Impacts of Projected Changes in Climate on Hydrology

27

David W. Hyndman

Contents

Abstract

Global temperatures are projected to rise by several degrees C over the next century, with more dramatic warming over land masses; precipitation is expected to become more variable with increases in polar regions and decreases in mid-latitude areas. Such changes in climate will have major impacts on hydrology, with more flooding expected in humid regions and more droughts in arid areas. Warming is also causing rapid shrinking of glaciers and decline of snowpack that are important to water supplies around the world. Such climate changes are likely to cause additional stress on water resources in many areas of the world at the same time demands are expected to increase due to population growth.

Introduction

Projected changes in climate will have significant effects on hydrology. Global temperatures are projected to rise by approximately 3.6–8.5 °F (2–4.7 °C) over the

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D.W. Hyndman
Department of Geological Sciences, Michigan State University, East Lansing, MI, USA
e-mail: hyndman@cns.msu.edu; hyndman@msu.edu

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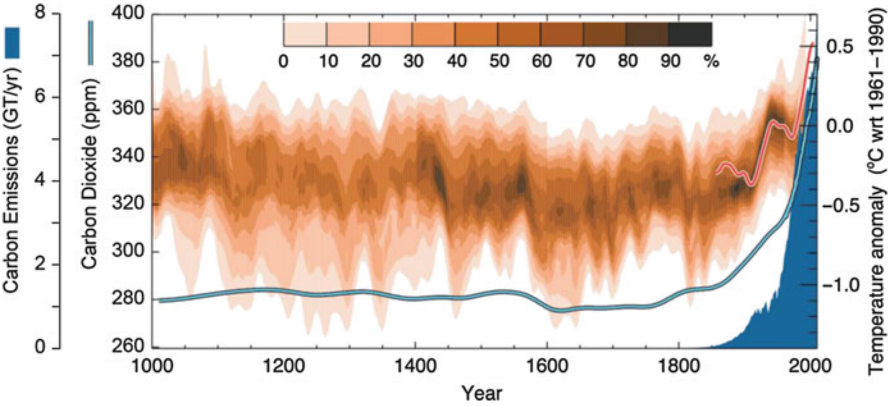

Fig. 27.1 Concentrations of carbon dioxide (*light blue line*; IPCC 2007) compared to carbon emissions (*dark blue shading*; USGCRP 2000) and globally averaged surface temperature anomalies (*Orange-shaded area* shows temperature proxies, with darker colors indicating less uncertainty shown on the % color scale, the *red line* shows twentieth century temperature observations; IPCC 2007)

next century, assuming a range of potential greenhouse gas emission scenarios (Walsh and Wuebbles 2013), which would result in dramatic effects on the hydrologic cycle. The projected temperature increases are significantly larger over land masses, with warming of up to 15 °F (8.3 °C) in polar areas (Walsh and Wuebbles 2013). Most of the projected warming is attributed to human uses of carbon-based fuel sources that have dramatically increased the concentrations of greenhouse gasses in Earth's atmosphere (Fig. 27.1). As carbon emissions dramatically increased starting in the mid-1800s with the Industrial Revolution, CO_2 concentrations based on ice core data began to depart from a relatively stable long-term average to approximately 40 % higher levels than the average from the previous 850 years (MacFarling et al. 2006). Recent direct observations of CO_2 concentrations from the Mauna Loa observatory, Hawaii, show a 26 % increase in CO_2 concentrations since 1958, with annual cycles driven by decreases during the Northern Hemisphere growing season as plants take up CO_2 (Fig. 27.2; Tans and Keeling 2013).

Significant changes are also expected in precipitation as warmer air will increase evaporation from the oceans and the terrestrial biosphere. In addition, temperature and precipitation are both expected to become more variable, which will likely result in more extreme and frequent droughts and floods.

Water is not being managed in a sustainable manner in many areas of the world. Withdrawals from surface water and groundwater reservoirs are creating large deficits in many regions of the world, including the High Plains Aquifer in the Central USA (Stanton et al. 2011), the central valley of California (Famiglietti et al. 2011), and the Indus Plains aquifer in northern India (Rodell et al. 2009). Climate change coupled with population growth, and the associated need for significant increases in water use for agriculture, will compound existing water sustainability problems. Exacerbating the issue, the expected increase in global

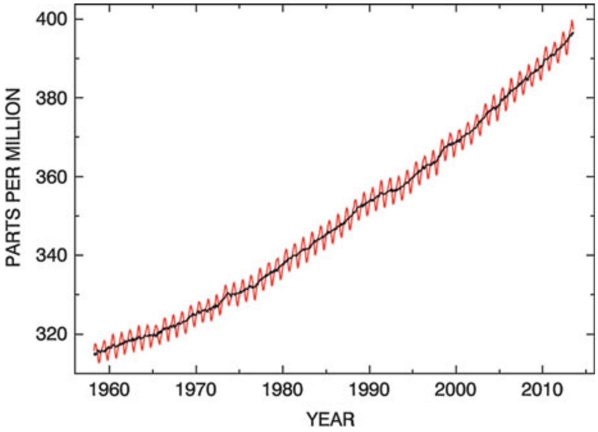

Fig. 27.2 Change in measured carbon dioxide (CO_2) concentrations from the Mauna Loa Observatory, Hawaii. Concentrations of this primary greenhouse gas are increasing at an exponential rate, with seasonal decreases during the Northern Hemisphere growing season due to the uptake of CO_2 by plants during the growing season (Tans and Keeling 2013)

population to approximately nine billion people by 2050 along with significant shifts toward diets with more meat are expected to result in a 70–110 % increase in food demand in this short period (FAO 2009; Tilman et al. 2011). This would cause a major increase in demand for irrigation water.

The likely impacts of projected changes in climate on hydrology are discussed below in the following categories: precipitation and evapotranspiration, glaciers, snow cover and stream discharge, groundwater recharge, and ice cover and surface water levels.

Precipitation and Evapotranspiration

Precipitation is expected to generally increase in polar regions and decrease and mid-latitude areas (IPCC 2007). Both changes are problematic as they would cause many wet regions to become wetter and dry regions to become dryer. Changes in precipitation have already been observed, including an average increase of 2 in. across the continental USA from 1895 to 2011 (Bales et al. 2012; Georgakakos et al. 2013). Decreasing precipitation in dry regions would enhance the risk of drought, causing increased stress for sustainable water supplies for both human and ecosystem uses. Increasing precipitation in wet regions would generally increase average stream flows and increase risk of flooding.

Although projected changes in the mean precipitation are a concern, the projected increasing variance of precipitation (IPCC 2007) is even more problematic as it would result in more extreme precipitation events. Historical observations already show this trend; for example, there has been a 40 % increase in the frequency of extreme rain events (greater than 6 in. in a day or multiday event) over the central USA over the last 31 years (Groisman et al. 2012). In the USA from 1958 to 2011, the most affected regions are the Northeast and Midwest, which have experienced 74 % and 45 % increases, respectively, in the amount rain falling in very heavy events (the heaviest 1 % of daily events) (Walsh and Wuebbles 2013; Karl et al. 2009).

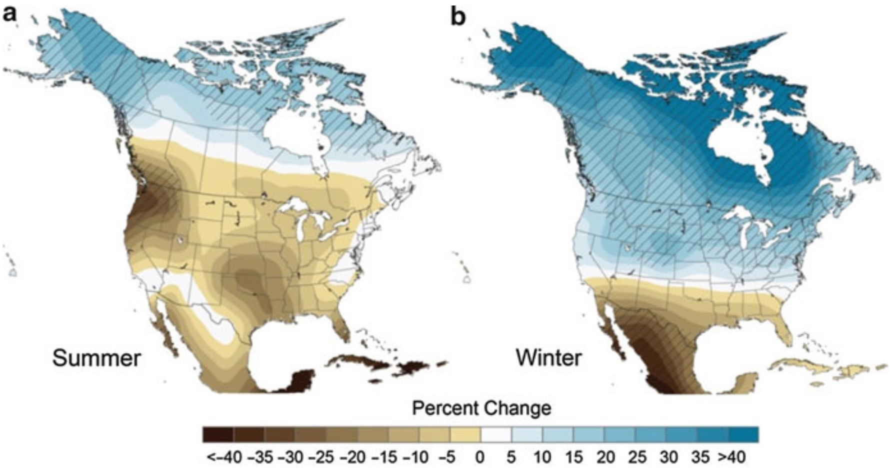

Fig. 27.3 Projected percent changes in (**a**) Summer, and (**b**) Winter precipitation by 2080–2099 (USGCRP 2009)

Such extreme events often lead to flooding, which in turn leads to major water quality problems including sewer overflows. Nutrient concentrations during extreme flow events tend to be elevated due to the enhanced overland flow, which carries nutrients from agricultural and urban fertilizers directly into surface water bodies. This in turn can lead to problematic blooms of algae including harmful algal blooms that release toxins to surface water.

Significant changes are also projected in the seasonality of precipitation. By the end of the century, less precipitation is projected for most of North America during summers, as well as in the Southern States and Mexico during the winters, while Canada and Central to Northern states are projected to see more winter precipitation (Fig. 27.3, USGCRP 2009). This will have significant effects on snowpack, discussed later in this chapter.

Increases in the temperature of Earth's atmosphere are also linked to warming of the oceans. Warmer air and ocean water both increase evaporation from the oceans, causing the atmosphere to carry more moisture. There is a positive feedback between more moisture in the atmosphere and global warming, because water vapor is a significant greenhouse gas that traps heat in the atmosphere. More moisture in the atmosphere will likely lead to stronger storms in the future.

Evapotranspiration (evaporation plus transpiration from plants) will also be affected by changes in climate, but the direction of change is not as clear as other aspects of the hydrologic cycle. Increases in temperature alone would increase the potential evapotranspiration (PET); however, humidity of the air and amount of cloud cover will increase in many areas, reducing PET (Georgakakos et al. 2013; Roderick and Farquhar 2002). The impact of such complex relationships is not yet been fully quantified.

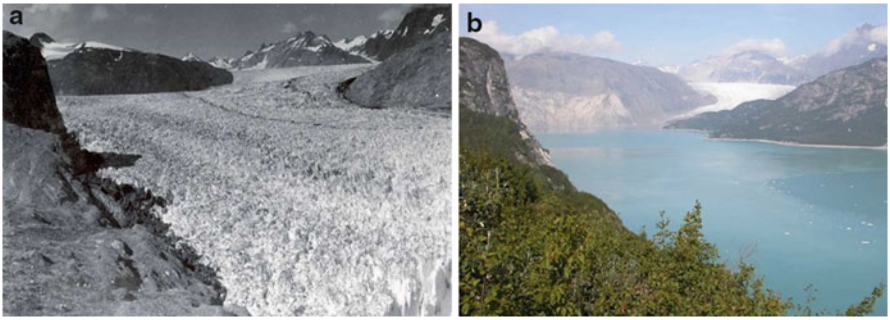

Fig. 27.4 Repeat photography in Muir Inlet, Glacier Bay National Park and Preserve, Alaska clearly shows the dramatic melting from (**a**) August 13, 1941 (W. O. Field, National Snow and Ice Data Center and Glacier Bay National Park), to (**b**) August 31, 2004 (USGS Photograph by Bruce F. Molnia)

Glaciers

Glaciers are rapidly shrinking as the climate warms, and this trend is expected to continue. The size of glaciers is controlled by the balance of new snowfall relative to the amount of melting snow and ice. A glacier could sustain a stable size if the annual melting and other losses were equivalent to the annual new snow supplied to the glacier. Increasing temperatures associated with climate change are increasing the melting rates, causing glaciers to recede to higher elevations (Fig. 27.4).

Glaciers are very important to hydrology, because they are important reservoirs of stored water, which supply rivers with water for downstream uses by humans and aquatic ecosystems. Faster melting rates in the short term increase streamflow relative to a long-term average; however, in the long term, there will be far less ice in many regions to serve as seasonal reservoirs for late season flows.

The Himalayan Mountain range is an important example where approximately 1.4 billion people get a portion of their water from seasonal melting of glaciers, including China and India (Immerzeel et al. 2010). More rapid melting in this region may portend a major water crisis for such regions that are already facing water shortages. Immerzeel et al. (2010) estimated that the average flow in the upstream portions of the Bramaputra, Ganges, Indus, and Yangtze rivers would decrease by approximately 19.6 %, 17.6 %, 8.4 %, and 5.2 %, respectively, despite projected increases in precipitation across the region. Their modeling results also indicate that there will likely be a significant shift to the seasonality of streamflow due to climate change.

Such dramatic shifts in streamflow will require significant adaptation strategies to avoid water and food crises. One approach is building major water engineering projects to store and transmit water to areas in need. The most significant example that is already being implemented is China’s South to North water transfer project.

Snow Cover and Stream Discharge

Snowpack in the Northern hemisphere is already on the decline as climate change is enhancing the rate of melting. There have already been significant changes observed including shifts of precipitation from snow to rain, less lake ice cover, and earlier melting of the snowpack (Fritze et al. 2011; Wang et al. 2012). The land surface area covered by snow was relatively stable until the late 1980s when it began to rapidly decline (Lemke et al. 2007).

Snowmelt provides over 50 % of the streamflow of many major rivers in regions such as western North America (Stewart et al. 2004). The trend of reduced snowpack is expected to continue due to increases in temperature linked to climate change (USGCRP 2009). Areas of the western USA have seen a shift of regime from snowmelt-dominant to rain-dominant discharge between 1948 and 2008 (Fritze et al. 2011). Permafrost is also warming and melting across many areas of the Arctic, with increases in active layer thickness and warming of deep permafrost layers (Romanvsky et al. 2010; Shiklomanov et al. 2010).

Surface water reservoirs capture the snowmelt in these regions and slowly release it to provide streamflow for the rest of the year. Significant change in the timing or amount of snowmelt is thus a major concern for regions such as California that have massive agricultural and municipal demands for this water. The shift of melting earlier in the year with warming increases the period of time between melt and the need for irrigation and urban uses. Changes in snowpack will also have consequences across vast areas with temperate climate. For example, most of the water that flows out of streams in Michigan is derived from groundwater and an important source of groundwater recharge is snowmelt (Jayawickreme and Hyndman 2007; Hyndman et al. 2007).

Most of the western USA is expected to have significant declines in snowpack (USGCRP 2009). Most stations in the western USA and Canada show significant declines, with the most dramatic changes observed from the Cascades range in western Washington and Oregon to the northern Sierra Nevada Range in California (Fig. 27.5; Mote 2009).

Climate change models project a nearly complete loss of snowpack for many of these regions by the end of the century (USGCRP 2000). If these models are correct, this will cause massive problems for aquatic ecosystems and humans that rely on this water for agriculture and urban activities.

Groundwater Recharge

Changes in temperatures, precipitation, and length of the growing season will likely have significant effects on groundwater recharge, which is the replenishment of groundwater from surface water and precipitation percolating through soils. This effect may be profound in mid-latitude regions that currently experience significant winter snowfall. In such regions, the bulk of the annual recharge often occurs during the spring snowmelt period when the evapotranspiration demand is low.

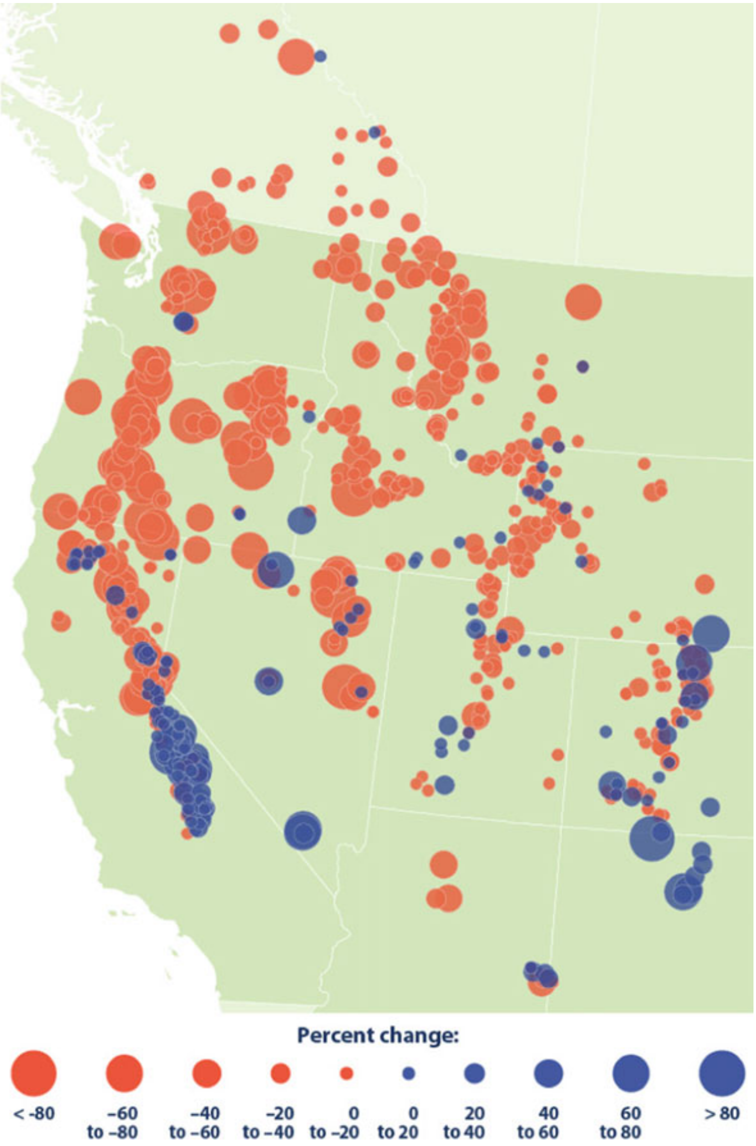

Fig. 27.5 Map of observed trends in snowpack in the western USA and Canada from 1950 to 2000 (Source EPA – Data from Mote 2009)

Groundwater provides a long-term water supply to vast areas of the world, as supplies are commonly available even during extended droughts unless long-term pumping has outstripped the recharge to aquifers. In addition to providing a reservoir of water supply for humans, groundwater provides the majority of streamflow during dry periods for many areas across the globe.

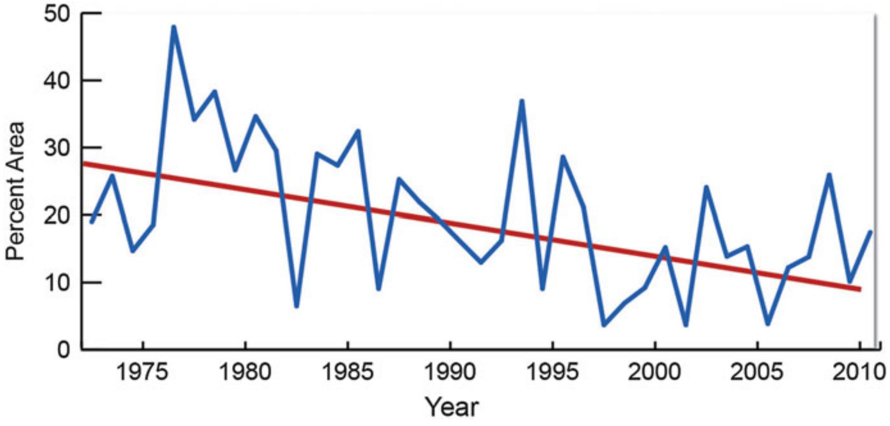

Fig. 27.6 Plot of Great Lakes Ice cover from 1973 to 2011 (Wang et al. 2012; Walsh and Wuebbles 2013)

Global warming associated with climate change will increase the length of the growing season and cause intermittent melting of snowpacks throughout the winter. Longer growing seasons will reduce recharge, as more of the available water will go to evapotranspiration earlier in the spring and later in the fall. Intermittent melting will also change the timing of recharge; the current seasonal cycle of snowpack building up and melting in the spring will transition into more small pulses of recharge in the winter. This is problematic as the current pulse of recharge in the spring sustains the late summer baseflow in streams across much of the northern portion of the USA and other northern latitude regions with significant glacial deposits. Earlier melting would thus likely reduce baseflows in such regions.

There has been limited predictive research on the impacts of climate change to groundwater (Hanson et al. 2012), because the models used to project changes in climate have simplified descriptions of hydrologic processes and commonly do not account for water below the root zone. With the importance of groundwater as a reservoir of water that is somewhat protected from contamination, understanding the linkages between changes in climate and groundwater is a critical area of research. This is especially true, because the reliance on groundwater for drinking water and irrigation is likely to increase as surface water supplies are reduced and more variable with changes in climate. Conjunctive use of groundwater and surface water is one adaptation strategy in regions that are facing water stress and increasing variability in streamflow, because water can be recharged to aquifers when streamflows are high and used later when streamflows are low.

Ice Cover and Surface Water Levels

The seasonal ice cover has decreased by 63 % in the Great Lakes since the 1970s (Fig. 27.6, Wang et al. 2012), which will likely lead to lower lake levels due to increased evaporation during the winter over areas of the lakes that used to have ice cover. Reductions in groundwater recharge discussed in the previous section would reduce streamflow that supplies lakes, likely causing reductions in lake levels, as well as stream and wetland levels. However, it is unclear how these factors will play out relative to each other as they respond to the projected increase in precipitation which would lead to water level increases, if all other factors remained the same.

Summary

Climate change will have significant effects on many aspects of the hydrologic cycle. The projected increase in temperatures associated with climate change, commonly called global warming, will alter the seasonal nature and amount of groundwater recharge, reduce lake ice cover, change seasonal snowpack dynamics, and increase the rate of glacial melting and retreat. Precipitation is projected to increase in areas that are generally wet, and decline in mid-latitude areas that are already dry. The variance of precipitation is also projected to increase, likely leading to more severe floods and droughts. The combined effects of changes in temperature and precipitation have not been well quantified as the General Circulation Models that are used for these climate change projections do not generally account for many aspects of hydrology. The changes in hydrology that will come along with climate change will require adaptation, especially in areas that are already dealing with significant water stress.

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