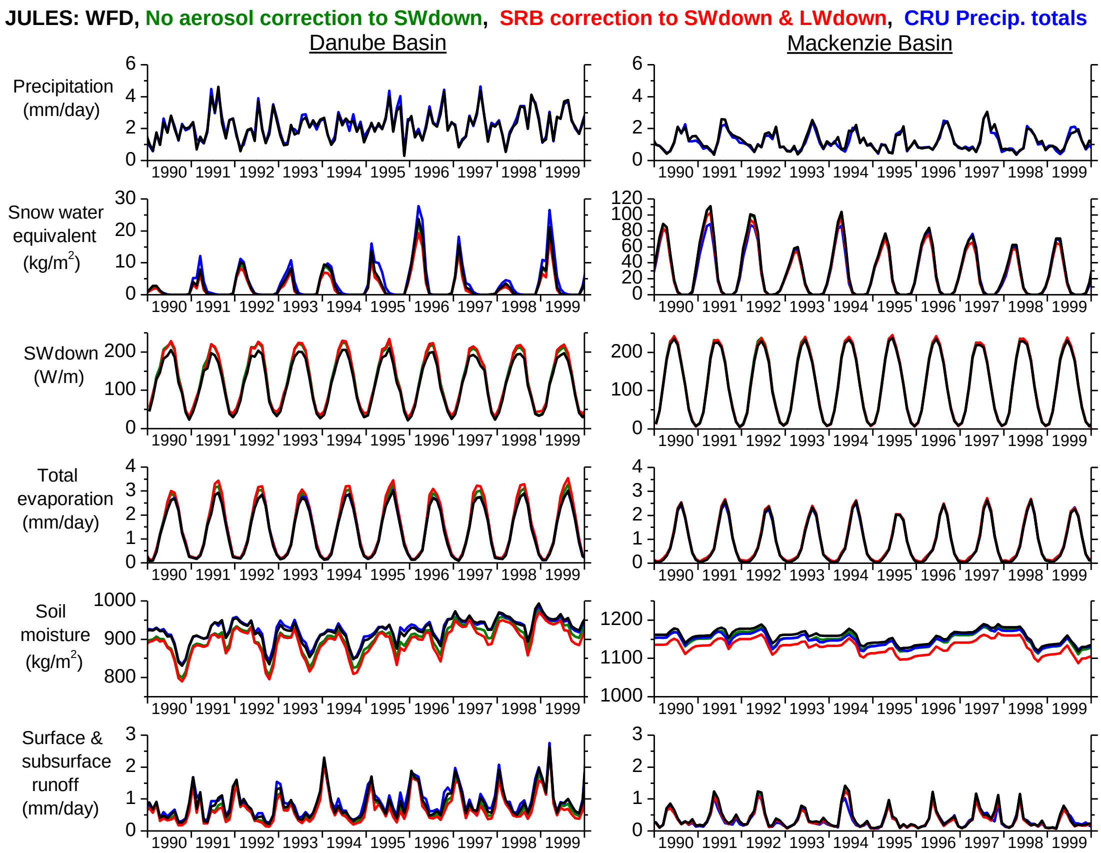
WATCH
Water and Global Change

Technical Report No. 36

CHANGES IN LAND SURFACE MODEL OUTPUTS DUE TO UNCERTAINTY IN THE WATCH FORCING DATA



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Abstract.

Uncertainty in the terrestrial water cycle, as represented by land surface model outputs, is investigated as a function of uncertainty in the WATCH Forcing Data. Three alternative forcing datasets were created involving changes to: a) rainfall and snowfall, b) downward shortwave and c) downward longwave and downward shortwave-radiation fluxes. The JULES land surface model was run using the standard and alternative forcing data to investigate changes in global snow water equivalent, evaporation, soil moisture and runoff.

Uncertainty in model outputs due to the forcing data is far smaller than uncertainty due to choice of hydrological model for all four hydrological variables. For snow water equivalent there is a very sensitive dependence on changes in precipitation and incoming radiation drivers such that relative changes in output represent an amplification of the relative changes in the forcing data input. For other variables the relative changes in outputs are in approximate proportion to relative changes in the input, except in semi-arid and arid regions where there is amplification for evaporation and runoff.

Introduction.

WorkBlock 1 within the EU WATCH programme is designed to assess the global terrestrial water cycle in the twentieth century. Objective 4 of WorkBlock 1 concerns assessment of the uncertainty in the terrestrial water cycle, as described by hydrological model output, as a function of uncertainty in the meteorological forcing data. Objective 7 is concerned with assessing whether land surface hydrological processes amplify or suppress the variability in meteorological forcing. This Technical Report is designed to contribute to both objectives by comparing the changes in model output of hydrological variables as a consequence of changing the meteorological forcing data.

The land surface and global hydrological models used in WATCH to assess the terrestrial water cycle all used the WATCH Forcing Data (WFD) as input meteorological information. The WFD were created by modification of the European Centre for Medium-Range Weather Forecasts's ERA-40 reanalysis product, with details of the process described by Weedon et al. (2010; 2011). In this study a single land surface model, JULES (Best et al., 2011), has been run using the WFD and three alternative versions of the WFD. The alternative versions of the WFD are based on changes to the forcing data with respect to precipitation (one alternative dataset) and radiation (two alternative datasets). Of all the variables in the WFD, precipitation and radiation are the least well constrained by existing datasets of global observations while having significant impacts on model hydrology. The other variables required to drive the models either have significant effects on modelled hydrological variables but are well constrained either observationally and/or via reanalysis (such as near-surface-temperature), or the models are not sensitive to modest uncertainty in the meteorological variable (such as surface pressure). The hydrological variables of interest here are snow water equivalent (SWE), total evaporation (bare soil plus canopy evapotranspiration), soil moisture (column integrated moisture) and total runoff (surface and subsurface runoff). The JULES model was chosen for the focus of the study because the authors are most familiar with that model.

Alternative forcing data.

i) WFD-CRU: Alternative rainfall and snowfall rates.

Biemans et al. (2009) demonstrated the large uncertainty in global precipitation datasets in the twentieth century – whether based solely on precipitation gauge observations or generated by merging of satellite observations and gauge data. The rainfall and snowfall data in the WFD were created by a multi-step adjustment of ERA-40 precipitation data

(Weedon et al. 2010; 2011). The monthly "wet-day" correction step used observations from the Climatic Research Unit at the University of East Anglia (CRU), but the adjustment of precipitation totals was based on the GPCCv4 full data product rather than CRU precipitation totals. This choice reflects the more complete dataset of GPCCv4 monthly gauge precipitation totals compared to CRU - especially in the 1990s and at high latitudes. Indeed the GPCCv4 data incorporates nearly all the CRU precipitation data and augments those with further data. When the WFD were created an alternative dataset was also generated, whereby the adjustment of precipitation totals was based on CRU monthly data rather than GPCCv4. All other adjustment steps were exactly the same as for the original WFD Rainfall and Snowfall. This alternative dataset therefore provides a way to assess the sensitivity of JULES model outputs to some of the uncertainty in precipitation observations.

ii) WFD-CLD: Alternative downwards shortwave radiation fluxes.

A key innovation of the WFD was to adjust the monthly average ERA-40 downwards shortwave radiation fluxes (SWdown) for the direct and indirect effects of seasonally- and decadally-changing atmospheric aerosol loading (Weedon et al., 2010; 2011). This aerosol correction step followed correction of the SWdown reanalysis data so that the cloud cover matched that of monthly observations from CRU rather than GCM modelled cloud-cover. In order to assess the impact that the aerosol corrections had on WFD SWdown within a detection and attribution study led by Nic Gedney, an alternative dataset was created where the aerosol correction step had not been applied. These SWdown data are referred to here as WFD-CLD (derived from "solely cloud-corrected WFD-SWdown").

iii) WFD-SRB: Alternative downwards longwave and downwards shortwave radiation fluxes.

Sheffield et al. (2006), in creating the Princeton Global Forcings from the NCAR-NCEP reanalysis, required an adjustment of both the downward longwave radiation fluxes (LWdown) and SWdown. No such adjustment was required for the LWdown and SWdown from the ERA-40 reanalysis (Weedon et al., 2010). The adjustment used by Sheffield et al. (2006) was based on offsetting the long-term (multi-decade) calendar month average LWdown and SWdown to match that in the NASA Surface Radiation Budget (SRB, Gupta et al., 1999) product. The principle is that the long-term calendar month averages match even though the trends may differ. While assessing whether such offsets were required for the WFD, alternative datasets of LWdown and SWdown using the SRB offset method of Sheffield et al. (2006) were generated, although this used a more up-to-date SRB product and a longer averaging period (details provided by Weedon et al. 2010).

The effects of alternative forcing data on hydrological variables from JULES.

To assess the uncertainty in model outputs that results from uncertainty in the forcing data, we compare outputs from a run of JULES using the standard WFD with outputs from three further runs in which the alternative WFD-based datasets are used. These runs changed a) rainfall and snowfall rates (WFD-CRU), b) SWdown (WFD-CLD) and c) LWdown and SWdown (WFD-SRB). JULES was not run with combinations of the alternative datasets so that the impacts of the changes could be more readily interpreted.

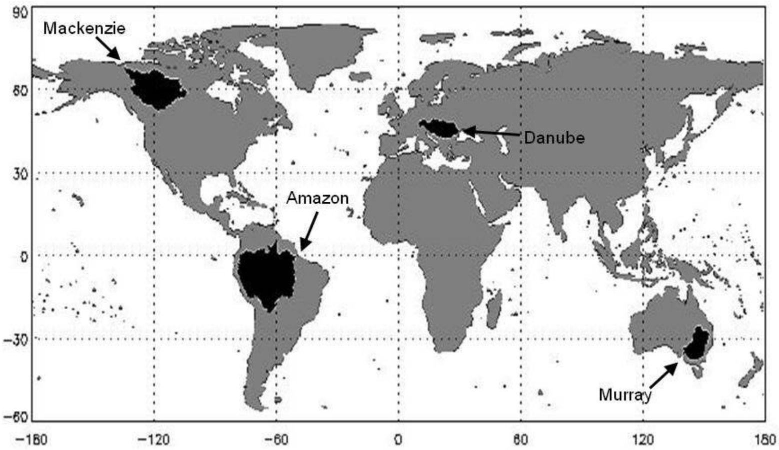

***Figure 1**: Location of the river basins discussed here.*

The comparisons illustrated here are designed to assess a) the changes in absolute and relative values of the meteorological variables in the alternative forcing data compared to the standard WFD, and b) the resulting changes in absolute and relative values of key modelled hydrological variables. All results presented here refer to the years 1990-1999, and we present both global maps and averages over selected river basins. The river basins were selected from the 18 WATCH target river basins to illustrate a range of climatic and hydrological conditions: i) hot, year-round humid: Amazon basin, Brazil; ii) hot, semi-arid: Murray basin, Australia; iii) temperate: Danube basin, SE Europe; iv) cold: Mackenzie Basin, Canada. The locations of these basins are shown in Fig. 1. All the basin average values are based on area-weighting of the half-degree grid box data.

Figures 2 demonstrates that the absolute differences in forcing data (precipitation and radiation), as well as changes in hydrological outputs from using the alternative forcing data, compared to using the WFD, are generally relatively small for the Amazon and Murray basins. (Note that in some of the figures presented in this report the lines from different datasets overlap completely or to a large extent. This is the case for several of the results shown in Fig. 2 for the Murray basin.)

Figure 3 shows results for the Amazon and Murray basins for several different models that were used in WATCH. All the runs reported in this figure use the standard WFD. Comparison of Figs. 2 and 3 shows that the uncertainty in model outputs that results from using different models is very much greater than the uncertainty that arises from the forcing data for total evaporation, soil moisture and total runoff for the Amazon and Murray basins (note that some of the vertical scales differ between Figs. 2 and 3).

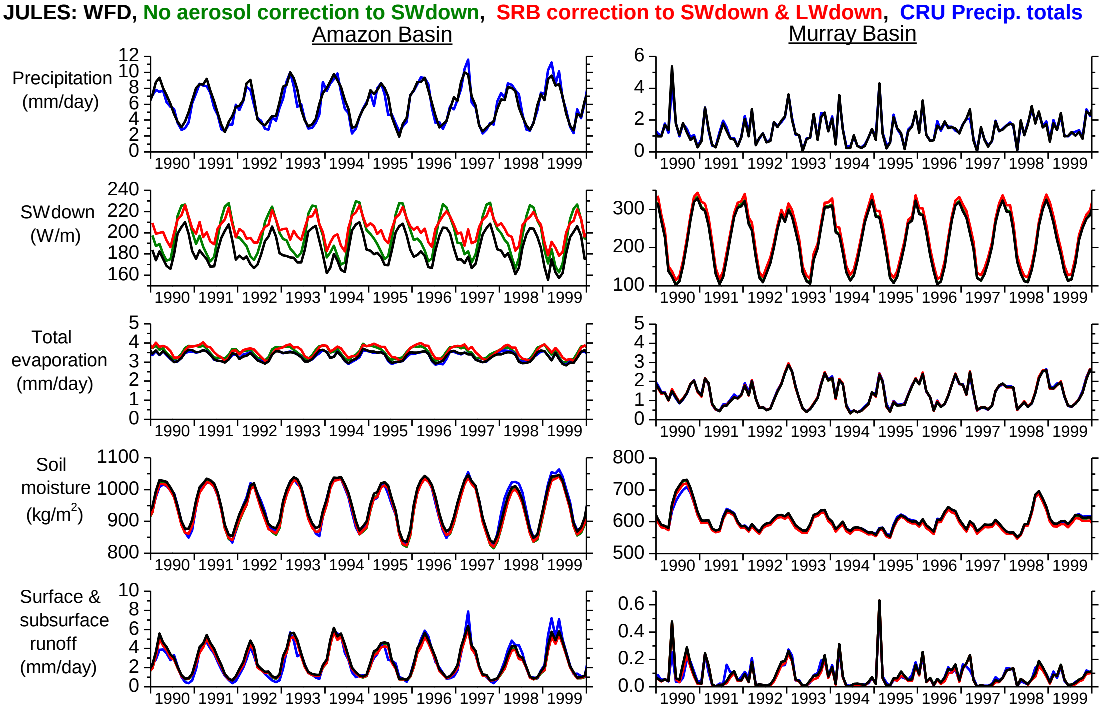

***Figure 2**: Monthly average values of the WFD and alternative forcing data for the Amazon and Murray basins in the 1990s.*

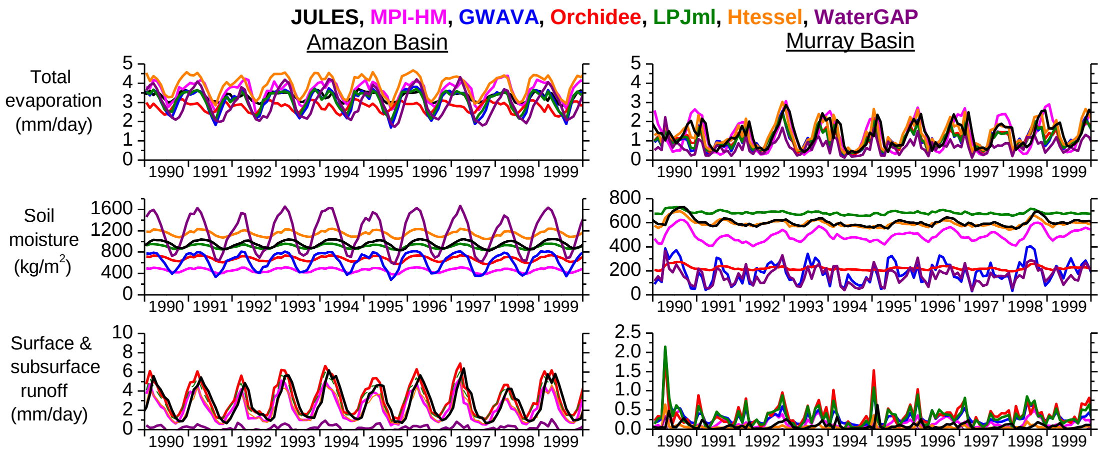

***Figure 3**: Monthly average values of hydrological variables output from seven land surface and general hydrological models (including JULES in black) all run using the standard WFD.*

The same inferences are also true for all the hydrological variables (i.e. including SWE) for the Danube and Mackenzie basins as illustrated in Figs 4 and 5.

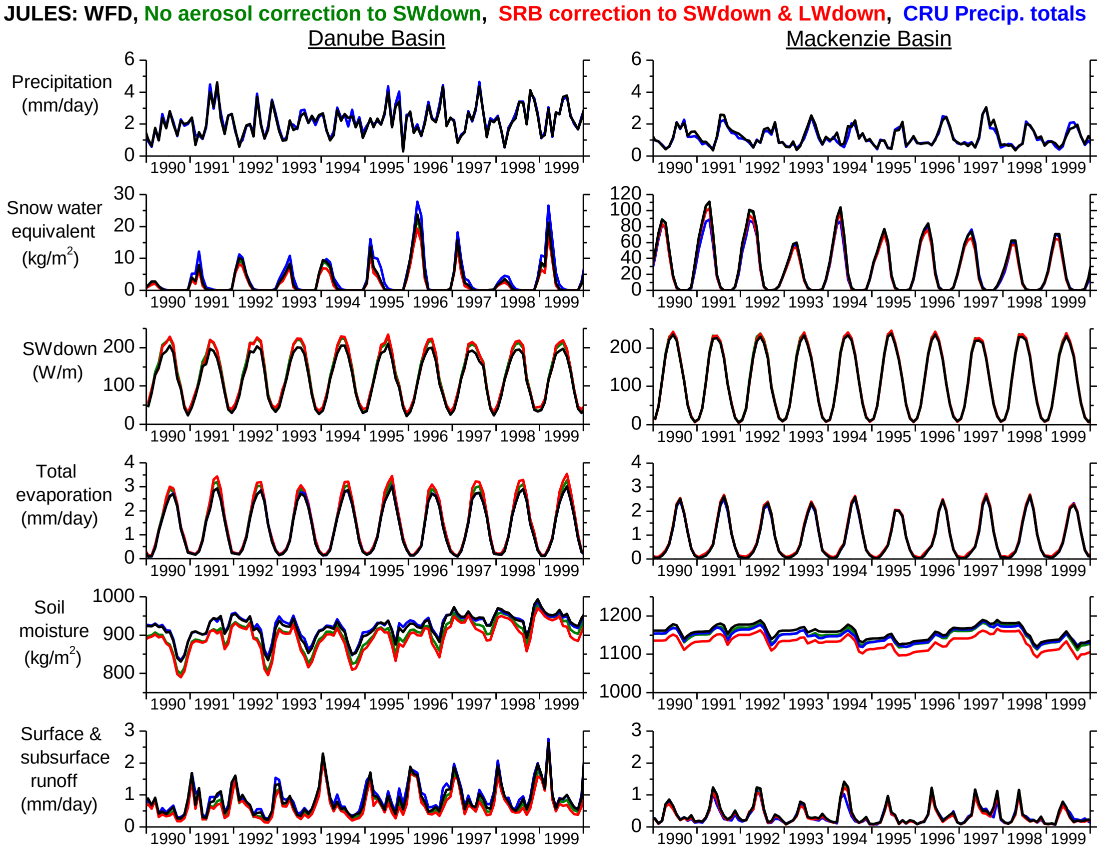

***Figure 4**: As for Fig. 2 but for the Danube and Mackenzie basins.*

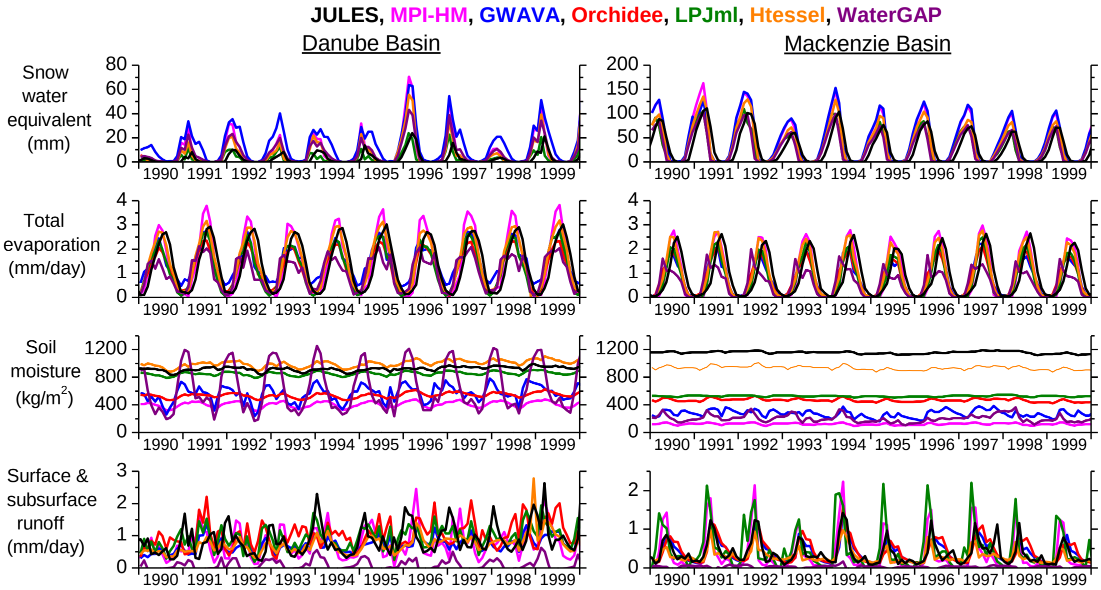

***Figure 5**: As for Fig. 3, but for the Danube and Mackenzie basins.*

The relative differences examined here are defined using:

Percentage relative difference = 100% x (*ALT* – *WFD*)/*WFD*

where *ALT* represents the output value from a model run with alternative forcing data (or alternative forcing data value) and *WFD* represents the output value from a model run using the WFD (or WFD value). Changes in relative differences are illustrated for the selected river basins in Figs 6 and 7.

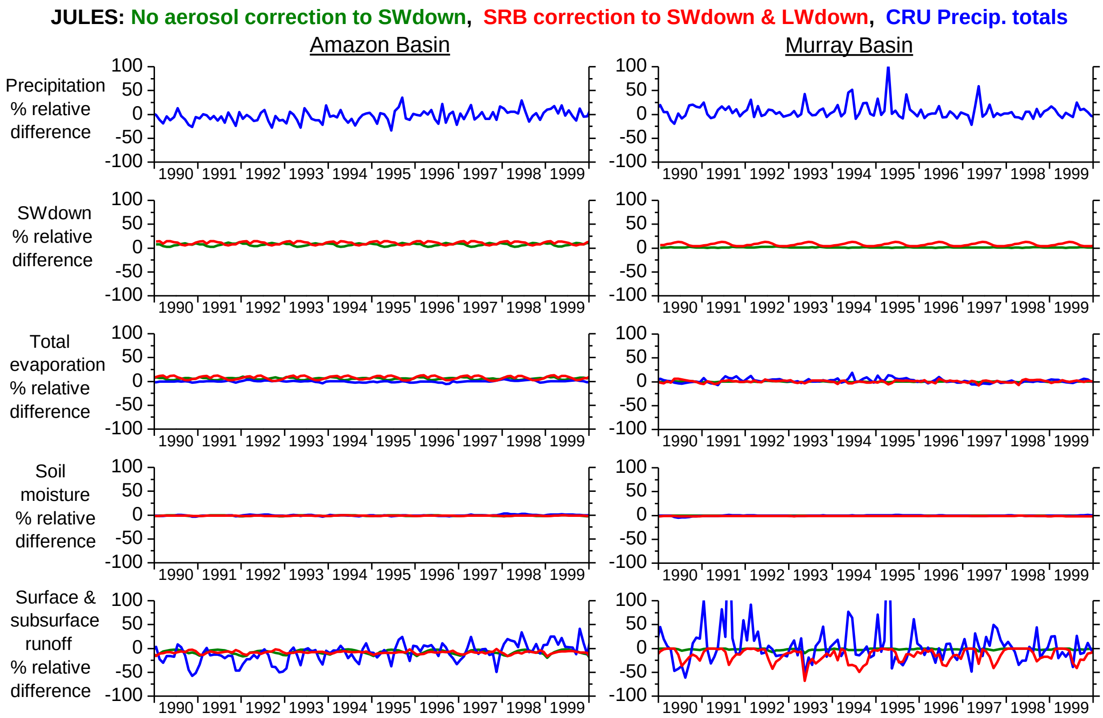

***Figure 6**: Percentage relative differences between the alternative forcing data (precipitation and SWdown) and the WFD and between the hydrological variables output from JULES based on runs using the alternative forcing data and using the WFD for the Amazon and Murray basins in the 1990s.*

For the Amazon and Murray basins the largest relative differences occur in the CRU precipitation totals, with changes of up to 100% in particular months. The radiation changes (WFD-CLD and WFD-SRB) are smaller; neither entailing relative differences exceeding a few tens of percent in these basins in the 1990s. The relative differences in total evaporation and soil moisture that results from use of alternative precipitation and radiation forcing data are small (less than a few tens of percent). In fact the relative changes in alternative forcing are suppressed or muted in the relative changes of total evaporation and soil moisture, especially for precipitation. In the Amazon the relative differences in total runoff are similar to those in precipitation, which is broadly consistent with this being a wet area (so extra precipitation tends to runoff) in which runoff is a large fraction of precipitation (so the relative changes are of similar magnitude). However, for the Murray basin relative changes in precipitation are amplified to become larger relative changes in total runoff, which is broadly consistent with the small values of runoff in this area (Fig.2). Similarly small relative changes of WFD-SRB are amplified in terms of changes in total runoff in the Murray basin.

In the Danube and Mackenzie basins (Fig. 7) the relative changes in radiation due to the SRB correction are much larger in some months than in the Amazon and Murray basins. In the Danube basin the size of relative changes in total evaporation are generally similar to those in SWdown, but in the Mackenzie basin there is clear amplification of the SRB radiation changes (N.B. LWdown changes are not illustrated). This is broadly consistent with evaporation in the high-latitude Mackenzie basin being limited by energy availability (although this is not a complete explanation of the signals seen).

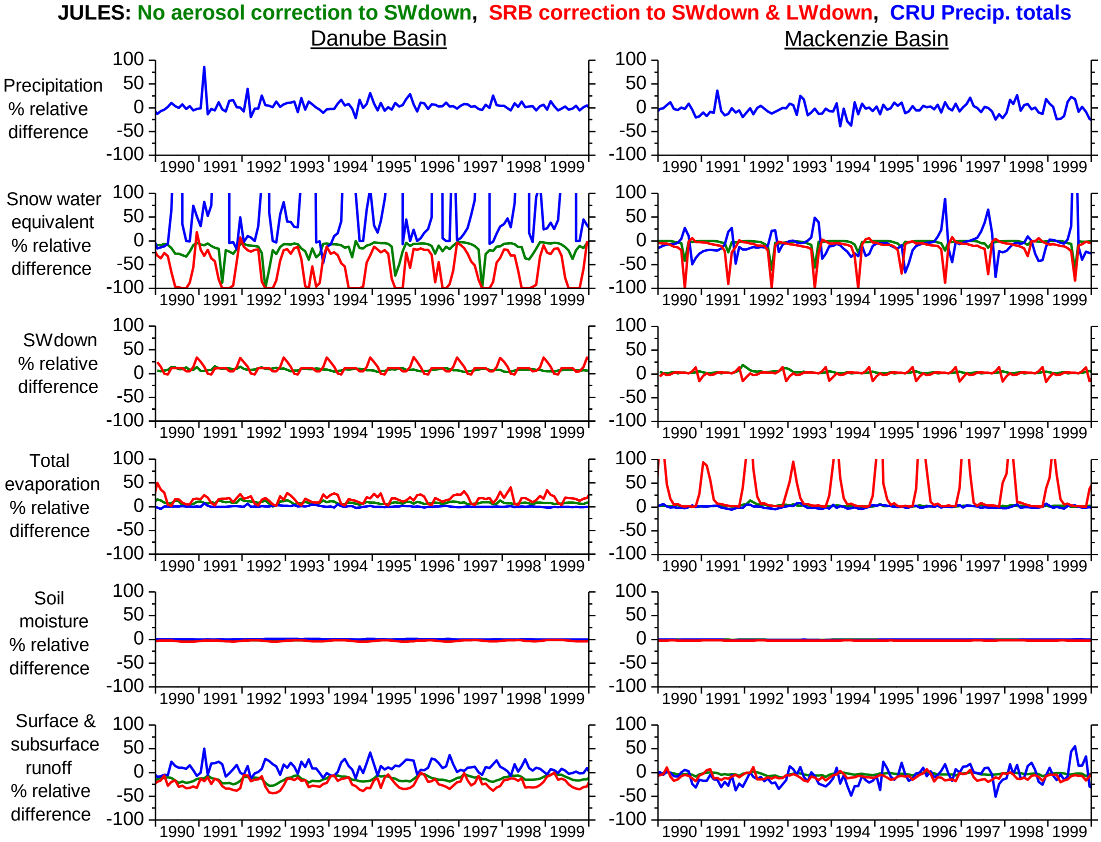

Figure 7*: As for Fig. 6, but for the Danube and Mackenzie basins.*

The relative changes in WFD-CRU are similar in size to the radiation changes from the SRB corrections, but the former are erratic whereas the changes in WFD-SRB follow a clear seasonal cycle. In the Danube basin the relative changes in total evaporation and soil moisture are comparable to the relative changes in WFD-CRU and WFD-SRB. However, in the Mackenzie basin the relative changes in total evaporation due to use of SRB-corrected radiation are exaggerated compared to the changes in the WFD-SRB data themselves. This reflects the effects of changes in radiation in the winter when, due to the high latitude, even small differences have a significant impact on the total radiation received at the surface. The erratic relative changes in total runoff in both the Danube and Mackenzie basins due to precipitation changes are broadly similar in both nature and size to the relative changes in precipitation (WFD-CRU). Similarly, in both these basins the relative changes in total runoff due to WFD-SRB are similar in size to the changes in SWdown in the forcing data.

The relative changes in SWE are highly amplified compared to the relative changes in all three alternative forcing datasets in both the Danube and Mackenzie basins. Changes in the amounts of lying snow are apparently especially sensitive (compared to total evaporation, soil moisture and total runoff) to both the input of moisture and the amount of incoming radiation though more investigations will be required to provide full explanation of the processes involved..

The following figures (Figs 8-15) show maps of relative differences in January and July for the hydrological variables to highlight large relative differences and widespread effects.

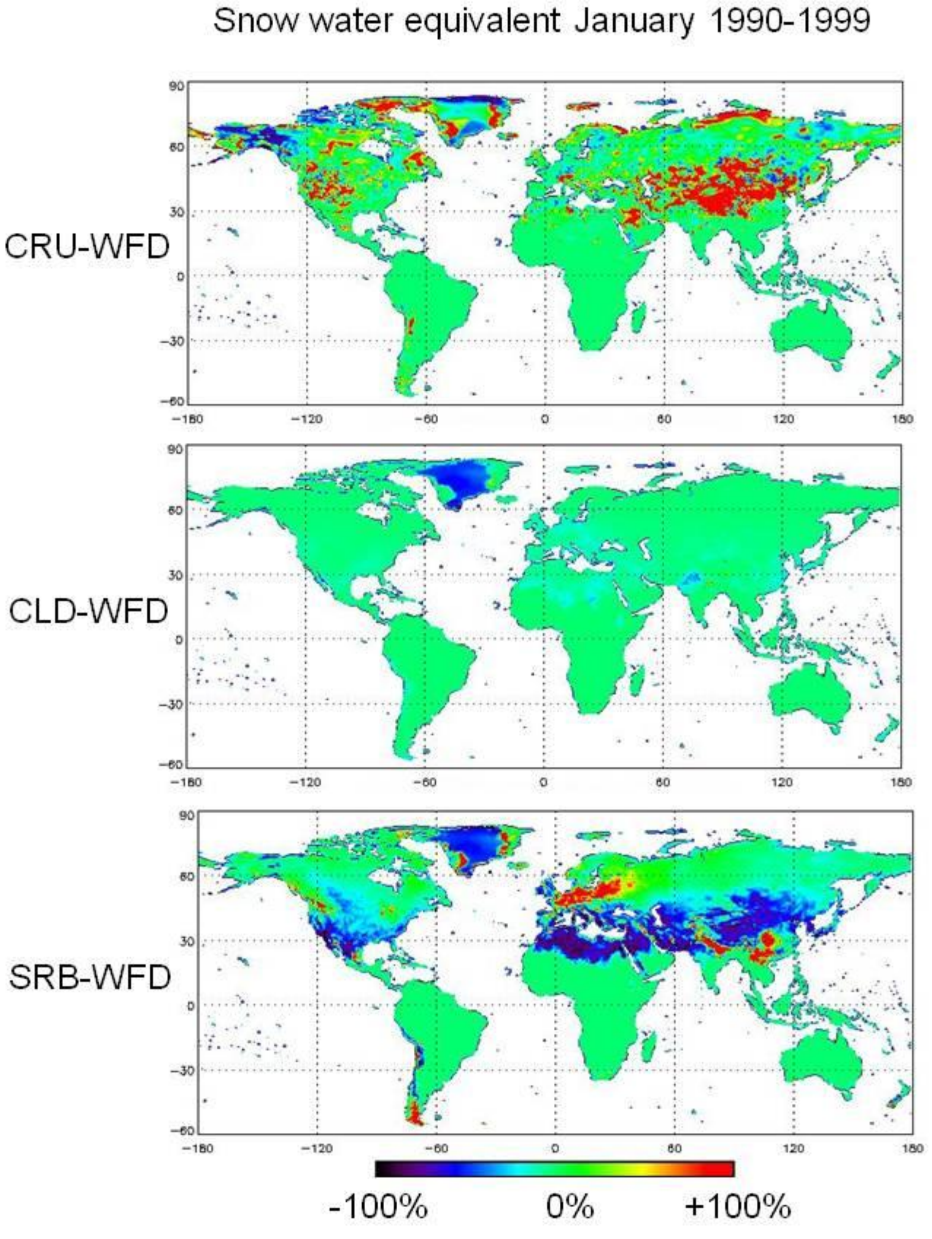

Figure 8: *Maps of average relative differences for 1990-1999 in the JULES SWE outputs due to alternative forcing data for January.*

In January use of the WFD-CRU leads to more SWE in the Himalayas and Tibet, but less on the edges of Greenland relative to use of WFD. SWE is generally unchanged with use of SWdown lacking aerosol corrections (WFD-CLD) except in Greenland where SWE decreases. WFD-SRB leads to less SWE in Greenland and in the arid belt between 20 and 40 degrees north (associated with more evaporation – Fig. 10 and less runoff – Fig. 14). Note that in January this low-latitude belt receives very little snow in absolute amounts so the relative changes appear large. The increased SWE in northern Europe, western Russia and central China, when using SRB-corrected radiation, is apparently linked to decreased evaporation (Fig. 10).

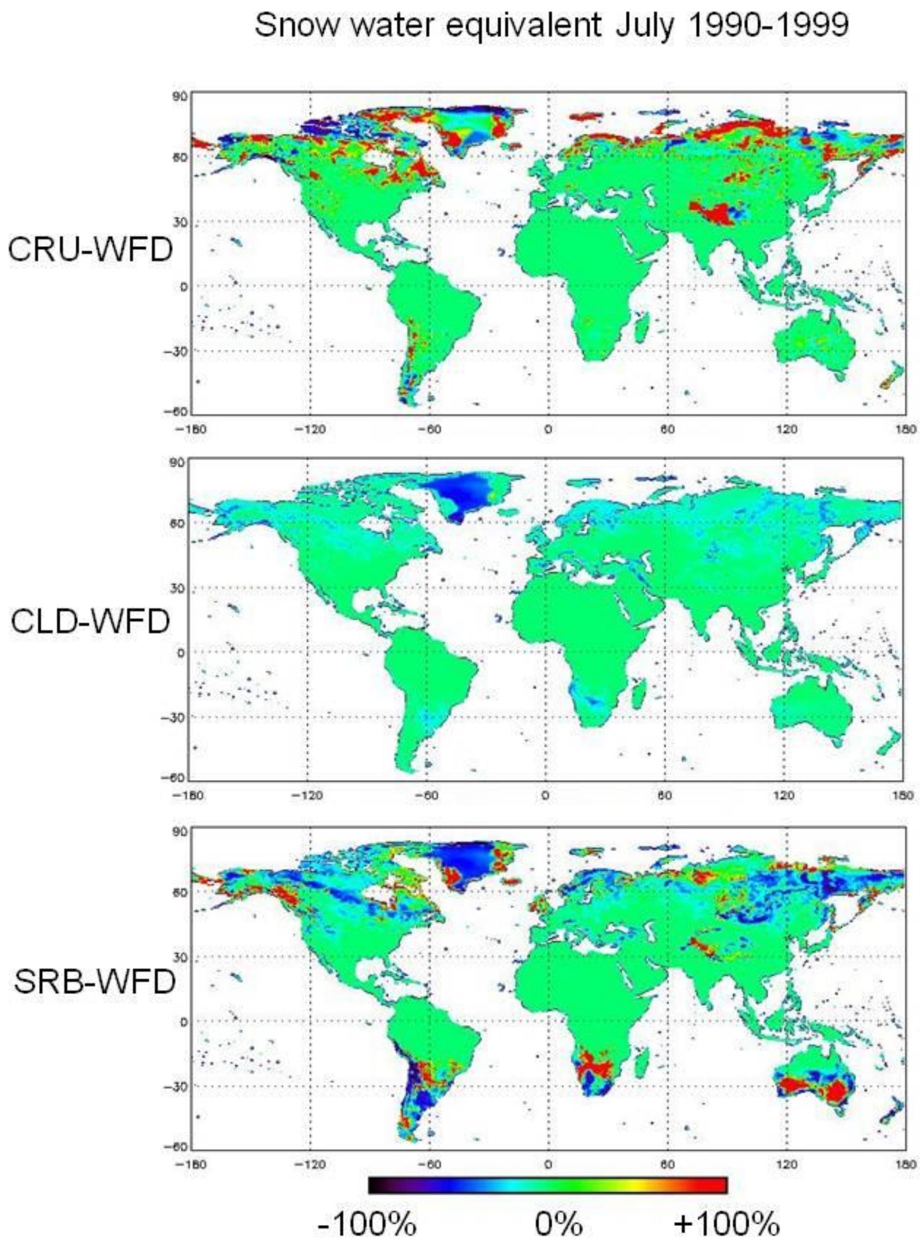

Figure 9: *As for Fig. 8 but for July.*

In July the Greenland changes in SWE, due to all types of alternative forcing data, match those in January. With much less snow generally in the northern hemisphere in July only the Himalayas shows the increased SWE due to the CRU data. The WFD-SRB data lead to a mixture of increases and decreases in southern S. America, S. Africa and S. Australia.

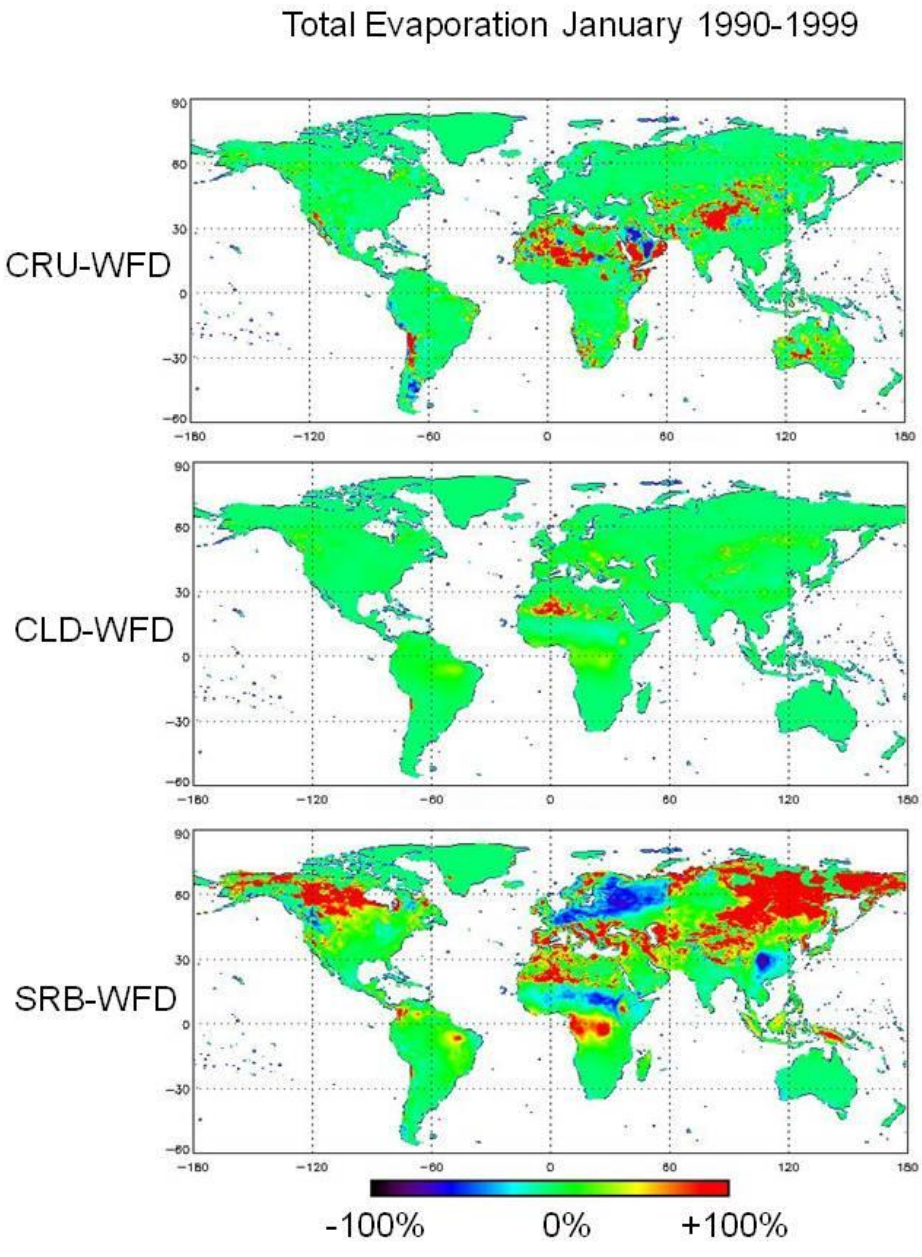

Figure 10: *Maps of average relative differences for 1990-1999 in the JULES Total evaporation outputs due to alternative forcing data for January.*

The WFD-CRU data lead to greater evaporation in January in the Sahara, Saudi Arabia and the Himalayas reflecting greater moisture availability. There is slightly increased evaporation in the Sahara and Congo- and Amazon-basins with use of the non-aerosol corrected SWdown (WFD-CLD, i.e. less aerosol-blocking leads to more SWdown and evaporation). WFD-SRB leads to less evaporation in northern Europe, western Russia and

China, but more evaporation in NW Asia, western Canada and the Congo compared to the WFD runs.

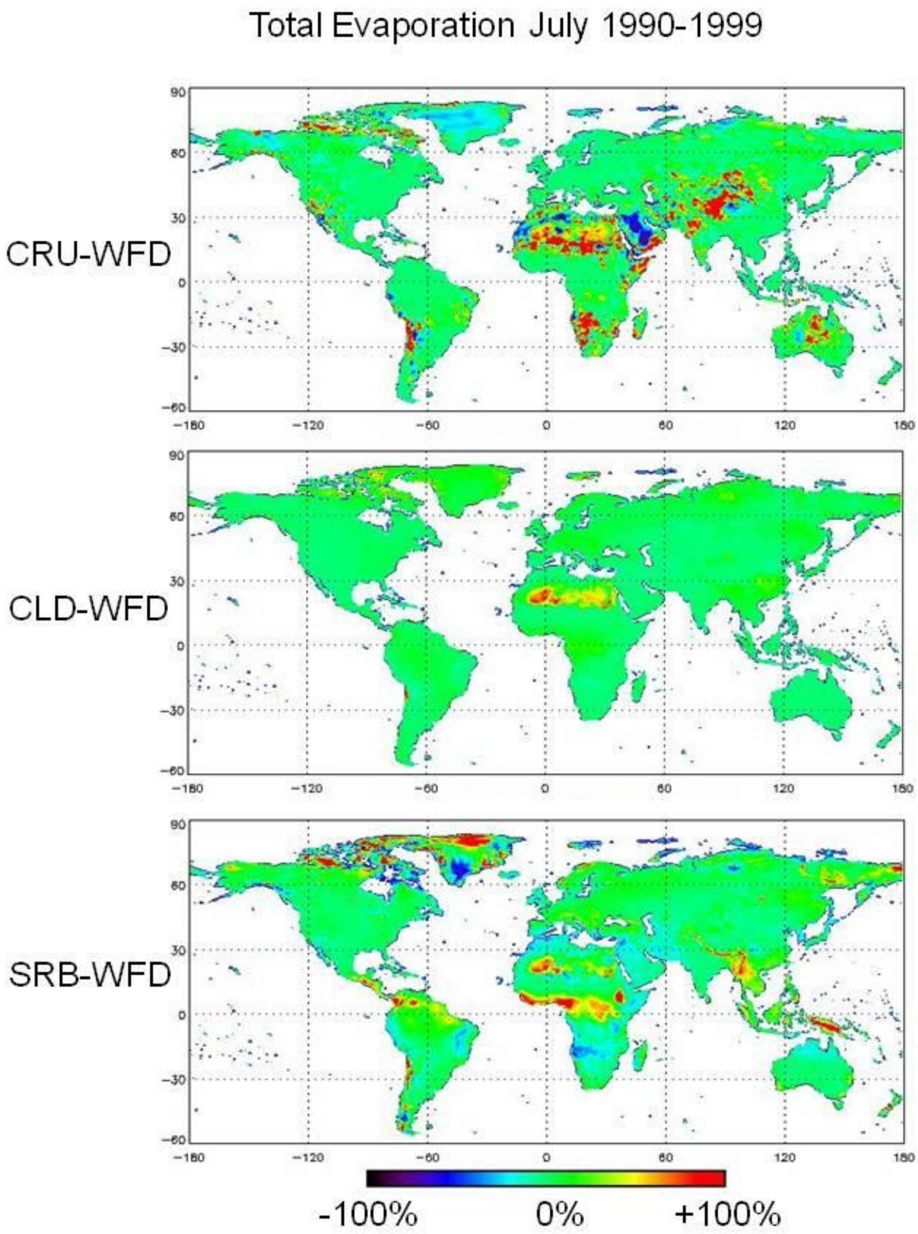

Figure 11: *As for Fig. 10 but for July.*

The increases in evaporation July in the Sahara and Himalayas and decreases in Saudi Arabia using WFD-CRU match the January patterns. There are also increases in western South America, South Africa and central Australia. The WFD-CLD changes also match their January counterparts. On the other hand, changes in evaporation due to the WFD-SRB are less widespread in July mainly occurring as increases along the Gold Coast of Africa, northern Greenland and Indonesia and decreases in southern Greenland.

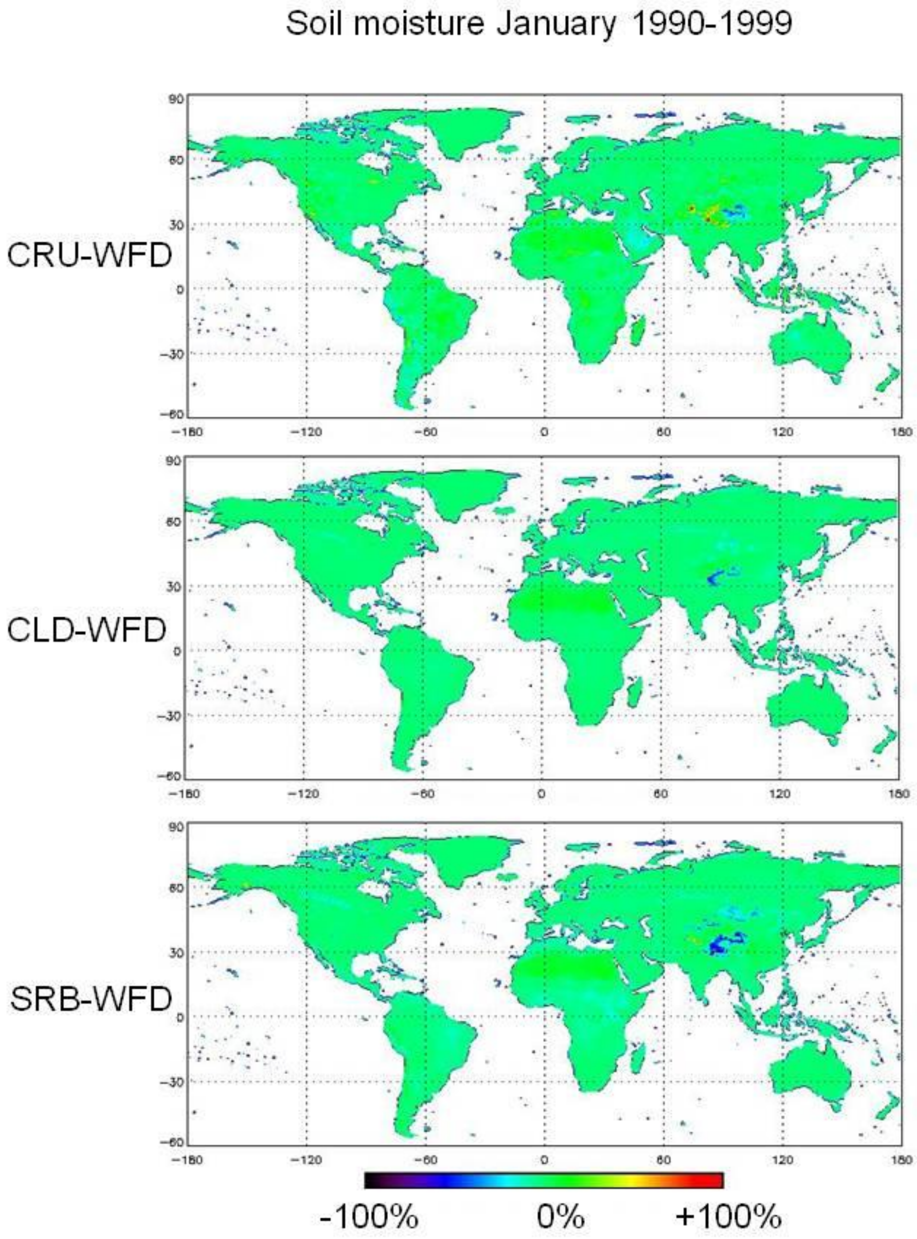

Figure 12: *Maps of average relative differences for 1990-1999 in the JULES Total soil moisture outputs due to alternative forcing data for January.*

Soil moisture changes are generally very small globally and similar for all alternative forcing variables and for both January and July. There are large decreases in the eastern Himalayas-southern Tibet and modest increases in the western Himalayas and northern Sahara.

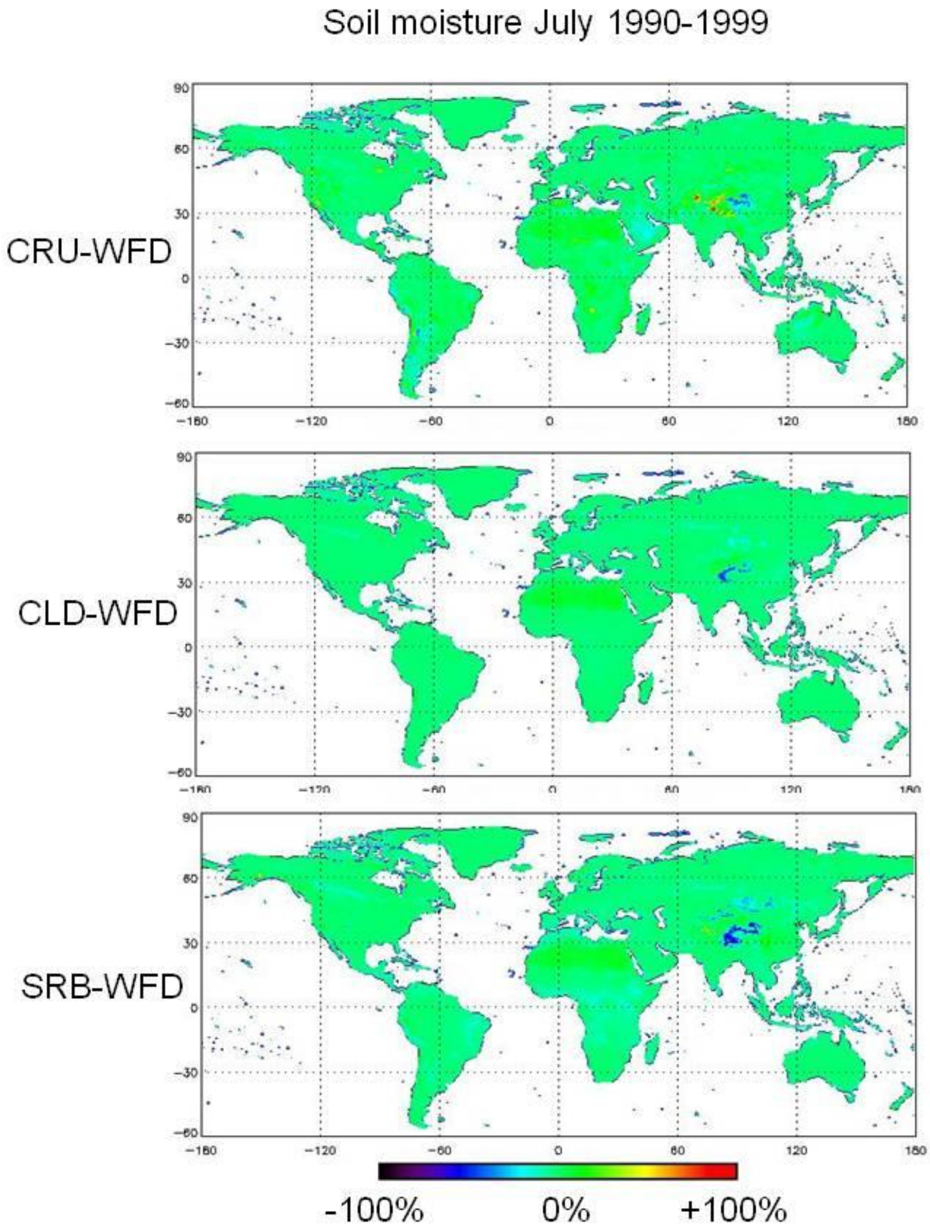

Figure 13: *As for Fig. 12 but for July.*

Total runoff increases in the Sahara are seen for all types of alternative forcing data in both January and July. These increases are from a very low base and associated with common patterns of increased evaporation and soil moisture (cf. Figs 10-13). Increases in runoff due to use of WFD-CRU are widespread globally and rather similar for January and July. There is also a similar pattern of decreased runoff in Saudi Arabia in both months. This may indicate a systematic bias in either the GPCC or CRU data. Note that locally these changes averaged over 1990-1999 mask significant trends. For example, in the Amazon basin (Figs 2 and 6) runoff using WFD-CRU was often less than for WFD in the early 1990s, but this reversed in the late nineties.

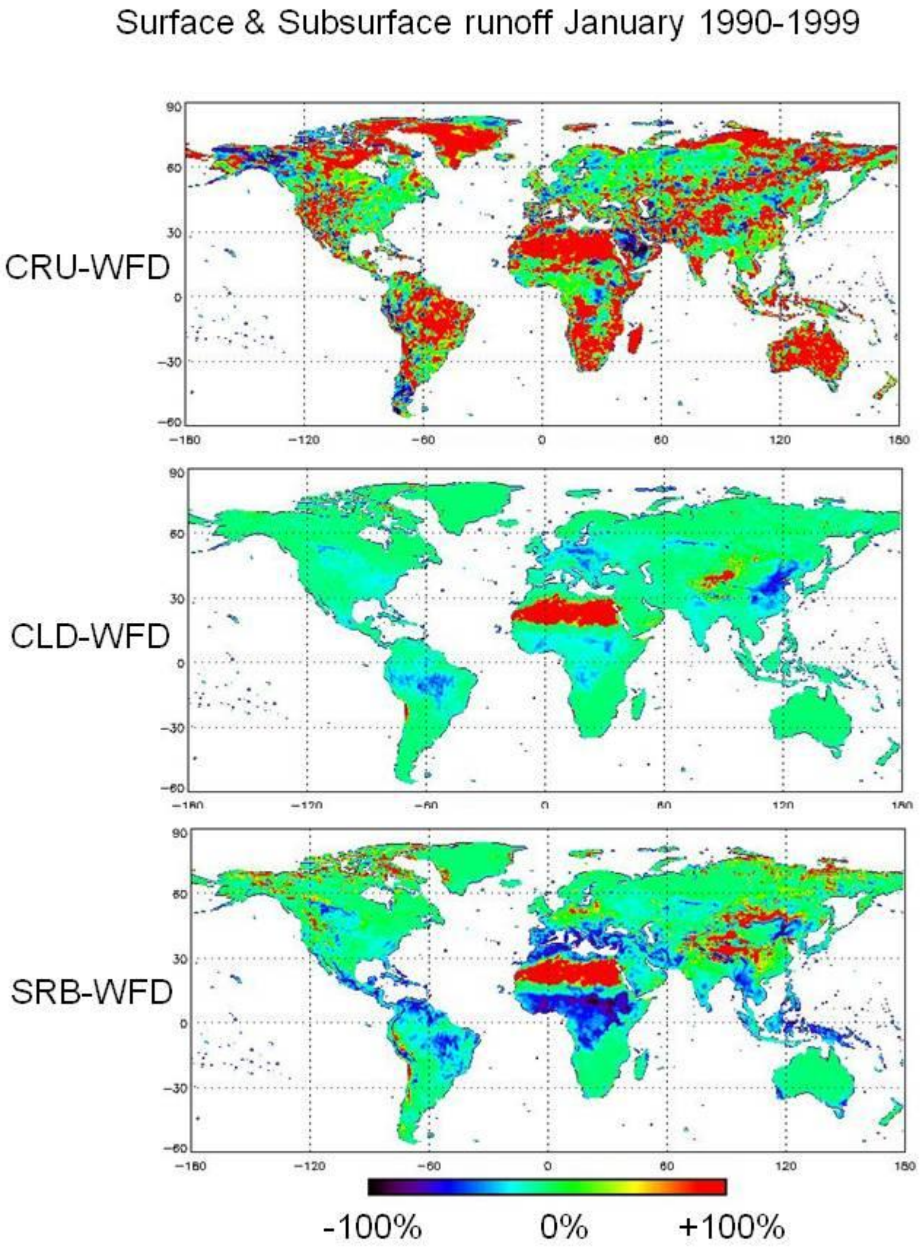

Figure 14: *Maps of average relative differences for 1990-1999 in the JULES Total runoff outputs due to alternative forcing data for January.*

Excluding the changes in the Sahara, there are only minor changes in runoff due to use of the WFD-CLD rather than WFD in both January and July with minor decreases in parts of western Asia, eastern Europe, the Congo and west central Africa, and central South America. The pattern of changes in runoff due to WFD-SRB are mainly increases in the Himalayas and Tibet and decreases in southern Europe, central Africa and north and east South America. There seem to be large-scale patterns of changes in the meteorology, and related, consistent patterns in the response of JULES.

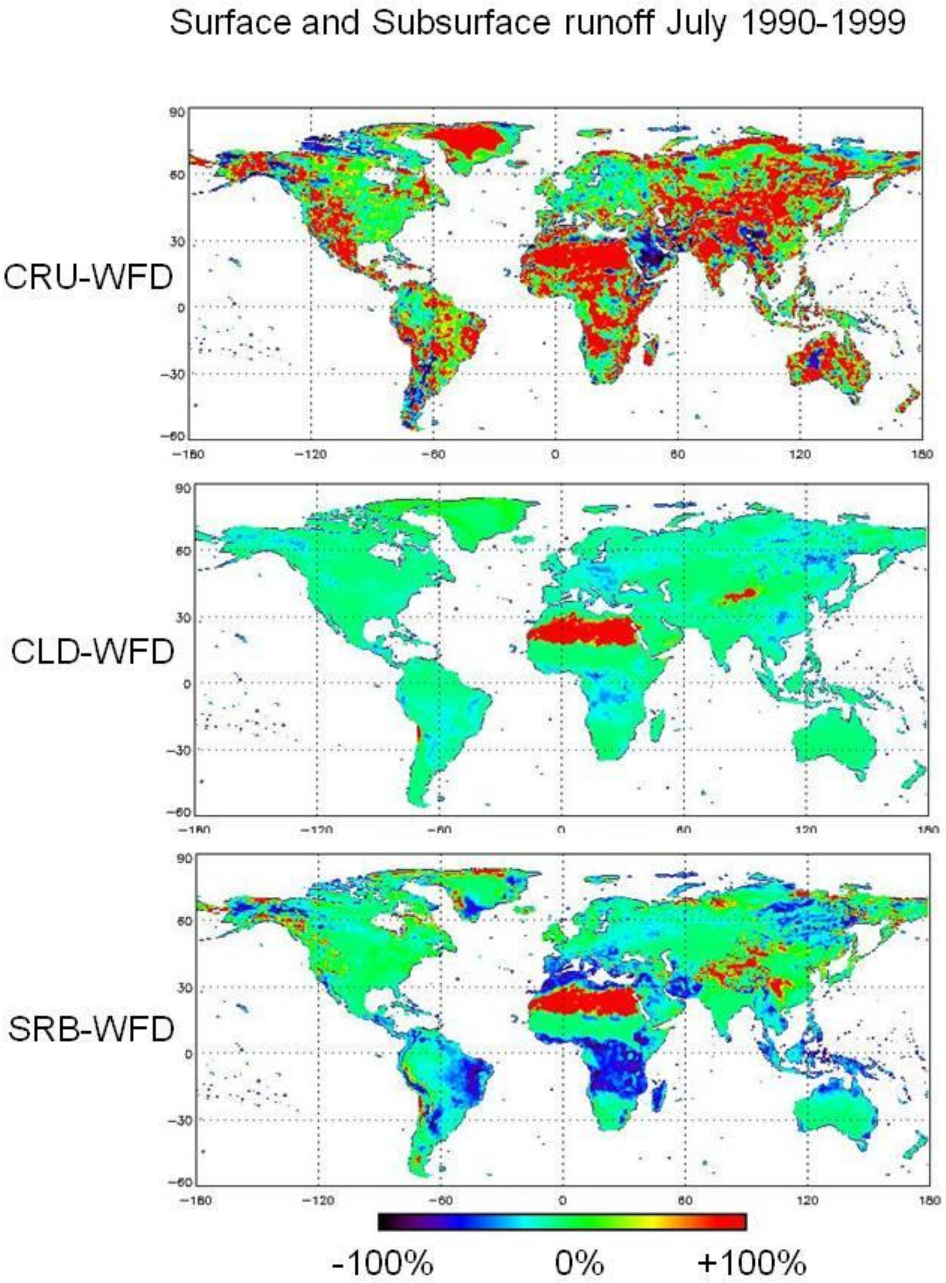

__Figure 15:__ As for Fig. 14 but for July.

Conclusions.

In terms of WorkBlock 1 Objective 4 it is clear that the uncertainty in components of the modelled terrestrial water cycle is largely due to uncertainty related to the differences between models, while the uncertainty introduced by the forcing data is much less (compare Fig. 2 with Fig. 3, and Fig. 4 with Fig. 5).

In terms of WorkBlock 1 Objective 7 the degree of amplification or suppression by the hydrology of changes in the forcing data depends on the meteorological variable, the hydrological variable and the location considered. Changes in modelled SWE are highly dependent on changes in precipitation and incoming radiation. This amplification of changes in meteorological forcing is much clearer for SWE than for the other hydrological variables. On the other hand, changes in soil moisture follow roughly proportionately from changes in precipitation and radiation.

Changes to total evaporation seems to generally be in proportion to changes in radiation & precipitation except at high latitudes when radiation changes are amplified (e.g. in the Mackenzie basin, Figs 4 and 7). Total runoff changes are also generally in proportion to changes in precipitation and runoff except in semi-arid and arid areas (e.g. the Murray Basin, Figs 2 and 6). Detailed explanations of the local processes involved in the relative changes in runoff will require further work.

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