Surface hydrology fields simulated by the IPCC multi-model data set

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1. Introduction

This note presents maps of some quantities associated with land surface hydrology that have been simulated by climate models worldwide for the IPCC AR4 data set. The focus is on the 'multi-model mean', a simple average over the available model results (around 20), for the SRES A1B scenario for climate change to 2100.

This multi-model mean is clearly representative of the models. For the present climate, there is some indication that biases of individual models cancel each other, for some fields at least. Thus the mean is more realistic overall than individual models. For the future, the mean is generally regarded as a reasonable 'best estimate' of the expected climate change. The A1B scenario is often presented as a mid-range non-mitigation scenario.

Models represent hydrology in a grid box (or 'square') fashion, with values nominally at grid points at the box centres. Since the resolution of global models is typically 3° latitude and longitude they can simulate only spatial averages over rather broad regions. For precipitation, this results in daily events that lack intensity compared to station data. Time-mean rainfall can still be reasonably accurate, through having more days with 'drizzle'. However, there can be little representation of variation in time-mean rainfall due to orography.

While some models include quite sophisticated land hydrology components, they are not intended to be accurate depictions of individual river basins or catchments. Runoff of water from the surface is idealised in most models. Nevertheless, the runoff should balance the precipitation and evaporation at each surface grid square.

While the focus here is on Australia, and particularly the Murray-Darling Basin, global maps of various quantities are also presented for comparison. Climatological annual means from two periods, 1980-1999 and 2080-2099, are considered.

2. Present climate means

Annual mean precipitation is available from 22 different models and the multi-model means were prepared by first interpolating each result to a common grid (64 latitudes, 128 longitudes). Simple averages were then taken. Since grid-square colouring is used in plots, the field was then interpolated to a 'doubled grid' with halved spacing (128 by 256). The result for the 1980-1999 climate in the Australian region is shown in Fig. 1a. The broadscale rainfall regimes are simulated.

Comparison with the BOM observational data for 1961-1990, on a 0.25° grid, (Fig 1b) shows that the models do not capture the magnitude of coastal and topographic rainfall, as expected. The models simulate a little too much rain in NW and central Australia (although this may be partly due to the observed period used, given recent trends). Elsewhere, the model average is rather good. Often the rainfall over the ocean is larger than that on nearby land. It is thus likely that the rain on land near the real coastline (as plotted) is a little larger than is actually simulated on land by the models, due to the interpolation process. Evidently the real coastal enhancement of rainfall is greater.

In the global mean, evaporation should closely balance the precipitation, and this is the case for the multi-model means (2.844 mm d^{-1} for precip, 2.832 mm d^{-1} for evap). The regional evaporation is shown in Fig. 2a. Evaporation is larger than rainfall over the subtropical ocean (where evap is typically 6 mm d^{-1}). This can allow rainfall over land to be larger, with the excess being removed by runoff. The interpolation process is likely to substantially enhance evaporation from land near the coast.

The mean runoff from land points from 19 available models is shown in Fig. 2b. Some care has been taken to produce a field that gives representive results near the coast, given that over ocean the field is 'missing'. For each model, values were interpolated to a doubled grid, with the new points on the land-sea interface being given the adjacent value from the land square of the original grid. This field was then interpolated to the common 128 by 256 grid (with points in between ocean and land grid points being left as missing). Averages were then taken where there are valid data from at least 10 models. Since model coastlines vary, there are some interpolated values just seaward of the real coastline. Over Australia the runoff field is nearly everywhere much smaller than the rainfall, and is especially low in the dry south.

The field used (named mrro in the IPCC data set) includes any drainage through the base of the soil layer, so there should be a close land moisture balance for individual models. For these mean fields, rainfall minus evaporation minus runoff is also usually close to zero (within a few percent of the rainfall). The exception is near the coast, where it is typically between 0 and –1.0 mm d^{-1}. It is clear that this is due to the artificially enhanced evaporation. The evaporation field seems reliable enough over the MDB, although closer examination of individual model results would be justified.

The soil moisture field in the IPCC data set (named mrso) is the total moisture in the model soil layers (typically a few metres deep). Land values are averaged in the same way as for runoff. The amount of soil represented varies widely across models, so the average field, shown in Fig. 3, is rather biased towards models with deeper soil. The range of moisture content across Australia is low, compared to that in runoff and rainfall.

3. Change in climate

The multi-model means for the 2080-2099 period, under the A1B scenario, are compared to the above base climate. The global mean warming in the multi-model data set for this case is 2.65 K. The percentage change in annual mean precipitation is small over much of Australia, as seen in Fig. 4a. The large increases in the equatorial band and in high latitudes (shown shortly) are well away from the continent. There is a small increase in the north and in the Tasman Sea, where warming is large. The widespread drying in the subtropics impacts on southern Australia, with the SW of WA being a region of substantial drying. Changes in evaporation (Fig. 4b) are even smaller than in rainfall. An exception is for the Tasman Sea, which shows how local evaporation can change the rainfall.

The simulated runoff field changes roughly in the pattern of rainfall, but with larger percentage changes, both positive and negative (Fig. 5). Runoff declines in the SE, even where mean rainfall doesn't change. Seasonal changes are likely to be behind this, as rainfall tends to decrease in the cooler months, when runoff is relatively more important compared to evaporation.

The ratio of runoff to rainfall percentage change is plotted in Fig. 6. Over most midlatitude points the ratio is between 1 and 4. In the tropical region of increase, it is often over 4. In between these regions, where rainfall barely changes, there is a band where annual means of rainfall and runoff have opposite signs. Naturally, extreme values of the ratio can occur there. Since runoff is averaged over fewer models than rainfall, particularly near the coast, it is possible that at some locations the ratio plotted is inaccurate.

The soil moisture change over Australia (Fig. 7) is also roughly in the pattern of rainfall. As a percentage, the changes in this total soil quantity are typically smaller than in rainfall.

The global change for precipitation is shown in Fig. 8. Decreases in the Mediterranean region are prominent. Decreases in runoff are larger there (see Fig. 9), and at some other regions of subtropical drying. Changes in runoff in some regions of rainfall increase (e.g. around Uruguay) are also relatively large. However, at high latitudes runoff does not increase as much as rainfall.

4. Summary

This brief presentation of available multi-model data suggests that the means have considerable validity in representing large-scale atmospheric moisture quantities. The changes in the warmer climate in rainfall are significant, and the drying in the south of Australia is of particular concern. Further, the runoff decreases there simulated by the models are substantial.

Overall changes in the Murray Darling Basin in both rainfall and runoff are small. However, there is some increase (from a small base) in the far north, and the decrease in the far south does encroach on the region. While the models simulate drying of the soil for the south, there is little change elsewhere in the MDB.

Previous assessment has shown there is some consistency in the changes in all these fields across the individual models, at least in the sign of change. Magnitudes of change must be regarded as uncertain. Nevertheless, I suggest that these results can be a useful indication of likely changes on the broad scale. Naturally, further assessment of these quantities using models able to represent the hydrological processes of the MDB more realistically is needed.

Acknowledgements

This work contributes to the CSIRO Climate Change Research Program and is in part funded through both the SEACI and IOCI research programs. Julie Arblaster prepared the multi-model means.

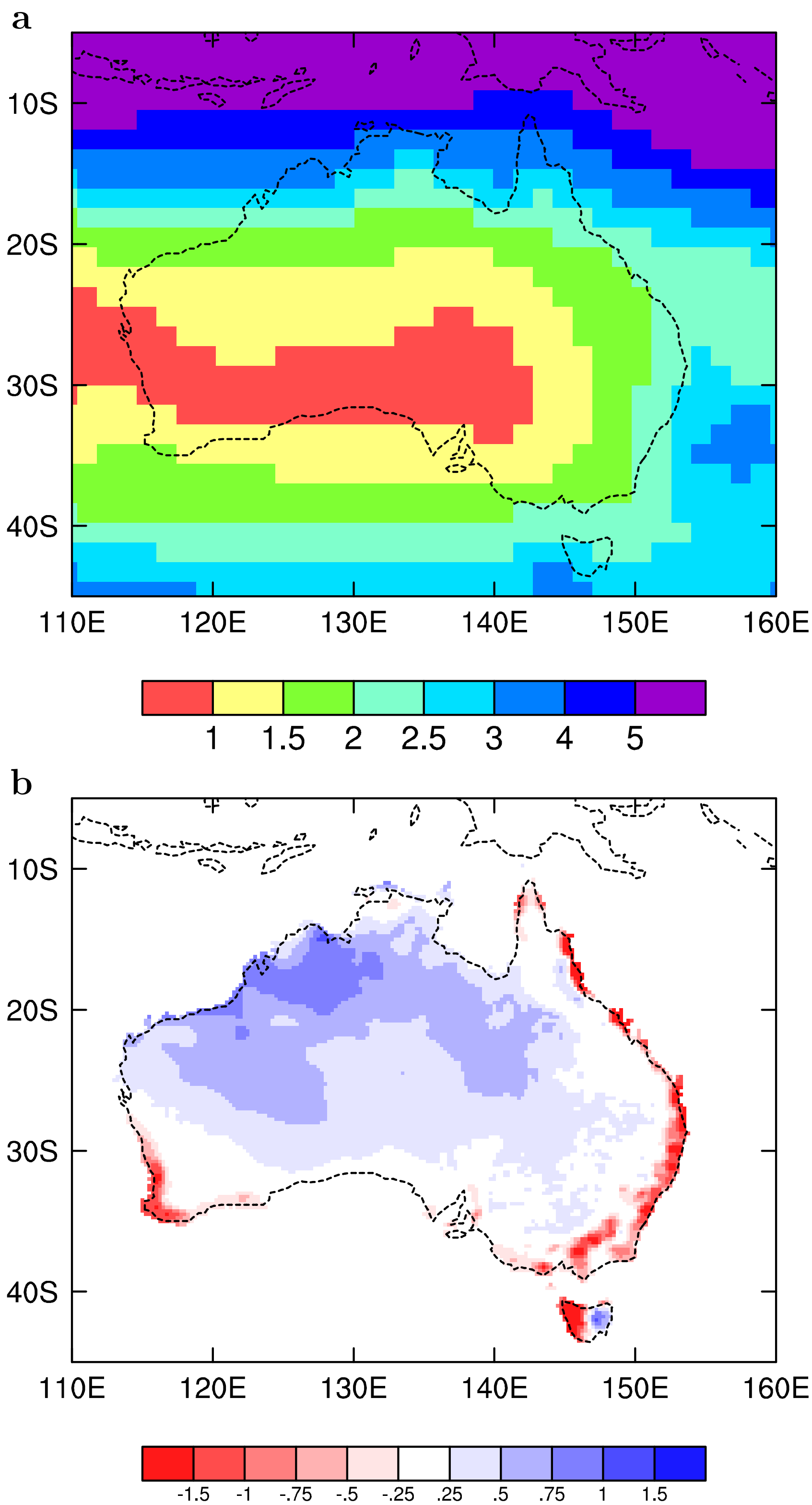

Figure 1: 1980-99 precipitation in mm d^{-1} (a) multi-model mean, (b) multi-model mean minus the BOM climatology.

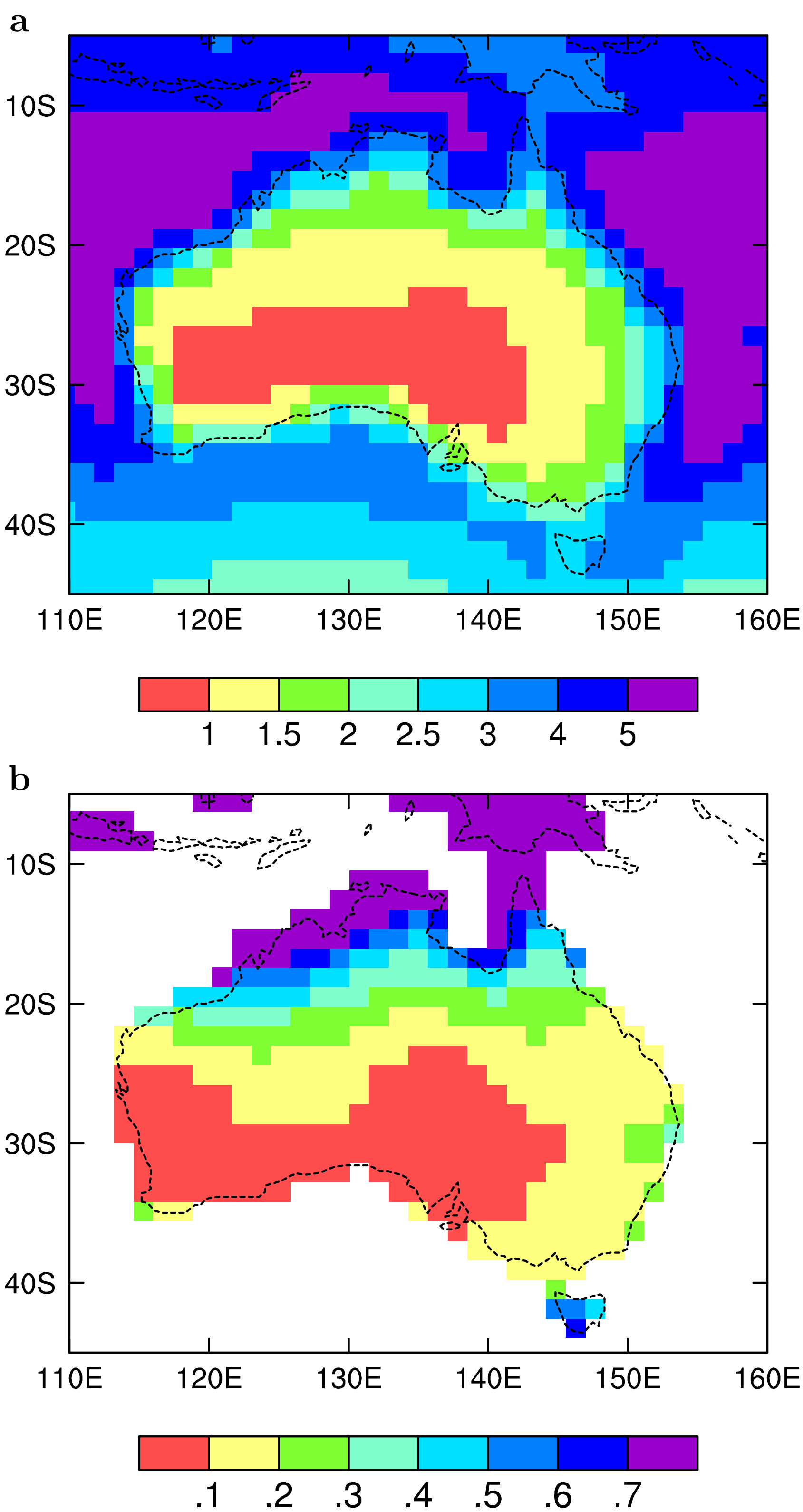

Figure 2: 1980-99 multi-model means in mm d^{-1} (a) evaporation, (b) runoff.

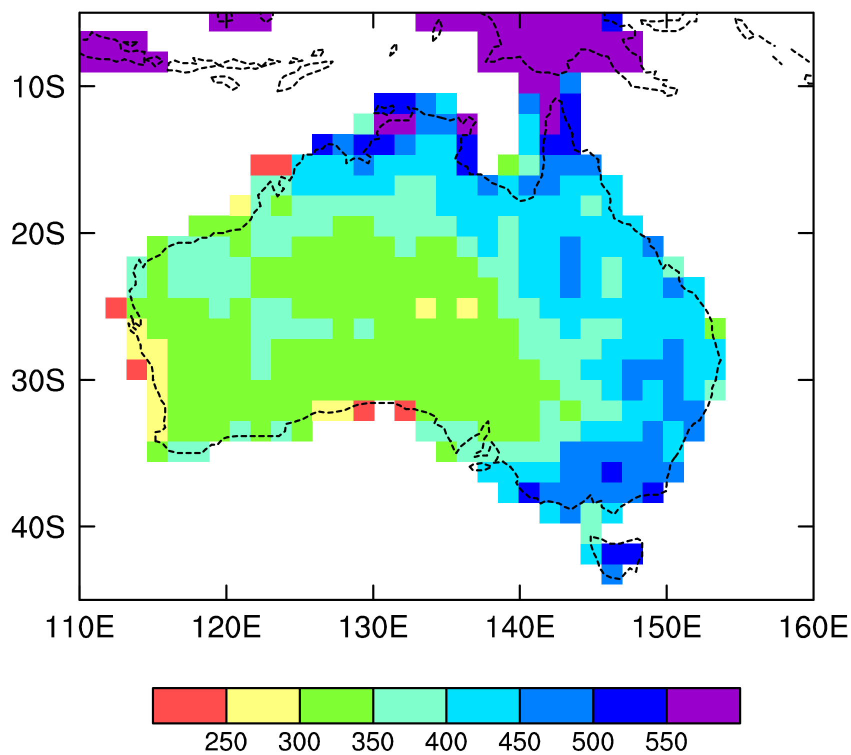

Figure 3: 1980-99 soil moisture in kg m^{-2}.

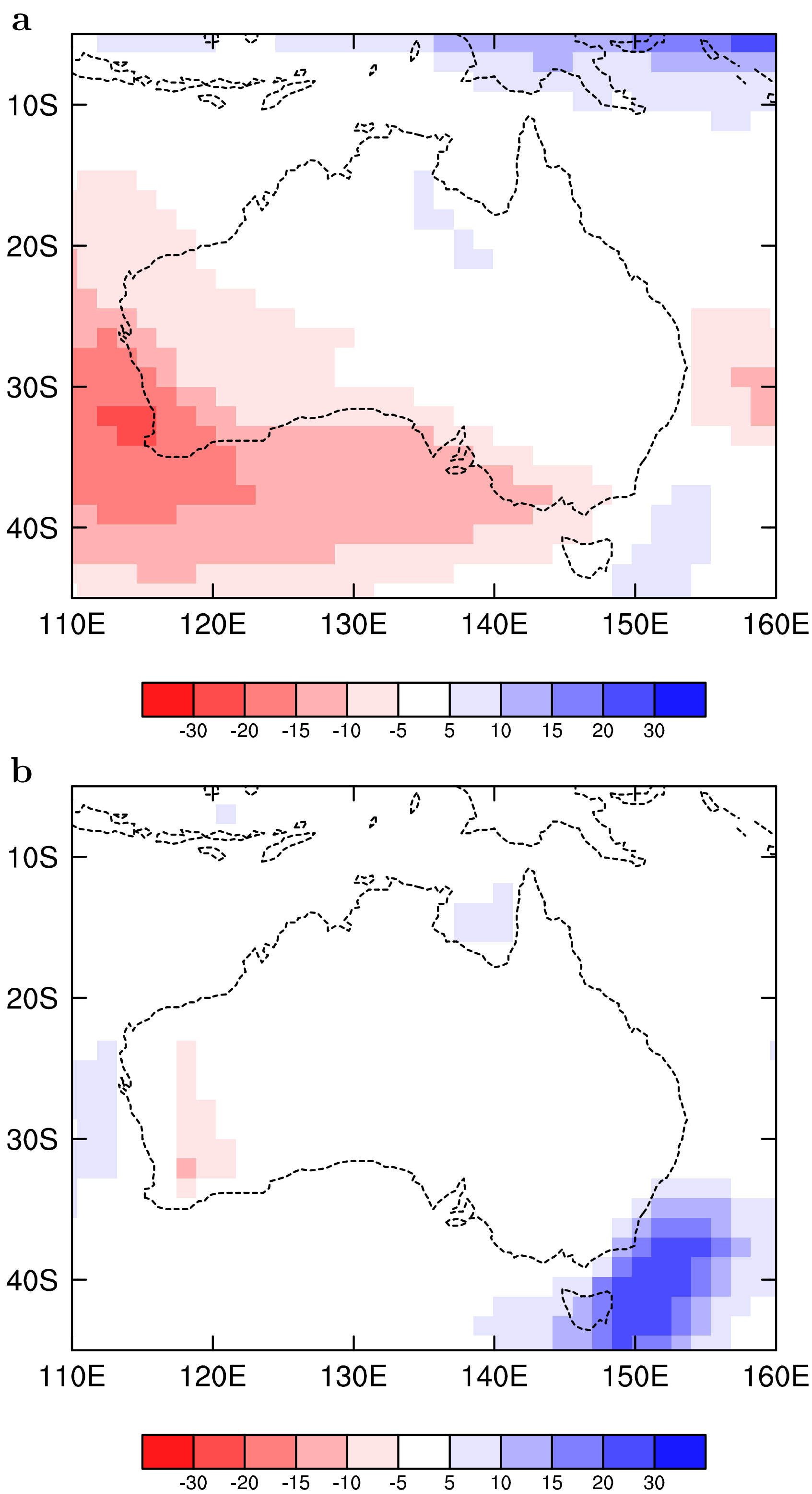

Figure 4: Percentage change in (a) precipitation, (b) evaporation.

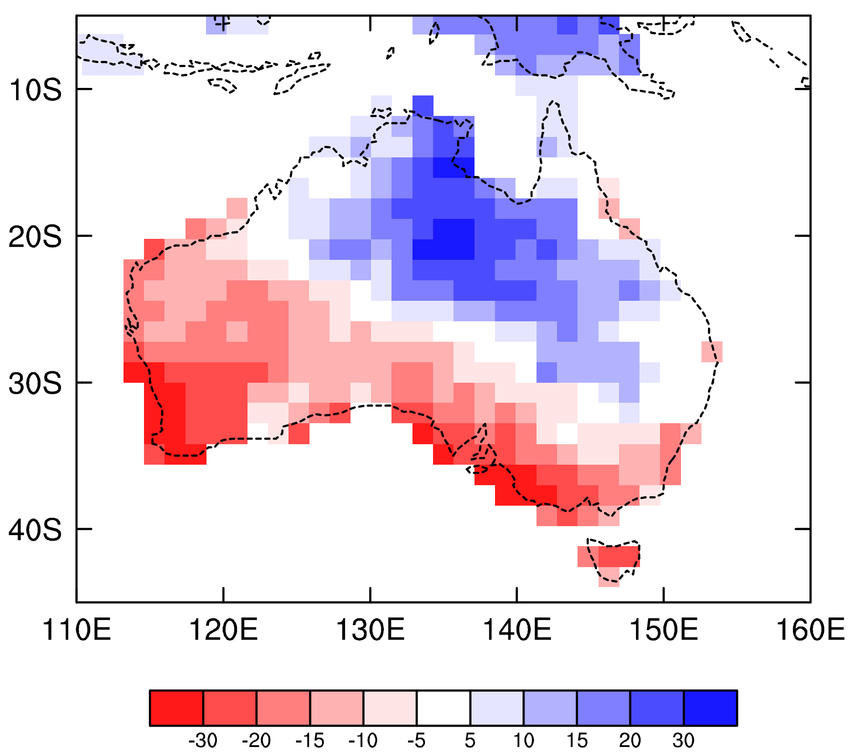

Figure 5: Change in runoff in %.

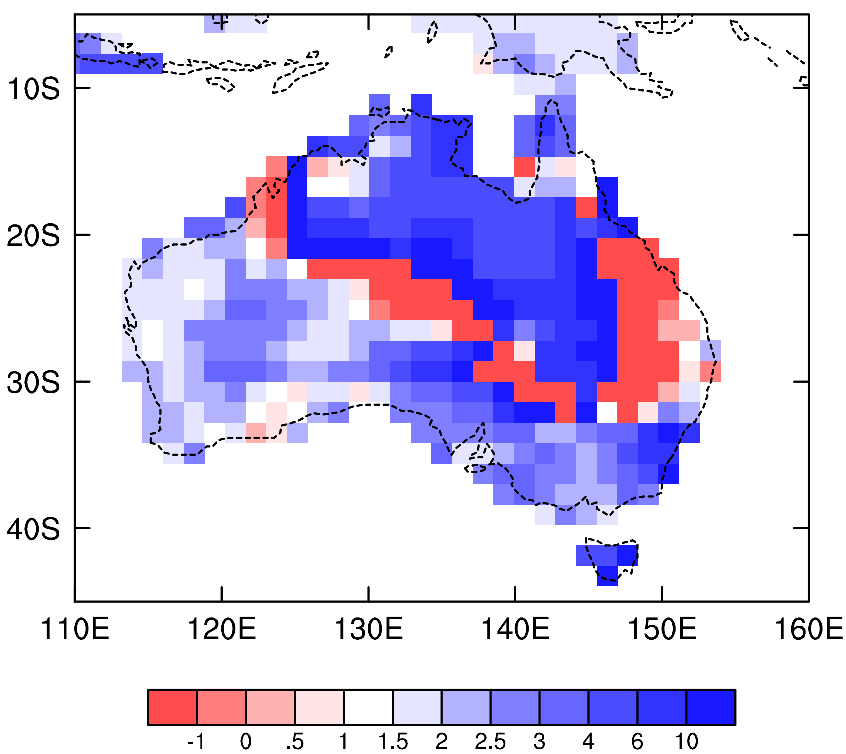

Figure 6: Change in runoff in %, divided by change in precipitation in %.

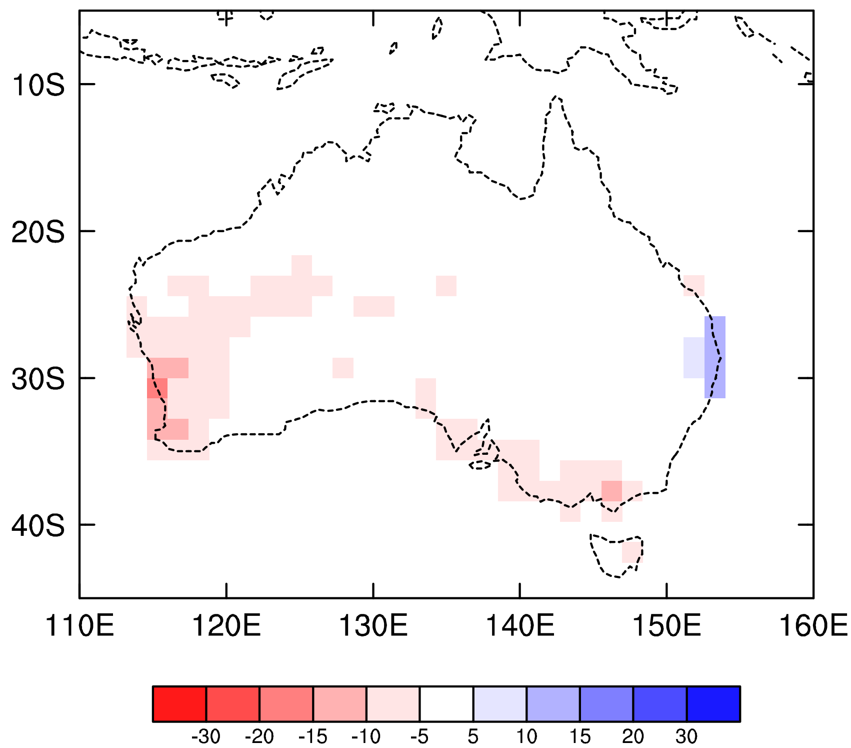

Figure 7: Change in soil moisture in %.

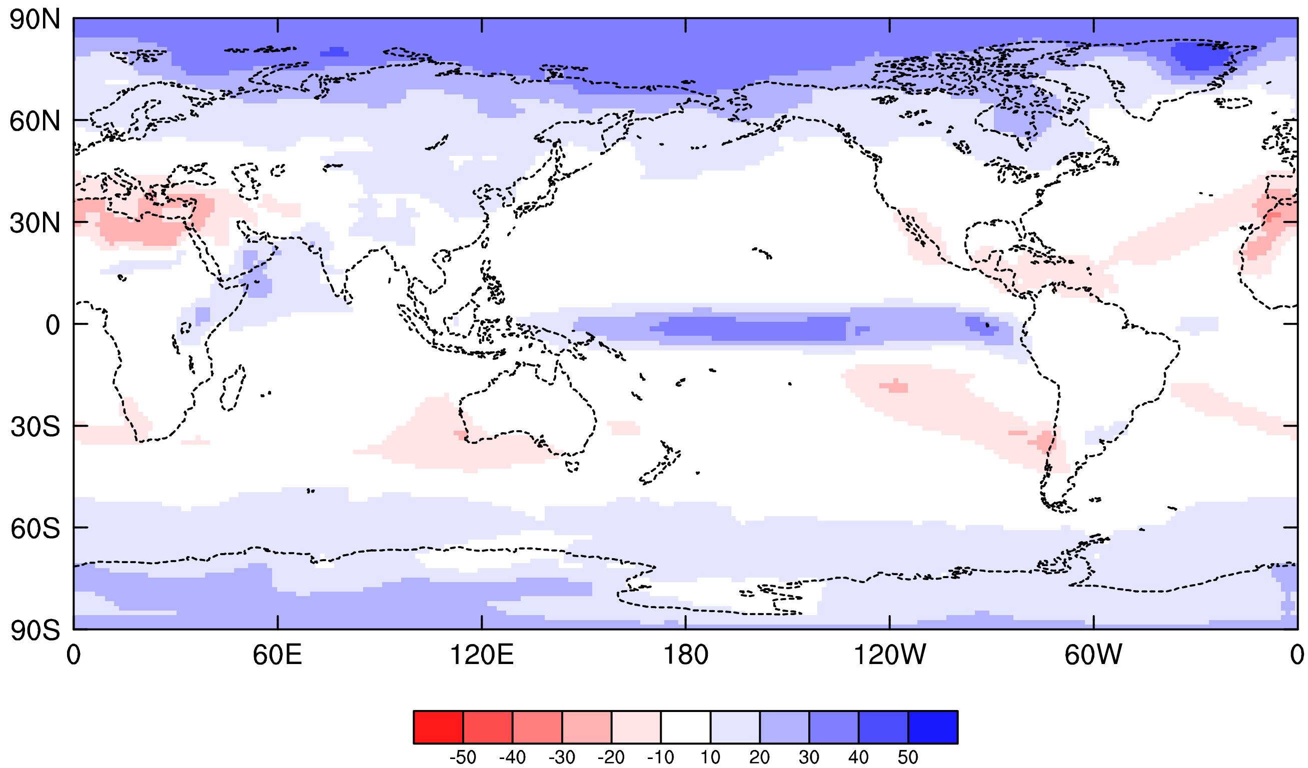

Figure 8: Change in precipitation in %.

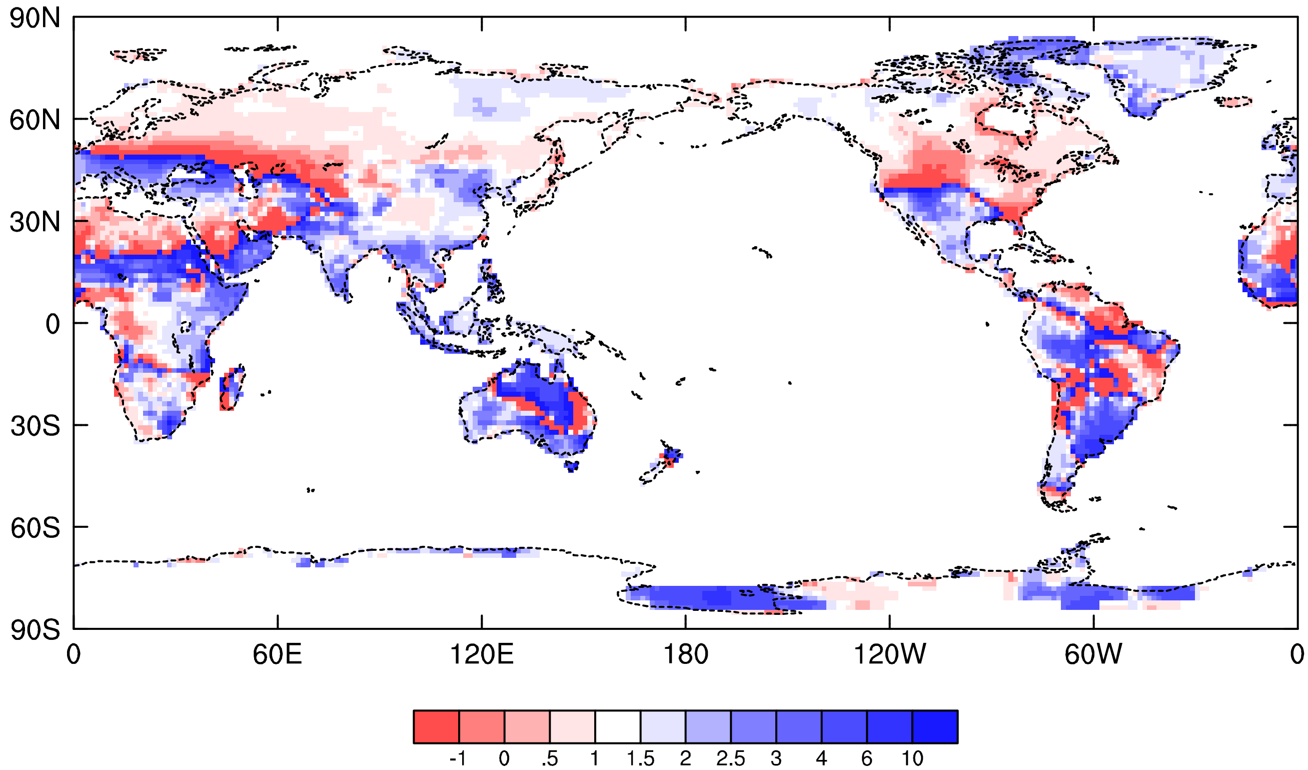

Figure 9: Change in runoff in %, divided by change in precipitation in %.