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Long-term climate change

1.1 WEATHER AND CLIMATE

The surface of the Earth is a three-dimensional system that is dominated by water that can exist in three phases: solid, liquid, and vapor. At any point in the evolution of the Earth’s climate, randomly varying factors such as winds, ocean currents, air masses, cloud formation, volcanic eruption, the spinning of the Earth, and other factors produce daily, monthly, and yearly fluctuations in the weather in various regions. If we average out these fluctuations over the whole Earth over a period of time, we can attempt to attribute a climate to the Earth over that time period. There is no universally accepted procedure for doing this.

First of all, it is not clear \textit{a priori} how long a duration is required to define a climate. Some books claim that an average of weather over 30 years is adequate, but this is rather arbitrary. There is some evidence that there might be multi-decade cycles within a basically stable climate, so it would be safer to use a century as the duration to define a climate. The yearly variations in weather are typically so large that it is very difficult to define a long-term average with only a few decades of weather data.

Lovejoy (2013) argued that the long-term average of weather is what he calls “macroweather”. He concluded: “True climate processes only emerge from macroweather at even longer times, and this thanks to new slow internal climate processes coupled with external forcings.” While there is no specific timescale for identifying climate, the implication is that it is usually longer than a century.

Secondly, it is not clear \textit{a priori} how to define the climate. Is it the average temperature of the air near the Earth’s surface for all locations on the Earth? What about tropospheric temperatures? And what about the oceans? How does the temperature profile of the oceans vs. depth enter into climate? Other factors that might enter into defining the climate include precipitation patterns, temperature extremes, degree of glaciation, and prevalence of intense storms.

It is fairly common for climatologists to define climate as the average temperature of the Earth near the surface. This introduces various problems. One problem is inadequate coverage by measurement stations. Another is the question of
how to average in ocean temperatures, noting that oceans cover about 70% of the Earth’s surface.

1.2 TIMESCALES TO CHARACTERIZE CLIMATE

Climatologists have attempted to characterize the Earth’s climate over many time periods, as discussed below.

Temperatures over the last decade: The Argo system to monitor world ocean temperatures was installed.

Temperatures over the past three decades: Use of satellite observations to infer global tropospheric temperatures.

Temperatures over the past ~ 120 years: Several groups have combined results from a worldwide network of land measurement stations plus sea-surface temperatures (SSTs) from ships to infer global average temperatures since about 1880 or 1890.

Temperatures over the past ~ 210 years: The so-called “BEST” group led by Richard Muller combined results from a worldwide network of land measurement stations to infer global average land temperatures since about 1800.

Temperatures over the past ~ 2,000 years: A number of groups have attempted to use “proxies”1 to estimate historical temperatures at various locations, and combine these into an estimate of global average temperatures over two millennia. Unfortunately, the number of proxies drops sharply as one goes back in time, and the spatial coverage leaves much to be desired. The veracity of many proxies is also suspect.

Temperatures over the past ~ 400,000 years: Ice cores drilled into the Greenland ice sheet reveal $^{18}$O/$^{16}$O ratios that can be used to infer temperatures near Greenland dating back as far as 400,000 years.

Temperatures over the past ~ 800,000 years: Ice cores drilled into the Antarctica ice sheet reveal $^{18}$O/$^{16}$O ratios that can be used to infer temperatures near Antarctica dating back as far as 800,000 years.

Temperatures over millions of years: $^{18}$O/$^{16}$O ratios in ocean sediments have been used to estimate global temperatures over millions of years.

Temperatures over hundreds of millions of years: Geological evidence in terms of fossil flora and fauna indicate the levels of global climate dating back as far as 500 million years or more. The data suggest that the Earth has gone through rather wide swings in climate over hundreds of millions of years, as shown in Figure 1.1.

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1 In the context of historical temperatures, proxies are residual data from processes that occurred in the past, when the processes were dependent on local temperatures at the times they took place, and the evidence is preserved in the present in an accessible form. In all cases, extraction of implied past temperature data from confounding influences requires considerable analysis and manipulation. Some prominent proxies include: tree rings (width, density, stable isotope composition), ice cores (oxygen isotope ratios, gas content in bubbles), ocean sediments (isotope ratios), pollen, boreholes, and corals.