Climate

EVERY WINTER, AFTER SNOWS HAVE CLOSED HIGH ELEVATION ROADS THROUGHOUT OLYMPIC NATIONAL PARK, National Park Service (NPS) scientists, rangers, and volunteers ski deep into the higher elevations of the Olympic Mountains, where the snow easily piles to depths of 10 to 20 feet. They make this trek to survey the snowpack at historic transects known as snow courses. There they gather data used to calculate the amount of water stored in the snow and estimate the volume of melt water that will trickle down in the coming spring and summer. Using an instrument called a federal sampler, they collect and weigh snow cores along a designated track, skiing back out of the mountains at the day's end. Pairs of NPS staff have consistently accomplished this task every winter since 1949, and today, they undertake it as one small part of the North Coast and Cascades Network's (NCCN) climate monitoring program.

"That 60-year dataset provides an important legacy," said Bill Baccus, an Olympic National Park scientist who regularly completes the snow course trip. "Some of our most compelling climate stories have come from measuring the decline in these snow packs. It's the same spot, the same instrument, and sometimes the same people, year after year."

As one of nine Vital Sign monitoring programs in the NCCN, the climate monitoring program tracks seasonal and annual trends in climatic conditions in-and-around the national parks of the Pacific Northwest, and it provides crucial contextual insights into all other studies occurring within them. In a testament to the inescapable influence of climate over the environment, all 32 Inventory and Monitoring networks in the NPS consider climate a primary Vital Sign for monitoring park health. The data gathered from climate monitoring applies to the study of every other Vital Sign in the network, as it sup-

By: James Andrews

Program Objectives

1. Provide a climatic context for the monitoring of all park resources including all other Vital Signs in order to better understand observed variations.
2. Compare current and historic climatic conditions to identify long-term trends.

Photo: A weather station operated near the Silver Glacier in North Cascades. This station collects hourly air temperature, net radiation, wind speed and wind direction, important parameters affecting annual glacier characteristics. NPS/Larrabee plies information on the baseline environmental conditions in which all other scientific observations are taken.

Climate consists of the prevailing weather patterns of a region, a composite of physical factors such as temperature, precipitation, and wind. It influences natural systems on every conceivable scale, from the size and distribution of massive glaciers to the lifecycles of microscopic invertebrates. Because of this, climate is considered a system driver, as it establishes the parameters within which all other natural processes function.

The climate monitoring program's goals are to provide a climatic context for all other scientific studies in the network, understand the variations in climate across the network, and compare current conditions with historic records, differentiating long-term changes from natural fluctuation. Seven of the network's eight national parks host equipment for recording climatic information year-round, and the program integrates data from a number of sites outside park boundaries. Climate influences every facet of the natural world, and our understanding of natural processes depends on thoughtful, accurate climate monitoring.

Monitoring Strategy

The NPS maintains the majority of its climate monitoring equipment in cooperation with numerous partner agencies such as the National Weather Service and the National Oceanic and Atmospheric Association. The cooperation from partner agencies has made the entire operation not just feasible, but affordable. Through these partnerships, the NCCN has amassed a broad

Park staff using a federal sampler weigh a snow core during a monthly snow survey near Hurricane Ridge, Olympic National Park. NPS/Baccus database of climate information across the Pacific Northwest despite having a relatively limited budget and a small staff.

To measure the full extent of climatic features in the region, the NPS and partner agencies share information from more than 50 weather stations within or near seven of the network's parks (all but Klondike Gold Rush National Historical Park). Simply put, weather stations are the foundation of the program, as they record nearly all of its relevant data. The NPS relies on data from such a large network of weather stations because the Pacific Northwest contains such a varied topography and, as a result, a complex climate.

"If you consider studies in the three large parks, we have coastal lowlands at sea level, which rarely freeze, and alpine tundra at 14,000 feet, which rarely thaws," Baccus said. "Areas of the Olympic Rainforest are routinely drenched with 180 inches of rain, while just across the range in the sheltered rainshadow of the Olympic Mountains, we'll measure 20 inches of rain."

Most weather stations are tripods or towers with branching arms that support equipment for measuring climatic parameters such as temperature, precipitation, and wind. By necessity, these stations sit outdoors in full exposure to the weather on a year-round basis and require regular maintenance. The NPS operates nine of these stations in Olympic, five in Mount Rainier, five in North Cascades, and a single station at San Juan Island. In addition, NPS staff perform maintenance on partner-owned weather stations in the parks.

"The most challenging part of monitoring the climate is just keeping electronic instruments functioning in a place with such an extreme climate. Some of these places are getting 180 inches of rain or as much as 80 feet of snow every year. At many of our high elevation sites, entire stations get covered in ice—a condition called riming. It'll freeze up, and then it's suddenly subjected to 120 mile per hour winds that can sheer parts of it off," Baccus said. "Another problem is the wildlife. I routinely repair sites where elk have chewed the wires thinking they're branches."

The network employs three scientists to focus on climate monitoring part-time, with one scientist stationed at each of the three large parks. They spend much of their time compiling and checking that the stations record. In the first ten years of the program, NPS weather stations alone recorded 15 million measurements. After assuring the quality of the data, park staff summarize it into annual reports for the use of other park scientists and staff.

Several times a year, these climate monitoring scientists will visit each weather station to perform routine maintenance, calibrate instruments, and download data. Within each park, the stations are distributed all over the place; to reach some, park staff might only walk 100 meters off a road, while reaching another might require a 15-mile backpacking trip or helicopter delivery to remote backcountry areas.

Ten types of stations operate in and around the NCCN parks, with each recording the data most relevant to the agency that owns it. For example, virtually all stations record air temperature and precipitation, with many recording more site-specific information such as wind speed, soil moisture, or snow depth. Most weather stations take automated readings at regular intervals, either transmitting them to a database remotely or recording information into a data logger until a technician retrieves it. A select few stations are still visited by a park ranger each day, such as the National Weather Service COOP station at the Paradise Ranger Station in Mt. Rainier. Manual observations at this site have been recorded daily since 1920.

Data Collection

Automated weather stations are equipped with electronic temperature sensors to record air temperature at regular intervals—typically once every hour—throughout the year, supplying the most important baseline measurement for understanding climate. Rainfall is measured with a number of different rain gauges, depending on the location of the weather station. NPS-operated low elevation stations use tipping bucket rain gauges, which measure not only the total rainfall over a given time, but also the varying rates at which it fell. A tipping bucket works by collecting rain into a funnel at the top, draining it into one of two alternating cups mounted on a beam, much like a seesaw. When the water fills one cup, the device tips the water out and the alternate cup begins filling. The gauge records each tip, revealing the amount of time passed between the tips and calculating the rainfall rate.

Beyond rainfall, the majority of the remaining precipitation reaches the ground in the form of snow, which supplies downstream ecosystems with cold and abundant water for much of the summer season. The snowpack is measured in three ways: snow depth, snow density, and snow-water equivalent.

Snow depth is the total accumulation of snow on the ground. Many remote climate stations are equipped with acoustic snow depth sensors to determine season-long snow depths in remote areas where manual measurements are difficult to take. Snow depth sensors hang from weather station towers and point at the ground to measure the time it takes an ultrasonic pulse to travel to the snow surface and back. Knowing the distance to the ground—or the snow depth at last measurement—the sensor calculates the new snow depth. Measuring snow depth allows the scientists to gauge how much snow remains on the ground after each snowfall, since the temperature, precipitation, and wind all influence how much snow accumulates or melts in an area.

A park ranger collects daily weather data from a National Weather Service COOP station at Lewis and Clark National Historical Park. NPS/Liang

Snow-water equivalent (SWE) is the volume of water stored in a snowpack—the amount of water that would result from all the snow melting. SWE is probably the most important snowpack index, as it is a direct measure of the snowpack's potential contribution to streams and rivers during the summer dry season. When a snowpack's depth is multiplied by its density (weight for a known volume), the product is the SWE. While this can be measured manually by using a federal sampler on a snow course, park scientists rely primarily on an automated snow measuring station known as a SNOTEL (short for SNOwpack TELemetry).

SNOTEL stations are operated by the National Resources Conservation Service, and are located throughout the mountainous regions of the western United States. SWE measurements are made with snow pillows—thin, 4-by-5 foot bladders containing an antifreeze solution. The snow pillows sit in the open, and when snow accumulates on them, the weight of the snow compresses the pillow, forcing the solution through a tube connected to measuring instruments.

Many climate stations measure wind speed with a rotating-cup anemometer, a device that consists of three half-sphere cups that spin on a central point in accordance with the speed of the wind. To detect the direction of the wind, they use a simple wind vane that points in the direction that the wind blows. Data on the wind's speed and direction are used to understand a wide variety of questions, such as the transport and deposit of snow, snow melt during rain events, transportation of airborne pollutants, damage from high-wind events, and even coastal bluff erosion.

A select number of climate stations are equipped with probes that measure the temperature and moisture levels in the soil at measured depths. Because soil temperature varies according to depth, researchers ideally place sensors at a number of depths: surface level, 5 cm, 15 cm, and 30 cm. Measuring the moisture requires a separate probe inserted down through the surface at a 45 degree angle, taking moisture readings at the surface, and then the ranges of 0-20 cm, 20-40 cm, and 40-60 cm. Each distinct depth interests scientists, as each is associated with microbial processes, the germination of seeds, or the uptake of nutrients by shrubs and trees.

Finally, some stations measure forms of solar radiation because of its importance in providing light to the earth and energy to plants for photosynthesis. The climate monitoring program relies on three types of sensors to measure solar radiation: pyranometers, net radiometers, and quantum sensors. Pyranometers measure total incoming or shortwave solar radiation (wavelength range of 400 to 1,100 nanometers) in watts per square meter. Net radiometers measure the difference between total incoming radiation from the sun and radiation reemitted from the Earth's surface. The quantum sensors focus solely on photosynthetic active radiation (PAR), the radiation wavelength range used in photosynthesis for plant growth (400 to 700 nanometers). Net radiometer measurements are generally used to understand melting rates on glaciers, while total radiation and PAR data are commonly used in ecosystem models for understanding processes such as forest growth and water cycles.

Climate's Role in Vital Signs Monitoring

The climate monitoring program is unique among the Vital Signs monitoring programs in that climatic information directly relates to the study of every other Vital Sign in the network. This section briefly identifies the relationships that tie the climate to the other Vital Signs.

Elk: As spring begins, herds of elk in Olympic National Park's survey area congregate on the valley floors. There, they partake of the offerings of the spring "green-up," a time when the temperature climbs and vegetation begins to emerge from the waning snow. Right at the beginning of the green-up, many of the trees have not yet sprouted full leaves, giving park staff a brief window of time to easily count the elk from a helicopter. To predict when each year's green-up will occur, NPS biologists rely on recent temperature data. Climate data can also help answer more specific questions about changes to elk populations. For instance, an especially hard winter could lower survival rates, causing fewer elk to appear for surveys.

Fish: Because fish are sensitive to water temperature fluctuations, awareness of climatic trends is helpful when monitoring fish populations. Salmonids, for example, cannot successfully spawn in streams with high temperatures. A study on bull trout (McPhail and Murray 1979) showed that trout eggs survived at a rate of up to 95 percent in stream temperatures between 2 to 6 degrees Celsius (36 to 43 F), while 85 percent survived at 8 degrees C (46 F), yet only 20 percent survived at 10 degrees C (50 F). Similarly, each species of salmonid spawns at very specific times of the year, requiring a certain level of stream flow, which is influenced by precipitation and snow-melt. A biologist studying fish populations would need data on all of these variables in order to help interpret the observed changes among the fish.

Glaciers: Glaciers serve as a physical record of the climate, both in its current state and historically through ice-core analysis. Glacial ice contains evidence of historic atmospheric conditions inside small air bubbles, and researchers can extract ice-core samples to get an idea of past temperature variations and atmospheric gas compositions—valuable information for climate scientists. Conversely, climate data aids glacier researchers by supplying contextual information on air temperature, wind speed, snowfall, and solar net-radiation, all of which influence whether a glacier grows and shrinks.

Intertidal Zones: Rocky surfaces within the intertidal zone of the Pacific Northwest coast typically display a vertical zonation of plants and animals, with barnacles dominant at the top, mussels below, and seaweeds dominating the lower areas. The upper end of each zone is typically set by physiological tolerances of organisms to heat and drying, while the lower end of each zone is set by organismal interactions such as competition and predation. During low tides, many of these organisms are exposed to the air for hours. As global air temperatures rise, the stress on these organisms will increase, especially during daytime low tides in the spring and summer. Elevated temperatures can also change the nature of organismal interactions. Increased temperature changes growth rates, and increased water temperature can introduce new species due to range extensions.

Landbirds: Climate dictates the timing of bird migration and breeding. In the last half-century, researchers around the world have observed hundreds of bird species adjusting their locations and breeding time according to changes in the climate, particularly by moving their ranges north as global temperatures rise.

Mountain Lakes: In the high elevations of the Pacific Northwest, it is typical for a lake to remain frozen for more than eight months of the year. The timing of spring thaw and summer lake stratification (the natural 'layering' of lake water densities according to temperature) depends entirely on climatic conditions. With increasing air temperatures, mountain lakes will have fewer days of ice cover and greater stratification, which can affect the lifecycles of the organisms living in and around them.

Vegetation: The composition of a forest depends almost entirely on the climate of the region. The elevation at which forests change from lowland species to subalpine is a result of temperature, summer drought, and the duration of winter snowpack. Observations commonly recorded by the forest monitoring program, such as tree growth and mortality, can be directly related to climatic conditions such as rainfall, soil moisture, and temperature. For example, if the climate monitoring program records a decade of warming temperature and smaller snowpacks at high elevation sites, this would help explain accelerated tree growth measured in subalpine forest plots. Likewise, a decade of lower than normal summer precipitation could help explain a rise in the spread of forest diseases or frequency of wildfire.

Current Trends

Average annual air temperatures in the Pacific Northwest have increased by approximately 0.8 degrees Celsius (1.5 F) in the last one-hundred years, with the warming expected to accelerate in the coming decades. This rate nearly doubles the global average, and though it may seem like a small increase, it has led to a number of observed changes in the surrounding ecosystems. Continual climate data—especially data from the mountainous areas of the NCCN parks—will allow scientists to better differentiate natural variability from long-term, global trends.

The state of Washington hosts the largest glacier cover in the contiguous United States. Approximately five percent of the total area within Olympic, North Cascades, and Mount Rainier national parks is covered by glacial ice, but these features are melting at alarming rates. According to one estimate (Granshaw 2001), 44 percent of glacier cover in the North Cascades has melted in the last 150 years alone, melting ice that took many centuries to form. Estimates of ice volume loss in Mount Rainier's glaciers suggest as much as 50 percent reductions over the last 100 years. In the last 25 years, the Blue Glacier in Olympic National Park has lost more than 100 feet of ice thickness, a volume change of 14 percent (Fudge, 2009). Similarly, estimates of April 1st snow-water equivalent in the Cascade Mountains indicate a 15 to 35 percent overall decline in the last 60 years, which correlate with observations that peak levels of spring stream runoff have shifted earlier by weeks.

Looking to the future, the National Park Service's ability to track climate conditions both regionally and nationwide will become an invaluable asset to the study of climate change and its impacts. The climate helps determine almost everything about our environment, and detailed knowledge of the climate is crucial to understanding everything else we observe in the natural world.

A park service volunteer skis through fresh snow to a remote snow course in Olympic National Park. NPS/Baccus

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