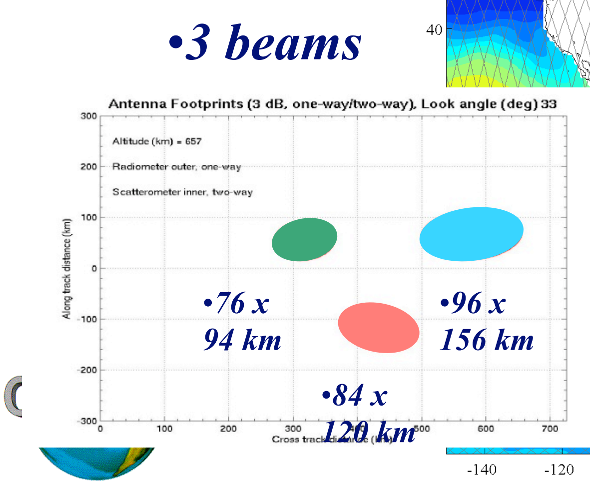
Climate

•Observations





•Data Products

•Product: Sea surface salinity (SSS)

•Repeat Interval: global in 7 days

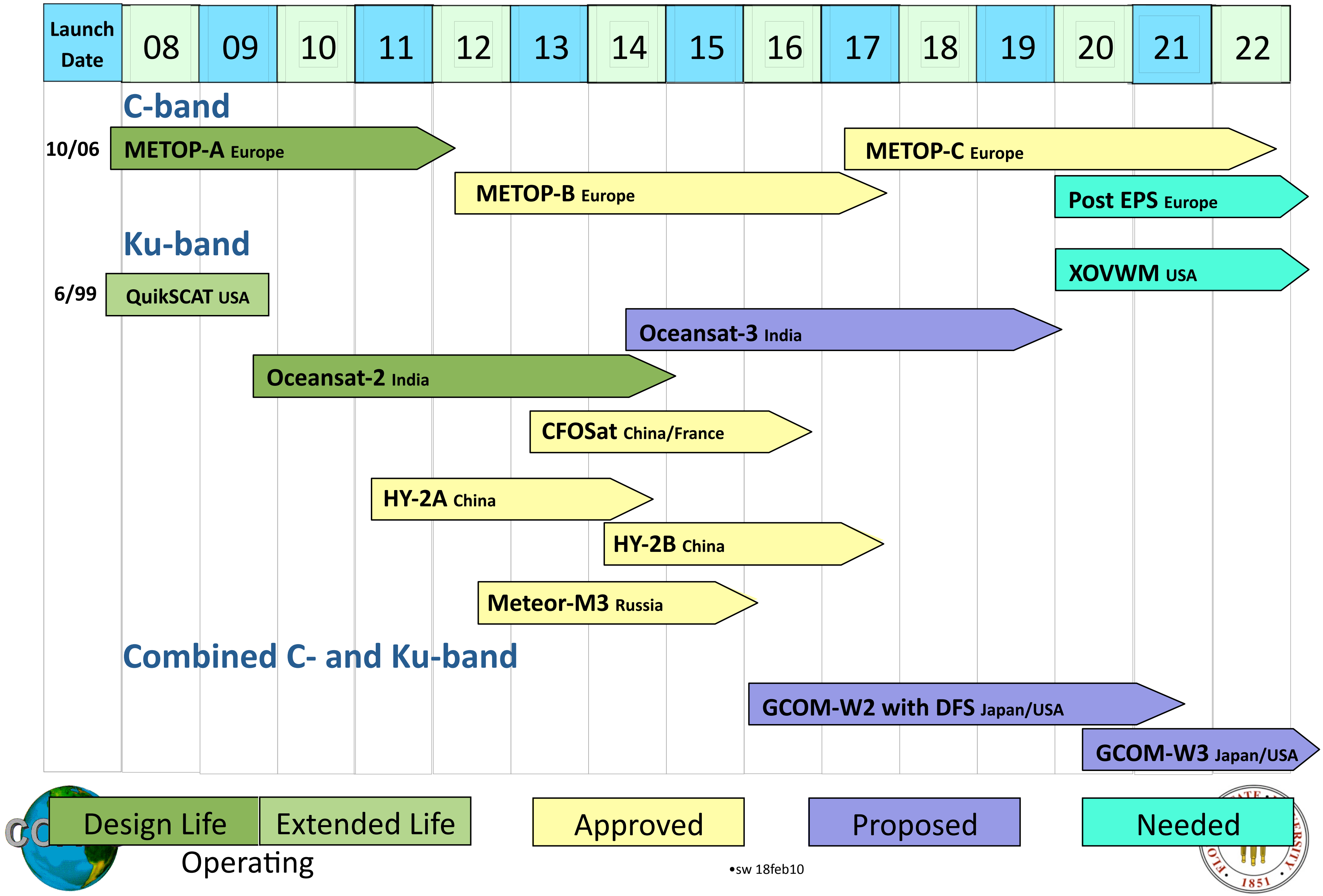
•Quicklook products: weekly map

•Map Scale: monthly & 150-kilometer

•Accuracy: 0.2 psu (practical salinity unit)

•Access URL: http://aquarius.nasa.gov

GLOBAL SCATTEROMETER MISSIONS



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To What Does a Scatterometer Respond?

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

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

- Does a scatterometer respond to $\mathbf{U}_{10}$ or to $\mathbf{U}_{10} - \mathbf{U}_{\mathrm{sfc}}$ 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 $\mathbf{U}_{\mathrm{sfc}}$. 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

Background

- The heat fluxes and the modified log-wind profile
  - Latent heat flux, $Q = \rho L_v q_* |u_*| = \rho L_v c_e (q_{sfc} - q_{air}) |u_*|$
  - Sensible heat flux, $H = \rho C_p \theta_* |u_*| = \rho C_p c_h (\theta_{sfc} - \theta_{air}) |u_*|$
  - The bulk of wave modifications enter through u_*; however, waves also modify boundary-layer stratification and roughness lengths for temperature and moisture, which do influence q_* and θ_*
- Waves influence u_* in several ways

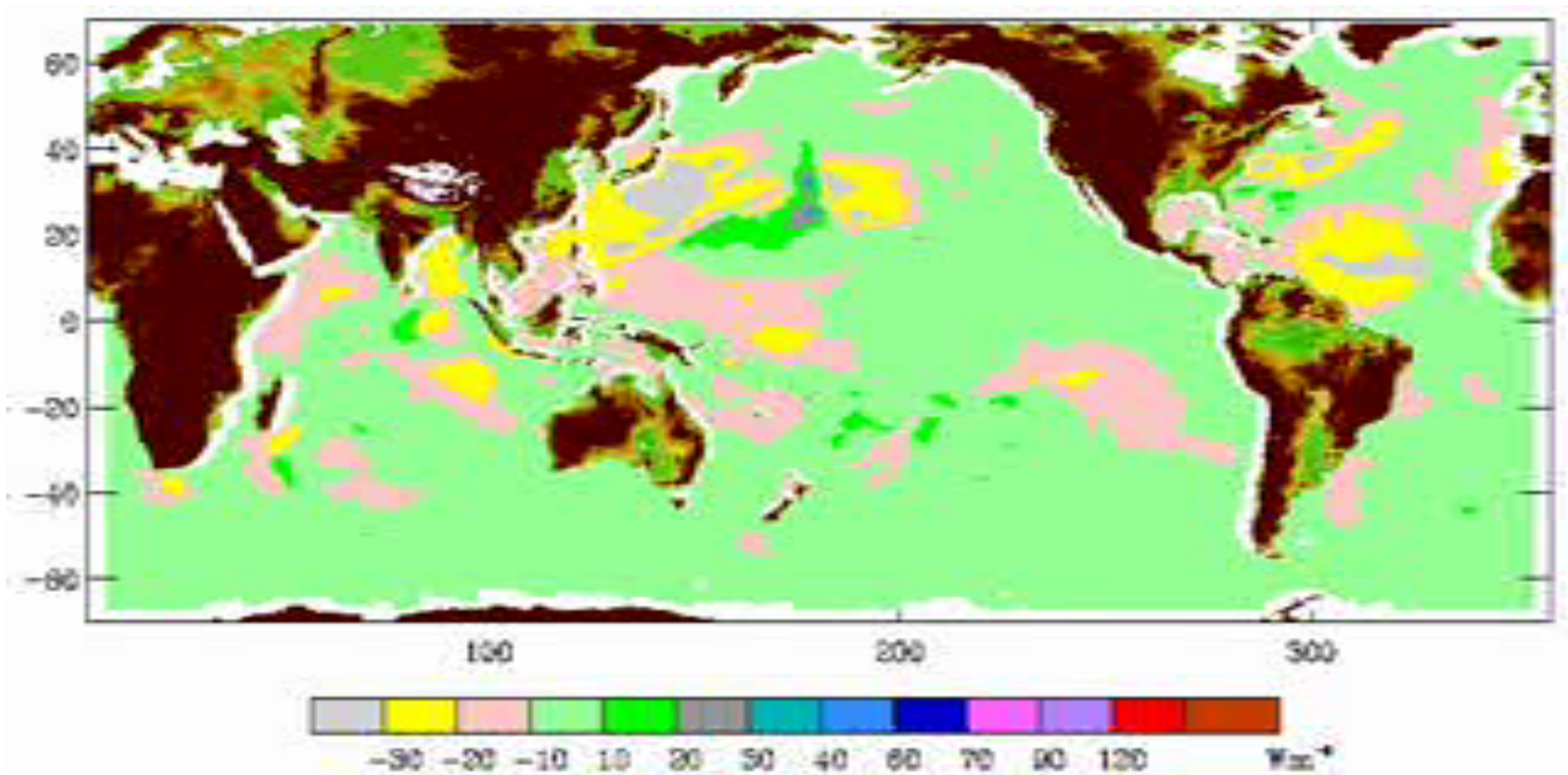
$$U(z) - U_{sfc} = \frac{u_*}{k} \ln\left(\frac{z-d}{z_o} + 1\right)$$

  - Modification of the momentum roughness, z_o for surface gravity waves (water waves) often parameterized as proportional to u_* squared: Charnock's relation
  - In some models the proportionality is a function of wave characteristics

Goal & Issues

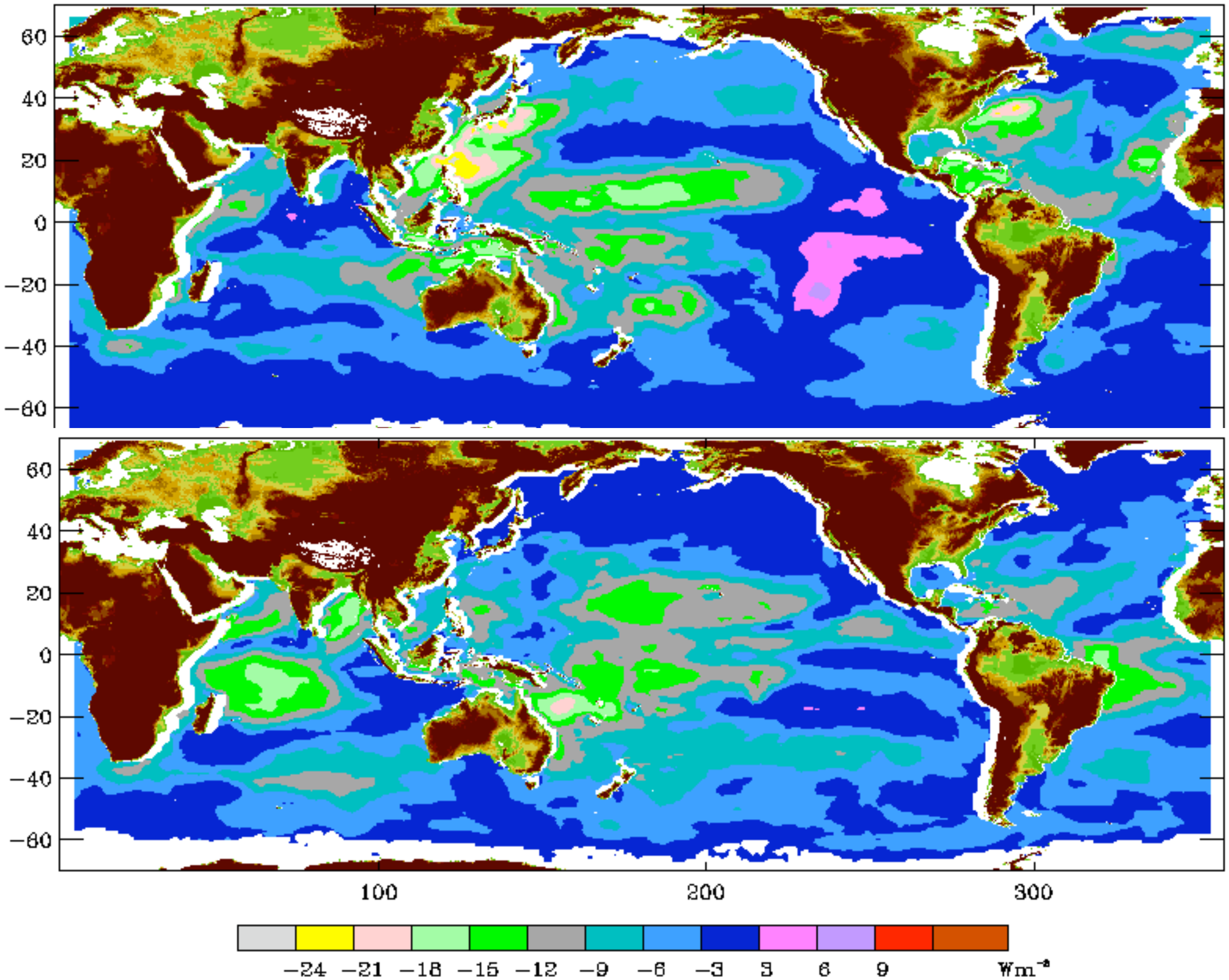
- Goal: Estimate the change in the magnitude in Global Ocean **surface fluxes of latent and sensible heat** due to **waves** (swell and wind waves) relative to a Charnock parameterization (waves modify U_{sfc}).
  - On event time scales (Meteorological meso and synoptic scales)
  - Monthly averages for larger spatial scale patterns
  - Annual averages for basin scale patterns
  - Consider directional issues (not considered in other models)
  - Implications on intercalibration and change
- Caveats:
  - This analysis is based on theory – observations and not sufficient
  - There is a wide range of proposed mechanisms for how waves modify surface fluxes.
    - Model used herein is Bourassa (2006):
    - Moisture roughness length based on surface renewal theory: Clayson-Fairall-Curry (1996) model.

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

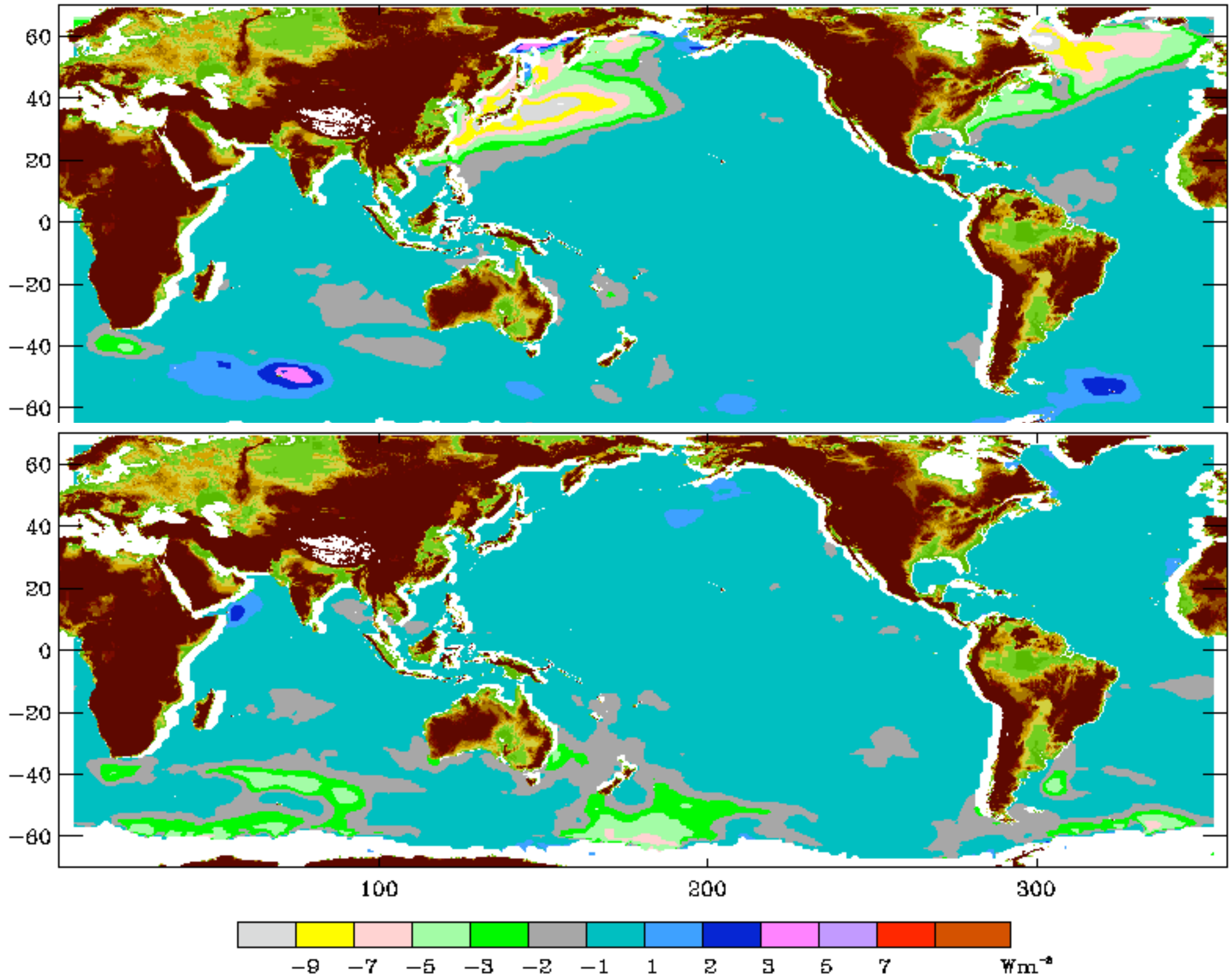
Monthly LHF Differences Due to Wave-Induced Shear



February 1999

August 1999

Monthly SHF Differences Due to Wave-Induced Shear

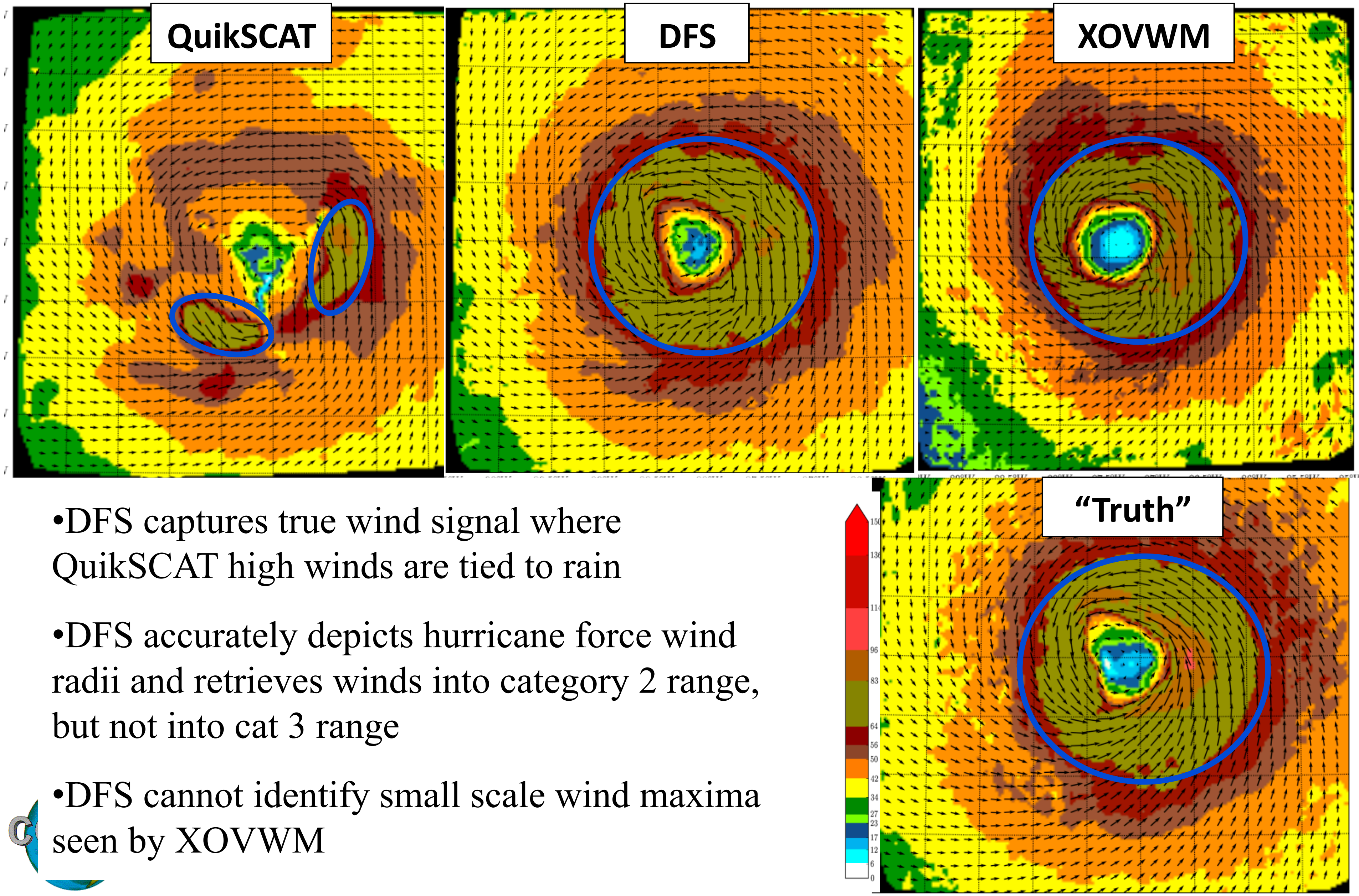


February
2000

August
1999

DFS vs. QuikSCAT and XOWVM

Simulated Retrievals based on Katrina (2005)



- •DFS captures true wind signal where QuikSCAT high winds are tied to rain
- •DFS accurately depicts hurricane force wind radii and retrieves winds into category 2 range, but not into cat 3 range
- •DFS cannot identify small scale wind maxima seen by XOVWM

Where Do We Go?

- More data for comparison & intercalibration
  - Primarily atmospheric humidity and temperature, particularly for high latitudes
  - High Wind Speeds
  - Sources: flux reference sites, other buoys, and Research Vessels, UAVs?
    - R/V data needs to be QC'd: SAMOS has automated system in place
- Flux train
  - AMSU, AMSR2, AIRS, AVHRR, scatterometer, (LIDAR)
  - A-Train orbit vs TRMM orbit (or both)
    - Sampling must be improved through wide international collaboration
  - GCOM-W2 will have AMSR2 and DFS on the same platform
- Pre-GHRSST-like activity??
  - Improve multi-sensor products (e.g., spinning up for winds)
  - Better understand limitations of the current observing system

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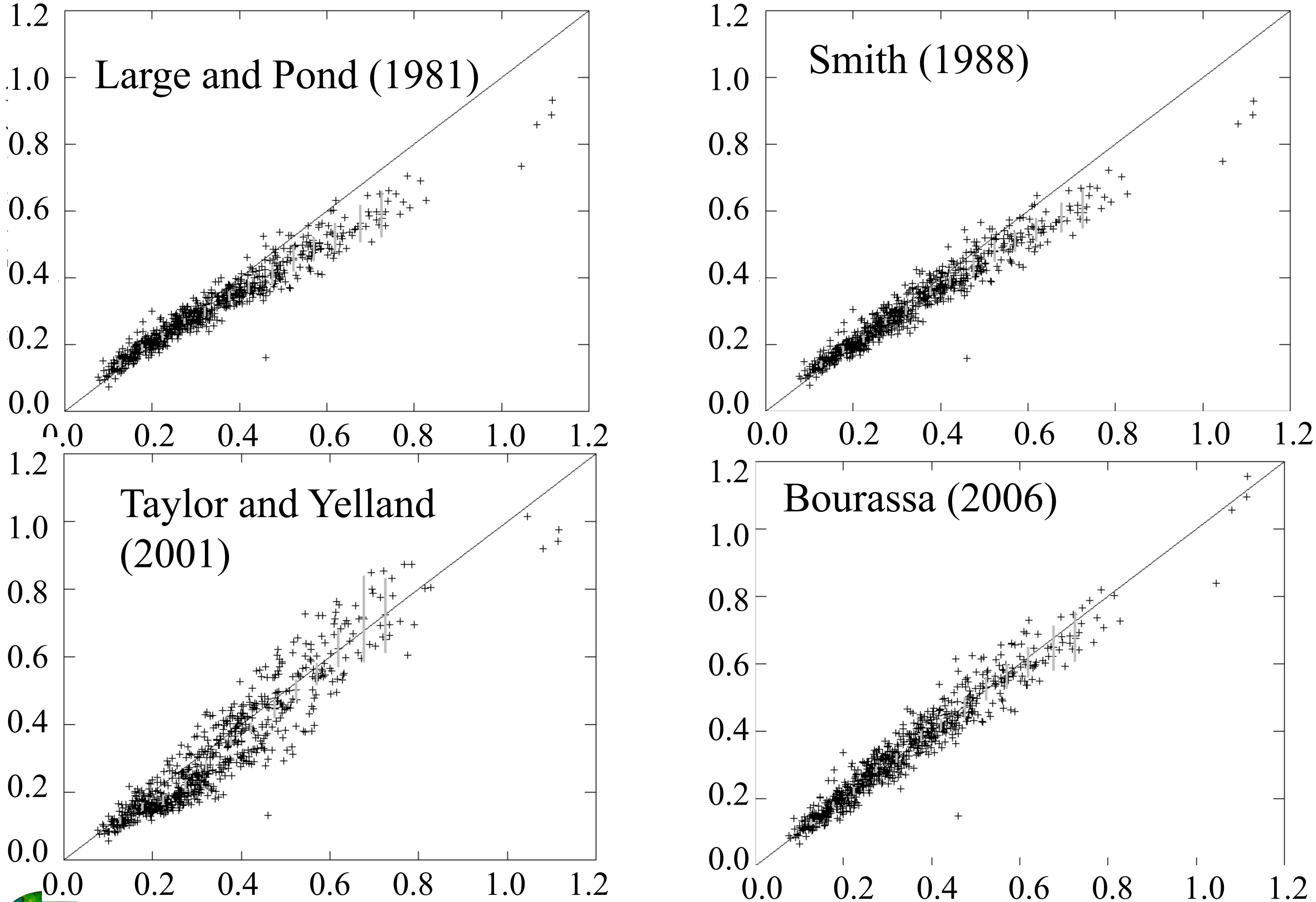
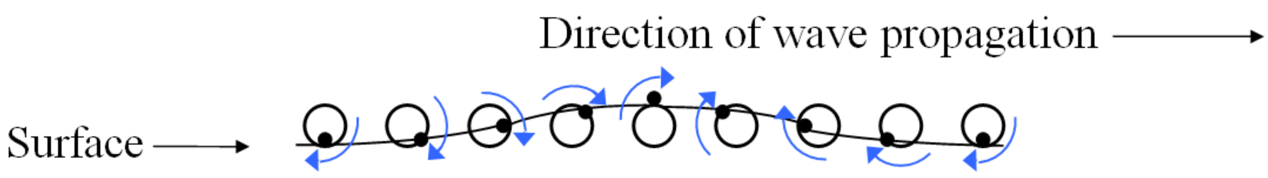
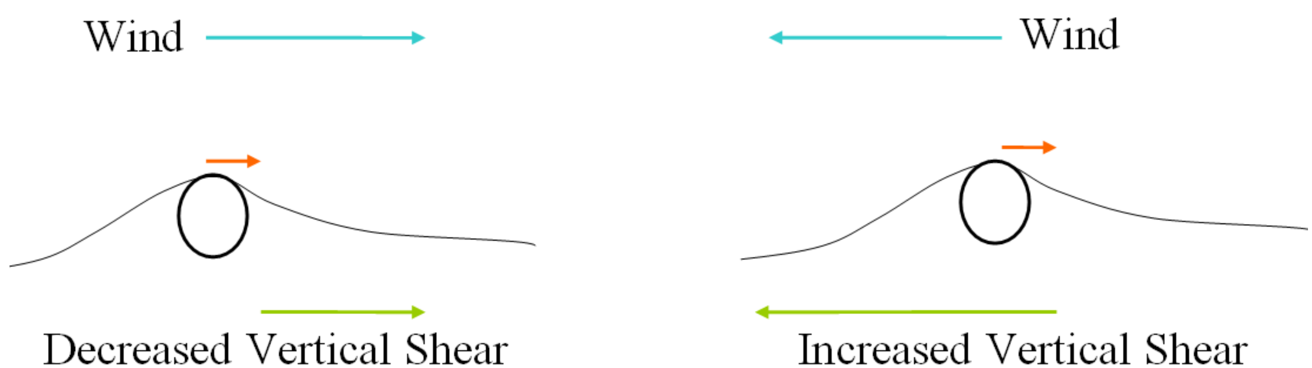
Observed (x) and Modeled (y) Friction Velocity (u_*)



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

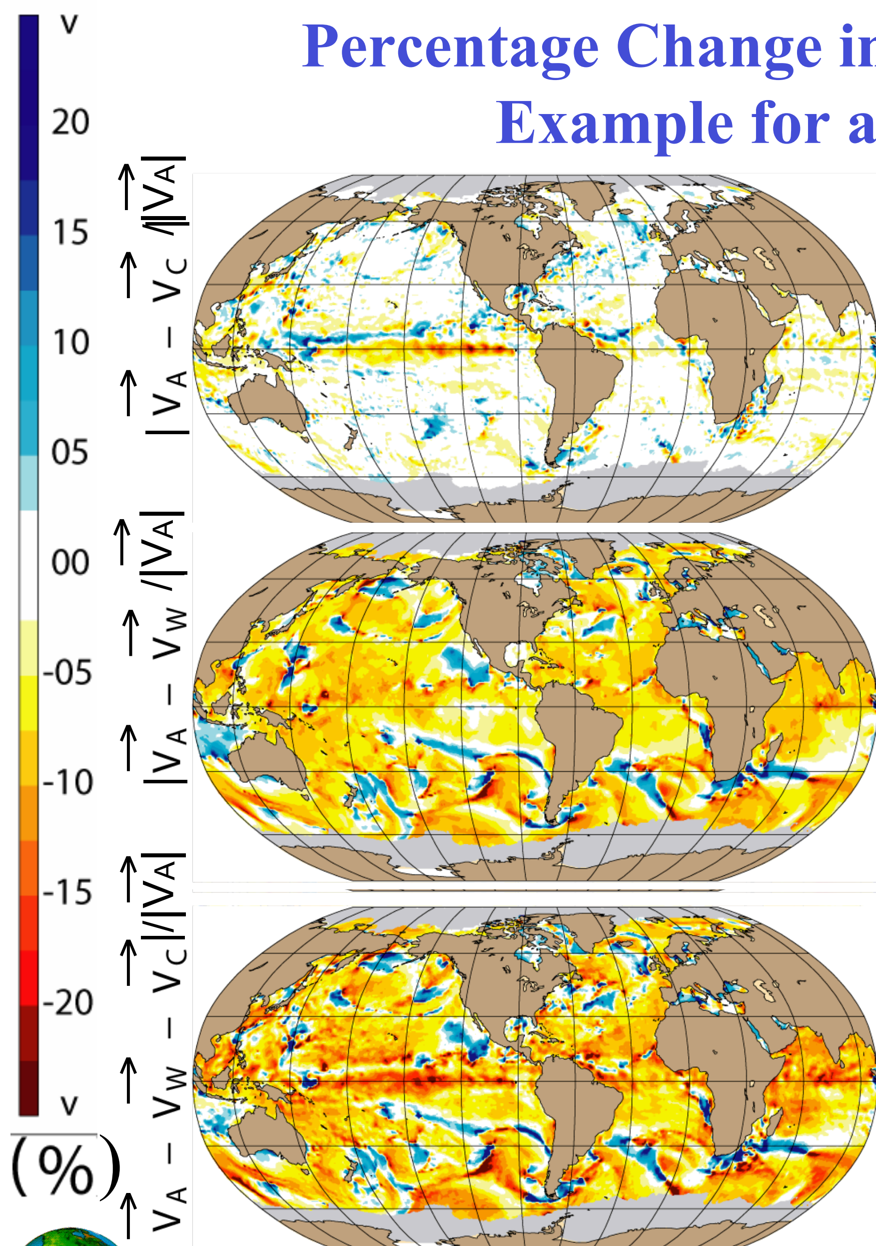


$$U_{\mathrm{orb}} = \pi H_{\mathrm{s}} / T_{\mathrm{p}}$$

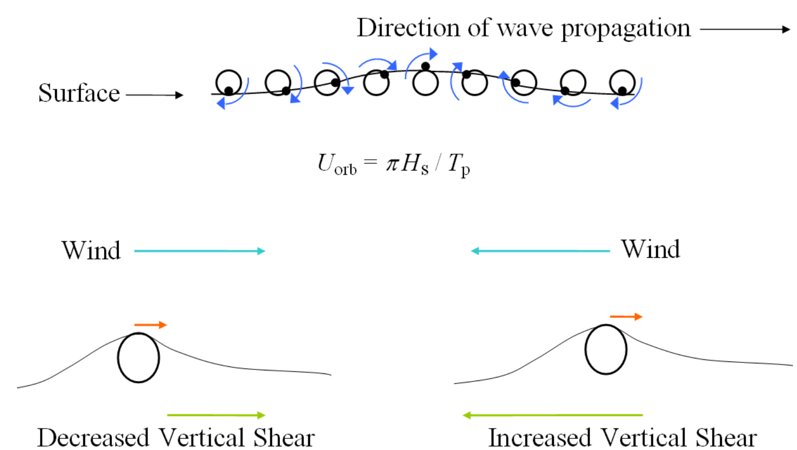


- For wind driven waves and common wave ages
  - this is qualitatively similar to the HEXOS results, and
  - qualtitatively similar to Taylor and Yelland (2001)

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



- 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