Estimation of Sea Surface Heating Anomalies During the Last Two Decades

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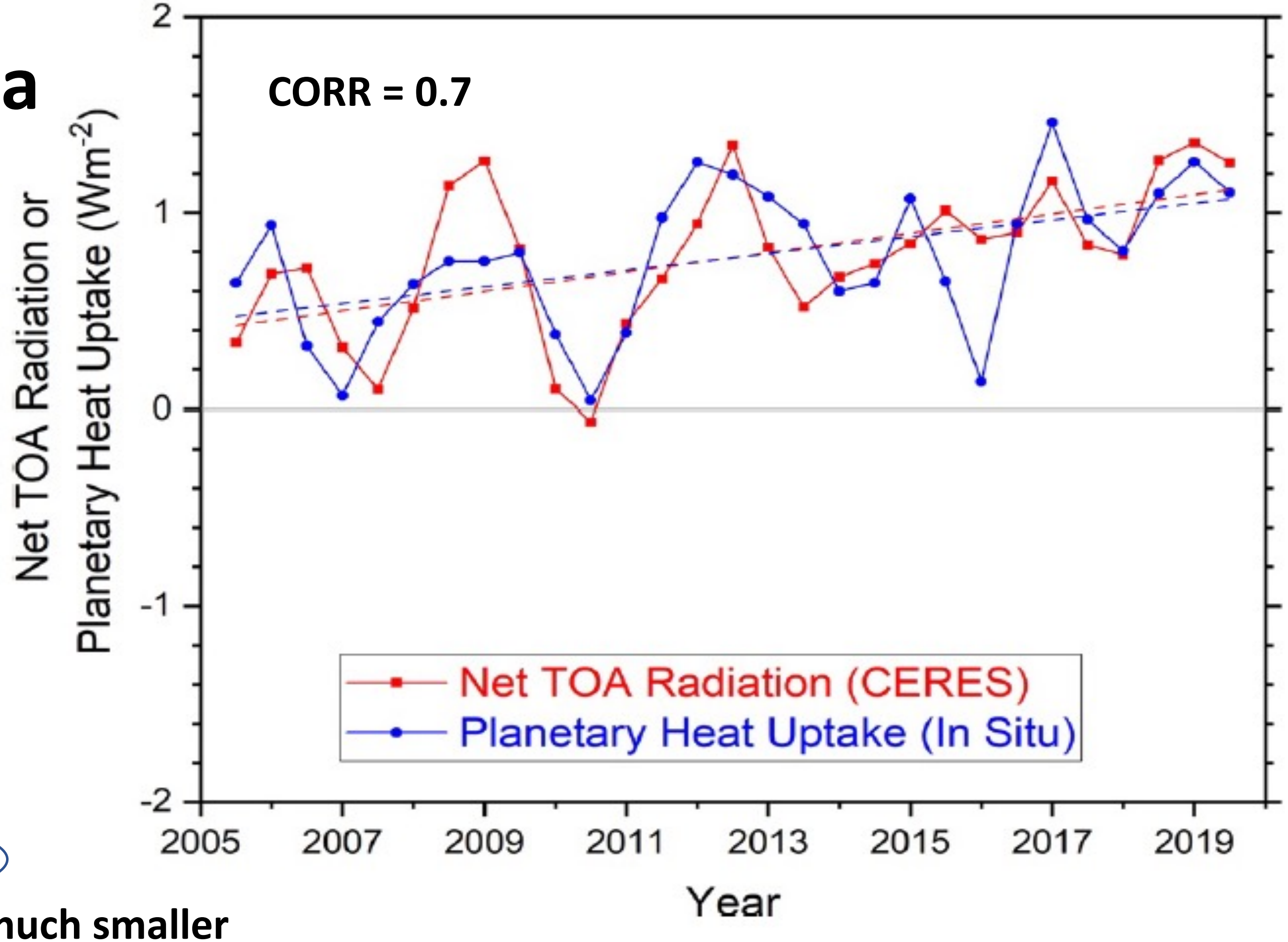
Introduction

Global climate change: warmer temperature, melting ice and sea level rise. Loeb et al. (2021) found accelerated heating, mainly for the ocean, from both TOA net radiation and in-situ observations.

Earth's Energy Imbalance and Global Heating



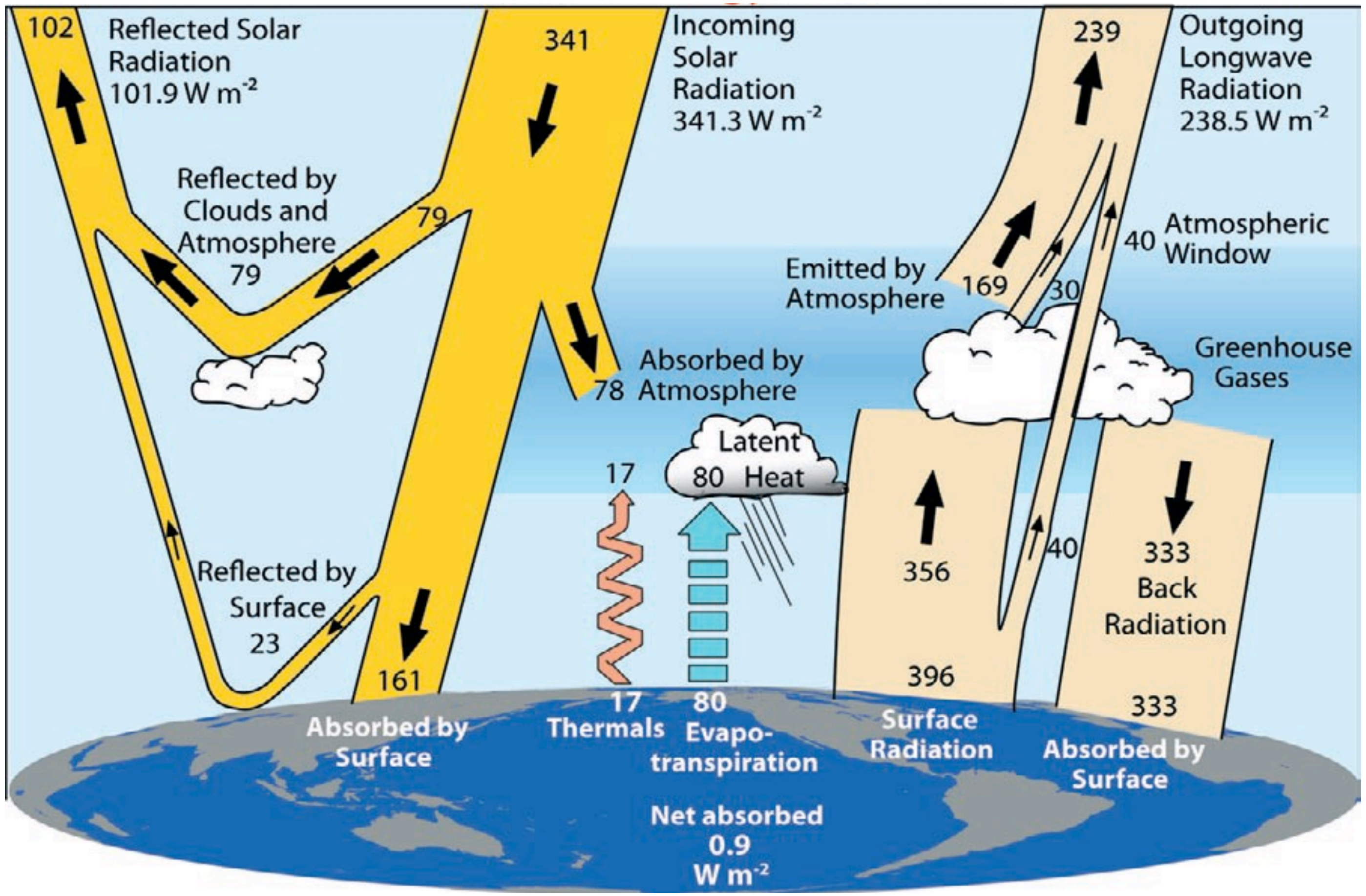
In-situ global net heat uptake: 0.77 ± 0.06 Wm^{-2}
Ocean: 0.62 ± 0.05; Deeper ocean: 0.062 ± 0.038
Land: 0.037 ± 0.004; Melting ice: 0.031 ± 0.006
Air T/q: 0.014 ± 0.009

much smaller

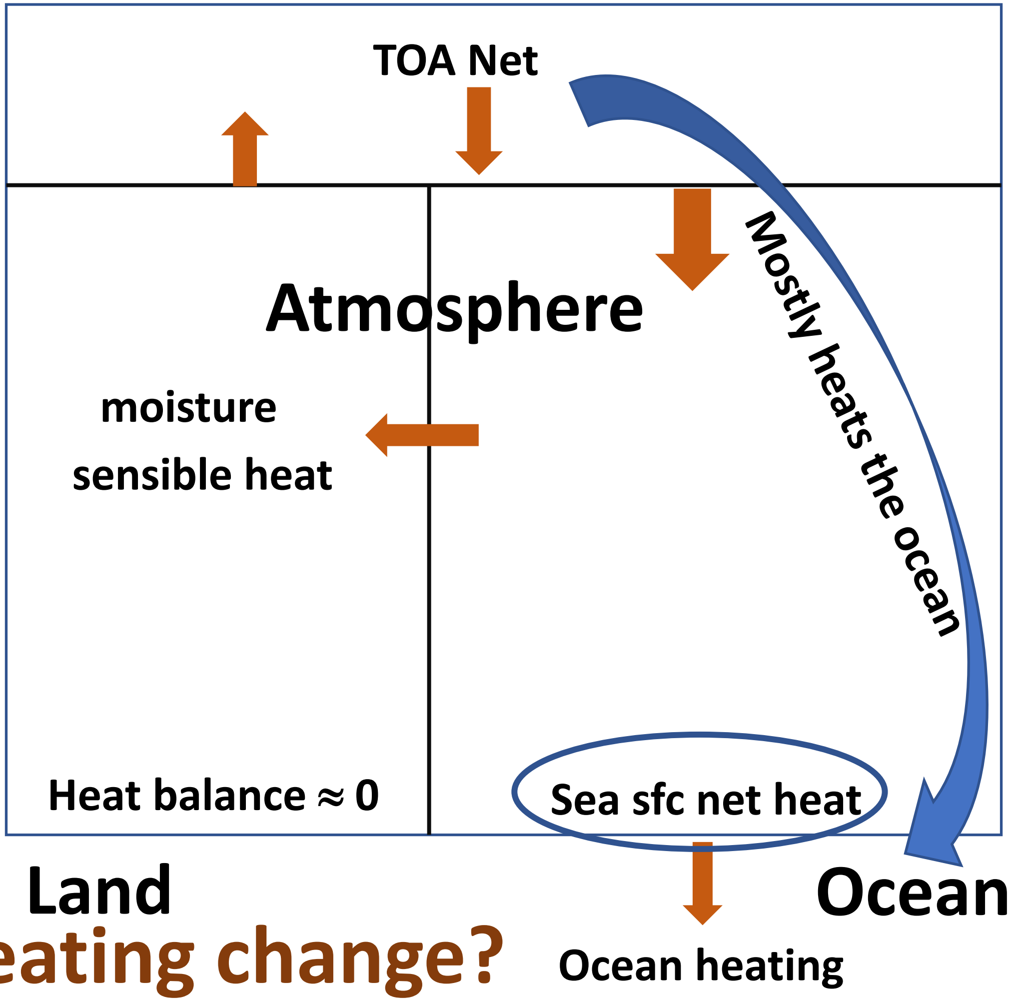
The trends of 0–2,000 m ocean and CERES TOA heat flux anomalies are is 0.43 ± 0.40 W m^{-2} decade^{-1} and 0.50 ± 0.47 W m^{-2} decade^{-1} , respectively. (Loeb et al., GRL 2021)

Introduction (conti.)

Other energy cycle components of the climate system could have related variations due to the fundamental linkage among these components within the energy cycle, especially over oceans such as turbulent heat (TH) flux.



Trenberth et al., BAMS, 2009

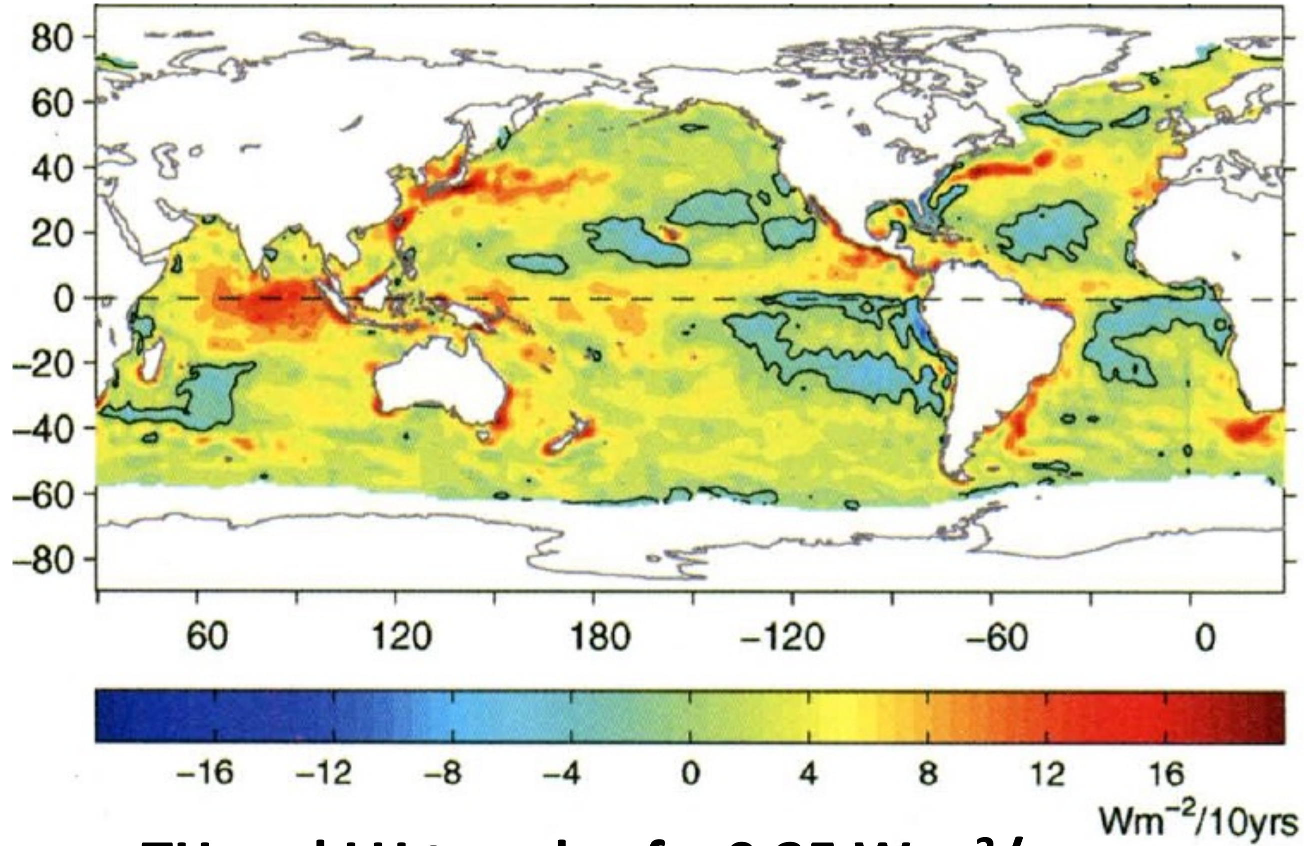


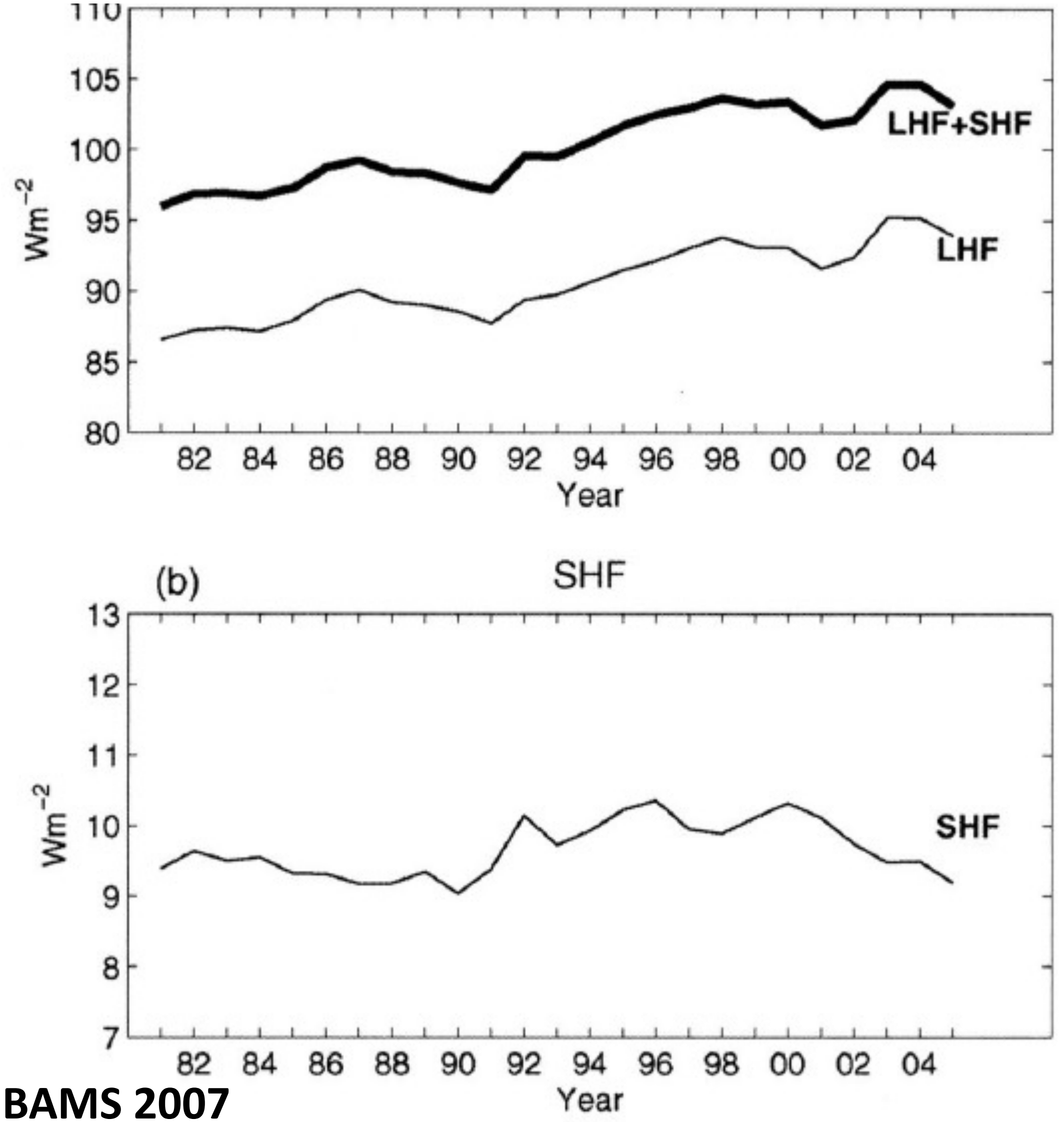
sea sfc heating change?

Previous Sea Surface Turbulent Heat Flux Estimates

(Objectively Analyzed Air-sea Fluxes, OAFlux)

Annual mean systematic error could be about 7 W/m^2 or 8% (Cronin et al. FMS, 2019; Yu et al., JC, 2017)





Large TH and LH trends of ~ 0.35 Wm^{-2}/year were found. Explained as the changes of meteorological variables affecting these fluxes, especially SST, Δq and wind.

Yu and Weller, BAMS 2007

Introduction (conti.)

- Global climate change: warmer temperature, melting ice and sea level rise. Loeb et al. (2021) found accelerated heating, mainly for the ocean, from both TOA net radiation and in-situ observations.
- Other energy cycle components of the climate system could have related variations due to the fundamental linkage among these components within the energy cycle, especially over oceans.
- This study tries to analyze ocean heating changes from surface turbulence and radiation observations during the 21st century.
- Data used: OAFlux data V3 monthly; CERES: EBAF Ed4.1 (monthly)

Oceanic Heat Flux and Energy Balance

- ❖ **Ocean heating from surface to deep ocean:**

  $R_{net\_sfc} - TH - \nabla \bullet F - OH = 0;$ (LH + SH = TH; SW + LW = R_{net_sfc})

  Or, global ocean heating: $OH = R_{net\_sfc} - TH \approx R_{net\_TOA}$

- ❖ **Ocean heat balance anomaly:**

  climatological heating removed; bias potentially reduced

  $\Delta OHB = \Delta TH - \Delta R_{net\_sfc} + \Delta OH = 0$ (focusing on TH fluxes here)

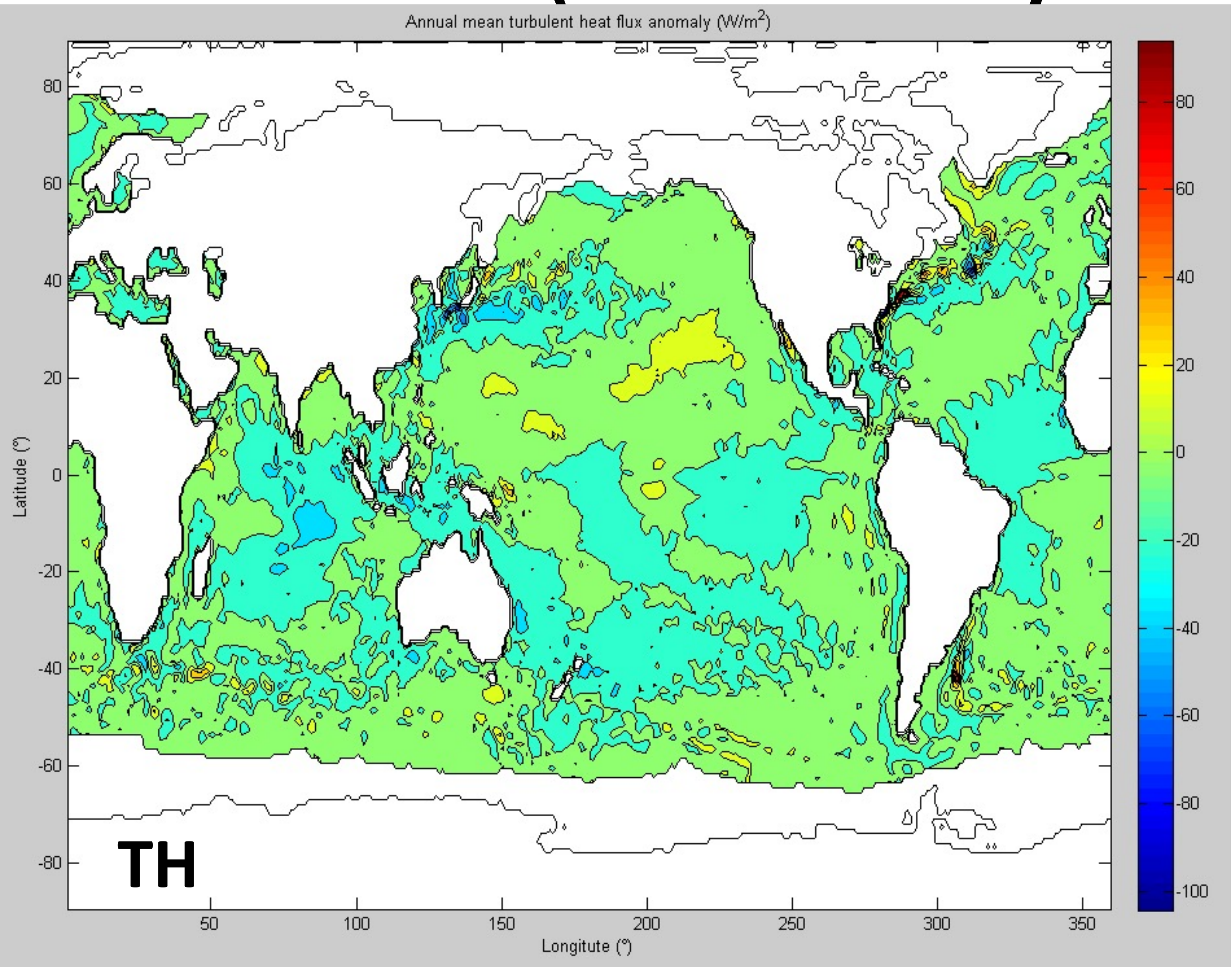
- ❖ **Climatology: 2001 – 2005**

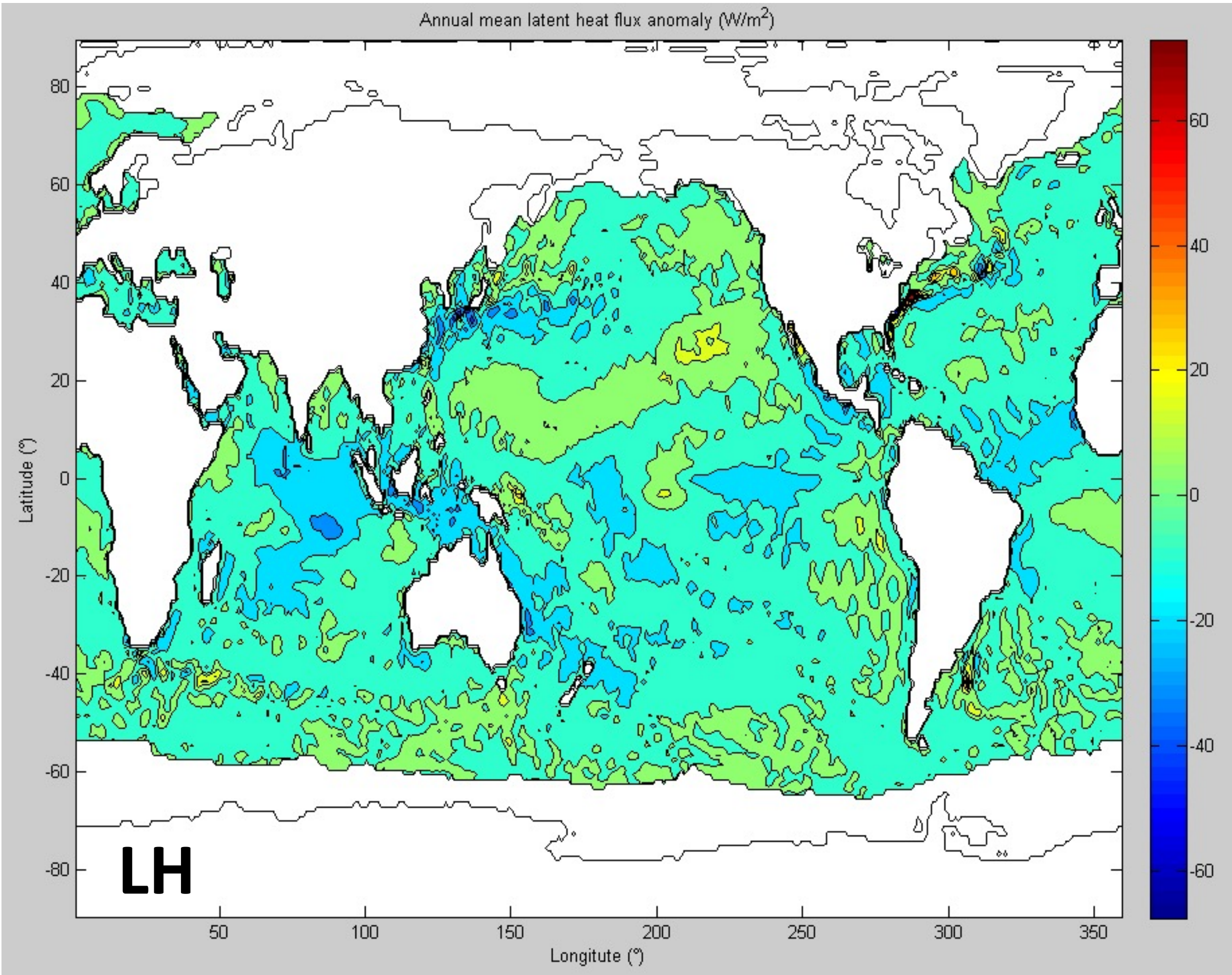
- ❖ **Observationally-based estimates of these anomalies may reveal systematic errors and/or uncertainties.**

SW & LW: downward short-/long-wave radiative fluxes, respectively; LH & SH: upward latent/sensible heat fluxes, respectively
$\nabla \bullet F$: horizontal heat transport. $\nabla \bullet F = 0$ when averaged over globe; OH: ocean heating, ocean warming, ≈ TOA Net;
note: no surface turbulent heat flux observations over sea ice

Annual mean sea sfc turbulent heat anomalies

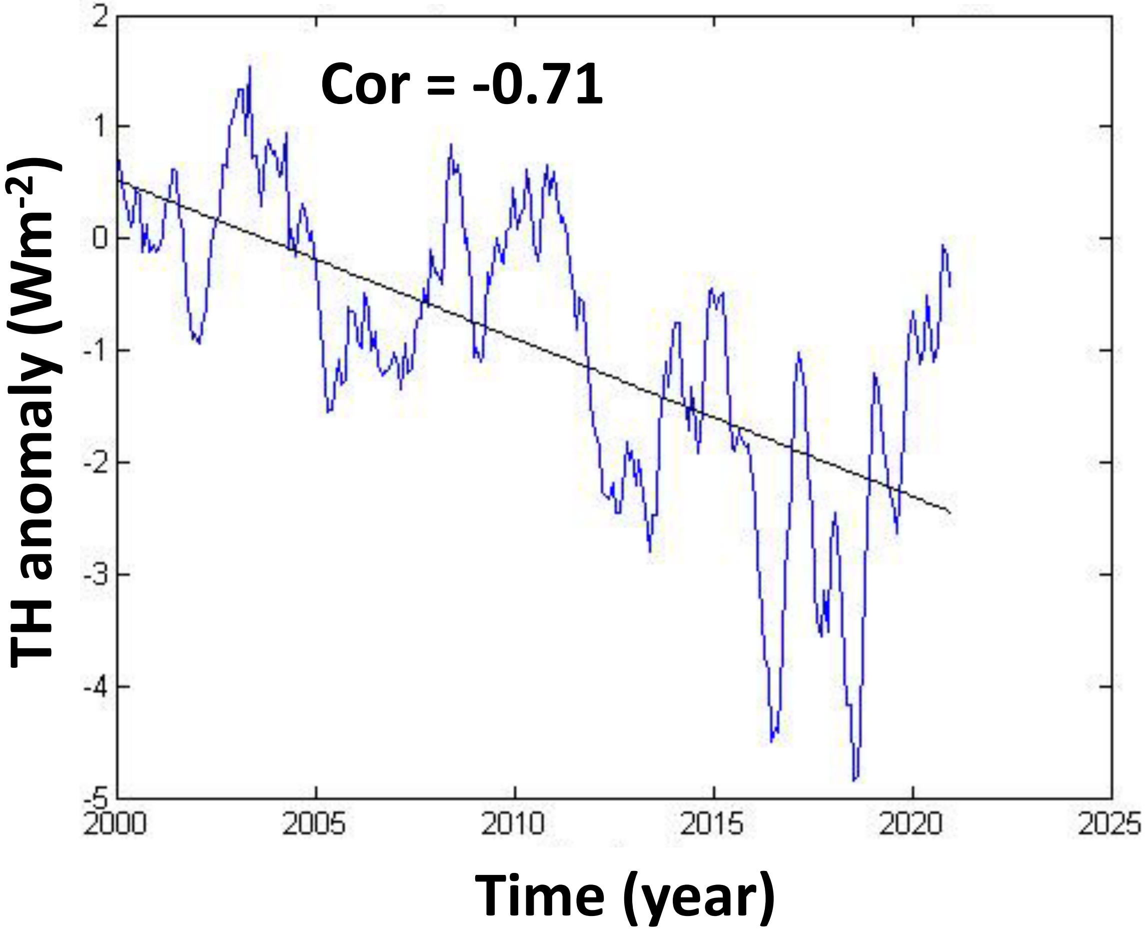
(last vs first 5 years of the two decades)

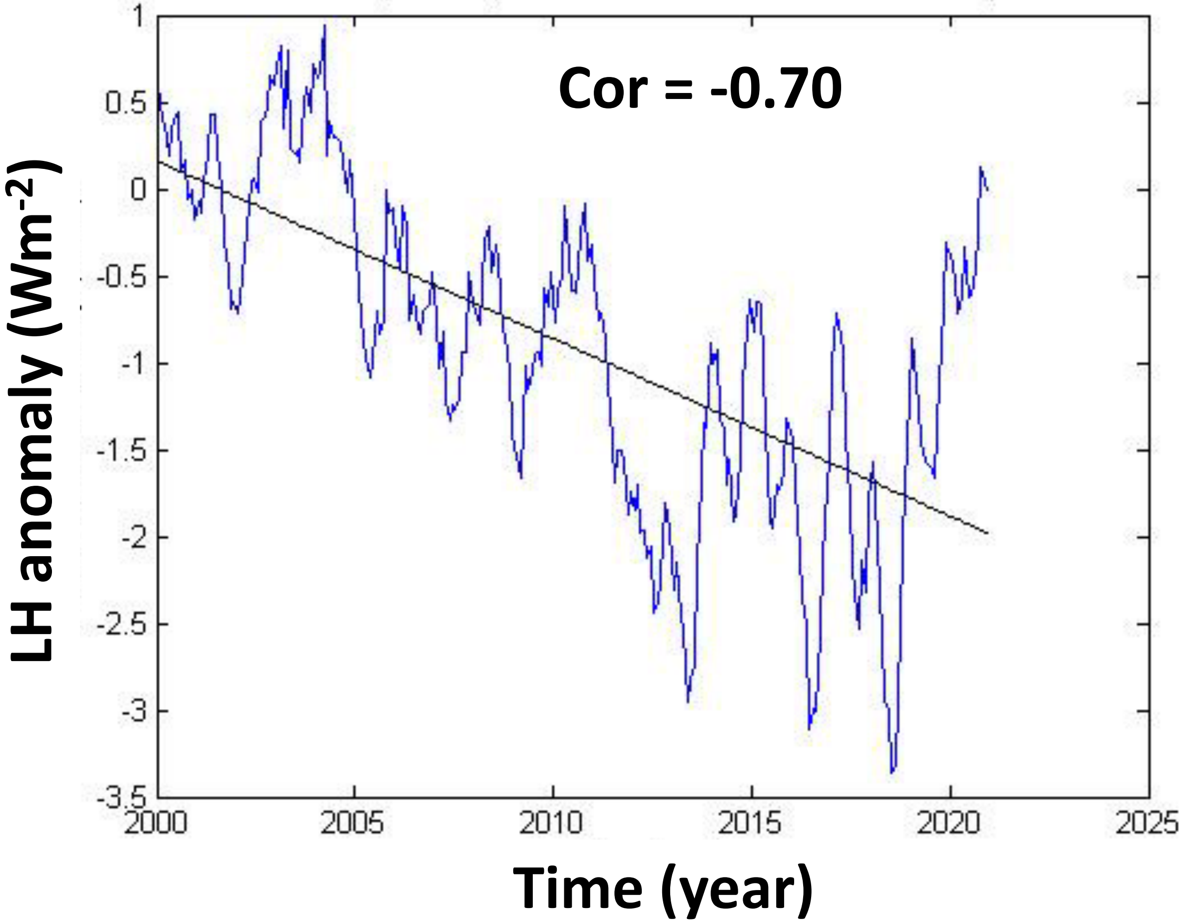




Generally, local TH changes are within 30 Wm^{-2}. Higher latitudes may have an increased TH release.
However, TH release may be decreased at lower latitudes >>> decreased TH globally.
TH and LH over Gulf Stream increased considerably, but no clear sign over Kuroshio, could be reduced.

Global monthly mean sea sfc TH & LH anomalies





Both estimated global sea sfc TH and LH fluxes showed a sign of decreases.
Reduced heat release to atmosphere would keep more heat within the ocean.

Sea surface turbulent flux estimation

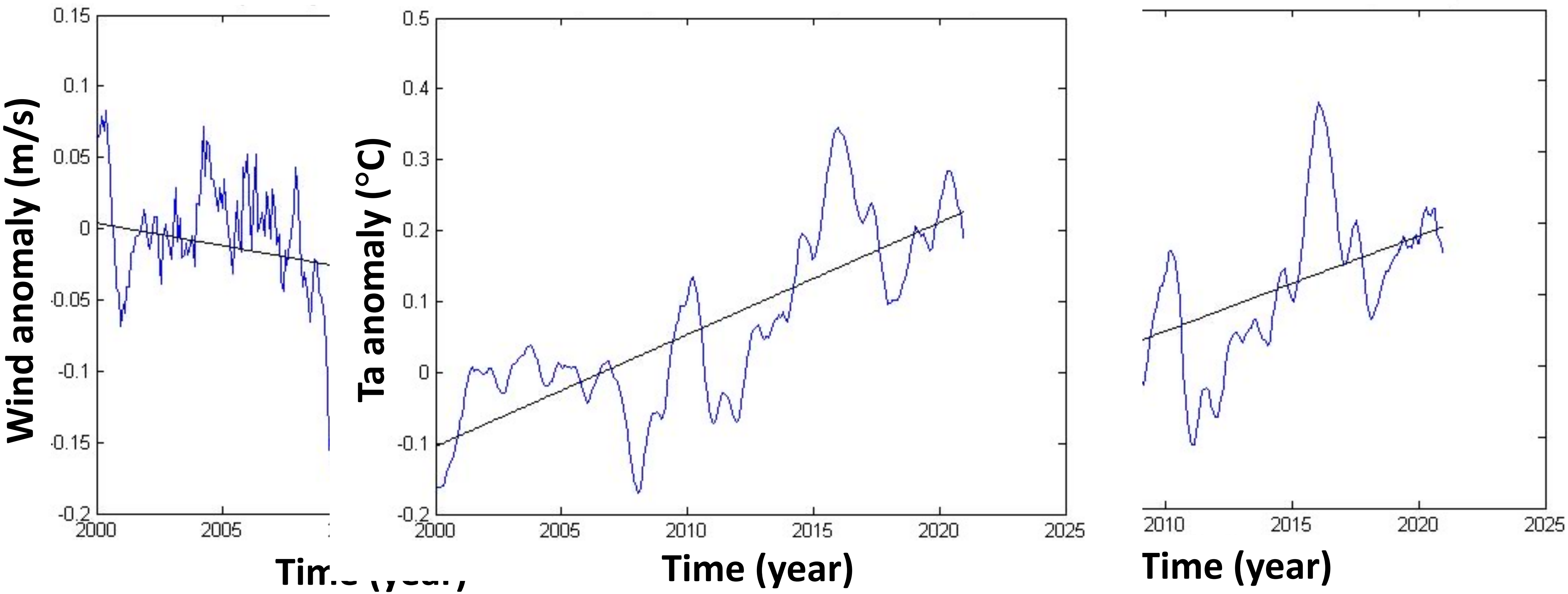
Bulk formula:

$$LH = \rho L_v C_e (U - U_s)(q_s - q_a)$$
$$SH = \rho C_P C_h (U - U_s)(T_s - T_a)$$
$$E = LH/(\rho_w L_v)$$

Annual mean systematic error could be about 7 W/m^2 or 8% (Cronin et al. FMS, 2019; Yu et al., JC, 2017)

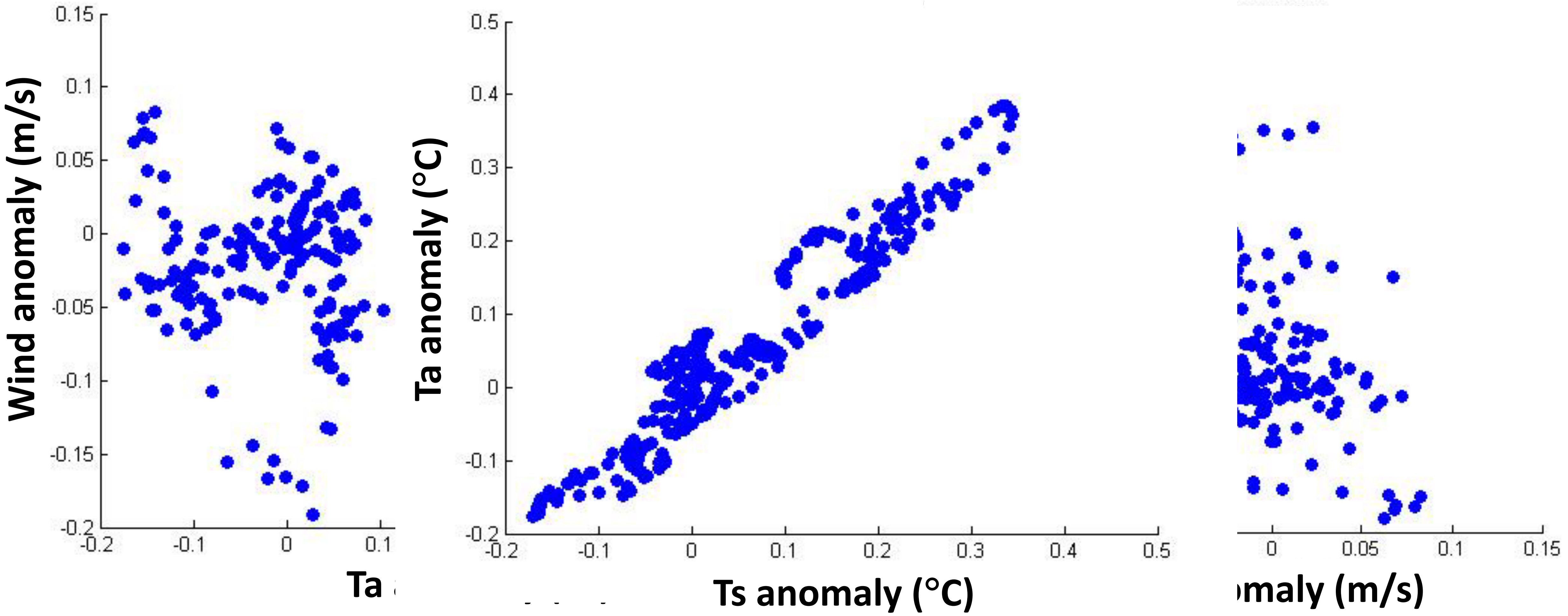
LH, SH, E*:* the latent heat, sensible heat and moisture fluxes
ρ, ρ_w *:* the air density, and sea-water density,
L_v *:* the latent heat of vaporization
c_P *: the* isobaric specific heat
c_e, c_h *:* turbulent exchange/transfer coefficients, stability dependent
U, U_s : wind speed & ocean-surface current velocity
T_s, T_a : sea-surface temperature (SST), and potential air temperature
q_a, q_s : specific humidity and saturation specific humidity

Global monthly mean SST, wind & humidity



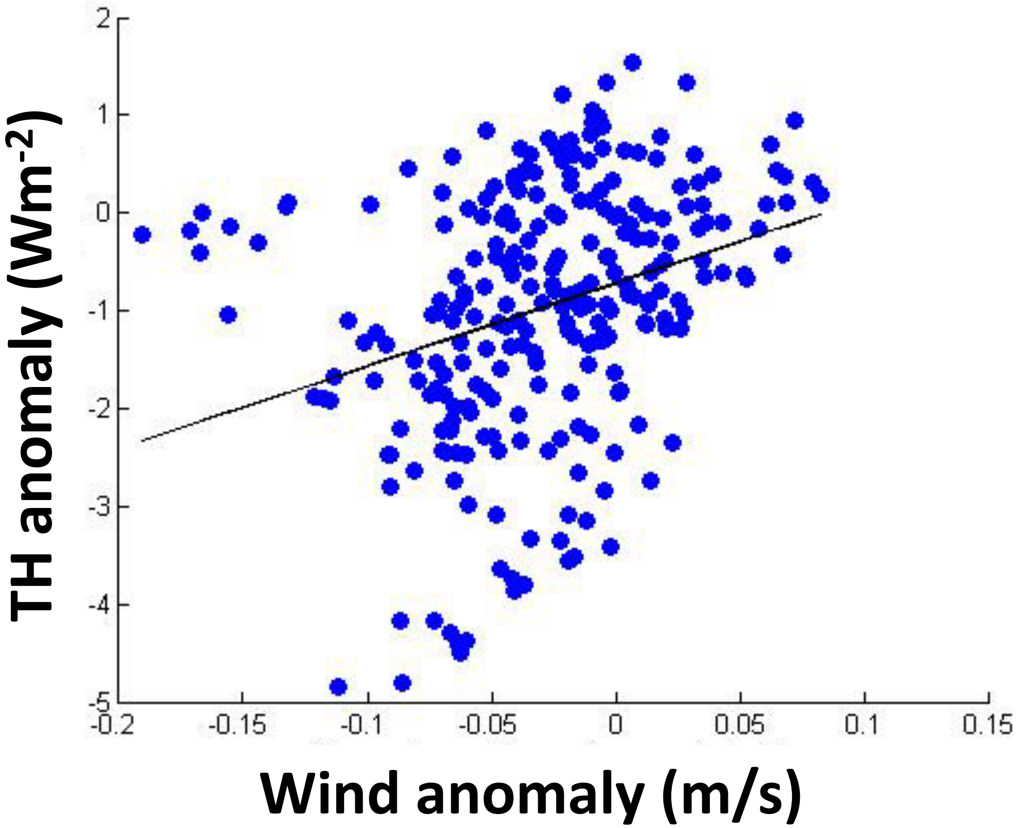
Decreased surface wind and increased SST and sea surface humidity (but unclear in change of humidity gradient).
Long-term trends in windspeed, humidity and temperature could cause estimated turbulent trends.

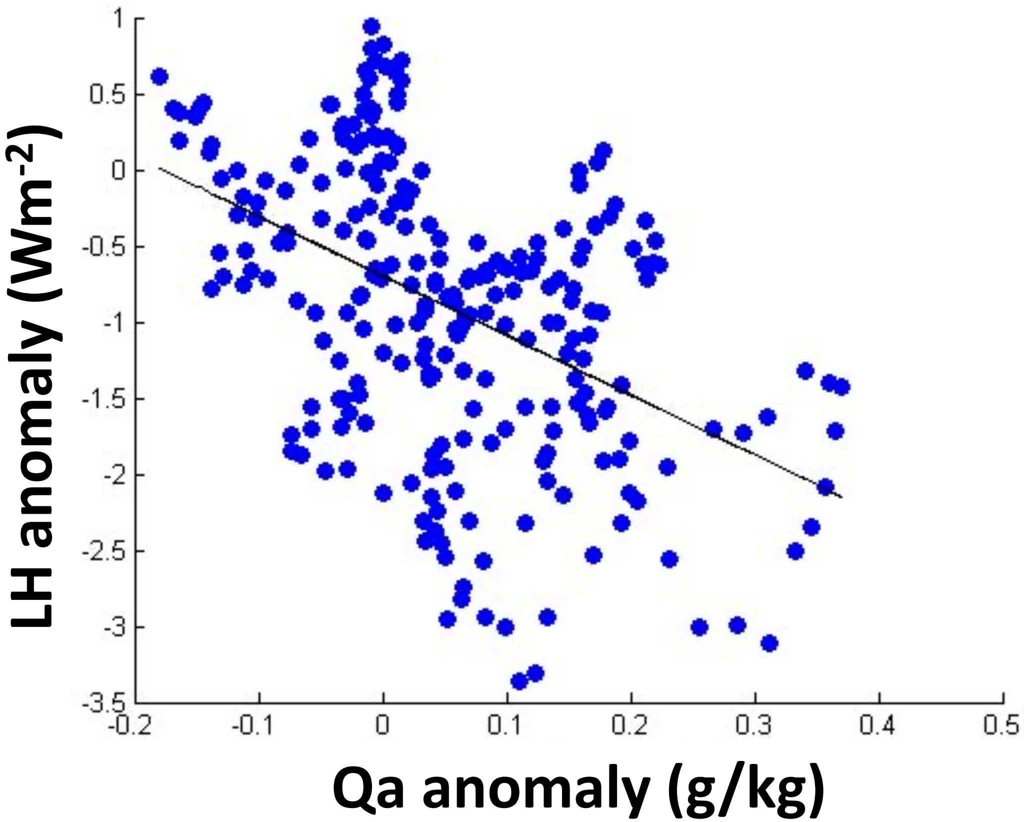
Relations among meteorological variables



Various changes in sea surface meteorological state variables: water/air temperature, humidity, and wind. Bulk formula and parameterized Ta vs Ts could generate spurious variations.

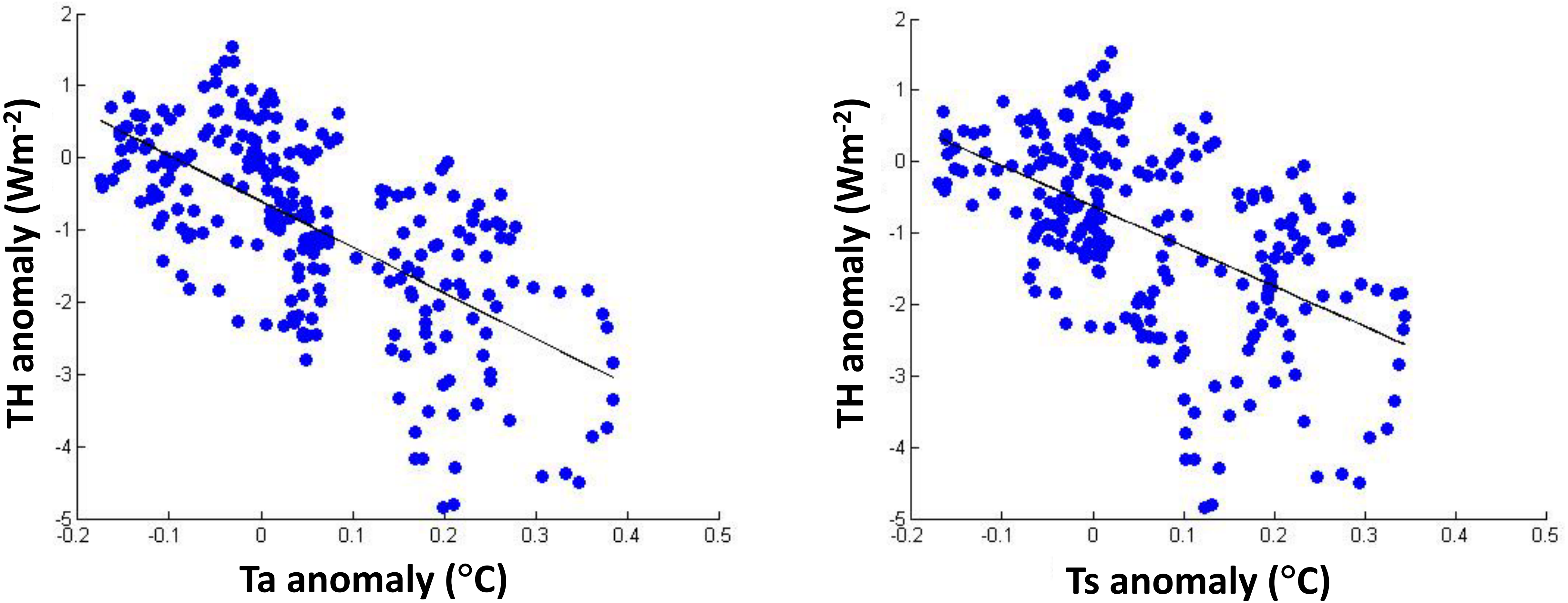
Sea fluxes with meteorological variables





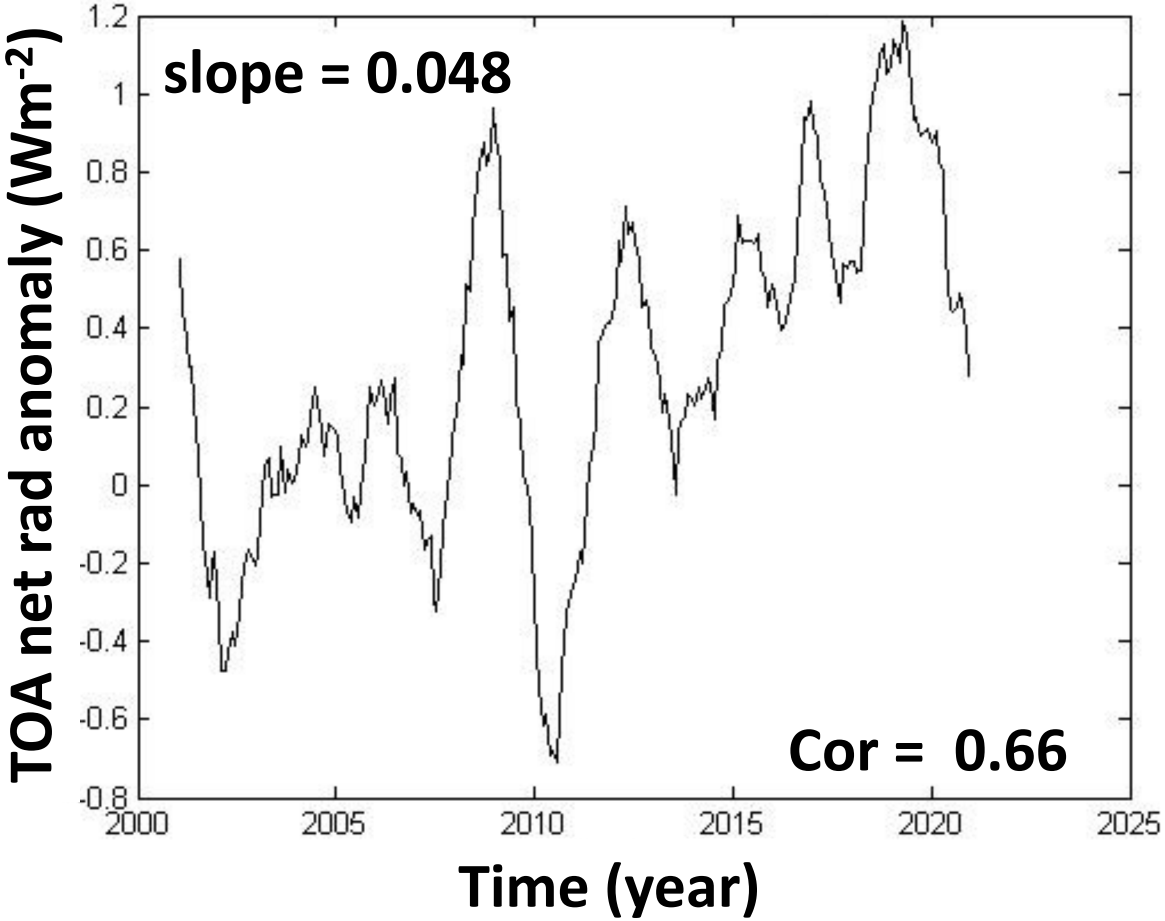
The estimated decreases in TH and LH fluxes are likely associated with the decreased sea surface wind and increased sea surface humidity (or decreased humidity gradient) estimates.

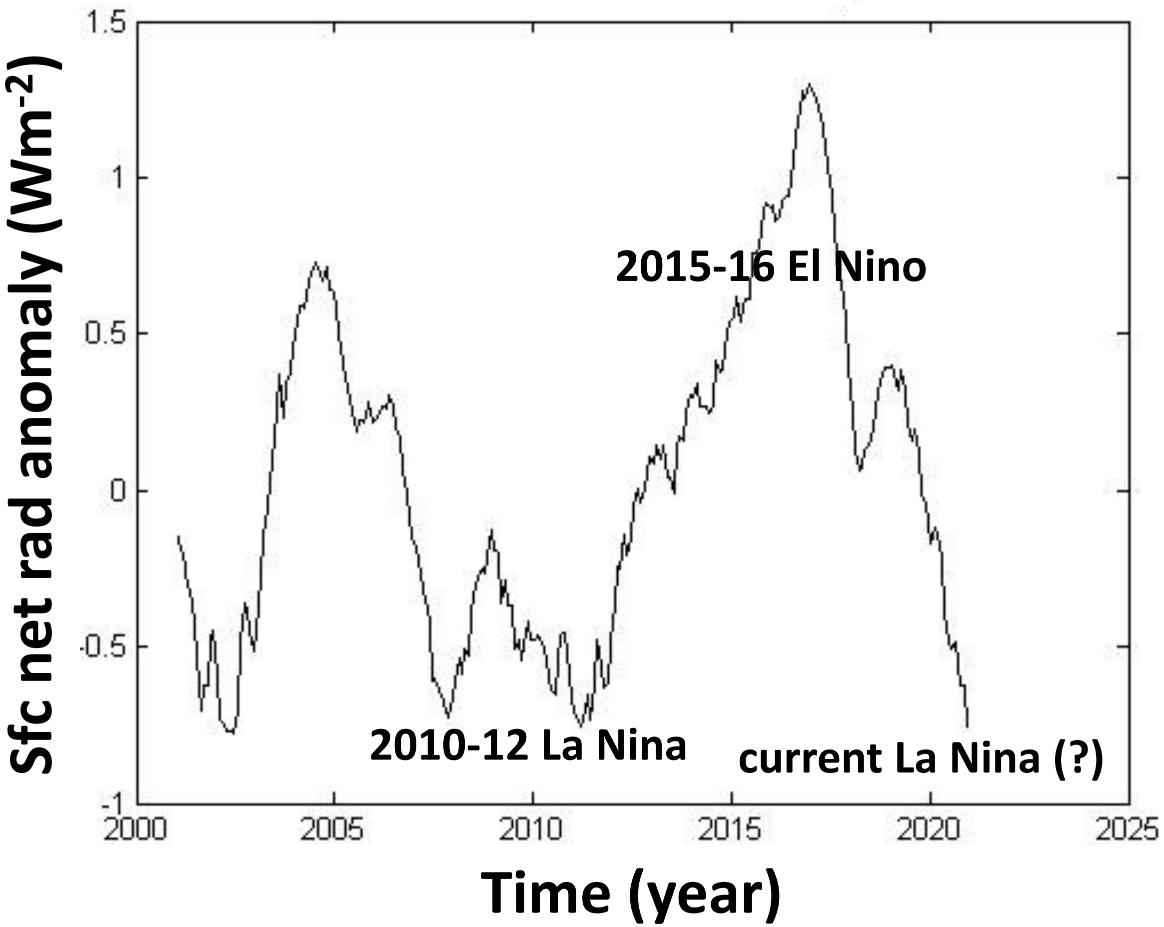
Sea sfc fluxes with meteorological variables (cont.)



Ta, along with Ts, is directly related to flux estimates. However, Ta CANNOT be observed remotely.

TOA & sfc net radiation anomalies over ocean



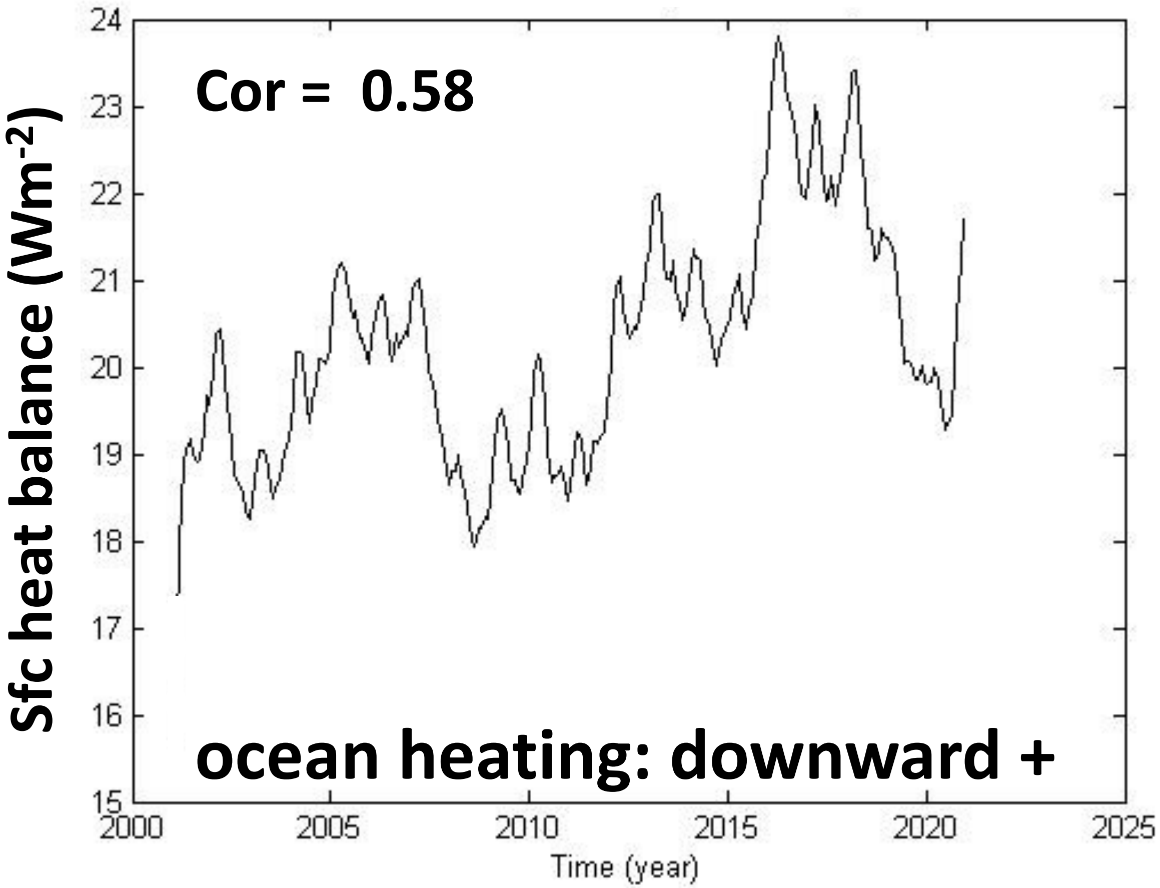


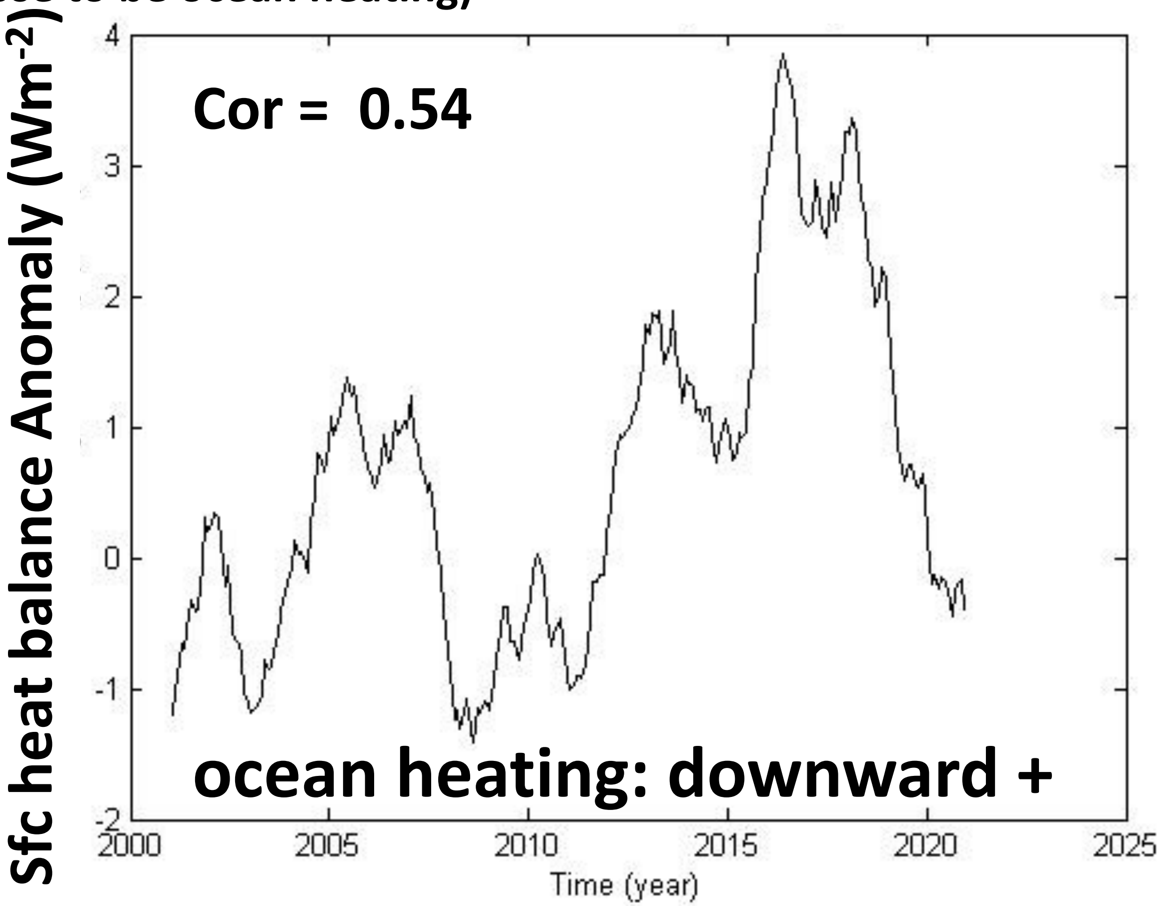
Could be large variations related to major climate events, especially for surface radiative fluxes?

Ocean Heat Balance and Anomaly

(extremely large heating? or significant systematic errors or uncertainties)

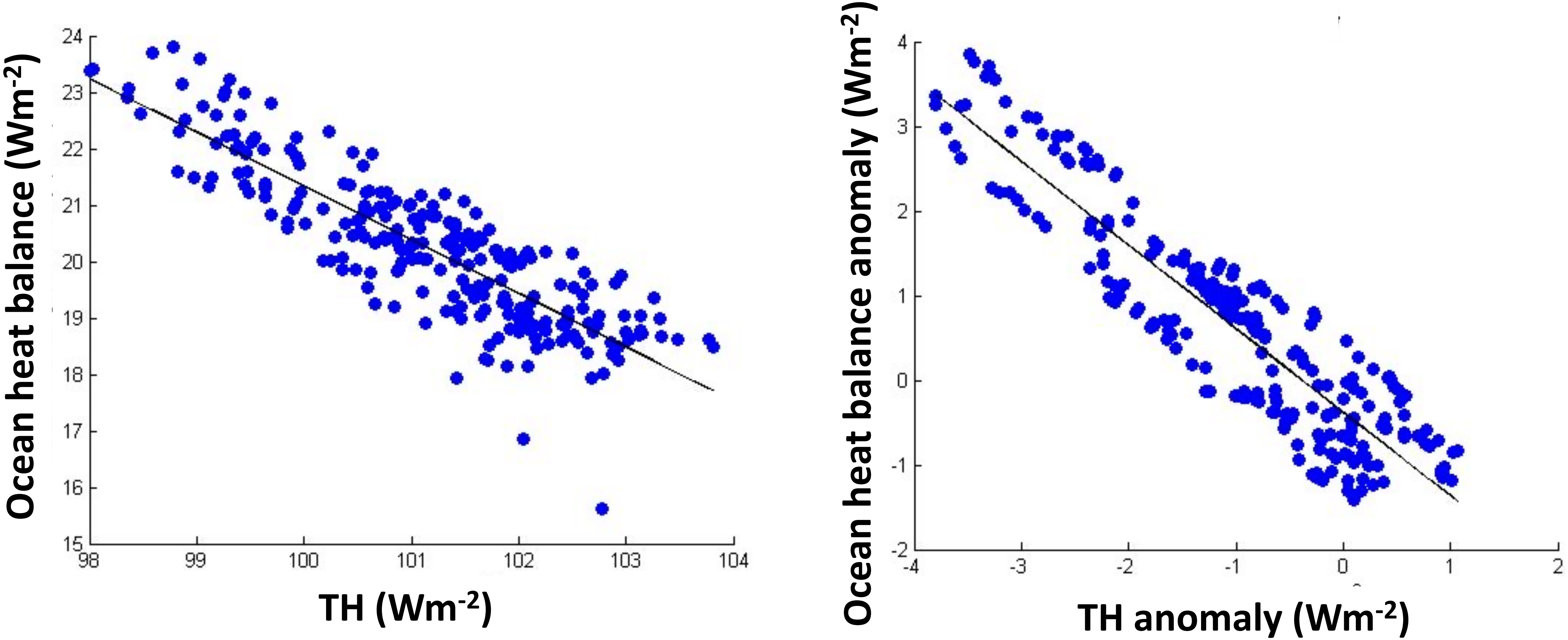
(Note: if TOA net removed, these suppose to be ocean heating)





Seem increases though not strong. Which are major error sources contributing to these estimates: turbulent and/or radiative fluxes?

TH vs ocean heat balance estimates



Strong relations among ocean heat balance errors and sea surface turbulent heat fluxes. Bulk formula, parameterized Ta vs Ts, and other variables could generate spurious variations.

Summary

- ❖ **Sea surface turbulent heat flux and its anomaly estimated have decreasing trends during the 21st century, a same sign as TOA net radiation and in-situ observations.**
- ❖ **The ocean 'heating' estimated from a combination of surface net radiation and turbulent heat is much bigger than those from TOA net radiation and in-situ estimates.**
- ❖ **The ocean heat balance and its anomaly estimated should be close to zero, however, they generally increase. Large systematic errors and uncertainties could exist based on the 20 years of data.**
- ❖ **All bulk formula, meteorological state variables and surface radiative fluxes estimated could contribute to the systematic errors.**

Thank you!

Sea surface turbulent flux data were obtained from OAFlux (http://oaflux.whoi.edu).
Radiation data were obtained from the CERES ordering site (http://ceres.larc.nasa.gov/order_data.php).