Title:

Analysis of atmosphere-ocean surface flux feedbacks in recent satellite and model reanalysis products

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Abstract:

Recent investigations have examined observations in an attempt to determine when and how the ocean forces the atmosphere, and vice versa. These studies focus primarily on relationships between sea surface temperature anomalies and the turbulent and radiative surface heat fluxes. It has been found that both positive and negative feedbacks, which enhance or reduce sea surface temperature anomaly amplitudes, can be generated through changes in the surface boundary layer. Consequent changes in sea surface temperature act to change boundary layer characteristics through changes in static stability or turbulent fluxes. Previous studies over the global oceans have used coarse-resolution observational and model products such as ICOADS and the NCEP Reanalysis. This study focuses on documenting the atmosphere ocean feedbacks that exist in recently produced higher resolution products, namely the SeaFlux v1.0 product and the NASA Modern Era Retrospective-Analysis for Research and Applications (MERRA). It has been noted in recent studies that evidence of oceanic forcing of the atmosphere exists on smaller scales than the usually more dominant atmospheric forcing of the ocean, particularly in higher latitudes. It is expected that use of these higher resolution products will allow for a more comprehensive description of these small-scale ocean-atmosphere feedbacks. The SeaFlux intercomparisons have revealed large scatter between various surface flux climatologies. This study also investigates the uncertainty in surface flux feedbacks based on several of these recent satellite based climatologies.

Analysis of atmosphere-ocean surface flux feedbacks in recent satellite and model reanalysis products

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Outline

* Brief background on feedback concepts and a methodology to calculate them
* Feedback relationships for surface fluxes and their components for a suite of satellite and model-based products.
* A look at the uncertainty between these products
* Conclusions

Feedback Concepts

- Common Concept:
  - A change in one variable, X, affects change in another variable, Y, whose change may or may not contribute to reinforcing (positive) or diminishing (negative) the original change in X.

- "Feedback" and "Sensitivity" different measures
  - The difference between 2 equilibrium states when some external forcing is applied (Stephens 2005)
  - The difference between 2 equilibrium states when atmosphere and ocean are coupled/uncoupled (Wu et al. 2006)
  - **Stochastic Feedback via atmosphere-ocean coupling (Hasselmann 1976; Barsugli & Battisti 1998)**
  - Nonlinear, multivariate relationships (Aires & Rossow 2003)

- These relationships are important to understand and are a critical test for any model of the "real" world.

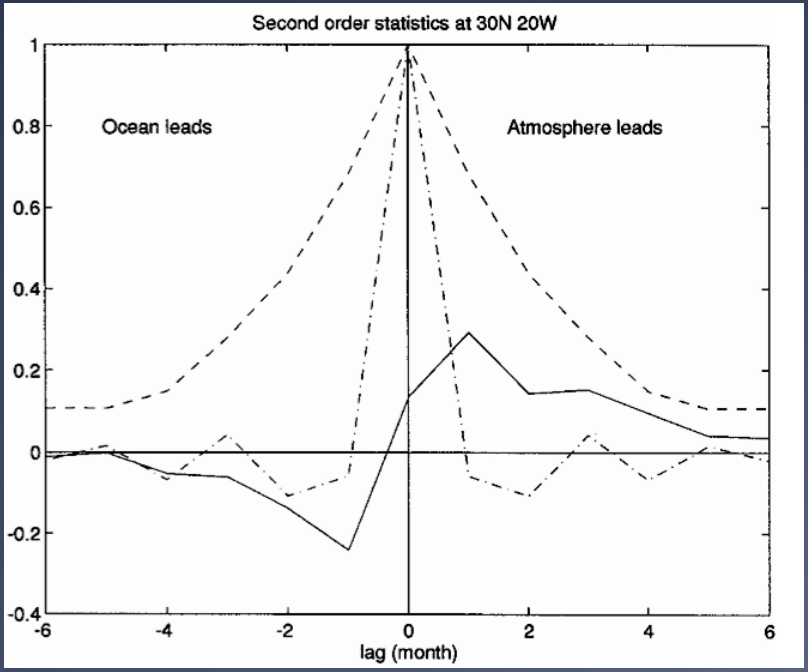
Methodology

- Follow the methodology of Frankignoul et al. (1998); also in Park et al. (2005)

$$\frac{\partial T'}{\partial t} = F' - \lambda T'$$

$$R_{TX}(\tau) = R_{Tf'}(\tau) - \lambda R_{TT}(\tau)$$

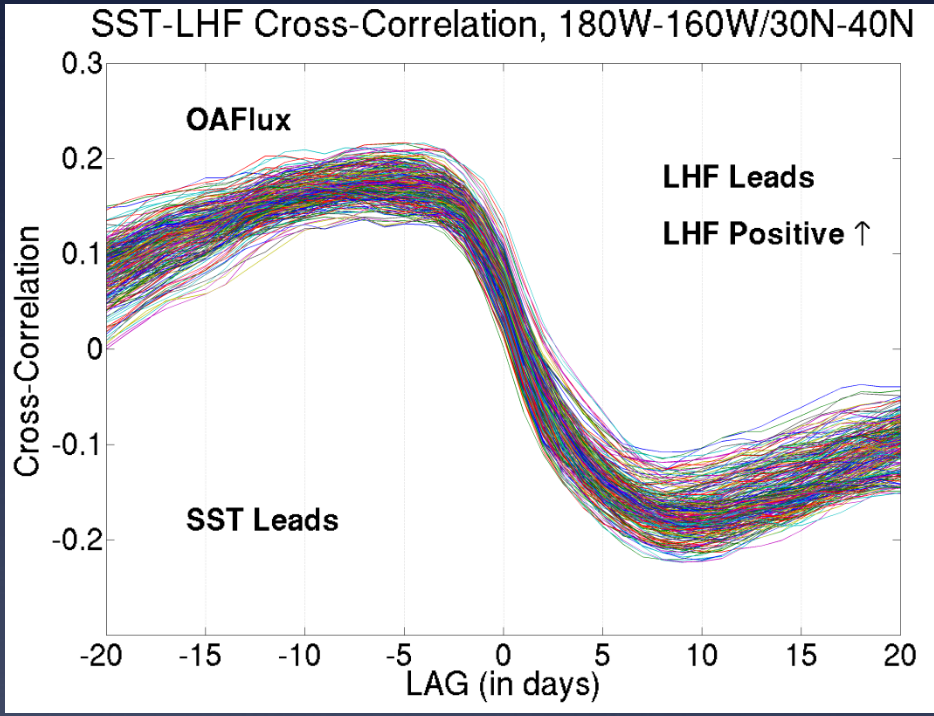
- Good approximation for many regions outside of the tropics.
- Difficulties arise when atmospheric persistence is long or when neglected forcing is important (such as strong advection)



From Frankignoul et al. (1998)
-Dashed = SST Autocorrelation
-Dash-Dot = Latent Heat Flux Autocorrelation
Solid= SST-LHF Cross-Correlation

Source Data for Study

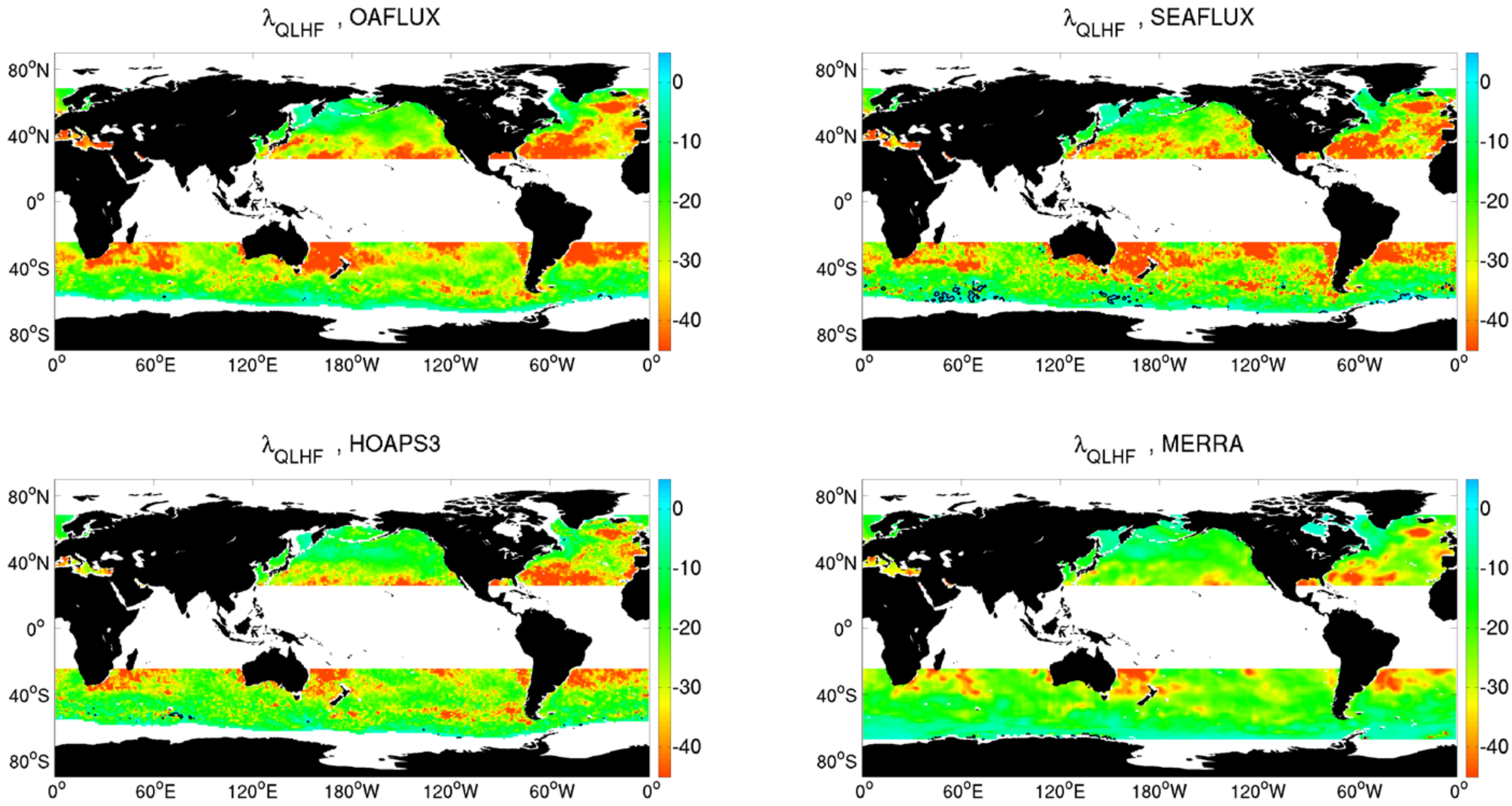
* Input Data (1998-2005):
  * SeaFlux v1 (0.25^0, 3-hr)
  * OAFlux v3 (1^0, daily)
  * Hoaps v3 (1^0, 12-hr)
  * MERRA ($2/3^0$x$1/2^0$,1-hr)
  * GEWEX-SRB v3 (1^0, 3-hr)
  * ISCCP Clouds (2.5^0, 3-hr)



- Processing Steps
  - Regrid via linear interpolation to 1 degree resolution
  - Remove spline-fit annual cycle
  - Remove long-term atmospheric persistence via 360-day hi-pass filter

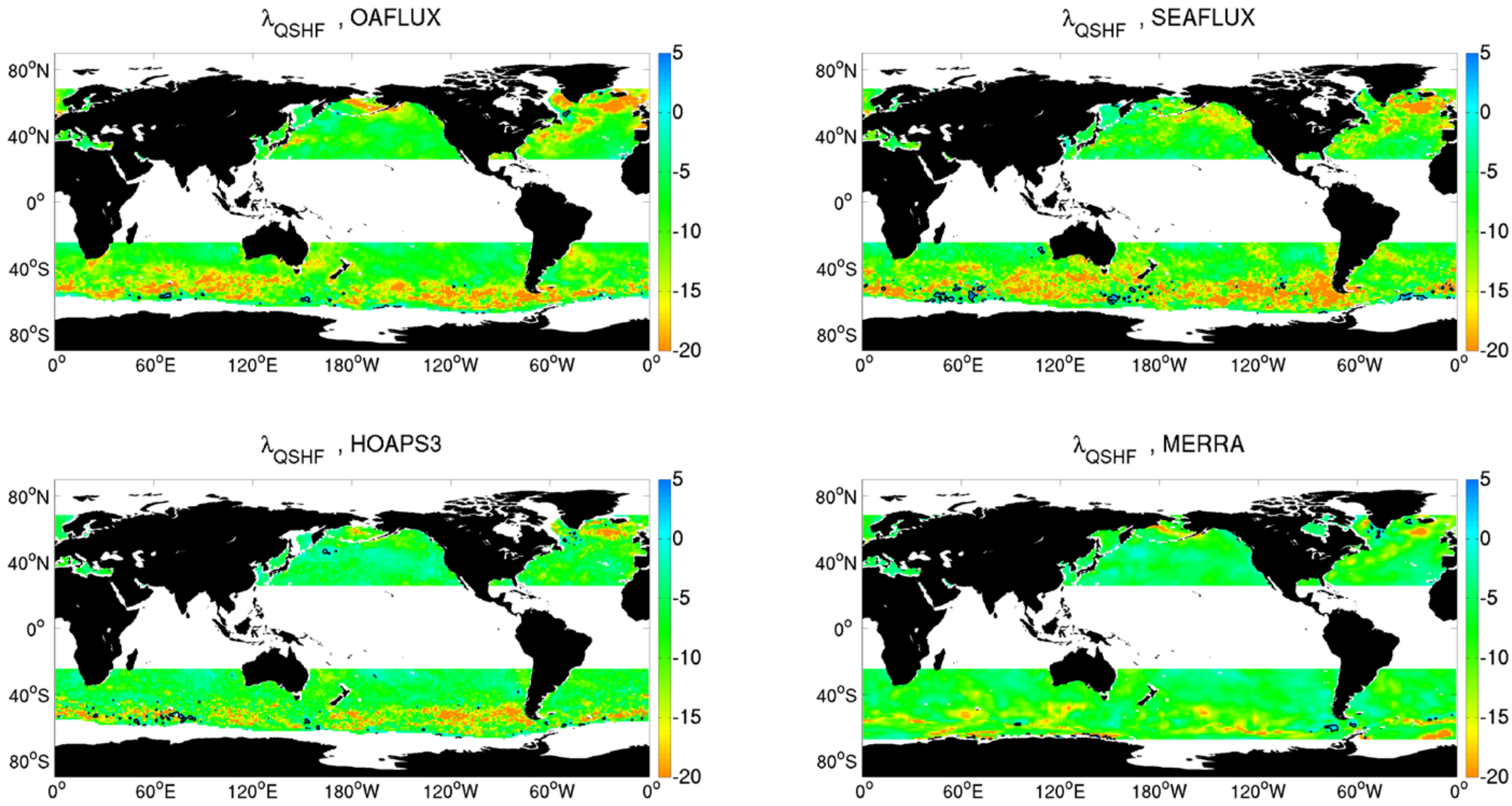
- Use -10 to -8 day lag for computing feedback
- Longer than the typical atmospheric persistence
- Use a few lags to enhance stability

Latent Heat Flux, W/Km^2



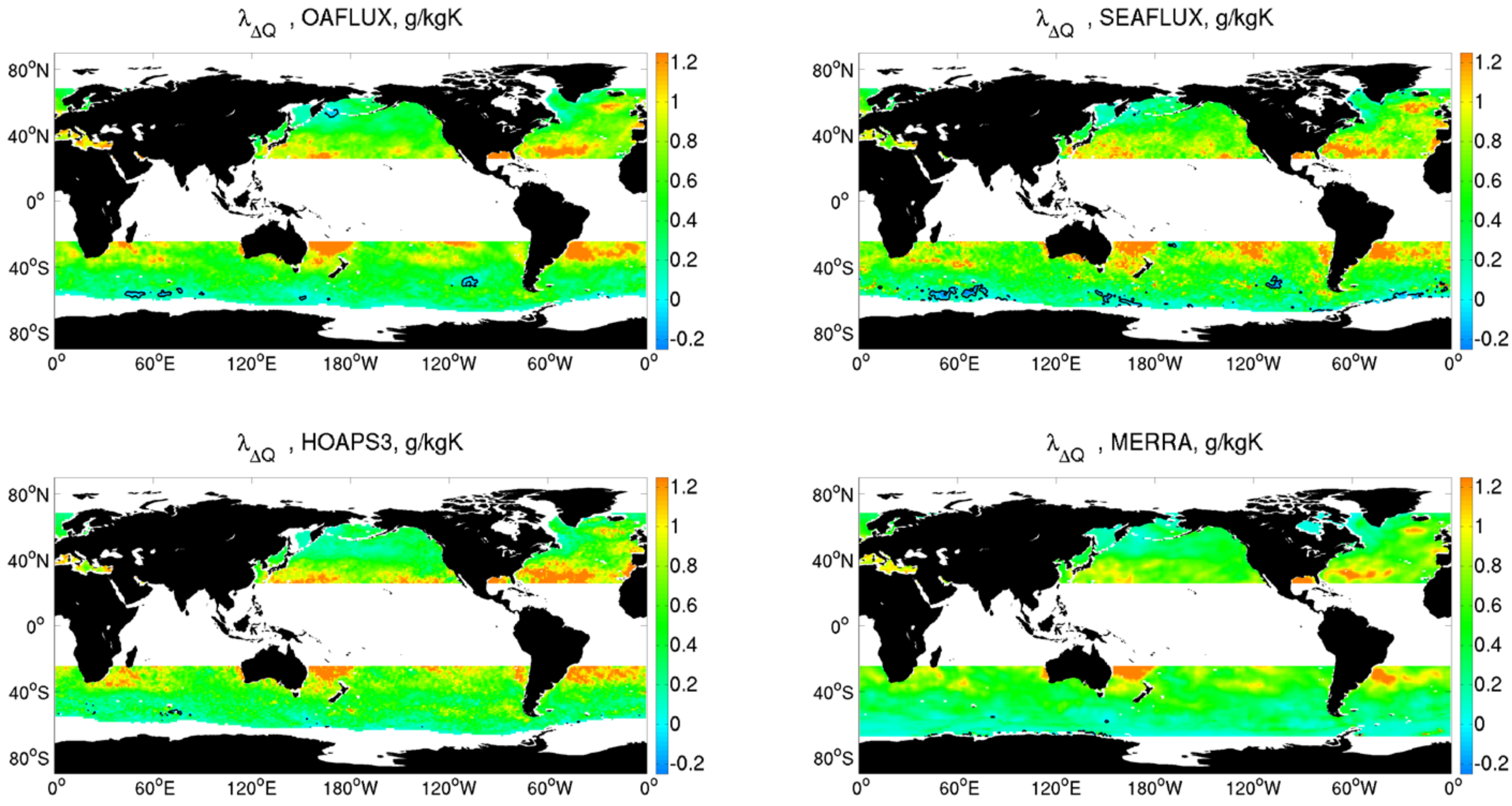
- The latent heat flux is primarily negative everywhere in the extratropics.
- OAFlux and SeaFlux show roughly the same pattern and amplitude while MERRA appears the least variable and lowest amplitudes.

Sensible Heat Flux, W/Km^2



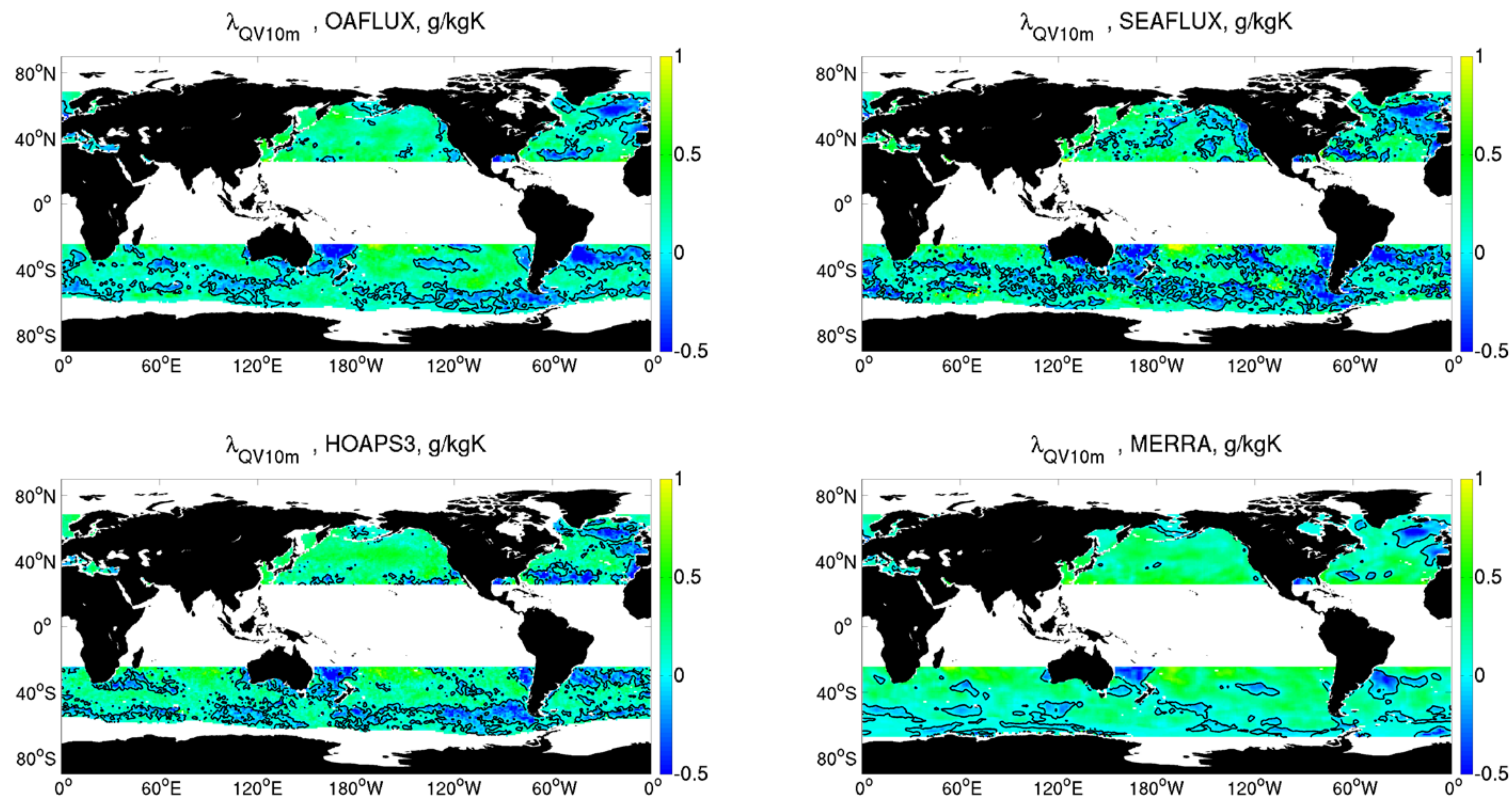
- Sensible heat flux feedback amplitudes are roughly half those of LHF.
- The satellite based products appear to show the strongest negative feedbacks over the Southern Ocean.

Qs-Qa, g/kgK



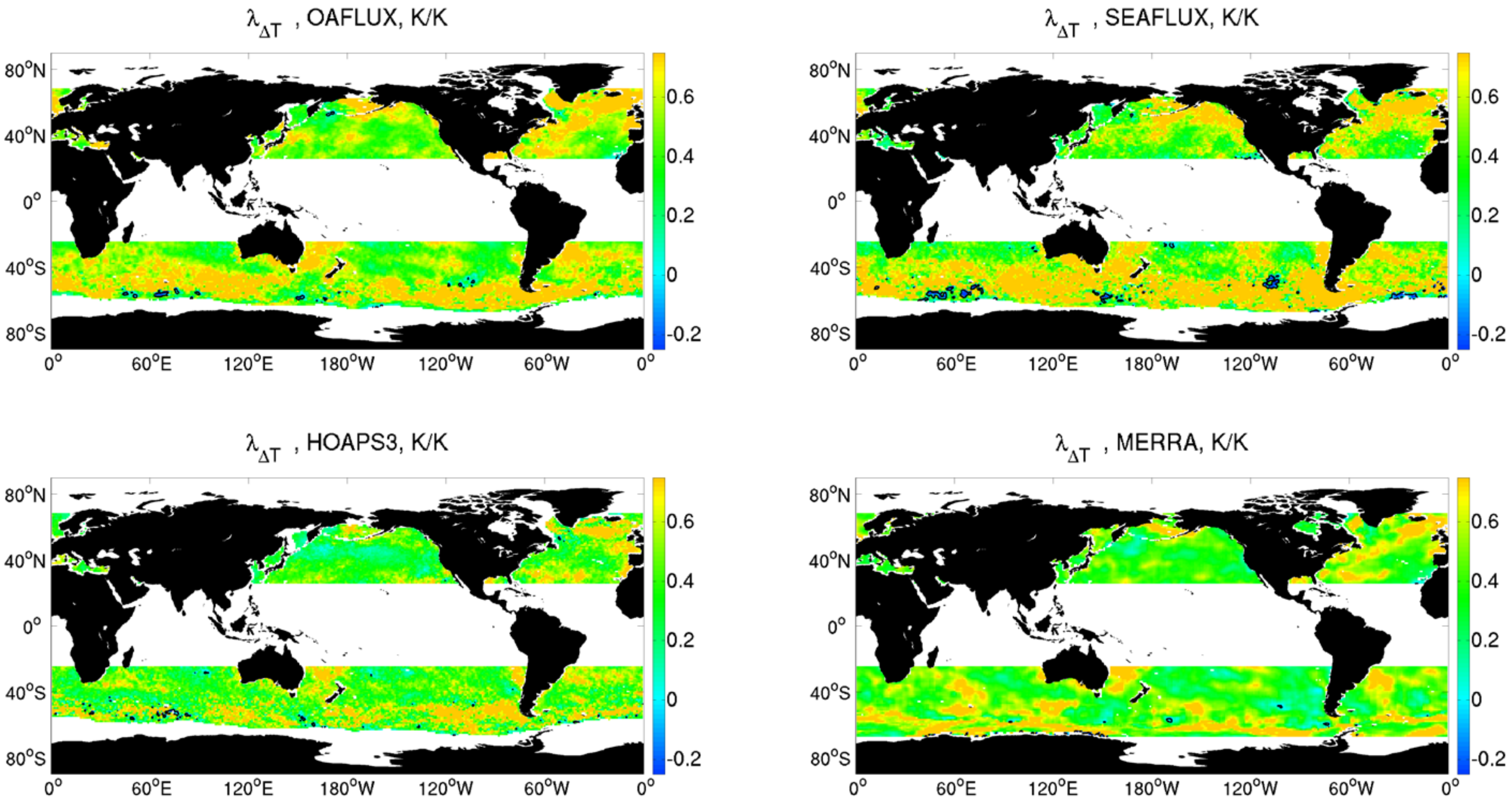
- Positive values now indicate the change in Qs-Qa with SST, no longer scaled as an energy feedback.
- Similar patterns are seen here as previously. Note that most areas are indicating the Qs-Qa coupling generates a negative feedback.

Qa 10m, g/kgK



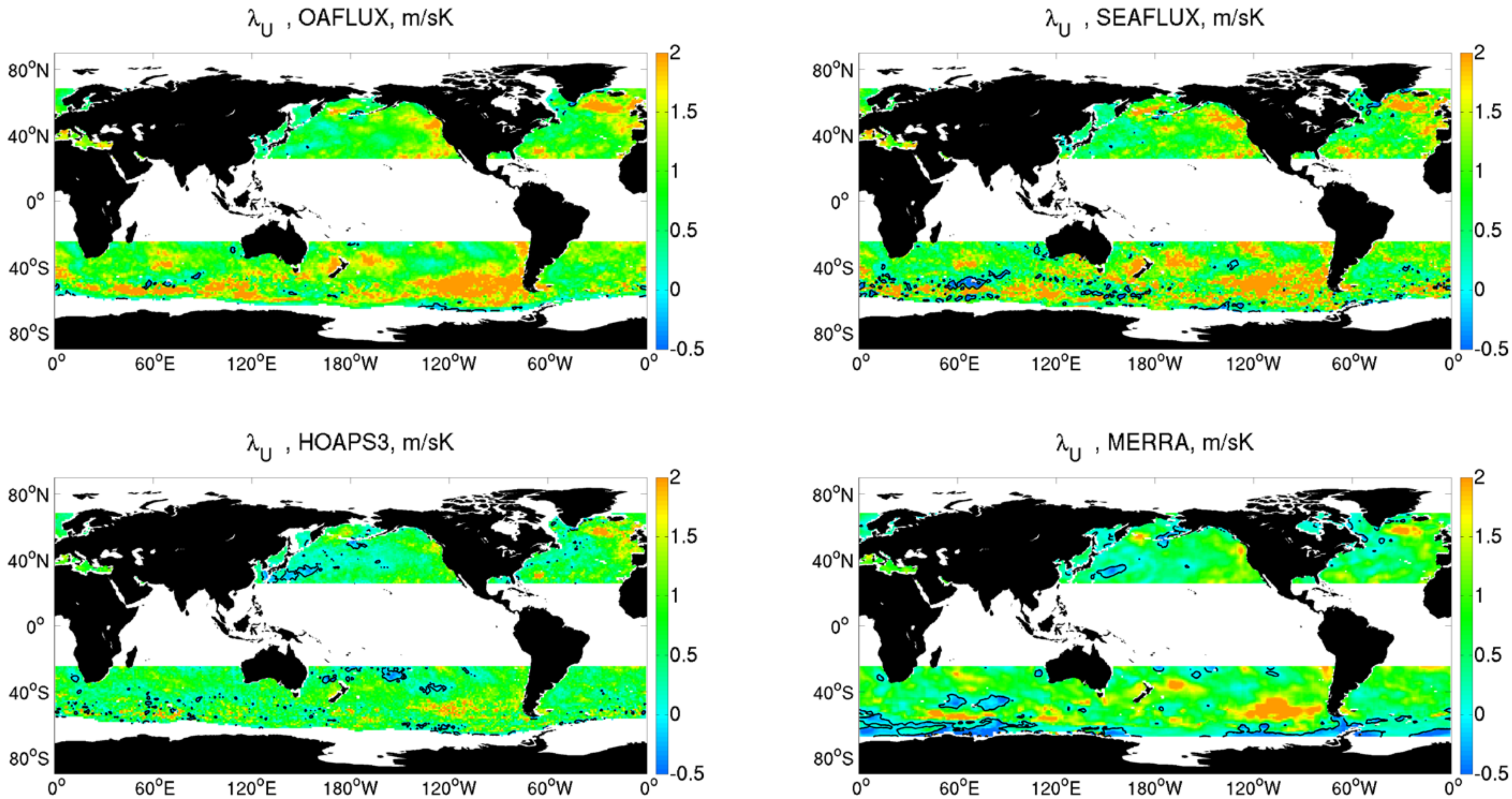
- The change in Qa alone shows both positive and negative changes with SST. How can this be when Qs-Qa is nearly everywhere positive?
- Merra shows a general agreement but appears to adjust more in-step with the SST change (positive correlations). Which is correct?

Ts-Ta, K/K



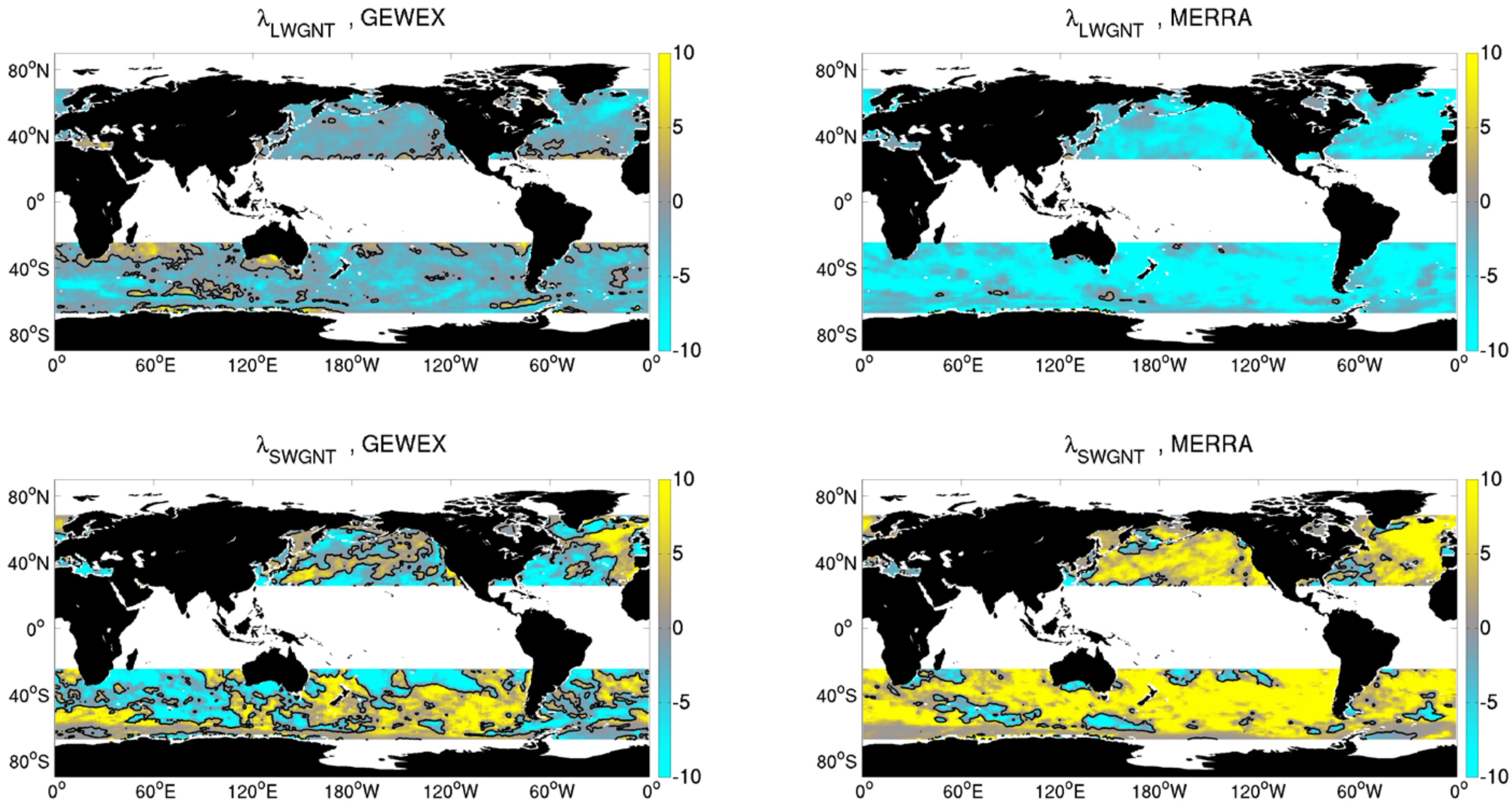
- There appears to be less overall agreement than with Qs-Qa with a split between the products, at least over the N. Pacific.
- For a 1K increase in SST, it appears there would only be a 0.4K adjustment to air temperature resulting in a 0.6K increase in areas.

Wind Speed, m/sK



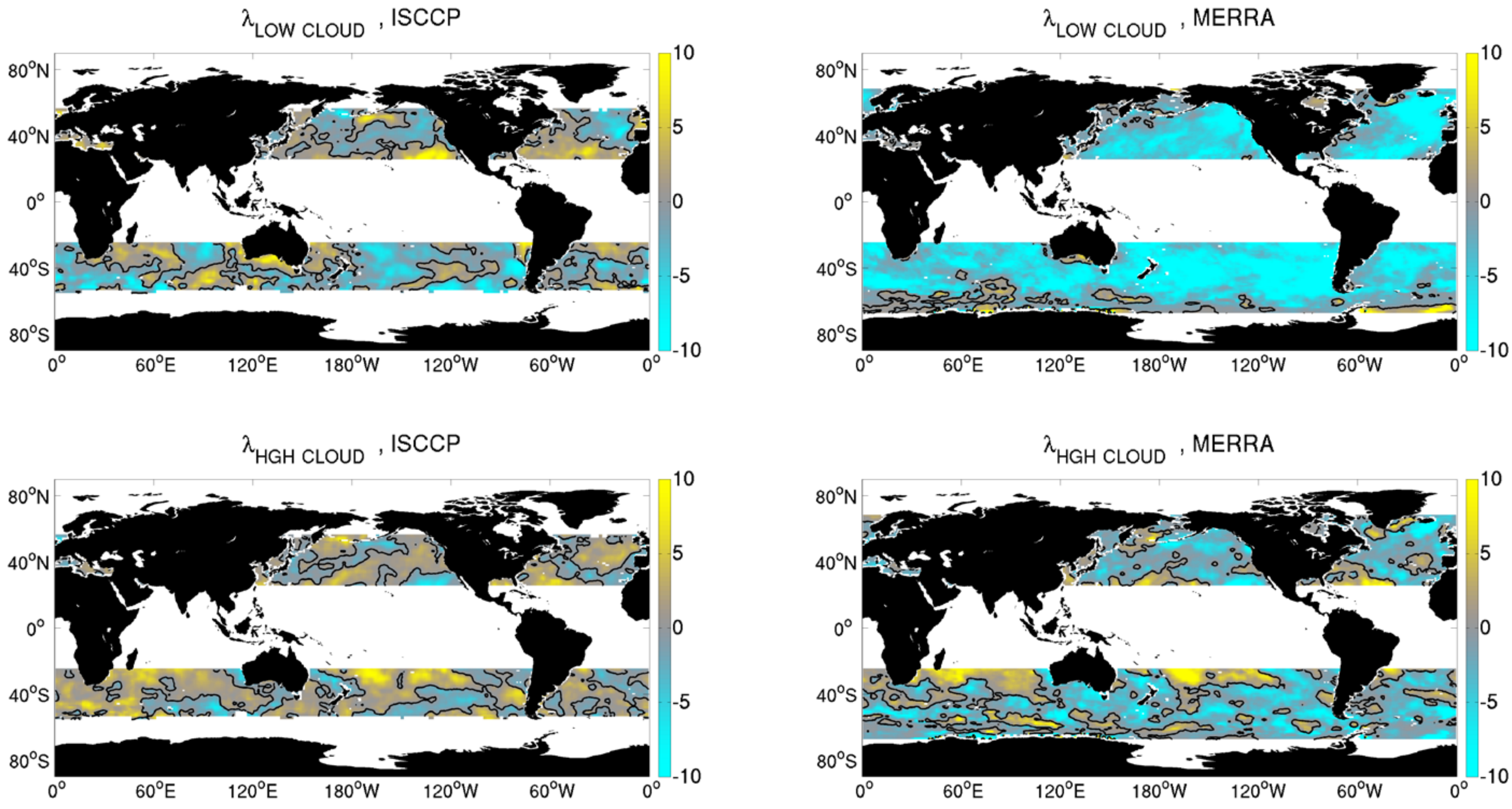
- Increases in wind speed appear to align well with the areas of increases in Qs-Qa and Ts-Ta in areas with the strongest damping.
- Areas of positive feedback are indicated, particularly over the western boundary current.

Net Longwave and Shortwave, W/m^2



•Positive/negative values indicate positive/negative feedback.
•Longwave appears mostly as a negative feedback while shortwave is more regionally variable (at least in GEWEX).
•GEWEX,MERRA use roughly the same inputs except for clouds.

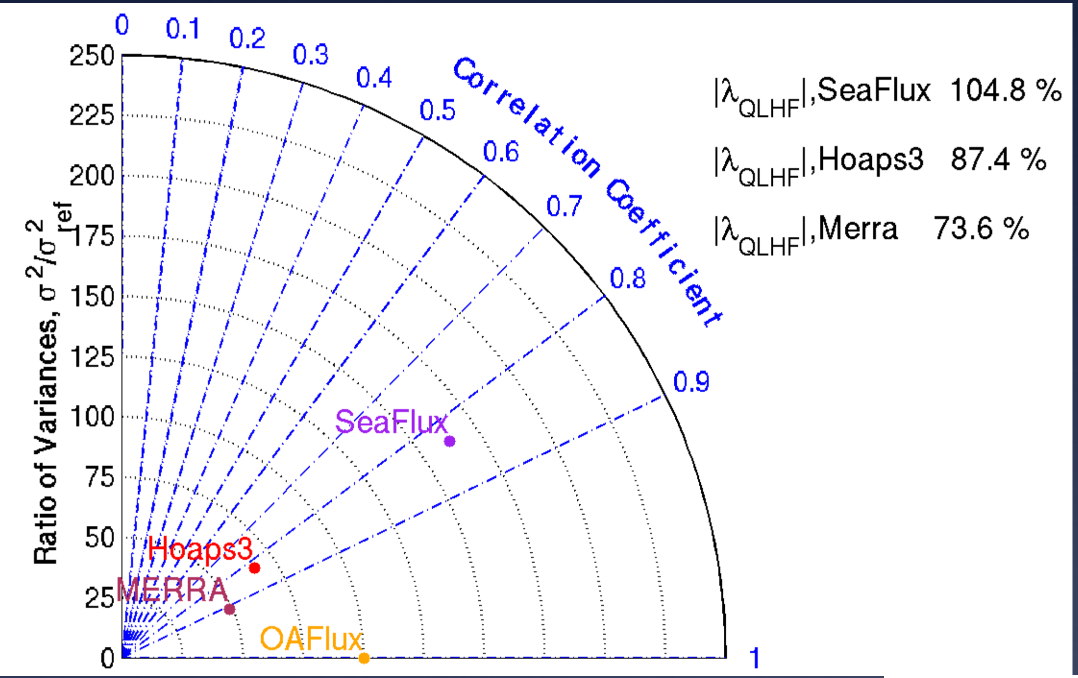
High and Low Cloud Fraction



•Now we are looking at cloud fraction sensitivity (positive value means increase in cloud fraction with warm SST or vice versa).

•Substantial difference in low clouds.. Is it real? ISCCP clouds are strongly anti-correlated. It appears low cloud fraction is the driver of the difference in radiative fluxes.

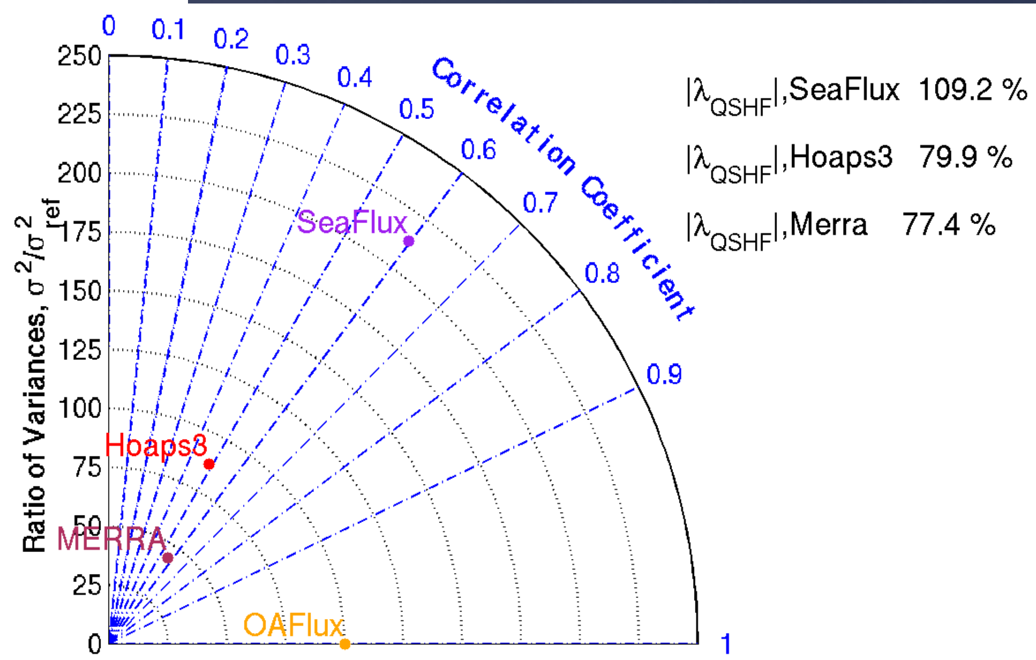
Measures of Spread



Modified Taylor Diagrams

- Radial distance is measure of the spatial variability relative to a reference, here OAFlux.
- Angle from origin represents the pattern correlation with that of the reference
- Also included are the ratio of the mean amplitudes relative to OAFlux.

- MERRA shows substantially reduced spatial variability but a fairly high pattern correlation for LHF.
- SeaFlux shows substantially higher spatial variability but roughly equal amplitudes.
- Closer agreement for LHF than for SHF.



Conclusions and Future Work

* The turbulent feedbacks appear to be mostly negative everywhere.
* The surface flux component sensitivities appear to align together in areas of the strongest damping.
  * Coherent increase in winds, decrease in Qa,Ta over warm SSTs and vice versa
  * Hint of positive wind speed feedback over boundary currents
* Radiative flux feedbacks appear to be primarily related to the cloud inputs
* Radiative feedbacks appear to be driven by the low cloud response to SST which are not well agreed upon in the products studied.
* MERRA has reduced variability. Why?
* OAFlux and SeaFlux appear most similar albeit SeaFlux containing higher variability.
* Results appear to reinforce earlier studies suggesting these higher resolution products are capable of capturing the signal within the noise.
* Would like to add significance testing - a Monte Carlo approach?

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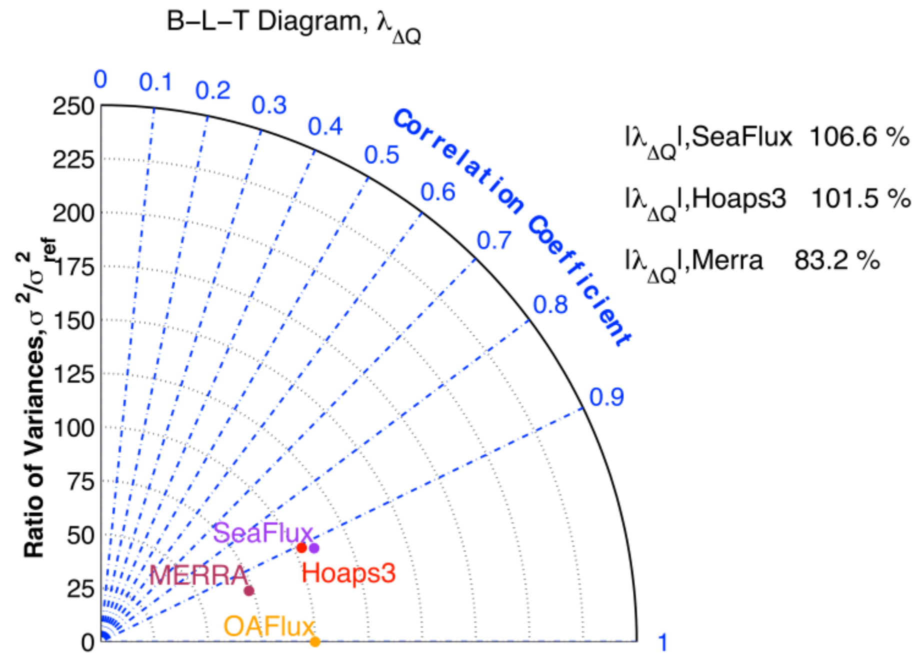
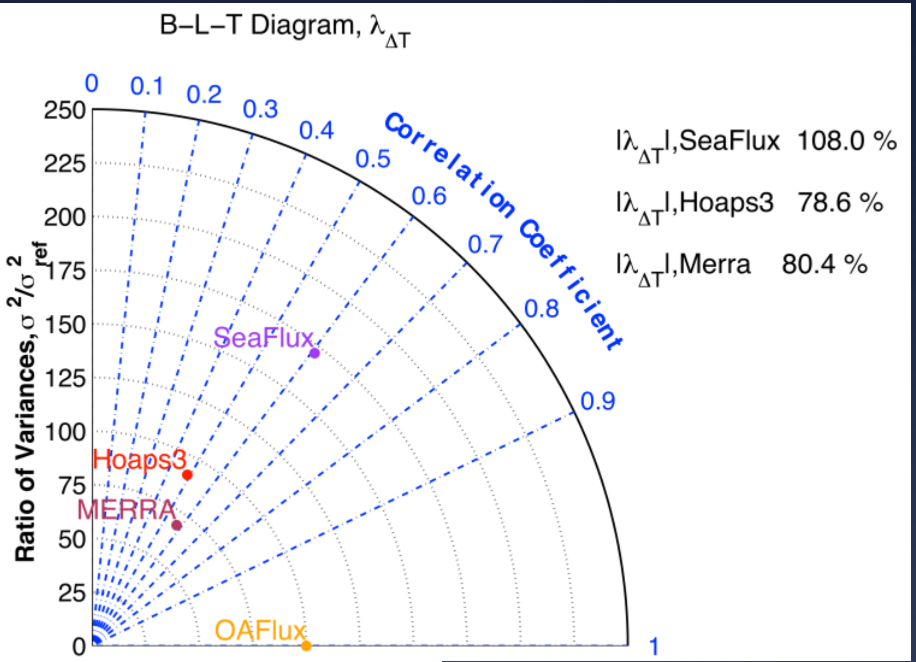
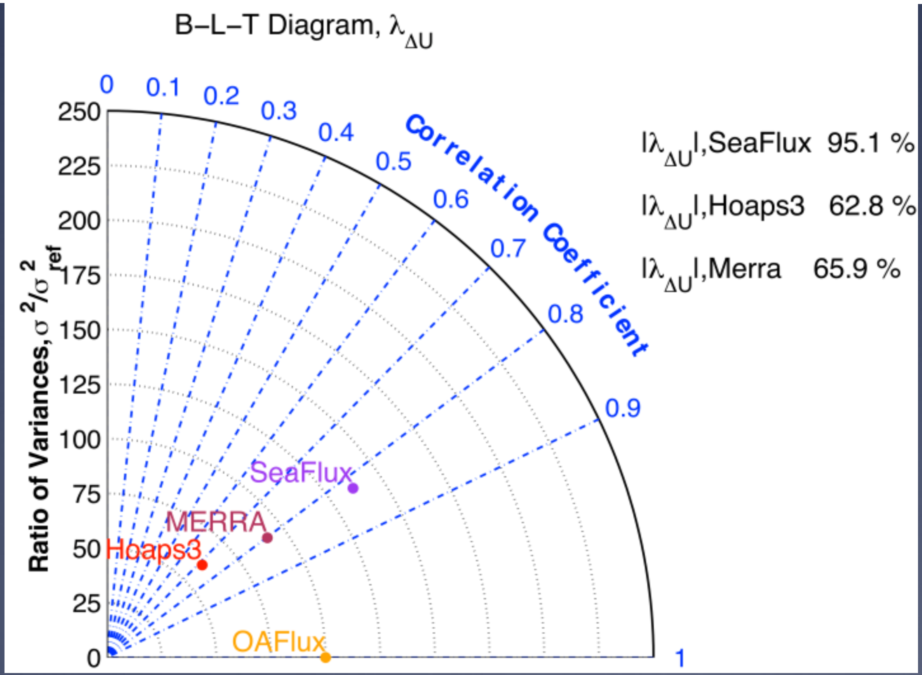
Extras


B–L–T Diagram, $\lambda_{\Delta Q}$
Correlation Coefficient
Ratio of Variances, σ^2/σ^2_{ref}
$|\lambda_{\Delta Q}|$,SeaFlux 106.6 %
$|\lambda_{\Delta Q}|$,Hoaps3 101.5 %
$|\lambda_{\Delta Q}|$,Merra 83.2 %
SeaFlux
MERRA
Hoaps3
OAFlux


B–L–T Diagram, $\lambda_{\Delta T}$
Correlation Coefficient
Ratio of Variances, σ^2/σ^2_{ref}
$|\lambda_{\Delta T}|$,SeaFlux 108.0 %
$|\lambda_{\Delta T}|$,Hoaps3 78.6 %
$|\lambda_{\Delta T}|$,Merra 80.4 %
SeaFlux
Hoaps3
MERRA
OAFlux


B–L–T Diagram, $\lambda_{\Delta U}$
Correlation Coefficient
Ratio of Variances, σ^2/σ^2_{ref}
$|\lambda_{\Delta U}|$,SeaFlux 95.1 %
$|\lambda_{\Delta U}|$,Hoaps3 62.8 %
$|\lambda_{\Delta U}|$,Merra 65.9 %
SeaFlux
MERRA
Hoaps3
OAFlux

Extras -N.E. Atlantic