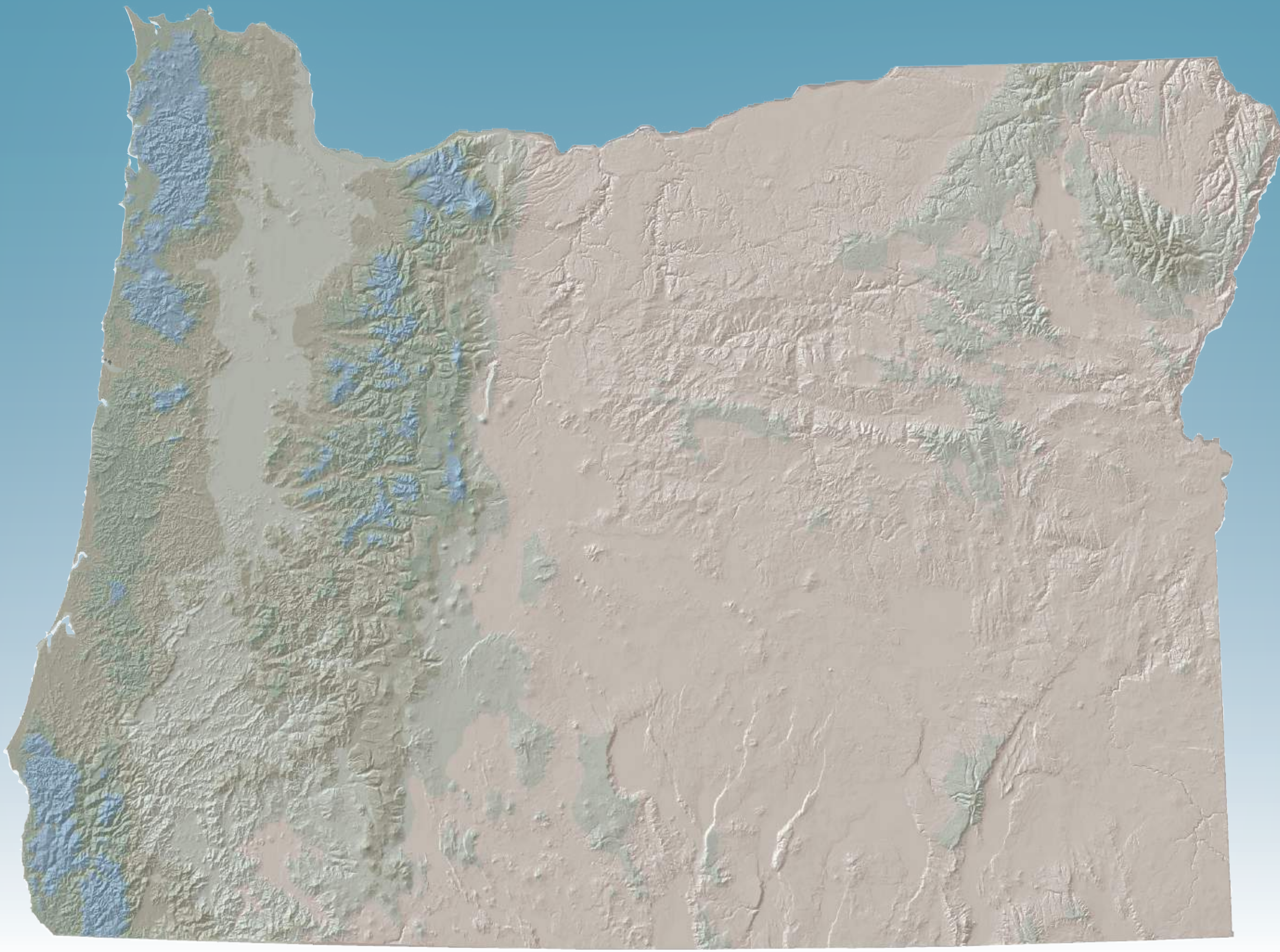
Atlas of Oregon Climate and Climate Change

A Classroom Atlas



Atlas of Oregon Climate and Climate Change

A Classroom Atlas

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Atlas of Oregon Climate and Climate Change

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http://www.pdx.edu/geography-education/

Cover Image: Oregon Precipitation (page 31)

Purpose

The purpose of this atlas is to provide Oregon's teachers with information on the fundamentals of Oregon's climate and the impacts of climate change in Oregon. We have not tried to cover every aspect of climate and climate change; there are abundant resources already in the public realm on those topics. Our focus has been the key components of Oregon climate and climate change.

Internet Resources

We have compiled a downloadable, searchable database of internet sites that provide teaching materials on various issues of climate and climate change. These sites range from curriculm and model lessons to policy and impact analyses. This database can be found at: http://www.pdx.edu/geography-education/file/676

Many individuals, community groups, and political entities such as cities and states are taking action to address climate change. We have compiled a downloadable, searchable database of climate initiatives in Oregon that gives you an idea of what Oregonians are doing to learn about and address climate change in Oregon. This database can be found at: http://www.pdx.edu/geography-education/file/675

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What is Climate Science?

Climate science (or ***climatology***) is the study and explanation of factors that impact weather conditions over a period of time and thus create areas with similar climate characteristics. Earth's geometric relationship to the sun and the interactions among the biosphere, atmosphere, hydrosphere, and lithosphere influence climate, and create broad zones of climate around the globe. In addition, human activities, such as land use practices and fossil fuel burning, can influence climate.

Climatologists (scientists who study climate) examine both the natural and ***anthropogenic*** (human) causes of variation in earth's climate.

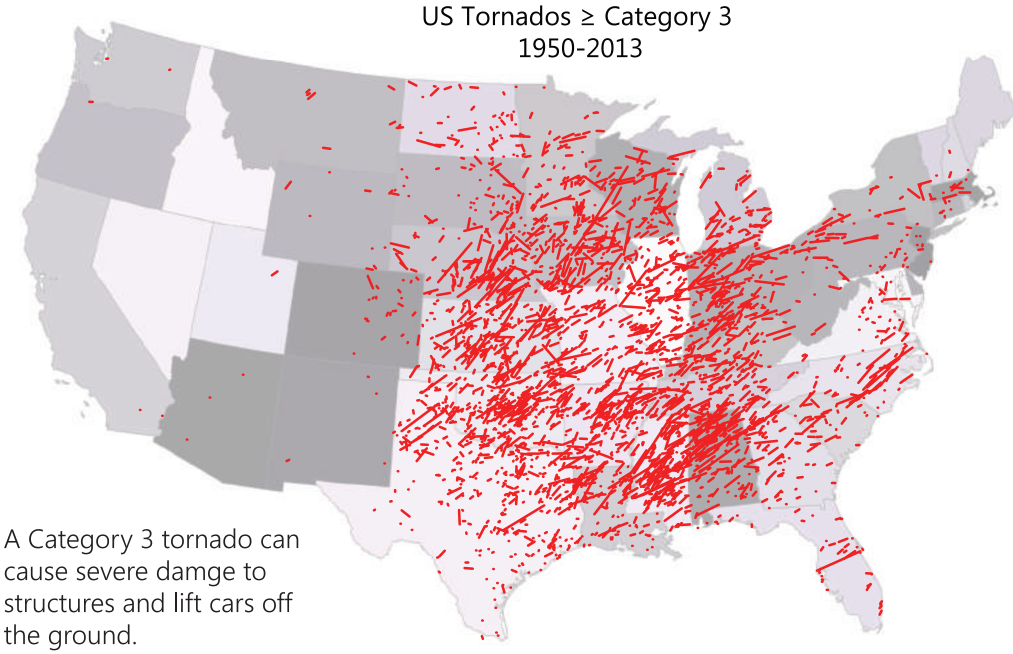
Weather station.

Climate scientist Dr. Gregory Jones, with his students at a weather station in southern Oregon.

Weather and Climate

What is Weather?

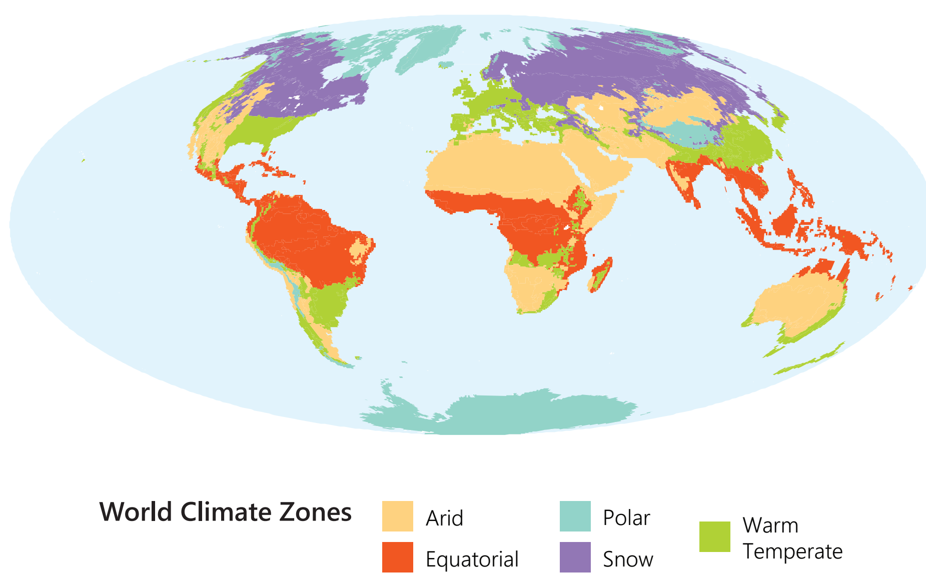
The term ***weather*** is used to describe the state of the Earth's atmosphere at any given time. The term ***weather conditions*** refers to the spatial distribution and the intensity of winds, humidity, air pressure, clouds, precipitation, and lightning. The variability in distribution, intensity, and interaction between these weather conditions results in a range of weather around the globe on any given day from hot, dry, calm conditions to extreme weather events such as tornadoes and hurricanes.



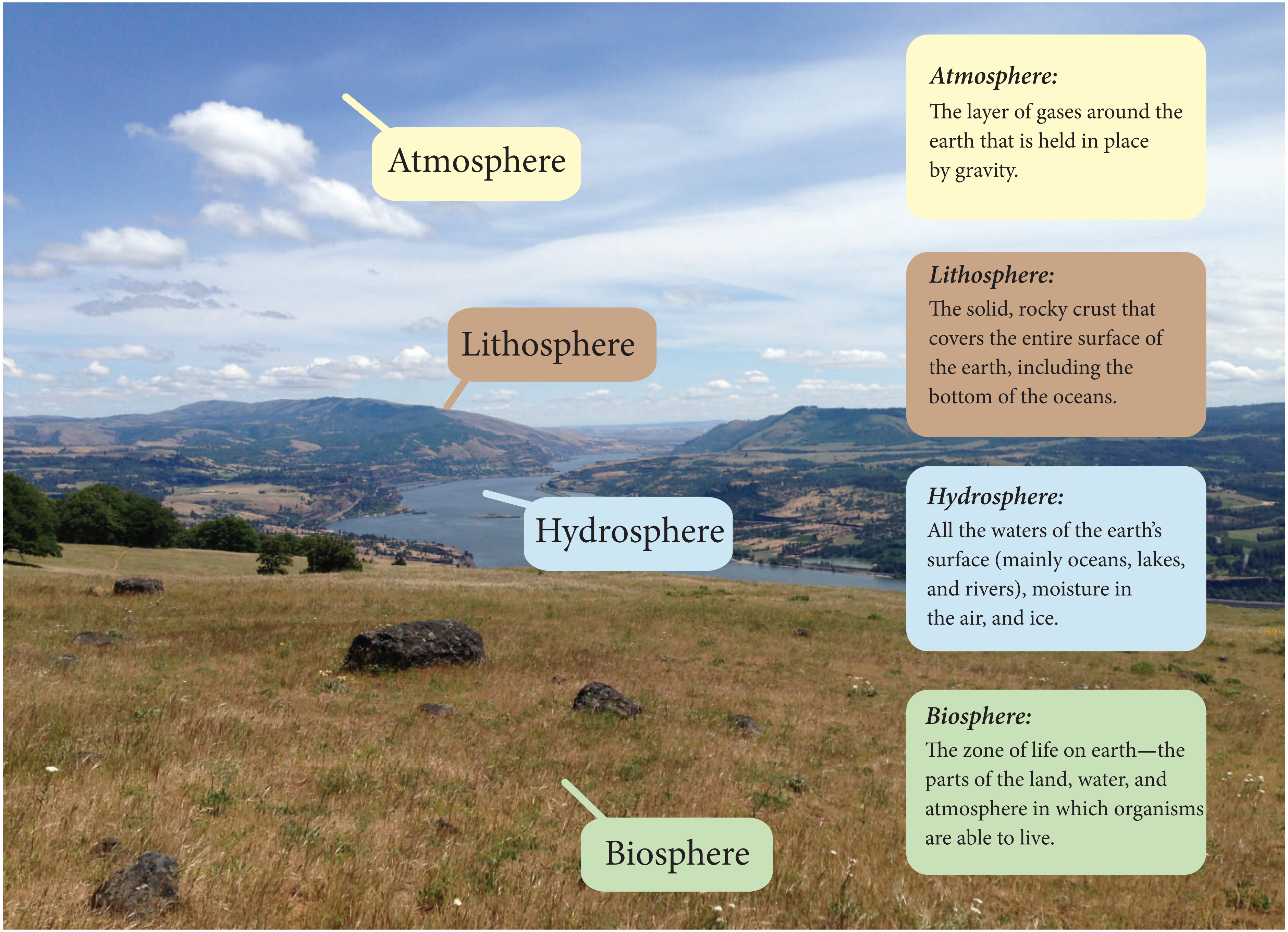
A Category 3 tornado can cause severe damge to structures and lift cars off the ground.

What is Climate?

Climate describes the patterns of weather over an extended period of time. The most common time-frame used is the 30-year climate normal, updated periodically (every 10 or 30 years depending upon the application of the climate statistic). Statistical analysis of weather conditions over time, including the variability, average, and extremes of each weather condition, is a key means of describing climate. The interaction of other variables, such as latitude, elevation, topography, and proximity to large bodies of water, completes the picture.

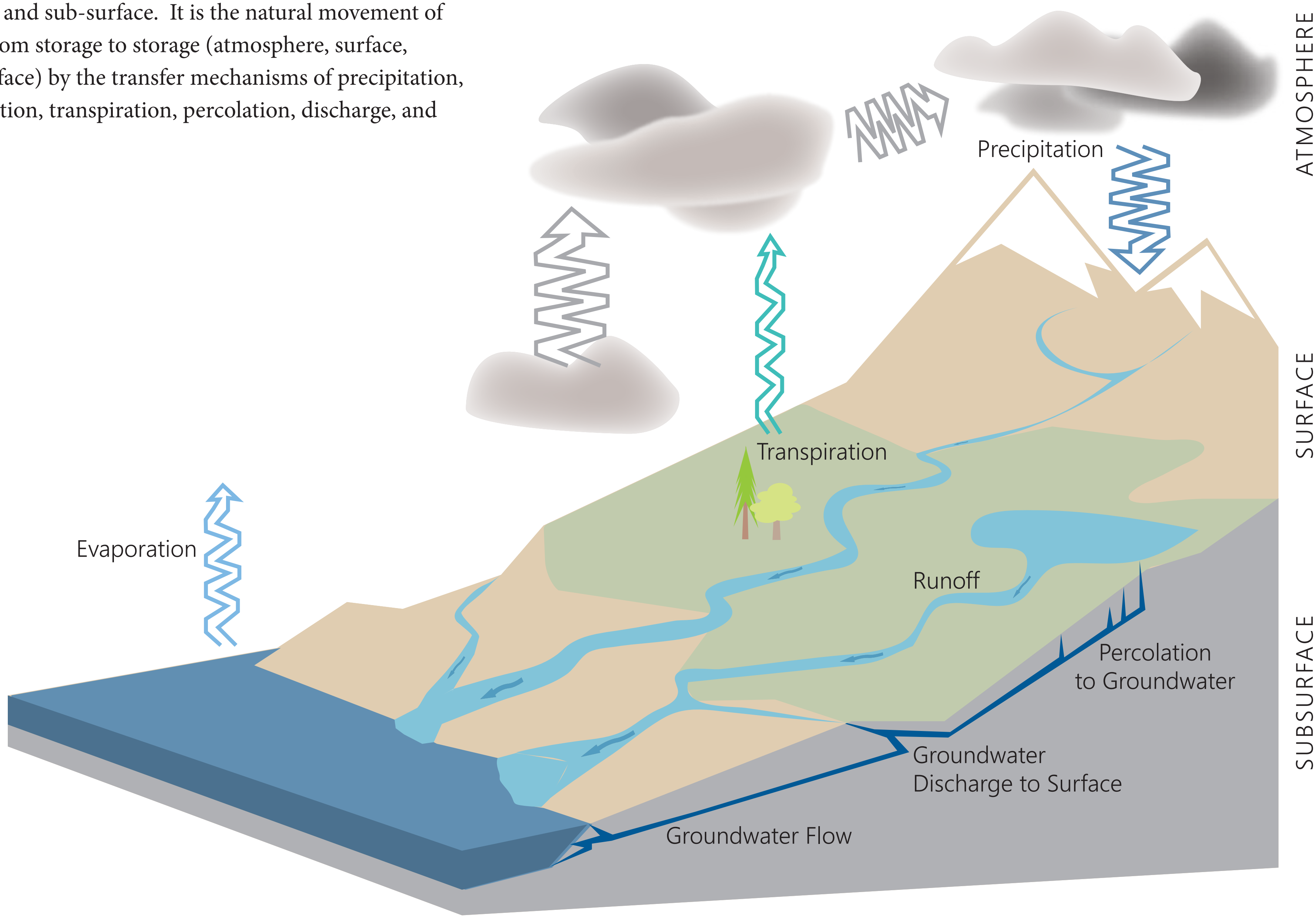


Elements of the Climate System



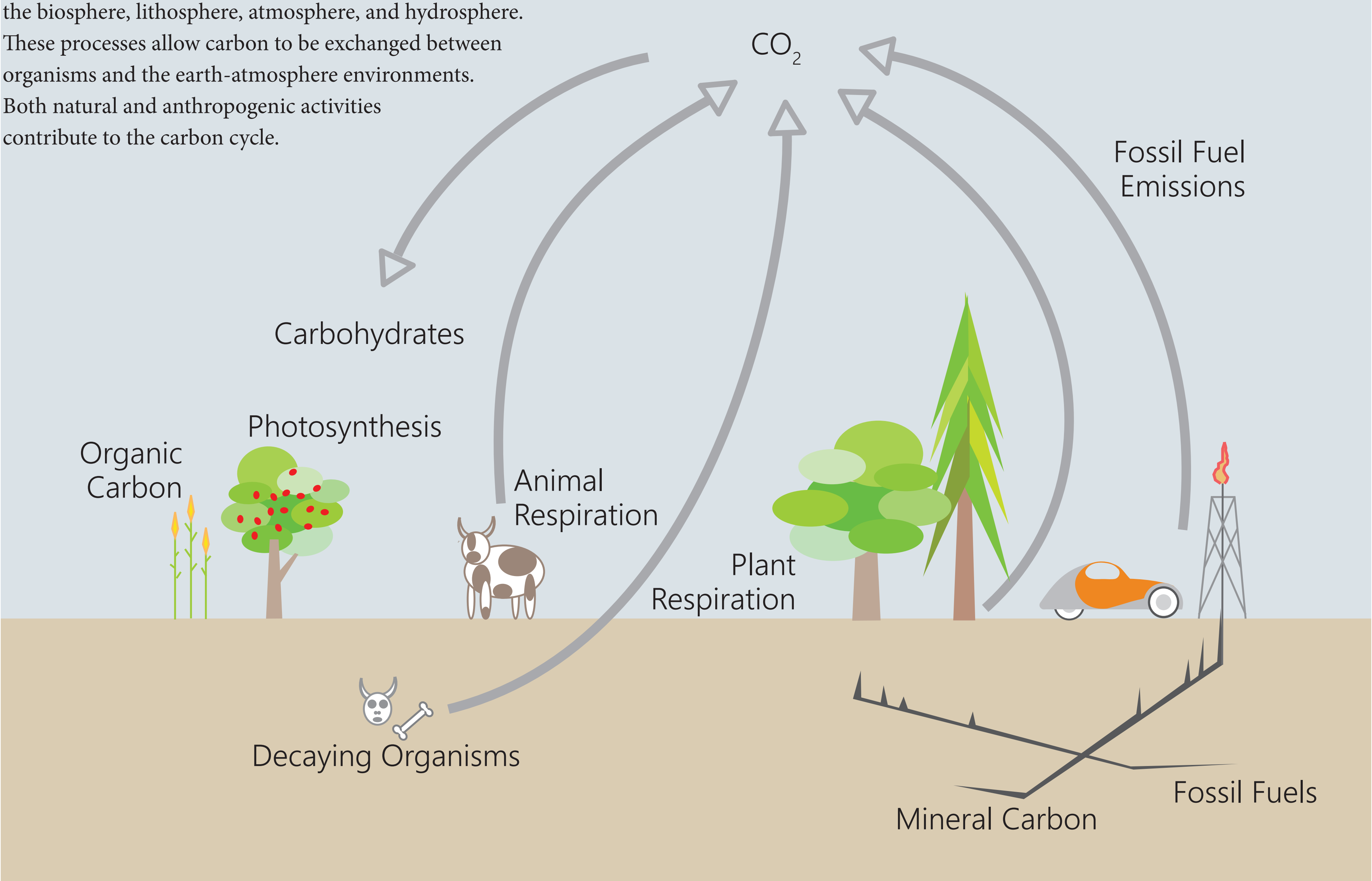
The Water Cycle

The ***water cycle*** (the ***hydrologic cycle***) is a system of storages and transfers of water through earth's atmosphere, surface, and sub-surface. It is the natural movement of water from storage to storage (atmosphere, surface, sub-surface) by the transfer mechanisms of precipitation, evaporation, transpiration, percolation, discharge, and runoff.



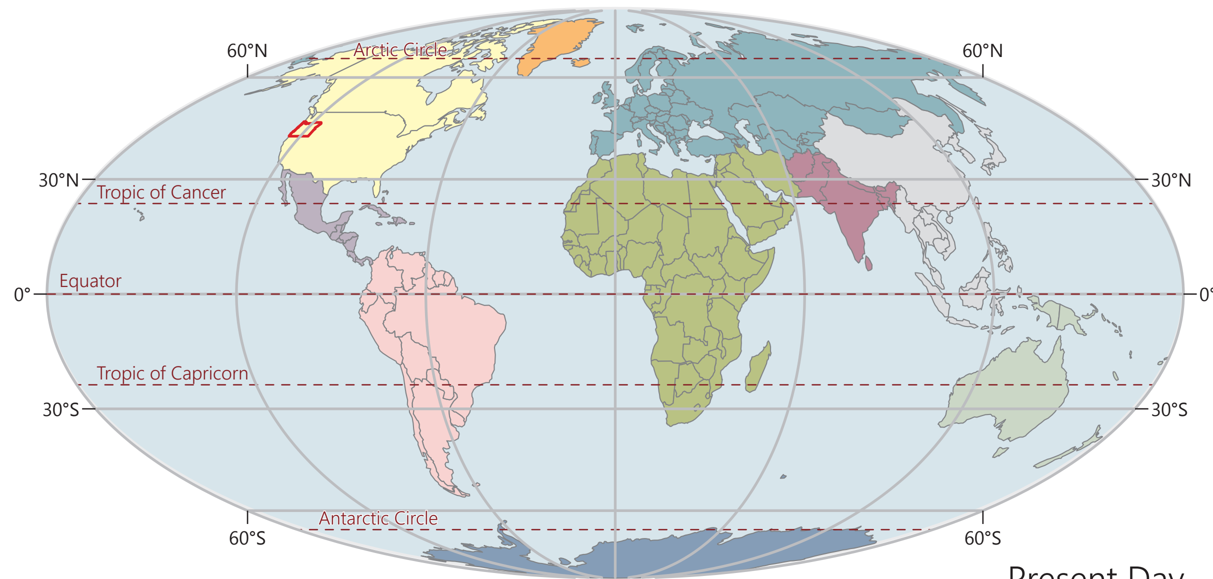
The Carbon Cycle

The ***carbon cycle*** is the combined processes of photosynthesis, decomposition, and respiration that circulate carbon among the biosphere, lithosphere, atmosphere, and hydrosphere. These processes allow carbon to be exchanged between organisms and the earth-atmosphere environments. Both natural and anthropogenic activities contribute to the carbon cycle.



Tectonics: Plates and Climate

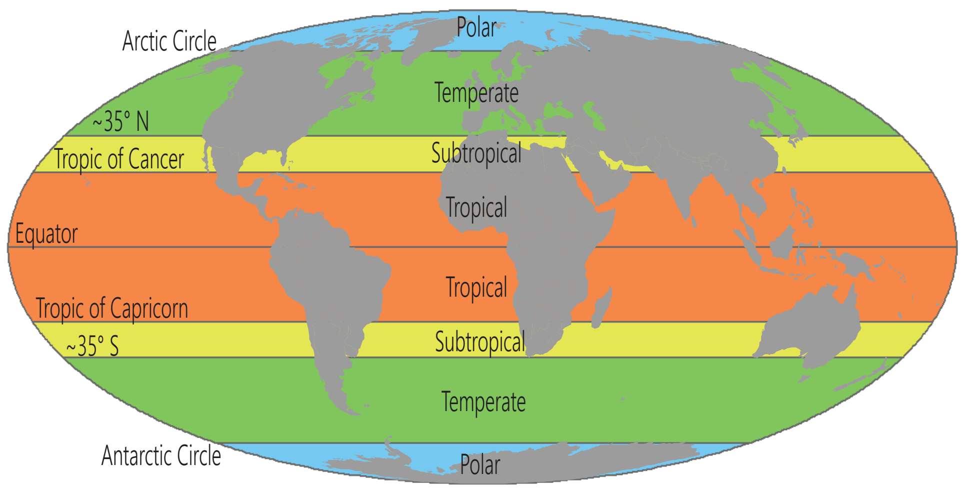
Over long periods of time, plate tectonics can influence climate as the horizontal movement of plates relocates land masses in relation to each other and across latitudes. For example, approximately 300 million years before the present, what we now call Oregon was located nearer the equator. In addition, movement of plates, creating and dividing land masses, diverts ocean currents and changes the movement of warm and cold currents around the globe.



Present Day

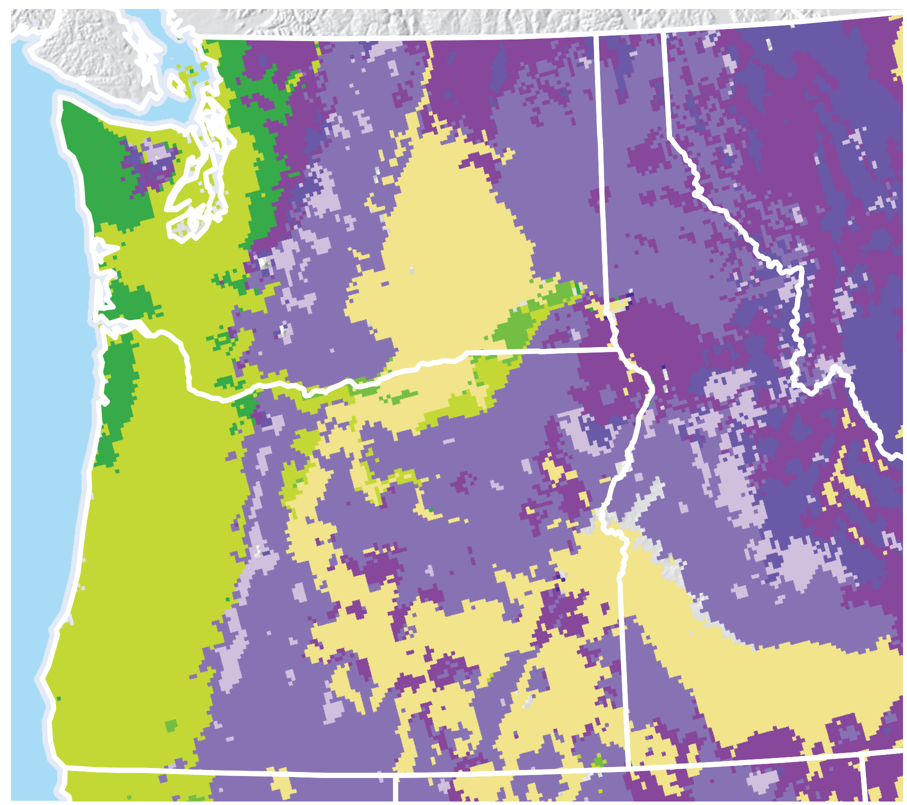
310 Million Years Before Present

Climate Zones and Climate Classification



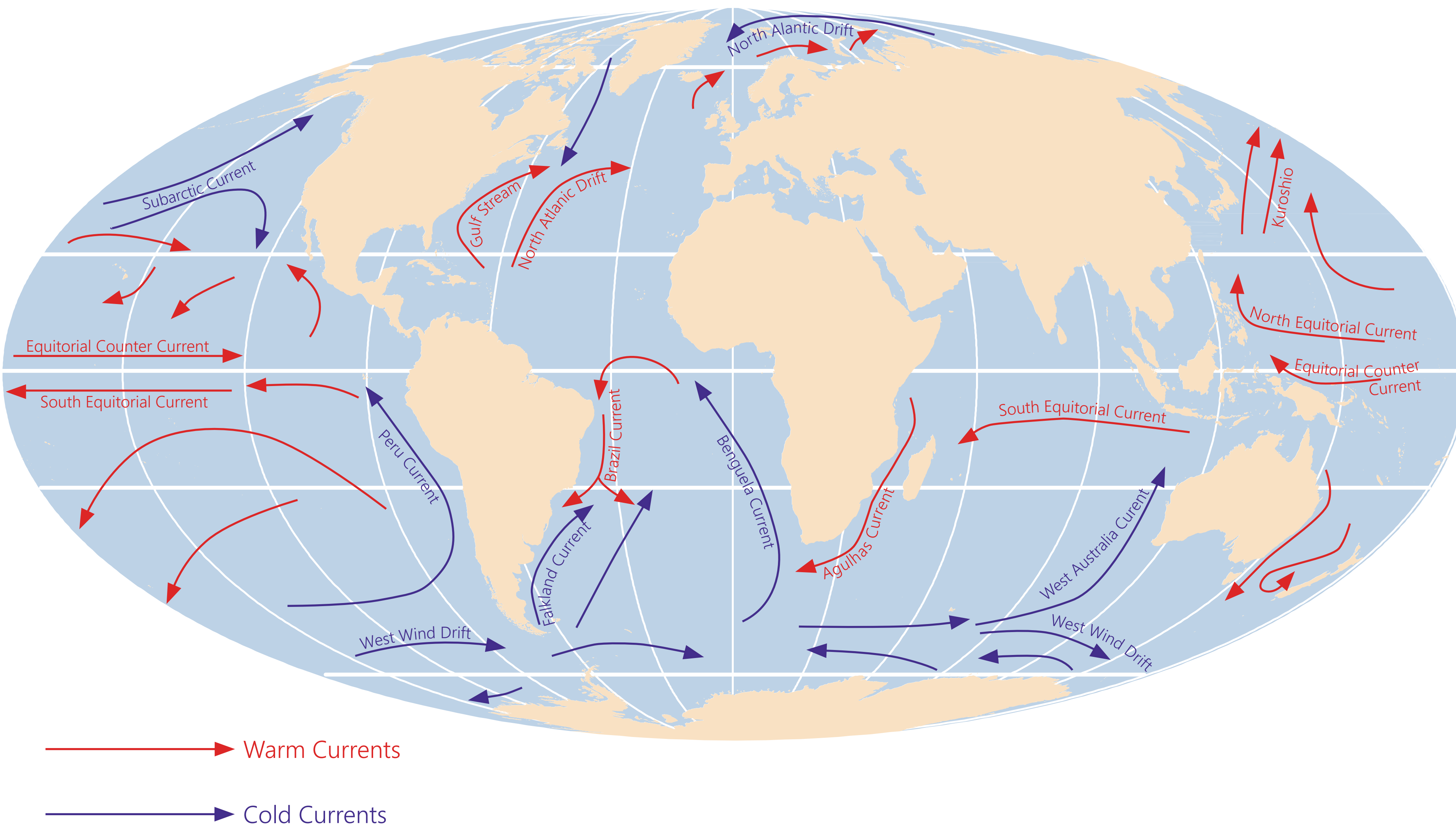
To a rough approximation, the world is divided into ***climate zones*** according to latitude, with climate becoming colder and drier at higher latitudes.

Most ***climate classification*** systems attempt to identify climate zones by correlating each zone with a specific temperature and precipitation regime that results in broadly defined climateregions. The Pacific Northwest has a range of climate zones from arid to warm temperate.



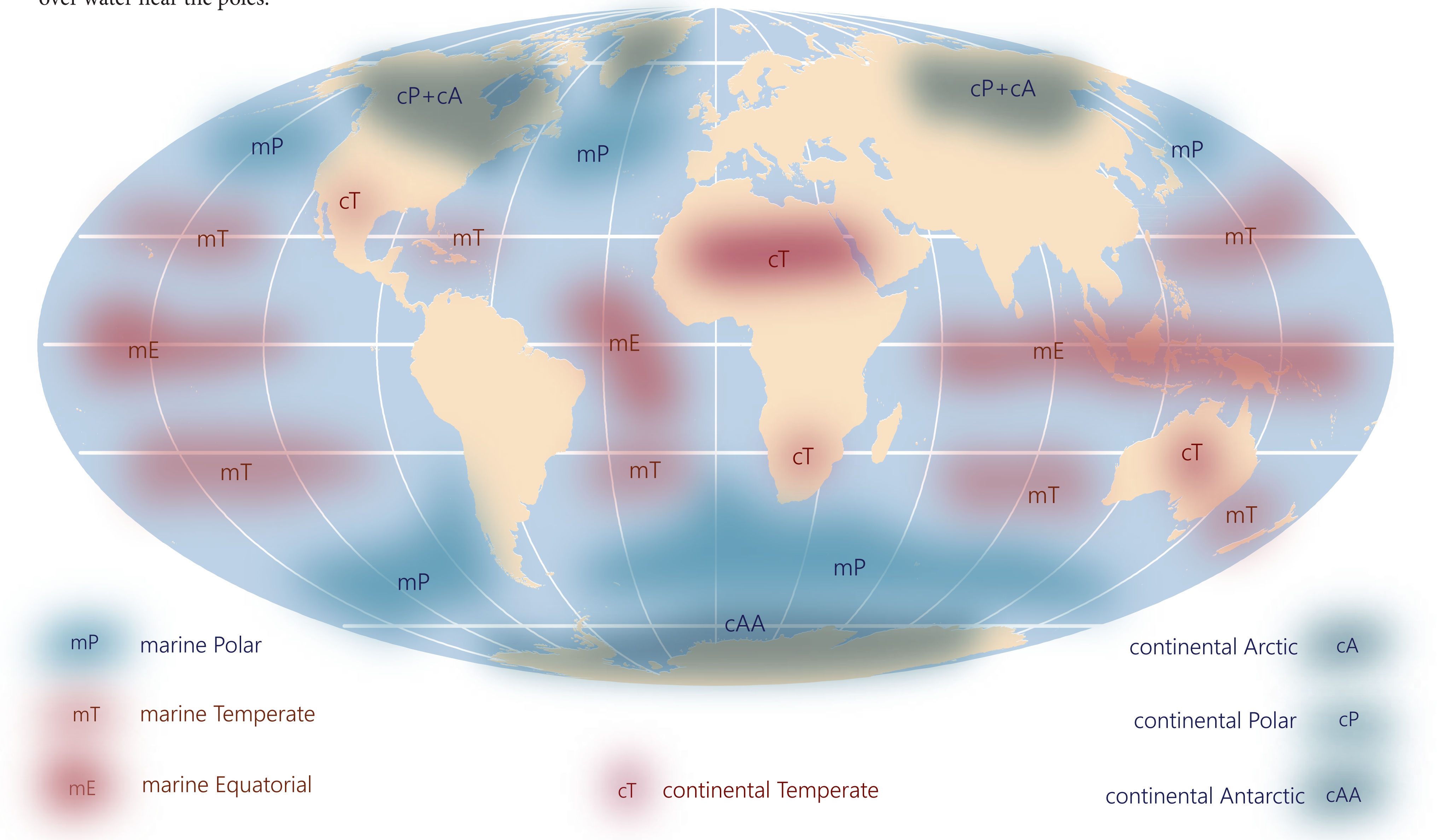
Ocean Currents : General Circulation of the Ocean

Ocean surface circulation reveals a pattern of warm and cold currents, and these currents impact climate. For example, coastal deserts are found near cold currents. The general distribution of land and water around the globe also influences climate. Because landmasses heat and cool more rapidly than bodies of water, air temperatures are warmer in summer and colder in winter over the continents than they are over the oceans at the same latitude. The interiors of large landmasses, such as Eurasia, are least affected by oceans, so they have greater annual temperature ranges than small landmassses.



Global Winds and Air Masses

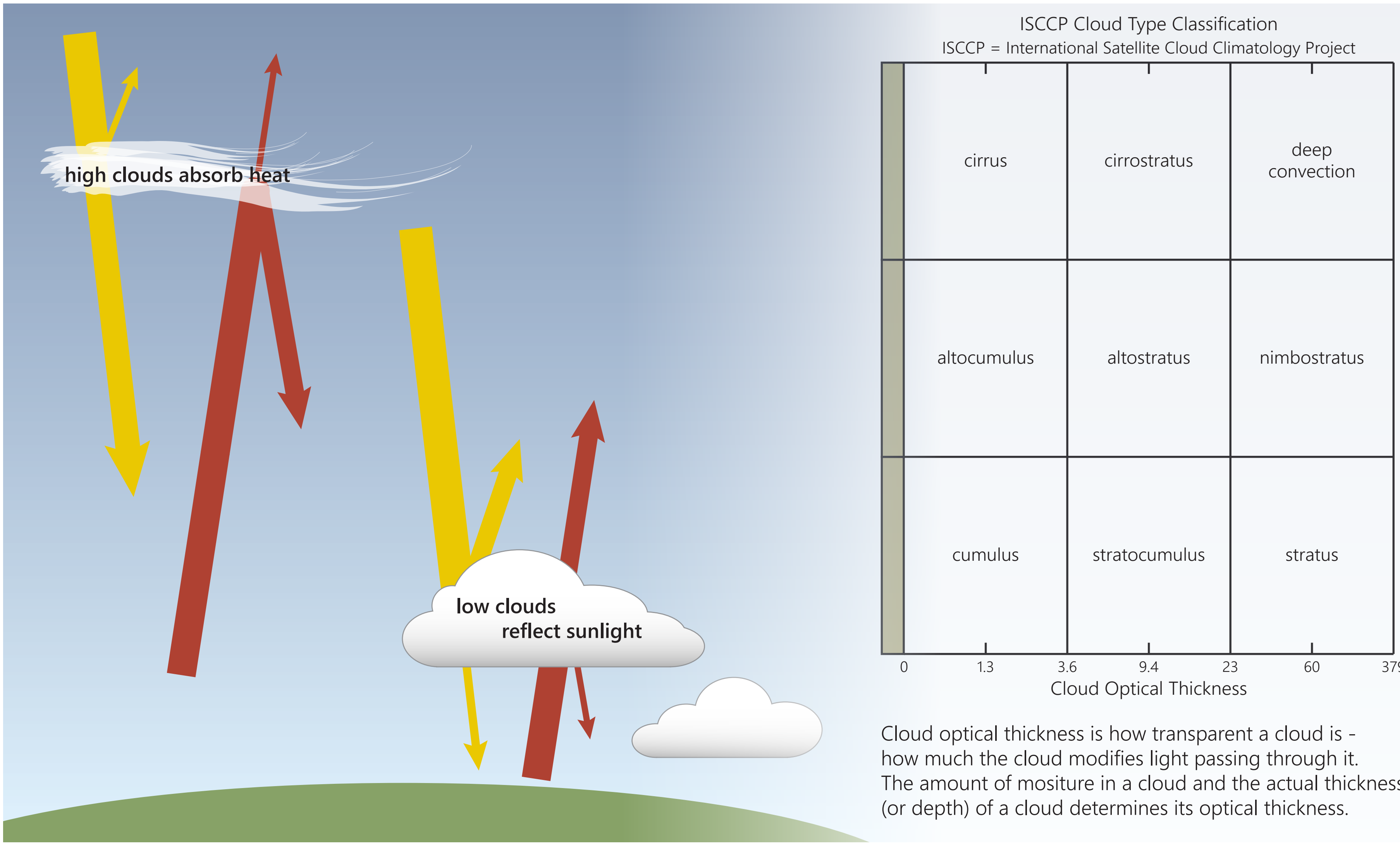
Air masses are labeled by the region over which they form. For example, *cT* indicates continental tropical, meaning that airmass was formed over land, near the equator; *mP* indicates maritime polar, meaning the air mass was formed over water near the poles.



Atmospheric Effect of Different Cloud Types

Different cloud types affect the atmosphere in different ways. High clouds absorb heat, and so tend to have a net warming effect on the atmosphere. Low clouds reflect sunlight more strongly than do high clouds, so low clouds tend to have a net cooling effect on the atmosphere.

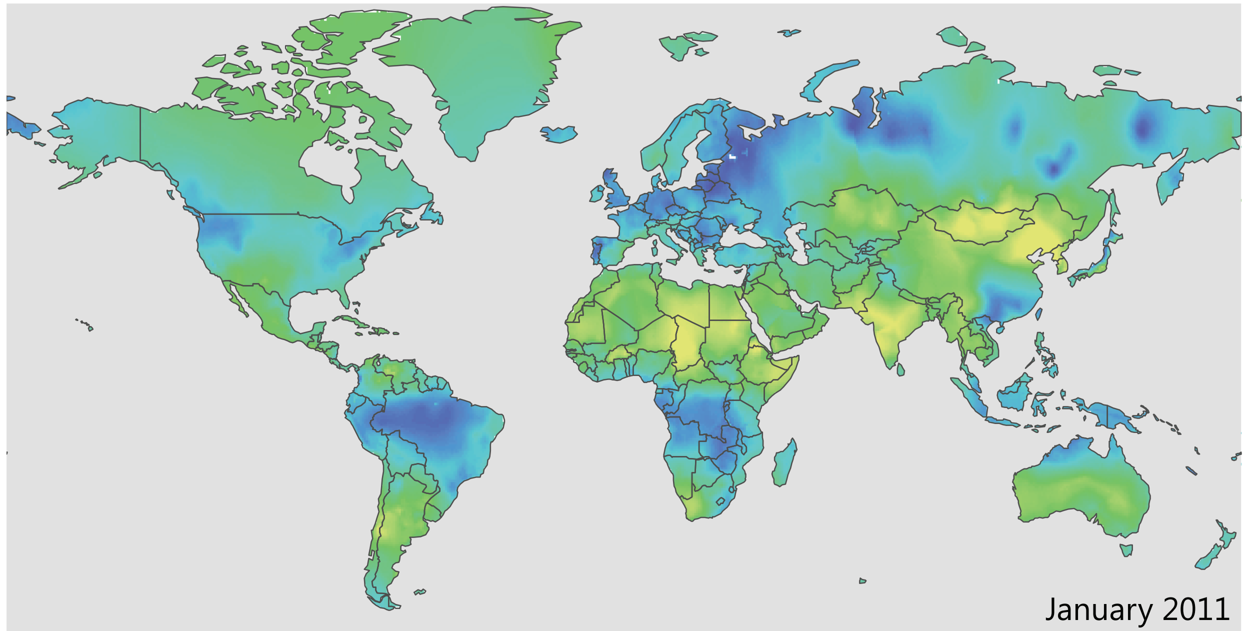
The average annual global effect of clouds is to cool the climate system, though the magnitude of the cooling is uncertain. The most important cloud parameter affecting the energy budget is cloud ***albedo***, which depends on cloud optical thickness. Albedo is the percent of solar radiation reflected by a surface back to space.

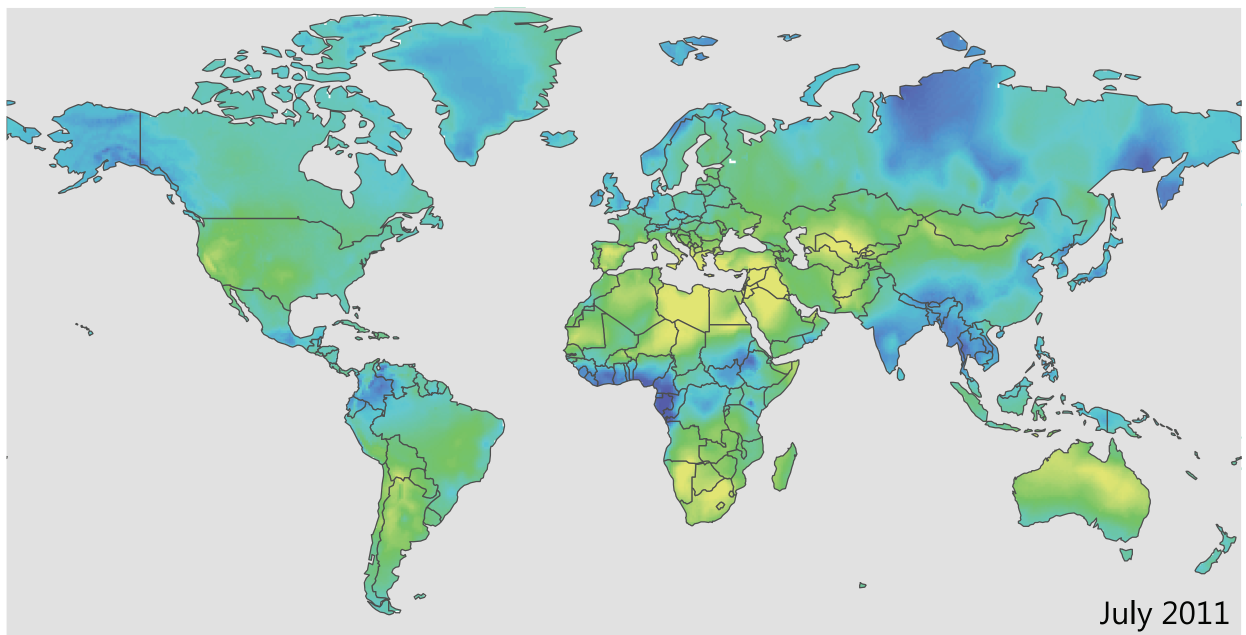


Cloud optical thickness is how transparent a cloud is - how much the cloud modifies light passing through it. The amount of mositure in a cloud and the actual thickness (or depth) of a cloud determines its optical thickness.

Cloud Cover

Clouds affect the temperature of the earth by: reflecting insolation (surface cooling), absorbing heat emitted from earth's surface and re-radiating to the surface (surface warming); absorbing heat and re-radiating it to space (atmospheric warming, then cooling); and forming precipitation (atmospheric warming). The net impact of clouds on climate is difficult to discern given our limited understanding of the formation, movement, and duration of clouds across the globe.

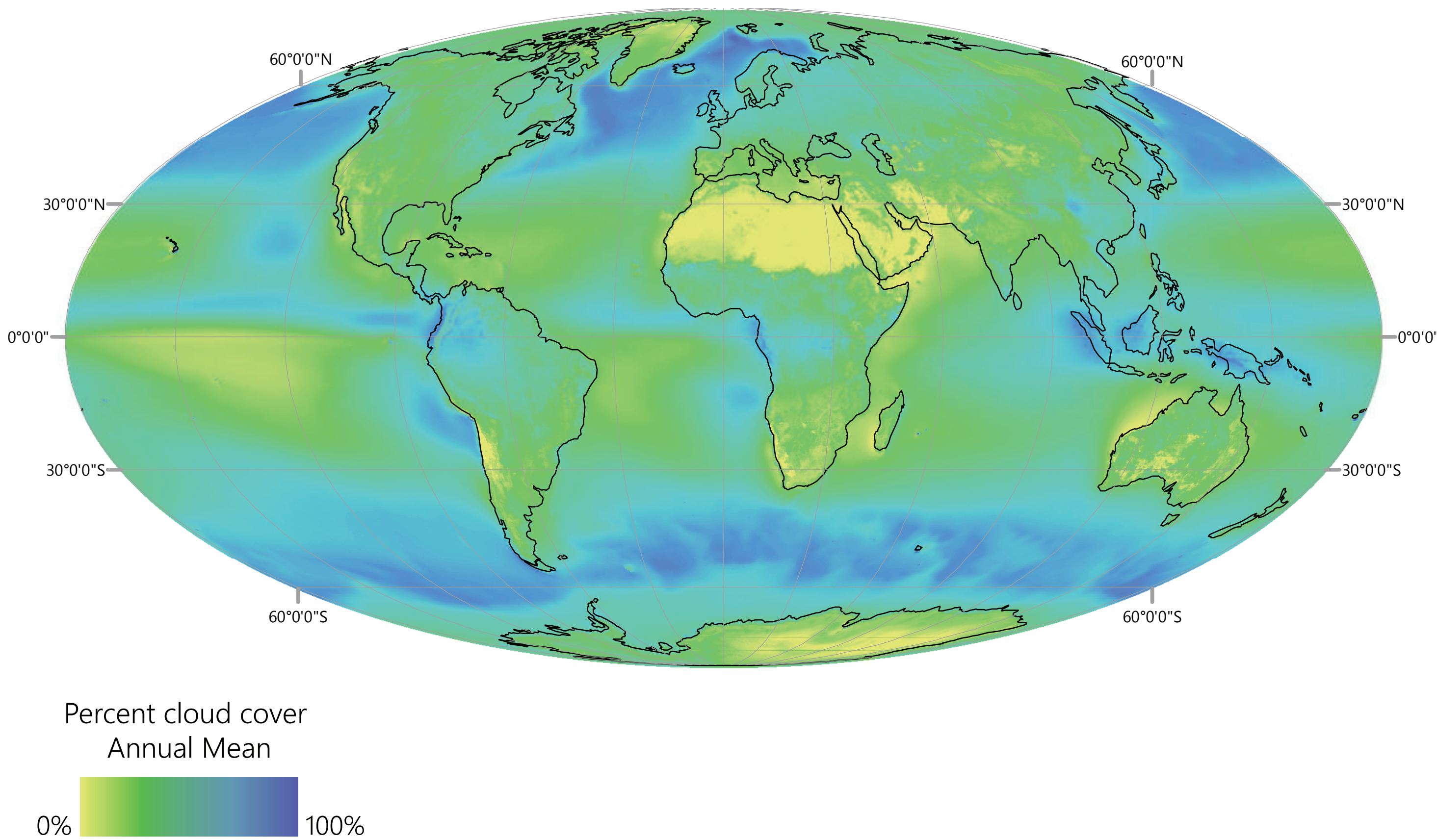


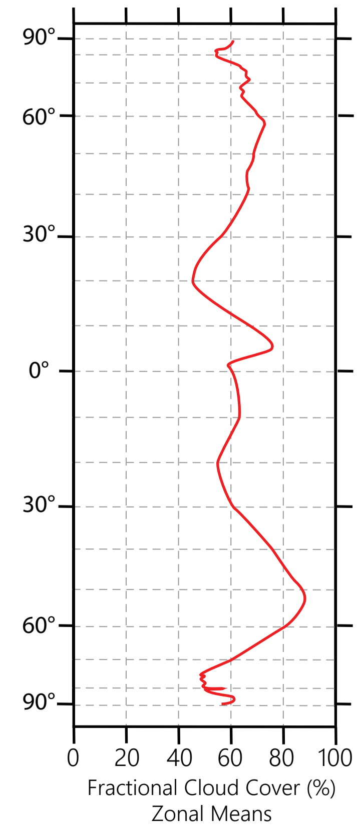


Percent cloud cover averaged over one month for all cloud types

Percent Cloud Cover: Annual Mean 1982-2009

One technique used to reveal underlying, long term patterns of cloud cover is to average together all of the cloud cover readings taken over the course of several years. However, climatologists today are developing complex models of global circulation to simulate the probable distribution, transmissivity, and vertical profile of clouds. The cloud cover pattern reveals the influence of low pressure (and high precipitation) at the equator, and high pressure in the mid-latitude.



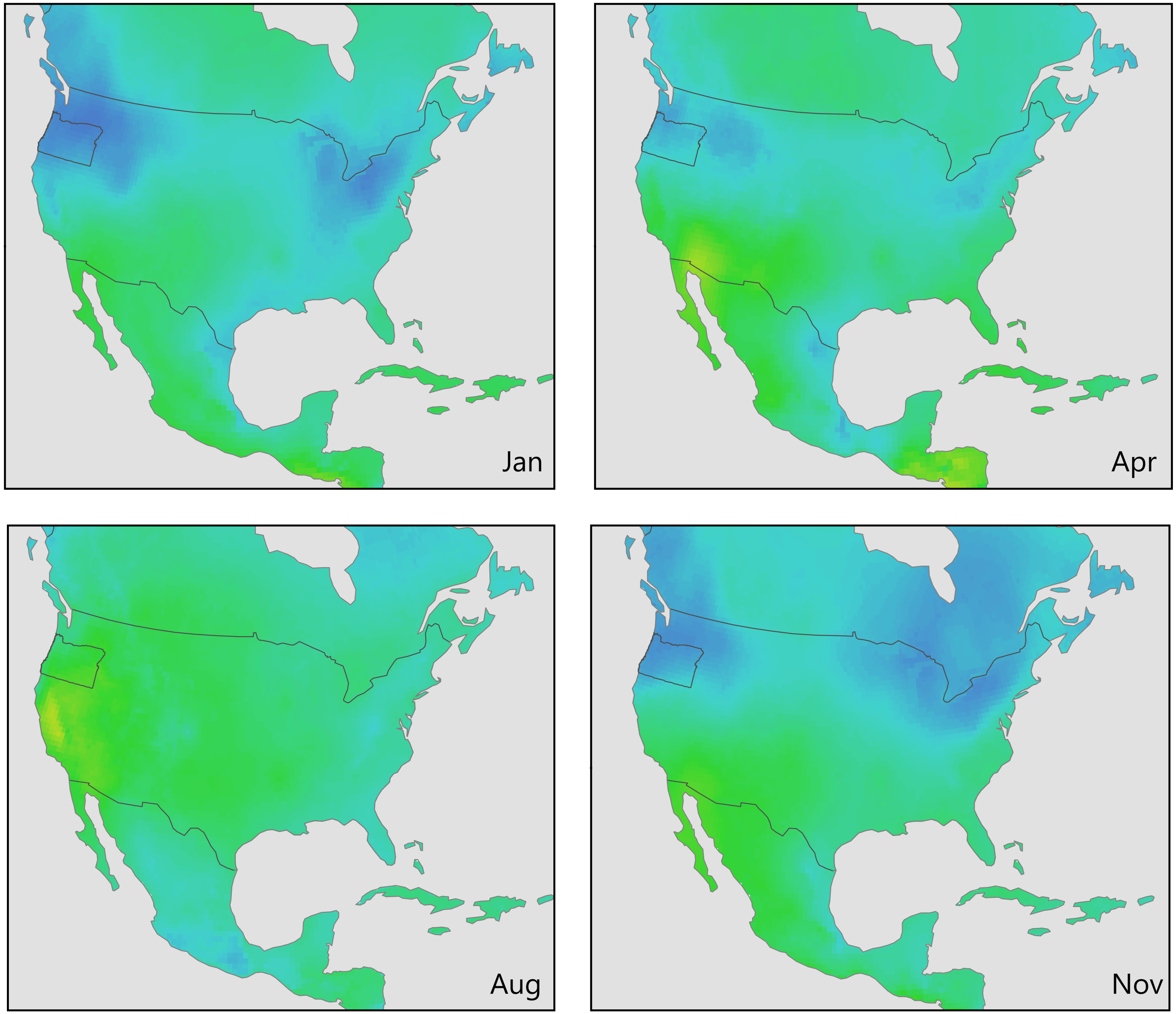


Percent Cloud Cover
Zonal Means

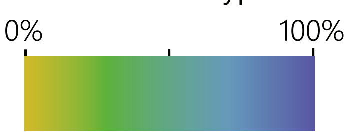
To calcluate zonal mean values, all of the values for a particular latitude are averaged together.

Percent Cloud Cover: Monthly Averages 1901-2011

The impact of cloud cover on climate is complex and our understanding of how cloud cover impacts climate is not fully developed. We know there is seasonal variability of cloud cover (as shown in these maps) and that the impact of cloud cover on temperature is a function of not only total cover but of type of cloud, latitude of cloud cover, and elevation of cloud.



Percent cloud cover averaged by month for all cloud types

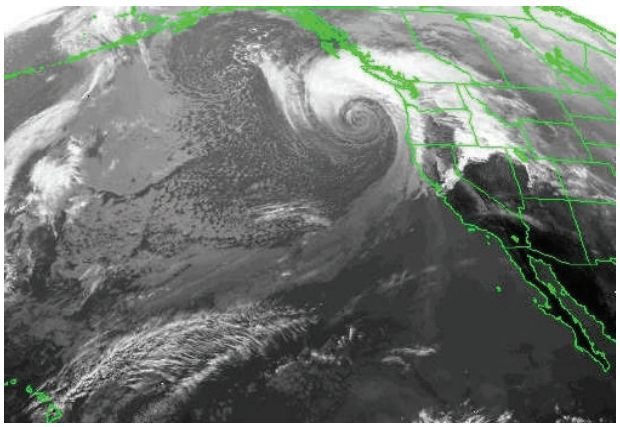


Pacific Northwest Storm Tracks

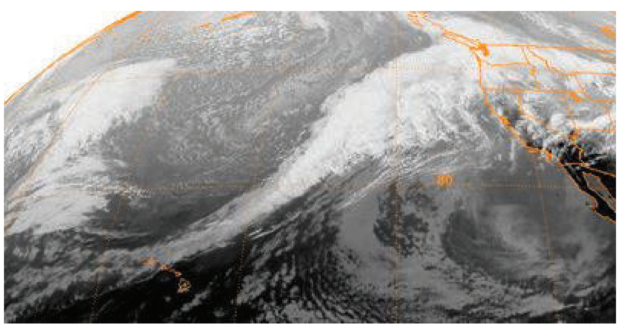
The Pacific Ocean is the birthplace of many weather systems that affect Oregon and the Pacific Northwest. The area in which a storm forms and the path it has traveled (its ***storm track***) help determine the location and impact of that particular storm.

Weather systems moving from one area of the Pacific may produce prolonged, heavy rains. Those from another area may generate only intermittent showers.

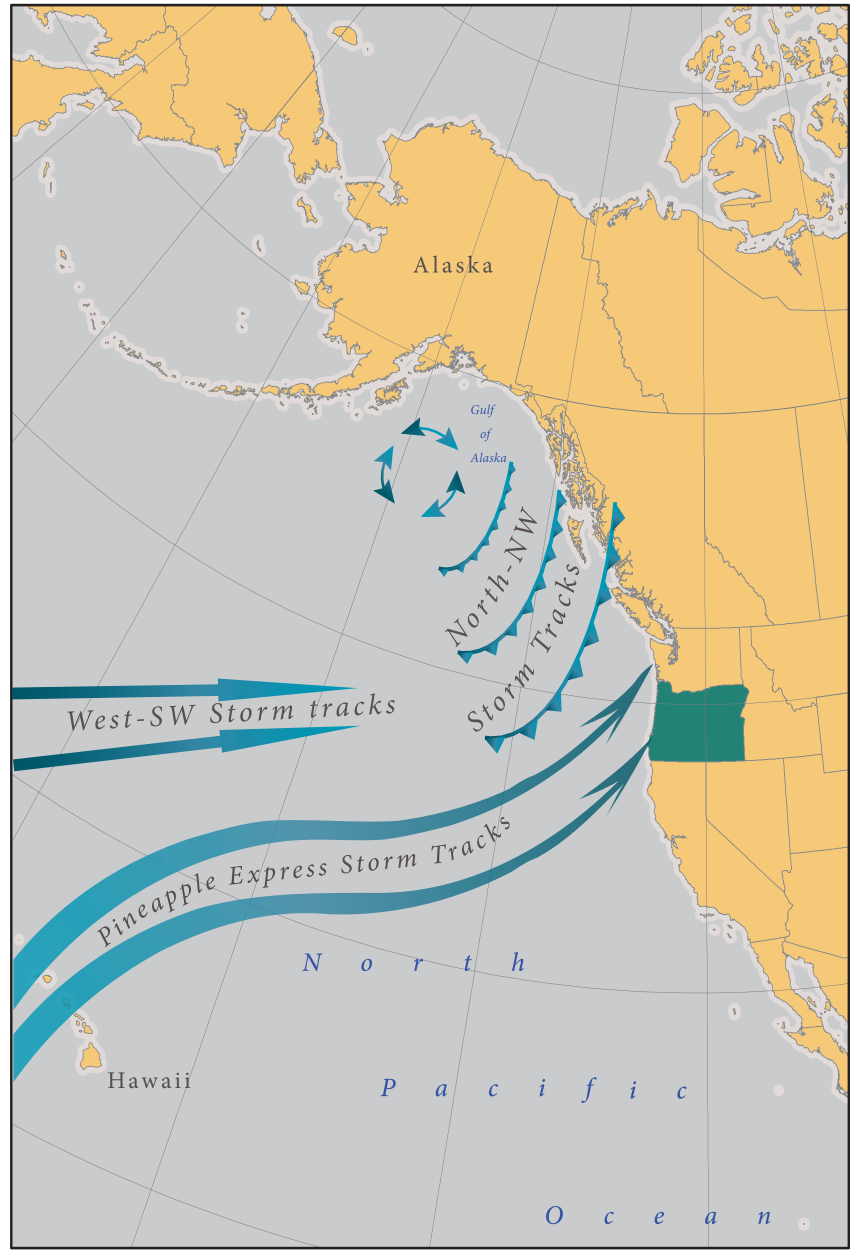
The ***Pineapple Express*** tends to direct warm and humid air up from the subtropics/tropics and can cause heavy rains in the Pacific Northwest region. Weather systems from the north-northwest or from the west-southwest can cause wind, rainfall, and snow.



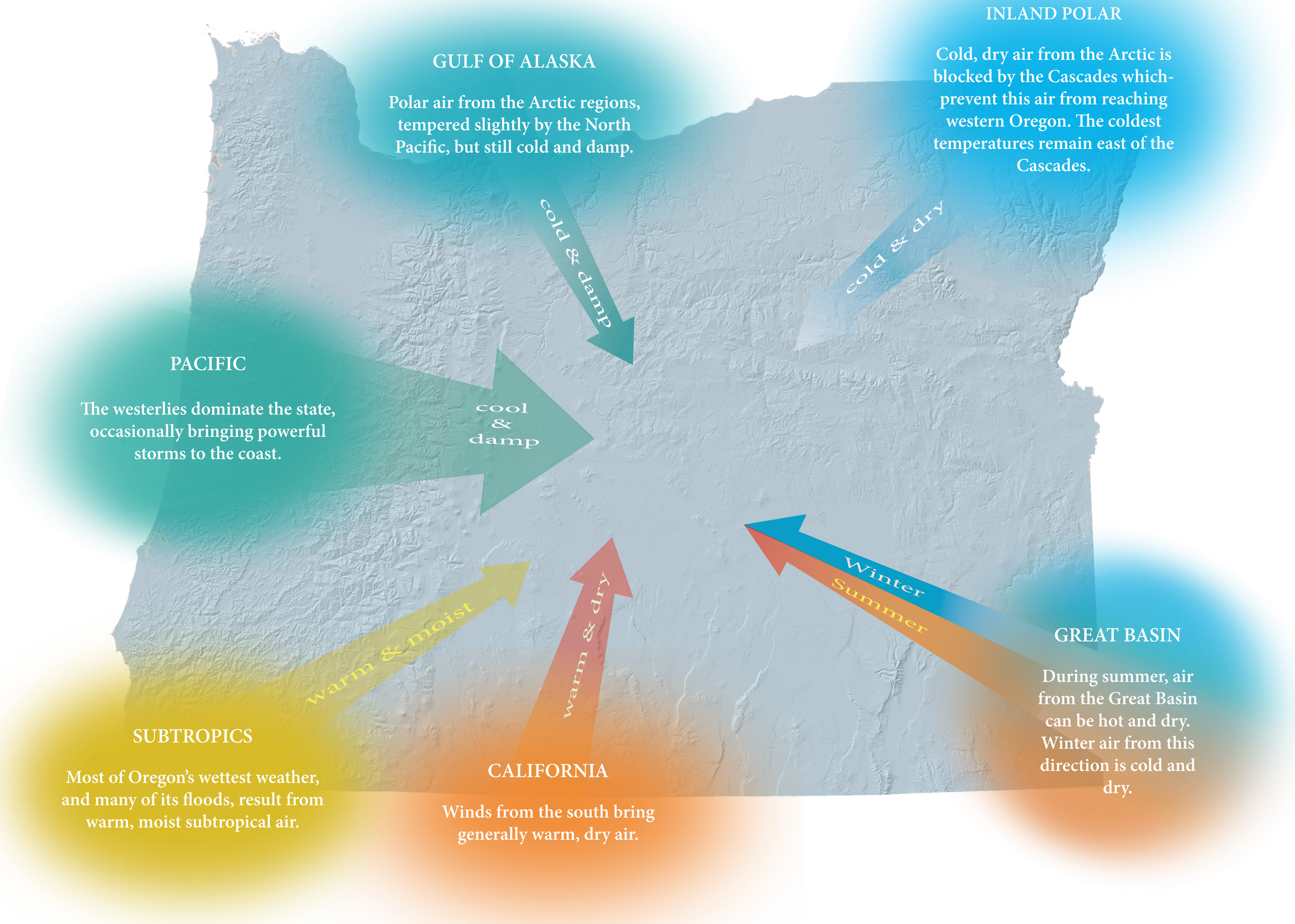
North-Northwest Storm Track



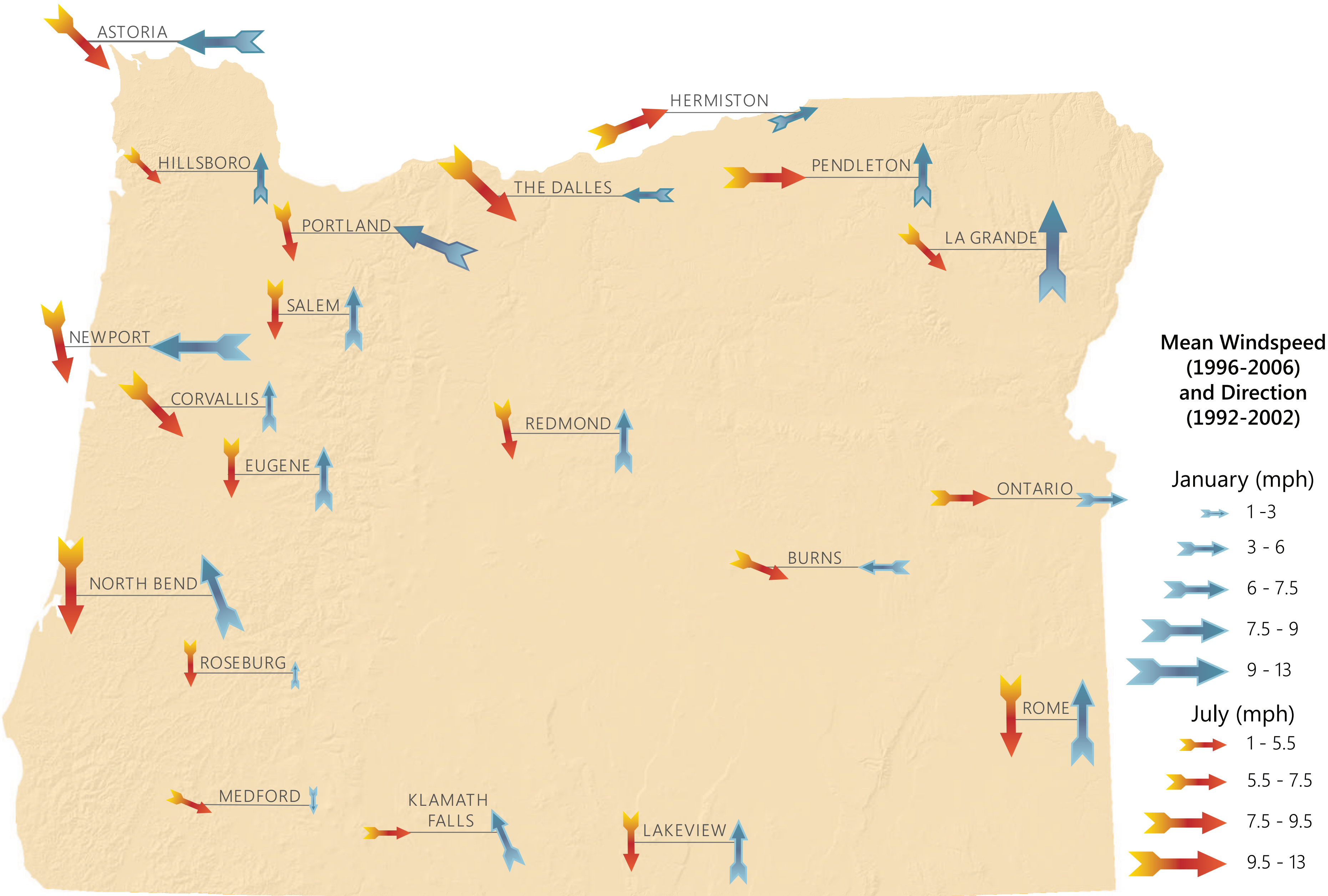
Pineapple Express Storm Track



Air Masses

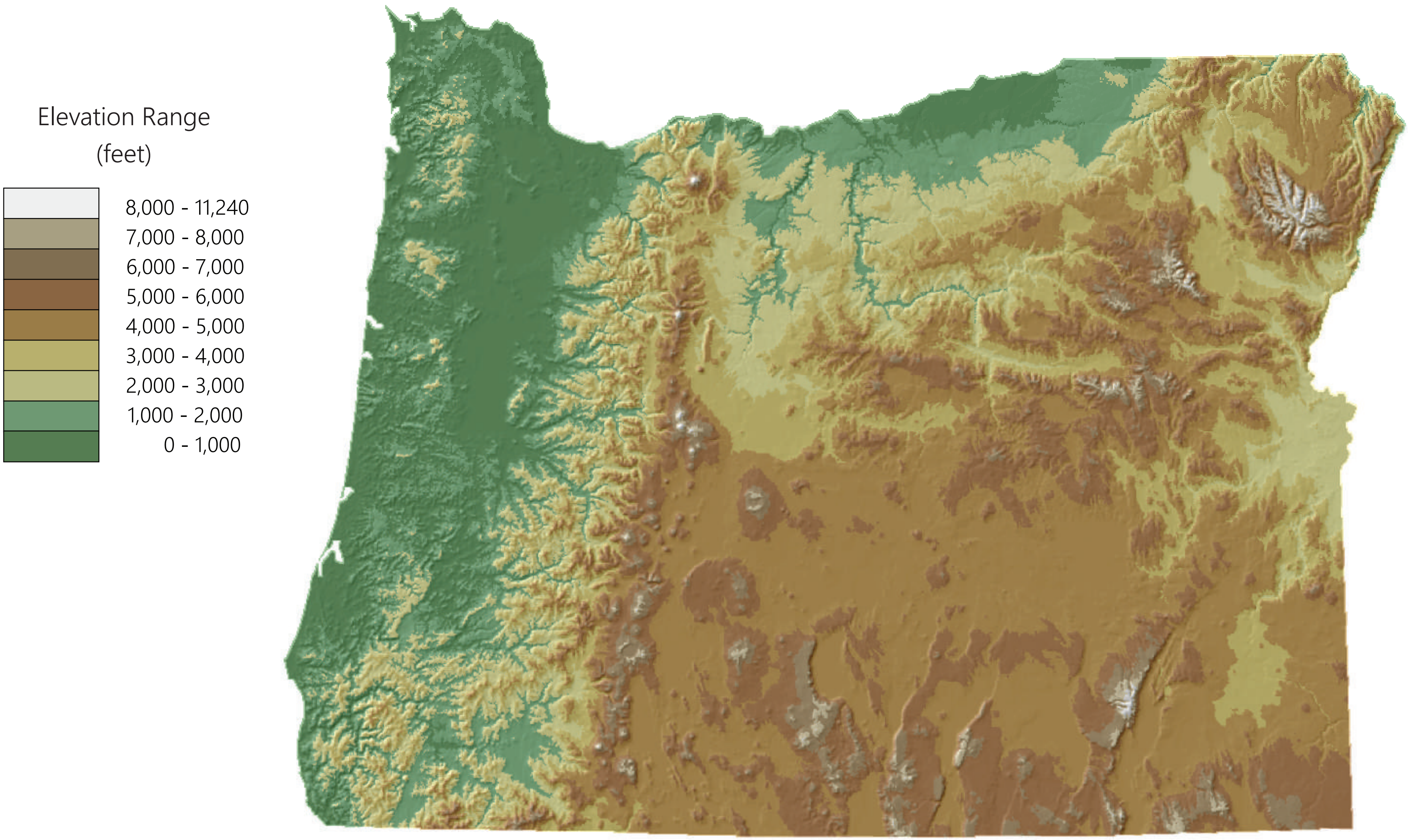

GULF OF ALASKA
Polar air from the Arctic regions, tempered slightly by the North Pacific, but still cold and damp.
cold & damp
INLAND POLAR
Cold, dry air from the Arctic is blocked by the Cascades which- prevent this air from reaching western Oregon. The coldest temperatures remain east of the Cascades.
cold & dry
PACIFIC
The westerlies dominate the state, occasionally bringing powerful storms to the coast.
cool & damp
warm & moist
warm & dry
Winter
Summer
GREAT BASIN
During summer, air from the Great Basin can be hot and dry. Winter air from this direction is cold and dry.
SUBTROPICS
Most of Oregon's wettest weather, and many of its floods, result from warm, moist subtropical air.
CALIFORNIA
Winds from the south bring generally warm, dry air.

Predominant Seasonal Surface Winds



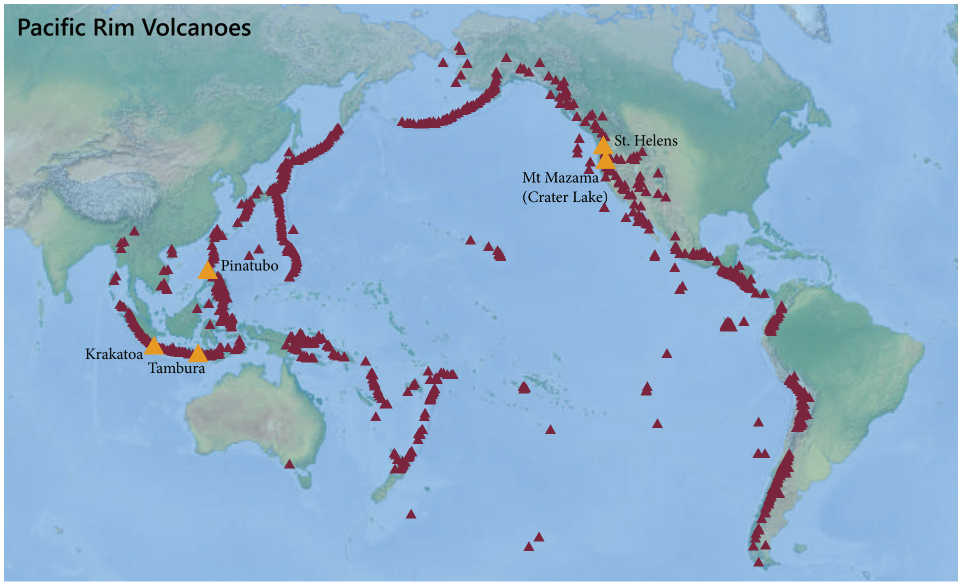
Elevation

Elevation affects climate in several ways. The higher the elevation, the cooler the temperature. Elevation creates relatively high precipitation on the windward side of mountains and ***rainshadows*** (relatively dry areas) on the downwind side of mountains.



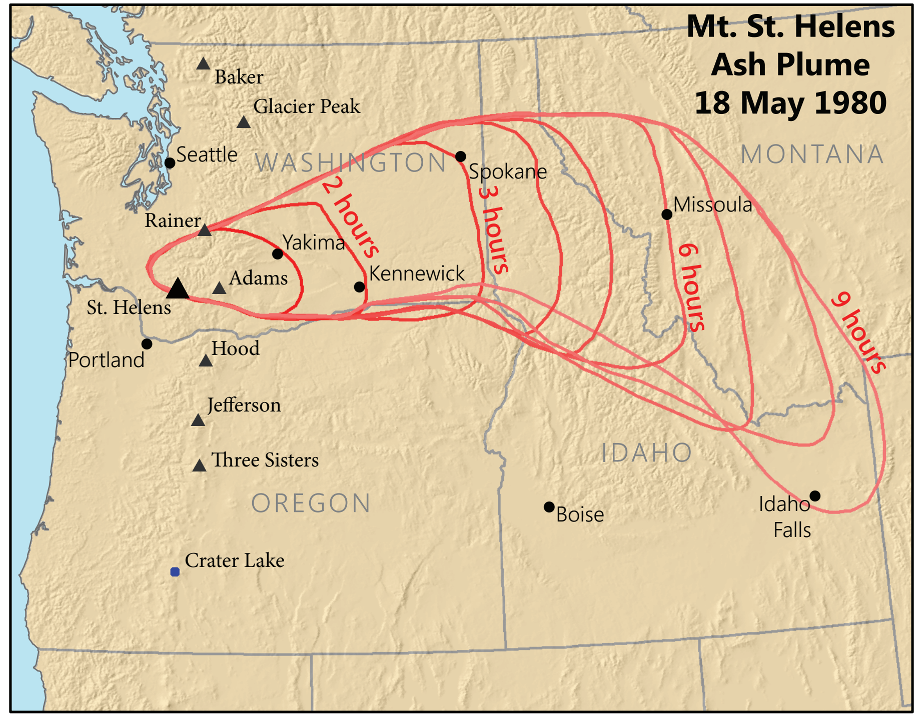
Volcanoes

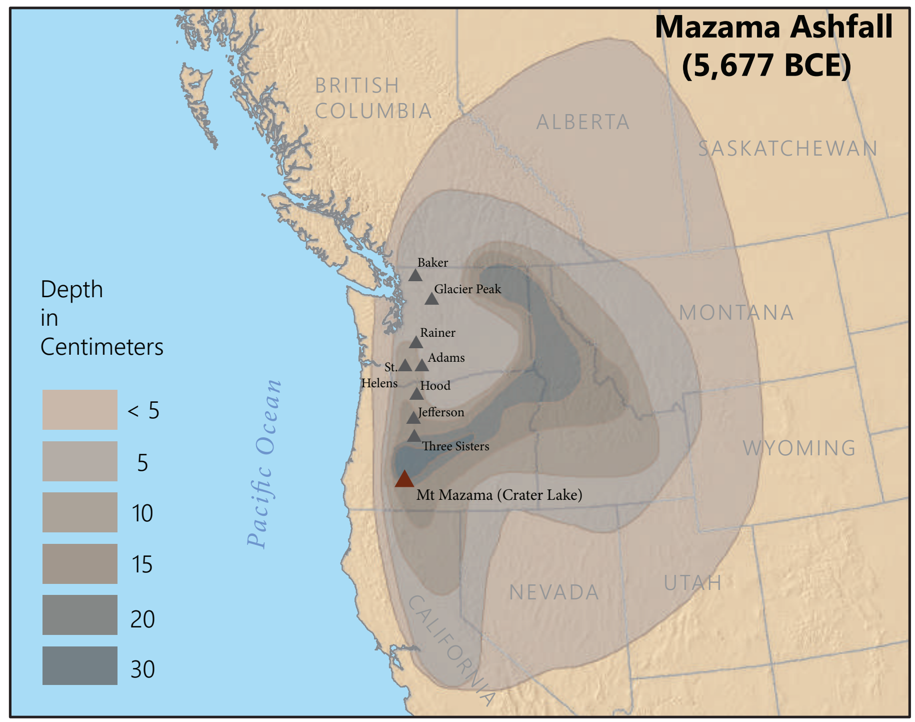
Volcanic explosions, especially those with high sulfur content, can influence global climate by blocking solar radiation, leading to cooling of the earth. The degree and duration of cooling, usually from a few months to a few years, are a function of how much material is ejected, how high it goes and the particle sizes released. The larger the volume of material, the higher it goes into the atmosphere, and the smaller the sizes of the particles, the greater the degree and duration of cooling.



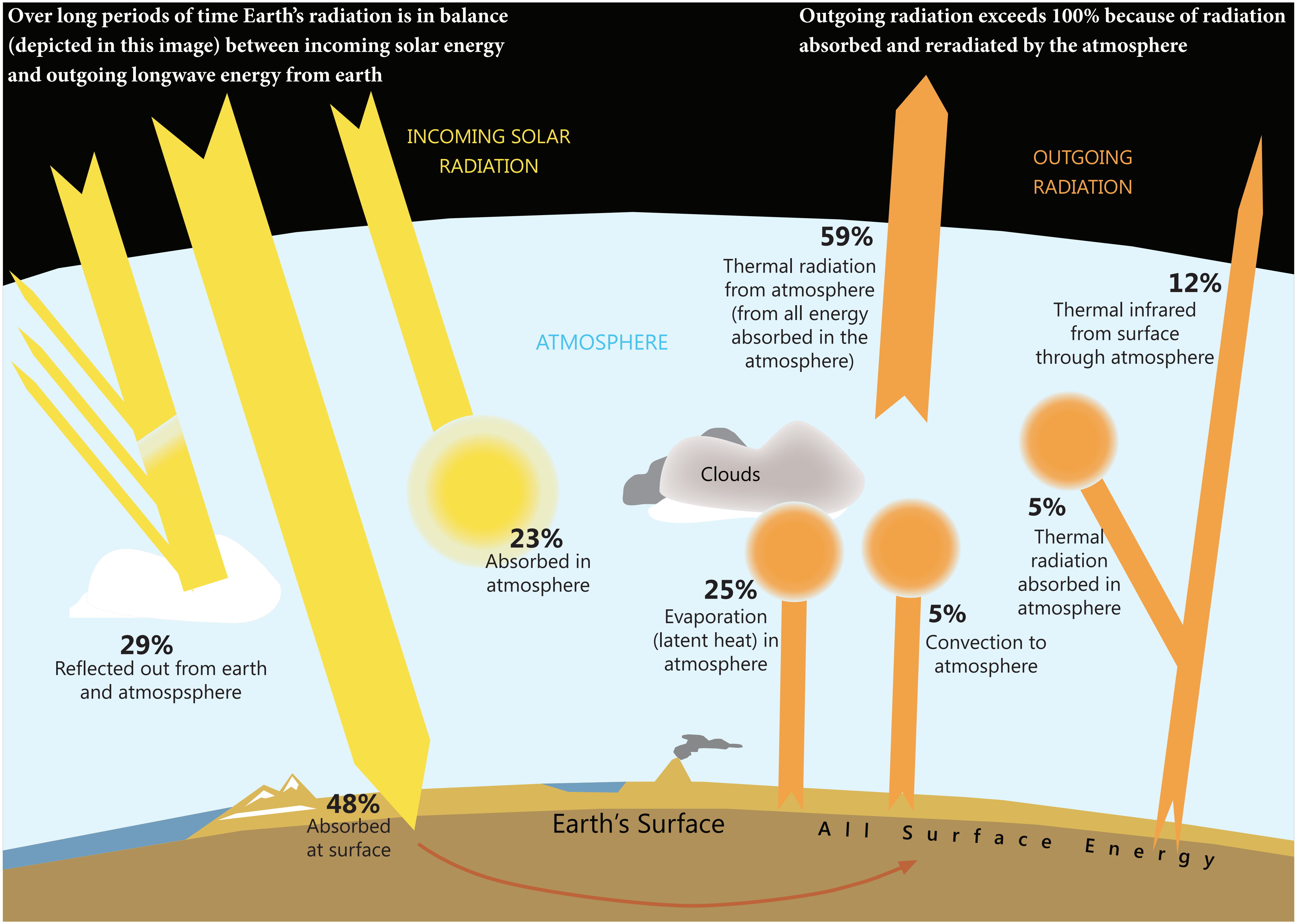
Mt. St. Helens' 1980 explosion had little impact on climate due to its small size, low sulfur content, and a dust cloud of limited size and height. In contrast, Mt. Tambura (1815, Indonesia), Mt. Krakatoa (1883, Indonesia), and Mt. Pinatubo (1991, Phillippines), each ejected a large volume of material high into the atmosphere. The resultant cooling created "The Year Without Summer" in 1816 in the Northern Hemisphere and reduced summer temperatures in the Northern Hemisphere in 1884 (by up to 2°F) and in 1992 (by up to 0.6°F).

Although we know the general distribution and depth of Mt. Mazama ashfall (approximately 7,700 years ago), there is no record of its impact on climate. The Mt. Mazama eruption formed Crater Lake.





Radiation Balance



Greenhouse Gases

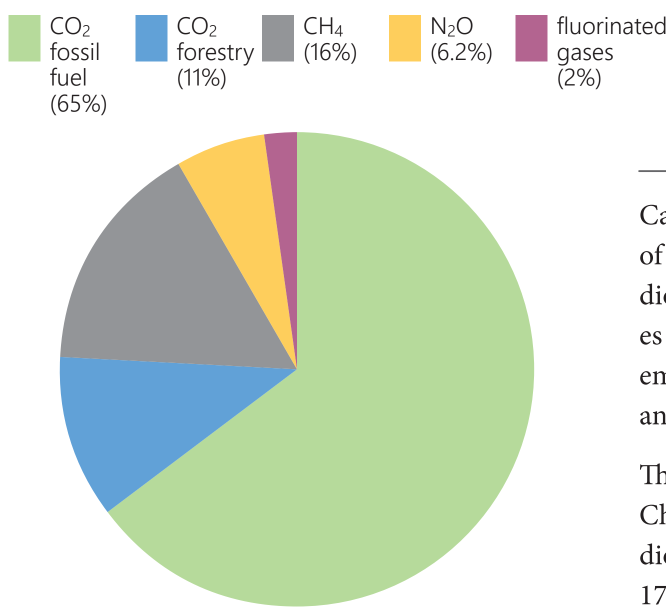
Earth's atmosphere is a mixture of gases. A few of those gases, such as water vapor, methane, and carbon dioxide, absorb infrared radiation very effectively. These are called ***greenhouse gases***.

Most of the solar radiation that reaches earth is absorbed, causing whatever absorbs the energy (the ground, plants, clouds, etc.) to heat up. Some of that energy may be re-emitted toward space as infrared radiation. If there were no atmosphere, that energy would simply be lost to space. However, if that infrared radiation encounters a greenhouse gas molecule, it is absorbed by the gas, and the thermal energy is transfered to the gas, heating the atmosphere. The gas molecule can also re-emit the absorbed thermal energy back towards earth, where it can cause additional heating.

The heat-trapping effect of greenhouse gases allows life on earth to exist; without it, the surface temperature of earth would fall to well below freezing. However, recent activity by humans is putting extra greenhouse gases into the atmosphere, especially carbon dioxide and methane, and this is causing the planet to heat up at an accelerated rate.

trichlorofluoromethane
also known as Freon-11,
an example of a fluorinated gas
CCl_3F

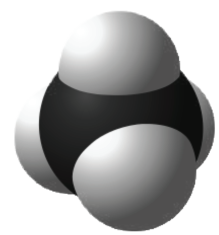
nitrous
oxide
N_2O



Relative percentages of human-generated greenhouse gas emissions

Carbon dioxide makes up the largest fraction of greenhouse gas emissions. In 2010, carbon dioxide from fossil fuel and industrial processes made up 65% of the total greenhouse gas emissions, and carbon dioxide from forestry and other land uses made up another 11%.

The Intergovernmental Panel on Climate Change estimates that half of all carbon dioxide produced by human activity between 1750 and 2010 has been emitted in the last 40 years.



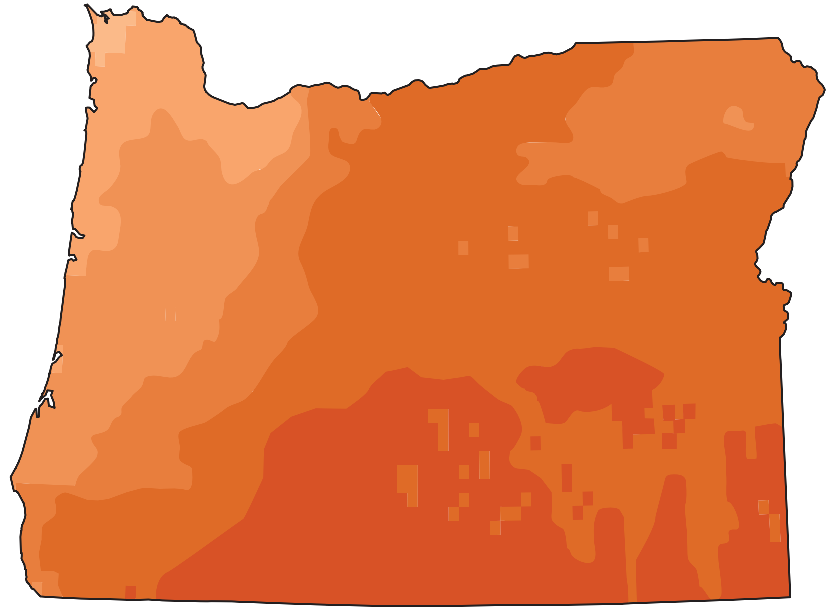
methane
CH_4

carbon
dixoide
CO_2

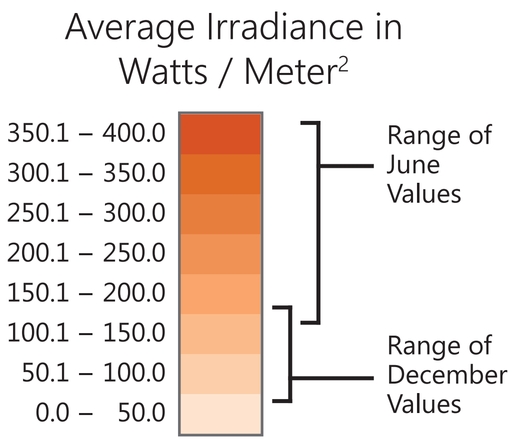
Solar Energy

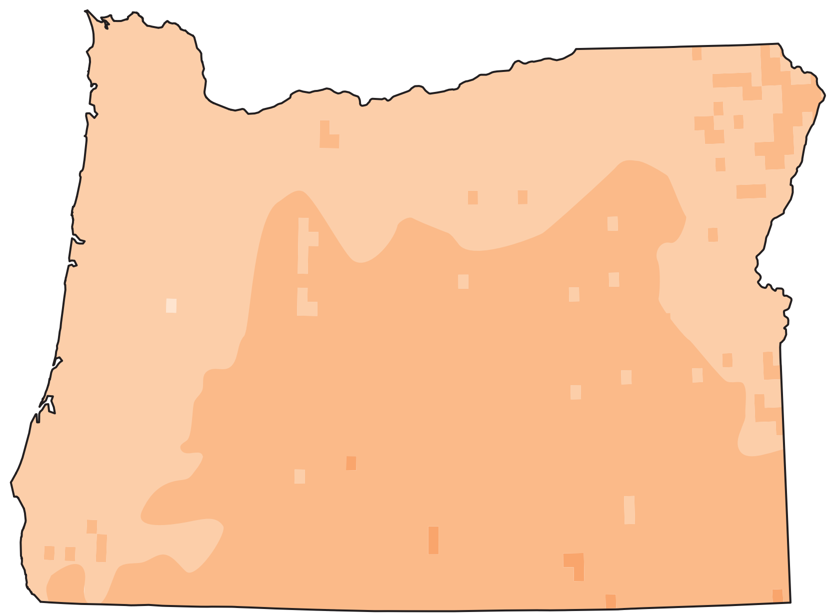
Solar energy is frequently expressed in terms of ***irradiance***. Irradiance is a measure of the rate at which solar energy in the form of electromagnetic radiation is delivered to an area at any given time. It is measured in power per area (for example watts / meter^2).

Solar energy can also be expressed in terms of ***insolation***, measured as the total amount of solar radiation energy delivered to an area over a specified time interval (kilowatt-hour / meter^2 / day).



June



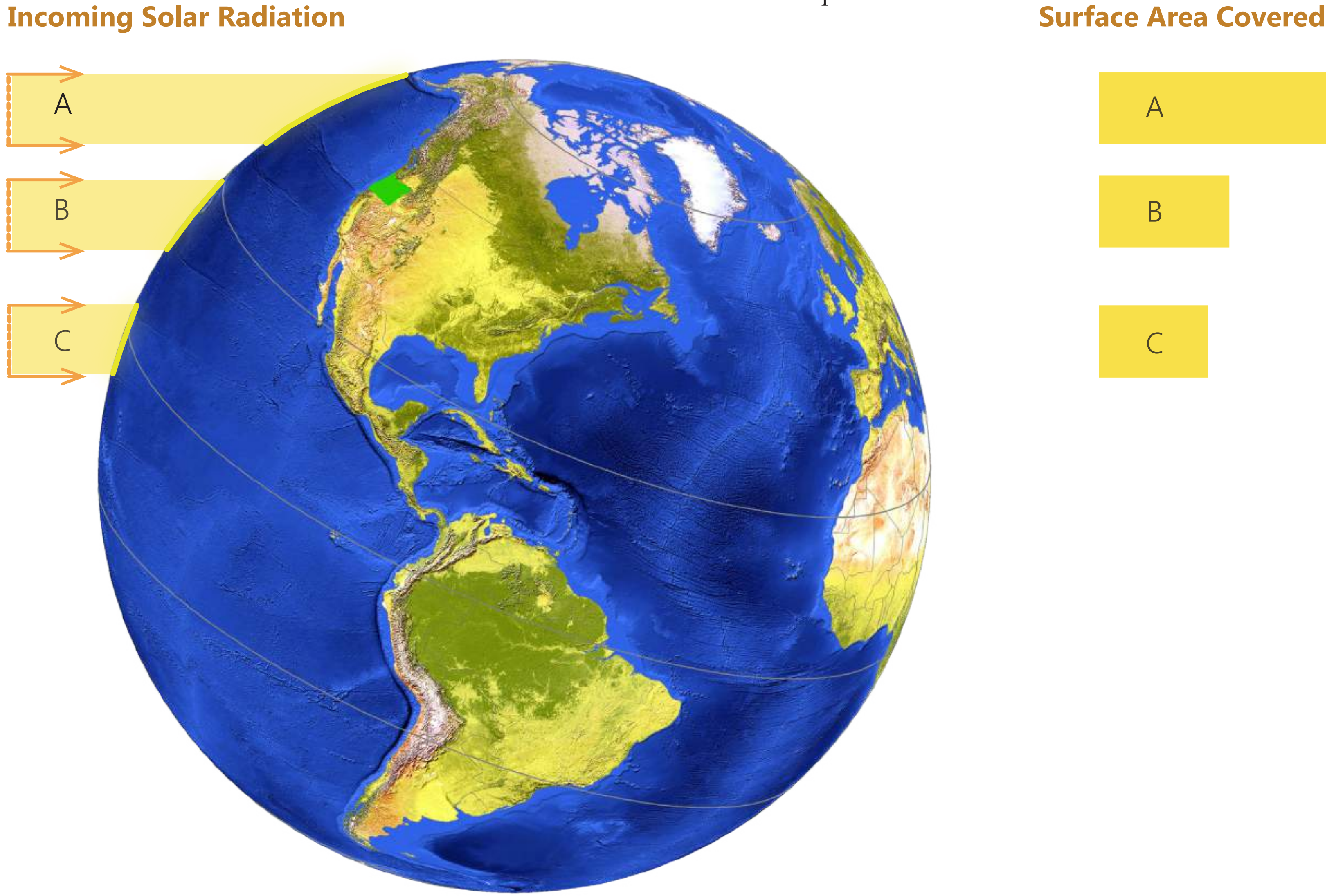


December

Latitude

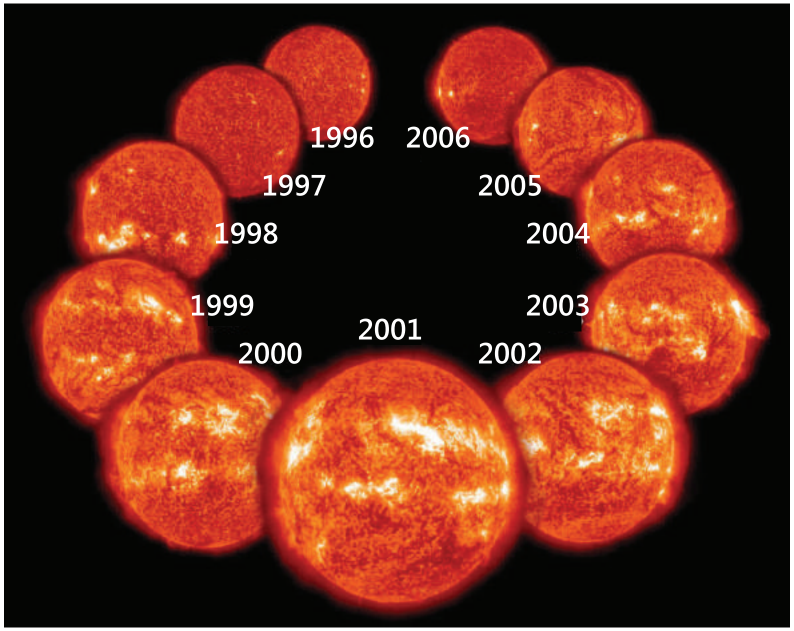
The angle of incoming solar radiation determines the intensity of the energy received at the surface of the earth. The higher the sun angle (the closer to 90°), the greater the rays – or intensity – per surface area (for example, per square meter).

The greater the intensity, the greater the heating and temperature. When the sun is at a lower angle, the solar radiation is spread over a greater surface area, reducing the intensity. This difference in intensity of energy received explains why the earth is colder near the poles and warmer near the equator.

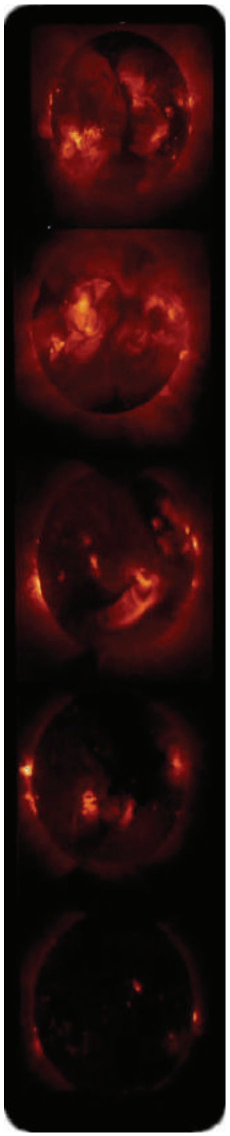


Solar Cycles and Sunspots

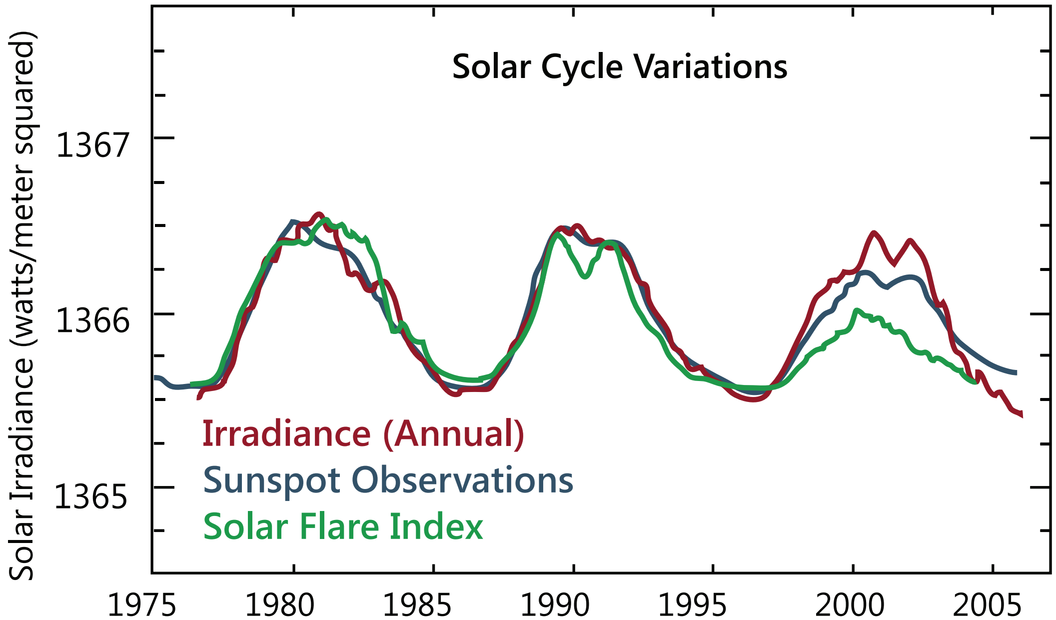
Sunspots cause the light emitted by the sun to vary on a time scale of a ***solar cycle,*** approximately 11 years. The greater the number of sunspots, the greater the energy radiated to space; the fewer the sunspots, the less radiatiated energy. There is no clear evidence that sunspots affect the earth's weather.



Solar cycle from solar minimum (upper left) to maximum conditions and back to minimum



Sunspots (from space satellite)



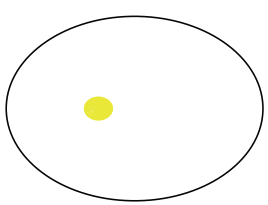
Earth-Sun Relationships: Milankovitch Cycles

Astronomer ***Milutin Milankovitch*** developed the mathematical formulas upon which earth-sun orbital variations are based. He hypothesized that when some parts of the cyclic variations are combined and occur at the same time, they are responsible for major changes to the earth's climate, including ice ages.

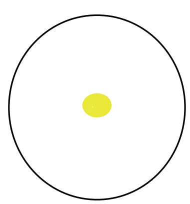
Milankovitch estimated climatic fluctuations over the last 450,000 years and described cold and warm periods. Though he did his theoretical work in the first half of the 20th century, Milankovich's results were not proven until the 1970s. A 1976 study examined deep-sea sediment cores and found that Milankovich's theoretical estimates corresponded to periods of climate change.

The Milankovitch cycles are:

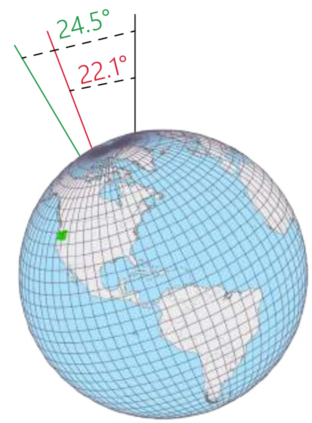
Eccentricity: The earth's orbit around the sun is an ellipse but its shape changes over time due to the gravitational pull of other planets. Eccentricity refers to how far the ellipse varies from a circular shape. The principal cycle of eccentricity is a period of ~400,000 years with a sub-cycle of ~100,000 years.



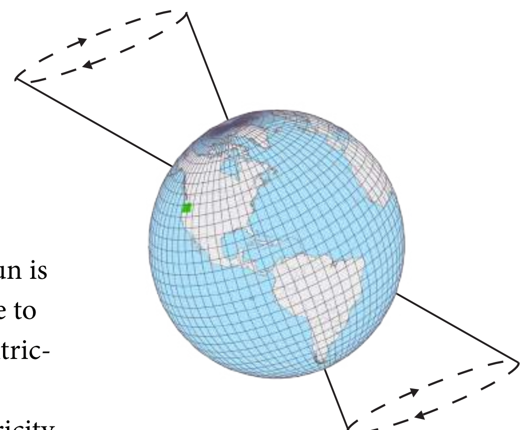
Elliptical Orbit



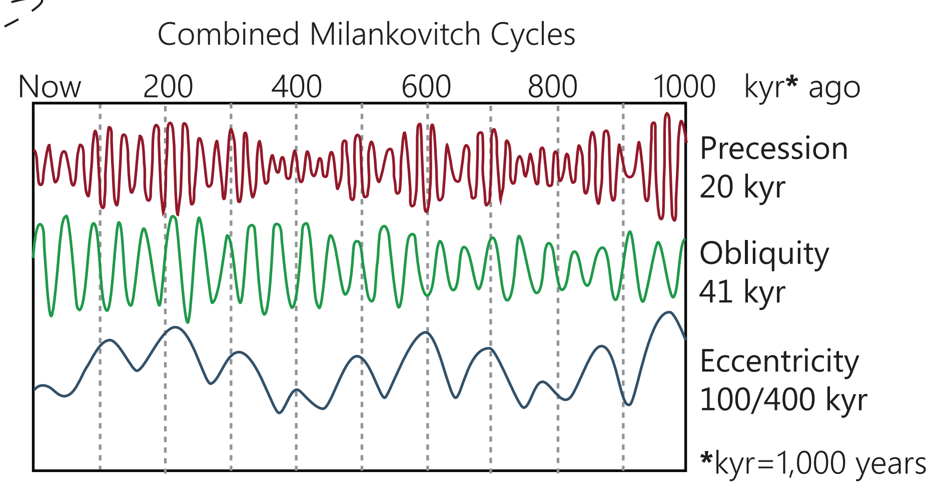
Circular Orbit



Obliquity: The axial tilt of the earth varies with respect to the plane of its orbit, varying from 22.1° and 24.5°, and back again. The change in axial tilt causes changes in the solar radiation received at the surface. For example, with a high amount of obliquity (24.5°) summers in both hemispheres receive more insolation, and winters receive less. Right now the earth's axial tilt is approximately 23.5°. The cycle of obliquity takes 41,000 years to complete (from 22.1° to 24.5°, and back again).



Precession: Due to gravitational forces exerted by the sun and moon on earth, the earth's axis has a gyroscopic motion. This motion – precession – is the trend in the direction of the earth's axis of rotation relative to fixed stars. When the axis points toward the sun in ***perihelion*** (when the earth is closest to the sun) the northern hemisphere experiences warmer summers; when the axis points away from the sun in ***aphelion*** (when the earth is furthest from the sun), it experiences colder winters. Today, perihelion occurs during the southern hemisphere's summer. The cycle of precession is approximately 26,000 years.

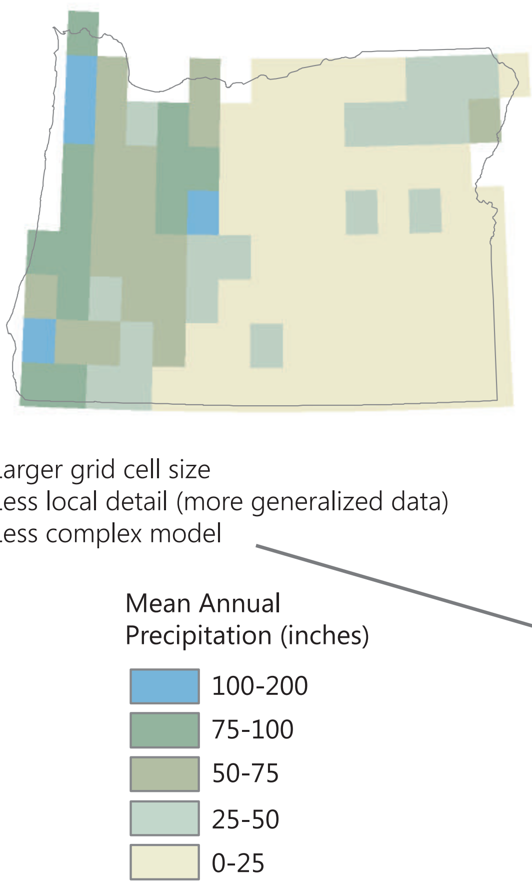


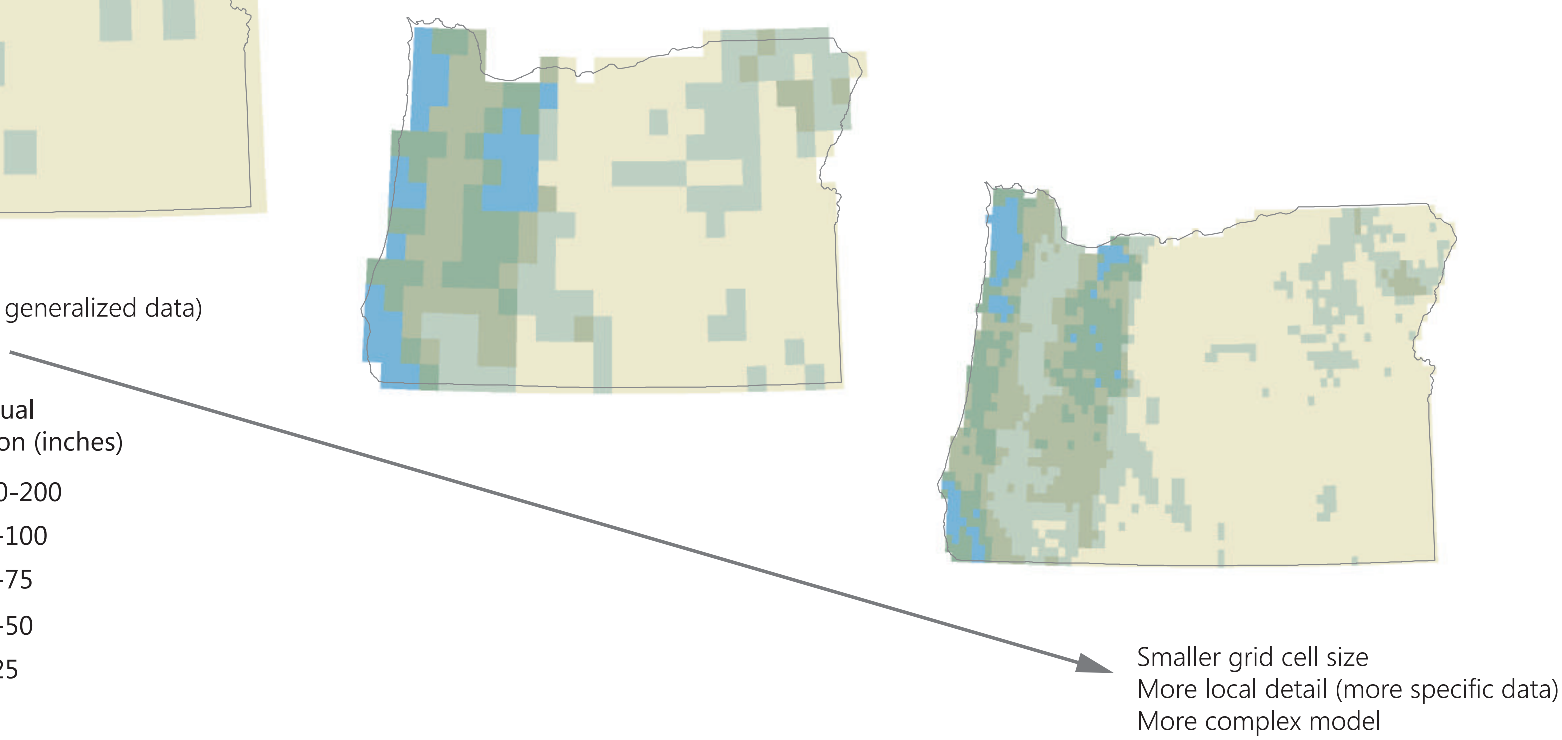
Climate Models: Grid Cells

Scientists use climate models to simulate the dynamic interactions of land, oceans, atmosphere and ice that create our climate. Simple models measure a single attribute (temperature or solar radiation, for example) at only a few points on earth. More complex models measure many attributes at many places over time. In climate models, the atmosphere, ocean, and earth surface are first divided into 3-D ***grids cells***.

The smaller the grid cells, the greater the amount of data that can be collected and the more precise the outcome of the model – but more calculations are required, too.

The data collected for each grid cell are programmed into a computer that solves mathematical equations using scientific laws governing energy, movement, behavior of gases, and other characteristics of the climate data. The results allow scientists to predict how the climate system will react to changes in the system, such as increases in atmospheric concentration of greenhouse gases.





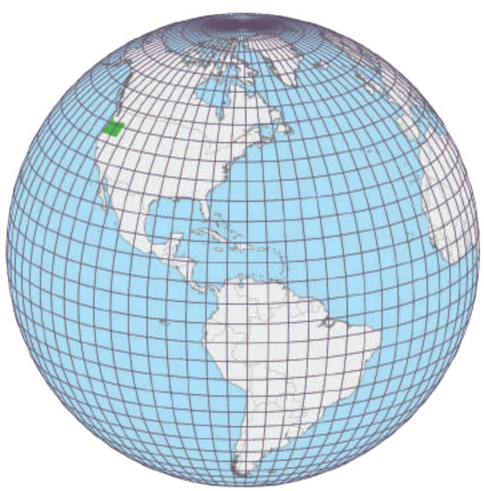
Climate Modeling and Projections

Climate models based on data gathered by satellites and other instrumentation are comprised of 3-D ***grid cells*** that contain information about the key physical characteristics of that cell, such as temperature, precipitation, ice cover, and gases. The information is represented by mathematical equations derived from physical, chemical, or empirical data.

The mathematical equations are translated into computer code, usually divided into climate components (ocean, atmosphere, land surface, etc.) that allows different elements of the model to interact among grid cells and between the different components of climate.

Climate models also incorporate time, allowing the model to simulate what happens in each grid at a particular time, and then advance forward in time by hours, days, months or years (climate projections).

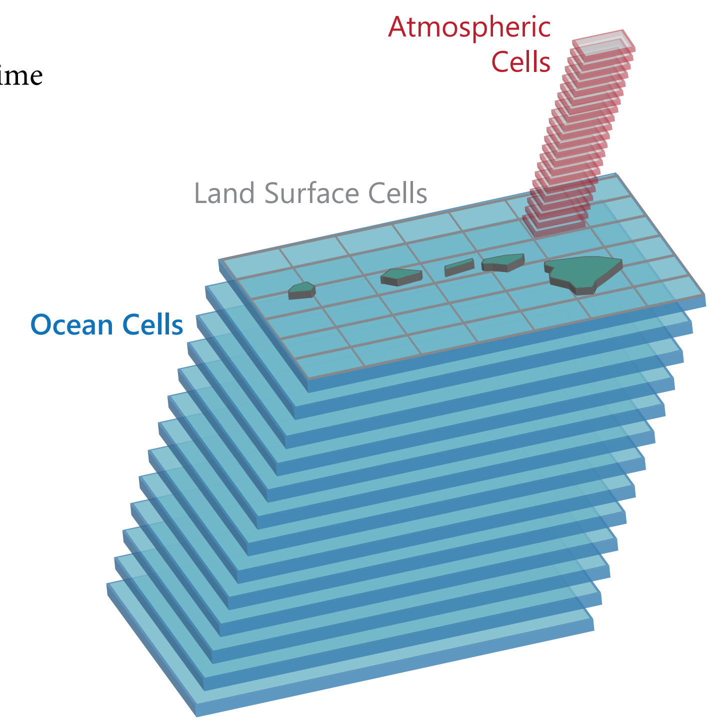
Climate projections create different scenarios for future time periods from climate models. Climate models are often referred to as ***general circulation models*** (GCMs).



5° x 5° latitude/longitude grid

How do we test a climate model?
To test, or validate, a climate model, we run a model simulation and compare what the model prediccts with the actual, observed climate information we have from current and historical data.

Why do climate models and projections differ?
The climate system is complex, and the interactions among all of its elements are not fully understood (for example, the role of clouds is not completely understood). Hence different mathematical equations may represent the same climate process but arrive at different projections. By constant comparison of results, climatologists can find the most accurate equation to match the observed climate.



Progression of Climate Models

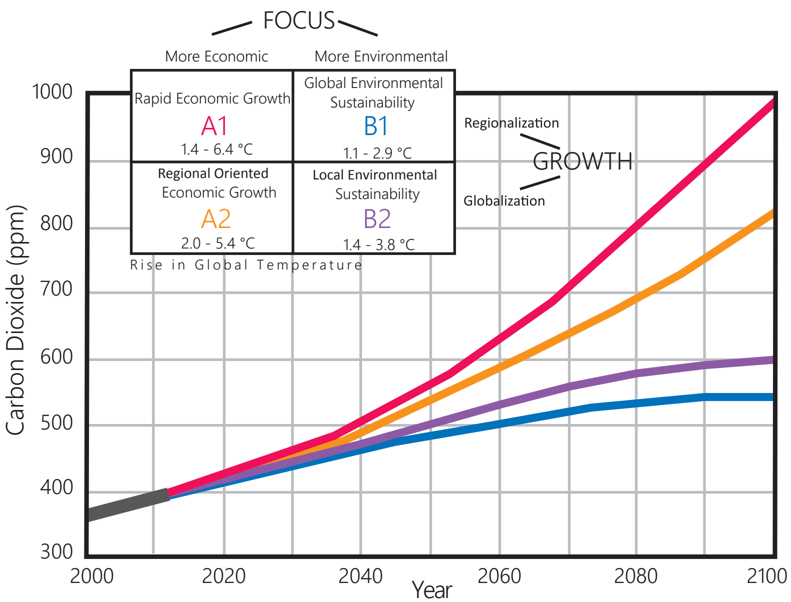
Over time, the number of grid cells and climate data associated with each cell has increased, improving the accuracy of climate models.

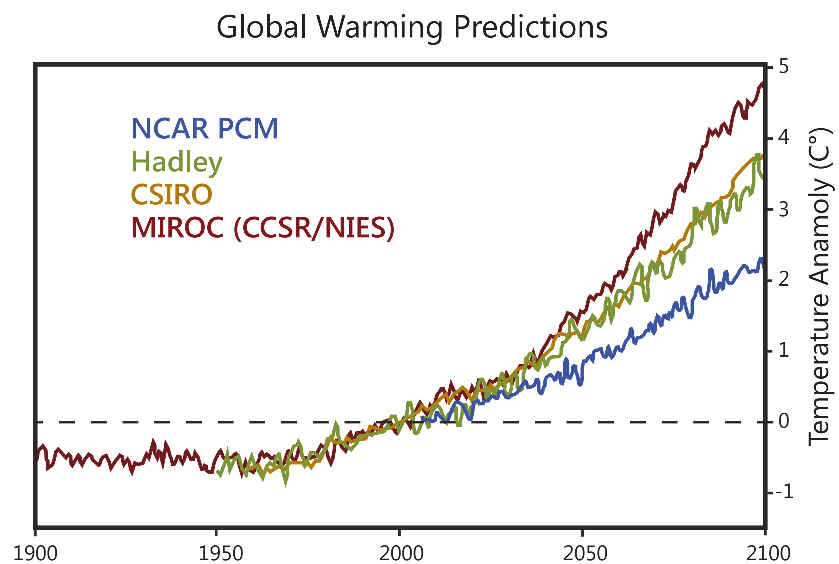
1990's	Present Day
Atmospheric Cell Size (19 levels)	Atmospheric Cell Size (38 levels)
270 x 270km	135 x 135km
Ocean Cell size (20 levels)	Ocean Cell size (40 levels)
1.25° x 1 .25°	1.0° x 1.0°

Climate Models and Scenarios

Climate model projections are used to help us predict the impacts of changes in the climate system. For example, what will be the impact of increased atmospheric CO_2 from economic growth? What will be the impact of attempts to increase sustainability on our planet? The climate model below estimates the impact on CO_2 from different scenarios of economic growth, sustainability practices, and local vs. regional actions.

Because of the complexity of climate models and slight differences in mathematical equations, not all climate predictions are identical. The Global Warming Projections below show the predicted increases in global temperatures from several climate models. A ***temperature anomaly*** is a departure from a long-term average. Each of the models shows an increase in the temperature anomaly, though the amount of the increase varies.





The climate models referred to on some of the maps in this atlas are:

NCAR: Climate models developed by the National Center for Atmospheric Research (in the United States)

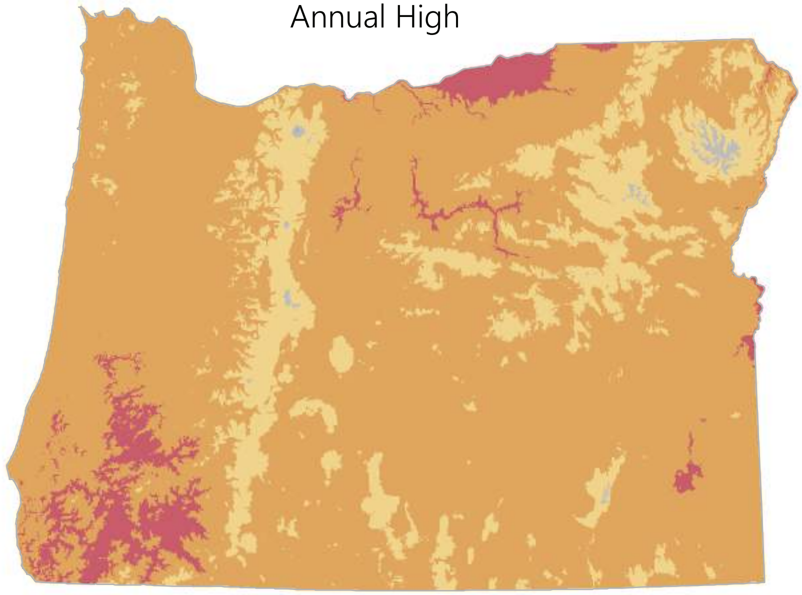
Hadley: Climate models developed by the Hadley Centre (in the United Kingdom)

CSIRO: Climate models developed by the Commonwealth Scientific and Industrial Research Oreganisation (in Australia)

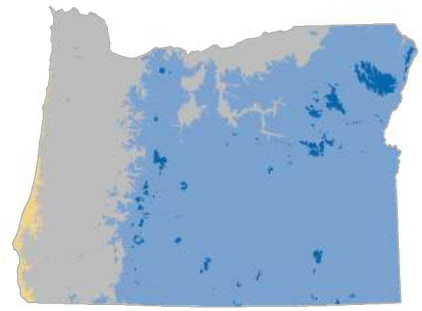
MIROC (CCSR/NIES): Climate models developed by the MIROC group (Model for Interdisciplinary Research on Climate) of the National Institute for Environmental Studies (in Japan)

Temperature 1981-2010

Annual High

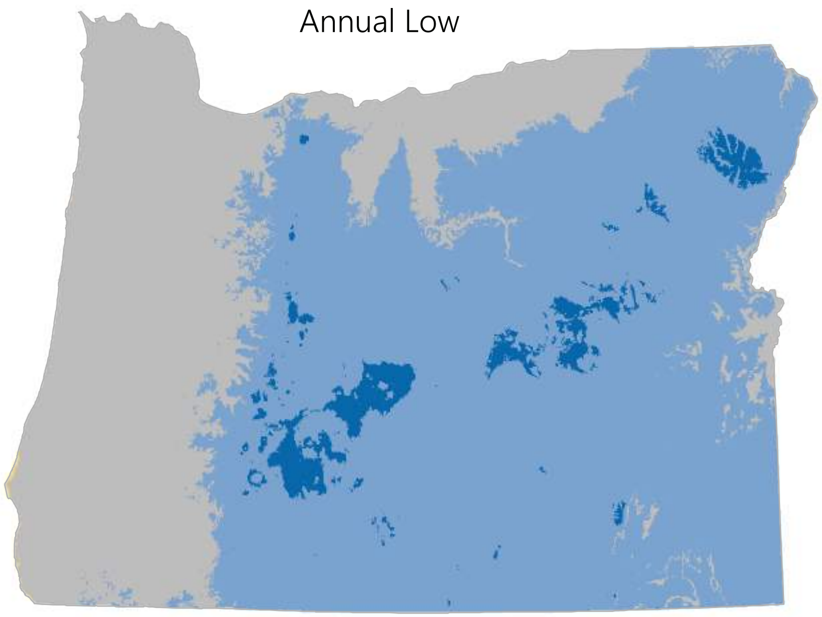


Average Winter Temperature
(Dec-Feb)

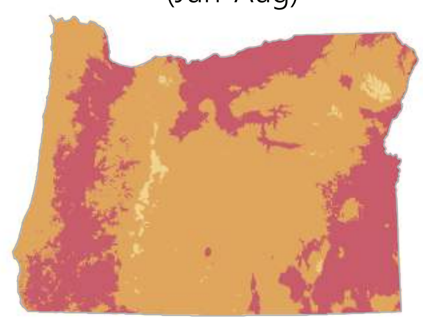


Average Spring Temperature
(Mar-May)

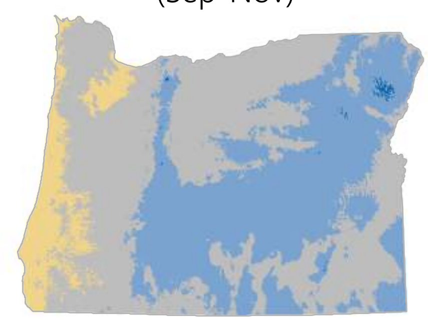
Annual Low

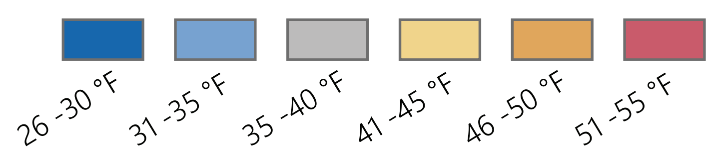


Average Summer Temperature
(Jun-Aug)



Average Autumn Temperature
(Sep-Nov)

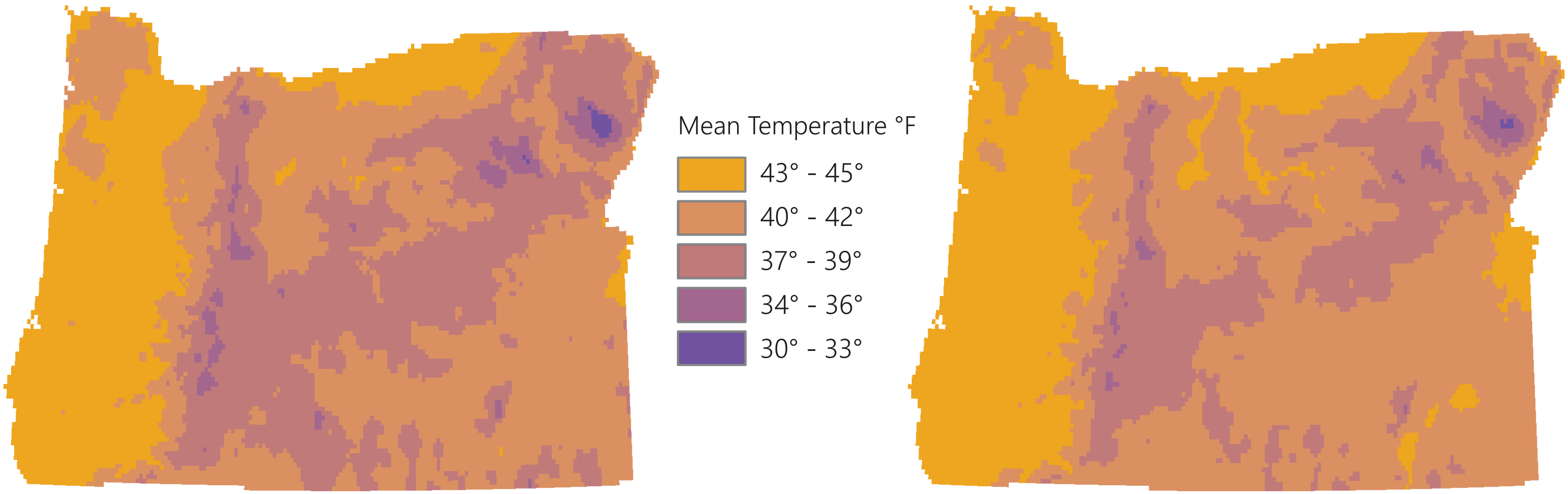




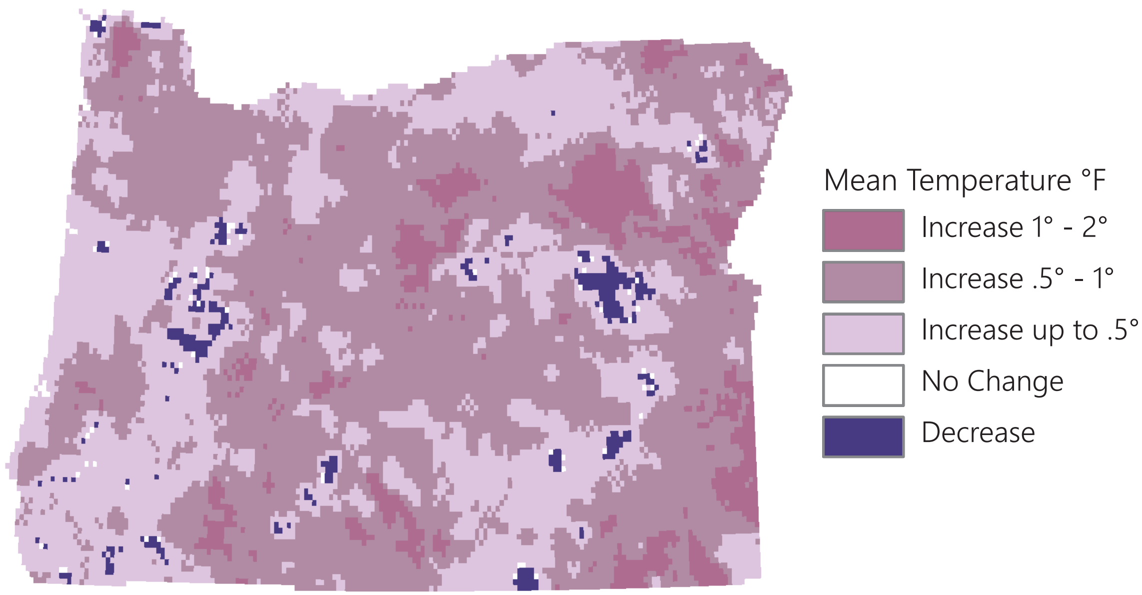
Temperature Change

Average Annual Temperature 1895 - 1924

Average Annual Temperature 1985 - 2012



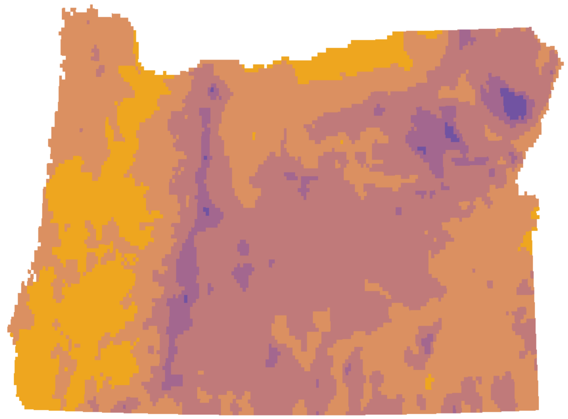
Temperature Change 1895-1924 to 1985-2012



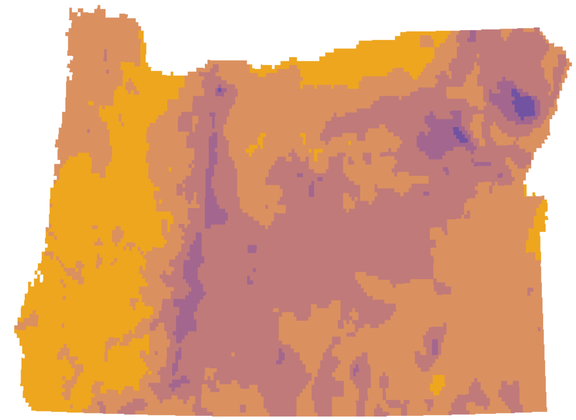
Average Temperature Model Predictions

These maps were made using an ensemble average of 16 General Circulation Models to show predictions based on both a B1 (global environmental sustainability) and an A2 (regional oriented economic growth) focus.

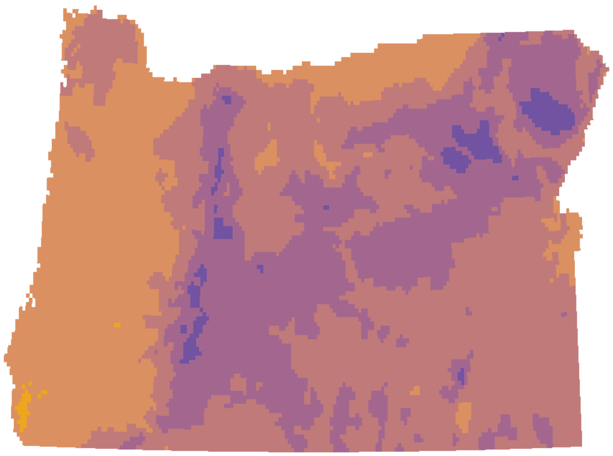
Predicted B1 Average Annual Temperature 2050



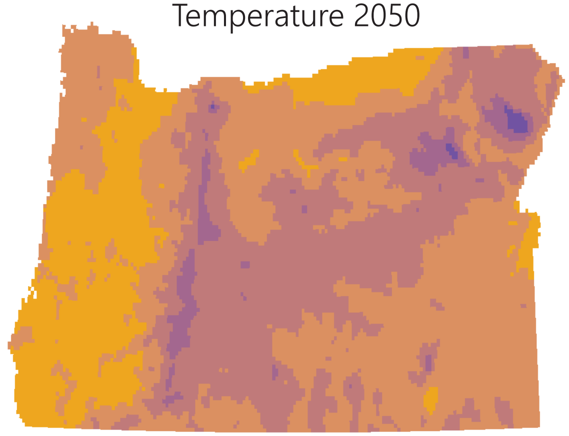
Predicted B1 Average Annual Temperature 2080



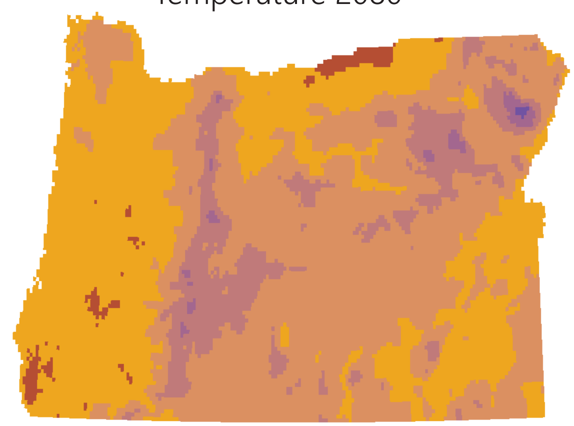
Average Annual Temperature 1951-2006

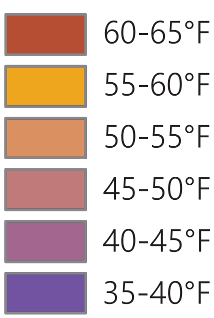


Predicted A2 Average Annual Temperature 2050

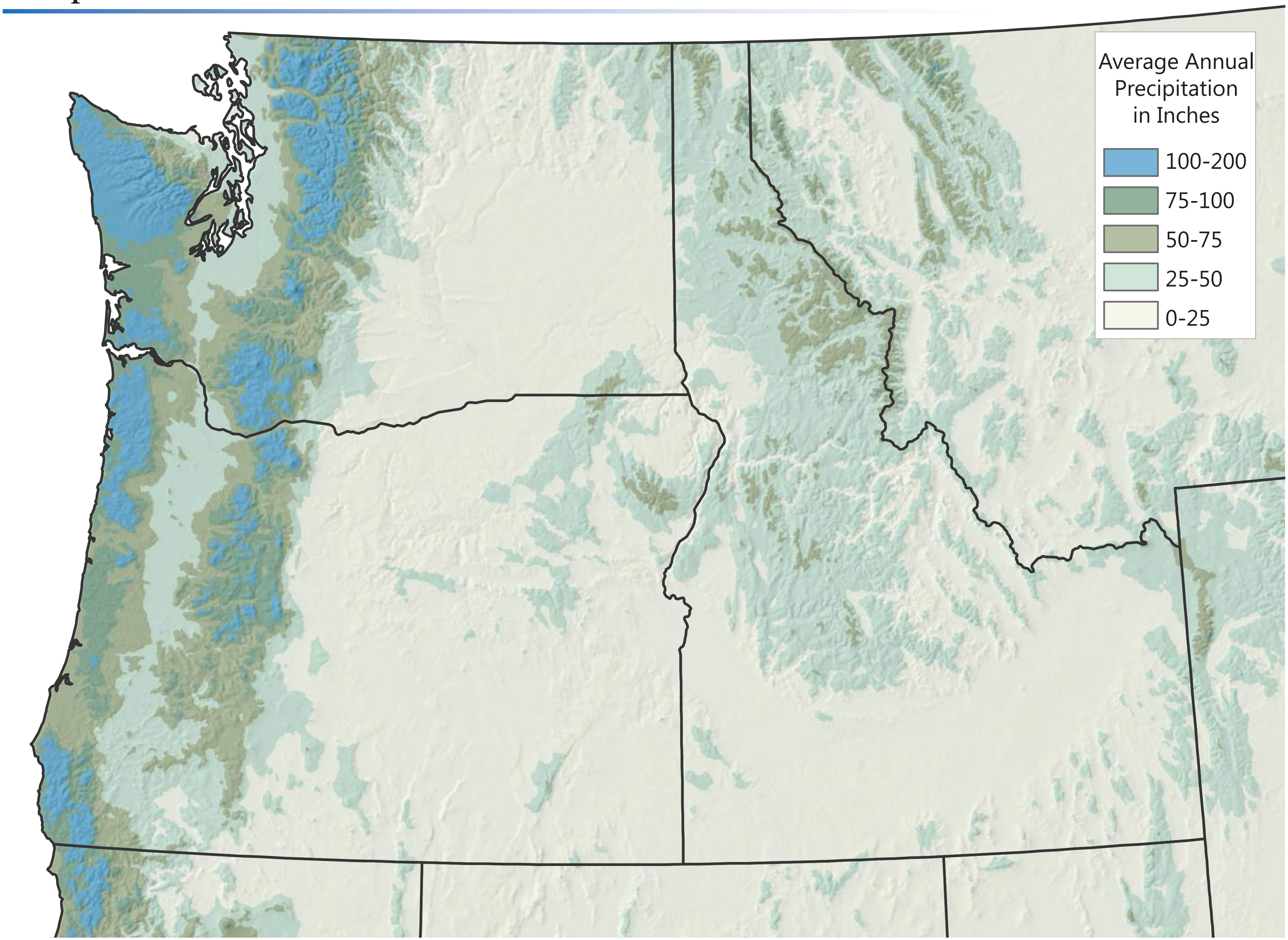


Predicted A2 Average Annual Temperature 2080



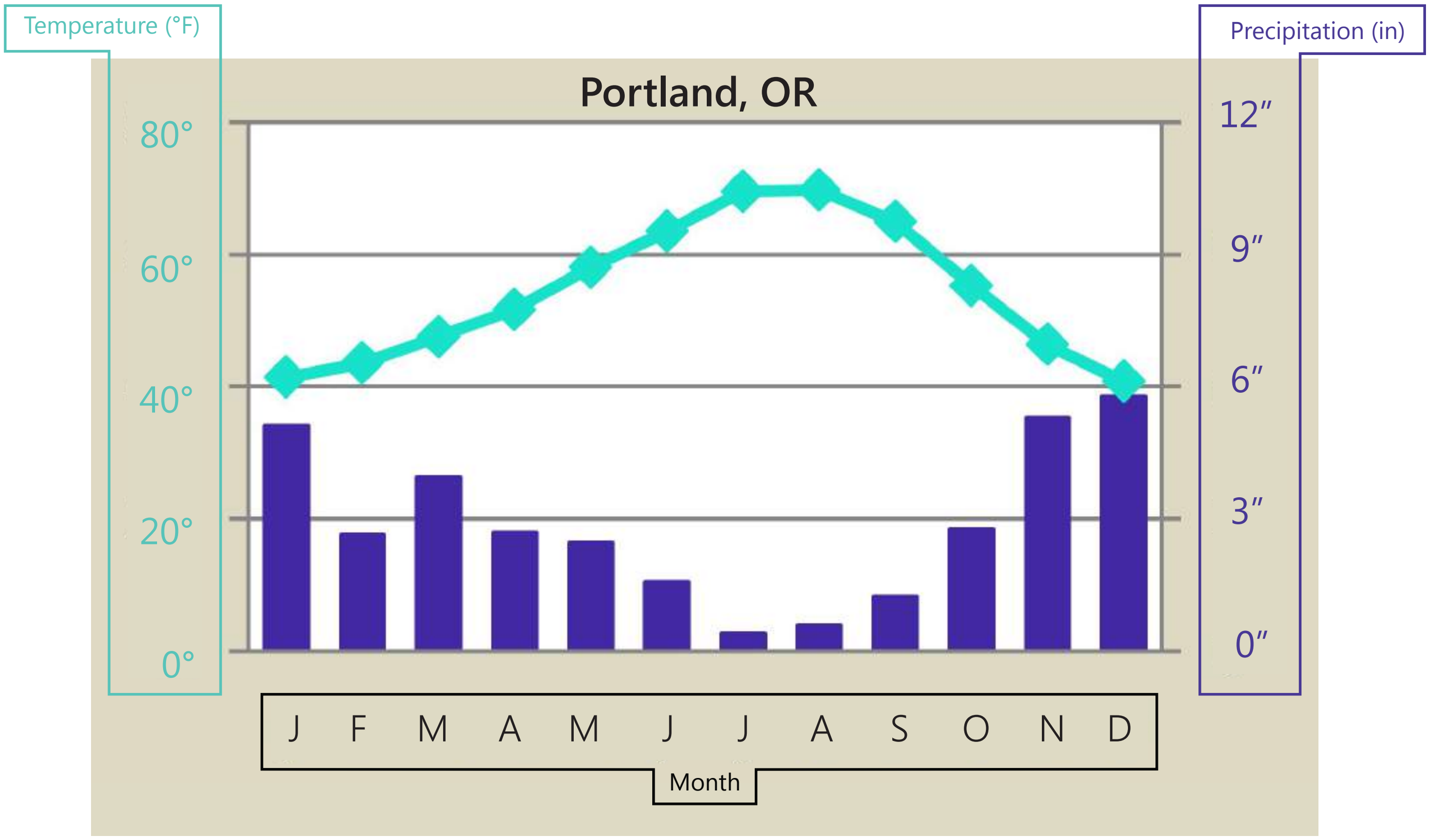


Precipitation 1981-2010



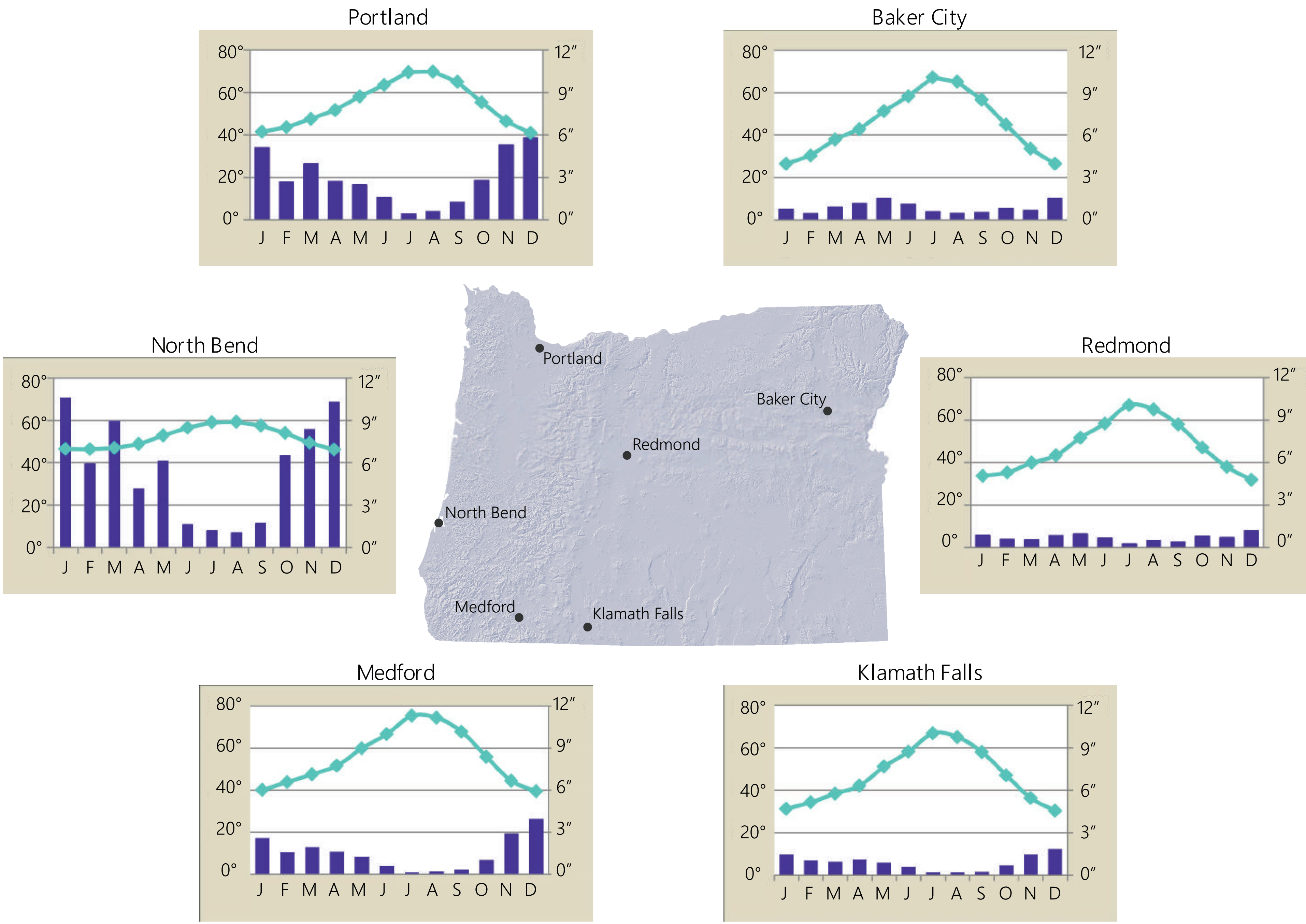
Displaying Climate Data: Climographs

A ***climograph*** is a graph showing the annual temperature and rainfall of a particular geographic location such as a city. On the graph, the horizontal axis shows the months of the year, one vertical axis shows the mean monthly temperature and the second vertical axis shows the mean monthly precipitation. Temperature is shown by the line with green diamond symbols and precipitation is shown by the bars.



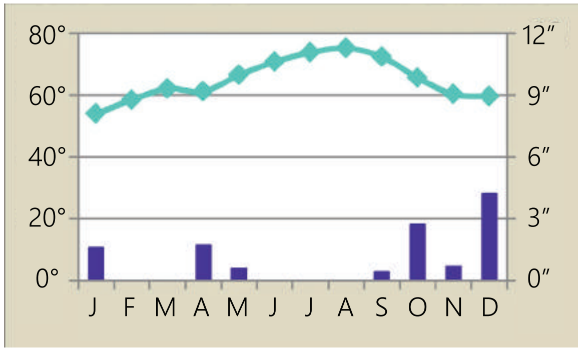
For instructions on how to make your own climograph for your town, go to this National Geographic website:
http://www.nationalgeographic.com/xpeditions/lessons/15/g912/creatingclimograph.pdf

Climographs: Oregon

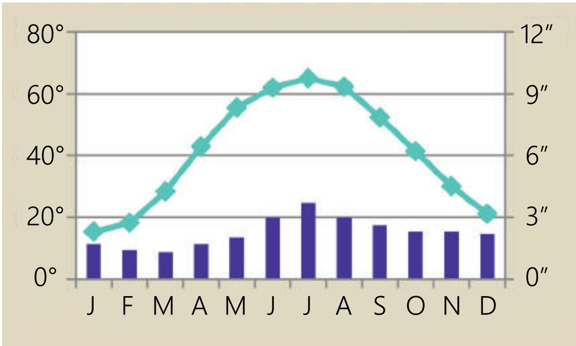


Climographs: Global

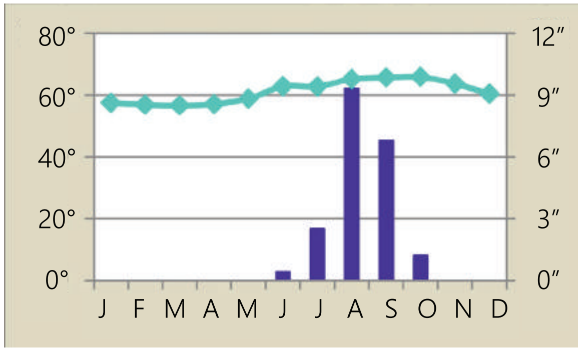
Casablanca, Morocco



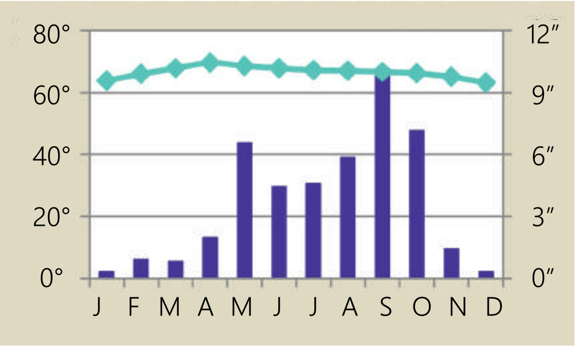
Moscow, Russia



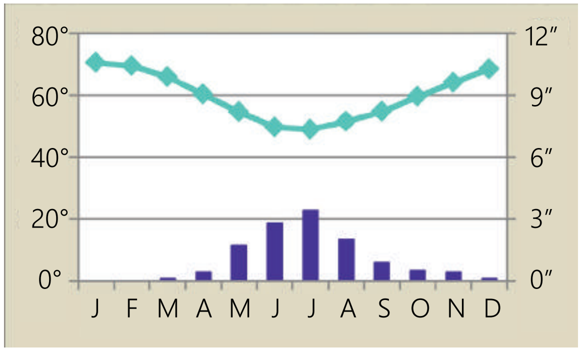
Dakar, Senegal



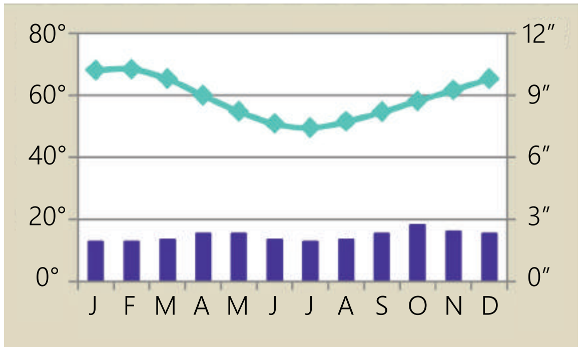
Bangkok, Thailand



Santiago, Chile

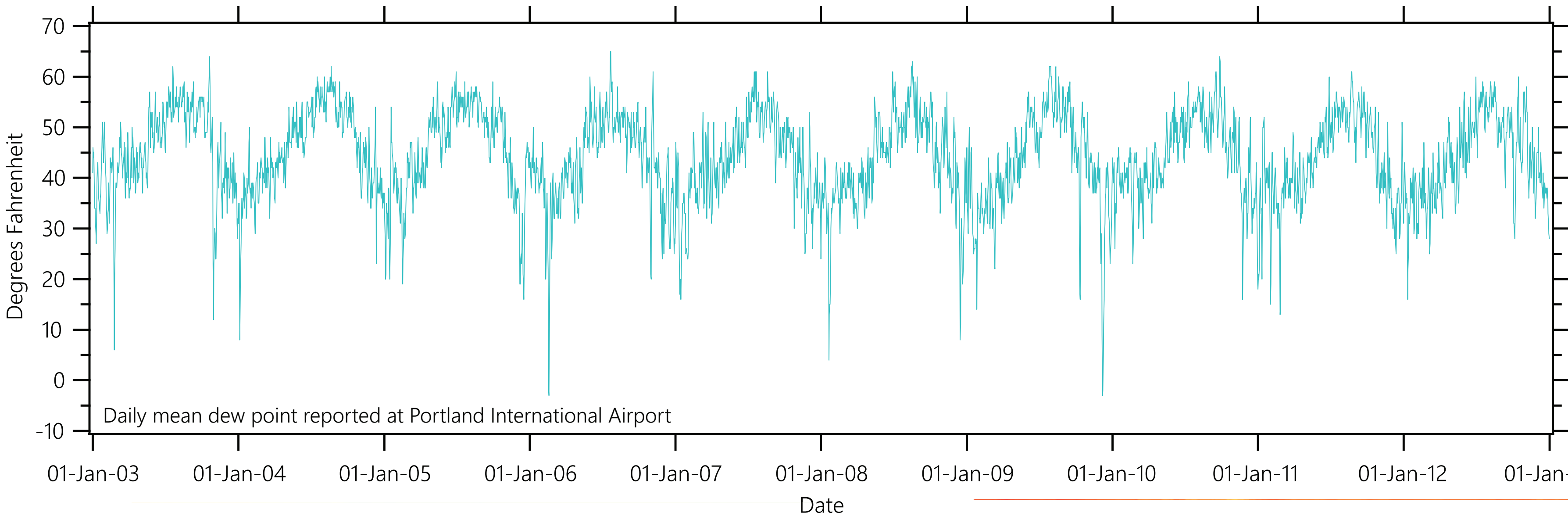


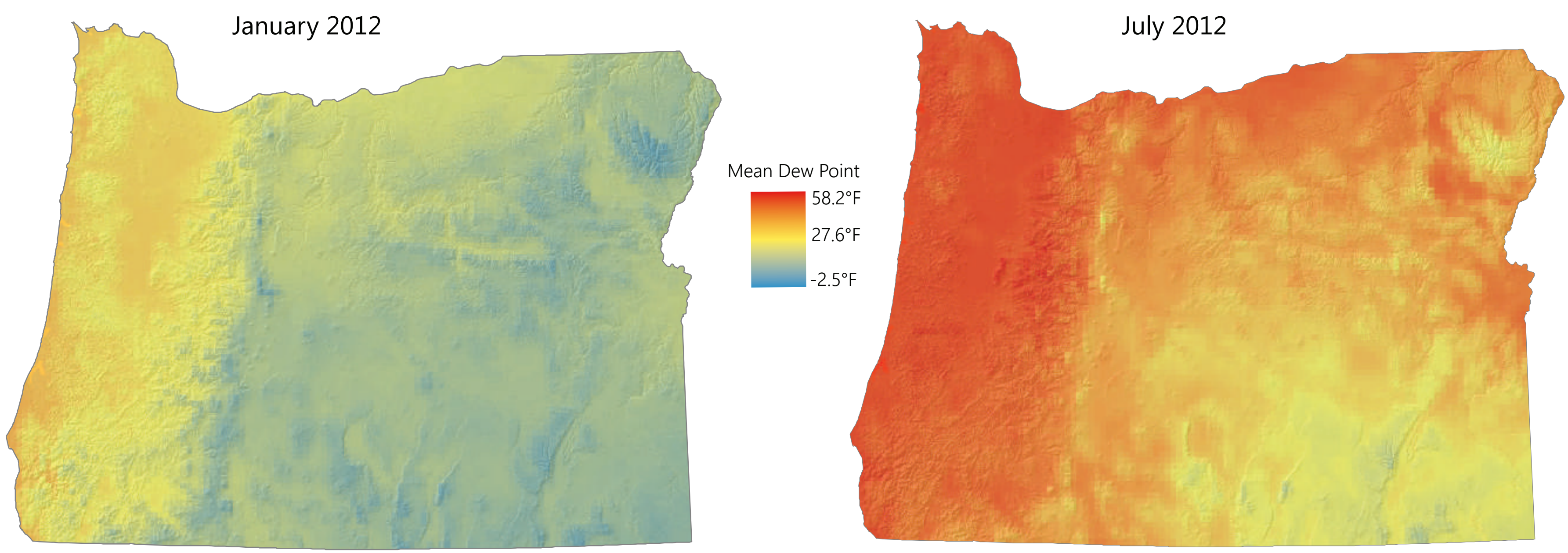
Melbourne, Australia



Dew Point

Dew Point is the atmospheric temperature below which water droplets begin to condense and form dew (or frost, fog, or clouds). It varies with the pressure and humidity of the air. At 100% relative humidity, the air temperature and dew point are the same.

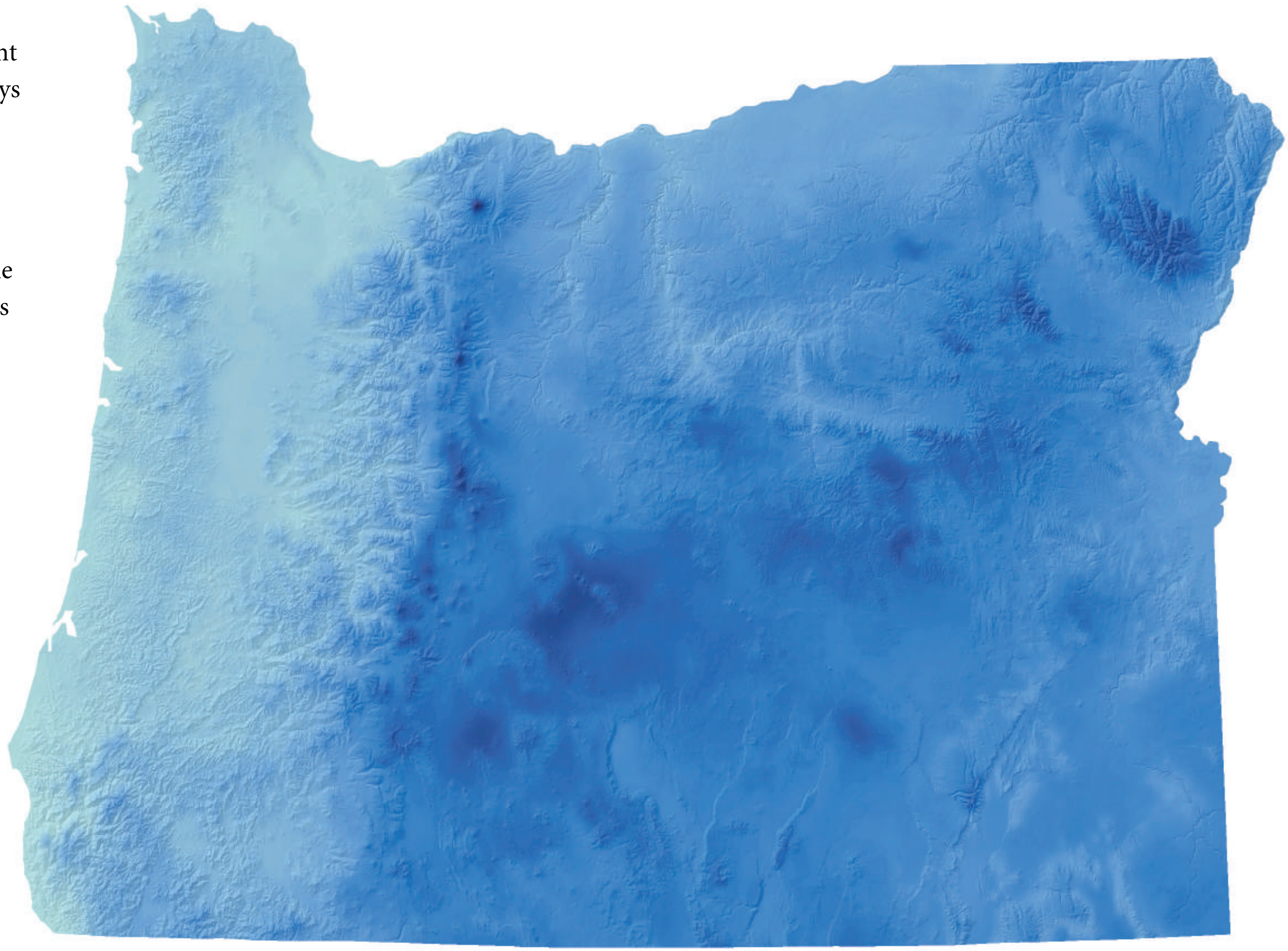




Frost Days

A frost day is any day when the minimum temperature dips below the freezing point of water. Typically, frost days are reported as the number of frost days that occur during a given year.

In the Pacific Northwest, the annual number of frost days decreased by an average of 2.6 frost days per decade between 1948 and 1999.



Number of Frost Days in 2012

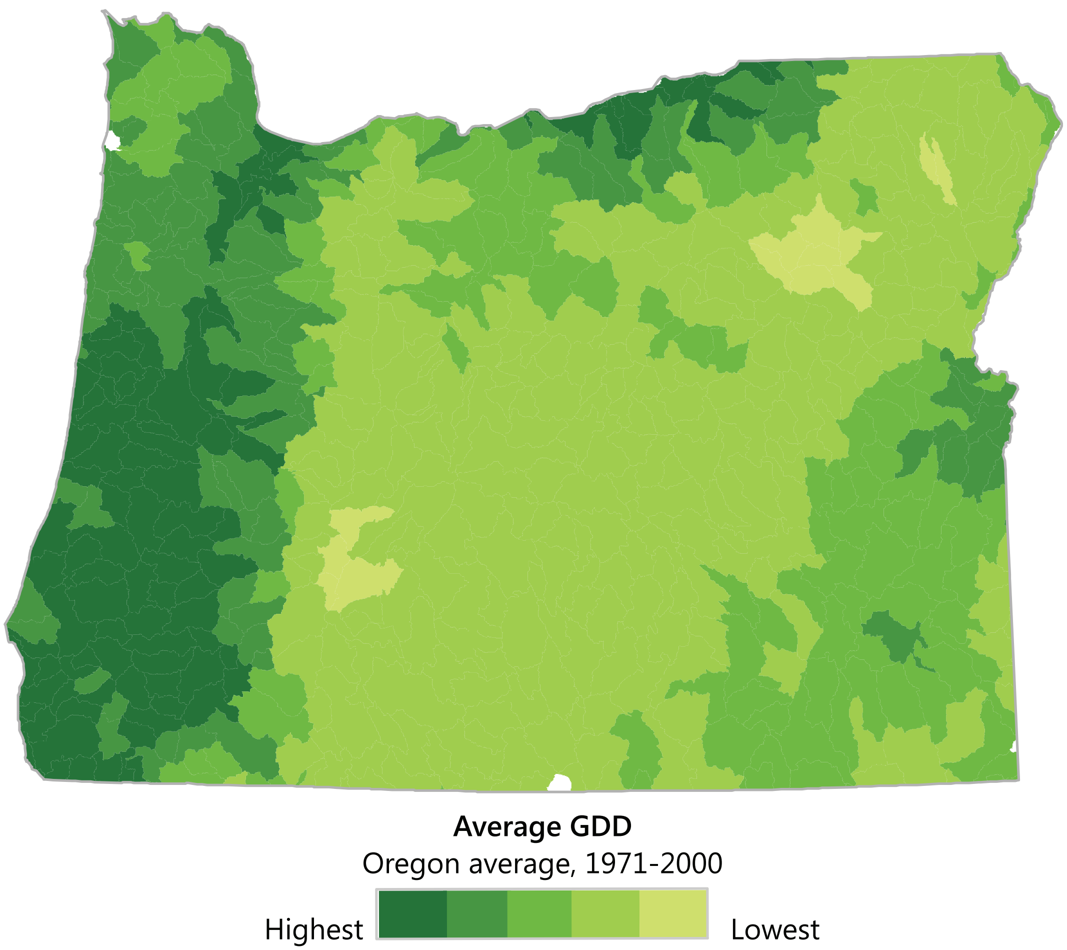
High : 351

Low : 0

Growing Degree Days

The term ***growing degree days*** (or *GDD*) refers to a measurement of heat accumulation during the growing season. It is frequently used in agriculture and gardening to assess crop suitability for a particular region and to manage the timing of fertilization and harvesting of crops. It is calculated by averaging the daily maximum and minimum temperatures and subtracting the base temerature (the temperature below which plant growth is zero).

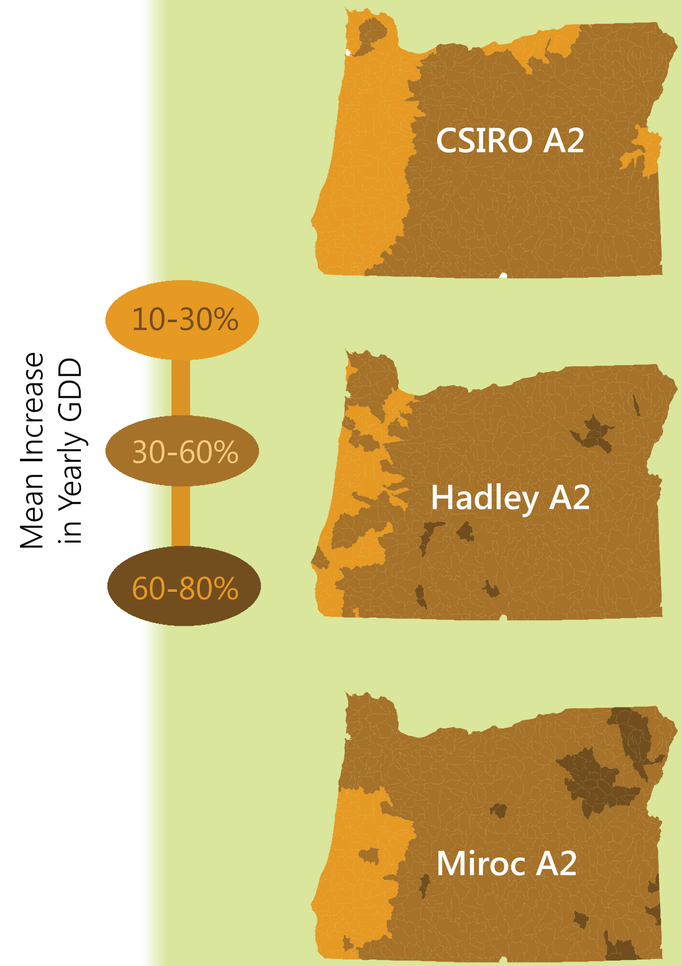
$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base}$$



GDD Projected Change

between historical (1971-2000) and future (2071-2100)

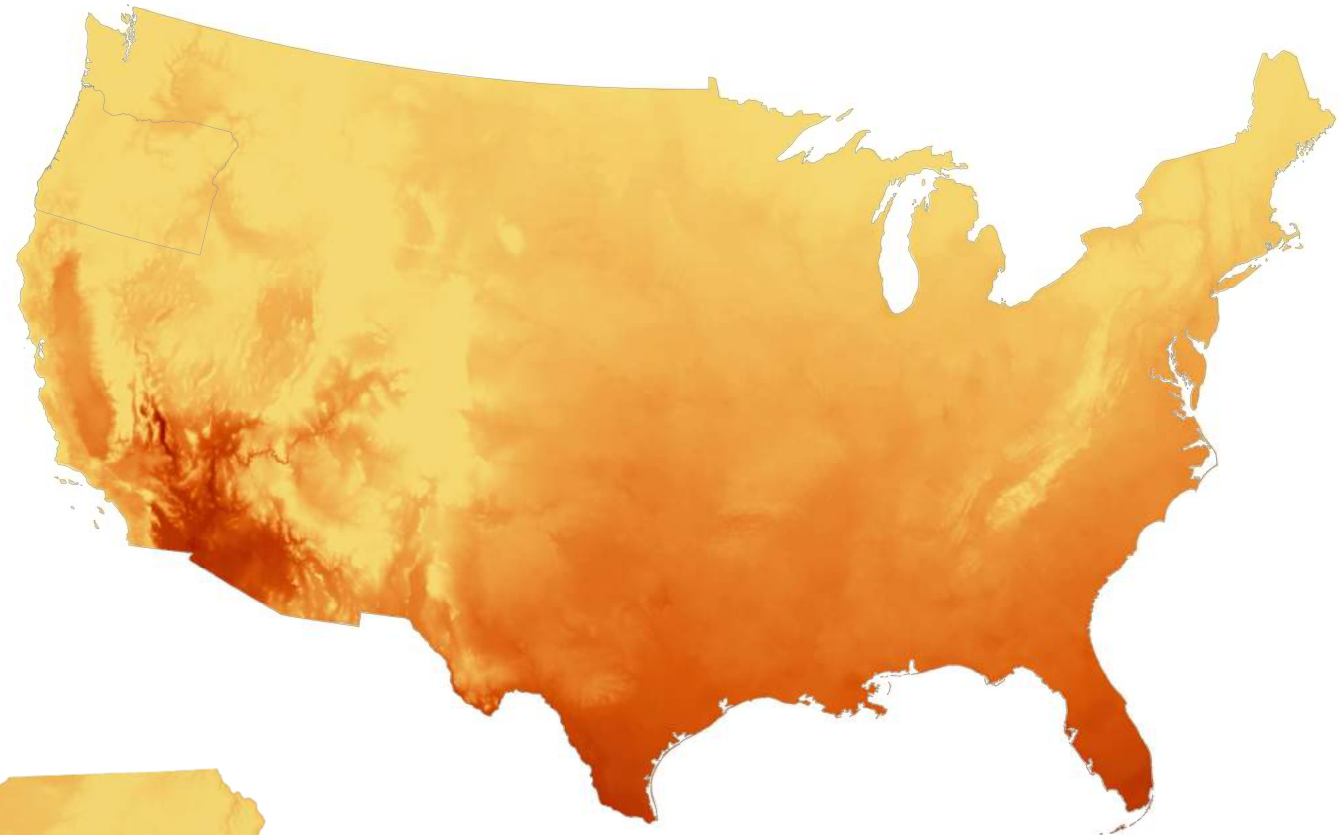
Several climate models have projected increases in growing degree-days in the future, which may improve conditions for some plants and crops, and degrade conditions for others.

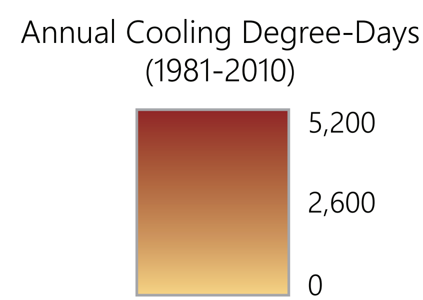


See page 27 for descriptions of climate models

Annual Cooling Degree-Days

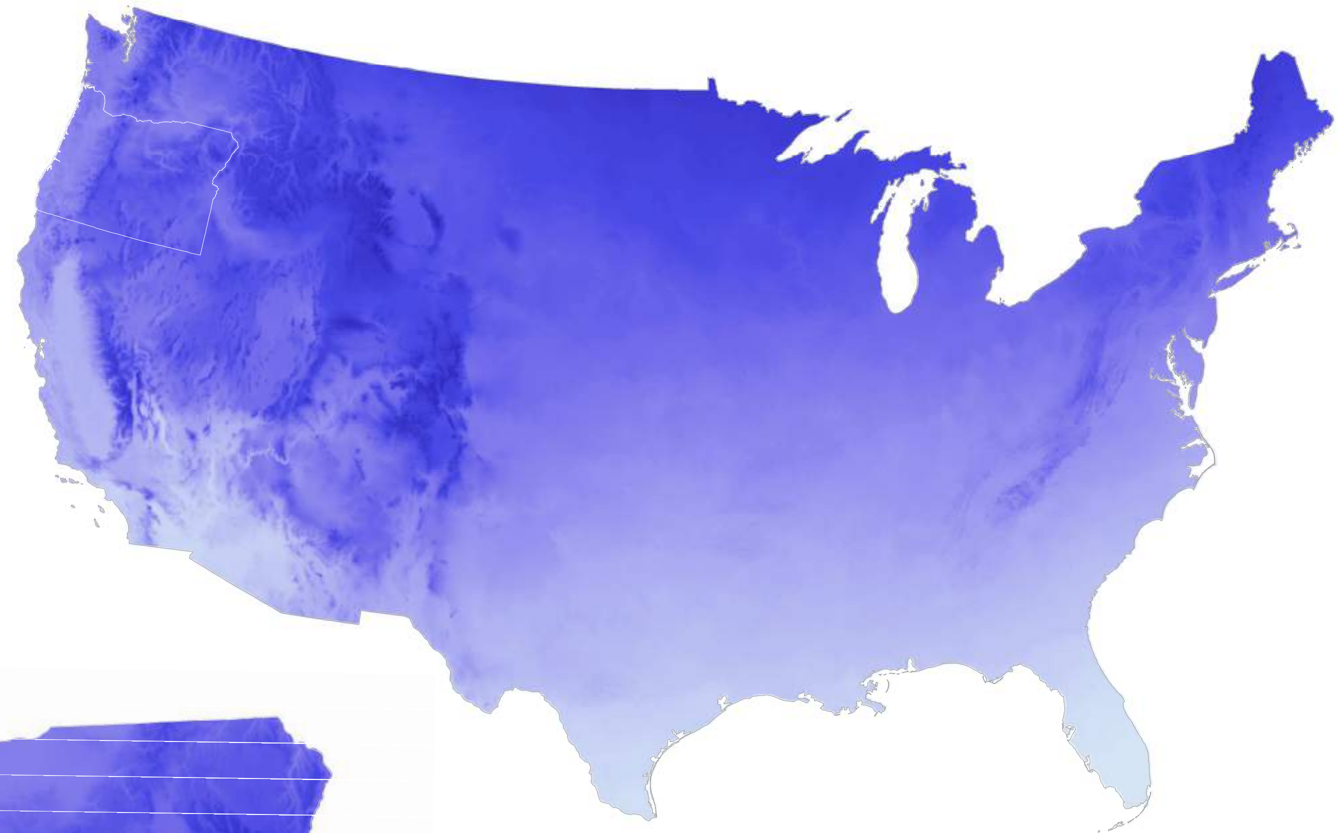
Cooling degree-days are similar to growing degree-days, but account for energy demand due to cooling needs. The concept of cooling degree-days was developed to relate the day's temperature to the energy demands of fuel for air conditioning and refrigeration. Knowing the number of cooling degree-days can help power companies anticipate energy demand for cooling in the summer.

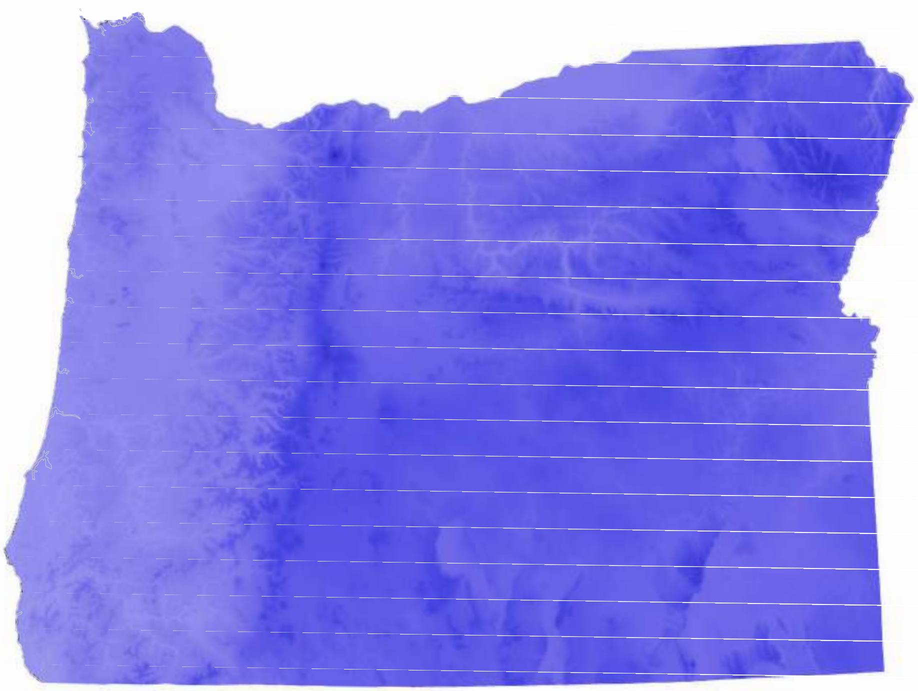


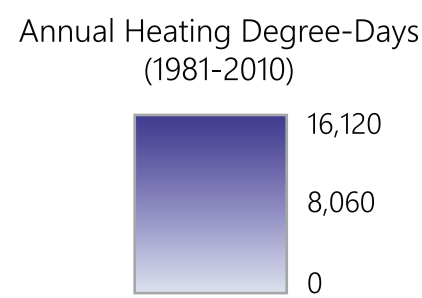


Annual Heating Degree-Days

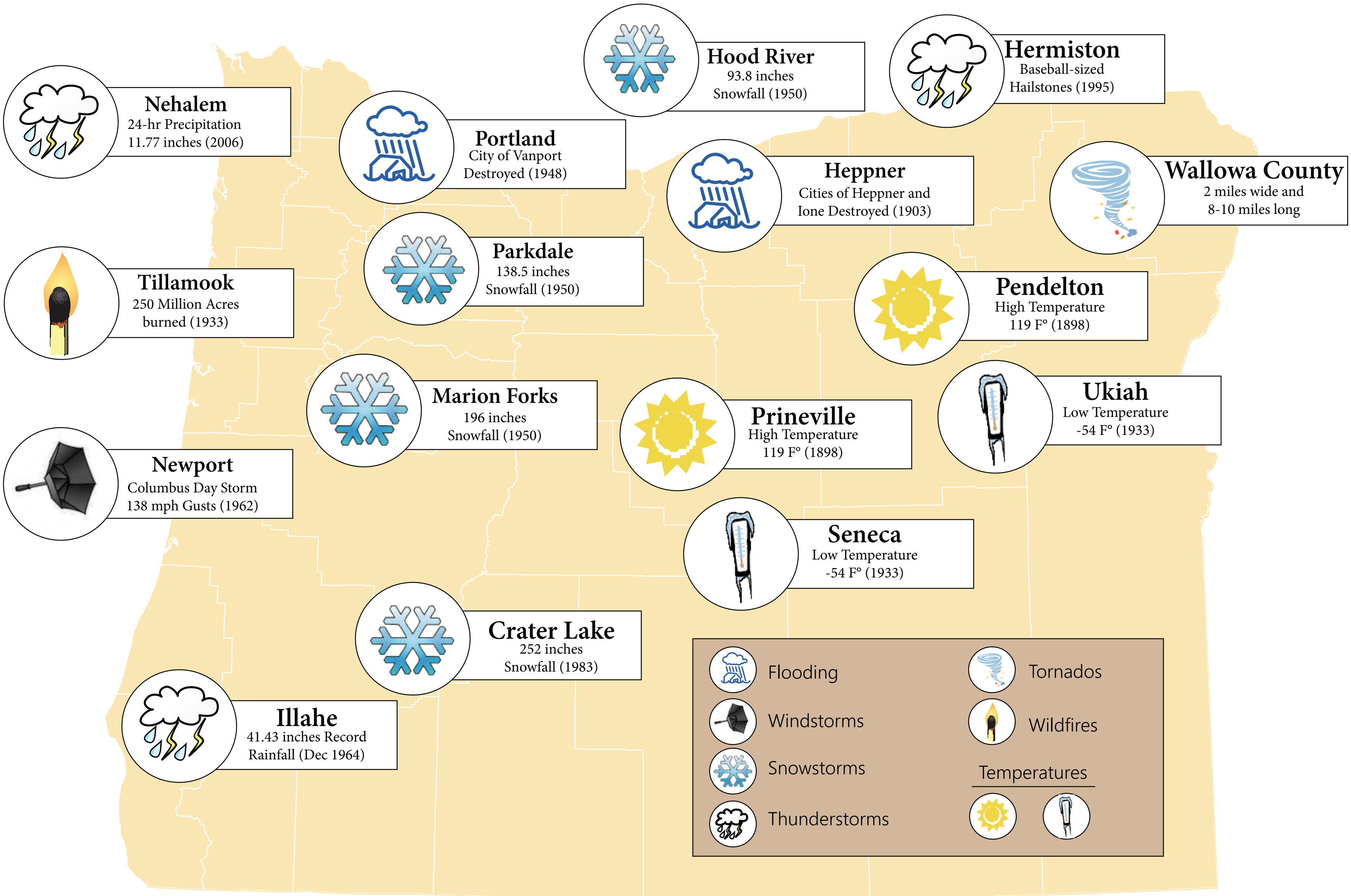
Heating degree-days account for energy demand due to heating needs. The concept of heating-degree days was developed to relate the day's temperature to the energy demands of fuel for heating. Heating degree-days can help fuel supply companies plan for winter demand.



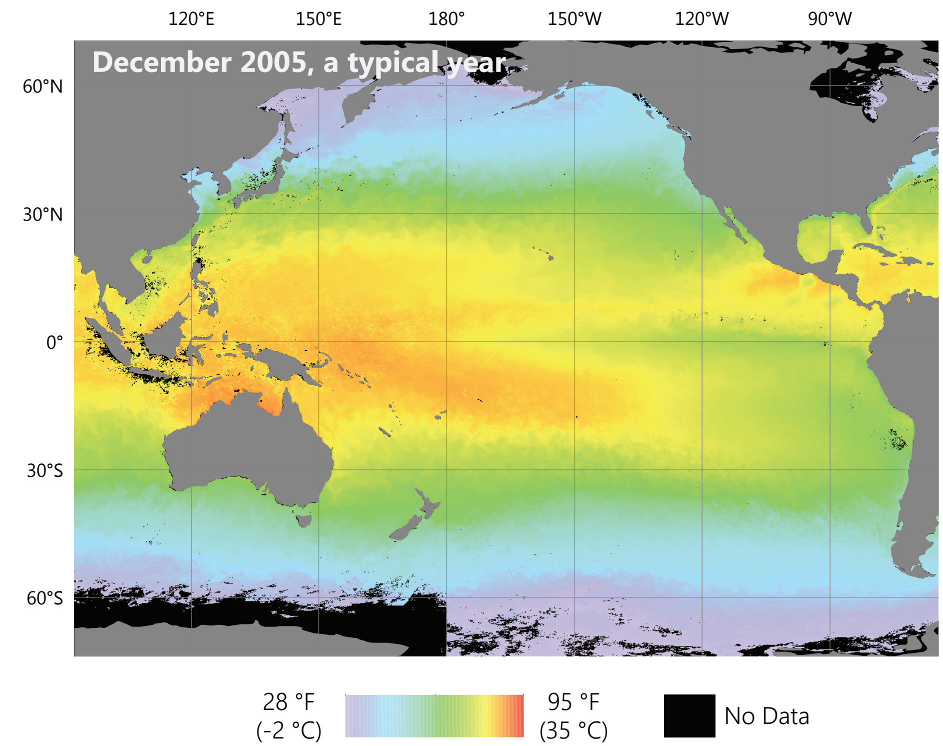


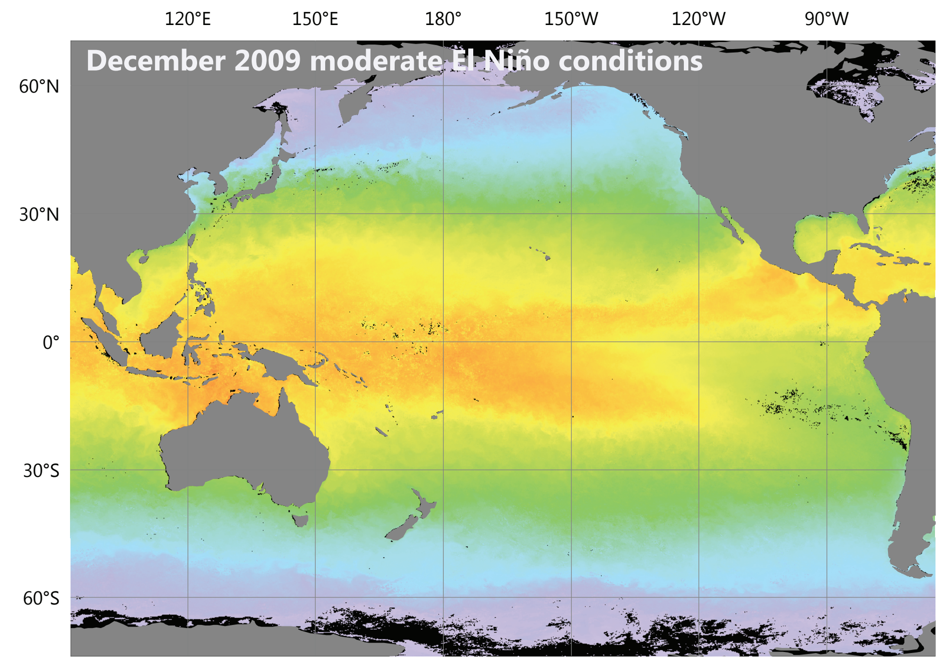


Extreme Weather Events



Sea Surface Temperature and El Niño

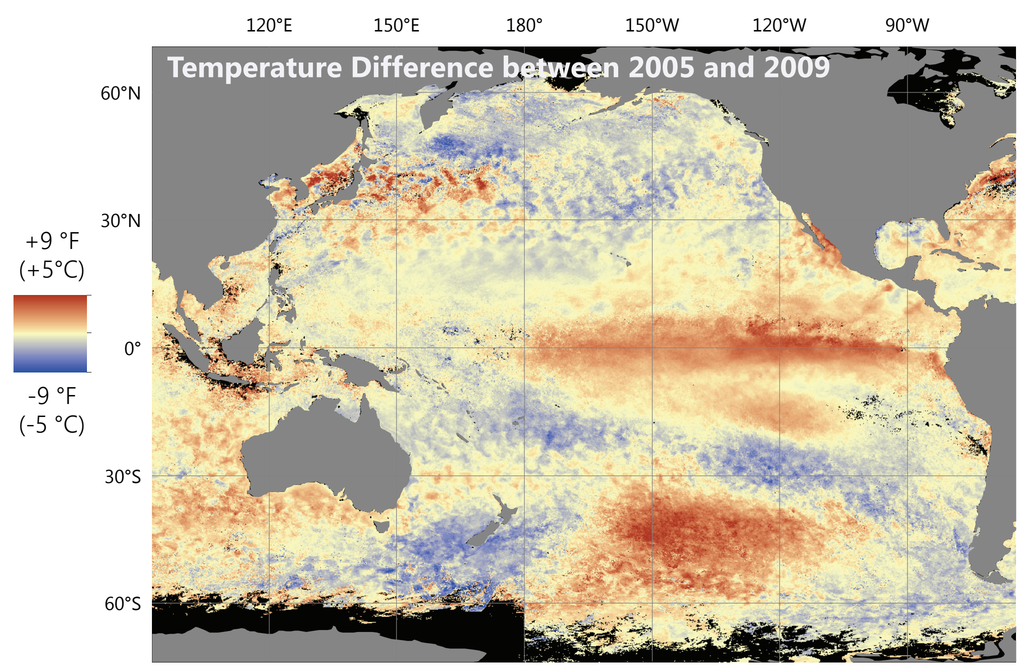




In typical years, there is a temperature gradient across the Pacific Ocean, measured along the equator: warmer in the west, and cooler in the east. The temperature of the equatorial eastern Pacific varies from year to year.

When the sea surface temperature in the tropical eastern Pacific is unusually warm, the band of warm water is called El Niño.

The map at right shows the difference in sea surface temperature that occurred between 2005, a typical year, and 2009, an El Niño year.



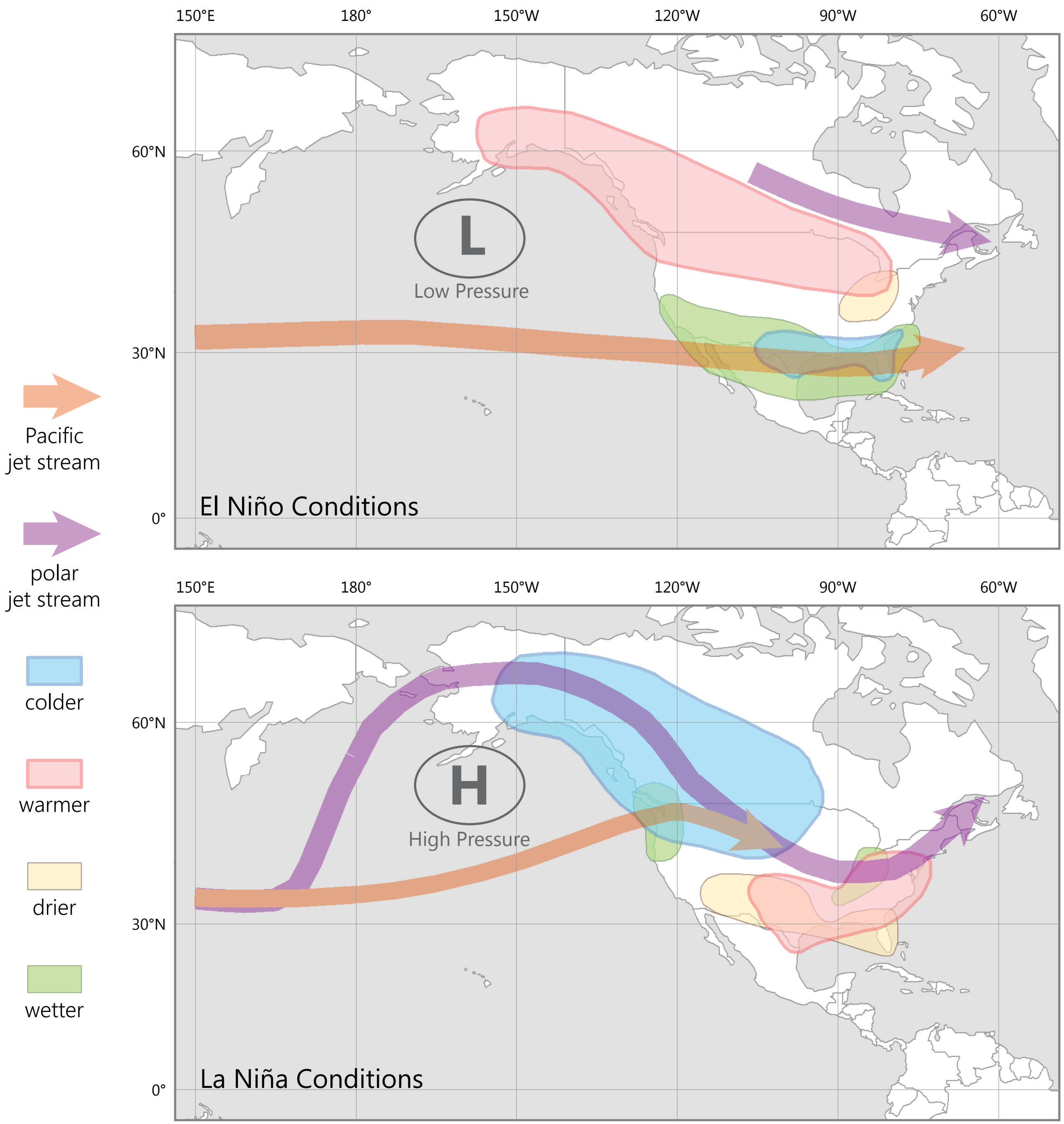
Influence of the El Niño-Southern Oscillation

Various climate mechanisms affect weather throughout the world. One of these, the ***El Niño Southern Oscillation*** (ENSO) produces weather anomalies throughout North America. During an El Niño, warm ocean water temperatures occur off the Pacific coast of South America.

During the winter (Jan-Mar) in years when El Niño conditions exist, the Pacific jet stream is strong and sustained, increasing the intensity of storms that sweep across the southern U.S. from the Pacific.

La Niña is the opposite (or negative) phase of El Niño, when water temperatures in the equatorial Pacific Ocean are cooler than normal.

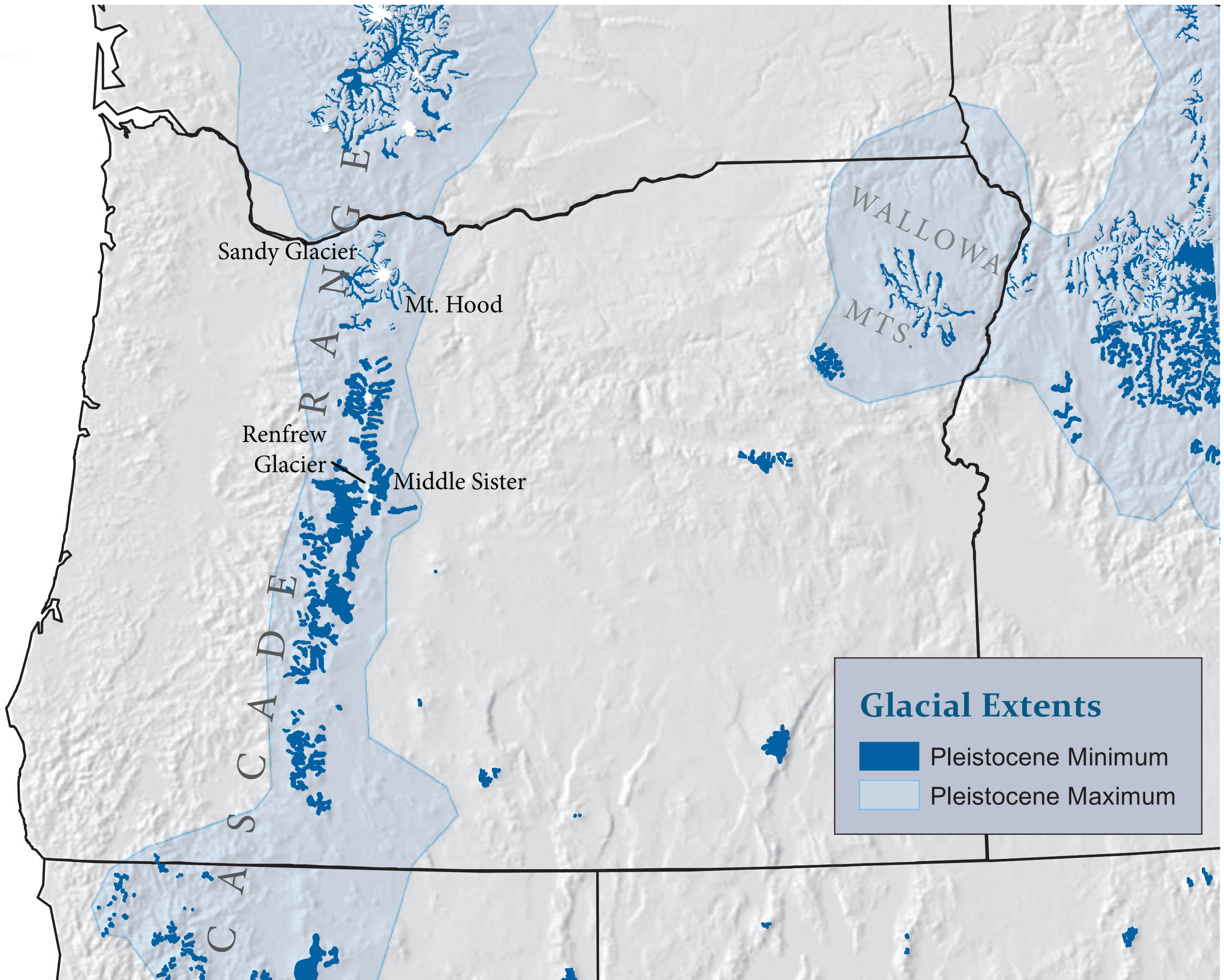
During the winter when La Niña conditions exist, the Pacific jet stream is weaker, more variable, and displaced northward so that storms are more likely to make landfall in the Pacific Northwest, and the polar jet stream tends to be displaced southward over the center of the U.S.



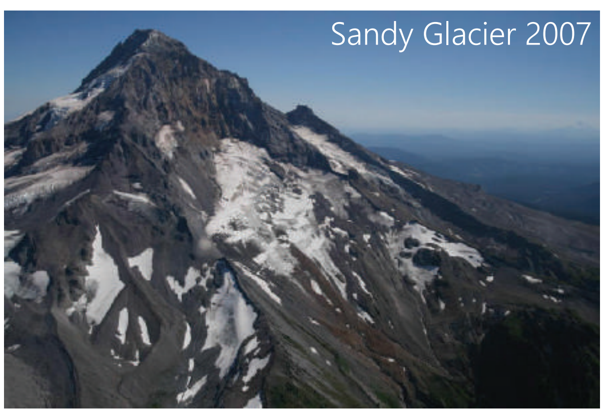
Glacial Recession

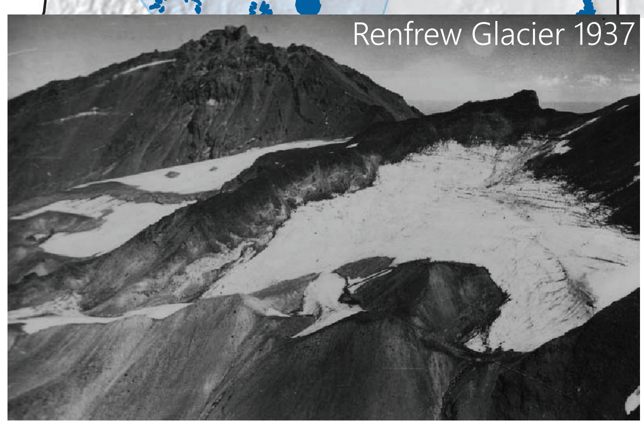
Many glaciers throughout the Cascade Range have experienced ***recession*** in recent decades. In recession, a glacier's rate of ***ablation*** (net loss of ice due to melting and similar erosive processes) exceeds its rate of accumulation of snow and ice.

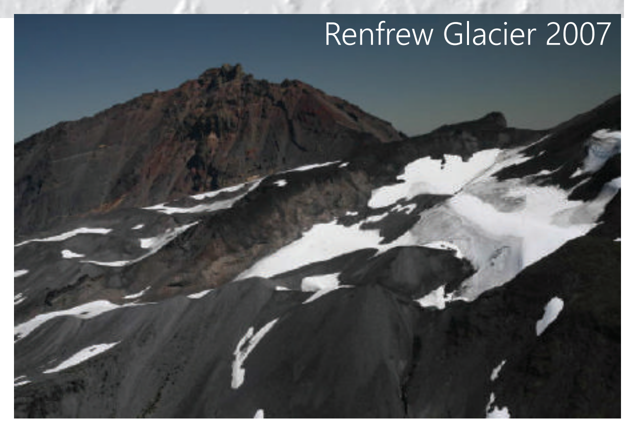
The map at right shows the minimum and maximum extents during the Pleistocene (2,588,000 to 11,700 years ago).




Sandy Glacier 1967

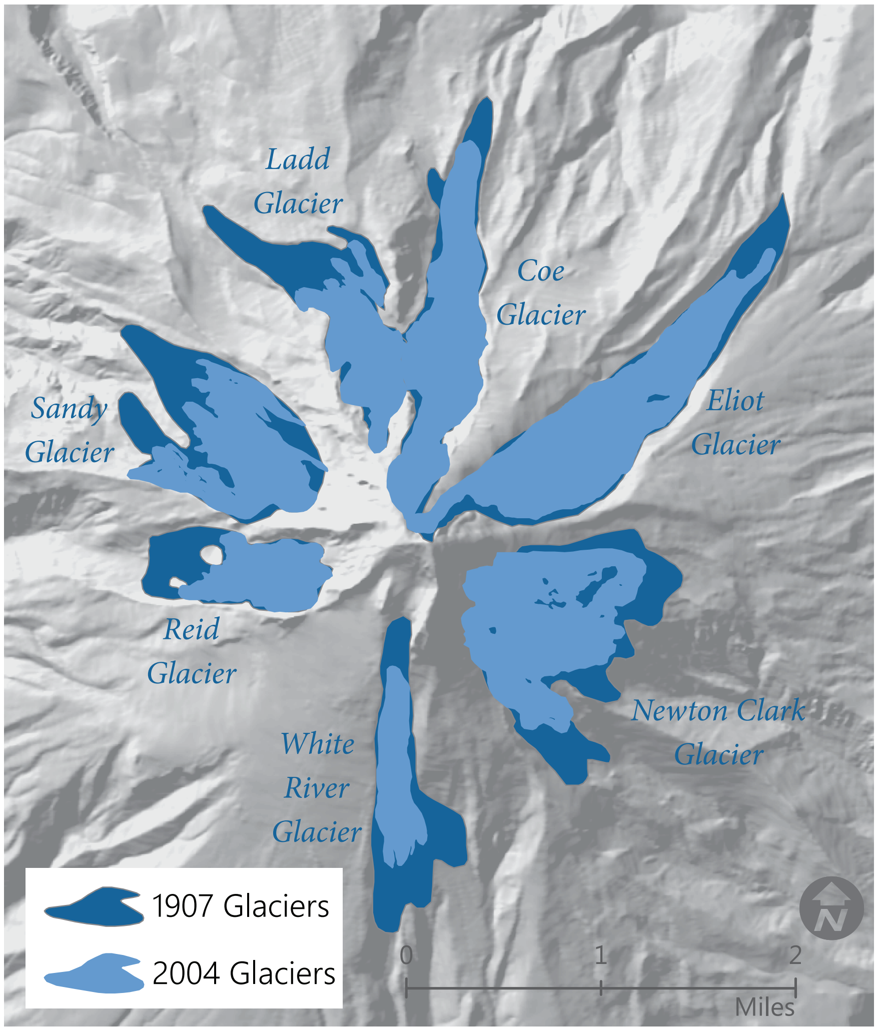

Sandy Glacier 2007

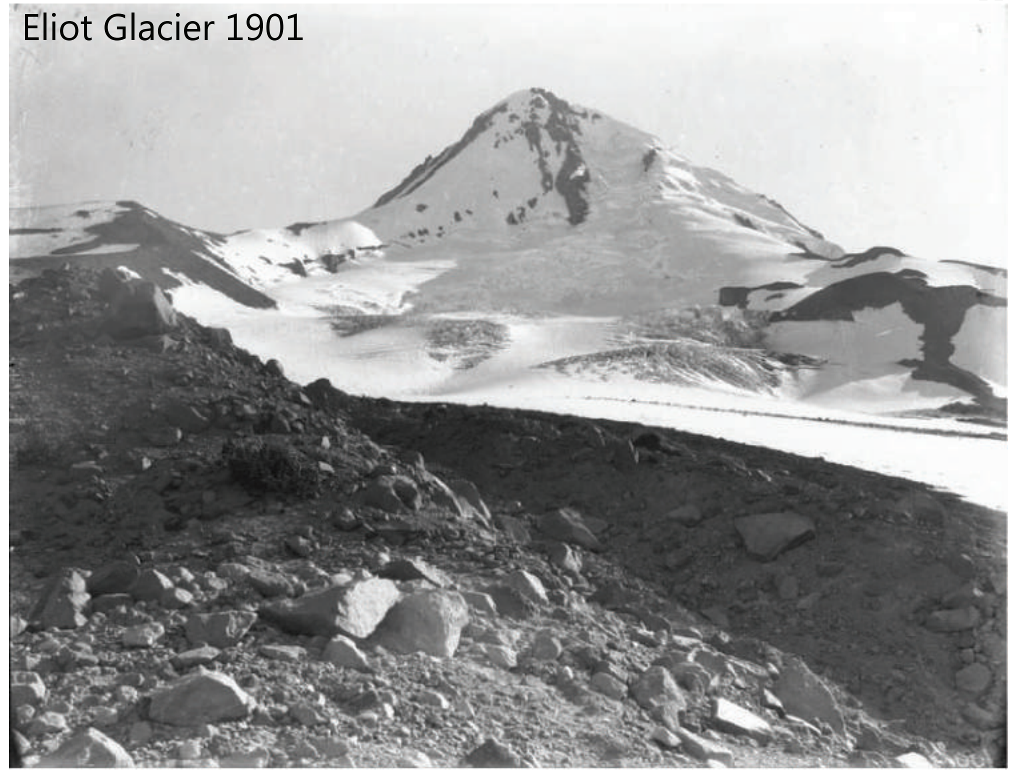

Renfrew Glacier 1937


Renfrew Glacier 2007

Glacial Recession: Mt. Hood

All glaciers on Mt. Hood are retreating. Photographic evidence of the Eliot Glacier, located on the northeast side of Mt. Hood, shows that the glacier retreated over 2,000 feet between 1901 and 2006.

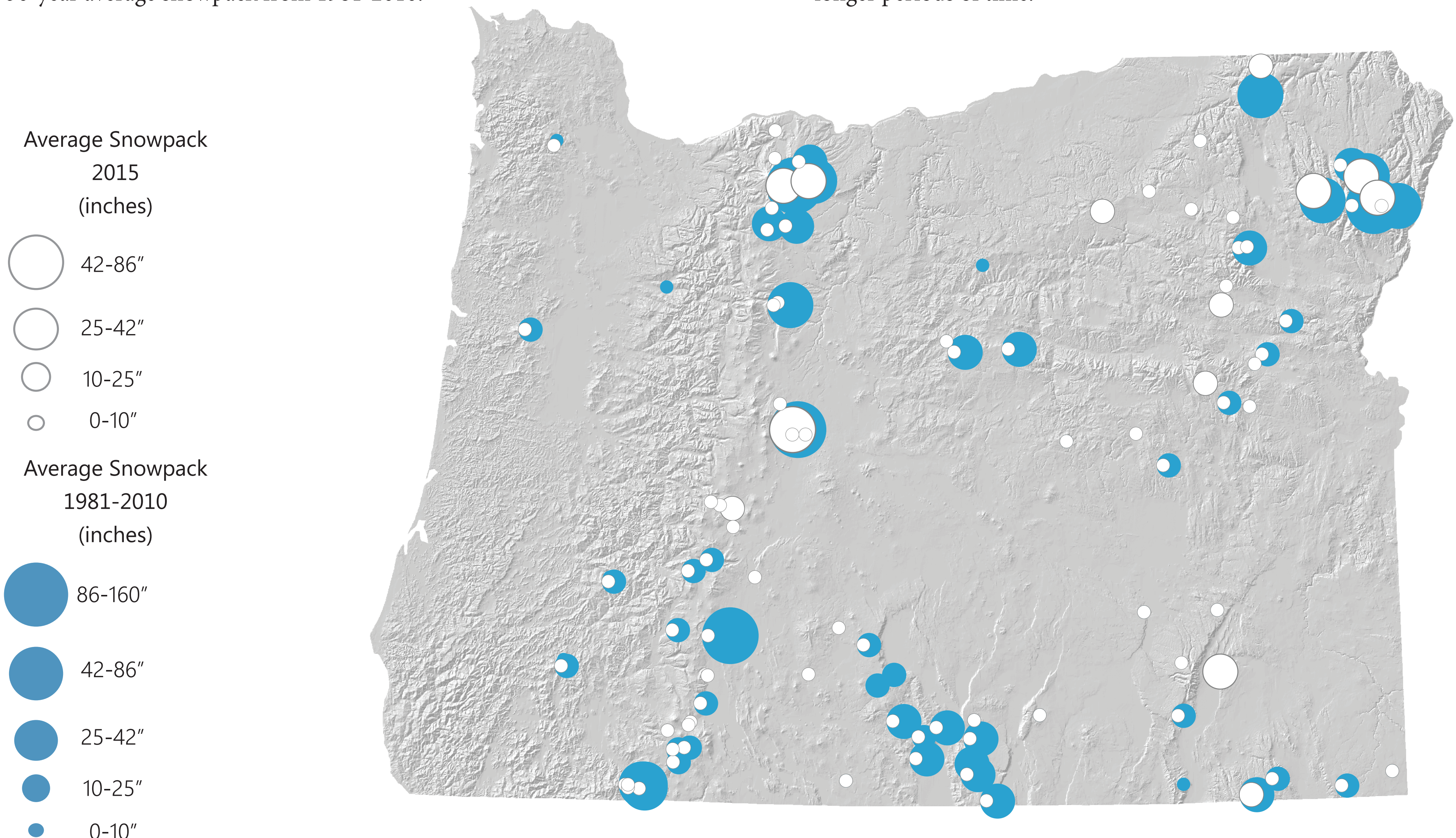




Snowpack Variability

Annual snowpack accumulation depends on yearly precipiation, elevation, sun exposure, and temperature. This map compares the yearly average snowpack of 2015 with the 30-year average snowpack from 1981-2010.

2015 had very low snowpack levels as compared to typical years. By comparing individual years with 30-year average values we can see trends in snowpack accumulation over longer periods of time.

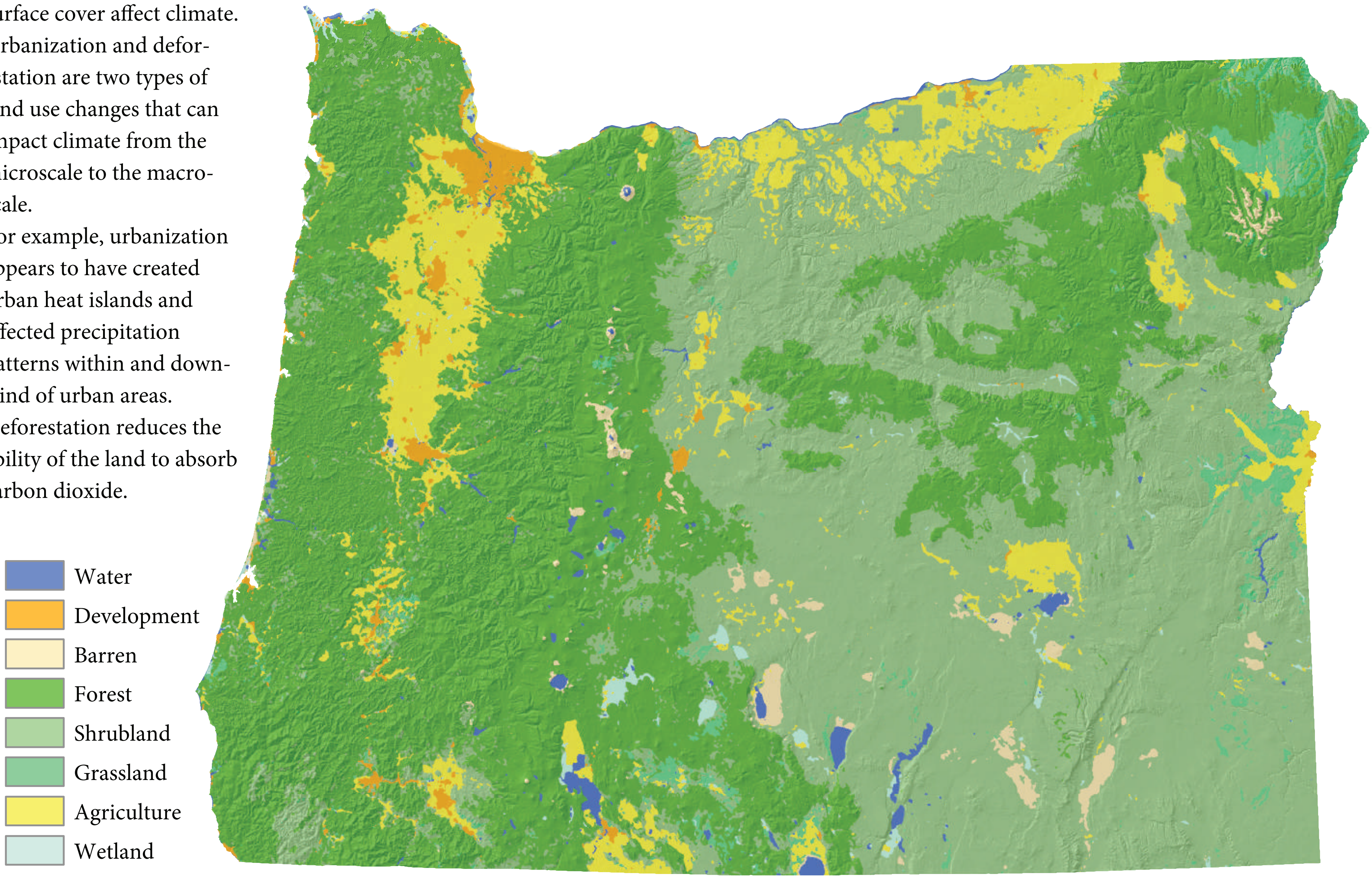


A white circle inside a blue circle indicates a decrease in snowpack in 2015 compared to the 30-year average.
Areas with only a white circle are newer measurement stations without historic data.
Areas with only a blue circle are measurement stations without available 2015 data.

Land Use

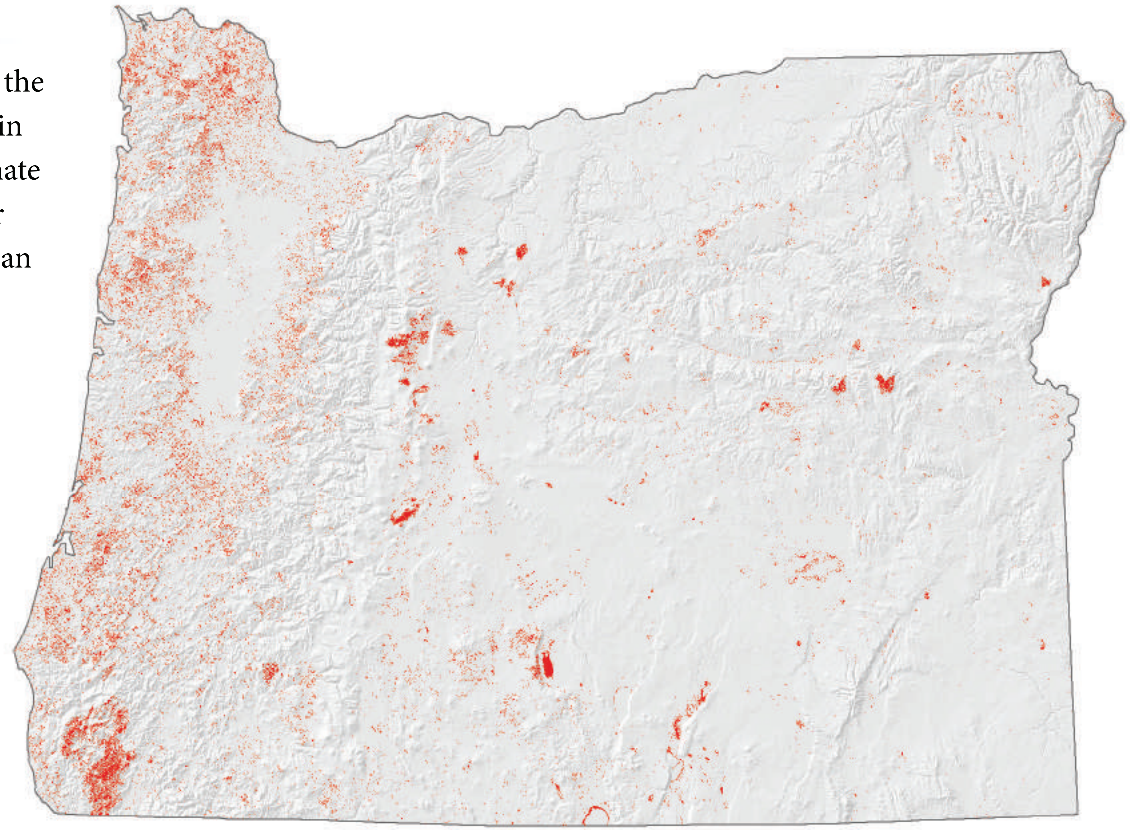
Variations in ***land use*** and surface cover affect climate. Urbanization and deforestation are two types of land use changes that can impact climate from the microscale to the macroscale.

For example, urbanization appears to have created urban heat islands and affected precipitation patterns within and downwind of urban areas. Deforestation reduces the ability of the land to absorb carbon dioxide.

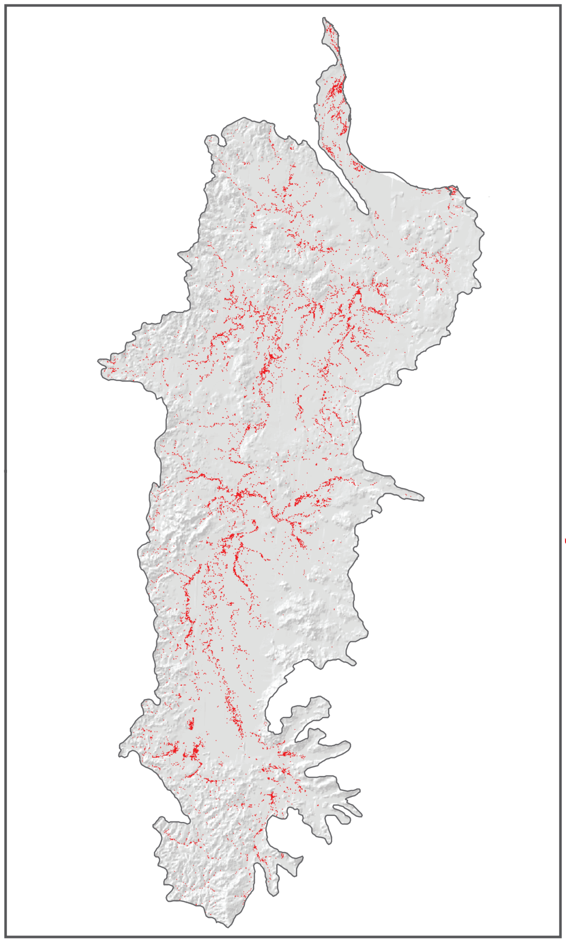


Land Use Change

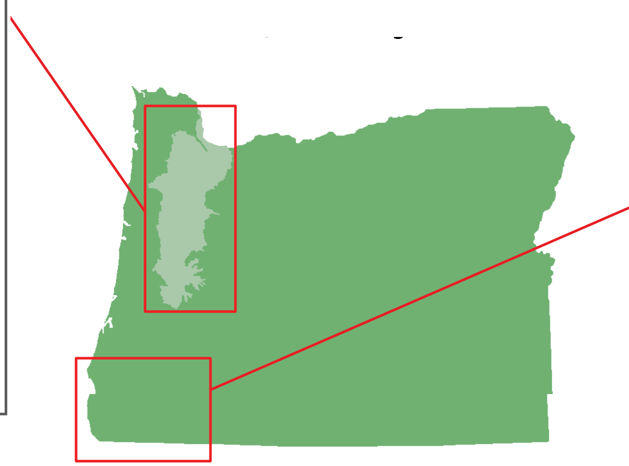
Land cover refers to the classification of the materials of the surface of the earth according to the dominant material in each area (e.g., forest, grassland). Land cover affects climate at the land-atmospheric interface. Changes in land cover can result in changes in local micro-climate (such as urban heat islands) and climate change can impact terrestrial ecosystems (such as wetlands and forests).

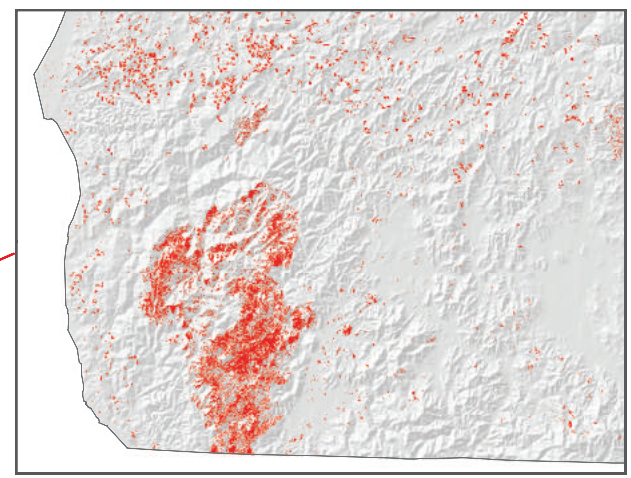


Land Cover Change
2001-2006



Loss of Wetlands in the Willamette Valley
2001-2006

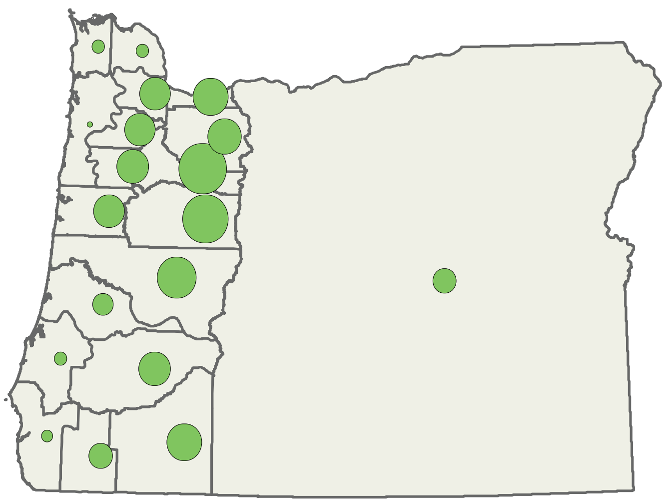




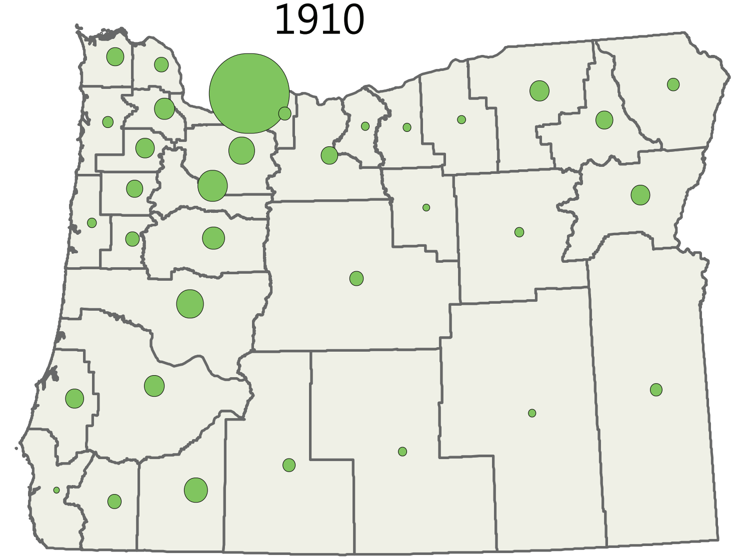
Loss of Forest in Southwestern Oregon
2001-2006

Population Growth

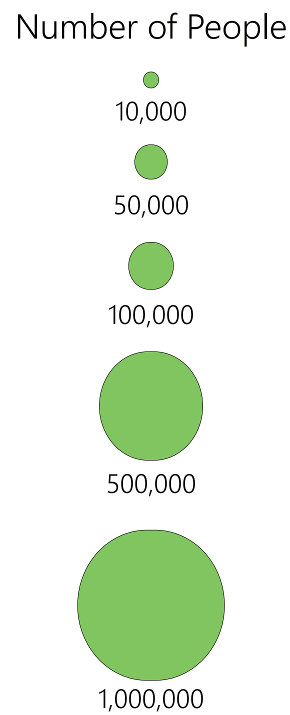
1860



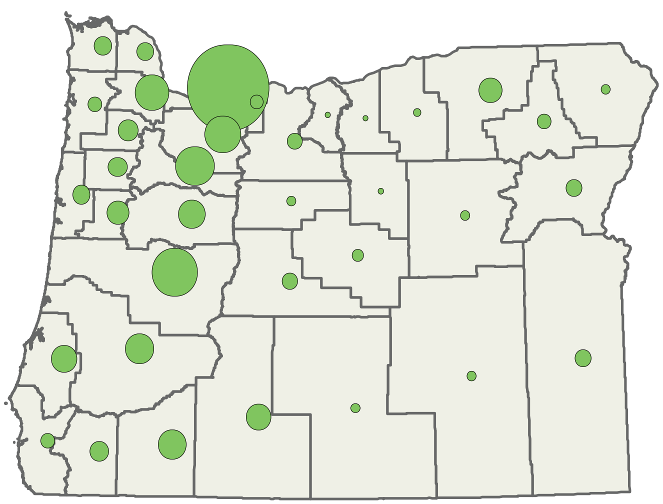
1910



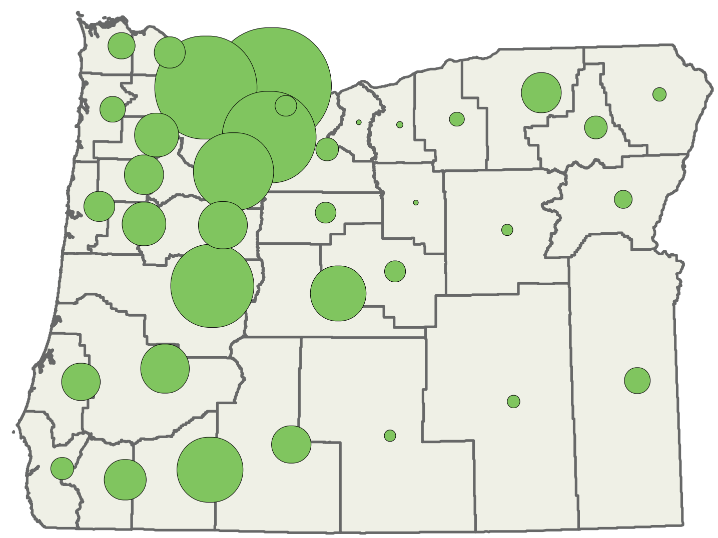
Each individual has a ***carbon footprint*** equal to the tons of carbon dioxide and other greenhouse gases the individual's choices result in each year. As population grows, so does the human carbon footprint. This carbon footprint can be mitigated by carbon offsets such as planting trees or supporting renewable energy.



1960



2010



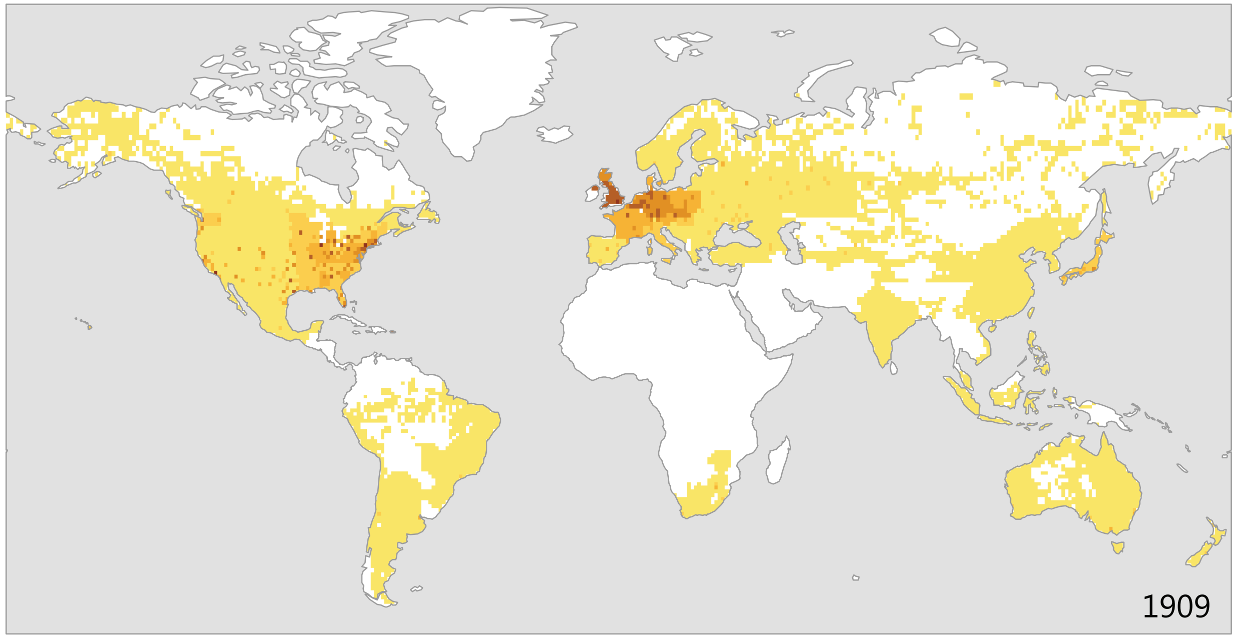
Fossil-Fuel Carbon Dioxide Emissions

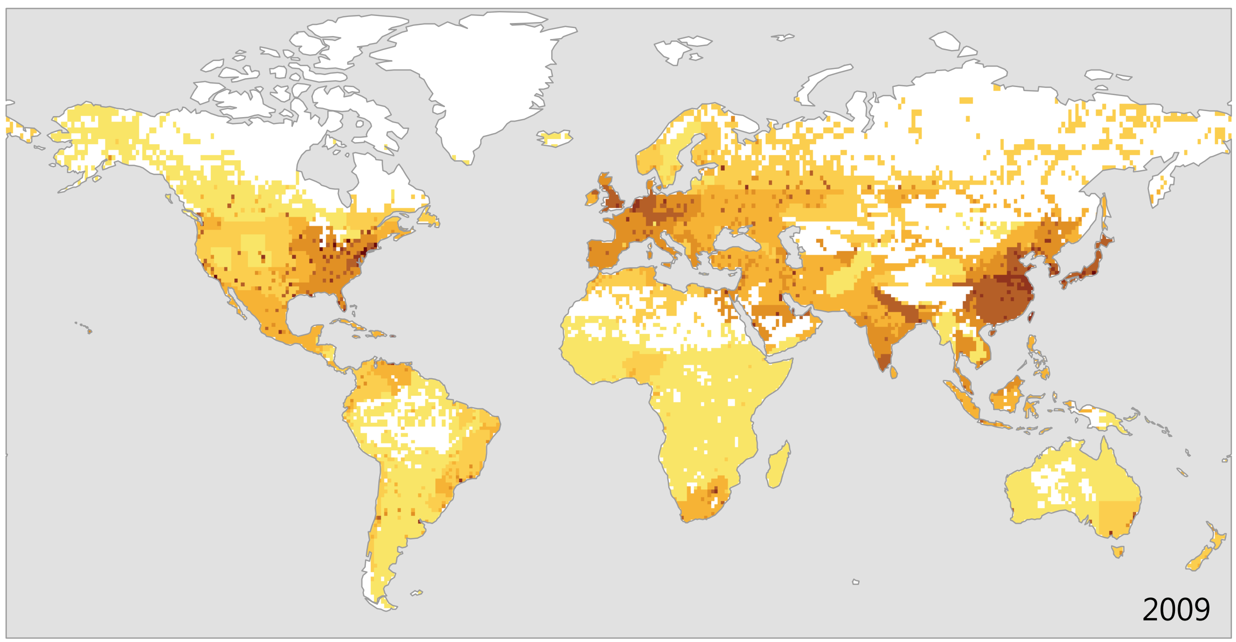
The total volume of annual fossil-fuel carbon dioxide emissions has increased over much of the earth's land surface over this 100-year period.

Mass of Carbon
in millions of metric tons

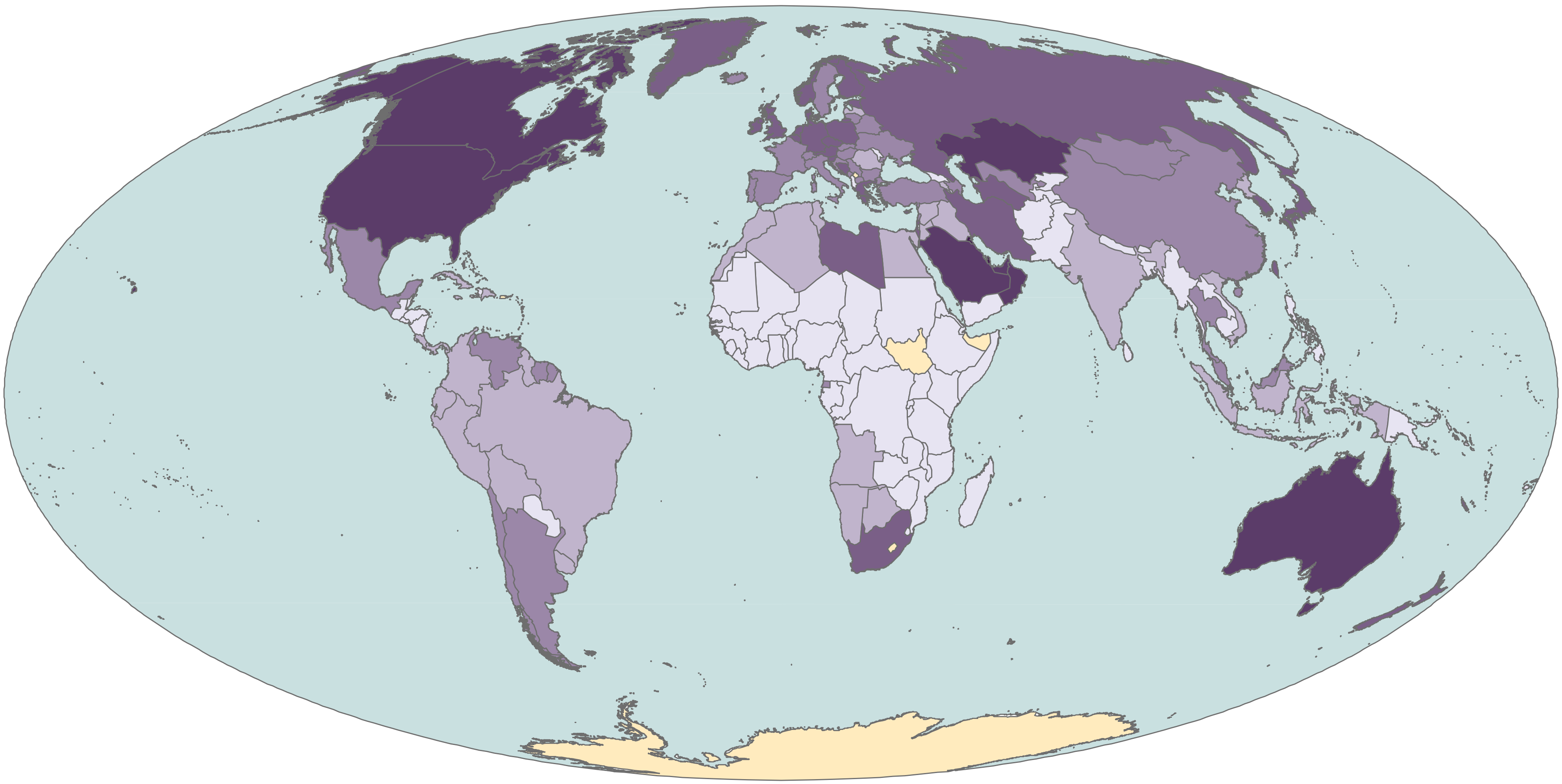
- 0.0
- 0.0 - 0.1
- 0.2 - 0.3
- 0.4 - 1.0
- 1.1 - 3.0
- 3.1 - 9.0
- 9.1 - 27
- 27 - 65

1 metric ton = 1,000 kg = 2,204.6 lbs





Per-Capita Fossil-Fuel Carbon Dioxide Emissions 2009



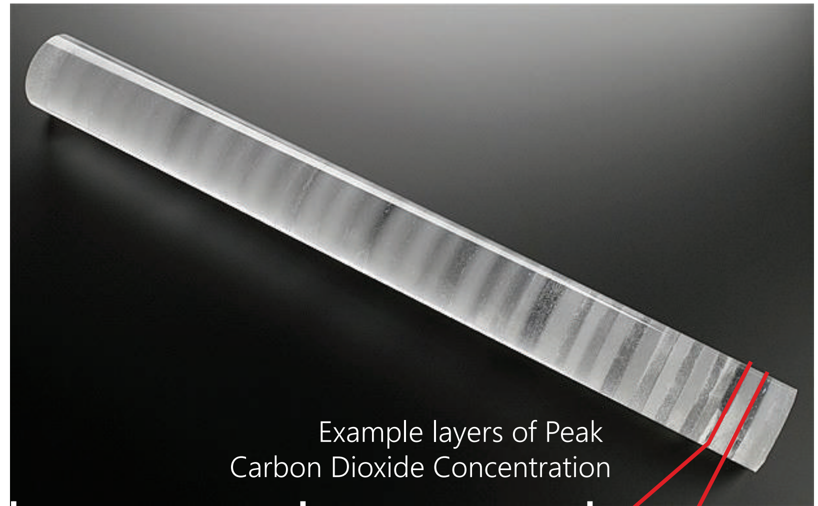
Metric Tons of Carbon, per person, 2009

- 0.01 - 0.37
- 0.38 - 1.02
- 1.03 - 1.94
- 1.95 - 3.28
- 3.29 - 6.46
- 6.47 - 12.01
- data not available

1 Metric Ton = 1,000 kg = 2,204.6 lbs

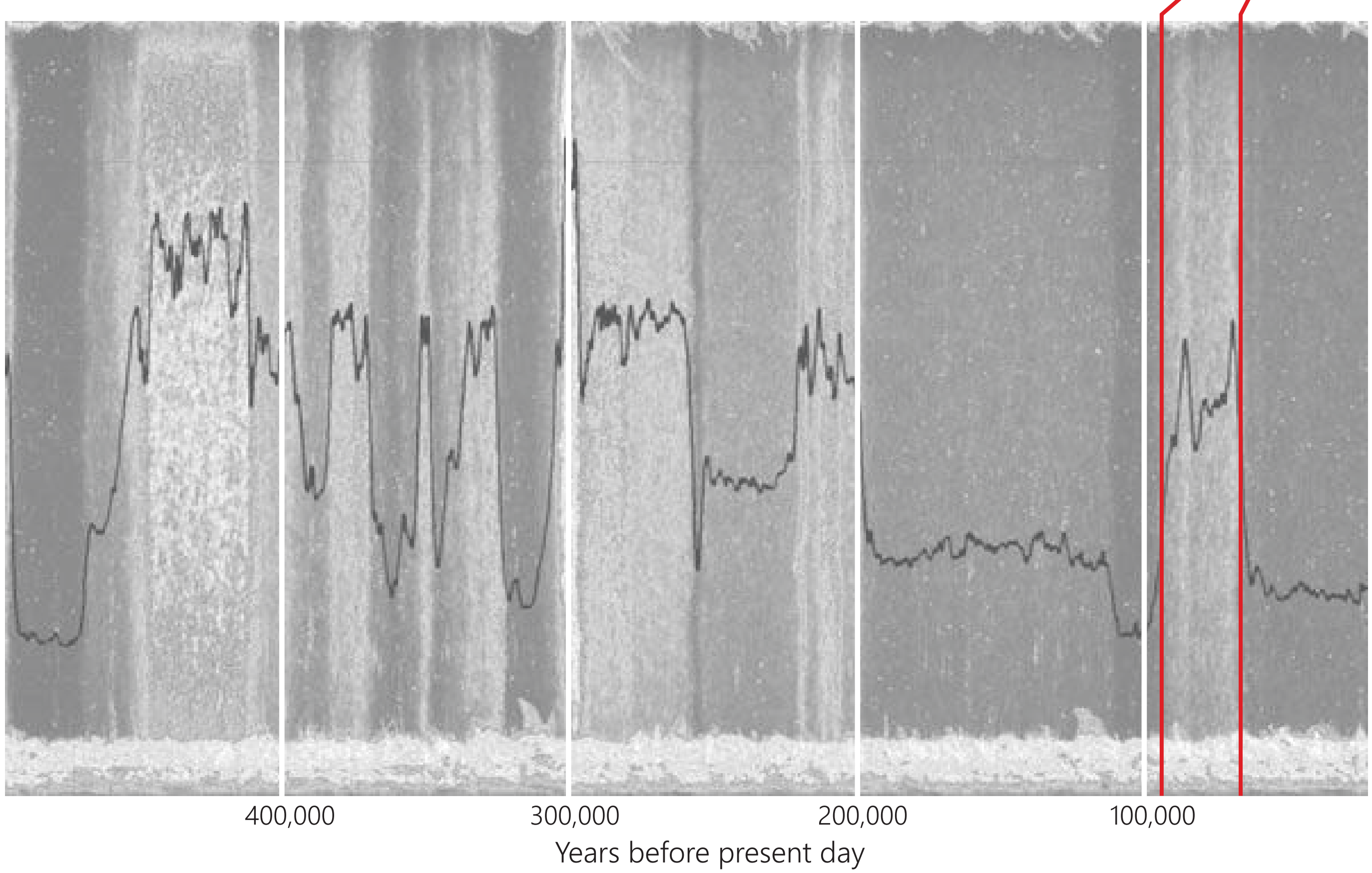
Using Ice Cores to Reconstruct Past Climates

Ice cores are used as a ***climate proxy*** to help reconstruct past climates. A climate proxy is affected by changes in climate, but does not directly measure those changes. ***Proxy data*** is data gathered from natural recorders of climate variability. Ice cores taken from polar or high elevation glaciers reveal annual layers of snow over a range of years. Each layer of ice contains materials (deposits such as wind-blown dirt) and atmospheric gas that serve as substitutes for direct measurements for a range of climate variables such as air temperature, air chemistry, and volcanic eruptions.



Ice Core Sample

Ice core drilling procedure

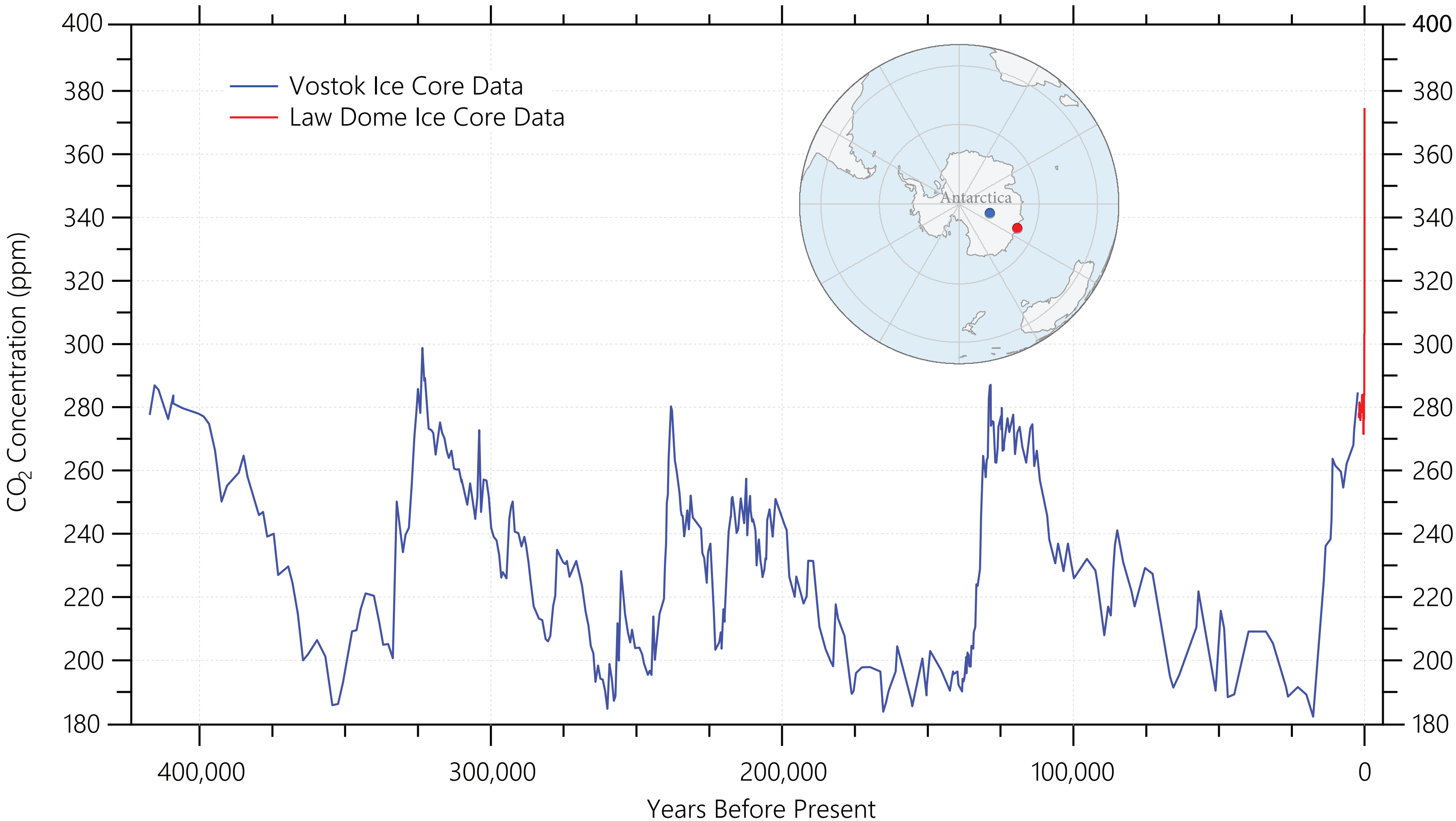


Intepretation of Chemical Concentrations within Ice Core

Atmospheric Carbon Dioxide Concentration: Last 400,000 years

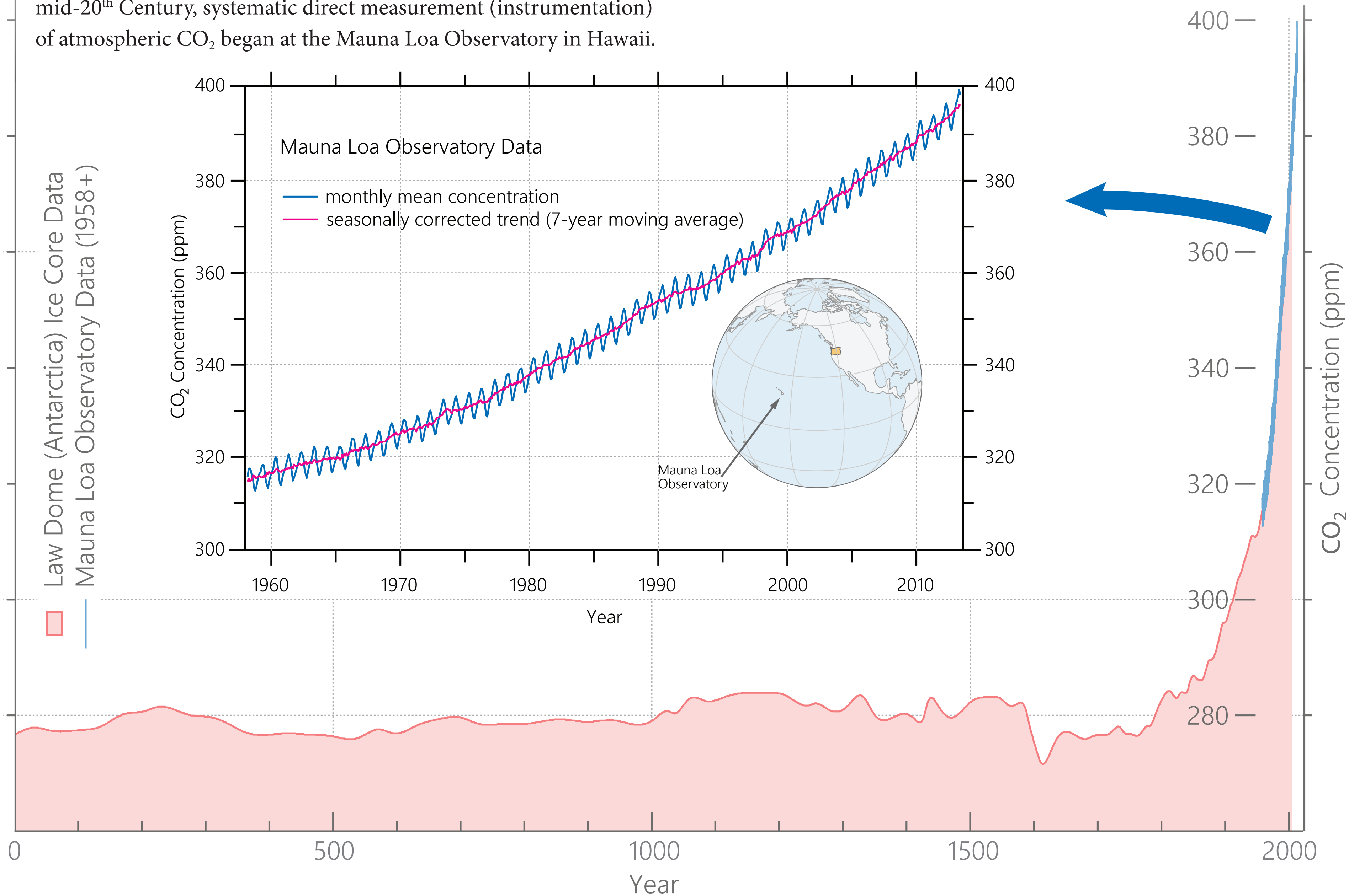
Scientists use ice cores (a form of proxy data) to measure the concentration of atmospheric carbon dioxide over the age range of the ice core. This enables reconstruction of temperature records and atmospheric composition. Many of the longest ice core records come from Antarctica.

They show a variation in CO_2 concentrations that matches with variations in glaciation: cooler glacial periods coincide with lower CO_2 concentrations; warmer interglacial periods with higher CO_2 concentrations.



Atmospheric Carbon Dioxide Concentration: Last 2,000 years

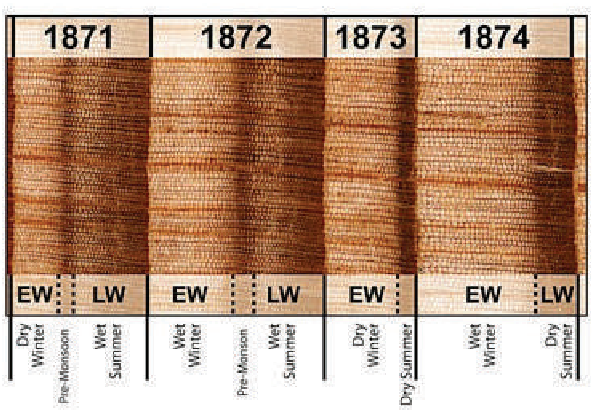
Using ice cores, scientists have reconstructed the atmospheric concentration of CO_2 over the last 2,000 years. Beginning in the mid-20th Century, systematic direct measurement (instrumentation) of atmospheric CO_2 began at the Mauna Loa Observatory in Hawaii.



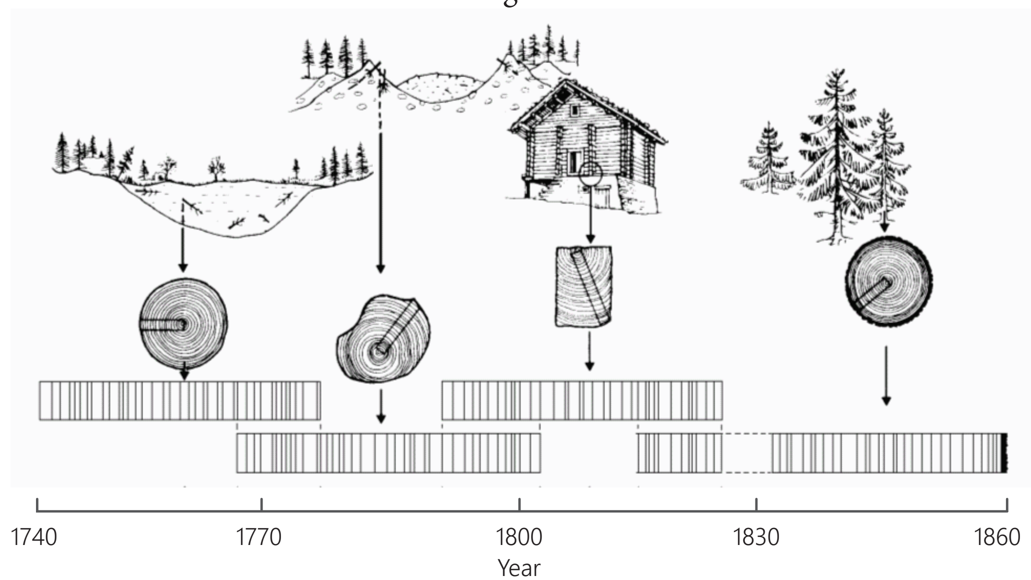
Using Tree Rings to Reconstruct Past Climates

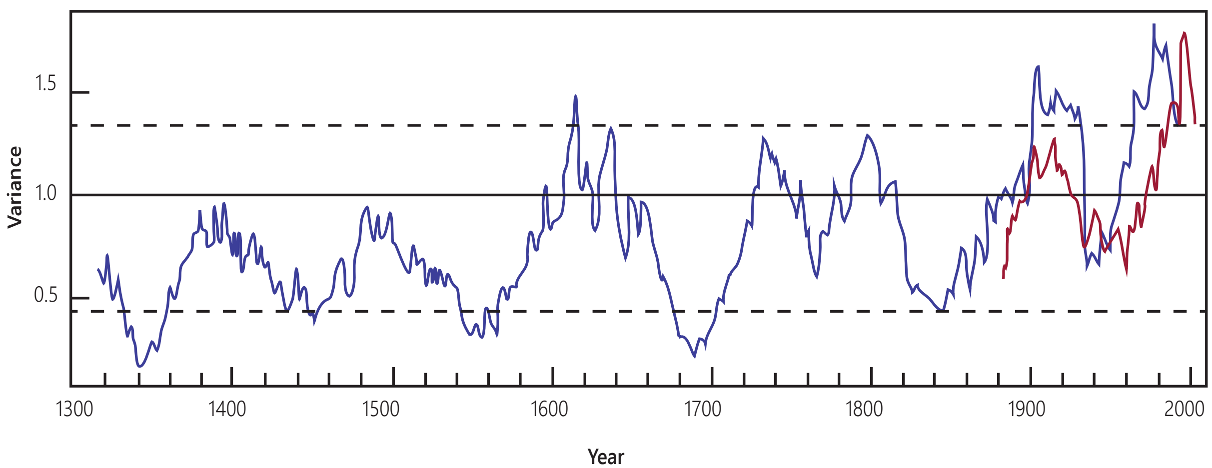
Dendroclimatology is the study of the relationship between tree growth and climate change. As a tree grows, it adds one ring for every year of growth. The width of each ***growth ring*** depends on a number of environmental factors, primarily temperature and precipitation. Tree rings are a type of proxy data: wide rings suggest wet years, while narrow rings imply dry years.

The growth rings in a living tree represent a record of the recent past. Since trees subject to similar environmental conditions produce similar growth rings, comparison of growth rings between trees of different ages, a process called cross-dating, allows the data record to be extended into the distant past. Scientists match a sequence of tree rings in one tree or log with those in another tree or log to extend the record.



Douglas-fir tree rings from southwestern New Mexico.





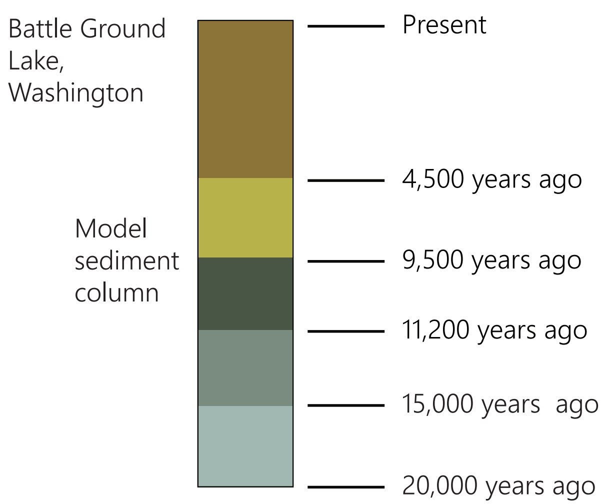
Dendroclimatology has been used to reconstruct El Niño variability over the past 700 years. El Niño has a significant impact on precipitation in Oregon. The red line reflects direct instrumental measurement, while the blue line reflects precipitation estimates determined using tree ring data.

Using Pollen to Reconstruct Past Climates

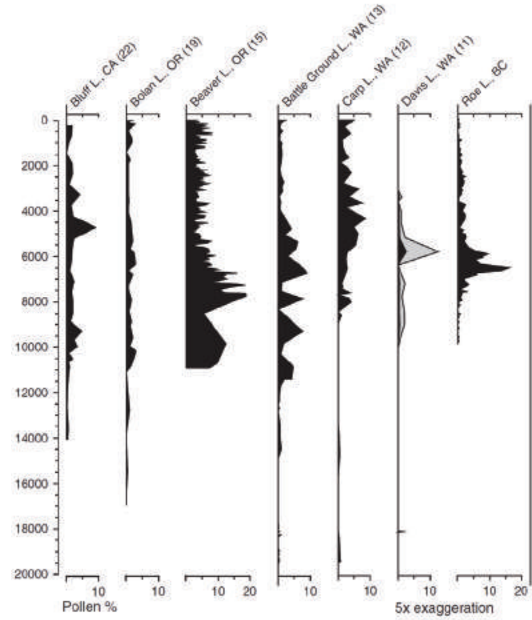
Sediments that accumulate on a lake bottom vary in both volume and composition according to the time of year. For example, in the spring, when rivers carry a relatively heavy load of sediment, a thicker layer of sediment will accumulate on the lake bottom than in autumn, when river levels and flowrates are lower.

Similarly, layers of sediment that accumulate during the spring and summer will include the pollen of plants that are blooming at that time of year, while pollen will be largely absent in sediment that accumulates during the winter.

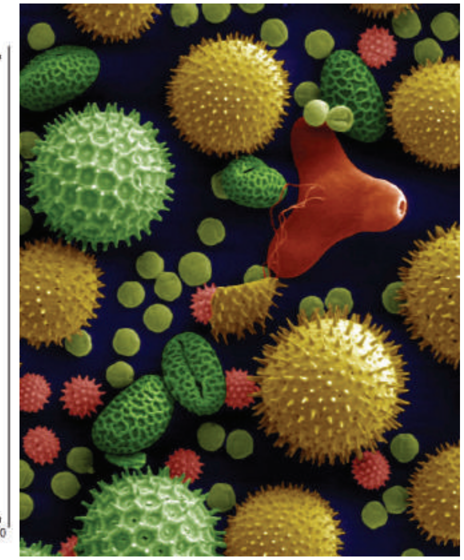
Scientists drill into the sediment at the bottom of lakes and extract a ***sediment core***.



Schematic of a sediment core



Examples of pollen



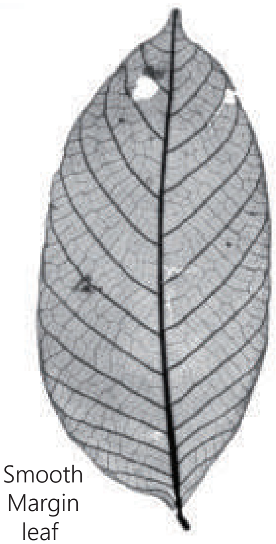
Garry Oak (Quercus garryana) pollen percentage from seven lake cores in the Pacific Northwest. This graph shows the percentage of pollen in each lake that has Garry Oak pollen. Change in the percentage of pollen over time indicates changes in vegetation which may be due to changes in climate (especially temperature and precipitation).

These annual processes produce rhythmic variation in the sediment column called ***varves***. One way to establish the age of a particular stratum of sediment is to use varves like tree rings by counting how many annual layers are present.

Pollen is proxy data that can be extracted from a particular sediment layer and used to identify types of plants living in the region at that time. The nature of the vegetation can, in turn, be used to infer what the climate in that area was like at that time. Using pollen collected from lake cores in the Puget Trough, we can infer that the climate was warmer and drier 9,500-4,500 years before present.

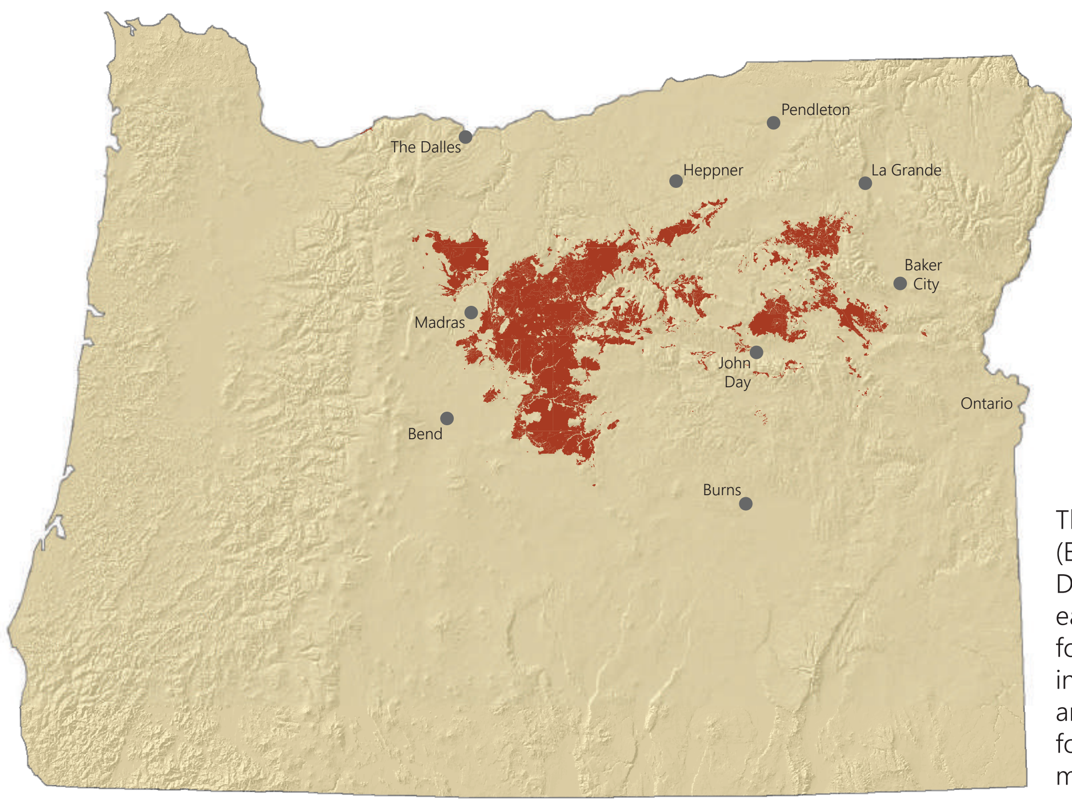
Using Fossils to Reconstruct Past Climates

Leaf fossils are used as a proxy to infer information about paleo-climates. In tropical climates, leaves tend to have smooth margins. In more temperate climates, leaves with toothed margins predominate. There is a linear correlation between temperature and the proportion of plant species with smooth versus toothed leaf margins. Using this property, leaf margin analysis allows us to infer information about paleotemperatures. A high proportion of leaf fossils with smooth margins implies that a tropical climate existed at the time and place where the fossilized plants lived.



Smooth Margin leaf

Toothed Margin leaf



The Clarno (Eocene) and John Day (late Eocene to early Miocene) formations in central Oregon are a rich source of fossils, including many leaf fossils.

Inferring Atmospheric Carbon Dioxide Concentration from Leaf Fossils

The surface of a leaf is covered in pores, called stoma, which are used for gas exchange in respiration. As atmospheric carbon dioxide concentration rises, the plant requires fewer stoma, and the density of stoma on leaf surfaces decreases.

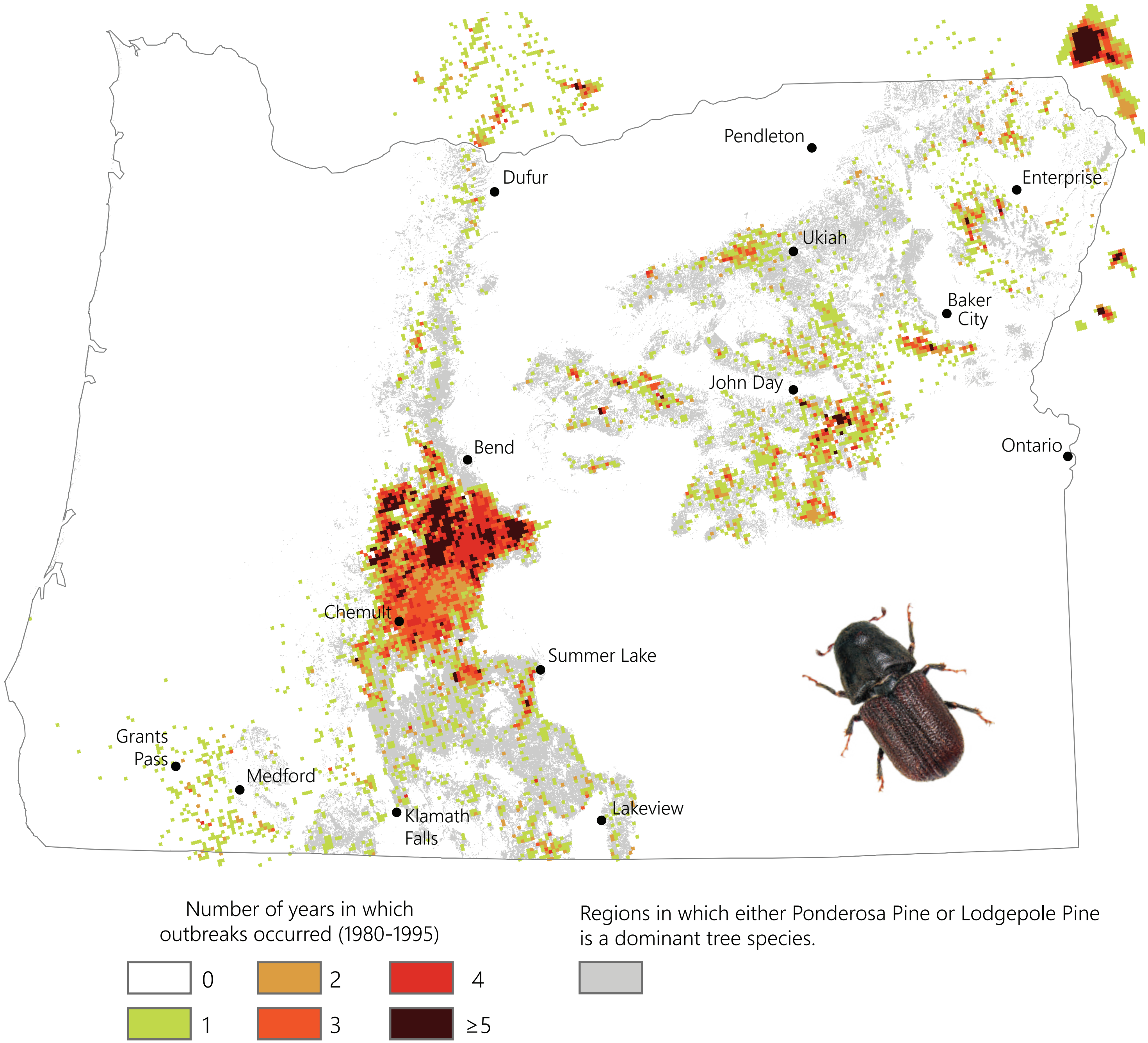
By examining the density of stoma on fossilized leaves, we can infer whether atmospheric carbon dioxide concentration was high or low at the time that the fossilized plant was alive.

Mountain Pine Beetle Outbreaks

The mountain pine beetle *(Dendroctonus ponderosae)* is a species of bark beetle that is native to Oregon. It inhabits a number of species of pine trees, including ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*).

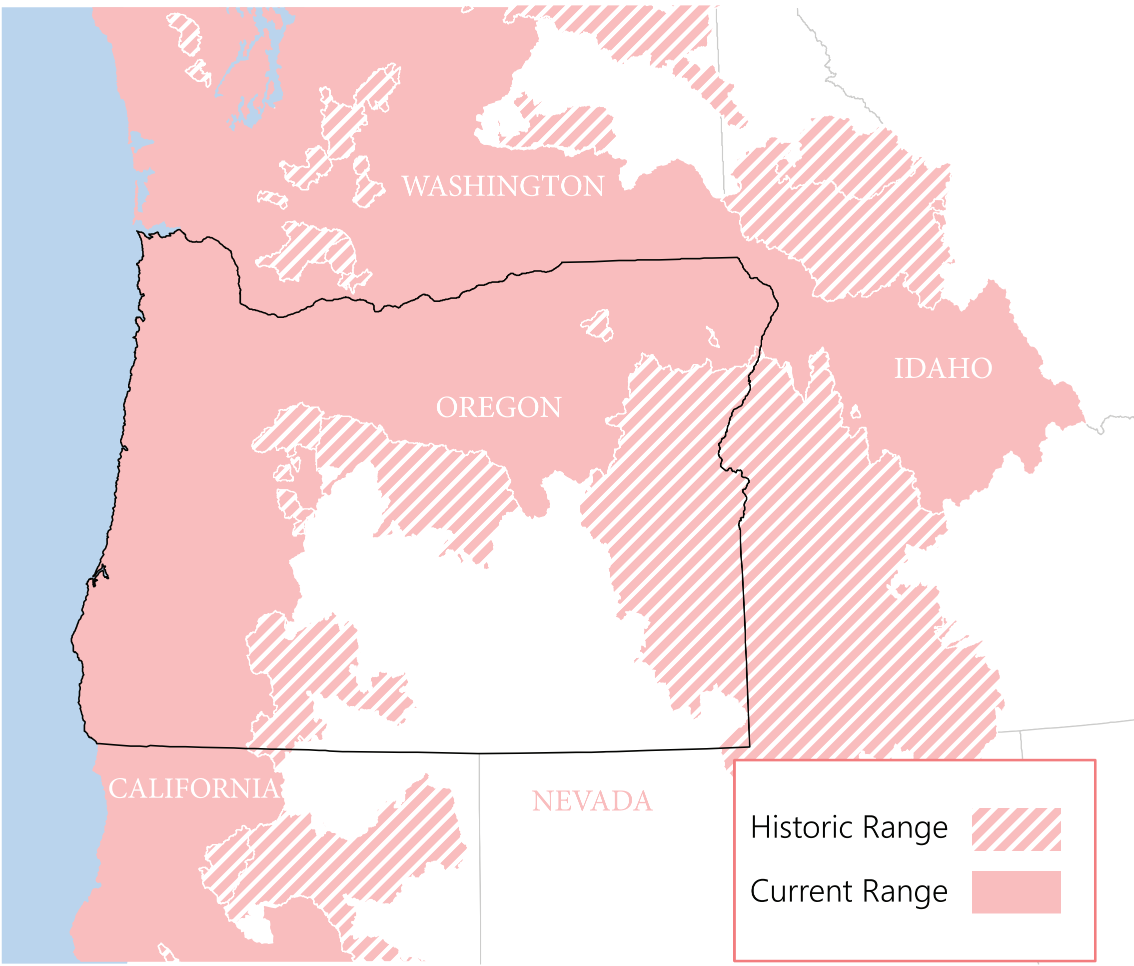
This beetle is a part of the pine tree's normal lifecycle. By attacking, and eventually killing, old and weakened trees, the beetle improves the overall health of the forest, and helps to generate fuel for the low-intensity forest fires that allow the pine cones to open and new seedlings to germinate. However, when trees become stressed, because of drought or other causes, the beetles proliferate, attacking otherwise healthy trees, and the pine tree population is depleted at a rate greater than the rate at which it can replenish itself.

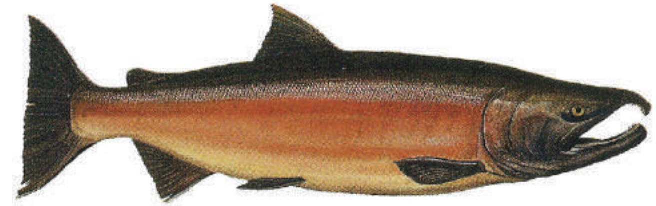
If drought frequecy or duration increase in Oregon, conditions may allow the pine beetle to thrive.

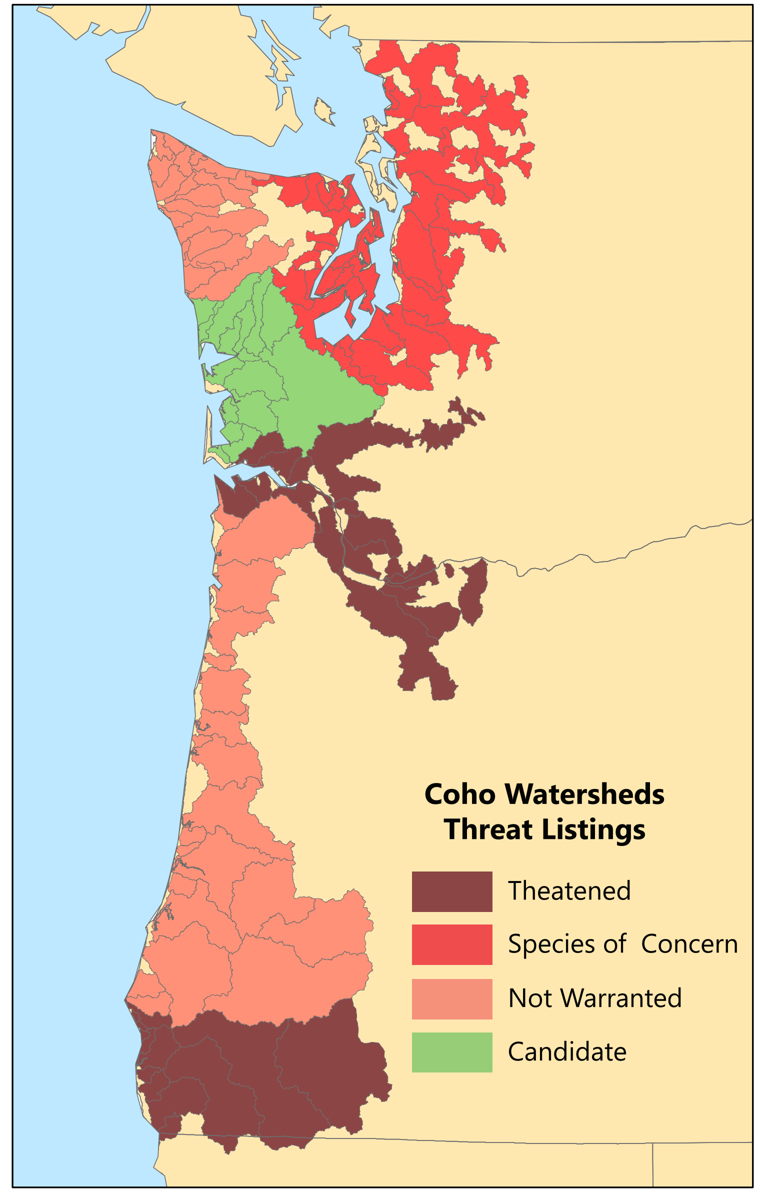


Fisheries: Salmon

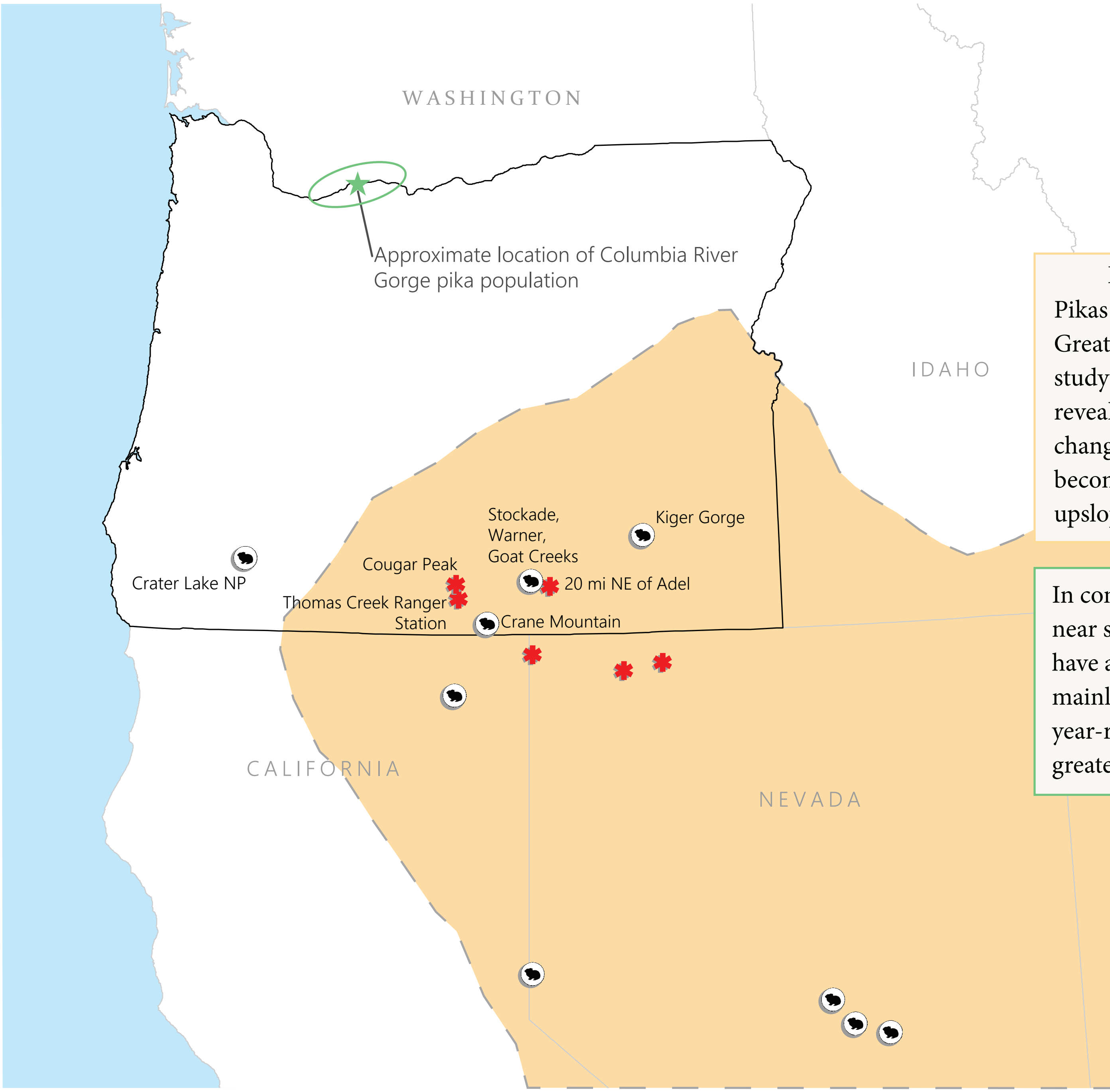
Many factors play a role in the health and survival of Oregon salmon species like Coho and Chinook, from marine environments (e.g., sea temperature, upwelling, sea level) to freshwater habitats (e.g., riparian zones, floods, dams). Known and predicted climate related impacts in Oregon include: degradation of freshwater habitat due to drought and temperature increases; changes in snowmelt affecting habitat and genetic diversity of species; and higher mortality levels due to increased flood flows.







Mammals: Pika



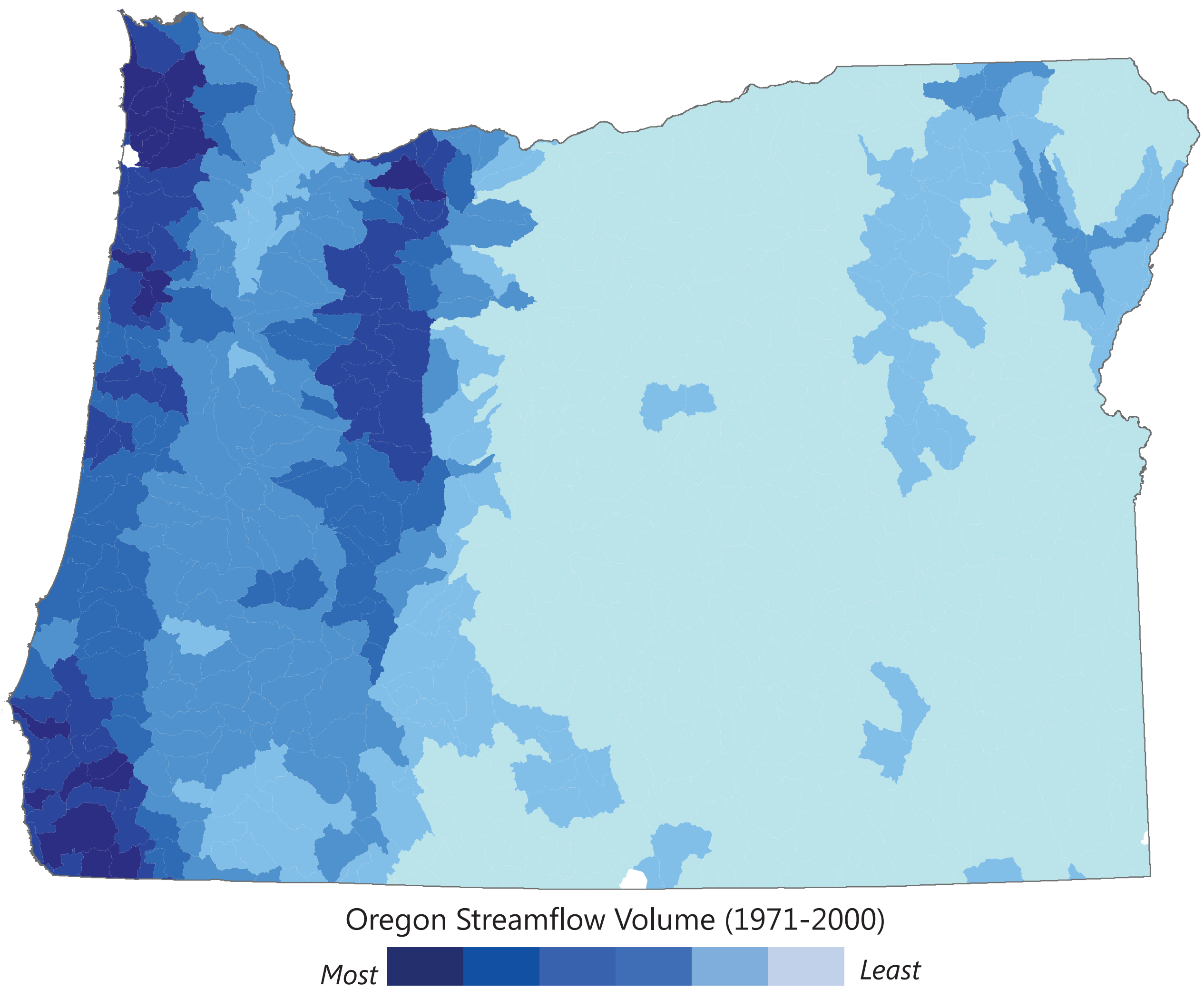
PIKAS (*Ochotona princeps*)

Pikas are climate-sensitive mammals. In the Great Basin, which includes SE Oregon, the study of pikas and microclimate data has revealed that in response to environmental change some local pika populations have become extinct and others are moving upslope where temperatures are cooler.

In contrast, a population of pika who reside near sea level in the Columbia River Gorge have an unusual, specialized diet comprised mainly of moss. The abundance of moss year-round in their region may give them greater tolerance to changes in climate.

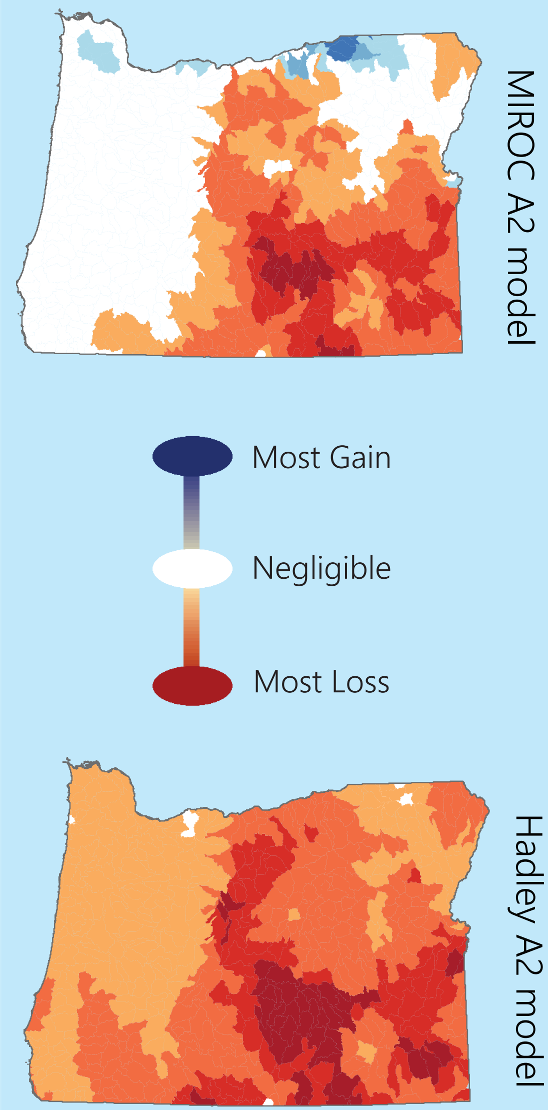
Streamflow Projections

Water managers have traditionally used historical streamflow data to project future streamflow conditions. The influence of climate change on the watercycle (principally through fluctuations in timing of runoff and in evaporation rates) means that past norms and extremes in streamflow no longer represent current streamflow. The ability to predict timing and volume of streamflow is important for reservoir management, irrigation scheduling, and similar water resource management practices.



Projected Streamflow Change

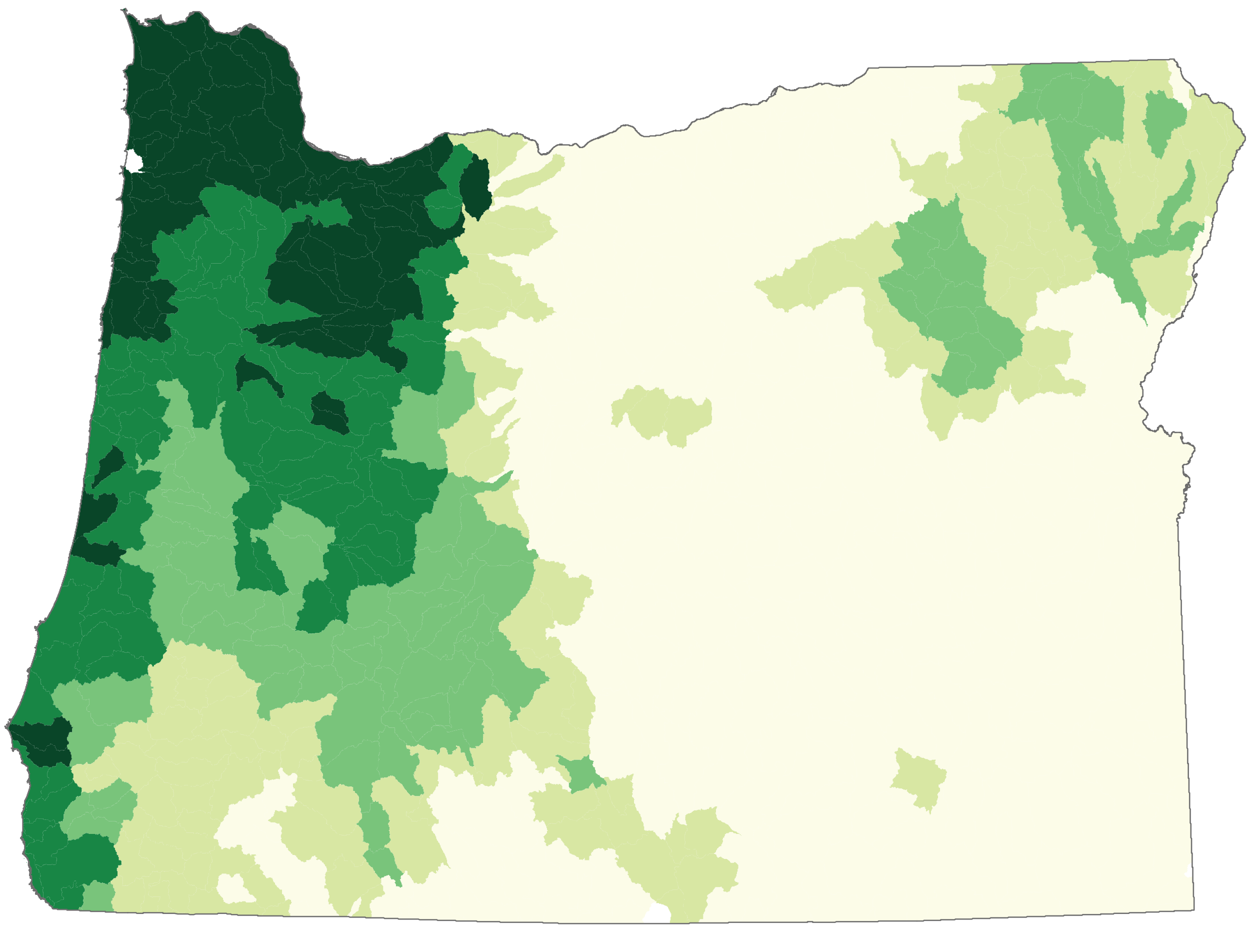
Between historical (1971-2000) and future (2071-2100)



See page 27 for descriptions of climate models

Vegetation and Carbon Projections

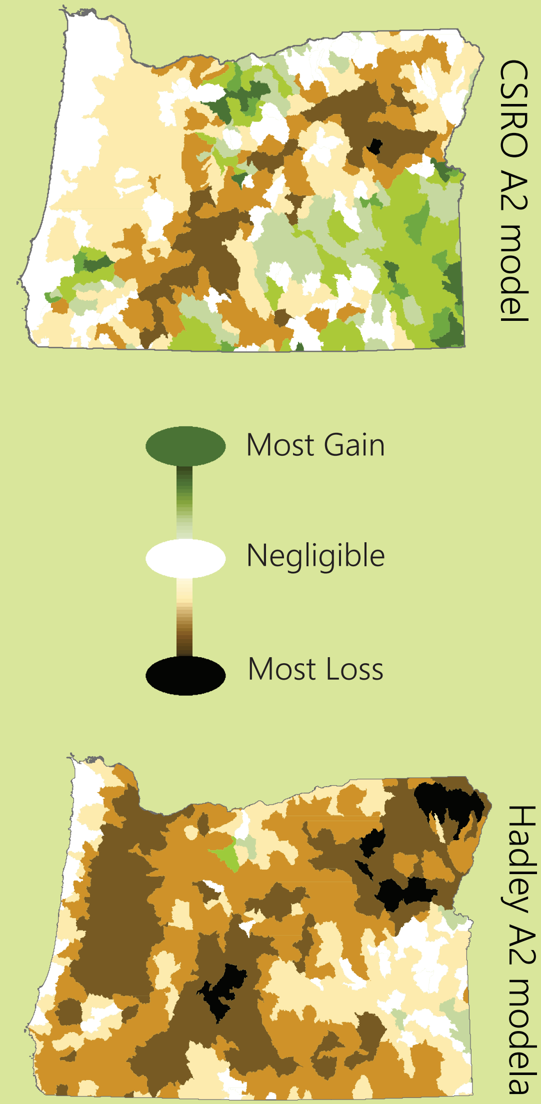
Vegetation can act as a reservoir for the ***sequestration of carbon***. Living plants absorb carbon dioxide during the growing season, sequestering it in the new growth. Naturally occurring fires and human activities such as deforestation that reduce vegetation cover lead to reduction in sequestered carbon.



Oregon Vegetation Carbon (1971-2000)

Projected Carbon Change

Between historical (1971-2000) and Future (2071-2100)



See page 27 for descriptions of climate models

Selected Impacts of Climate Change I

Water Resources
Changes in precipitation patterns and increasing temperatures have already impacted Oregon's water resources, altering streamflow magnitude and timing, water temperature, and water quality.

Wildfires
Forest wildfire activity has increased since the 1980s with larger fires of longer duration, and longer wildfire seasons. The pattern is strongly associated with increased temperatures and early snowmelt.

Insects
Warming has increased insect infestations (spruce budworm, mountain pine beetle) in Oregon's spruce, pine, and Douglas fir stands.

Coastal Areas
Increasing sea levels and increasing wave height will impact coastal communities through more flooding and erosion. Communities and roads will see increased flooding and landslides.

Vegetation
Species sensitive to changes in temperature and precipitation, particularly during the growing season, appear to be responding to local climate change. Douglas fir is growing more slowly in our warmer summers.

Selected Impacts of Climate Change II

Snow and Snowmelt
Snowpack is reduced and snowmelt is occurring earlier. This impacts water resource availability, reservoir management, fish, recreation, agriculture, and other functions that rely on summer water.

Agriculture
Rising CO_2 benefits most crops, and longer growing seasons can increase the variety and yields of crops that can be grown. However, reduced water availability for irrigation, drought, and changes in pests could threaten crops and yields.

Ranching
As temperatures rise and drought increases, rangelands may grow grasses with fewer nutrients for livestock. Hotter days can result in less milk from dairy cows and leaner beef cattle.

Fisheries
Predicted decreases in summer stream flows, increases in stream temperatures, and changes in suitable stream habitat are likely to cause economic losses in recreational fishing as cold-water fish reach their tolerance thresholds.

Mammals
Changing climate means changing habitats for mammals, who when possible respond by moving to more tolerable regions (such as cooler areas upslope).

Internet Resources

We have compiled a downloadable, searchable database of internet sites that provide teaching materials on various issues of climate and climate change. These sites range from curriculm and model lessons to policy and impact analyses. This database can be found at: http://www.pdx.edu/geography-education/file/676

Many individuals, community grounds, and political entities such as cities and states are taking action to address climate change. We have compiled a downloadable, searchable database of climate initiatives in Oregon that gives you an idea of what Oregonians are doing to learn about and address climate change in Oregon. This database can be found at: http://www.pdx.edu/geography-education/file/675

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