

that same interval are less clear in other regions because of limited data, regions of Southeast Asia and southern South America have likely experienced increases in heavy precipitation as well. Other areas have seen greater drought, notably southern Australia and the southwestern United States.

A warmer atmosphere holds more water vapor; specifically, there is 6–7.5% more water vapor per degree (Celsius) of warming in the lower atmosphere. For areas that have traditionally had more precipitation on average, warming tends to promote heavier precipitation events. In contrast, in regions prone to drought, warming tends to result in greater periods between rainfalls and in the risk of drought.

HURRICANES

The world's oceans have absorbed 90% of the excess heat that greenhouse gases have kept in Earth's atmosphere since the 1960s. Ocean heat provides energy for hurricanes, and warmer years tend to have greater hurricane activity. Atlantic hurricanes are the best studied and have the most data available. An analysis of satellite observations from 1983 to 2005 has shown a trend toward increasing severity—albeit decreasing frequency—of Atlantic hurricanes. Modeling of future tropical cyclones suggests that their intensity may increase 2–11% by 2100 and that the average storm will bring 20% more rainfall.

SEA LEVEL RISE

Between 1901 and 2010, the global sea level rose ~200 mm, or ~1.7 mm per year on average. From 1993 to 2010, the rate of rise nearly doubled—i.e., to 3.2 mm annually. Most of this sea level rise has resulted from the thermal expansion of water. Glacial ice melt is the second greatest factor, and its contribution is accelerating. By 2100, global sea level may rise by ≥ 500 mm from 1986–2005 levels, with an annual rate of rise of 8–16 mm at the century's end. A large section of the West Antarctic ice sheet has begun to fall apart, and its melting alone may cause sea level to rise by ≥ 3 m in coming centuries.

Sea level rise is not uniform. The rate of rise on the eastern seaboard of North America has been roughly double the global rate. Compounding sea level rise is the subsidence of coastal areas due to human settlement. In the absence of levee upgrades, an estimated 170 million people living near coasts worldwide will be at risk of flooding in 2100 because of the combined effects of subsidence, erosion, and sea level rise.

Along with extreme storms and overuse of coastal aquifers, rising seas also contribute to salinization of coastal groundwater. About 1 billion people rely on coastal aquifers for potable water.

EL NIÑO SOUTHERN OSCILLATION

The *El Niño Southern Oscillation* (ENSO) refers to periodic changes in water temperature in the eastern Pacific Ocean that occur roughly every 5 years. ENSO cycles have dramatic effects on weather around the globe. Warmer-than-average water temperatures in the eastern Pacific define *El Niño* events (see below), whereas cooler-than-average water temperatures define *La Niña* periods. Evidence is accruing that climate change may be increasing the frequency and severity of *El Niño* events.

El Niño events drive alterations in weather worldwide (Fig. 151e-4) and are associated with extreme events and consequently higher rates of morbidity and mortality. Hurricane Mitch, one of the most powerful hurricanes ever observed, with winds reaching 290 km/h, dropped 1–1.8 m (3–6 feet) of rain over 72 h on parts of Honduras and Nicaragua. As a result of this storm, 11,000 people died and 2.7 million were displaced. Outbreaks of cholera, leptospirosis, and dengue occurred in the storm's aftermath.

POPULATION MIGRATION AND CONFLICT

The final common outcome of all climate change effects is population migration. Sea level rise, extreme heat and precipitation, droughts, and salinization of water supplies all conspire to make regions (including some inhabited by humans for millennia) uninhabitable. Among climate change migrants in the near future may be the inhabitants of low-lying South Pacific islands that are vulnerable to sea level rise and residents of the Alaskan archipelago, where melting of permafrost has rendered traditional means of cold food storage difficult.

Climate change may also be contributing to humanitarian crises and conflicts. A severe 2011 drought in East Africa may have incited the Somali famine that resulted in 1 million refugees; mortality rates reached 7.4/10,000 in some refugee camps. Crop losses associated with the 2010

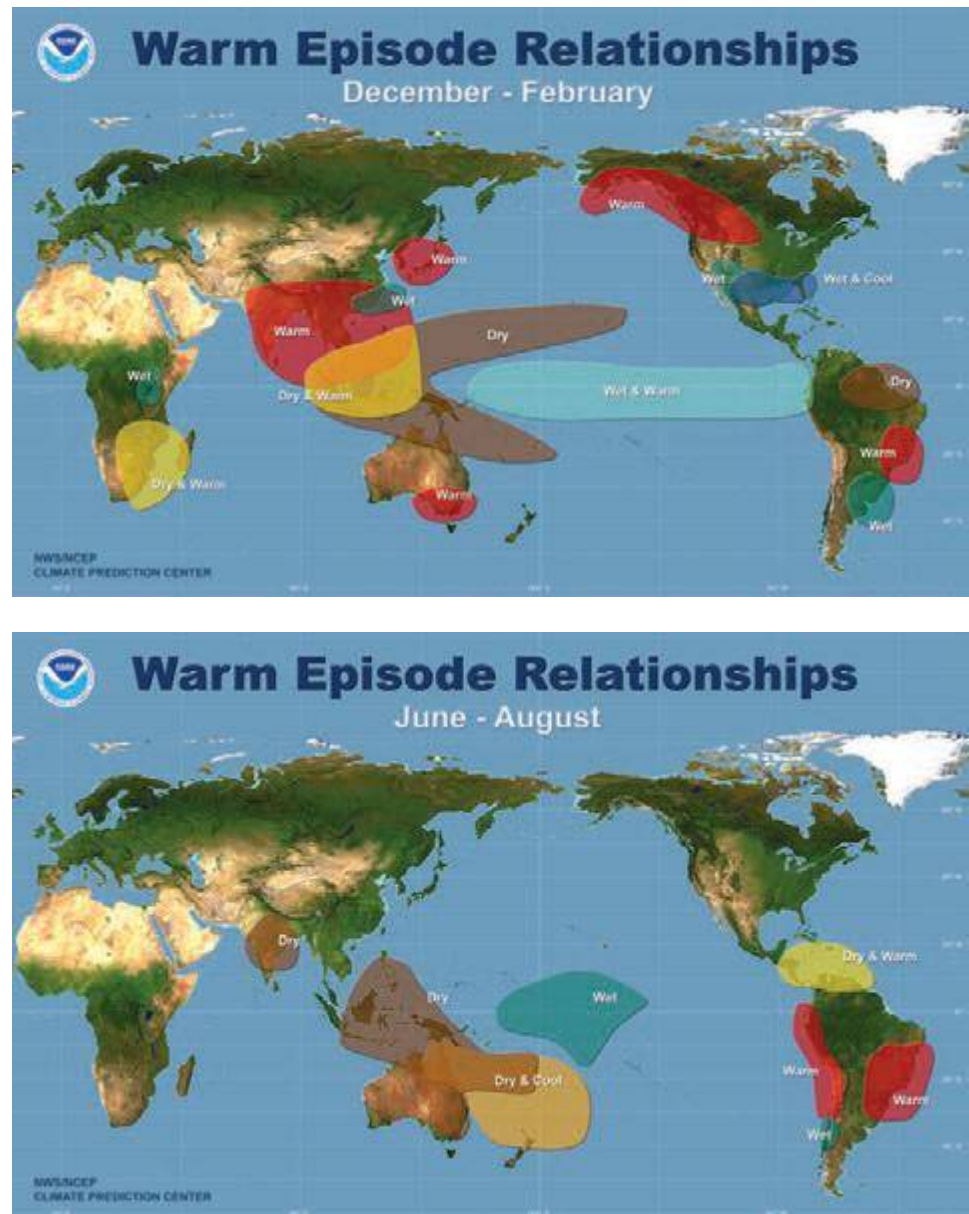


FIGURE 151e-4 Characteristic weather anomalies, by season, during *El Niño* events. (Source: www.cpc.ncep.noaa.gov/products/precip/CWlink/ENSO/ENSO-Global-Impacts/High-Resolution/.)