# Coupled models, climate variability and flux adjustments

Steven J. Phipps[1,2,3], Jason L. Roberts[3], Scott B. Power[4], William F. Budd[2] and Nathan L. Bindoff[1,2,3]

[1]Antarctic Climate and Ecosystems CRC, University of Tasmania, Australia (E-mail: sjphipps@utas.edu.au)
[2]Institute of Antarctic and Southern Ocean Studies, University of Tasmania, Australia
[3]Tasmanian Partnership for Advanced Computing, University of Tasmania, Australia
[4]Bureau of Meteorology Research Centre, Melbourne, Australia

## Introduction

Coupled climate system computer models play a vital role in the study of climate variability and change. However, flux adjustments are generally required to ensure that the control climate is both realistic and stable on long timescales. The magnitude of the adjustments can exceed that of the climatological mean fluxes in places, and their effect on the behaviour of the model requires careful examination.

Simulations are conducted with and without flux adjustments, using a coarse-resolution atmosphere-sea ice-ocean general circulation model. Two techniques for reducing the magnitude of the flux adjustments are also assessed. The simulated climate variability, and the response to increased atmospheric $CO_2$, is examined.

## Flux Adjustments

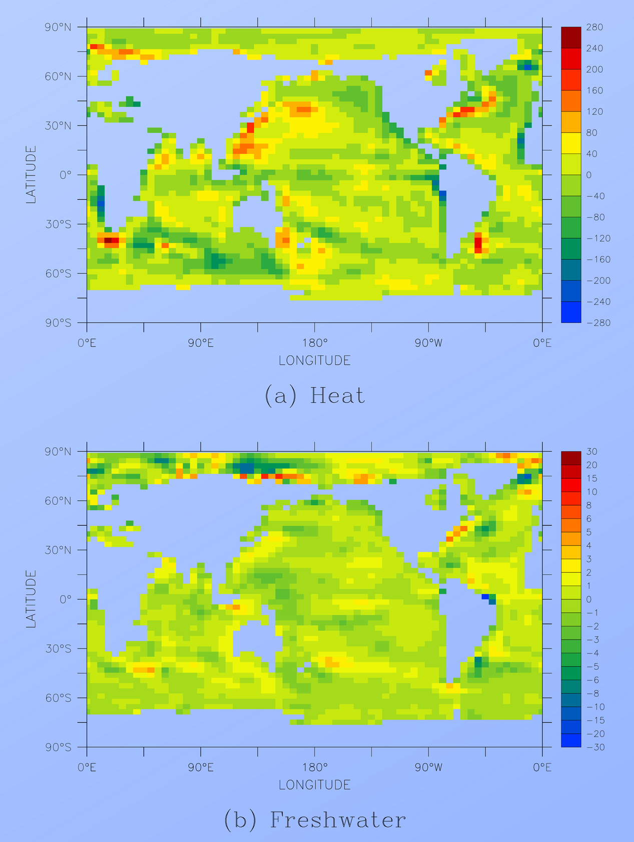


**Figure 1.** Annual-mean flux adjustments. **a** Heat (W m$^{-2}$) and **b** Freshwater (m year$^{-1}$).

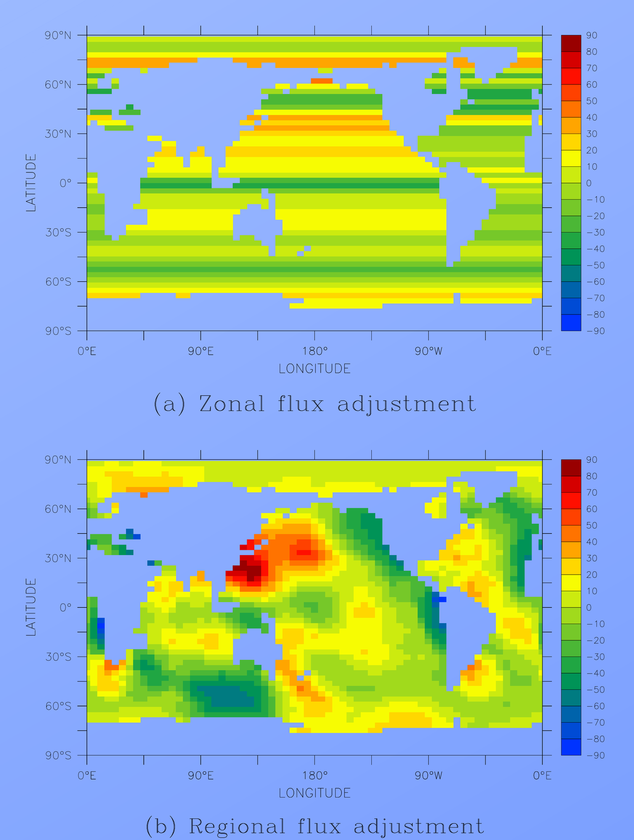


**Figure 2.** Heat flux adjustments (W m$^{-2}$). **a** Zonal and **b** Regional.

We use the CSIRO climate system model (Gordon 2002). The horizontal resolution is R21 ($\Delta\lambda \approx 5.6^\circ$, $\Delta\phi \approx 3.2^\circ$), with 18 vertical levels in the atmosphere and 21 in the ocean. The atmosphere and ocean models are spun up independently, and the surface heat and freshwater fluxes are diagnosed for each model. The mismatch between the atmosphere and ocean model heat and freshwater fluxes gives rise to the flux adjustments required by the coupled model.

The annual-mean flux adjustments are shown in Figure 1. They are both large in magnitude and exhibit a rich spatial structure. As "traditional" flux adjustments also vary with the annual cycle, the actual corrections applied can be even larger. The heat flux adjustments, for example, approach 500 Wm$^{-2}$ in places. Such large corrections to the surface fluxes might be expected, at the very least, to influence the modes of internal variability within the model.

We therefore investigate two techniques for reducing the magnitude of the flux adjustments. Both involve taking the annual means of the adjustments, combined with a degree of spatial averaging. The first technique is the "zonal" (or "minimum") flux adjustment (Weaver and Hughes 1996), whereby the adjustments are zonally averaged across each ocean basin. Such adjustments correct only for errors in the simulated meridional heat and freshwater transports.

We also investigate a "regional" flux adjustment, whereby the adjustments are averaged over a circle of diameter 3000 km. This approach assumes that, as climate models only have skill in simulating the climate system on a regional scale, it is only necessary to correct the surface fluxes at this level.

As can be seen from Figure 2, both techniques reduce the size of the flux adjustments considerably. In the case of the zonal flux adjustment, the heat flux adjustment does not exceed 50 Wm$^{-2}$ at any point, while in the case of the regional flux adjustment, it does not exceed 90 Wm$^{-2}$. While the regional flux adjustments are slightly larger in magnitude, the spatial structure is more realistic.

## Climate Drift

Four control runs are conducted. One run uses no flux adjustments, while the others use traditional flux adjustments and the zonal and regional flux adjustments respectively. The duration of each run is 300 years, and a constant atmospheric $CO_2$ concentration of 280 ppm is used.

Figure 3 shows the difference in surface air temperature between the start and end of each run. Without flux adjustments, there is considerable drift, particularly at high latitudes. While the traditional flux adjustments reduce this drift almost to zero, the regional flux adjustments perform almost as well. The zonal flux adjustments are less successful.

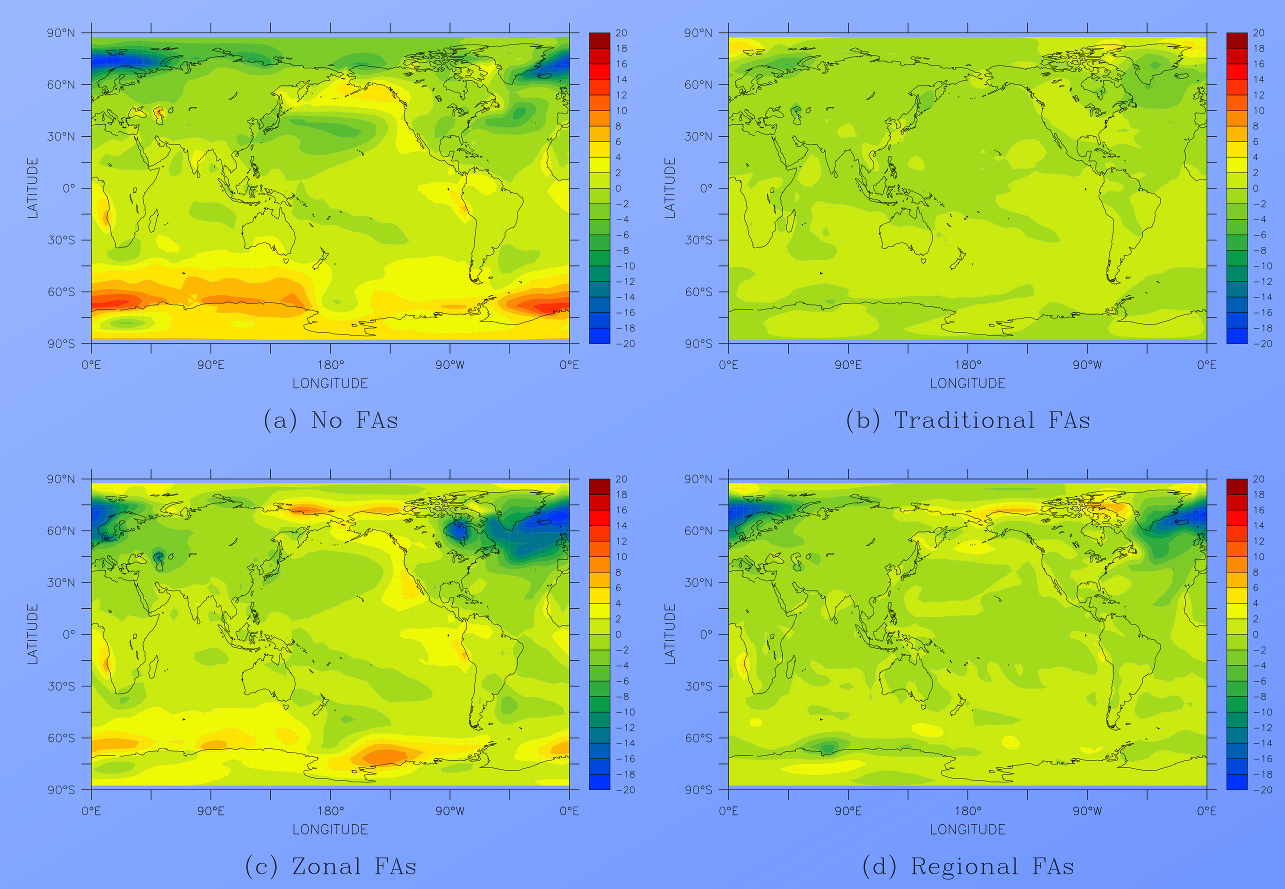


**Figure 3a-d.** Change in annual-mean surface air temperature during each control run (K).

## Climate Variability

Figure 4 shows timeseries of the Niño 3.4 index (the sea surface temperature anomaly in the region 5°S–5°N, 170°–120°W) derived from years 101 to 200 of each control run. The standard deviations range from 0.29 to 0.47 K, as compared to the observed value of 0.71 K (Trenberth 1997).

The large difference in the strength of the simulated El Niño suggests that flux adjustments have a strong influence on the internal variability of the model.

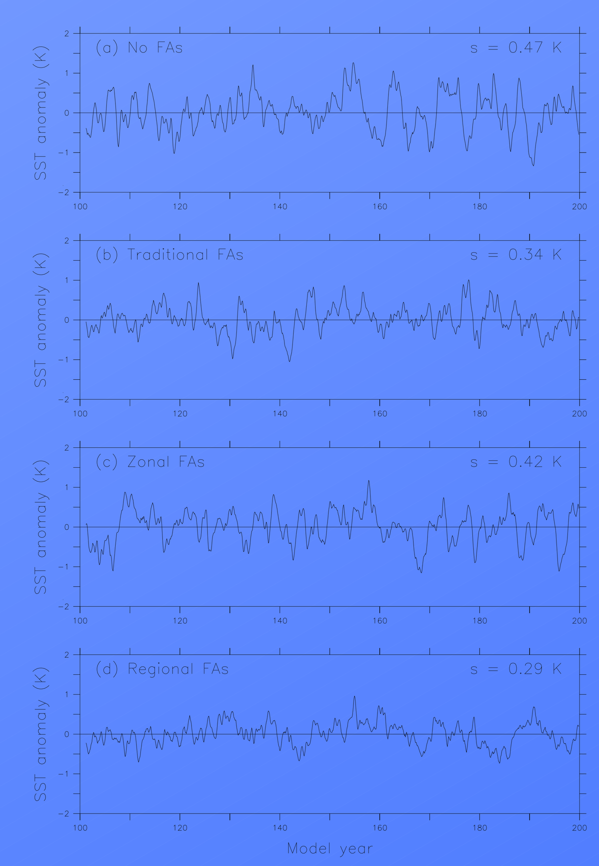

**Figure 4a-d.** Niño 3.4 index.

## Climate Sensitivity

Transient runs are started from the end of year 100 of each control run. The atmospheric $CO_2$ concentration is increased at 1% per year, until it reaches 840 ppm (three times the original concentration) in year 211. The runs are then continued to year 300, with the $CO_2$ concentration held constant.

Figure 5 shows the change in surface air temperature (transient minus control) at the time of trebling of $CO_2$. All four simulations show a similar response at low latitudes, but large differences can be seen at the poles. The spread in global-mean temperature change for the four simulations is just 0.12K, with an increase of between 2.69 and 2.81 K relative to the control run.

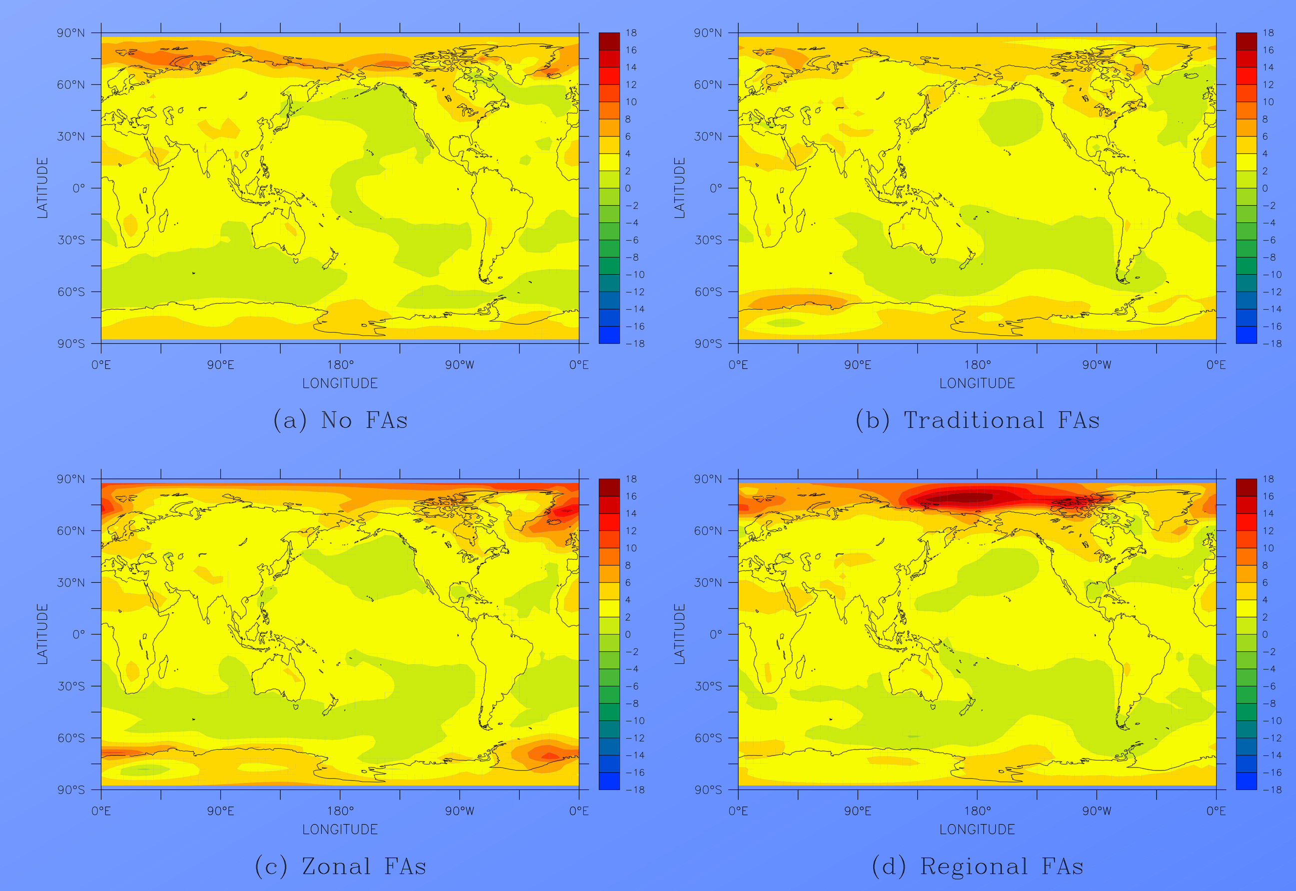


**Figure 5a-d.** Change in annual-mean surface air temperature at the time of trebling of $CO_2$ (K).

## Conclusions

We have shown that flux adjustments are necessary in order to obtain a stable control climate in the coarse-resolution climate model used here.

While we have found no evidence that flux adjustments affect the global climate sensitivity, they do affect the regional response to increased atmospheric $CO_2$. They also appear to affect the simulated climate variability in the tropical Pacific Ocean. Thus we have shown that, while flux adjustments are necessary, they must be used with caution.

We have also demonstrated that it is possible to reduce the magnitude of the flux adjustments, without necessarily sacrificing a stable control climate.

## References

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