



A warmer world is, generally speaking, one where extremes in the water cycle are intensified. Dry regions become drier and wet regions become wetter. For the continental United States, the most commonly quoted estimate is that there was a seven to 15 percent increase in total accumulated rainfall during the 20th century, with the largest increases occurring in the eastern and central United States. Heavy (95th percentile) and very heavy (99th percentile) precipitation events became 14 and 20 percent more frequent respectively and accounted for the majority of the overall increase. Most of the regional and year to year variability witnessed during this period has been linked to fluctuations in sea-surface temperature gradients through cycles like the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation which control upper-atmospheric circulation and thus the relative strength and positions of storm tracks.

THE EAST

Despite the increase in heavy precipitation, there has been a lack of trends in high stream flows in the East because precipitation increases have been concentrated in the autumn months, when the region's streams are at their annual low points. Since the 1970s there has been a doubling during the warm season (period of the year when the mean daily temperature is persistently above 41 degrees Fahrenheit) of the frequency of 30-day periods when no rain falls. The region can roughly be divided into north and south.

The Southeast

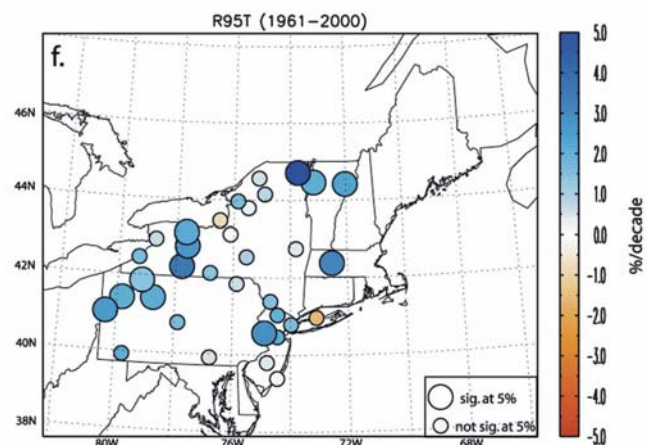
Since the 1970s, Georgia and the Carolinas have been receiving more wintertime precipitation on average than they did in earlier parts of the 20th century but less precipitation in late spring and early summer. Some other precipitation patterns in the southeast include:

- A strong increase in the number of winter storms along the Gulf Coast during El Niño phases of ENSO.
- The coastal southeastern U.S. receives between eight and 17 percent of its total annual rainfall in the form of tropical cyclone precipitation. Atlantic tropical cyclone frequency has been increasing since the mid-1970s. Also, positive phases of the Atlantic Multidecadal Oscillation (AMO), or the periodic shift in North Atlantic sea surface temperatures between positive (warm) and negative (cool) phases, mean there is less vertical wind shear over the tropical Atlantic Ocean, resulting in more cyclone formation there. The AMO entered a predominately positive phase in about 1995, where it is likely to stay for several decades.

The Northeast

The Northeast is the region in the continental United States that exhibits the least amount of precipitation seasonality, and there do not appear to be trends towards increased seasonality there. Some trends specific to the Northeast include:

- Despite an overall lack of trends in high stream flows since 1970, there has been an increase in the intensity of floods when they occur. This increase corresponds to a shift in the Northern Annular Mode from predominately negative to predominately positive phases, which has worked to keep winters in the Northeast wet and mild, leading to more snowpack and earlier spring snowmelt.
- With more wintertime precipitation falling as rain instead of snow, the date of peak streamflow (which occurs as the snow melts) is now arriving 2.5 days earlier than it did in the 1950s.



Above: Stations in the northeastern U.S. reporting increased “very wet” days, or days exceeding the 95th percentile for precipitation. The stations with large circles exhibited trends significant at five percent. Image courtesy of AMS (Griffiths, 2007)

THE UPPER MIDWEST/GREAT LAKES

Half of the upper Midwest's total annual rainfall occurs during the summer months. The warm season in the upper-Midwest has featured the sharpest trend in increasing precipitation, meaning that the wet season is becoming wetter. The dry season has become wetter to a much lesser extent. The Pacific North American Pattern (PNA), a periodic (30 year) shift in the strength and positions of high and low pressure centers covering the North Pacific and western North America, strongly affects winter rainfall in the upper Midwest by regulating the strength of the dry, continental air masses from Alberta that can dominate the region. Positive PNA phases allow these air masses to strengthen, keeping the region dry. Negative PNA phases weaken the influence of these air masses, allowing warm moist air from the Gulf of Mexico to make its way to the region, leading to above average rainfall. For more information on the PNA, visit: <http://www.cpc.ncep.noaa.gov/data/teledoc/pna.shtml>.

THE GREAT PLAINS

The Great Plains witnessed a shift over the 20th century to relatively more rain in March and April and relatively less in May and June, and since the 1970s, there has been an overall trend of increased annual precipitation. The increase has generally been less pronounced in the sections closer to the Rockies, which are farther away from the heat and moisture transport of the Gulf Stream.

THE WEST

Because 75 percent of the West's water supply ultimately comes from snowmelt, the proportion of snow to overall annual precipitation may be the biggest determining factor for the region's water security. More precipitation falling as rain instead of snow during the late winter/early spring makes spring floods more likely and means that more water must be discharged to the ocean instead of stored in dams – leading to lower summer flows, warm season water scarcity and warmer water temperatures which imperil the region's cold-water salmonoid fisheries. Across the West, there has been an 11 percent decline in overall snowpack over the last 50 years and the average day of year when snowpack and rivers reach their peak is now arriving 10-40 days earlier than it did in the 1950s.

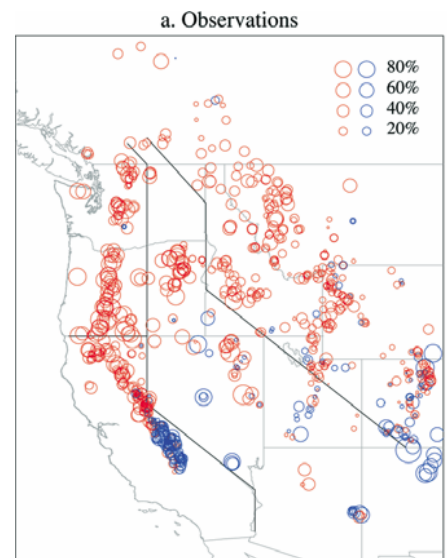
Cool water temperatures off America's west coast work to drive winds from the Canadian interior into the West, as opposed to from the Pacific Ocean, making the Intermountain West drier. The opposite trend happens during periods when the water temperatures are warmer. These water temperatures fluctuate on a period of 50-60 years, a phenomenon known as the Pacific Decadal Oscillation (PDO). Also, the West as a whole is drier during positive phases of the AMO and tree ring records going back 500 years indicate that the entire region consistently experiences more wildfires during positive phases as opposed to negative phases. Since the 1980s, there has been a decrease in the frequency of August to October mid-latitude cyclones that move across the region. These cyclones have traditionally helped to end the fire season by bringing rainfall to the region, and the decline in their frequency has corresponded to a lengthening of the fire season by 78 days.

Southwest

In contrast to the eastern United States, California's Mediterranean climate demonstrates extreme seasonality in rainfall, with wet winters and dry summers. About half of California's annual precipitation has fallen by the end of March, although over the 20th century there was a slight increase in late spring precipitation. In both California and Nevada, snow is now melting about 19 days earlier than it did in the 1950s. In the Four Corners region, while things have warmed, the trend in greater winter precipitation has led to a significant increase in snow cover and the date when there ceases to be snow on the ground now arrives nine days later in the year, simply because there is more snow to melt.

Pacific Northwest

Since the middle of the 20th century in the Pacific Northwest, the annual proportion of precipitation falling as snow has been declining at a rate of 8.62 percent per decade, the most rapid decline in the country. This has been accompanied by a nine percent decline in the average extent of March snow cover, and the date when there ceases to be snow on the ground is now arriving an average of 16 days earlier. Winter rainfall in the Pacific Northwest has essentially the opposite response to ENSO phases as the Southwest does. La Niña phases work to deflect the storm track poleward, putting it over the Pacific Northwest during winter. During El Niño phases, the storm track runs over the southwest, missing the Pacific Northwest and causing drier winters there.



Above: 1950 – 1997 trends in snow water equivalent (the water content of the snowpack) for April 1. Red circles indicate negative trends, blue circles indicate positive trends. Image courtesy of AMS (Mote, 2004)

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