

# CLIMATE CHANGE AND FRESHWATER RESOURCES: LESSONS FROM IPCC'S FOURTH ASSESSMENT REPORT (AR4)

In April 2008, the IPCC Technical Paper on Climate and Water (TP) was approved by the IPPC Bureau. The TP brings together all the knowledge about the relation of climate change and freshwater resources that is scattered among and within the three books which make up the AR4: on the physical science basis of climate change (Working Group I), on impacts, adaptation and vulnerability (WG II), and on mitigation (WGIII). From WGII, for example, information was not only drawn from the “freshwater chapter”, but also from other sectoral chapters like the chapter on health impacts, and the regional chapters. While AR4 was developed between 2004 and early 2007 by reviewing and synthesising scientific literature that was published mainly after 2001, the TP was written in the following year based only on the literature already considered in the AR4. In my opinion, the TP has achieved to be a compendium of the relation between climate and water.

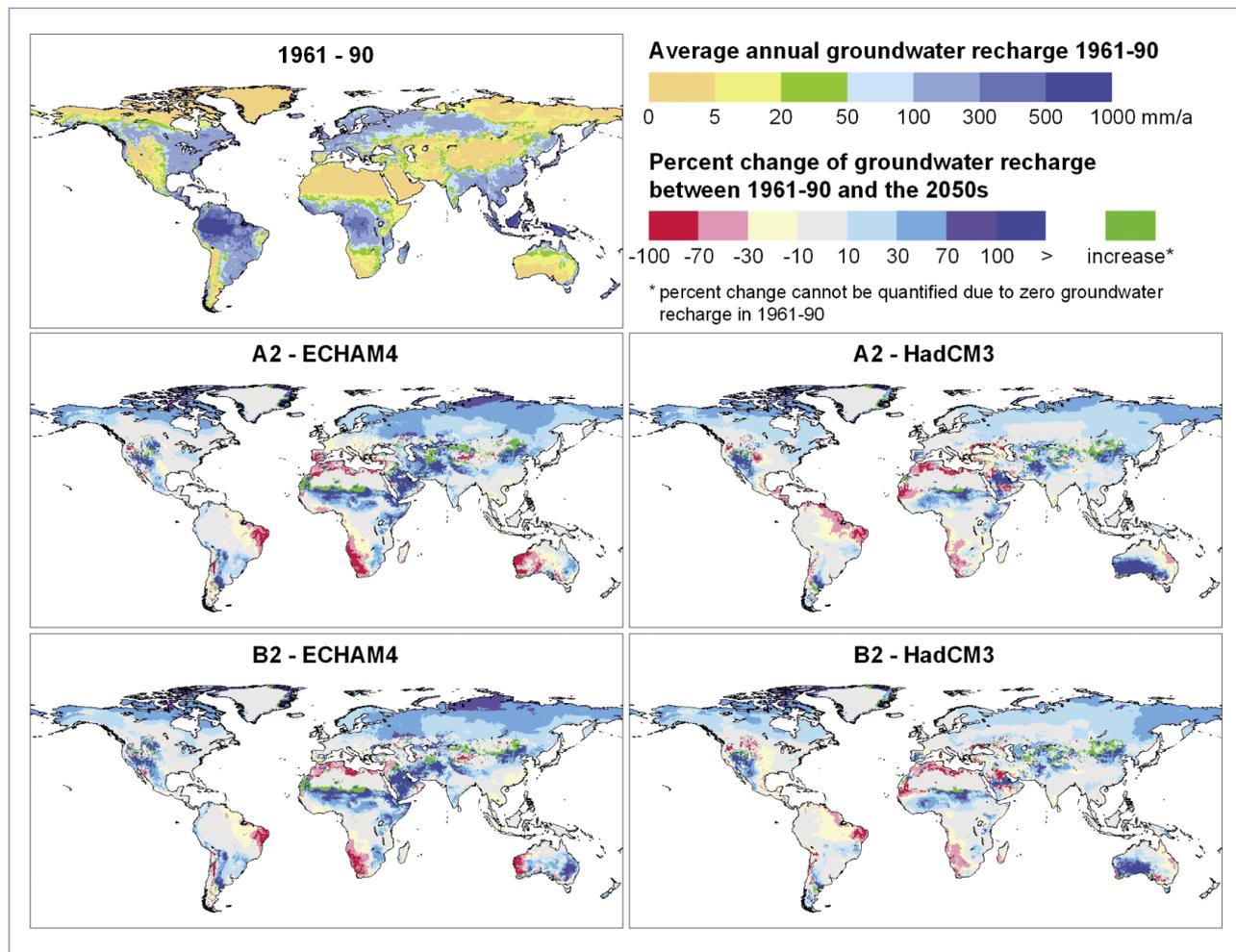
The most important conclusions of the IPCC with respect to climate and water can be found in the executive summaries of the TP and the freshwater chapter of the AR4 WGII report, which are both available at <http://www.ipcc.ch>, and in Kundzewicz *et al.* (2008). Many of those conclusions have been widely published in the media. Here, I will only present my personal selection of the most pertinent information that is now available.

## Mean precipitation and renewable water resources

Considering the advances in knowledge about the impacts of climate change on freshwater since the Third Assessment Report of the IPCC in 2001, the improved characterisation of the uncertainty of projected precipitation changes stands out. It was made possible by ensemble predictions that are based on about 15 different climate models (or model runs). Even when looking at precipitation change over a period of 100 years, until the end of the 21st century, there are only very few land areas where the magnitude of the changes of the multi-model ensemble mean exceeds the inter-model standard deviation: The Arctic and Northern Asia with increasing precipitation, and the Mediterranean region with decreasing precipitation (figure 2.8 of TP). On most land areas, less than 80% of the climate models agree on the same direction of change (increase of decrease) in annual precipitation, soil moisture and runoff (figure 2.9 of TP).

The multi-model ensembles allow to conclude that increases of precipitation and renewable water resources throughout the 21st century are very likely in high latitudes and parts of the tropics, while decreases in some subtropical and lower mid-latitude regions are likely. Many semi-arid and arid areas (e.g. the Mediterranean basin, western USA and Mexico, southern Africa and north-eastern Bra-

**Figure 1:** Impact of climate change on long-term average annual diffuse groundwater recharge. Percent changes of 30-year averages groundwater recharge between 1961–1990 and the 2050s (2041–2070), as computed by the WaterGAP Global Hydrology Model by applying four different climate change scenarios (climate scenarios computed by the climate models ECHAM4 and HadCM3, each interpreting the two IPCC greenhouse gas emissions scenarios A2 and B2) (Döll and Flörke, 2005).



zil), which are particularly vulnerable to climate change, are projected to suffer from decreasing water resources due to climate change. While increased annual runoff, predicted for many regions of the globe, potentially leads to increased water availability, this will not always be beneficial. While annual runoff is increased, this may still be associated with decreased water availability during the dry season or lead to a water table rise that is problematic in urban and agricultural areas and can mobilise salt.

### Variability of climate and terrestrial water flows

While even the sign of precipitation change is highly uncertain for most areas, the climate models do agree in predicting an increasing variability of temperature and precipitation. This is consistent with observed trends since the 1960s. Heavy precipitation events are very likely to occur more often almost everywhere, even in areas with lower mean precipitation. The higher the greenhouse gas emissions, the more variable precipitation becomes. The proportion of land surface under drought conditions at

any one time is likely to increase, in addition to a tendency for drying in continental interiors during summers (outside high latitudes). More extreme events including heavy rainfalls, floods and droughts, together with higher water temperatures, are likely to exacerbate many forms of water pollution. As an example, pathogen transport will be accelerated by more heavy rainfalls, with negative effects in developing countries in particular.

Due to the temperature increases, less precipitation will be stored as snow (or ice in glaciers), which reduces water availability in surface waters by reductions in summer low flows. This has already been observed in the past. Glacier melting will lead to an increase in river discharge only for a restricted period of time (approximately a few decades, depending on glacier size and other factors).

### Groundwater

The increased variability and thus decreased reliability of surface water flows that is caused by climate change will, in general, make the use of groundwater even more

attractive than today. Groundwater is not only protected from pollution much better than surface water, the large natural storage capacity of aquifers allows constant water withdrawals even in the dry season and in dry years. It will, however, not be possible to increase reliance on groundwater in all regions of the globe. Only 30% of the continental areas are underlain by relatively homogeneous aquifers ([www.whymap.org](http://www.whymap.org)), and some aquifers are already pumped in an unsustainable manner. In coastal areas, in particular islands, groundwater resources will be diminished significantly by salt water intrusion that is caused by sea level rise if the land surface is less than 5 m, approximately, above sea level (Kundzewicz and Döll, submitted). Besides, where total water resources decline, renewable groundwater resources, which are only a fraction of the total renewable water resources which are equal to the long-term average of groundwater recharge, will decline, too. In those semi-arid regions where a strong reduction of total water resources is projected, groundwater recharge is projected to decline by more than 30% or even 70% (red colours in figure 1). Using the WaterGAP Global Hydrology Model (WGHM), which has been specifically tuned for groundwater recharge in semi-arid regions (Döll and Fiedler, 2008), Döll and Flörke (2005) computed that in semi-arid areas with decreasing groundwater recharge, the percentage decrease of groundwater recharge is higher than the percentage decrease of total runoff, which is due to the model assumption that recharge only occurs if daily precipitation exceeds a certain threshold.

These model-based projections, like all hydrological climate change impact studies, are highly uncertain. First, the climate input as computed by climate models is uncertain. Second, the projected increased variability of precipitation is not taken into account by impact models like WGHM. This is caused by the low skill of climate models in computing precipitation, so that precipitation calculated by climate models cannot be used as direct input to models which aim to represent (current) water resources and flows in a plausible manner. Up to now, changes in long-term average monthly precipitation as computed by climate models are generally used to scale observed monthly precipitation, and there is not yet an established method to represent increased variability of daily precipitation. More intense precipitation may lead to increased groundwater recharge in semi-arid areas where only high-intensity rainfalls are able to infiltrate fast enough before evapotranspiring, and where alluvial aquifers are mainly charged during floods. In humid areas, more intense precipitation may lead to decreased groundwater recharge as the infiltration capacity of the soil will be exceeded more often.

## Freshwater-related costs of climate change, adaptation and mitigation

AR4 and TP conclude that the negative impacts of future climate change on freshwater systems are expected to outweigh the benefits. However, very little work has been done to support any monetarisation of the costs of climate change with respect to freshwater. The most important adaptation strategy to climate change, given the large uncertainties with respect to quantifying specific hydrological changes, is to lower the stress on freshwater systems by decreasing human water use, water pollution and structural modifications of surface waters, at least in my opinion. Mitigation of climate change reduces adaptation needs, but negative effects of certain mitigation measures (e.g. afforestation, hydropower and bio-energy crops) on freshwater systems need to be carefully considered.

## References

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