Evidence #1: Since 1950, Earth's atmosphere and oceans have changed. The amount of carbon released to the atmosphere has risen. Dissolved carbon in the ocean has also risen. More carbon has increased ocean acidity and coral bleaching.

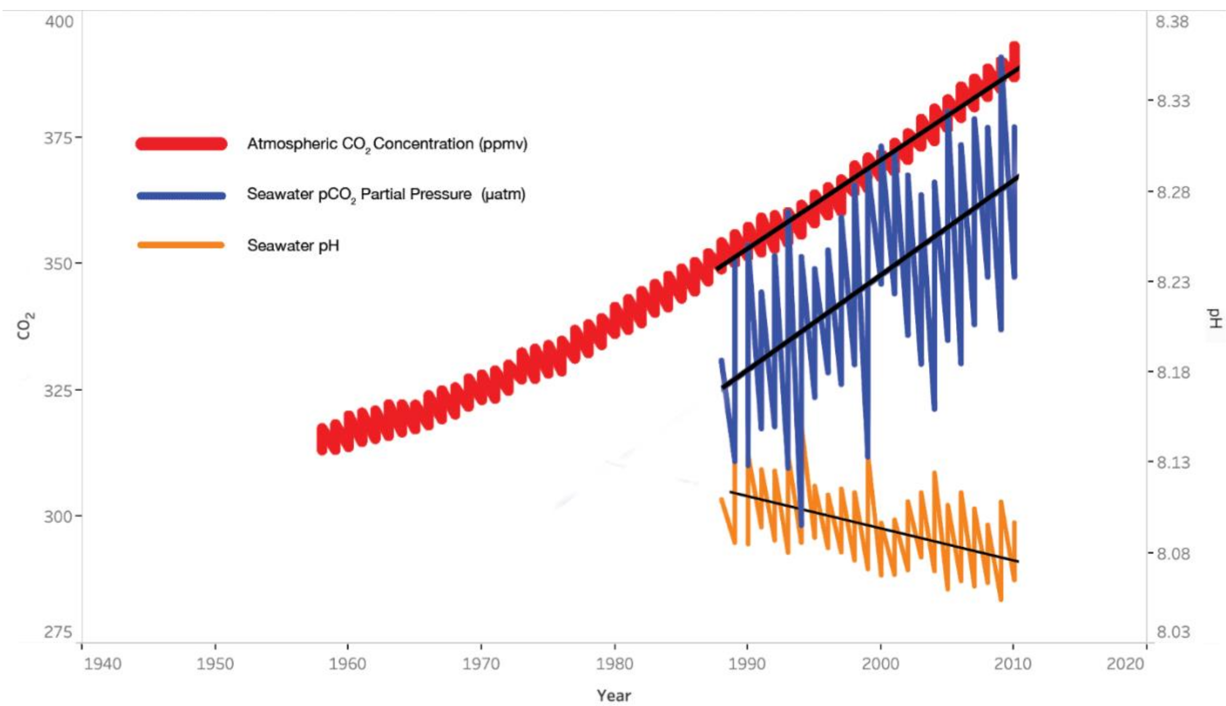

Figure 1. Carbon dioxide time series in the North Pacific Ocean. Credit: Wright Seneres based on NOAA data.

Figure 1 shows the amount of carbon dioxide in the air and ocean. In the figure, the symbol CO_2 stands for carbon dioxide. The red line show that atmospheric CO_2 (or CO_2 in the air) has been increasing. This increase is about 18% over 50 years. The blue line shows that seawater CO_2 (ocean CO_2) has also been increasing. The orange line shows that seawater pH has been decreasing, which means the oceans are more acidic.

Algae dies in acidic waters. Algae is plant-like and often exists with coral. Coral is an ocean animal and needs algae to be strong. Coral turns white (bleaches) when it weakens.

Corals can form living reefs that exist just under the ocean surface. Some of the reefs can act as barriers. These barriers buffer shores from waves, storms, and floods. When coral reefs weaken, they are not strong barriers. Coral reefs also provide shelter for many marine organisms.

Evidence #2: From 1910 to 1995, record rainfall events increased across the United States. Over the same time period, there was a sharp increase in the amount of carbon released to the air. Much of this carbon comes from fossil fuel use.

Figure 1. Global carbon emissions from fossil fuels from 1900 to 2014. Credit: Wright Seneres based on Boden et al. (2017).

Fossil fuels include coal, oil, and natural gas. When humans burn fossil fuels, carbon is emitted into the air. The blue line in Figure 1 shows the total amount of carbon released to the air from human activities over the past 100+ years.

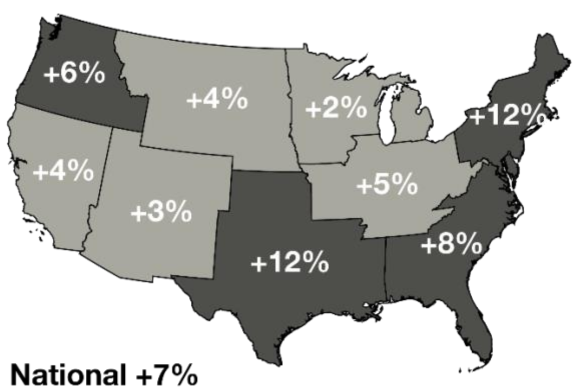

Figure 2. Trends in extreme 1-day precipitation events in the US. Credit: Wright Seneres based on Karl & Knight (1998).

Figure 2 shows that the amount of rain from extreme events (highest 1-day rain events in a year) has increased over the entire US. This increase has been over about the same 100-year period as increasing carbon emissions.

Evidence #3: Ocean sea surface temperatures have increased since about 1970. In the North Atlantic, tropical storm power has also increased over this same time period. A storm's power depends on its strength and how long it lasts.

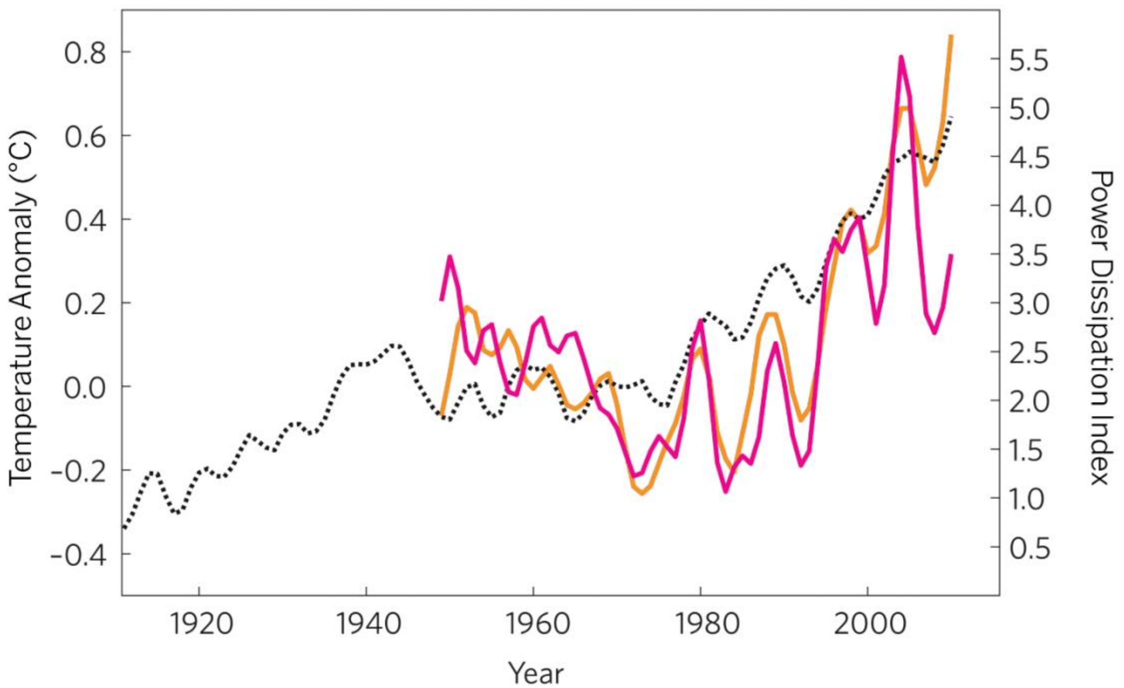

Figure 1. Relations between Atlantic tropical storm cumulative annual intensity and Atlantic sea-surface temperatures. Credit: Wright Seneres based on Coumou & Rahmstorf (2012).

Tropical storms form over oceans. The solid orange line in Figure 1 shows ocean temperature anomalies in the Atlantic. Anomalies are things that differ from the "normal" or average conditions. "0" on the left axis represents that average. It is the long-term global average ocean temperature between 1910 and 2010 in the Atlantic. The solid orange line shows that ocean temperatures have increased since 1970. The dotted line shows land and ocean temperatures combined are also increasing over time.

The solid red line in Figure 1 shows the power dissipation index (PDI) for tropical cyclones in the Atlantic. The PDI measures the amount of energy storms release. The PDI of a storm depends on its strength, how long it lasts, and how often it occurs. It reflects the total destructive power in all tropical cyclones for a year. The PDI has been also been increasing since about 1970.

Evidence #4: Since 2000, there have been more intense, extreme, weather events around the world. Record rainfall fell in Europe. The southeastern United States had the most active month of tornadoes. The decade from 2000 to 2010 was the warmest ever during the past 1000 years.

Year	Region	Record-breaking event	Impacts
2000	England and Wales	Wettest autumn on record since 1766	$2 billion in damages
2002	Central Europe	Highest daily rainfall record in Germany since 1901	Flooding of Prague and Dresden, with about $15 billion in damages
2003	Europe	Hottest summer in 500 years	Death toll exceeding 70,000
2004	South Atlantic	First hurricane in the South Atlantic since 1970	Three deaths, with about $425 million in damages
2005	North Atlantic	Record number of hurricanes since 1970	Costliest US natural disaster, 1,836 deaths (Hurricane Katrina)
2007	Arabian Sea	Strongest tropical cyclone in the Arabian Sea since 1970	Biggest natural disaster in the history of Oman
2007	England and Wales	May–July wettest since records began in 1766	Major flooding causing about $4 billion in damages
2007	Southern Europe	Hottest summer on record in Greece since 1891	Devastating wildfires
2009	Victoria (Australia)	Heatwave breaking many temperature records	Worst bushfires on record, 173 deaths & 3,500 houses destroyed
2010	Western Russia	Hottest summer since 1500	500 wildfires around Moscow, with 30% losses in grain harvest
2010	Pakistan	Rainfall records	Worst flooding in Pakistan's history, nearly 3,000 deaths, affected 20 million people
2010	Eastern Australia	Highest December rainfall recorded since 1900	Brisbane flooding in January 2011 cost 23 lives and an estimated $2.55 billion in damages
2011	Southern US	Most active tornado month on record (April) since 1950.	Tornado hit Joplin, MO, causing 116 deaths
2011	Texas, Oklahoma	Most extreme July heat and drought since 1880	French grain harvest down by 12%
2011	Western Europe	Hottest and driest spring on record in France since 1880	73 deaths, 20 missing, severe damage
2011	Republic of Korea	Wettest summer on record since 1908	Flooding of Seoul, 49 deaths, 77 missing, 125,000 affected

Table 1. Record-breaking weather events - worldwide between 2000 and 2011. Adapted from Coumou & Rahmstorf (2012).

Table 1 shows extreme weather events from 2000 to 2011.

Evidence #5: Frequency and size of large wildfires have increased in the Western U.S. since 1970. Average spring and summer temperatures have also risen in the Western U.S. during this time.

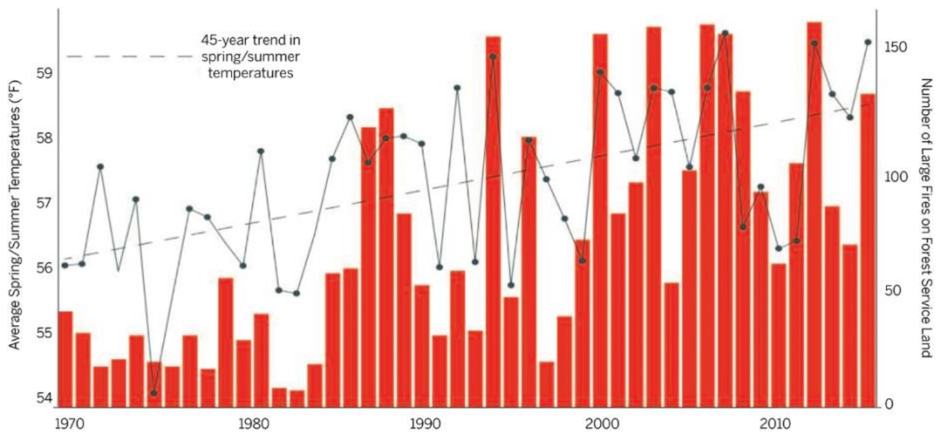

Figure 1. Average annual temperatures overlaid with number of large fires (≥ 1000 acres). Credit: Wright Seneres based on Kenward et al. (2016).

The bars in Figure 1 show the annual number of large fires on U.S. Forest Service land. Most of this land is in the Western U.S. The solid line shows the average spring and summer temperatures on these lands for each year. The dotted line shows an upward trend in these temperatures.

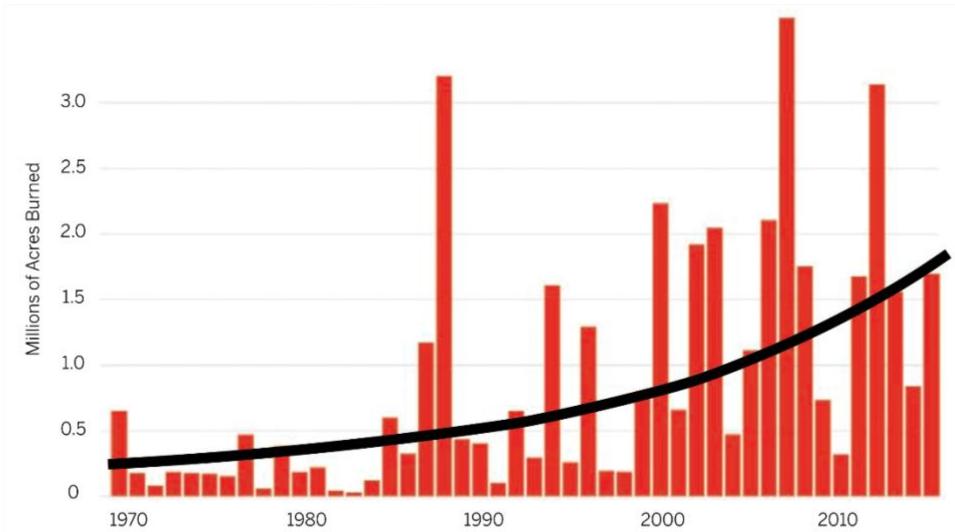

Figure 2. Millions of acres burned by large wildfires. Credit: Wright Seneres based on Kenward et al. (2016).

In Figure 2, the red bars show how many millions of acres have burned each year. The black line in Figure 2 shows the increasing trend of acres burned.

Evidence #6: In the last 100 years, global temperatures have increased. In that same time period, heavy precipitation events have also increased.

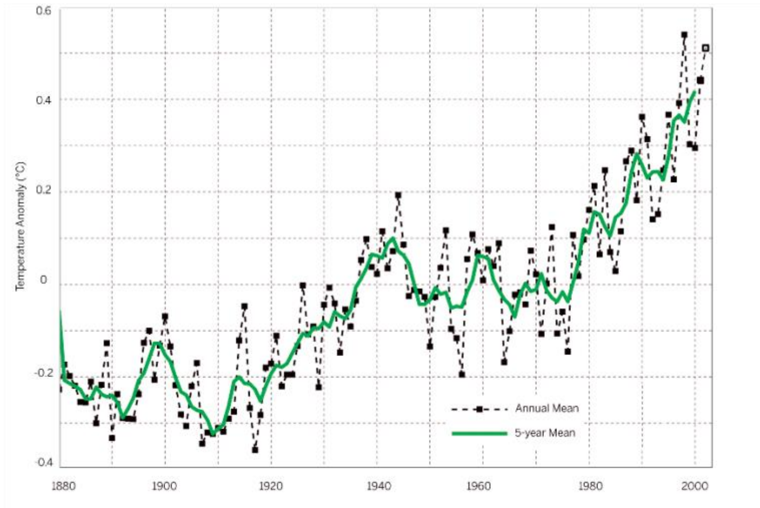

Figure 1. Trend of global annual surface temperature. Credit: Wright Seneres based on NASA data.

The black dotted line in Figure 1 shows annual, average, global temperature anomalies. Anomalies are things that differ from the "normal" or average conditions. "0" on the left axis represents that average. It is the long-term, global, average, temperature between 1951 and 1980. The black dotted line shows that global temperatures have increased since 1951.

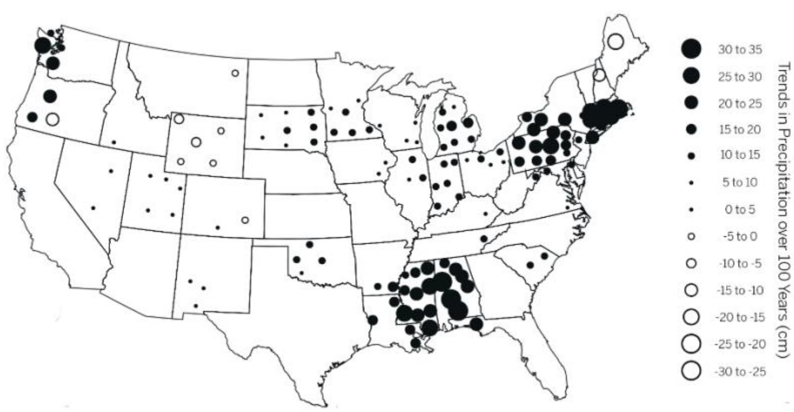

Figure 2. Trends per 100 years for precipitation (cm). Shaded circles represent an increase. Unshaded circles represent a decrease. Credit: Wright Seneres based on Grundstein (2009).

Figure 2 shows changes in precipitation patterns across the U.S. Shaded circles show the amount that has increased over 100 years. This occurred in most parts of the U.S. Unshaded circles show the amount that has decreased over 100 years. This occurred mainly in the Rocky Mountain region.

Evidence #7: Arctic Ocean sea ice extent has declined, with the Arctic warming at a pace two to three times the planet's average. Over the last decade, record cold temperatures and snowfall have occurred in Europe and Asia.

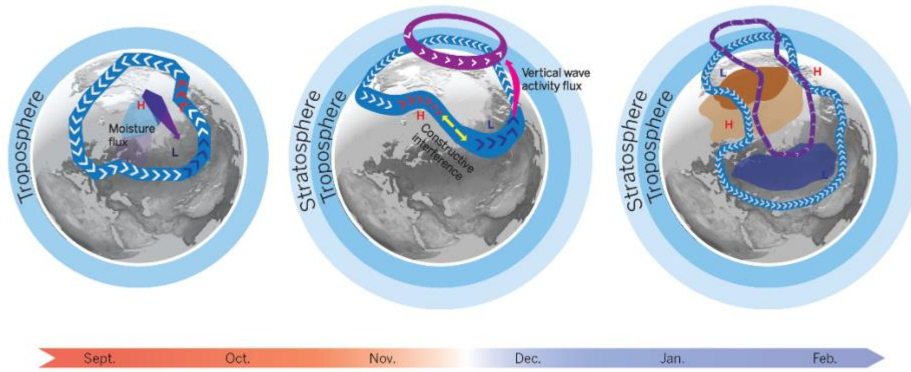

Figure 1. Relations between decreasing sea ice and increasing snow cover in Europe and Asia. Credit: Wright Seneres based on Cohen et al. (2014).

Figure 1 shows relations between Arctic sea ice loss and weather patterns in the Northern Hemisphere. In the late summer and early winter, moisture from melting sea ice shifts the tropospheric jet stream (blue band with arrows). Energy is transferred up higher in the atmosphere. This creates a stratospheric polar vortex (purple band with arrows). This polar vortex allows cold air to move from the Arctic into Europe and Asia (blue shaded region on right image). At the same time, the Arctic is warmer in the winter (brown shaded region on right image).

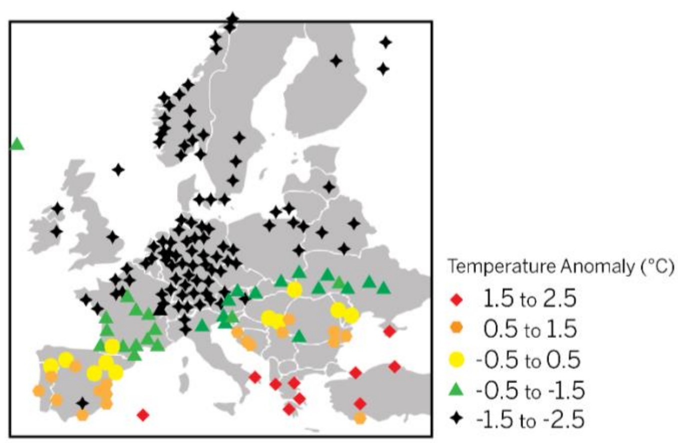

Figure 2. European temperature anomalies in winter 2010. Credit: Wright Seneres based on Cattiaux et al. (2010).

Figure 2 above shows temperature anomalies in Europe during winter 2010. Anomalies are things that differ from the "normal" or average conditions.

Evidence #8: Earth's orbit is elliptical. But, the shape of the ellipse is almost a perfect circle. In the Northern Hemisphere, Earth is slightly closer to the Sun in winter than in summer.

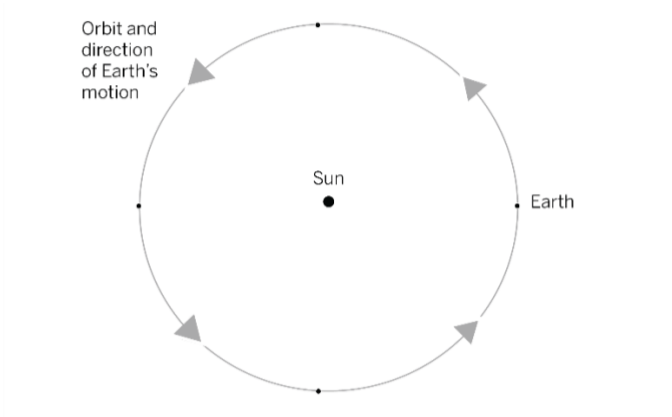

Figure 1. Earth's orbit around the Sun. Credit: Wright Seneres

Figure 1 shows the shape of Earth's orbit around the Sun. This view is looking directly down on the Sun and Earth from above the North Pole. Although the orbit is elliptical, the eccentricity is very small. This means that the orbit is almost a perfect circle, but not exactly. Because Earth's path is not perfectly circular, the amount of energy received from the Sun varies by about 3.5% during the year. The date when Earth is closest to the Sun shifts slightly over time. Currently, Earth is closest to the Sun in the middle of the Northern Hemisphere winter.

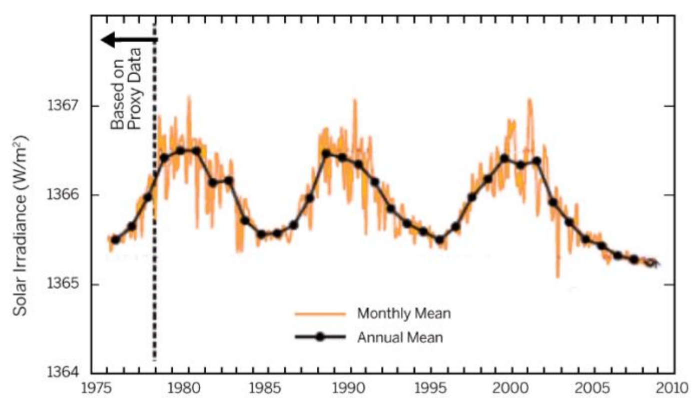

Figure 2. Total solar irradiance as observed directly by satellites. Credit: Wright Seneres based on NASA data.

Energy received from the Sun is called solar irradiance. Figure 2 shows changes in solar irradiance. The orange line shows monthly solar irradiance. The black line shows the smoothed average. The irradiance depends some on Earth's orbital position.