Improving understanding of drivers of near surface biases using a novel heat flux climatology

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Talk Outline

1) Introduction
2) The observational heat flux products and inter-comparisons.
3) Some headline results from Southern Ocean applications on near surface bias drivers:
   a) CMIP models and improving HadGEM3
   b) Ocean forcing sets
4) Conclusions

Thanks to Caroll Anne Clayson, Liz Kent, Margaret Yelland, Lisan Yu, and Norman Loeb for advice on heat flux products.

Note – all quoted 'errors' are error estimates versus our observational estimates, given their unknown uncertainties.

Coupled surface energy flows reflect inter-twined ocean and atmospheric errors (associated biases must impact on future change)

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A) For a perfect ocean model, atmospheric forcing errors result in ocean transport errors which depend on associated errors in:

- ***(1) Heat fluxes.***
- (2) Wind stress (and curl).
- (3) Scalar mean wind stress.
- (4) Freshwater fluxes (P-E+IM-IF).

B) But ocean models are obviously not perfect so we also have errors in:

- (5) ocean model response (to ‘perfect’ forcing).
- (6) Errors in ocean initialisation.

C) And:

- (7) Coupled feedbacks due to SST biases due to all of the above on air-sea fluxes, winds, clouds, storms, etc.

- We focus on (1) but we are starting to look at (2), (3), (4) & (7).

What do we need surface flux observational estimates for?

- To asses errors in atmosphere only simulations, and link the errors to process deficiencies (and constrain perturbed parameter runs).
- To assess errors in ocean forcing sets (by running them over observed SSTs) to allow us to attribute ocean model biases to ocean model errors or forcing errors.
- To better understand ocean processes, e.g. hiatus ocean heat uptake (DEEP-C with stringent accuracy requirements).
- To assess ocean model errors (in future) through the use of flux bias reduction to ocean forcing).

Note that:

1) Need good estimates of individual flux terms to link net flux errors to process errors.

2) For forced/coupled ocean models SST biases alter the fluxes making them difficult to compare with observational estimates (except for variability).

Requirement for improved and globally balanced air-sea flux observational estimates for model evaluation

More effort much needed:

- WCRP/WWRP WGNE 2013 systematic errors in weather/climate models workshop key recommendation: "The lack of and/or inaccessibility to some key observations remains a major challenge. These include **surface fluxes (especially over the oceans)**, and observations in polar and tropical regions."

The novel globally balanced observational heat flux estimates (net flux from Reading University)

Liu, Allan, Berrisford, Mayer, Hyder, Loeb, Smith, Vidale and Edwards (2015, JGR in press). Combining satellite observations and reanalysis energy transports to estimate global net surface energy fluxes 1985-2012 , JGR atmos.

Atmospheric energy conservation approach to estimate net fluxes (after Trenberth and Caron (2001); Trenberth, Caron, Stepaniak (2001); Mayer and Haimberger (2012))

TOA fluxes - CERES-EBAF– anchored by long term change in ocean heat content

SPACE

ATMOSPHERE

Energy divergence
& storage tendency
ERA I analyses

Net surface fluxes

Radiative transfer modelling to get - radiative surface flux

SURFACE

Residual- turbulent fluxes

John Edwards initially developed a MO ERA40-based product but we now use an improved ERAI-based product developed under NERC DEEP-C by Chun-Lei Liu, Richard Allan et al.

Liu et al (2015) approach to net air-sea fluxes

- Net flux estimates are subject to large errors accumulating from errors in **large mostly opposing seasonal and individual heat flux terms**.
- We directly estimate net flux using conservation of total energy in atmospheric column
- Radiative TOA fluxes from EBAF well observed (mean pinned to ocean heat content change estimates).
- Energy divergences should be better constrained by assimilation, and depend less on large cloud/radiation errors, than actual re-analysis surface fluxes, e.g. short wave TOA and surface biases partially cancel and there is a correction term over land (some problems over high heat flux and gradient regions of boundary currents and equatorial Pacific.

Our globally balanced heat flux term estimates and their assumptions

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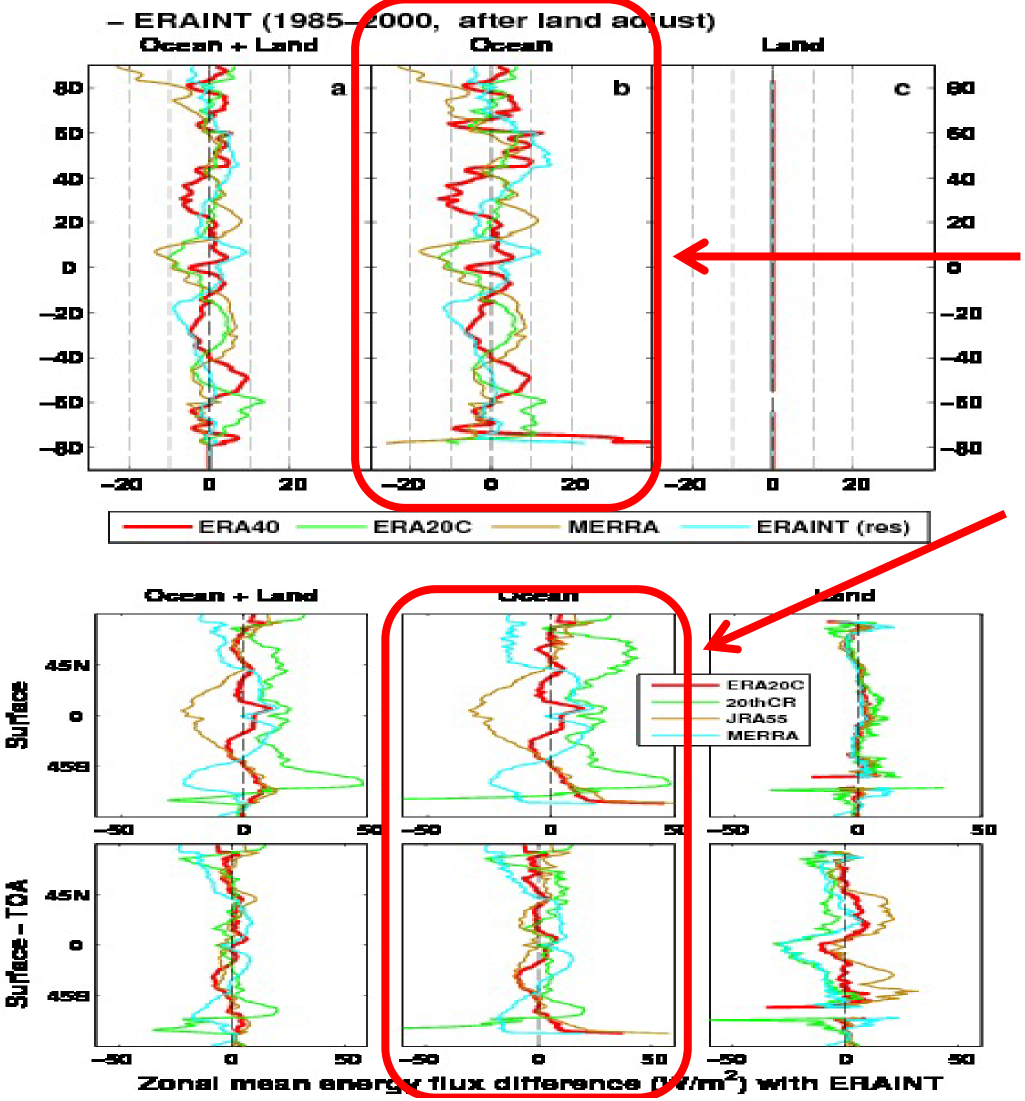
- Combining ISCCP/CERES with OAFLUX/SEAFLUX produces large global imbalances so we can't use them.

- We therefore estimate turbulent flux as residual from our net flux estimate and CERES radiative estimates at each point, making (risky) assumption that we believe CERES - errors obviously accumulate in our turbulent flux estimate.

- This approach seems best possible option as spread across turbulent heat flux products are much larger than radiative and surface relative humidity and air-temperature are hard to observe.

- We also use Bowen Ratios (sensible/latent) from OAFLUX to estimate sensible and latent fractions from this turbulent residual.

Towards uncertainties – spread across several re-analyses
(difference from Liu et al estimate)

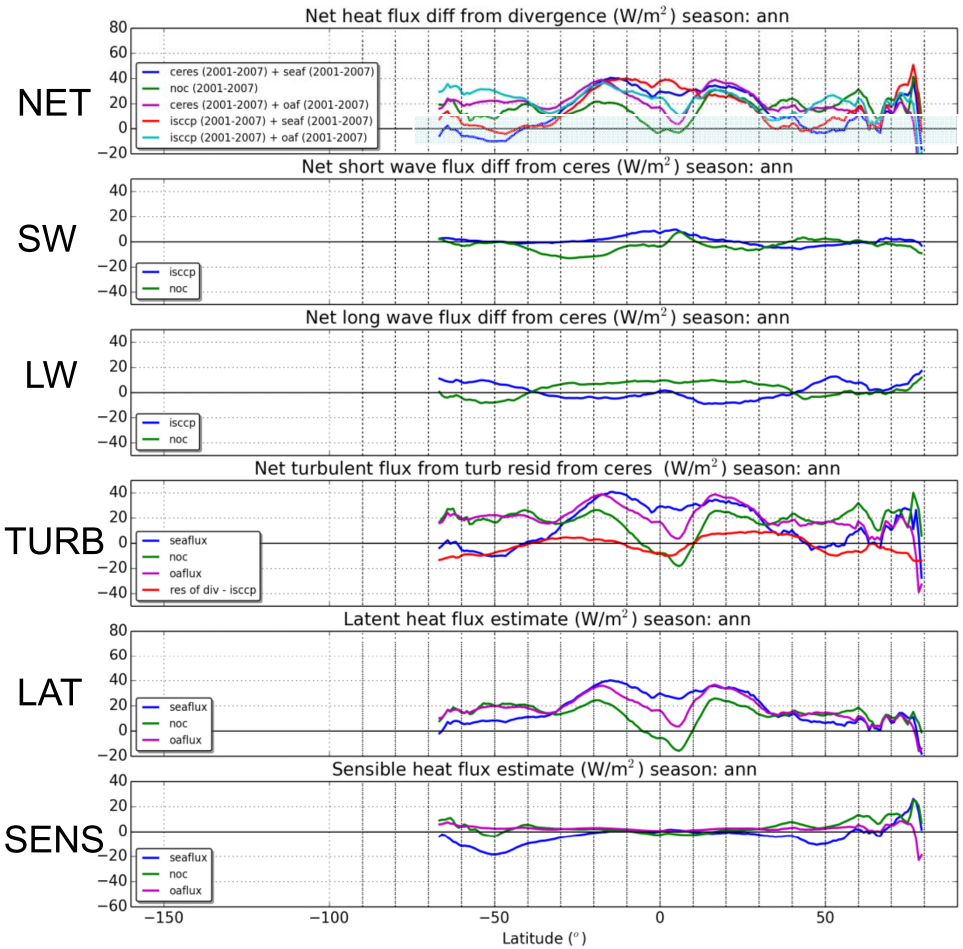


•This method provides a component of the uncertainty from spread across re-analyses which is around +/-10W/m^2.

• Using divergences narrows the spread compared to raw fluxes by around half.

• We need comparisons with all the available flux buoys (for buoys with nearly complete months).

Differences between other products and our estimates: annual mean



- Uncertainty in zonal mean net flux is huge ~40-50W/m^2.
- We know there are errors in other products as they don't balance globally.
- Uncertainty in radiative flux estimates appears to be ~10W/m^2.
- Uncertainty in turbulent flux estimates are very large ~30-40W/m^2, mainly due to uncertainty in larger latent heat term. We agree best with NOC, particularly in summer when they have more obs.

Applications to understanding ocean near surface bias drivers:

a) CMIP models and HadGEM3 Southern Ocean

CMIP Mean net flux, SST and 300m heat content biases and STDs

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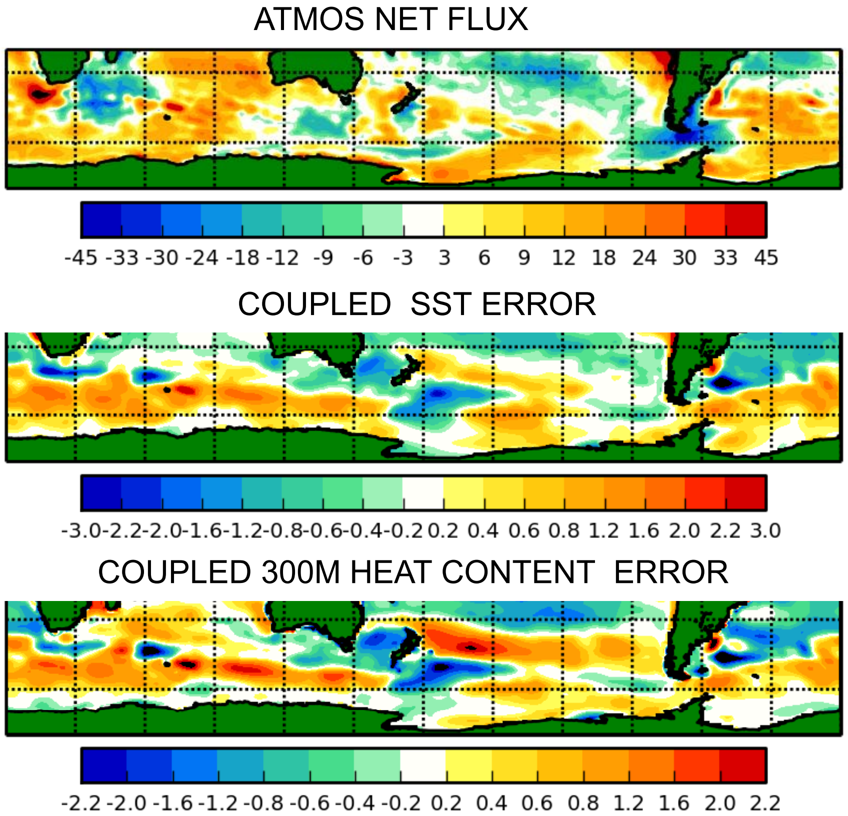


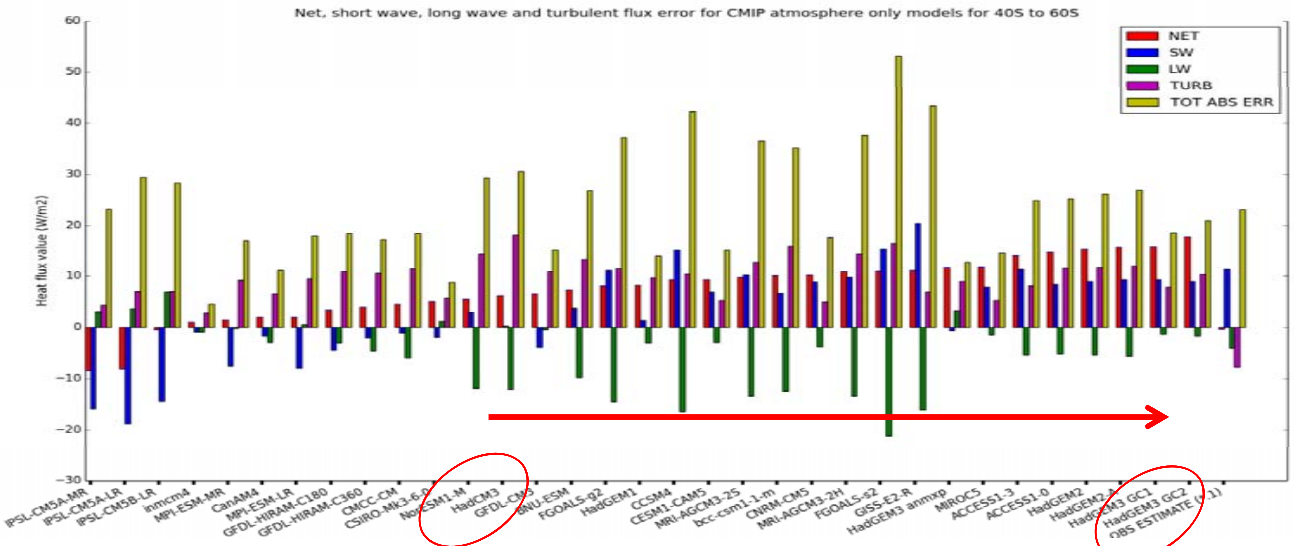
Associated T biases extend to many hundreds meters and must impact future change

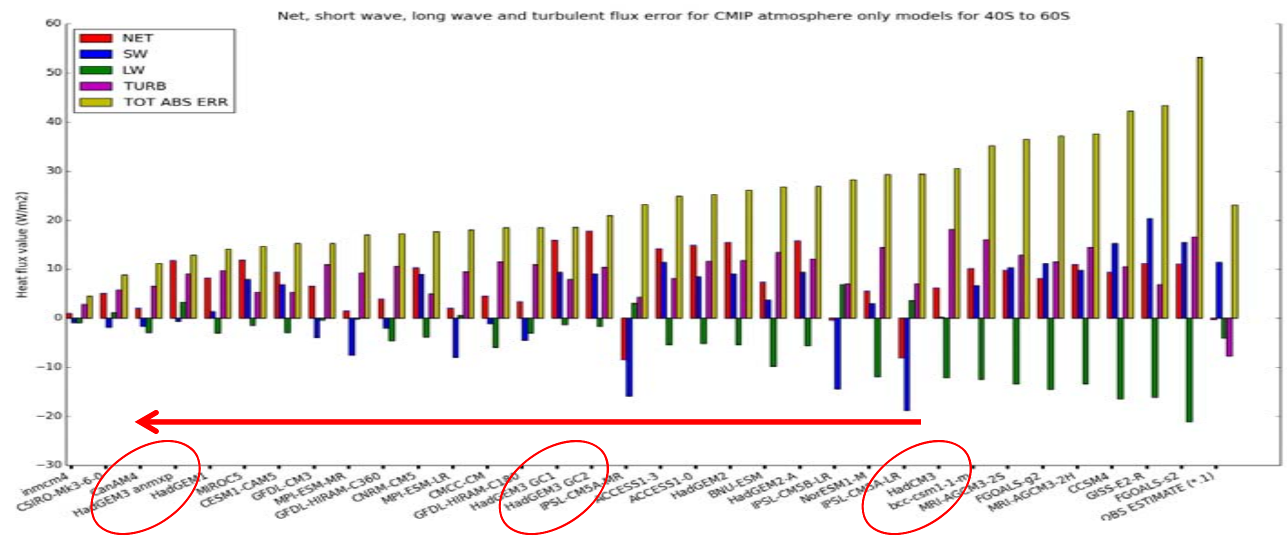
- Across 18 models for which we have both atmosphere only and coupled experiments there is good spatial correspondence in atmosphere only net flux error and coupled SST and upper ocean heat content error.

- The net flux error is about half due to short wave and half due to turbulent error but the spread is much larger in short wave (i.e. they all have a common underestimation of turbulent heat loss).

- Winds and wind curl and ocean model errors obviously also contribute.

Error cancellation in CMIP5 Southern Ocean atmos-only air-sea fluxes

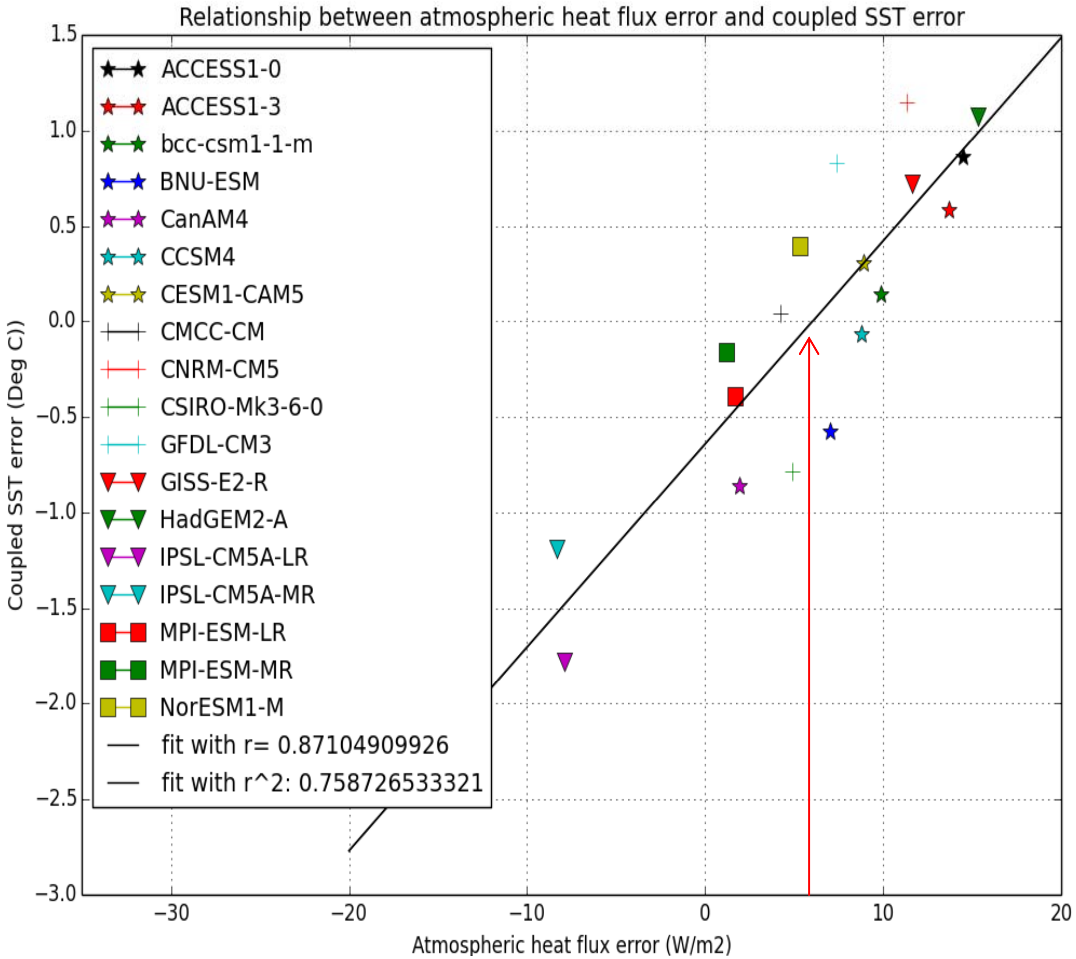




- Models which look good in net flux are not those that look good for total absolute error!
- Our model net flux and SST bias get worse over time BUT get better over time when ranked by total abs error!
- Net flux that determine SST biases and feedbacks but balance between terms is important for future change

Atmospheric errors and CMIP5 coupled Southern Ocean SST biases (40-60°S)

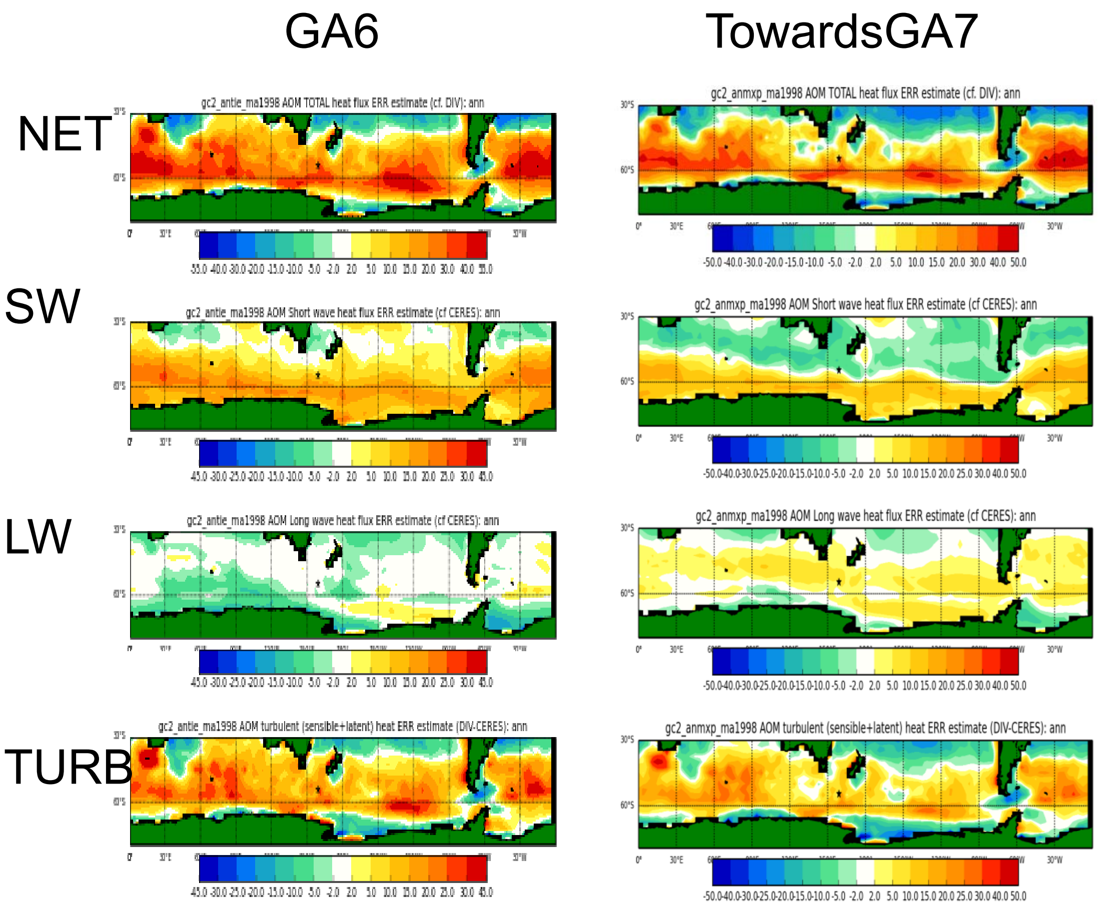
(have also done global spatial correlations, including wind parameters)



Independent of observational estimate (except intercept)

- The net flux errors in atmosphere only simulations explains ¾ of the variance.
- This means that ocean model/wind/P-E errors contribute to less than ¼ of spread in CMIP5 coupled model biases.
- Common structural errors don't show up!
- The correlation is ~0.7 for short wave alone.
- For 300m heat content the correlation is ~0.7.

HadGEM3-A model heat flux errors



- Summarises lots of develop & process assessment work on aerosols, clouds, winds, storms, ocean sensitivities, etc.

- With many of the planned GA7 changes the 40-60^{o}S net flux bias reduced by around ~40%

- This is mainly due to MODE and MIXED PHASE, and an associated increase in cloud (super-cooled) liquid water.

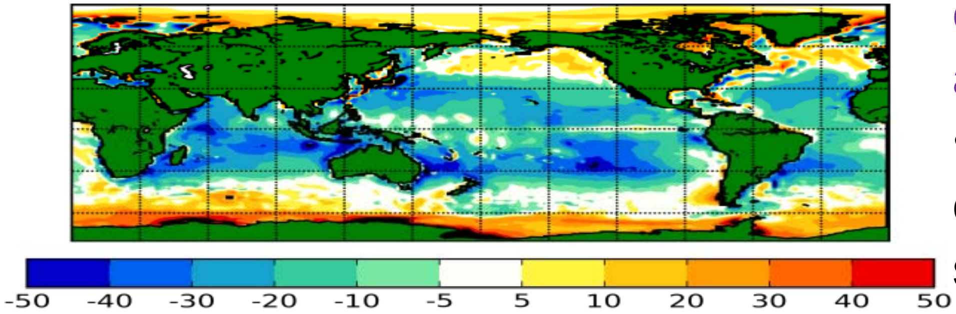
- 50% assoc improvement in coupled SST biases

Applications to understanding ocean near surface bias drivers:

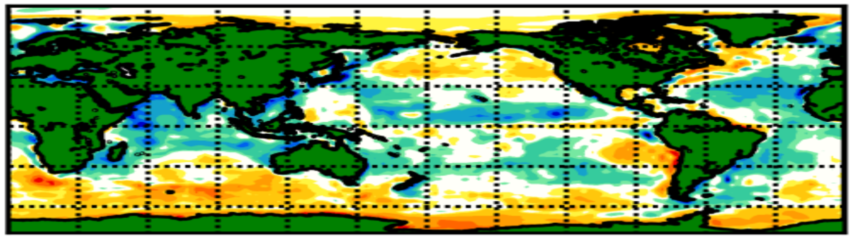
b) Ocean forcing sets (work in progress)

Ocean forcing set errors (work in progress)

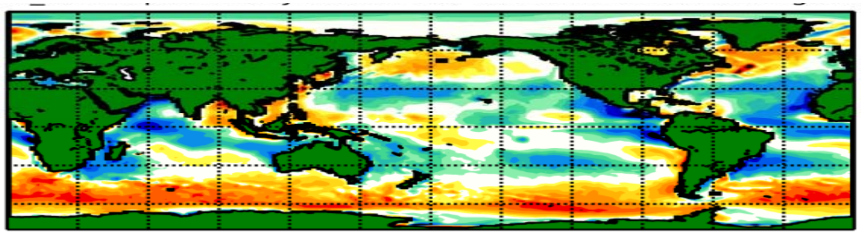
DFS4 forcing set



CORE II forcing

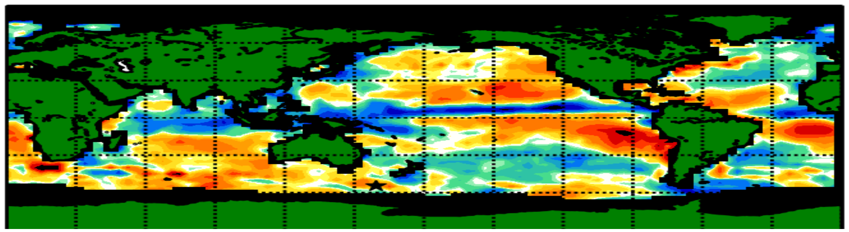


HadGEM3 ATM only



- Errors in forcing set heat fluxes (over observed SSTs) are comparable to those in free atmosphere model (>20W/m^2) !
- SST biases appear to broadly correspond to forcing biases on basin scales.
- Assimilation increments are another source of information (Keith/Maria).
- Also assess vector & scalar mean winds versus CCMP (constrained by scatterometer).

JMA



Conclusions

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- Our globally-balanced global heat flux estimates appear (given the uncertainties) to improve our ability to assess models and processes but we need to better understand uncertainties
- This complements other products and in no way negates the need for more direct observations of air-sea fluxes.
- The use of the product has highlighted apparent:
  - **Large spread in turbulent fluxes** highlighting need for more observations
  - **Prevalent flux errors (& error cancellation) in CMIP atmosphere only models** that appear to drive coupled SST biases.
  - **Process deficiencies in our atmospheric model** that, through targeted development, has reduced coupled Southern Ocean SST biases by ~50%.
  - **Errors in ocean forcing sets** that limit our ability to assess ocean models

Ongoing effort on:

  - **Uncertainties in observational estimates**, particularly turbulent fluxes (with NOC).
  - **Flux bias reductions experiments** to better understand ocean model errors.

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Thanks for listening

Any questions?