The impact of a dynamic CAPE timescale on the surface energy budget in the Hadley Centre GCM

John Donners and Pier Luigi Vidale*
UK-Japan Climate Collaboration (UJCC), Earth Simulator Center
* NCAS-Climate, University of Reading (UK)

Summary

The parameterization of convection in a climate model impacts both the distribution and variability of precipitation and the model's climate sensitivity. In the UK Met Office Unified Model (UM), the strength of atmospheric convection depends on the convective available potential energy (CAPE), as controlled by a "CAPE timescale". In a companion poster (The impact of a dynamic CAPE timescale on precipitation variability and distribution in the Hadley Centre GCM) we show how an alternative treatment of convection is able to improve the timing and global distribution of convection.

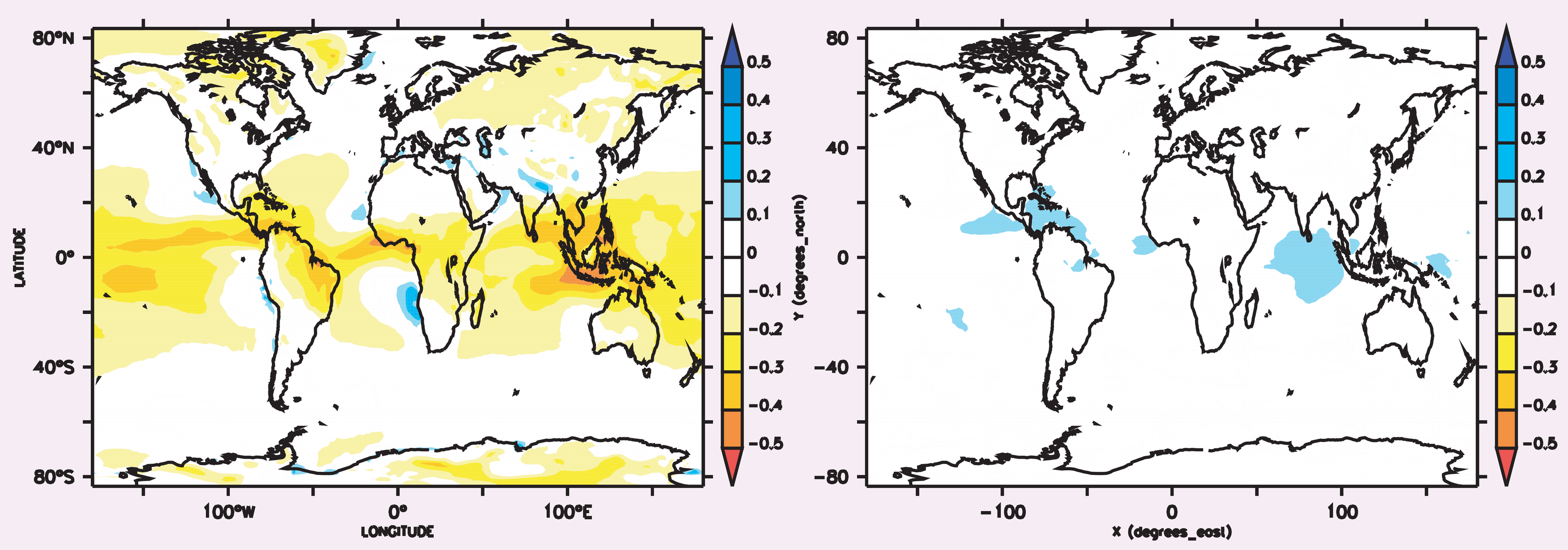
By virtually eliminating time-step level oscillations in convection and the intermittent cloud cover thereof, we have also been able to reduce the excessive amount of solar radiation impinging on the surface. This reduction is especially important over the oceans, where the optically thicker (in time) convective cloud deck decreases the error in solar radiation that reaches the surface by about 20 W/m2. The weaker convection also keeps the marine boundary layer more moist, decreasing the excessively large latent heat flux, which has been shown to be responsible for too cold SSTs in the AOGCM. Over land, the reduction in excess short-wave has also a positive effect on the positive surface temperature bias, largest during the growing season, due to direct and indirect (via vegetation physiology) processes.

In summary, allowing the CAPE timescale to be longer than 1 hour in the UM has decreased the strength of the hydrological cycle and brought the surface heat balance closer to observations.

1. Impacts on the global climatology

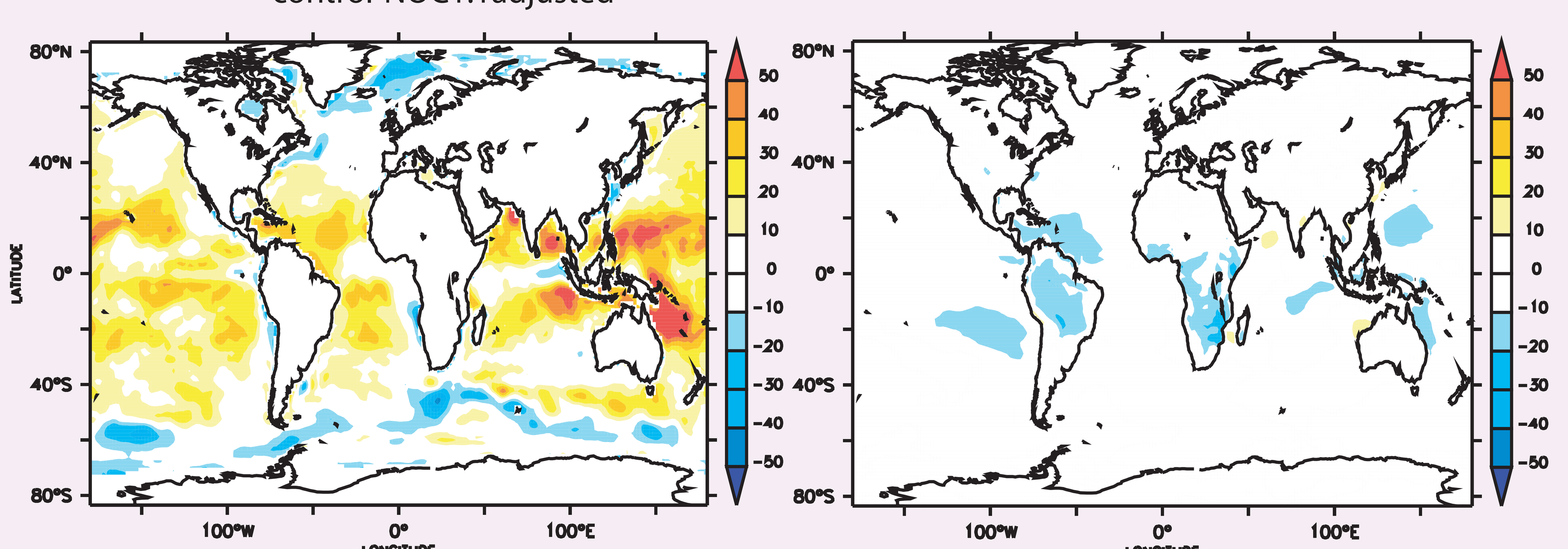
Cloud cover fraction

control-ERA40 wCAPE-control



Surface latent heat flux (W/m2)

control-NOC1.1adjusted wCAPE-control



Net surface shortwave radiation over the ocean (W/m2)

control-obs. wCAPE-control

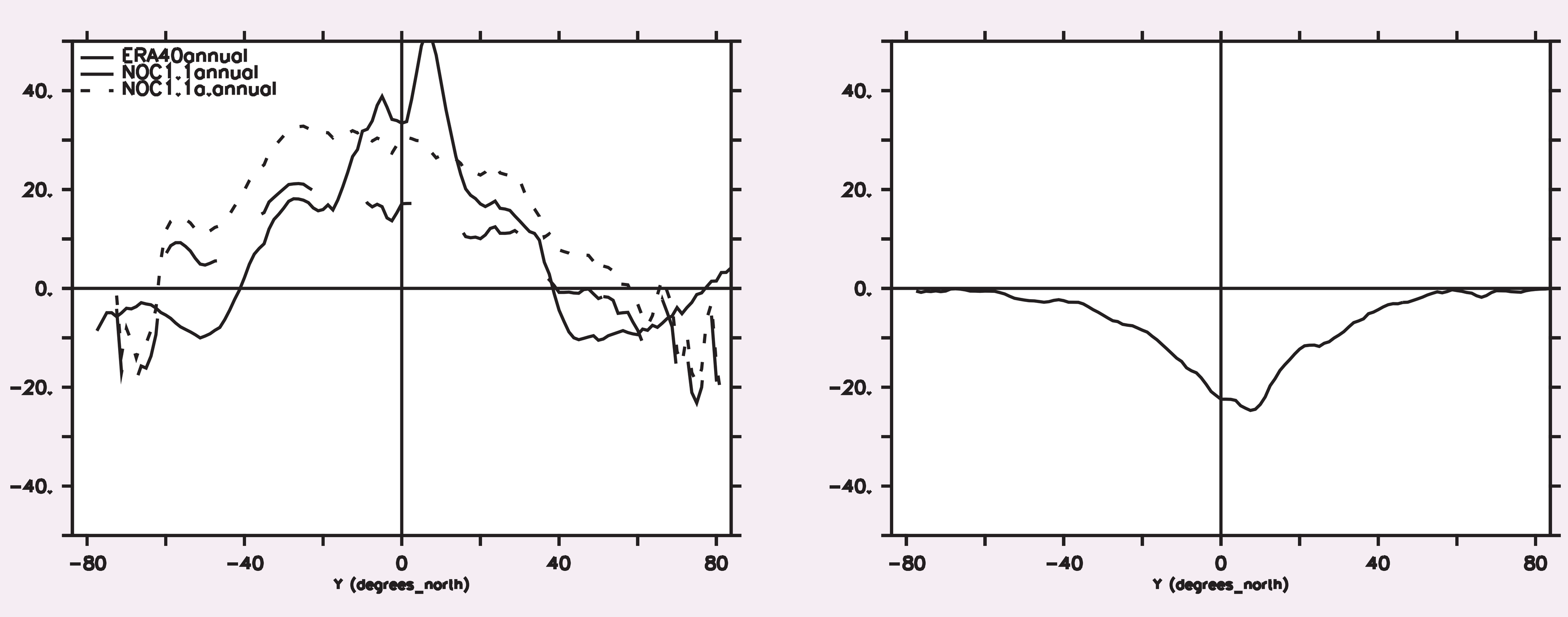


Figure 1. The two upper panels show the bias of the control model against the ERA40 reanalysis and the change in cloud cover fraction in the wCAPE experiment. The two center panels show the bias in latent heat flux (W/m2) against the NOC1.1 adjusted observational dataset (ocean only) and the change in the wCAPE experiment. The two lower panels show the bias in zonal mean surface net shortwave flux (W/m2) over the ocean of the original model against several observational datasets and the change in zonal mean surface net shortwave flux over the ocean in the wCAPE model. The dynamic CAPE timescale creates less vigorous, but more abundant convection. This results in an increased cloud cover in the wCAPE run. The vigorous convection in the control run exhausts the boundary layer moisture and that increases the latent heat flux from the surface. The latent heat flux in the wCAPE decreases because the weaker convection keeps the boundary layer more moist. The more abundant clouds cause more incoming solar radiation to be reflected, which decreases the amount that reaches the surface, especially over the oceans.

References

Yang, Gui-Ying and Slingo, Julia, The Diurnal Cycle in the Tropics, 2001. Monthly Weather Review, 129, 784-801.
Dai and Trenberth, The Diurnal Cycle and Its Depiction in the Community Climate System Model. 2004. Journal of Climate, 17.

Acknowledgements

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Impact on window brightness temperature

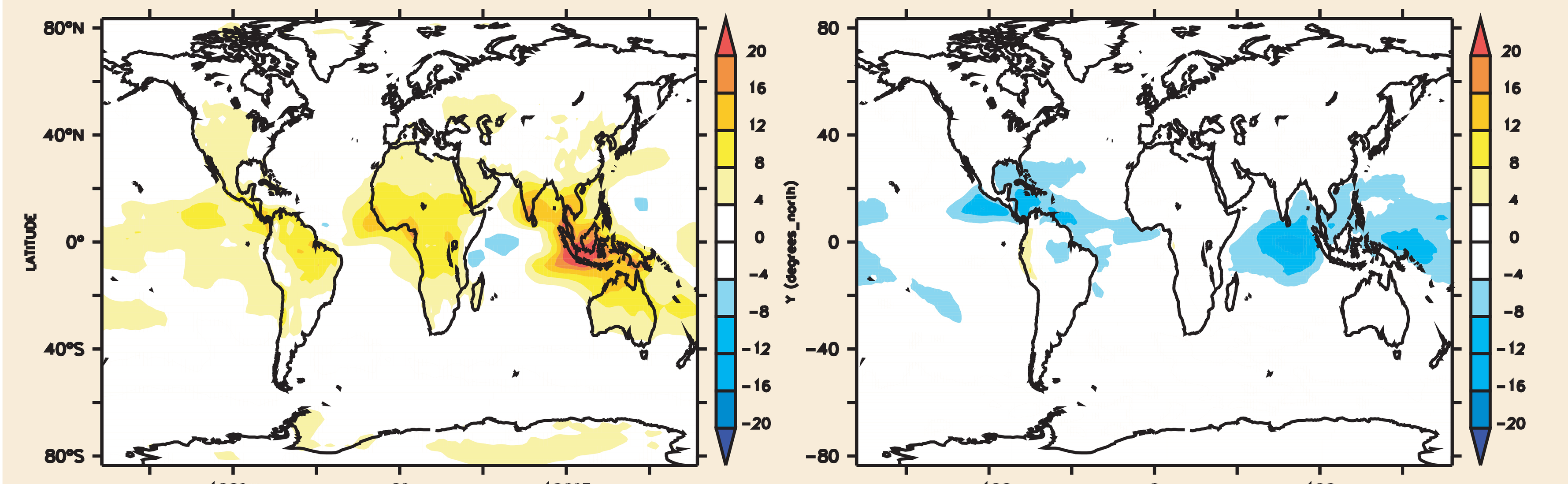

Figure 2. Left: bias in window brightness temperature (K) against ERBE observations. Right: change in window brightness temperature in the wCAPE run. Lower window brightness temperatures point to colder cloud tops, which is a result of increasing cloud height. Although the change in the wCAPE run seems to be in the right direction, the locations of the biases and the changes do not overlap, especially around the Maritime Continent. Local circulation biases in this region cause anomalous upward motion over the Indian and West Pacific Oceans. The wCAPE parametrization further exacerbates the anomalous convective activity in these regions.

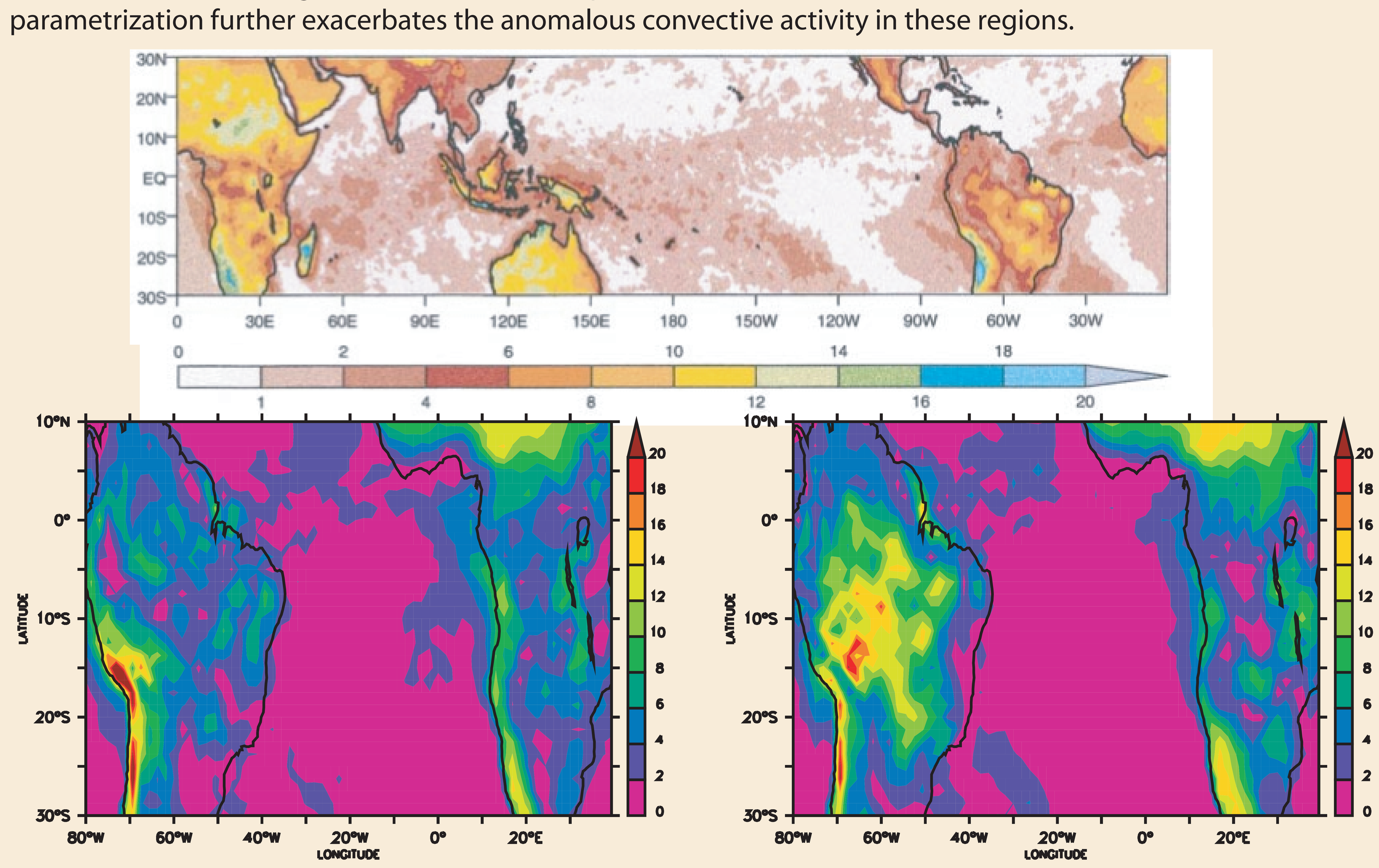

Figure 3. Top: diurnal phase of the window brightness (K) described by the CLAUS data for DJF(see Yang and Slingo, 2001). The lower figures shows the diurnal amplitude of the brightness window temperature for DJF for the control and the wCAPE run. Over South America the mean window brightness temperature hardly changes (see Figure 2), but the diurnal amplitude of window brightness temperature is much higher in the wCAPE run. This implies higher clouds during the day, reducing the shortwave radiation that reaches the surface in this region.

Regional impacts

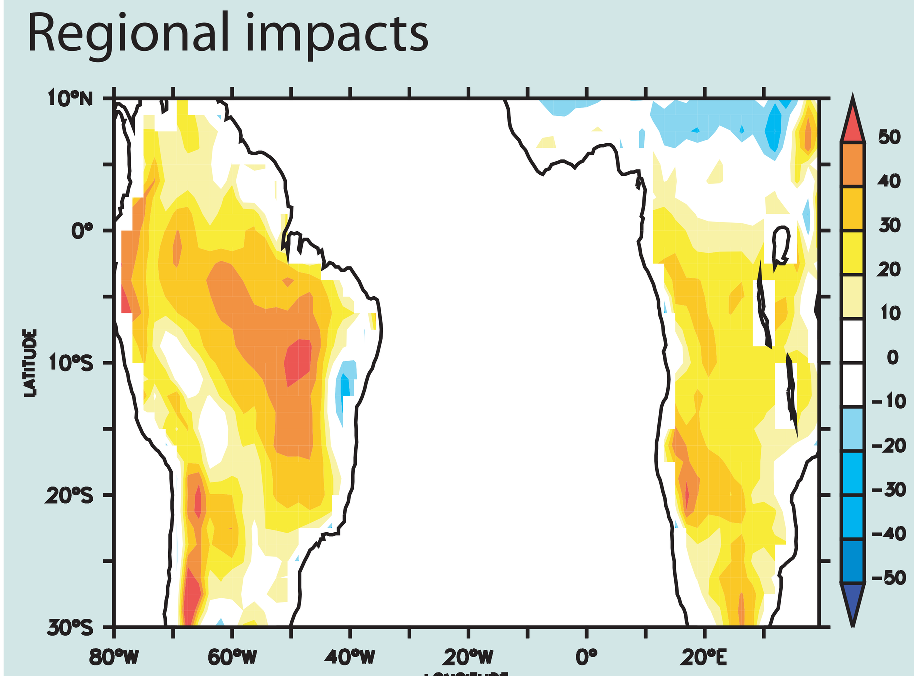

Figure 4. Bias in latent heat flux for DJF in the control run against latent heat fluxes from the GSWP2 (land only dataset). Figure 1 shows that the latent heat flux over South America and southern Africa has decreased significantly in the wCAPE run. Vidale and Donners show in a companion poster that the positive bias in precipitation has decreased, which shows that the hydrological cycle over southern Africa and South America has slowed down in the wCAPE experiment. The higher cloud cover compensates for the lower latent heat flux, resulting in slightly cooler soil temperatures over the northern Amazon. (not shown).

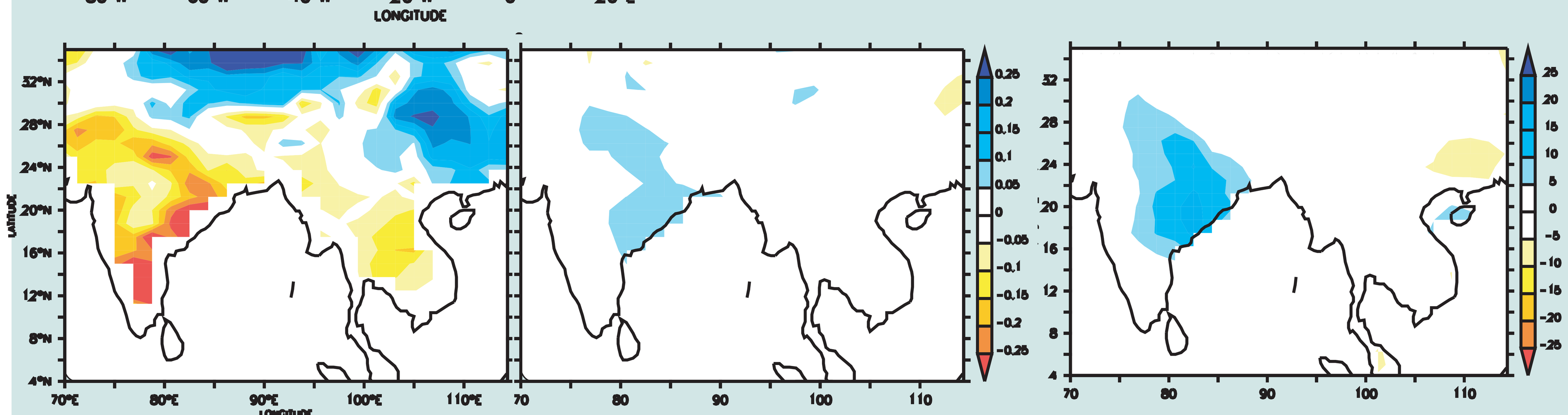

Figure 5. Left: bias in the volumetric soil moisture (m m-1) at 20 cm depth of the control run against GSWP2. Center: soil moisture change in the wCAPE experiment. Right: Change in net primary production over India in autumn in the wCAPE experiment. The extra precipitation over India in summer and autumn in the wCAPE experiment recharges the soil with moisture. This extra soil water is used by the vegetation to grow in autumn. Vegetation growth does not increase during the summer season, which can be attributed to a combination of too high surface temperatures and too little precipitation over India in our simulations.

Conclusions

This poster discusses the impact of the use of a dynamic CAPE timescale on the Hadley Centre climate model. The CAPE timescale depends on the vertical velocity in the convective cloud, abbreviated as wCAPE. It allows for a much weaker convection (a CAPE timescale of up to 6 hours) than the control run (a CAPE timescale of up to 1 hour). In the wCAPE experiment the abundance of clouds increases and their mean cloud top temperature over the oceans increases. This dramatically decreases the positive bias in incoming surface solar radiation over the ocean. The weaker convection in the wCAPE run keeps more moisture in the boundary layer which decreases the too high latent heat fluxes, both over the land and the ocean. Furthermore, the development of convective clouds over South America has been modified significantly: the diurnal amplitude of window brightness temperature has increased, which seems to be supported by CLAUS observations. The increased precipitation over India in summer and autumn has recharged the soil moisture, which is essential for the vegetation. As a result, net primary production increases in autumn, but not in summer; although the extra latent heat cools down the Indian continent, it is still too warm for the vegetation.