Southern Ocean climate model biases traced to Atmospheric model surface heat flux errors

Pat Hyder, John Edwards, Keith Williams, Alejandro Bodas-Salcedo, Jane Mulcahy, Paul Field, Kalli Furtado, Dan Copsey, Claudio Sanchez, Livia Thorpe, Richard Allan and Chun-lei Liu (Reading University), Chris Roberts, Simon Josey and David Berry (NOC), Malcolm Brooks, Daley Calvert, Tim Graham, Jeff Ridley, Catherine Guiavarch, Steve Hardiman, Stephen Belcher, Helene Hewitt, Andrew Meijers and Tom Bracegirdle (British Antarctic Survey).

June 2017

1) CMIP5 Southern Ocean Biases

- **IPCC coupled climate models often have large warm Southern Ocean SST biases (Flato et al, 2013).**
- **These biases extend to several hundred metres depth and are expected to adversely impact on future projections.**
- We employ a new method (Liu et al, 2015) to estimate net flux and estimating turbulent flux as a residual of net flux and CERES radiative fluxes.
- Across 18 models for which we have both atmosphere only and coupled experiments there is spatial correspondence in atmosphere only net flux error and coupled SST and upper ocean heat content errors (Fig 1).
- The net flux error is about half due to short wave and half due to turbulent error.
- However, the spread is much larger in short wave than turbulent flux, i.e. they all have a common underestimation of turbulent heat loss (not shown).
- There is also considerable error cancellation between errors in the individual flux component terms in the majority of the models (not shown).

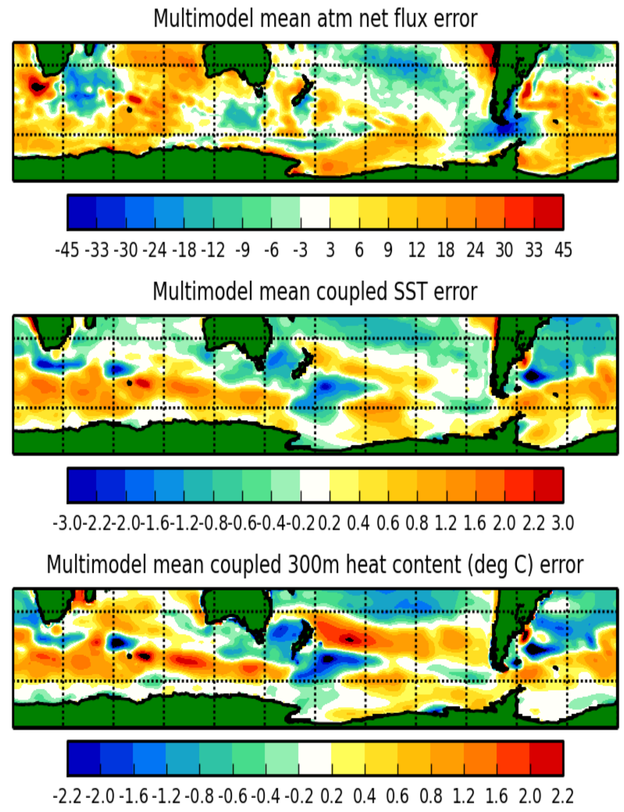
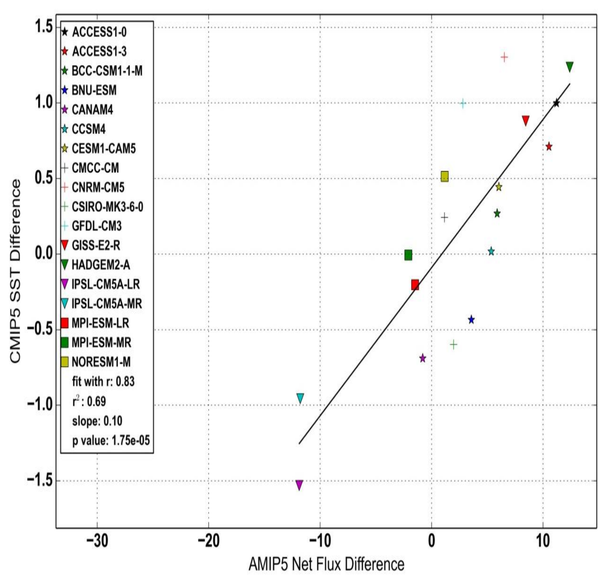


Fig 1

Fig 2



2) DRIVERS OF CMIP5 SST BIASES

- We regressed the simulated coupled SST, and upper ocean heat content, biases against stand-alone atmosphere only net and component flux biases for 40-60ºS.
- **70% of the variance in coupled SST biases is explained by atmosphere-only net flux biases (Fig 2) (it is 50% for short wave component alone).**
- **This suggests that stand-alone ocean-ice model mixed layer ocean-heat transport convergence errors contribute to less than 30% of spread in CMIP5 coupled model biases (common structural errors, e.g. vertical mixing, would not be identified by this regression analysis)**.
- The fraction of 300m heat content variance biases explained atmosphere-only net flux biases is only ~50% implying a larger possible contribution from ocean model errors.
- The SST biases feedback onto the near surface zonal winds, altering the latitudinal location of the surface wind maxima.

3) A ROUTE TO IMPROVING THE MODELS

- In 2012 a Process Evaluation Group (PEG) comprising atmospheric, ocean and sea-ice scientists was set up to investigate the causes of the large Southern Ocean biases in HadGEM3-GC2.
- This group undertook a significant development & process assessment work on cloud and aerosol, wind and storm, stratospheric, ocean, and sea-ice processes.
- Critically, targeted developments were undertaken on a new mixed phase cloud scheme and to a new MODE aerosol scheme and, resulting in an increase in cloud (super-cooled) liquid water, which is prevalent in observations of Southern Ocean clouds but deficient in most CMIP5 models.
- **In consequence, between HadGEM3-GC2-A and HadGEM3-GC3.1-A the 40-60ºS net flux bias has been reduced by ~65% (fig 3), contributing to a coupled SST bias reduction of ~75% (Fig 3).**

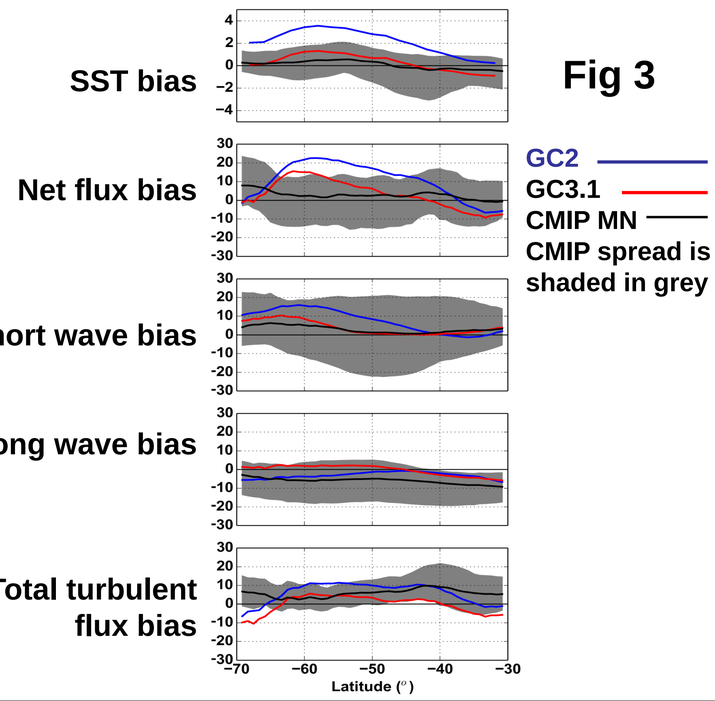


Fig 3

Refs:
Flato et al (2013). Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. WG I contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
Liu, Allan, Berrisford, Mayer, Hyder, Loeb, Smith, Vidale, Edwards (2015). Combining satellite observations and reanalysis energy transports to estimate global net surface energy fluxes 1985-2012 , JGR atmospheres,120, 9374–9389.

.

Met Office Hadley Centre, FitzRoy Road, Exeter, Devon, EX1 3PB United Kingdom
Tel: +44 1392 885680 Fax: +44 1392 885681
Email: patrick.hyder@metoffice.gov.uk