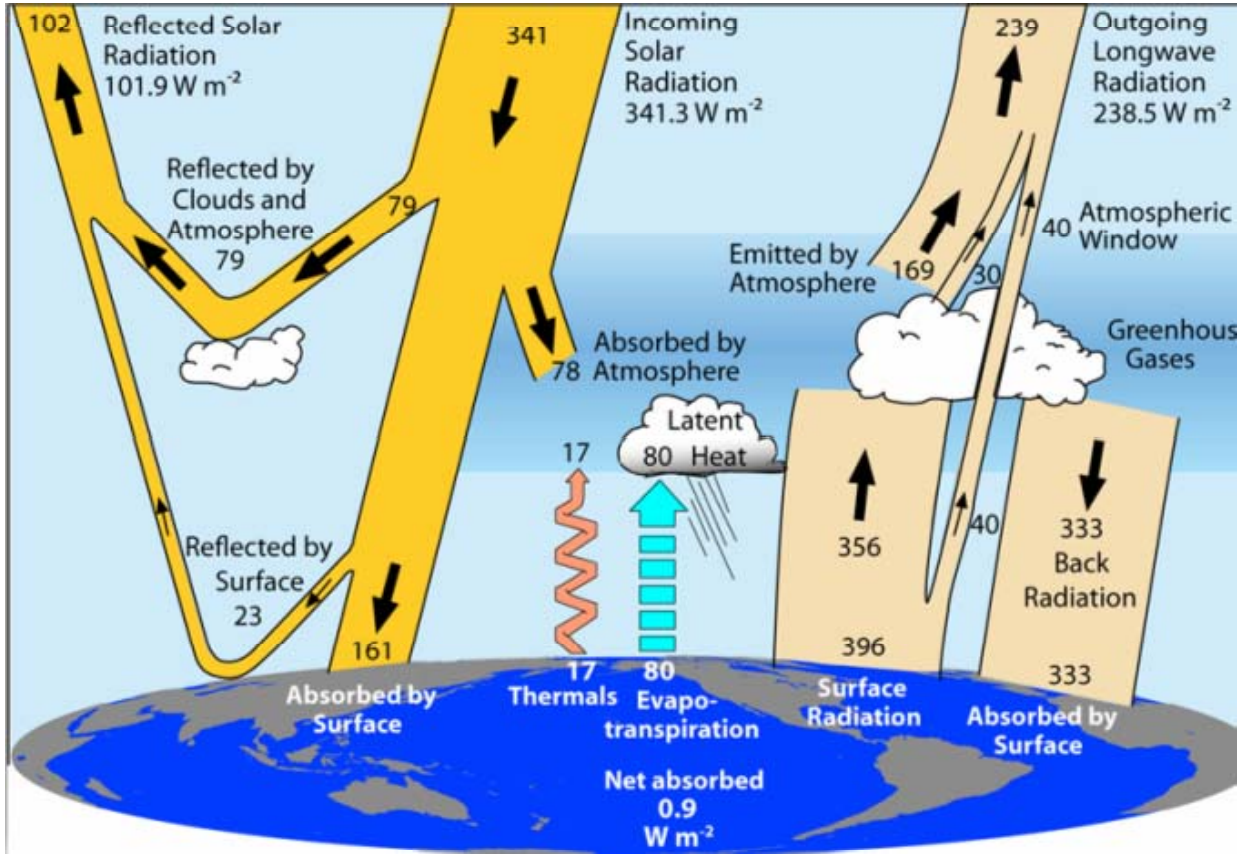
Roles of Air/Sea Exchange in the Cycles of Energy, Moisture and CO_2

Mark A. Bourassa, Toste Tanhua, Carol Anne Clayson, Jim Edson, Sarah T. Gille, Sergy K. Gulev, Johnny Johannessen, Simon A. Josey, Masahisa Kubota, Matt Mazloff, Seb Swart, Brain Ward, Bob Weller, Lisan Yu

Outline

- Review of cycles and the roles of surface fluxes
- The importance of regional fluxes
- Issues with estimation of fluxes and recent breakthroughs for the oceans
- A way forward for the oceans

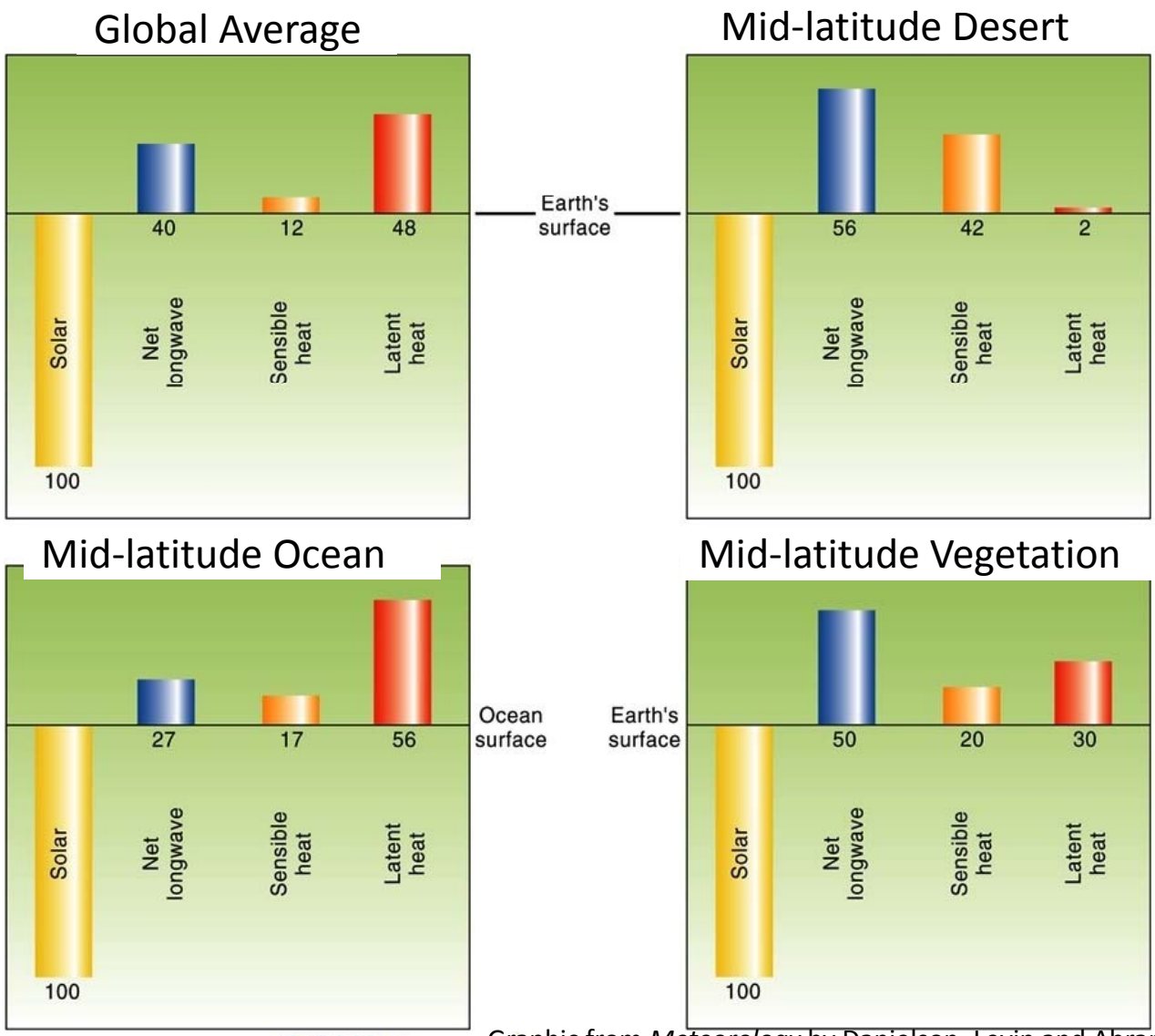
Energy Cycle – Transports in Wm^{-2}



- Numbers are good ball park estimates, but not consistent with GCOS observations

Graphic from Trenberth et al. (2009) – based on model

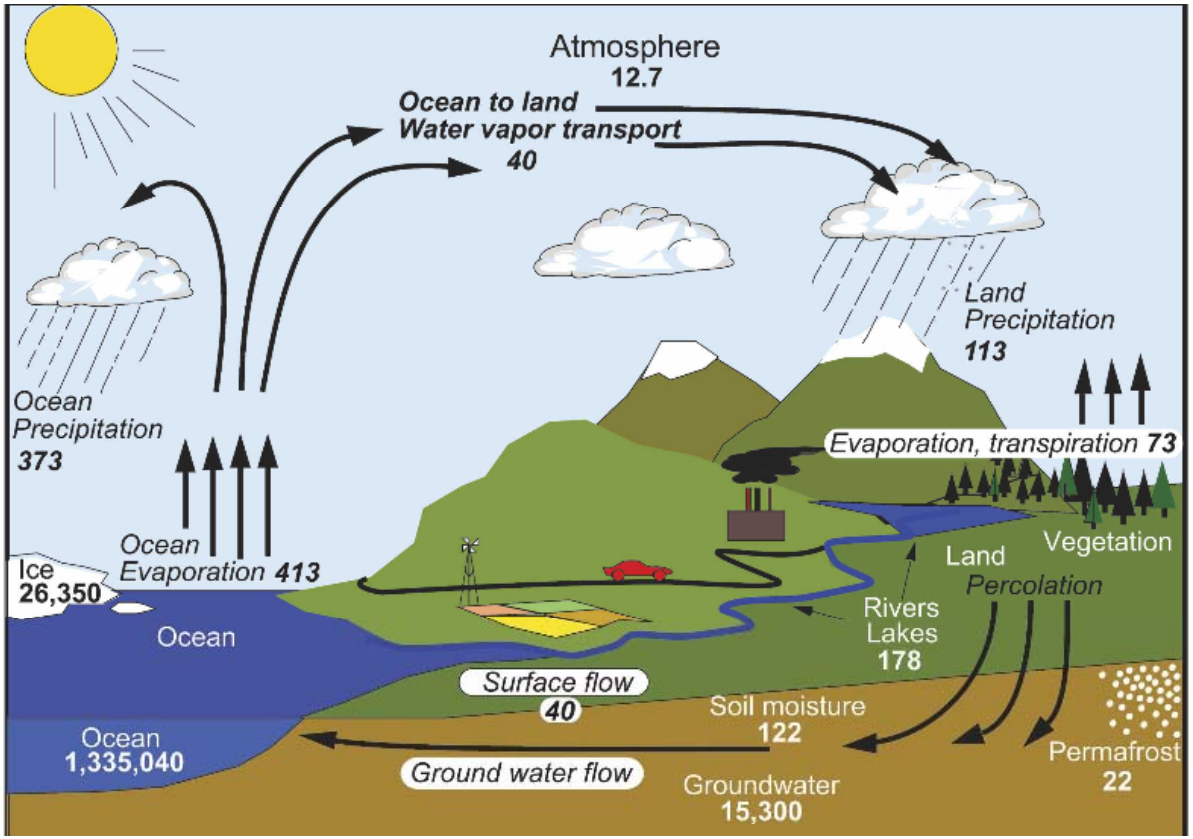
Regional Fluxes Are Far from the Global Average



Graphic from *Meteorology* by Danielson, Levin and Abrams

- Examples of how surface fluxes change with difference types of surfaces.
- 100 units of solar radiation is assumed.
- Regionally, the assumption of balance is questionable because of transport and seasonal and diurnal imbalance

Water Cycle

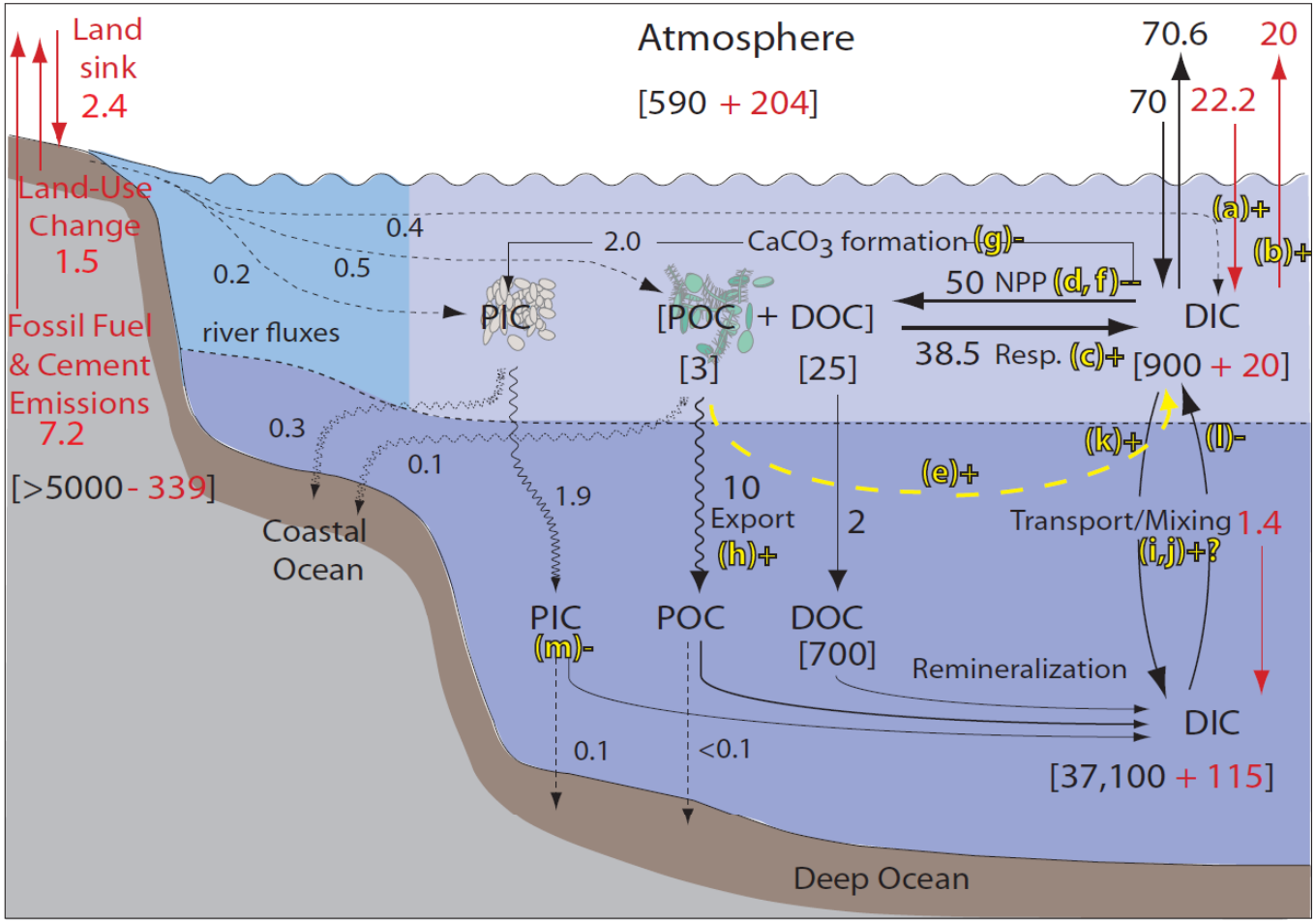


- Reservoirs in units of 1000km^3
- Transports in units of 1000km^{3}yr^{-1}
- Evaporation, precipitation, and atmospheric transport are greater than atmospheric storage, when totaled over a year

Changes in the energy budget change the latent heat flux and hence the water cycle and hence changes in the patterns of weather

Graphic from http://earthscience.stackexchange.com/questions/233/what-is-the-percentage-of-the-global-water-cycle-evaporation-precipitation-th

Carbon Cycle



- Numbers in brackets are storages
- Numbers without brackets are fluxes
- Red is anthropogenic
- Black is natural
- Again, there are large regional differences

Flux Units of PgC/y (Petagram Carbon per year), sensitive to changes in surface stress and temperature

Graphic from Sabine and Tanhua, 2000, Annual Reviews of Marine Science

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Calculation of Global Average Net Fluxes

- Globally (over ocean) averaged net fluxes of energy, water, and carbon are not determined from the sum of regional observations of fluxes
- They are determined by the observed change in the ocean, which is a good integrator of changes due to fluxes

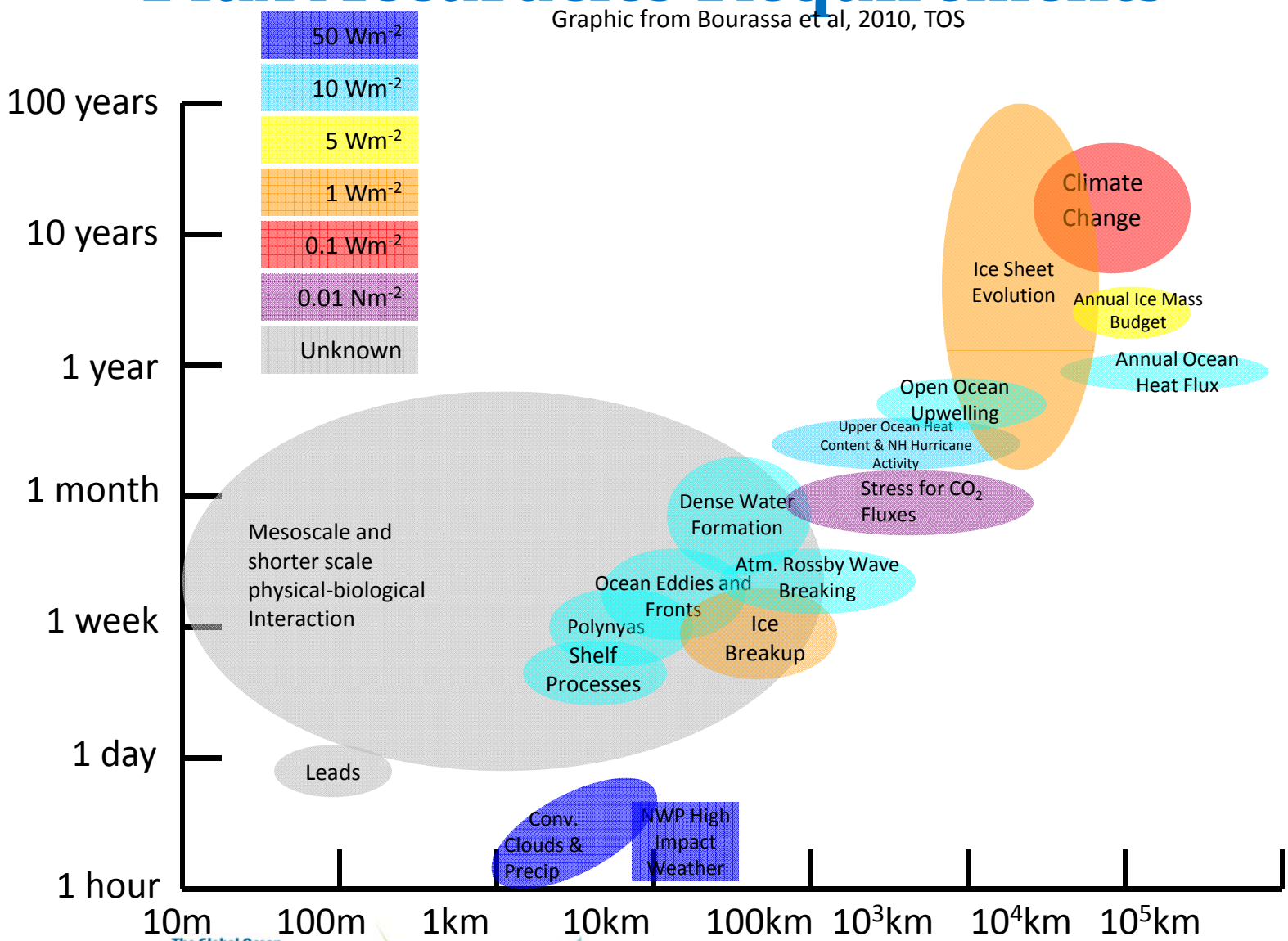
- At this time, we cannot measure fluxes accurately enough to average them to determine the rather small global and annual average net changes
  - Biases need to be reduced
- However, regional fluxes can have a quite substantial impact on the transport of energy, water and carbon

Regional Fluxes

- Regional Stress (momentum flux)
  - Largely influences upper ocean currents (stress)
  - Largely influences deep ocean currents (line integral of stress)
  - A large influence on upper ocean upwelling and downwelling
- Net Energy fluxes (radiative fluxes + latent heat + sensible heat)
  - impacts temperature of the ocean surface; weather patterns
  - Changes the density of water and influences circulation
- Water fluxes (precipitation – evaporation + runoff)
  - Impacts the salinity
  - Changes the density of water and influences circulation
  - Latent heat release powers a great deal of active weather
- Carbon Fluxes are highly impacted by local transport

High Latitude Estimates of Flux Accuracies Requirements

Graphic from Bourassa et al, 2010, TOS



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Traditional Approach to Determining Fluxes

- Turbulent have traditionally been estimated based on mean ECVs near and at the air/sea interface
- Stress: **vector wind**, **sea surface temperature**, **air temperature and humidity**, **surface pressure**, **vector current**, **sea state**
- Latent heat flux and sensible heat flux: **scalar wind**, **sea surface temperature**, **air temperature and humidity**, **surface pressure**, **(vector surface current)**, **sea state**, **evaporation over land**
- CO_2 Flux: **wind speed**, **sea surface temperature**, **pCO_2 in air and in water**
- These traditional estimates, when calculated with GCOS accuracy requirements on the input variables have
  - uncertainties of about $25Wm^{-2}$ in a monthly average, and
  - the potential for large regional and seasonal biases.
  - Measuring **stress** largely removes these regional and seasonal biases (but not other biases)

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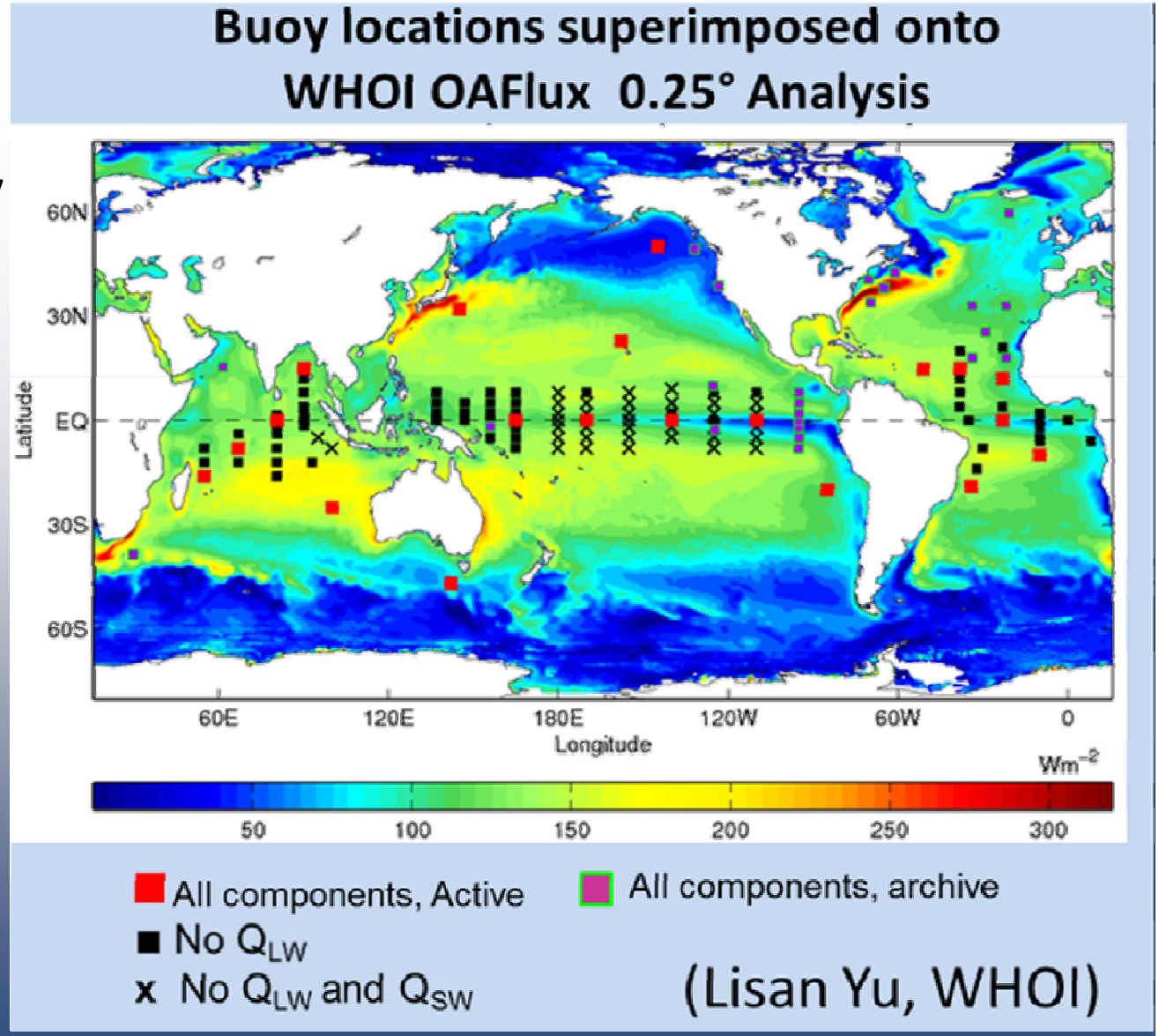
Spatial Coverage of In Situ Observations is Sparse

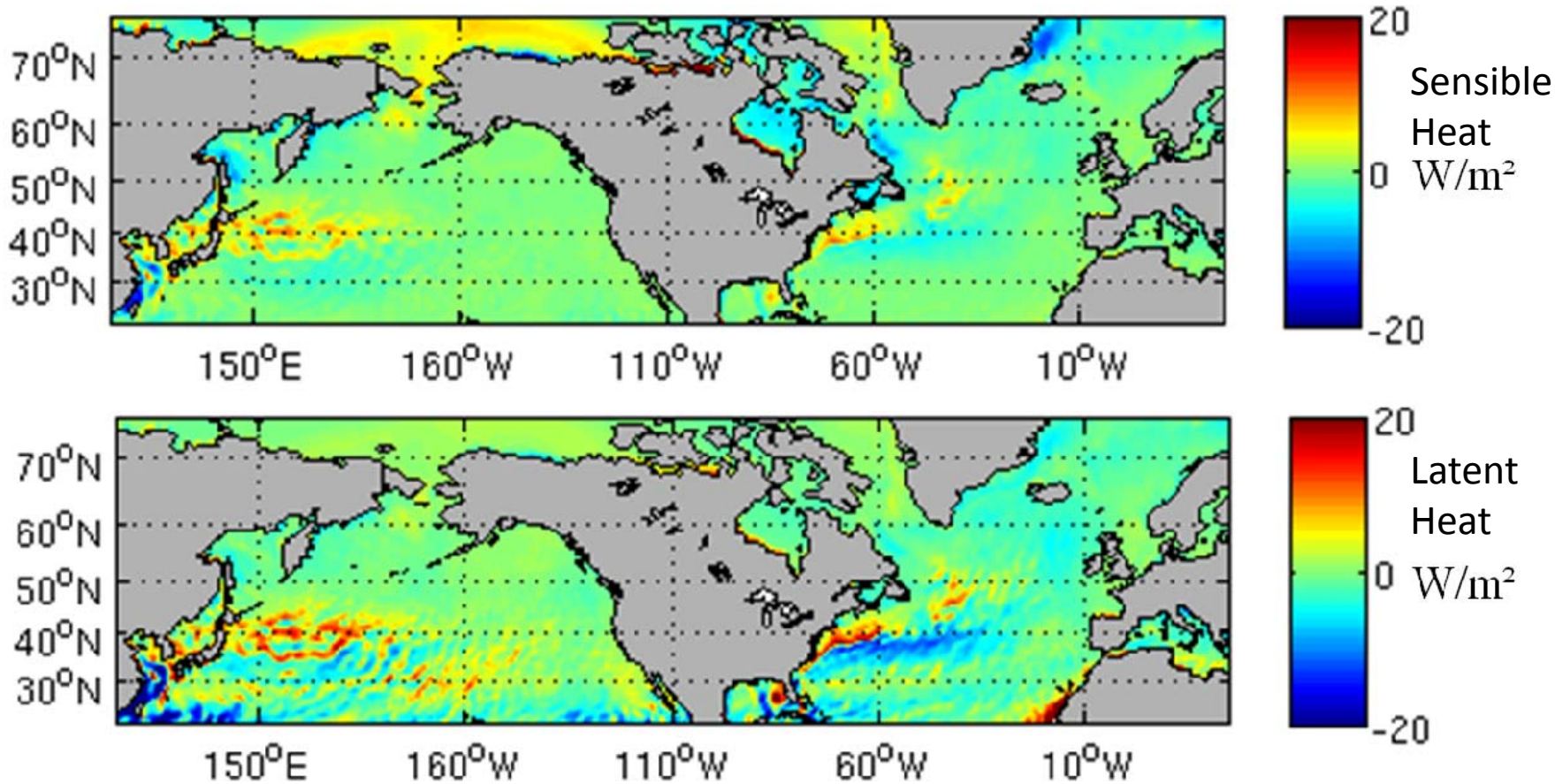
- There is a lack of clearly defined measures of accuracy to validate existing ocean flux products.
- Buoy air-sea measurements set the accuracy standard for gridded flux products but they are limited.
- NWP is not a suitable alternative, particularly in the tropics and high latitudes



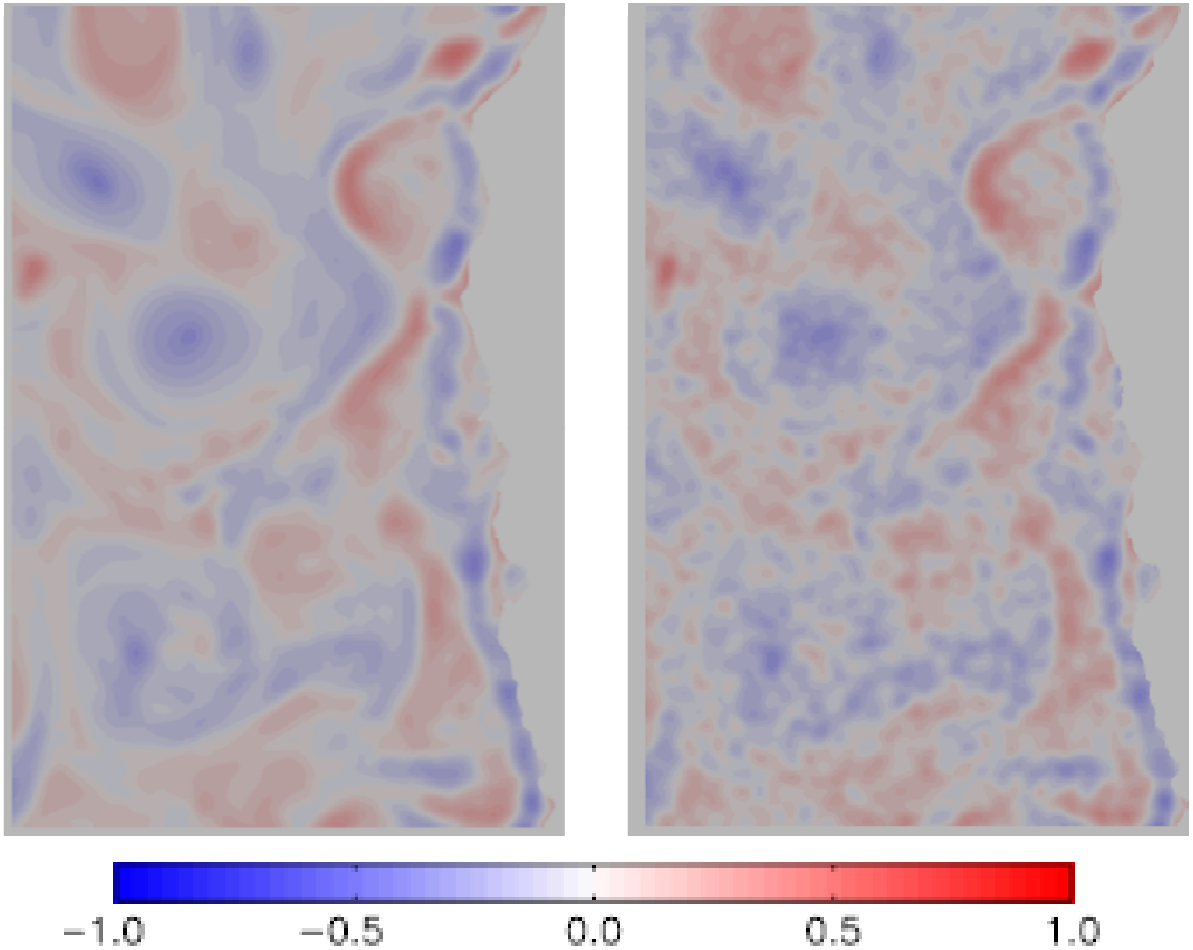
Example Showing Importance of Small Scales

- The next 2 slides show examples of changes in fluxes associated with small scale (25 to 1000km)
  - Sea surface temperature features impacting seasonally averaged latent and sensible heat fluxes
  - Changes in upwelling due to small scale changes in surface currents

Example: Changes in Winter Season Heat Fluxes



‘Small’ Scale Change in Upwelling



- Modification of traditional upwelling due to small scale gradients in currents, proportional to 1 + number in plot
- Left = modeled
- Right = what we think we can observe in the future
- Both are smoothed to 50km and about 15 days

Traditional calculation is largely a function of surface stress

Graphics from Dudley Chelton and Michael Schlax

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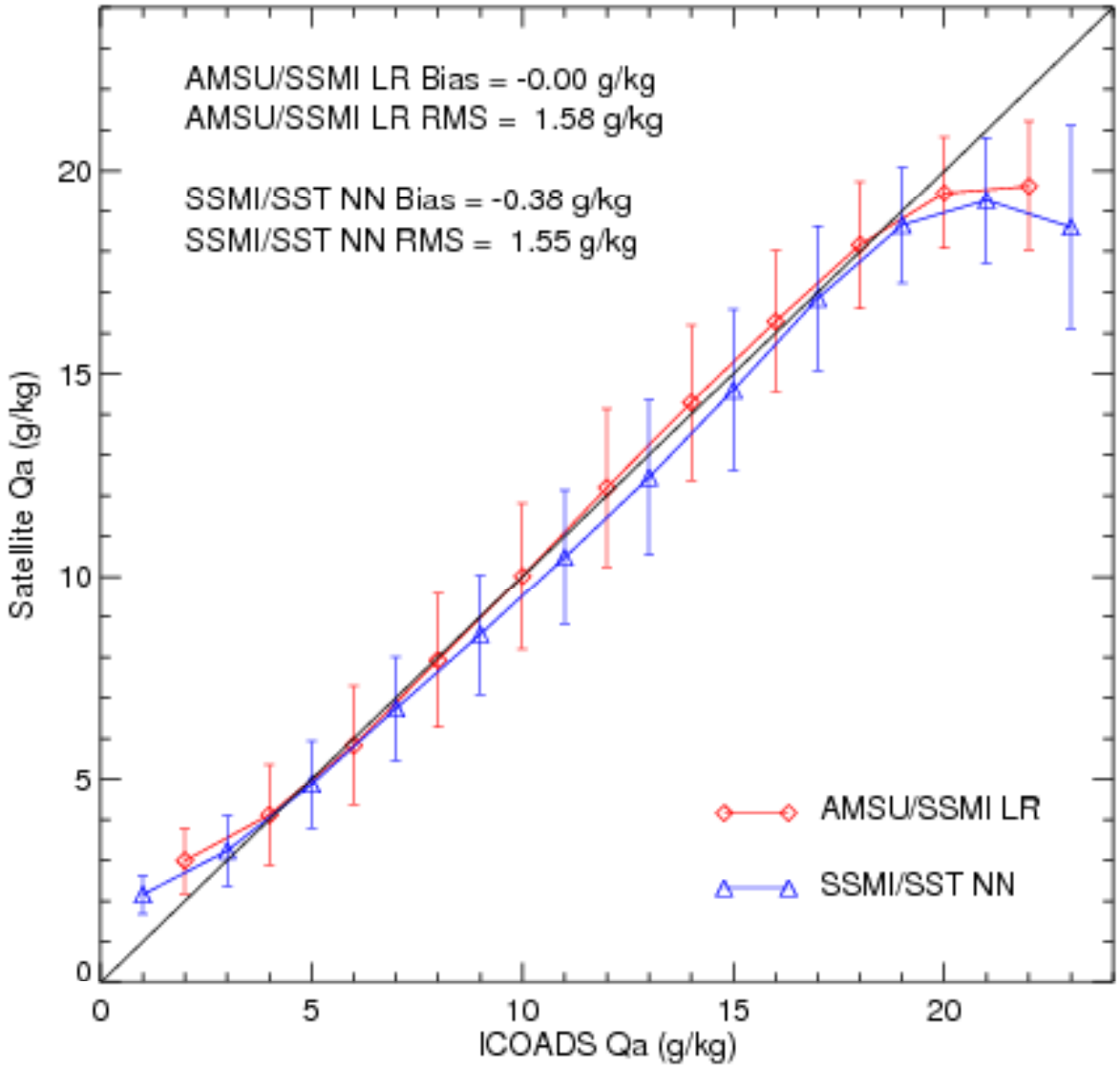
Outstanding Issues and Solutions

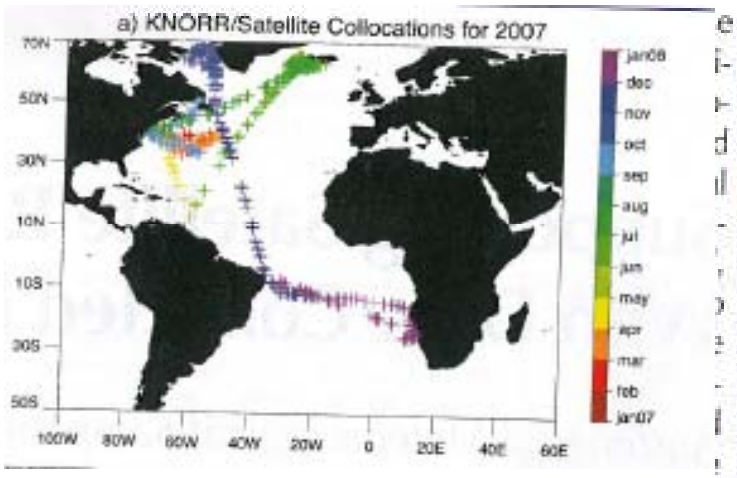
- Sampling from in situ observations provides insufficient coverage over the oceans
  - Particularly outside the tropics
- However, it is critical for calibrating satellite data
  - For which calibrations for latent and sensible heat fluxes have historically been rather poor
  - But are now demonstrated to be quite good – due to a better approach to calibrating the satellite observations

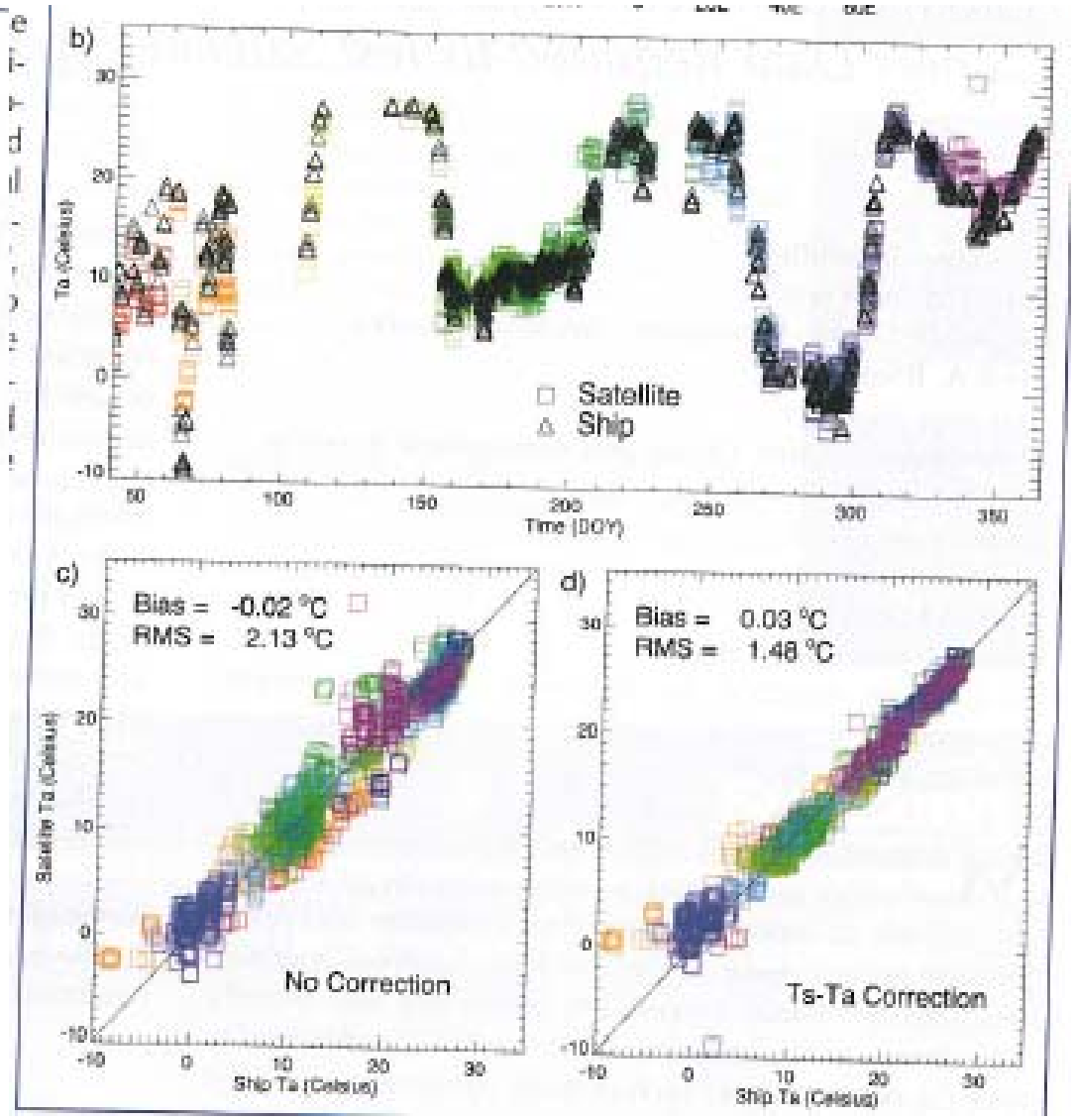
Comparison of Two Retrieval Techniques



- Blue – Roberts et al. (SeaFlux)
- Red – Jackson and Wick
- Need more data to improve extremes
- Differences in biases are likely due to differences in quality of calibration data

Evaluation of Satellite Retrievals of 10m Ta and Qa





- Comparison to research vessel observations from SAMOS (research vessels)
- Graphic from Darren Jackson, Gary Wick and Shawn Smith

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Summary: Recent Successes and a Way Forward

- We can observing stresses through satellites
- We can observe sensible and latent heat fluxes through satellites
  - All the observations can (and are) taken from single satellites
  - Therefore we can calibrate retrievals of latent and sensible heat rather than working through bulk variables
- We need a more in situ observations of fluxes to better calibrate these flux observations
  - Particularly for removal of biases
  - To account for the diurnal cycle far better than can be accounted with satellite data
- Ocean surface vector stress, latent heat flux and sensible heat flux are new ECVs

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