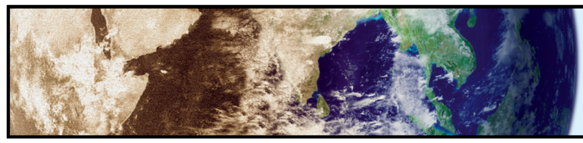

Water resources - How severe will freshwater resource shortages be on a regional scale?

PRESENT PAST

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The terrestrial water budget is at the heart of many environmental issues. Water is crucial to agricultural production, the healthy functioning of biogeochemical cycles, biodiversity, industrial production and human health. Extremes play an important role: floods and droughts provide pressure points on water scarcity and environmental damage. Increasing population and wealth in many regions of the world are increasing the pressure on available water, a situation likely to be exacerbated by human activities including climate change.

As yet it is difficult to discern an increase in rainfall globally despite its likelihood in a warmer world, partly because changes in precipitation in different regions tend to cancel out. With increasing precipitation at high latitudes, decreasing precipitation in the subtropical regions and possibly changing distribution of precipitation in the tropics by the shifting position of the Intertropical Convergence Zone (see e.g. Zhang et al. 2007).

Extremes of rainfall have increased in Europe and worldwide (e.g. Zolina et al. 2010) and these are likely to be linked with increased greenhouse gases (Pall et al. 2011). Overall droughts have also increased through the 20th century and are predicted to increase further in the 21st century. However, the projected changes in rainfall patterns depend on atmospheric circulation patterns, which are not always represented well in the climate models. And the basin-scale response of river flows also depends on the regional-scale basin characteristics and human interventions, besides the warming induced by greenhouse gases.

In fact many of the observed trends in the hydrological cycle can be attributable to human activities beyond increasing CO_2. A decrease in groundwater, particularly noticeable in mid-western USA and northern India can be inferred from GRACE satellite data (e.g. Rodell et al. 2009), almost certainly due to over extraction for irrigation. Terrestrial evaporation has increased through the 1980s and 90s, most probably due to decreasing aerosols (Jung et al. 2011). Increasing runoff and increasing high flows linked to the melting of glaciers have been observed in the Alpine region. Flows in the northern rivers have increased, but it is unclear whether this is due to land-cover change, increasing precipitation or increasing CO_2 levels (see Gerten et al. 2008).

It is very likely that global warming has influenced river flows, but often either the long-term river-flow data are not available or the changes are masked by changes in land cover or extraction. Collaboration between climate, hydrological and water resource scientists working across a wide variety of scales is thus essential. In recent years this has been achieved with the bringing together of a wide variety of data sets and models (see e.g. Weedon et al. 2011; Haddeland et al. 2011).

Climate models continue to suggest decreases of rainfall in the semi-arid regions of the world, such as the Mediterranean region, southern USA and Central America, southern Australia and southern Africa. When translated into river flows and available water we predict increasing water scarcity in these regions but also in China, India and the Middle East, where populations and water consumption are rising fast (Fig. 1).

There is considerable variation in the both the global hydrology and climate models (Haddeland et al. 2011). Also regional analyses require the incorporation of many additional processes, such as irrigation and groundwater (and the interactions between them). At present the best approach seems to be to use an ensemble of available hydrological models in tandem with the ensemble of climate models used by the Intergovernmental Panel on Climate Change.

There has been considerable progress on quantifying the global and regional terrestrial water balance in recent years. Considerable uncertainties, however, remain particularly at the regional scale where in situ data on rainfall and runoff are limited. Satellite products and modeling can to an extent fill these gaps, but there remains a need to maintain surface based networks and the free flow of data.

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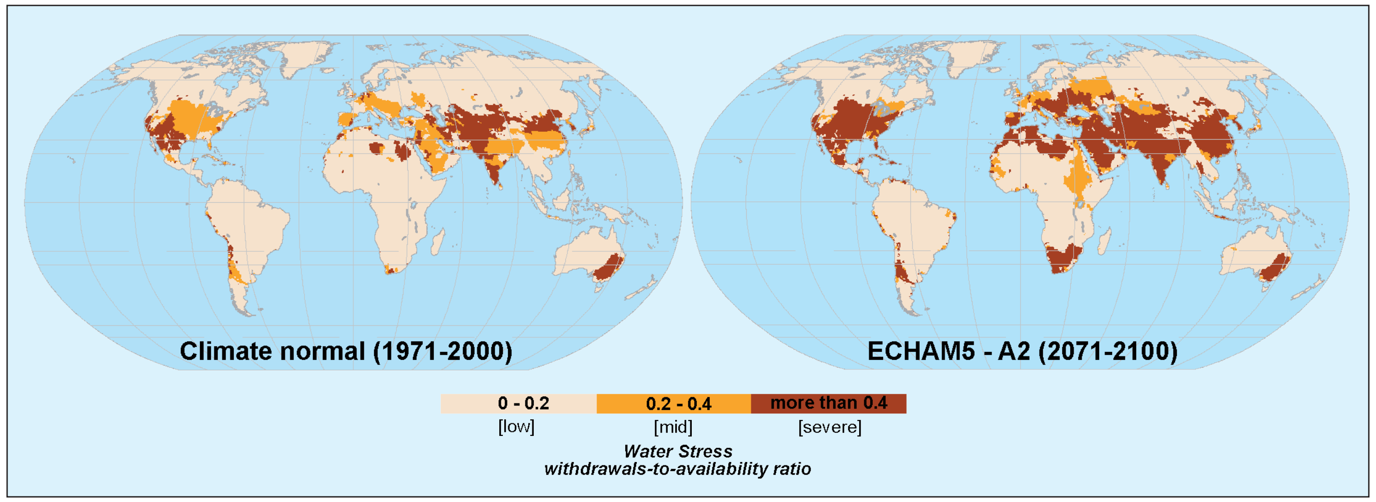

Figure 1: Water stress, calculated as the ratio between water withdrawals and availability, for the late 20th and 21st centuries (see Flörke and Eisner 2011).

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Climate model projections of future hydroclimatic change associated with increasing atmospheric greenhouse gas concentrations are sobering and, depending on where you live, very alarming. For example, southwestern North America is projected to enter into a long-term drying trend in the sub-tropics to mid-latitudes, and this trend in increasing aridity may have already begun (Seager et al. 2007a). Thus, the unprecedented 2011 Texan drought (www.ncdc.noaa.gov/sotc/drought/2011/8) is an example of what might happen with increasing frequency and duration in the future. Independent of whether or not model projected radiatively forced drying is actually happening now, there is abundant paleoclimate evidence for the occurrence of past "megadroughts" in North America (Stine 1994; Woodhouse and Overpeck 1998; Cook et al. 2004, 2007; Stahle et al. 2011), Asia (Buckley et al. 2010; Cook et al. 2010a), and Europe (Helama et al. 2009; Büntgen et al. 2011) that dwarf any periods of drought seen in instrumental climate records over the past century. The seminal property of megadroughts that differentiates them from even the most severe droughts observed today is duration (Herweijer et al. 2007), with the former often lasting several decades to a century or more compared to just a few years to a decade or so for the latter. Figure 1 shows three such megadroughts reconstructed from tree rings (Cook et al. 2010b) that hit the Mississippi Valley of the United States during early, middle, and late medieval times. These megadroughts lasted 46, 148, and 61 years, respectively, and are ominously located in the American "bread basket" where similar droughts in the future would have catastrophic consequences on agricultural production. This also means that water resources planning and infrastructure design based on observed hydroclimatic data are unlikely to be resilient enough to handle the possible return of megadroughts that we now know have happened in the past.

The cause of past megadroughts is still not fully understood, but persistent patterns of cold La Niña-like sea surface temperatures in the eastern equatorial Pacific ENSO region have been strongly implicated in North America (Herweijer et al. 2006; Seager et al. 2007b; Graham et al. 2007), along with the possible influence of the Atlantic Ocean there as well (Feng et al. 2008). Perhaps more importantly, the paleoclimate record indicates that megadroughts occurred more often during an earlier period of generally above average temperatures called the Medieval Warm Period (MWP), approximately 700 to 1,200 years ago. It is not important to know whether or not the MWP was as warm as today (cf. Crowley and Lowery 2000; Bradley et al. 2003; Mann et al. 2009; Ljungqvist et al. 2011). Rather, the paleoclimate record of past megadroughts simply tells us that 1) they are a natural part of the climate system with no need for anthropogenic greenhouse gas forcing to ignite and sustain them, and 2) rather ominously they appear to "like" warmer climates such as that which occurred during the MWP. Given the climate model projections of future drying and the high likelihood that global warming will continue throughout the 21st century (IPCC 2007), we may therefore be entering into a new era of megadroughts with potentially catastrophic consequences to water supplies needed for human consumption, agriculture, energy production, and for maintaining the aquatic environment. The degree to which any future megadroughts caused by human-induced global warming will resemble those in the past is unclear because the climate forcings operating today are different from the past. Regardless, the stage appears to be set now for some possibly radical future changes in hydroclimatic variability if the past is any guide.

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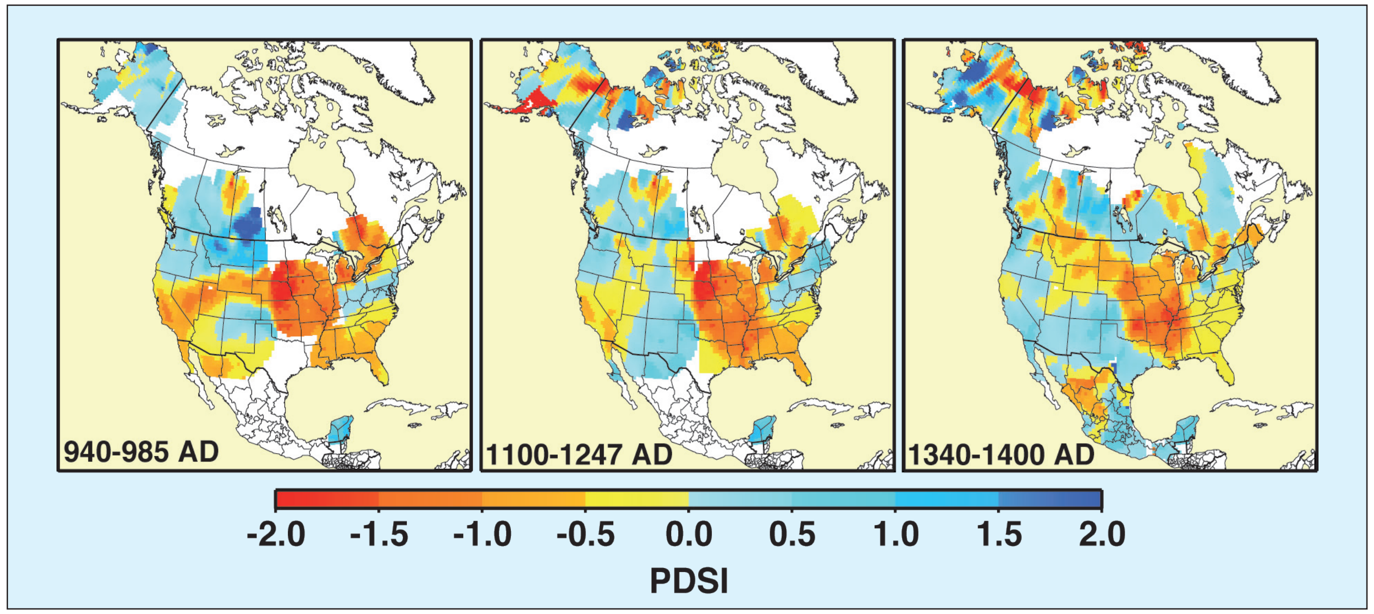

Figure 1: Examples of three megadroughts reconstructed from tree rings that hit the central Mississippi Valley of the United States during early, middle, and late medieval times. See Cook et al. (2010b) for details.

Paired Perspectives on Global Change