Estimating Global Sea Surface Turbulent Heat Anomalies Based on Energy Balance

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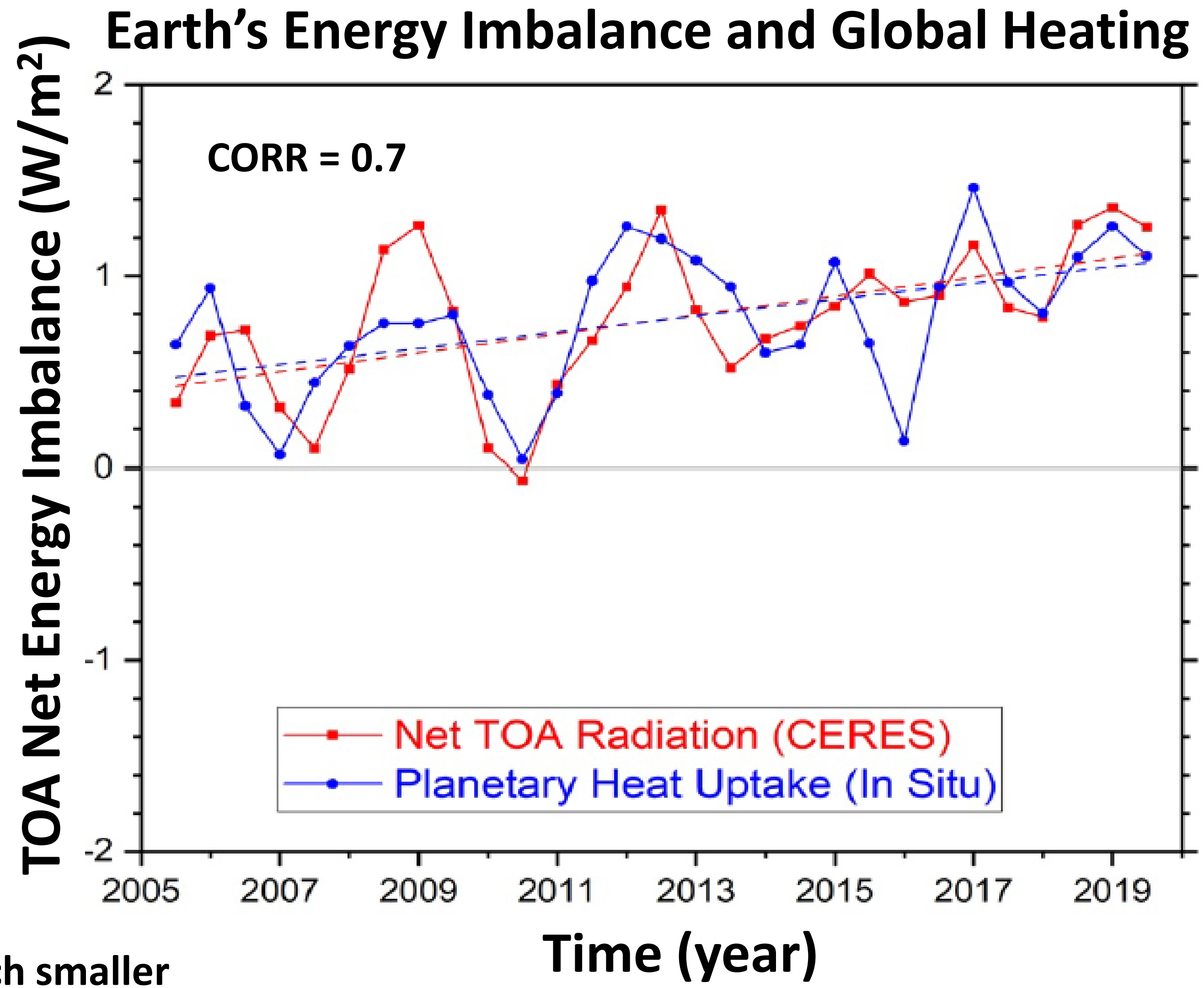
Introduction

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



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

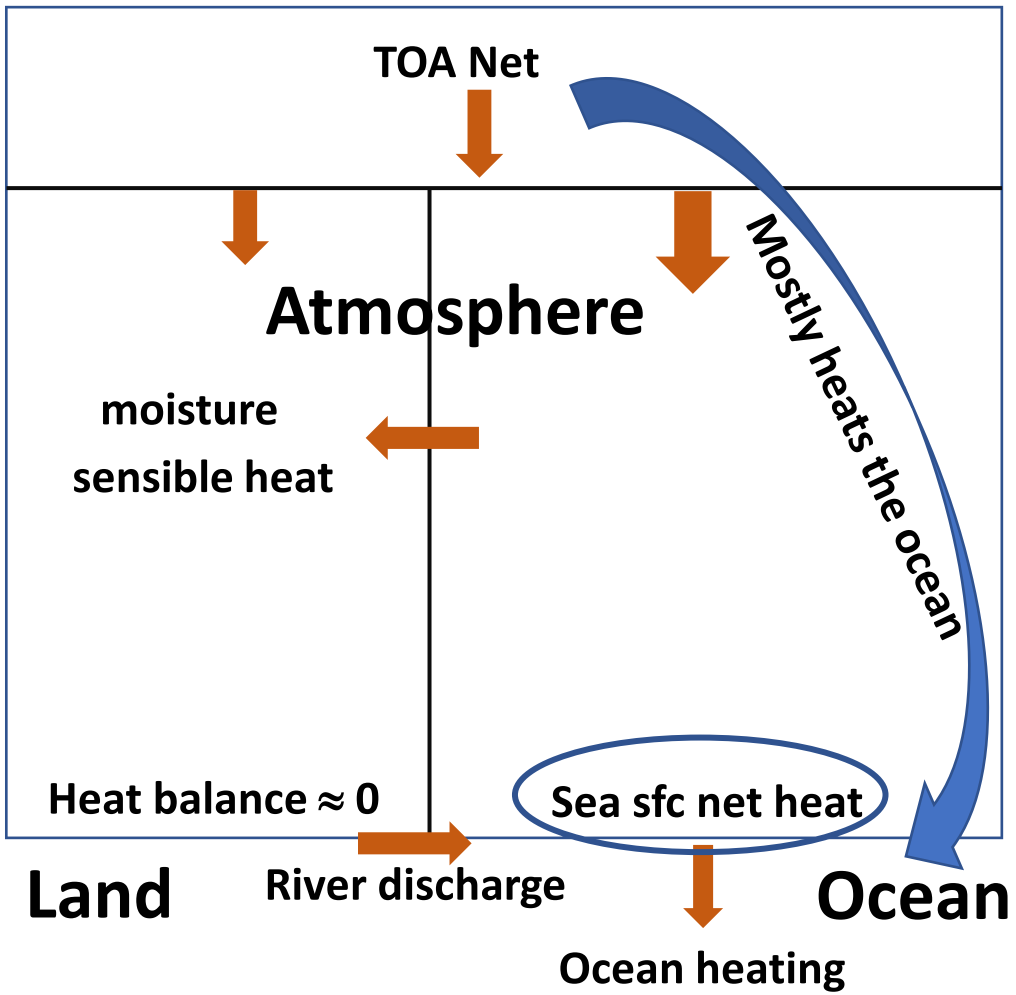
Air T/q: 0.014 ± 0.009

much smaller

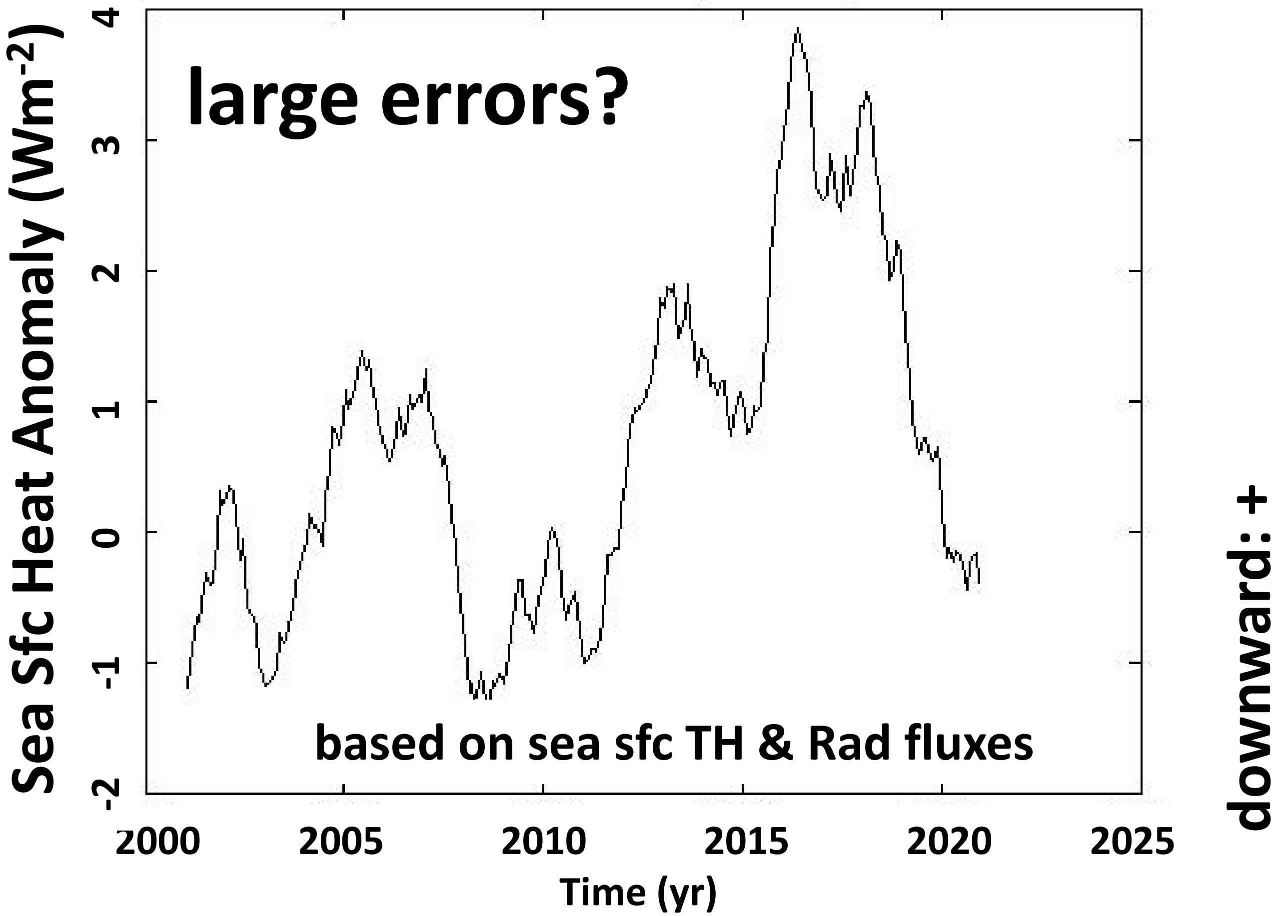
The trends of 0–2,000 m ocean and CERES TOA heat flux anomalies are is 0.43 ± 0.40 W m^{-2} $decade^{-1}$ and 0.50 ± 0.47 W m^{-2} $decade^{-1}$, respectively. (Loeb et al., GRL 2021)

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.



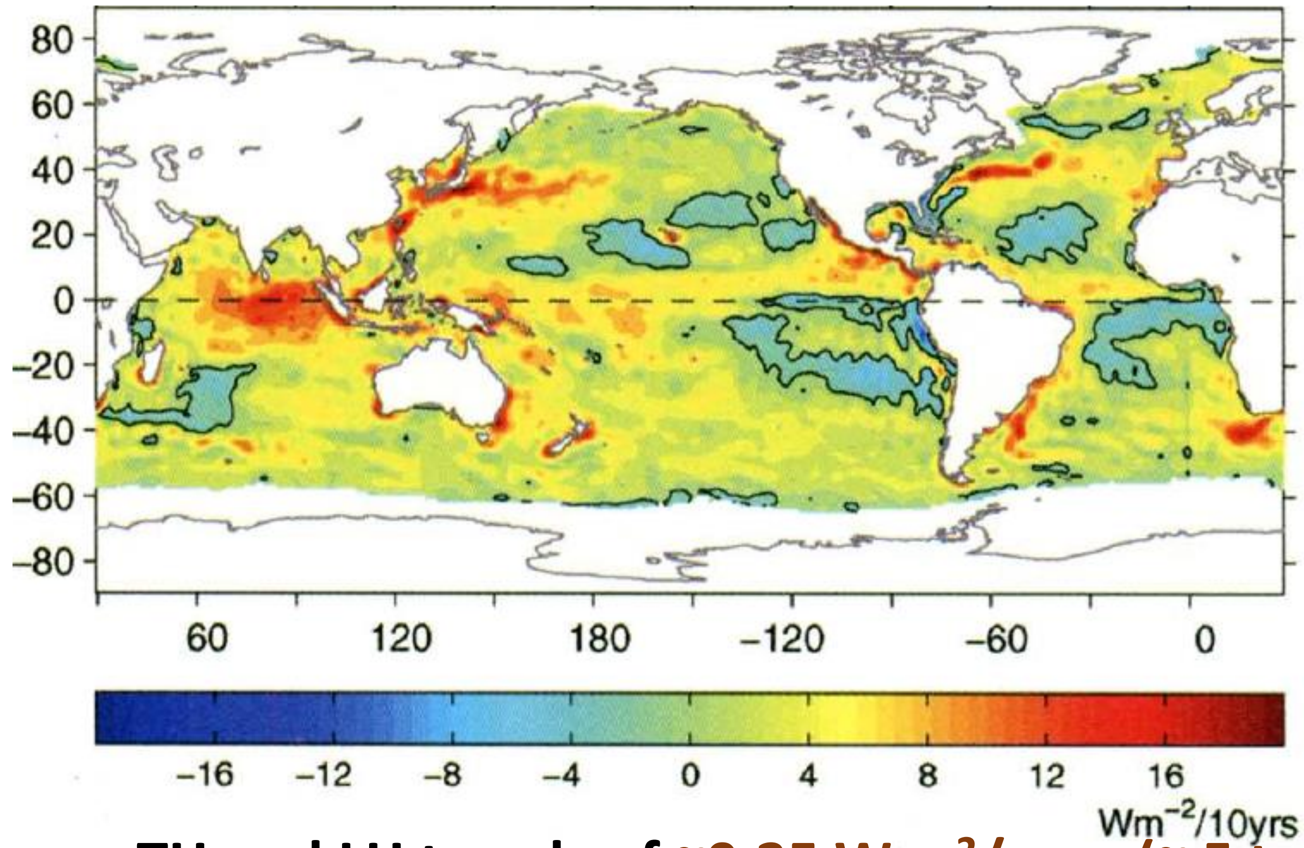
even much larger heat biases

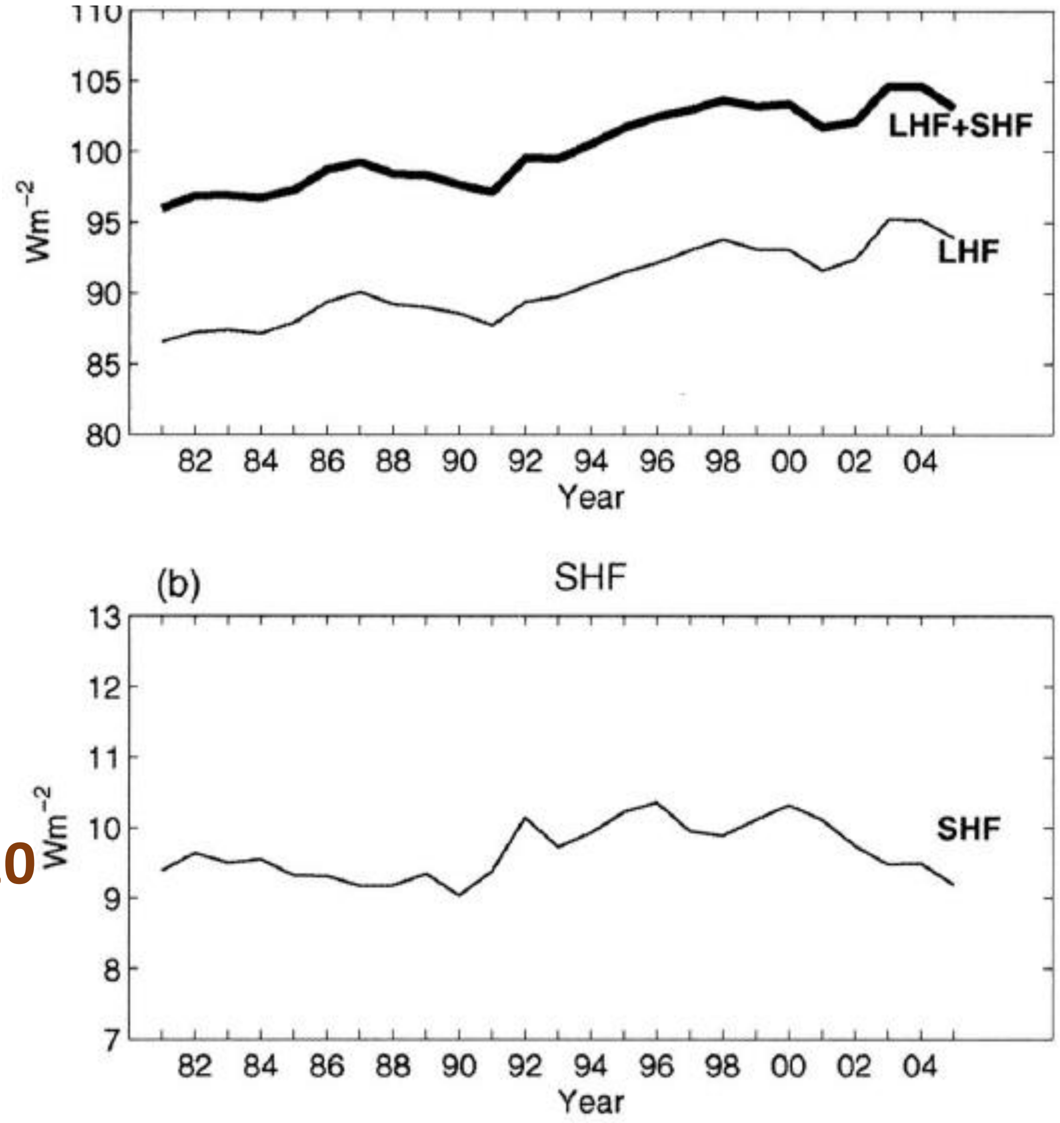


Large errors mainly from sea surface TH estimates

(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)



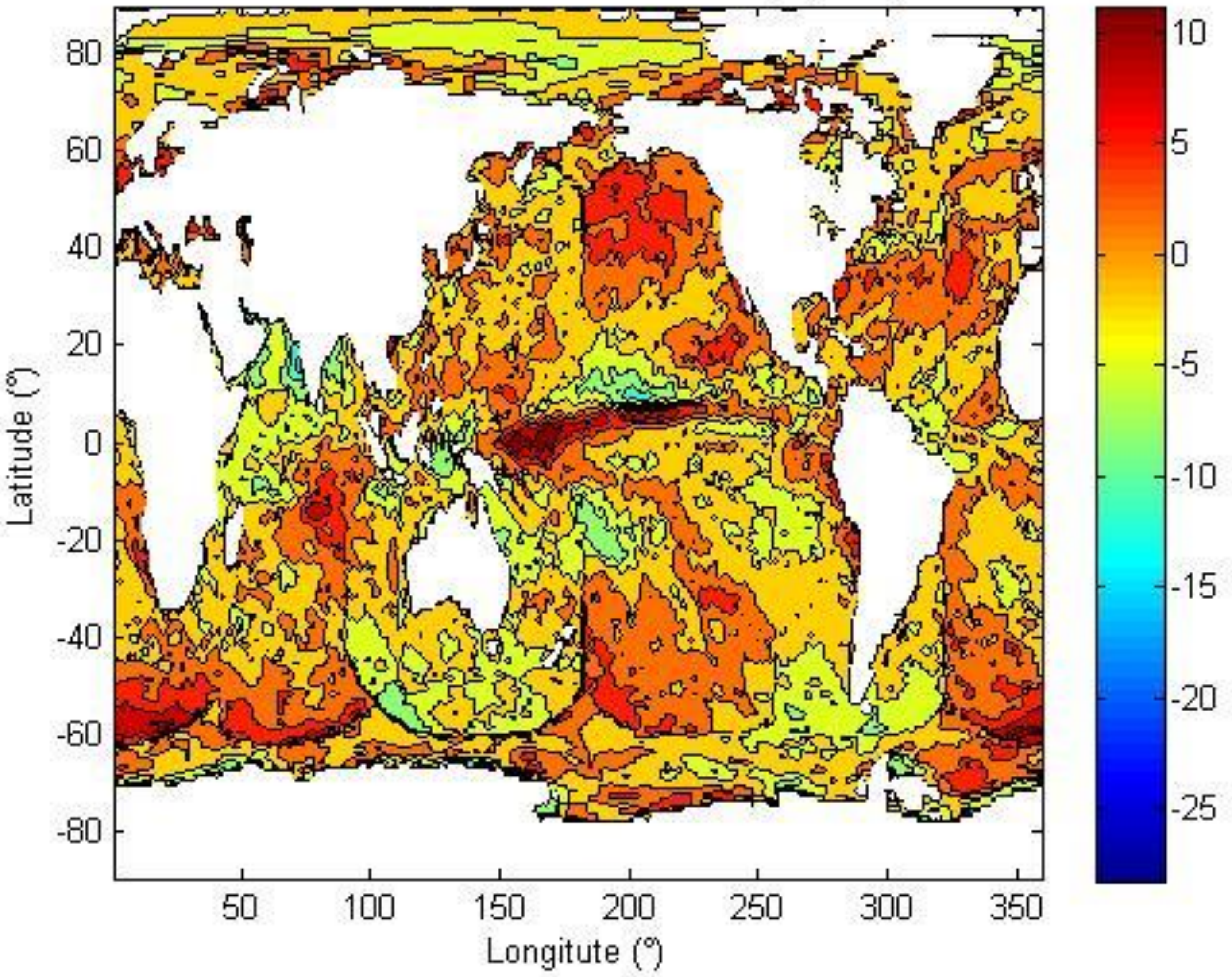


Yu and Weller, BAMS 2007

Large TH and LH trends of ~0.35 Wm^{-2}/year (~ 5 to 10 times bigger than that from radiation data) were found. Meteorological variables such as Δq & wind and turbulent transfer coefficients may be the key.

Uncertainties of sea surface radiative estimates

2016 - 2020 mean sfc net radiation anomaly (W/m^2)



Boundaries among GOES & LEO satellites are shown. LW radiation may have certain difficulties.

Currently, PBL profiles and cloud base conditions cannot be remotely sensed effectively.

Note: This is from EBAF Ed4.1. Newly released Ed4.2 may have significant improvement.

Introduction (conti.)

- **Accelerated heating for the climate system, dominantly for the ocean, is found from 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.**
- **Surface TH and radiation approach may have large uncertainties.**
- **This study tries to analyze ocean heating changes/anomalies based on TOA radiation, precipitation and land-ocean heat transport estimates, along with sea surface Bowen ratios, for the 21st century. The sea surface latent heat is basically obtained from water cycle.**
- **Data: monthly CERES EBAF Ed4.1, GPCP V2.3, and OAFlux V3**

Oceanic Heat Flux, Energy Balance & Anomaly

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

  $OH = R_{net\_sfc} - TH \approx R_{net\_TOA}$;

- **Ocean to land heat transport:**

  $T_{OtoL} = R^{O}_{net\_TOA} - OH$;   it's a divergence could be obtained from radiation

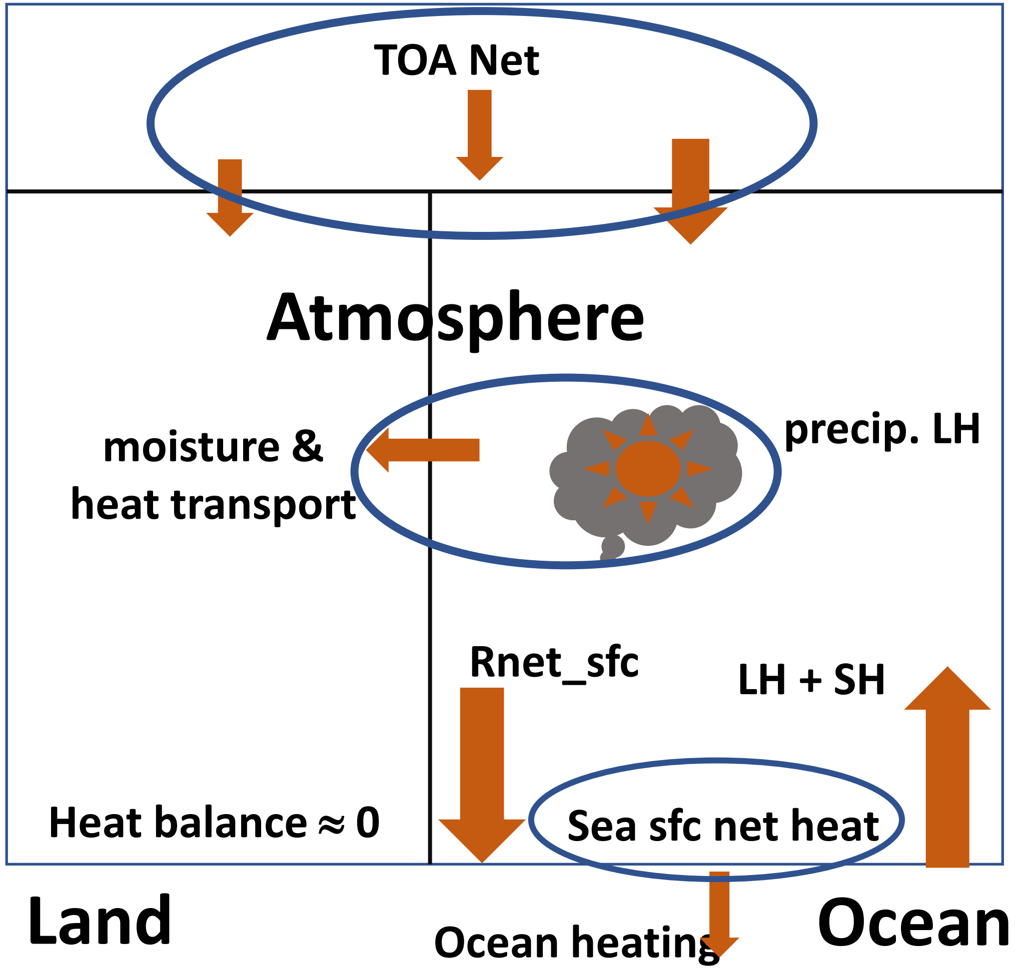
- **Oceanic LH & SH fluxes**

  $LH^{O} = LH^{O}_{P} + LH_{T}$; $BR^{O} = SH^{O}/LH^{O}$

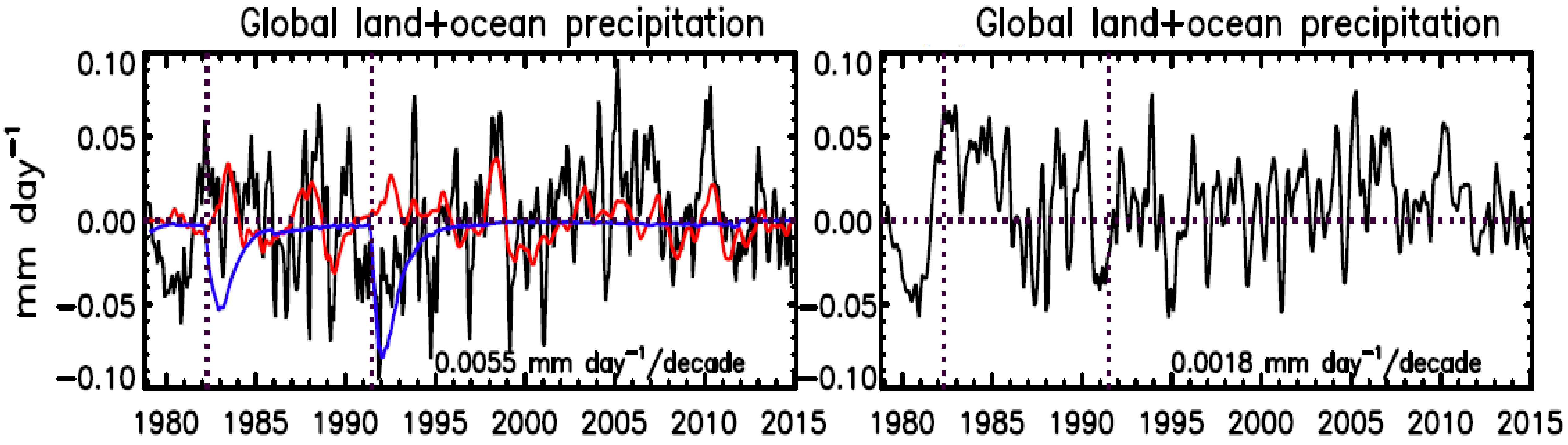
  $TH^{O} = LH^{O}\,(1 + BR^{O})$

- **Climatology: 2001 – 2005**

Note: ^{O}, ocean; L, land; T, transport; BR, Bowen ratio



Global Precipitation Time Series



Red : ENSO effect
Blue: volcano effect

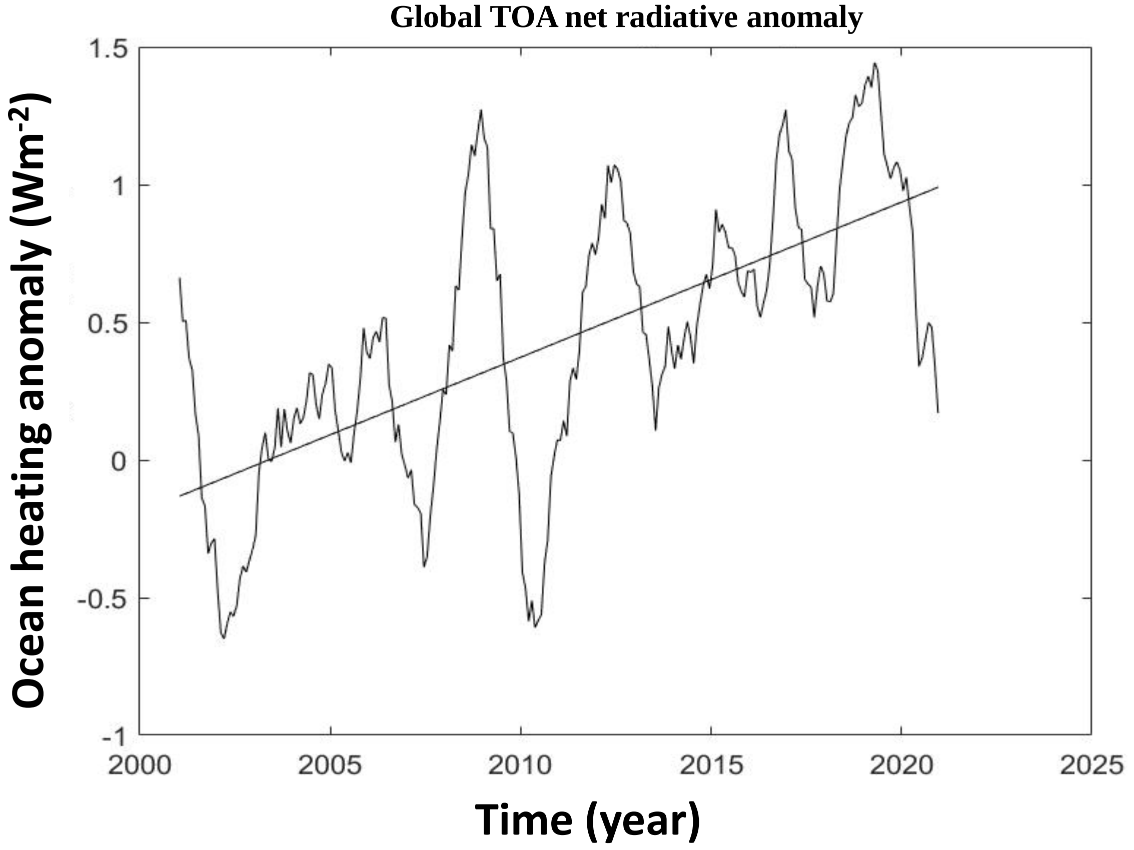
	Ocean	Land	Ocean + Land
Precipitation	2.89	2.24	2.69
Standard dev	0.29	0.16	0.25

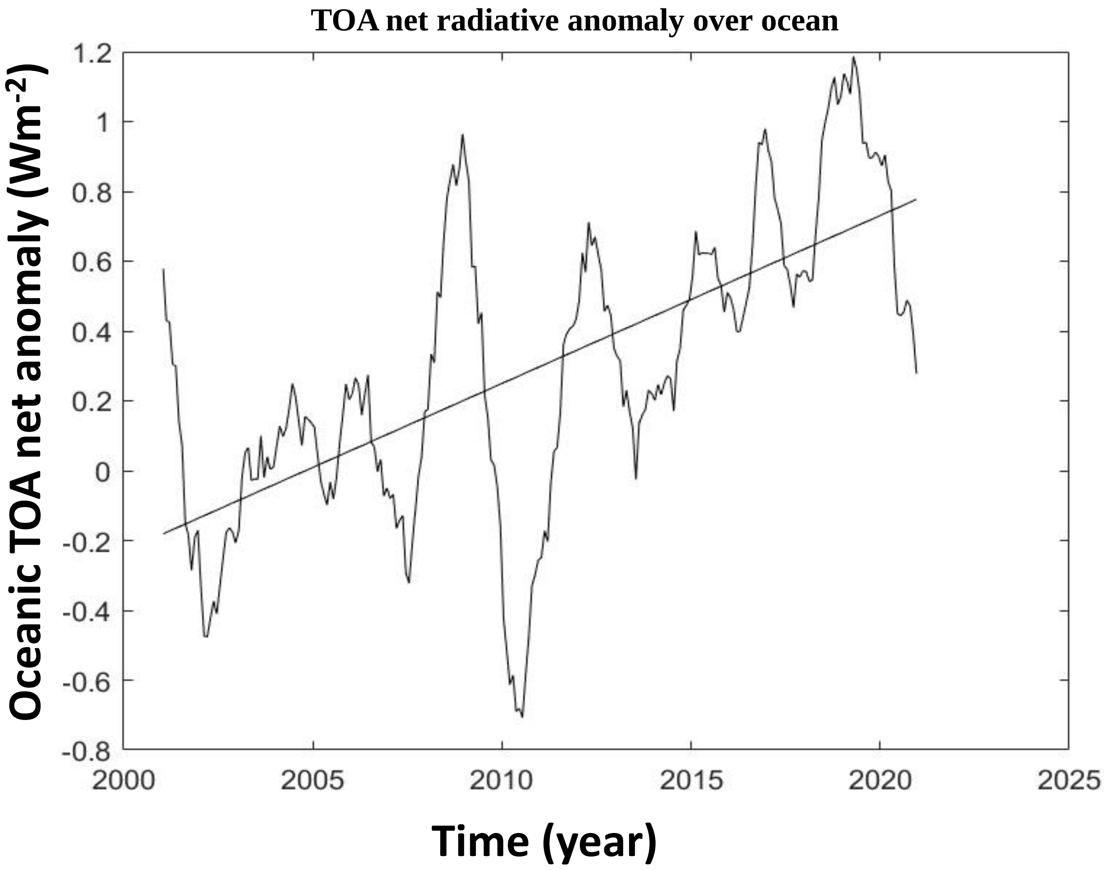
a very small insignificant trend

Adler et al., Surv Geophys, 2017: 3% lower than others (even lower than energy estimates)

Global & Oceanic Radiation Anomalies

(obtained from TOA radiative energy imbalance)



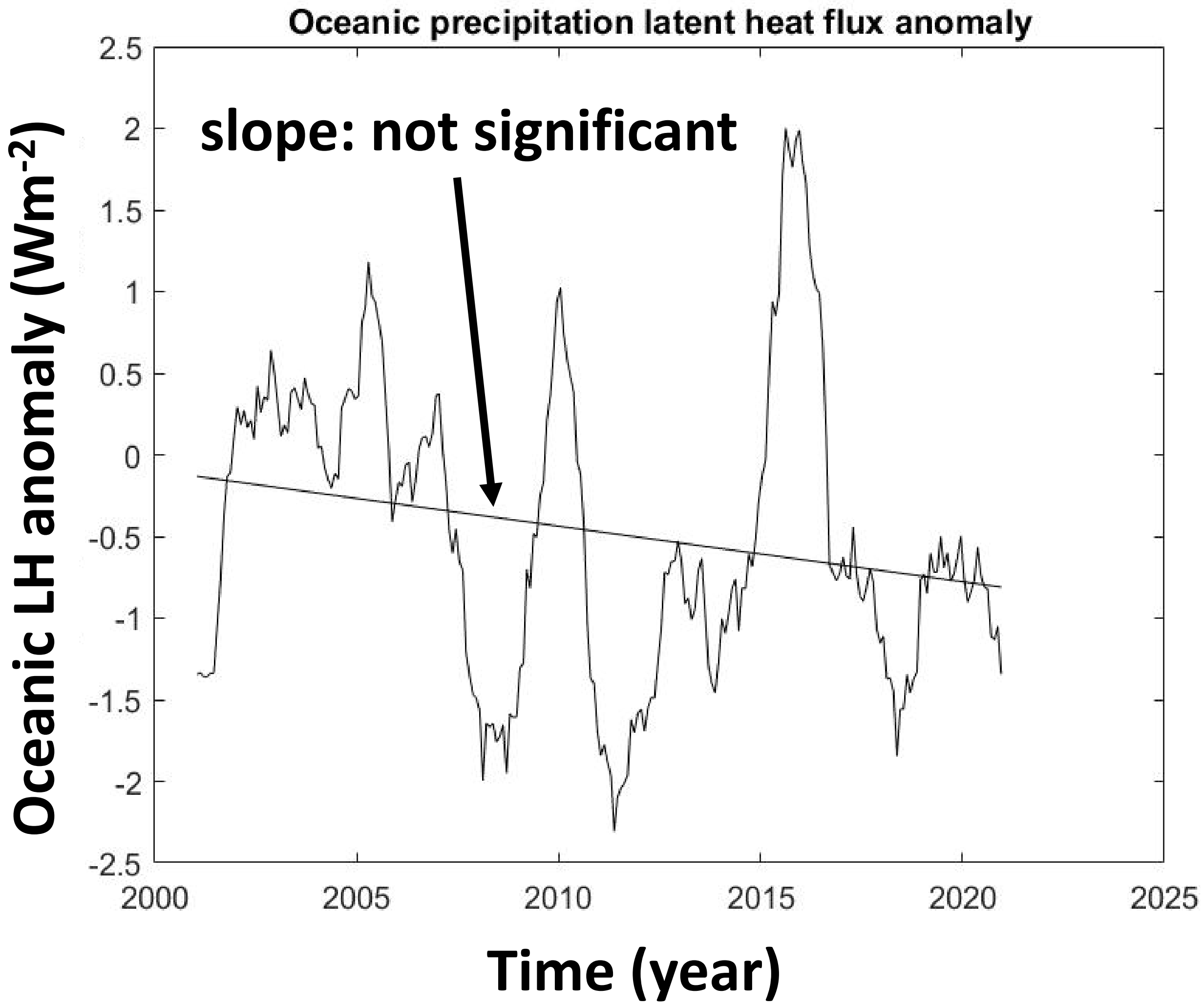


Global TOA net radiative anomaly: dominantly for heating oceans.

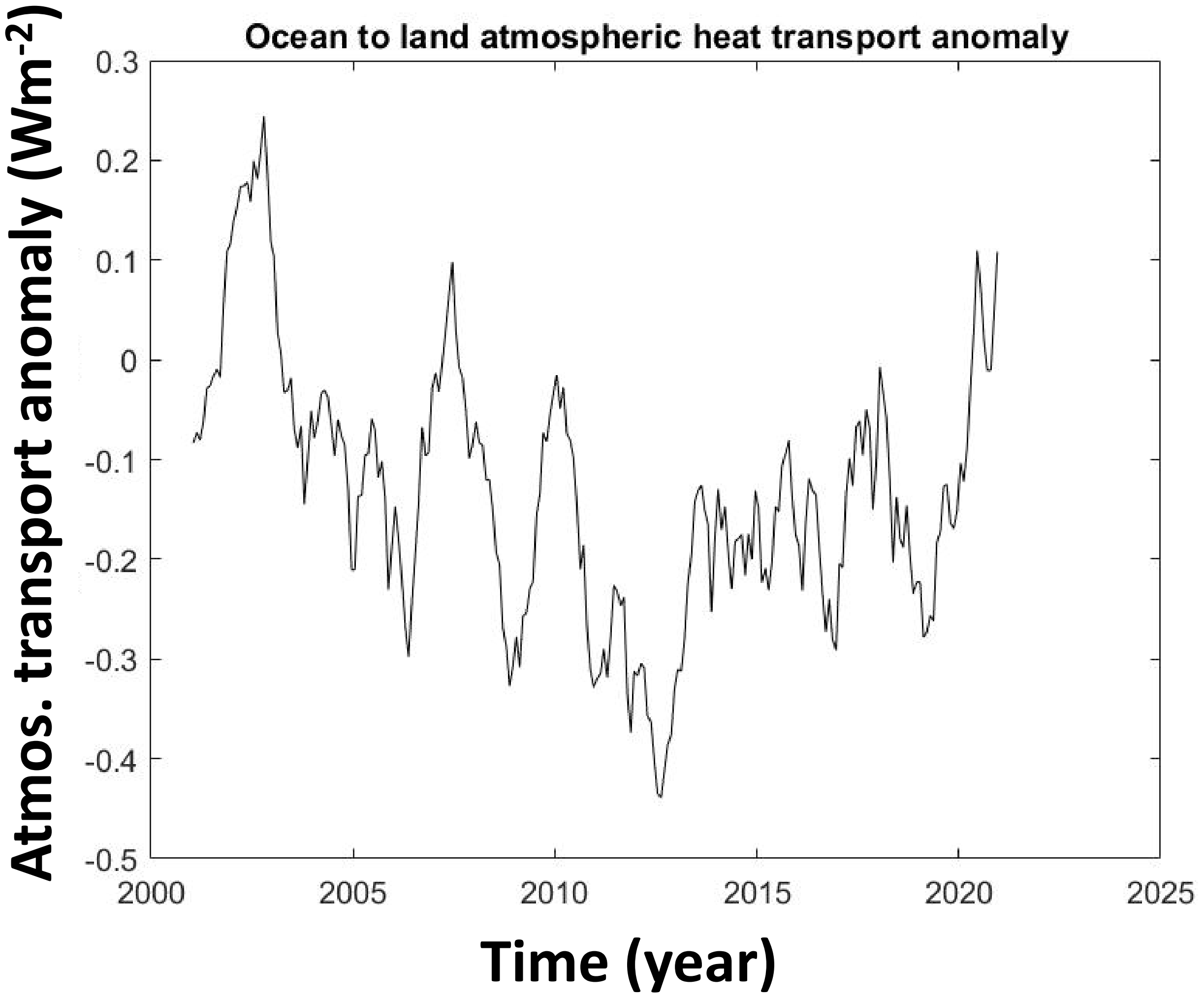
Oceanic TOA net anomaly: a component for ocean to land heat transport.

$T_{OtoL} = R^{O}_{net\_TOA} – OH$; similar to left

Oceanic Precip. & Atmos. Transport Heat Anomalies



No significant trend, but big variability.

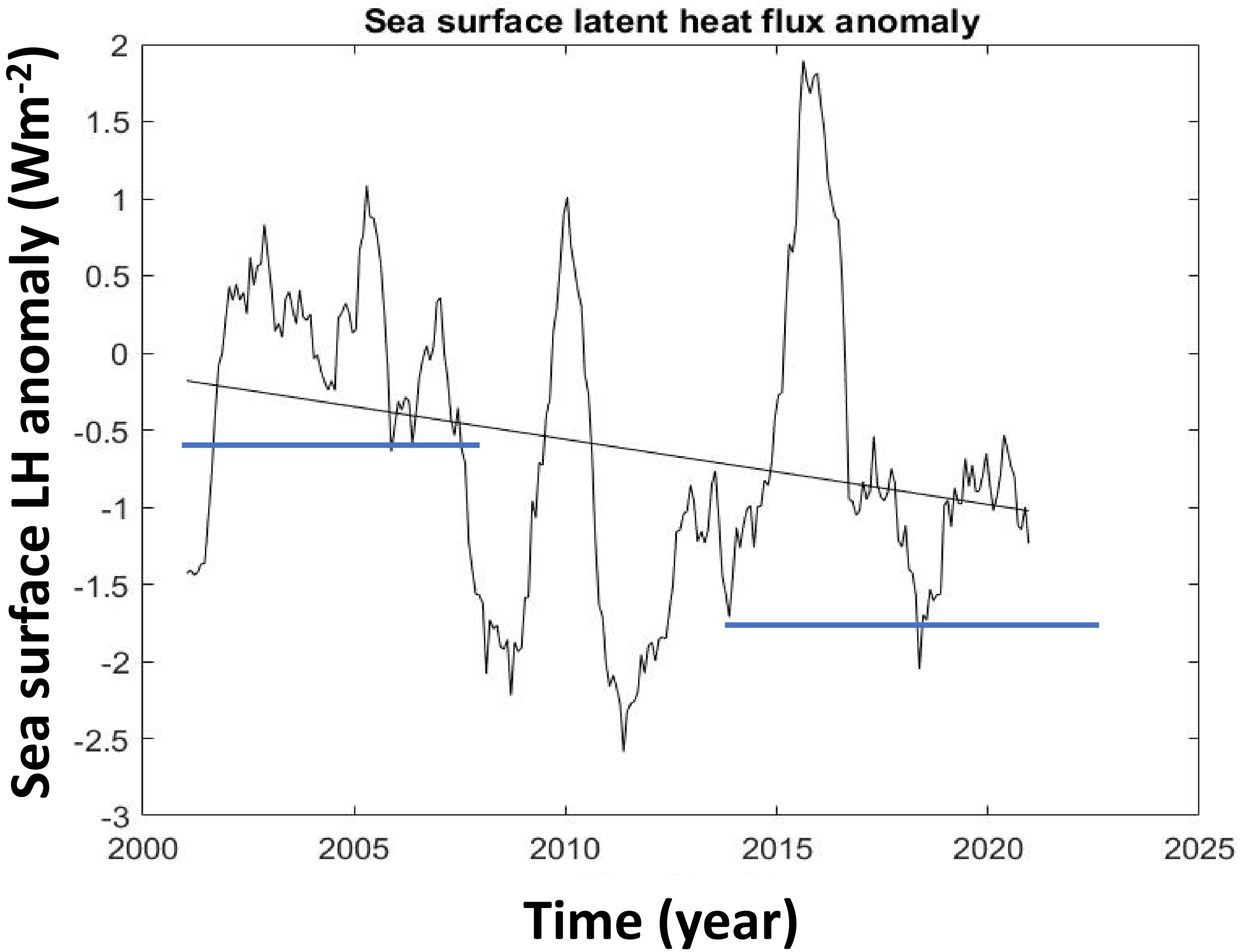


Indicating weaker transport? or Slower dynamics with warmer climate?

Sea surface LH Anomalies

beginning & ending phases?

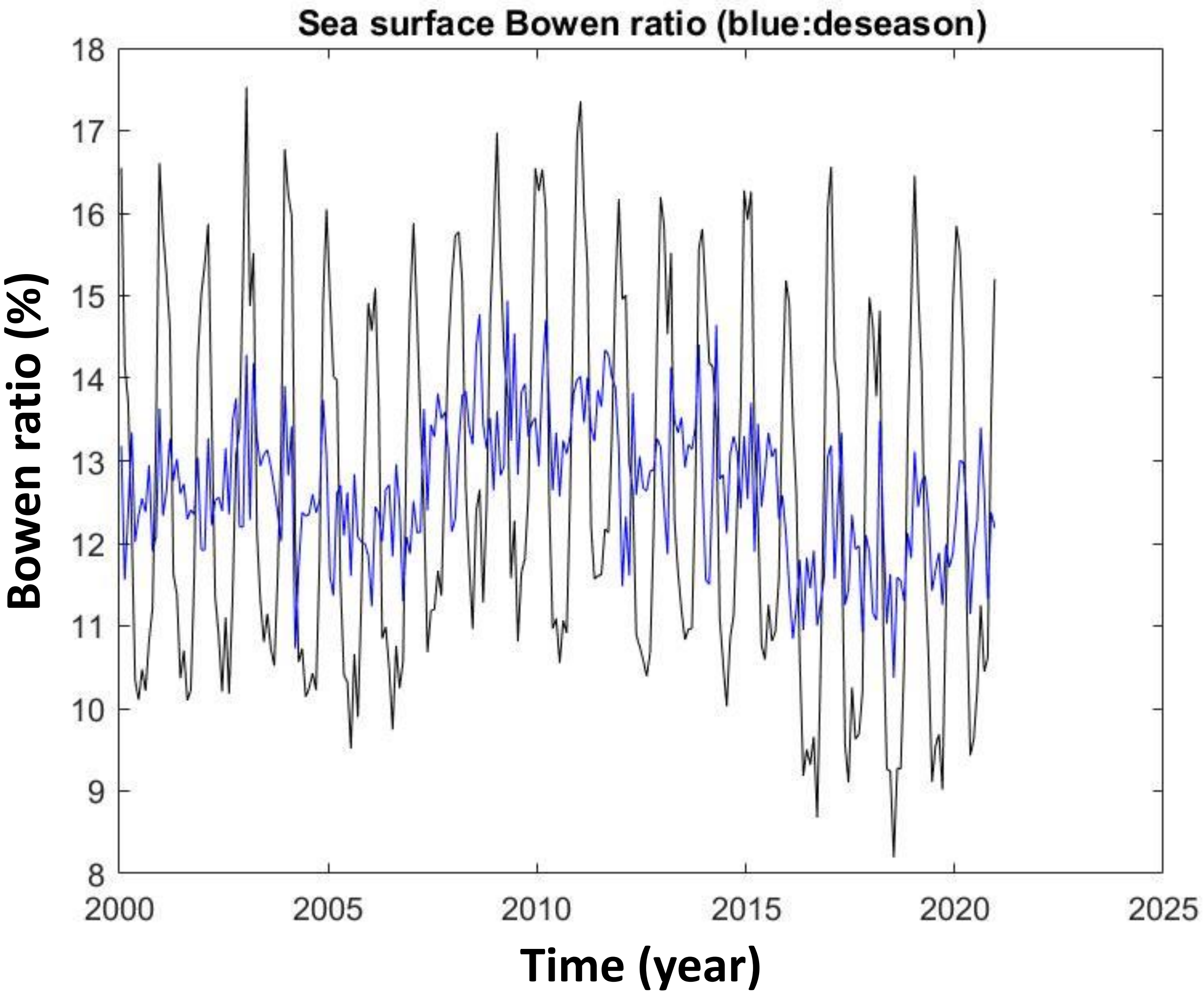
large variability, bi-mode or oscillation?



obtained from precipitation, along with transport, observations

No clear trend is found for sea surface latent heat release anomalies during last two decades. However, variations are large. May in different modes.

Relationship of Sea Surface LH and SH Fluxes



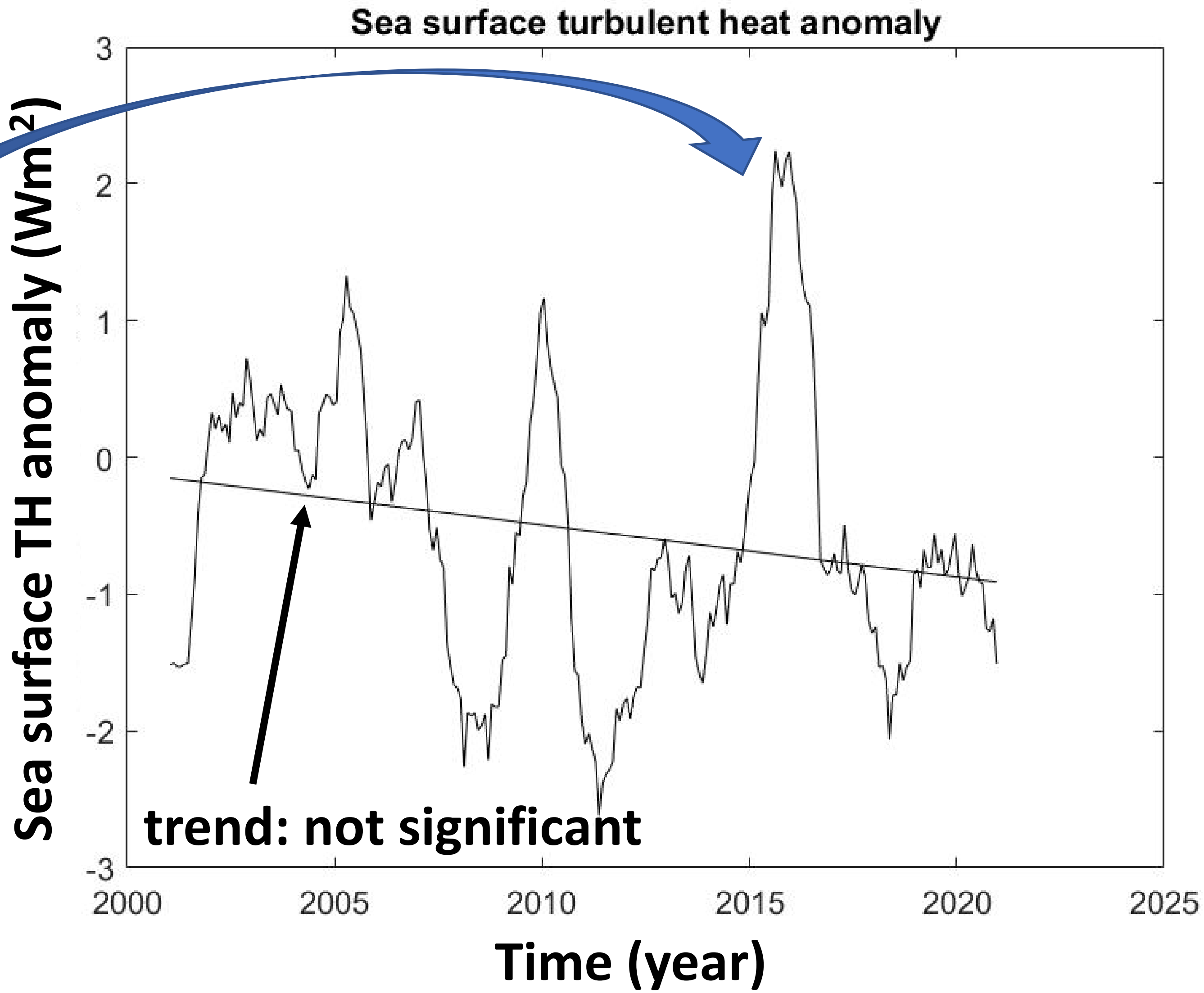
SH is about 12.5% of LH over oceans.

Based on this Bowen ratio & LH, TH can be estimated.

Sea surface TH estimated from precipitation

Caused by strong precip. anomaly: real for TH or rad?

That is, does the system have memory?

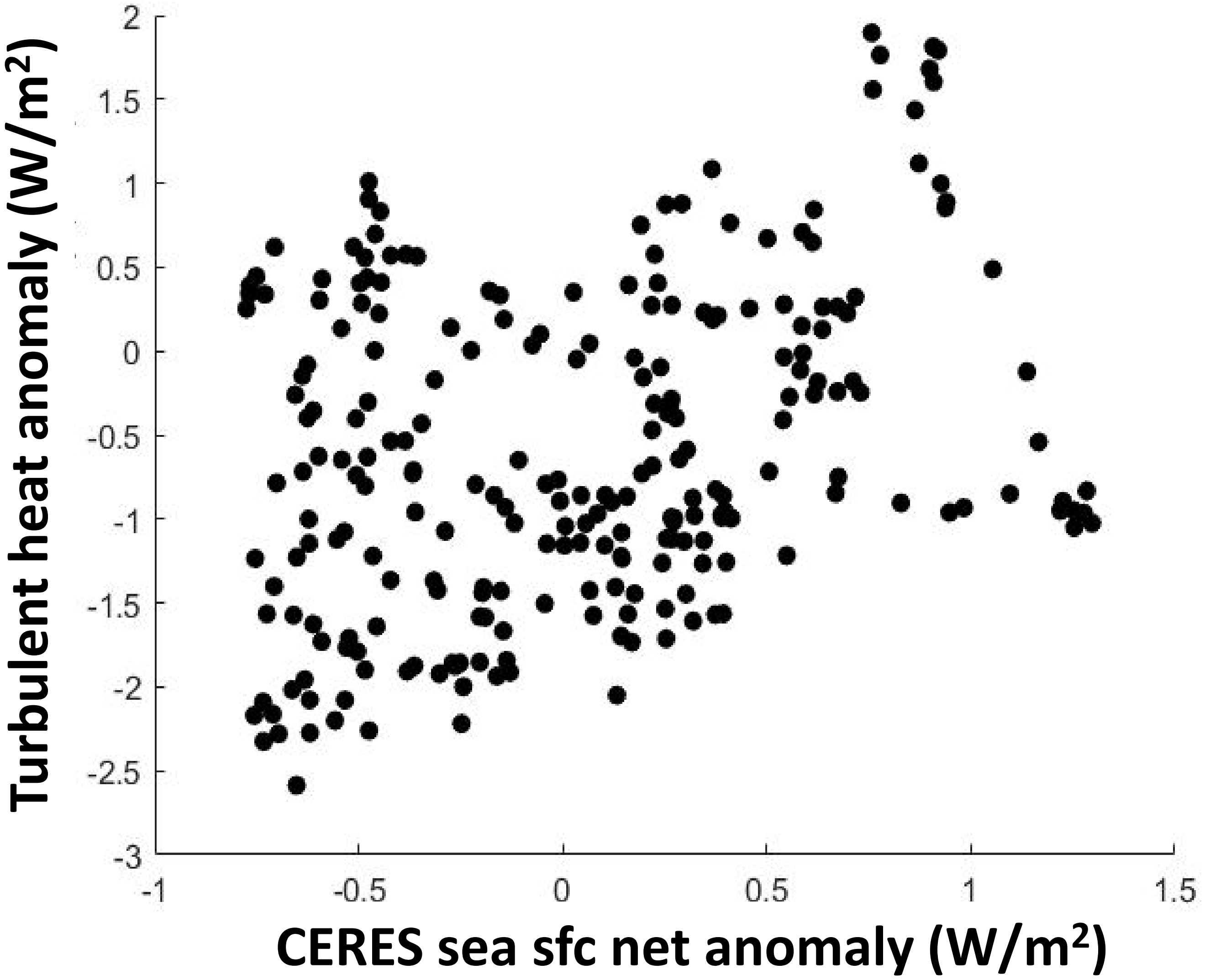


over ocean:
$TH = LH_P + LH_T + SH$

Slow down atmospheric dynamics?

Sea surface TH flux anomalies estimated from global mean oceanic precipitation have similar variations as LH due to small transport & Bowen ratio variations.

Sea surface net radiation vs TH



EBAF Ed 4.1

Better for Ed 4.2 (?)

Summary

- Sea surface turbulent heat fluxes estimated from bulk formula may not be reliable for accessing decadal climate variations due to uncertainties of the formula and meteorological state variables, which, along with some surface radiation uncertainties (note: this is for Ed 4.1 only), contributes large systematic errors in sea surface energy balance estimates.
- Atmospheric latent heat release and its anomaly over oceans estimated from precipitation observations does not show significant trends during the last two decades though the last decade values may be lower than the previous ones. This could potentially indicate a slight slowdown of the atmospheric dynamic system for a warmer climate.
- Sea surface turbulent heat anomalies estimated from water balance are generally decided by precipitation variations since other components such as ocean to land moisture transport are much smaller.
- The uncertainty on sea surface energy balance using precipitation data may be still large comparing the sea surface net radiation data from CERES and the turbulent heat fluxes obtained from water cycle though difference is considerable smaller.
- Further studies on heat transport and surface radiation are needed.

Thank you!

These sea surface flux data are available for the team.

Please send your request to bing.lin@nasa.gov if need the data

Radiation data were obtained from the CERES ordering site (http://ceres.larc.nasa.gov/order_data.php).

GPCP global precipitation data were found from the NOAA ESRL/PSL site (https://psl.noaa.gov/).

Sea surface turbulent flux data were from OAFlux (http://oaflux.whoi.edu).