A Climate Primer

The overall consensus among climate scientists worldwide is that the Earth's climate has changed substantially over the last century and will continue to change in the coming decades as a result of increasing greenhouse gas emissions associated with human activities. The impacts of a changing climate are being observed throughout the world: global temperatures are increasing, mountain snowpack is declining, mountain glaciers have receded dramatically (Figure 1), habitats and species' ranges are shifting, and sea level is rising (IPCC 2007). In the Pacific Northwest, average annual temperature increased about 1.5°F (1920-2000) (Mote 2003), snowpack in the Washington Cascades declined about 25% (averaged across all elevations) during the 20th century (Mote et al., 2008)\(^1\), glaciers in the Cascades and Olympics are receding, and the timing of peak spring snowmelt shifted up to 20 days earlier in much of the Pacific Northwest between 1948 and 2002 (Stewart et al. 2005). Similar changes have been observed within the Skagit basin and adjacent areas. For instance, average annual temperature at Sedro Woolley increased 1.6°F (1895-2010), mean sea level at Friday Harbor increased by four inches (1934-2006), and the nearly 400 active glaciers in the North Cascades have lost an estimated 50% of glacial mass since the start of the 20th century (Granshaw 2002).

\(^1\) Trends in Washington Cascades April 1 snowpack through 2006 vary depending on the starting year. This analysis looked at trends for periods ranging from 1916-2006 through as late as 1970-2006. The decline in April 1 snowpack during these periods of analysis range from roughly –15% to –35%, with most averaging around –25%.

Figure 1: Cumulative specific mass balances of glaciers and ice caps since 1960, calculated for several large regions globally. Negative values show decreasing mass of glaciers. (Source: Kaser et al., 2006)
As Skagit Basin communities look to the future, it is helpful to understand how weather and climate differ and how scientists project future changes in climate. This paper provides basic background information on these topics and a brief summary of some important global impacts.

The Meaning of Words: Weather, Climate, Climate Variability, and Climate Change

The Skagit Valley’s environment, economy, and communities have been shaped over time by weather and climate. We can think of weather as a snapshot of conditions, such as amount of cloudiness or sunshine, temperature, or wind direction, at a specific location (e.g. Mount Vernon) and point in time (typically minutes to perhaps a few weeks). Climate, on the other hand, is the statistics of weather conditions over longer time periods, ranging from years to centuries. For example, while the weather forecast for Mount Vernon on August 30, 2011, was for a high of 69°F, the average high for that day (the climate “normal” based on 30 years of record) is 73°F.

In any given season, year, or decade, natural variations in ocean temperatures, winds, and other factors may cause climate to deviate from average for that time period. Two important cycles of natural climate variability affecting the Pacific Northwest are the El Niño/Southern Oscillation and the Pacific Decadal Oscillation. The El Niño/Southern Oscillation is more commonly known as El Niño (the warm phase) and La Niña (the cold phase), with each phase typically lasting six to 18 months. The Pacific Decadal Oscillation also has a warm and cool phase, but these phases generally tend to last (with some annual variation) for 20 to 30 years. Warm phases of either cycle increase the odds for warmer, drier winters with below average snowpack and streamflows. Cool phases are associated with cooler, wetter winters and above average snowpack and streamflows. For example, the winter and spring of 2011, which saw precipitation in the North Cascades at 123% of average (compared to 1970-1999) and exceptionally high snowpack throughout the Cascades late into the spring (NRCS 2011), was a La Niña and a cold phase Pacific Decadal Oscillation year. Neutral phases of both cycles have about equal odds for above and below average winter conditions in the Pacific Northwest.

Unlike natural climate variability, present day2 climate change is recognized as

2 Earth’s geologic history includes past changes in climate brought on by regular variations in the Earth’s orbit around the sun, explosive volcanic eruptions, and changes in the energy output from the sun, among other factors. Research has shown that these natural causes, or “forcings”, have had very small influence (in the case of volcanic activity and solar energy output) to no influence (in the case of orbital variations) on observed trends in 20th century average temperature, and that human activities are responsible for most of the warming observed over the past 50 years. See IPCC 2007 FAQ 2.1 and 6.1, http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-2-1.html.
being caused by human activities that emit heat-trapping gases such as carbon dioxide, methane, and nitrous oxide into the atmosphere. Since the start of the Industrial Revolution around 1750, the atmospheric concentration of carbon dioxide, methane, and nitrous oxide have increased 35%, 142%, and 18%, respectively (Figure 3) (IPCC 2007). Long-term natural climate archives like ice cores have shown us that these changes are enormous by geologic standards. (Ice cores provide pockets of air that remain undisturbed for hundreds of thousands of years and can be sampled by scientists to study past climates.) For example, analysis of Antarctic ice cores has helped scientists determine that the current concentrations of carbon dioxide and methane in the atmosphere far exceed the natural range of these gases over the last 650,000 years (Jansen et al. 2007).

As greenhouse gases have increased, global temperature has increased. Between 1906 and 2006, average annual global temperature increased 1.3°F (range: 1.0°F to 1.7°F) (IPCC 2007). Most of the warming observed since the 1950s has been substantially and directly influenced by human activities such as the burning of fossil fuels. The modeling experiments that form the basis for this conclusion are shown in Figure 4. If the effects of both natural

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Figure 3: Long-term changes in three important greenhouse gases from ice core measurements and atmospheric samples. (Figure source: IPCC 2007)
changes that influence global temperatures, such as variations in solar radiation and the emissions from volcanoes, are combined with human caused increases in greenhouse gases the models reproduce the observed global warming in the late 20th century quite accurately (Figure 4, top panel). If human caused greenhouse gases are left out of the simulations, the globe cools slightly over the same period due to the natural variations (Figure 4, bottom panel), which is fundamentally at odds with the observed temperature trends. Changes at the regional scale in different areas of the globe are not as clearly delineated in the model simulations, but observed temperature trends in the Pacific Northwest have tended to track global trends fairly closely from decade to decade, suggesting a close correspondence between global and regional temperatures in the future as well.

Climate variability and climate change are occurring simultaneously, but operating over different timescales. This distinction is important when thinking about how we will experience climate change and its related impacts. Natural variability will continue to bring relatively cold and warm years (and cold and warm decades) to the Pacific Northwest even as climate change increases the overall average temperature. This means, for example, that we will continue to see colder than average years (such as the La Niña winter and spring of 2010-2011) and warmer than average years even as the baseline of average global and regional temperatures increases over longer timescales. Likewise, regional precipitation is expected to continue to vary from year to year and decade to decade due to natural variability.
Projecting Future Climate

Understanding how climate may change in the coming decades is critical to knowing if, when, and where it may be necessary to prepare for climate change impacts. Climate models and the use of climate reconstructions from the fossil and geological record are two essential tools for projecting climate change. Climate models are mathematical representations of the Earth’s physical, chemical, and biological properties and their interactions, all of which contribute to the climate we observe. Climate models project global climate trends on very large spatial scales using a variety of future greenhouse gas emissions scenarios as inputs. These scenarios are based on differing assumptions about future global population growth, social and economic development, energy sources, and technological advances. Differences in global greenhouse gas emissions scenarios, combined with differences in how individual models respond to the scenarios, result in a range of possible futures for the coming decades rather than a single, definitive future. This range is often referred to as the “uncertainty” in the future projections (see Box for more on scientific uncertainty).

Global climate model simulations project increases in global average annual temperature of 2.0°F to 11.5°F by the 2090s (relative to 1980-1999), with a “best estimate” range of 3.2°F to 7.2°F (IPCC 2007). Global mean sea level is projected to increase seven to 23 inches (almost two feet) during this period, although more recent studies have raised this projection to as much as six feet (with a best estimate of approximately three feet) given increased melting of the Greenland ice sheet (Pfeffer et al. 2008, Vermeer and Rahmstorf 2010). Other projected changes include more frequent extreme heat and precipitation events, increased acidification of the ocean, and further declines in sea ice (IPCC 2007).

Investigations at the scale of North America reveal some important information about changes in temperature and precipitation at the regional scale in the western U.S. Figure 5 summarizes the changes in annual, winter, and summer temperature and precipitation over N. America at the end of the 21st century simulated by about 20 GCMs for the A2 emissions scenario. Most areas show substantial warming of about 5.4°F (3°C) on an annual basis, but in the mid-latitudes (the continental U.S.), temperature changes are focused more on summer than on winter, whereas at high latitudes (the far north) the changes are largest in winter. Annual precipitation changes reflect a shift in the dominant storm track to the north in the simulations, resulting in generally wetter conditions at higher latitudes (e.g. western Canada), and drier conditions in the sub-
Climate Change and Scientific Uncertainty

When scientists talk about climate change impacts, they often mention the inherent “uncertainty” in future outcomes. These statements are sometimes misinterpreted to mean that scientists don’t know what will happen in the future and therefore cannot provide any meaningful guidance on future conditions. What is meant, however, is that there is a range of plausible future outcomes which have about equal scientific merit. Thus the amount of scientific uncertainty refers to the precision with which impacts can be specified. For example the uncertainty in temperature projections from Global Climate Models is less than the uncertainty in precipitation projections.

The scientific community is continually changing and updating information to reflect the latest knowledge, and scientists often try to focus their research efforts on areas where uncertainties are large in the hope of providing more precise answers. This is sometimes referred to as “narrowing the range of uncertainty”.

While it is not always possible to achieve this goal, accounting accurately for uncertainty is an important part of what climate scientists do. While some uncertainty in future climate projections will always be present, the scientific community has created robust and scientifically rigorous methods for developing climate scenarios that quantify these uncertainties. These kinds of tools are available to decision makers in the Pacific Northwest.

![Summary projections of temperature and precipitation change over N. America for annual, winter (DJF), and summer (JJA) conditions. Results shown are average changes for about 20 GCM simulations for the A2 emissions scenario at the end of the 21st century. (Source: IPCC 2007)](image_url)
tropics (southwestern U.S.). The Pacific Northwest is positioned in the "no-change zone" between the two extremes on this map, and relatively small systematic changes in annual precipitation are projected for our part of the world. However, winter conditions are generally wetter and summer conditions are drier over most of the western U.S. including the Pacific Northwest.

Although large-scale climate change projections are valuable in many ways, it is also essential to know how more localized conditions might change in the future. In response to this need, many research institutions have developed techniques for "downscaling" global climate data to provide information on climate changes and impacts at a more regional level, including the Pacific Northwest. Downscaling of global climate models into regionally specific information is one of the key products that the Climate Impacts Group at the University of Washington and the Skagit Climate Science Consortium provides. For more information on projected changes in climate for the Pacific Northwest, and the impacts of those changes, see the fact sheet Climate Impacts in the Skagit Valley.

References

This fact sheet was prepared by the University of Washington Climate Impacts Group for the Skagit Climate Science Consortium, September 2011.
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