

NEW MEXICO Climate

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About NMSU’s Climate Center

NMSU’s Climate Center is home to the state climatologist who helps New Mexicans understand the impact of climate changes on the environment, human health, and agricultural production.

The state climatologist is responsible for archiving weather data and distributing climate information to the public. Unlike meteorologists, climatologists do not provide weather forecasting or up-to-the-minute bulletins. Instead, they use a computerized data collection system to provide statewide weather reports for previous days, as well as for historical information.

The state climatologist puts climate data into a form people can use to make decisions about their lives. During fire sea-

son, people use climate data to assess potential fire hazards and to evaluate fire-fighting conditions. Engineers use information about rainfall and flooding to design bridges, culverts, storm sewers, and sanitary sewers.

Business owners use climate data to evaluate new business or relocation sites. Farmers use it to anticipate outbreaks of insect pests or crop diseases. People also use climate data when making their recreation and travel plans.

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The office of the state climatologist and its head, the state climatologist, are described in New Mexico Statute 75-4-1 through 75-4-4

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Water Harvesting

By: Ted Sammis *

Since 1993 Santa Fe County passed an ordinance that requires commercial developments to collect all roof drainage into cisterns to be reused for landscape irrigation, and all residential development to collect roof drainage from a minimum of 85% of roof area to also be reused for landscape irrigation. Homes consisting of 2,500 square feet or greater must install underground, partially buried, or insulated cisterns, while homes under 2,500 square feet must submit a rainwater catchment plan with their development permit application. Santa Fe County, NM was the first area in the United State to instigate this requirement, but Tucson, Arizona in 2009 pass an ordinance that developers building new business, corporate or commercial structures will have to supply half of the water needed for landscaping from harvested rainwater. Average 30 year rainfall in Santa Fe, NM is 14.07 inches and the average rainfall in Tucson, AZ is 13.91 inches. Yearly potential evapotranspiration where water is not limiting and the ground cover is 100 percent is 74-76 inches for both locations, but the growing season in Santa Fe is only 155 days compared to 305 days for Tucson. Consequently, in Tucson the water requirements for fescue grass would be about twice the amount compared to Santa Fe. A detailed water budget involve the amount of rainfall runoff, the water harvesting index of the roof material, and the evapotranspiration requirement of vegetation and the vegetative cover % would need to be conducted. These calculations are demonstrated in a publication by the city of Albuquerque, NM entitled "Rainwater Harvesting from the Sky"

<http://www.ose.state.nm.us/water-info/conservation/Albq-brochures/rainwater-harvesting.pdf>.



Rainfall in Las Cruces NM for water harvesting

Because the most important input to the calculations is rainfall and that is highly variable from location to location and year to year, information on rainfall for specific locations should be acquired from the Cocorahs web site <http://www.cocorahs.org/> or the western regional climate center.

<http://www.wrcc.dri.edu/summary/climsmnm.html> . The water harvesting system can be designed for average long term regional rainfall conditions realizing that at your house rainfall conditions may be different. Because the main cost of a water harvesting system is the cost of the storage tanks, the cost of storing rainfall can range from \$0.3 to \$1.25 per gallon stored.

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Global Warming

By: Ted Sammis *

California Agriculture April-June 2009 contains an article on the impact of rising carbon dioxide on irrigated agriculture food production in C3 plants (wheat, rice, barley, oats, legumes, vegetables and fruit and nut trees). The article indicates that elevated carbon dioxide concentrations (567 ppm) will inhibit photorespiration which will in turn inhibits shoot nitrate assimilation with an end result that biomass will only increase in the long term by 12 % but the protein concentration will decrease by more than 12% . Consequently, the way in which plants are fertilized will have to change from applying large amount of nitrate fertilizer to apply small frequent amount of ammonium fertilizer to prevent this decline in protein content. This fertilizer management change will require a change in irrigation method from flood and sprinkler irrigation to drip irrigation. Because drip irrigation has the potential to have high irrigation efficiencies (85-90%) water resources will also be conserved by changing irrigation technology. However, drip irrigation systems currently cost more than flood or sprinkler systems.



Southern California from the MODIS Satellite Data

As second article on climate change and insect pest problems reports that as increasing temperatures occur there will be a need to change the way integrated pest management is operated. Pest development is a function of heat units which will increase. Consequently, the timing of pest control will change from current conditions. Also the increase in biomass produced with elevated carbon is offset by an increase in insect consumption of leaf area. The increase in carbon dioxide will increase the carbon-based defenses of plants against insects but the decrease in nitrogen will decrease the nitrogen based compounds that act as toxins or repellents. Also, the increase in temperature will change pest species and diversity.

For a detail discussion of these two issues see Arnold J Bloom. 2009. As carbon dioxide rises, flood quality will decline without careful nitrogen management and J. T. Trumble and C. D. Butler. 2009. Climate change will exacerbate California's insect pest problems

California Agriculture 63(2) <http://californiaagriculture.ucanr.org/issue.cfm?volume=63&issue=2>

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Lewis and Clark: “Big Science” at the Dawn of the Nation

By: Terrence R. Nathan*

“A change in our climate is taking place very sensibly. Both heats and cold are become much more moderate within the memory even of the middle-aged. Snows are less frequent and less deep. ...The elderly inform me the earth used to be covered about three months in every year.” (Jefferson, 1955)

Thomas Jefferson penned these words more than two-hundred years ago, yet they resonate with today's concerns about anthropogenic influences on global warming. Jefferson's comments also reflect his life-long interests in weather and climate. Those interests would manifest as key objectives in the United States' first mission to explore the trans-Mississippi West. That mission – known today as the Lewis and Clark Expedition – provided the first systematic instrumental and proxy weather data of the trans-Mississippi West. In this note, I will provide a brief overview of the expedition, focusing on its weather and climate aspects by synthesizing recent work by Solomon and Daniel (2004), Nathan (2005, 2006) and Preston (2006).

The Expedition: From Conception to Execution

Thomas Jefferson's conceptualization of a transcontinental expedition to explore the interior of North America began several decades before the Lewis and Clark embarked on their epic journey. Surrounded by a westering philosophy in his early childhood and concerned by threats of British and French efforts to colonize portions of the West for commercial purposes, Jefferson made three unsuccessful attempts prior to 1794 to launch expeditions to explore the trans-Mississippi West. Once Jefferson became the third President of the United States in 1801, he was better positioned to launch an expedition to carry out his dream of finding an overland route to the Pacific Ocean – the so-called Northwest Passage. On

January 18, 1803, Jefferson submitted a letter to Congress requesting a \$2,500 special appropriation to fund an exploratory expedition to the “Western ocean” for the purposes of commerce and science (Jackson 1978). To lead this expedition Jefferson chose his personal secretary, Captain Meriwether Lewis.

Lewis spent part of 1803 preparing for the expedition. Part of this time was spent receiving advice and training in science and a variety of other topics from Jefferson’s fellow American Philosophical Society members. Topics included botany, surveying and medicine. Because meteorology and climate were not yet sciences in the way physics and chemistry were at the time, Lewis would not have received tutoring in these subjects.

Immediately following Lewis's training, he wrote to his longtime friend, William Clark, asking him to co-lead the expedition. Clark accepted several weeks later. On June 20th, Jefferson wrote a letter to Lewis, who mapped out the objectives of the mission:

...The object of your mission is to explore the Missouri river, & such principal stream of it, as, by it's course and communication with the waters of the Pacific ocean, ..., for the purposes of commerce... You will take ,<careful> observations of latitude and longitude, at all remarkable points on the river...make yourself acquainted ...with the names of the nations and their numbers,...their language; their ordinary occupations in agriculture... Other objects worthy of notice will be the soil and face of the country...; animals of the country;...mineral productions;...climate, as characterised by the thermometer, by the proportion of rainy, cloudy & clear days, by lightning, hail, snow, ice, by the access & recess of frost, by the winds prevailing at different seasons, the dates at which particular plants put forth or lose their flower, or leaf... (Jackson 1978) (original spelling is retained in the quotes)

As Ronda (1998) notes, this was the young nation’s first venture into what is now called “big science.” This moniker is apt given the broad-based objectives that Jefferson assigned to the expedition. The objectives dealt with issues relating to economics, ethnography, geography, and science. Moreover, the execution and planning of the expedition required federal funding, involvement of several branches of government, and multidisciplinary training in the natural sciences.

From late June until the end of August, most of the time was spent obtaining additional supplies, maps, and books, commissioning men for the expedition, purchasing a pirogue, and having a keelboat made in Pittsburgh. The keelboat was completed on August 31st. By 11 o’clock that morning the boats were loaded and Lewis and several recruits were headed down the Ohio River for their rendezvous with Clark.

On August 31st Lewis makes the first entry in what is known as the Lewis and Clark Journals. September 1st marks the first entry about the weather, and on September 2nd Lewis recorded the first temperature of the expedition.

Lewis and Clark rendezvoused in mid October on the north side of the Ohio River in Clarksville, Indiana Territory. After a couple of weeks in Clarksville selecting enlisted men for the expedition, the party moved down the Ohio then up the Mississippi. On December 13th, 1803, they arrived at their winter camp on the Wood River, near the mouth of the Missouri River. Lewis and Clark would spend five months at the Wood River camp. During their stay at the camp they were busy collecting and describing the local flora and fauna, practicing using their celestial instruments, and recording the daily weather.

On May 21st, 1804, the Corps of Discovery was on the eve of its epic journey.

Climate Science and Lewis and Clark

The earliest theories of weather and climate can be traced back to the philosophers of ancient Greece. Hippocrates and Aristotle, for example, proposed climate theories that related the character tendencies of the various peoples of the world to the warm, cold, and middle zones on Earth. Their theories were based on an axiomatic approach, wherein self-evident truths were postulated and built upon by deductive reasoning to reach conclusions about the natural world. It wasn’t until the Enlightenment and the emergence of the scientific revolution in the seventeenth century that this Aristotelian philosophy was replaced with rationalism and the scientific method.

Francis Bacon’s crystallization of the scientific method in the seventeenth century is rooted in systematic, controlled observations or experiments that lead to hypotheses. If through further work the hypotheses are found to be valid, theories may be formulated that lead to generalizations about the natural world. These theories are then further refined by additional observations and experiments. Not surprisingly, the advent of the scientific method coincides in large part with the invention of scientific instruments.

By the time the Lewis and Clark expedition came to fruition in the early nineteenth century, several scientific instruments had been invented that became an integral part of the expedition (Preston 2006). Among these instruments were an octant and sextant for determining latitude, a theodolite and chronometer for determining longitude, a telescope, a surveying compass, and a spirit level. Lewis and Clark also carried

three thermometers, which had been invented more than 175 years before the expedition. The barometer was more than a century and a half old by the time Lewis and Clark placed their paddles in the Missouri River, but they didn't carry one on the expedition. Even if they did, the connection between barometric pressure, air masses and fronts was unknown and would remain so for decades.

During Lewis and Clark's time, meteorological science was still in its infancy. The study of meteorology was confined to isolated observations recorded in personal diaries. From Ancient Greece to Colonial America, meteorological science made very few advances. Lewis and Clark's observations were made at a time that Fleming (1990) has called the "expanding horizons" in meteorology, when more reliable meteorological instruments began to emerge allowing for the systematic acquisition of weather data.

A Climate Journey

Figure 1 shows the Lewis and Clark outbound trail superimposed on the various Köppen climate classes. At the time of Lewis and Clark, the climate of the trans-Mississippi West was unknown. Even Jefferson, who was among the most enlightened on weather and climate issues at the time, assumed that the expedition would traverse a "moderate climate" (Jackson 1978), a characterization that contrasted sharply with reality.

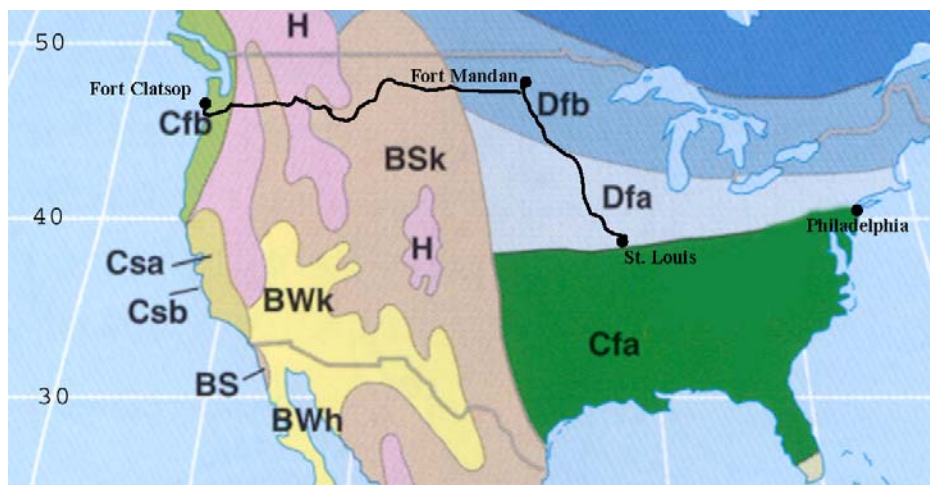


Figure 1. Lewis and Clark's outbound trail from St. Louis to Fort Clatsop superimposed on the Köppen climate classes for the conterminous United States. These classes and their characteristics are: BSk=mid-latitude steppe (semi-arid); BWk=mid-latitude desert (arid); BS=mid-latitude steppe; BWh=subtropical desert (arid); Cfa=humid subtropical climate (hot summer, no dry season); Cfb=marine west coast climate (mild throughout the year, no dry season, warm summer); Csa=Mediterranean (dry, hot summer); Csb=Mediterranean climate (dry, warm summer); Dfa=humid continental climate (severe winter, no dry season, hot summer); Dfb=humid continental climate (severe winter, no dry season, warm summer); H= highland climate (cold climate due to elevation). Figure adapted from Nathan (2005)

September 1, 2004 marks the first journal entry about the weather. In that entry Lewis attributes the fog on the Ohio River to ".....the Fog appears to owe it's origin to the difference of temperature between the air and water the latter at this season being much warmer than the former; the water being heated by the summer's sun dose not undergo so rapid a change from the absence of the sun as the air dose consequently when the air becomes cool which is about sunrise the fogg is thickest and appear to rise from the face of the water like the steem from boiling water..." (Moulton 1986). Lewis was describing evaporation-mixing fog. Although instruments to measure the amount of water vapor in the atmosphere were around since the fifteenth century, theories regarding the condensation and evaporation of water vapor were only beginning to emerge in the mid eighteenth century (Middleton 1969). A full explanation of the processes involved in the formation of fog would have to wait until the late nineteenth century when the kinetic theory of gasses was well established and the seminal experiments on condensation were being carried out (Mason 1957).

At 6:00 a.m. on May, 22, 1804, under cloudy skies, the Corps of Discovery began its first full day as a unit, moving upstream against the powerful Missouri River. Until the party reached the site of their winter quarters at Fort Mandan near present-day Bismarck, North Dakota in November, the party toiled against powerful river currents, recorded information on flora and fauna new to science, traded with the local Indian tribes, and made weather observations on a daily basis.

From St. Louis to Fort Mandan, the party traveled through what the Köppen system broadly classifies as a humid continental climate. The party traveled through the heart of this climate zone during summer, when the heat and humidity can be oppressive. On July 29, while on the Missouri between present-day South Dakota and Iowa, Lewis notes the destruction caused by an apparent tornado: *...above this high land & on the S. S. passed much falling timber apparently the ravages of a Dreadfull harican which had passed obliquely across the river from N.W. to S.E. about twelve months Since, many trees were broken off near the ground the trunks of which were Sound and four feet in Diameter...*(Moulton 1986).

During October 1804, the party crossed into today's North Dakota. By early November the party was at the site of their winter quarters, Fort Mandan, named after the local Mandan Indians. Fort Mandan was about 45 miles northwest of present-day Bismarck, North Dakota. While at Fort Mandan, Lewis and Clark systematically recorded the daily weather, producing the first long-term, systematic tabulation of weather data west of the Mississippi. Comments on the weather were included in the regular journal entries as well as in a separate weather diary. The weather diary also contained tables that listed the weather observations. Solomon and Daniel (2004) found that the temperatures experienced by Lewis and Clark at Fort Mandan were not unusual compared to modern observations.

In early April, when the ice had broken up on the Missouri, the 33 member party loaded their boats and proceeded on. The party was slowly entering terra incognita, where the geography, Indian cultures, and climate were virtually unknown. The party was entering into present-day Montana and a climate that was outside of their life experience – the steppe climate of the Northern Plains. Lewis found the low humidity of this region noteworthy enough to carry out a crude experiment:

[May 30, 1805]... circumstances indicate our near approach to a country whos climate differs considerably from that in which we have been for many months. the air of the open country is asstonishingly dry as well as pure. I found by experiment that a table spoon full of water exposed to the air in a saucer would evaporate in 36 hours when the mercury did not stand higher than the temperate point at the greatest heat of the day; my inkstand so frequently becoming dry put me on this experiment. (Moulton 1987)

By early August the party was in the shadow of the continental divide. Preparations were being made to cross the divide in the Bitterroot Mountains, the most formidable mountain crossing yet attempted by citizens of the United States. The crossing of the divide was arduous. Steep cliffs, confusing and narrow ravines, and lack of game were exacerbated by the cold temperatures of the highland climate. Traveling was dangerous. The horses frequently fell and on September 3rd the last of the three thermometers was broken. Clark summed up the situation on September 16th: *“...began to Snow about 3 hours before Day and Continud all day...I have been wet and as cold in every part as I ever was in my life...”* (Moulton 1988).

The grueling trek across the Bitterroot Mountains was completed by late September. Upon exiting the mountains the party was fatigued and hungry, and many of the men were suffering from gastrointestinal disorders. Fortunately for the party, contact was made with the Nez Percé people, who provided them with food and horses. The Nez Percé also provided the party with important geographical information that indicated they were within striking distance of the rivers that would ultimately take them to the Pacific Ocean.

In preparation for their journey to the coast, dugout canoes were made, and on October 7th the party was on the Clearwater River heading for the junction with the Snake River. In three days the party reached the Snake River and two weeks after that the Columbia River. As the party traveled down the Columbia from the east to the west side of the Cascade Mountains, there was a dramatic change in climate. The steppe climate east of the cascades rapidly transitioned into a marine west coast climate of the Pacific Northwest. Upon the party's arrival to the region in early November, powerful storms were occurring almost daily. The inclement weather and the lack of permanent shelter were proving extremely difficult to the party. Clark wrote: *“[November 22, 1805] ...the wind increased to a Storm from the S.S.E. and blew with violence throwing the water of the river with emence waves out of its banks almost overwhelming us in water, O! how horriable is the day...”* (Moulton 1990).

Tillamook Head, Oregon

"...from this point I beheld the grandest and most pleasing prospects which my eyes ever surveyed..." William Clark, Lewis and Clark Expedition (1806)

This view of Tillamook Head is likely similar to what Clark observed as he and a small contingent of the expedition crossed the area to view a beached whale at present-day Cannon Beach, Oregon.

Photo credit:
<http://www.terrbynathanphoto.com/>



On December 8, 1805, the party began the first full day at the site that would become Fort Clatsop, named after the local Clatsop Indians. Although Lewis and Clark noted in October a change in climate as they paddled down the Columbia from the east to the west side of the Cascades, they now realized that they were in a winter climate that was foreign to them. The distinct climate of the Pacific Northwest is noted by Lewis on January 3rd, when he writes, *"I am confident that the climate is much warmer than in the same parallel of Latitude on the Atlantic Ocean tho' how many degrees is now out of my power to determine."* (Moulton 1990)

At the time of the expedition, the connection between latitude and climate was well known. The ancient Greeks were among the first to make this connection. In fact, climate derives from the Greek word *klima*, meaning inclination, underscoring the connection between climate and the inclination (or height) of the sun above the horizon, which depends on time and latitude. Not fully known at the time of Lewis and Clark, however, was the role that ocean currents and land-sea heating contrasts played in climate, factors that largely account for the differences in the climates between the Pacific Northwest, Central Plains, and the East Coast.

From the beginning of the party's stay at Fort Clatsop on December 8th until their departure on March 23rd, the weather remained stormy. Of the 106 days that the party stayed at Fort Clatsop, there were 90 days of precipitation, of which there were 17 days of snowfall. There were only 12 days without precipitation; the sun shone fair for only six days. Although prolonged periods of rainfall are common for the Pacific Northwest, Nathan (2005) has shown that the time spent at Fort Clatsop was indeed anomalous.

Nathan (2005) made comparisons between averaged conditions for present-day Astoria, Oregon and Lewis and Clark's observations at Fort Clatsop during the winter of 1805-1806. He showed that the frequency of precipitation, the frequency of snowfall, and the persistent southwesterly winds were all dramatically different than present-day. What accounts for these dramatic differences? There are several possibilities. The position of the storm track within a given year or between given years can be quite different than its long-term averaged position. This intra-seasonal and inter-annual variability may simply be due to the natural variability inherent in thermally driven, rotating stratified fluids such as the atmosphere. The emergence out of the Little Ice Age climate may also have been a factor, or there may have been some external forcing process such as the anomalous warming or cooling that takes place in the equatorial eastern Pacific during El Niño or La Niña events. In fact, other than the change of seasons, El Niño and La Niña have the greatest impact on the global atmospheric circulation. During La Niña, for example, the Pacific storm track is displaced north of its climatological position, resulting in above normal precipitation and below normal temperatures for the Pacific Northwest, which is consistent with the weather at Fort Clatsop.

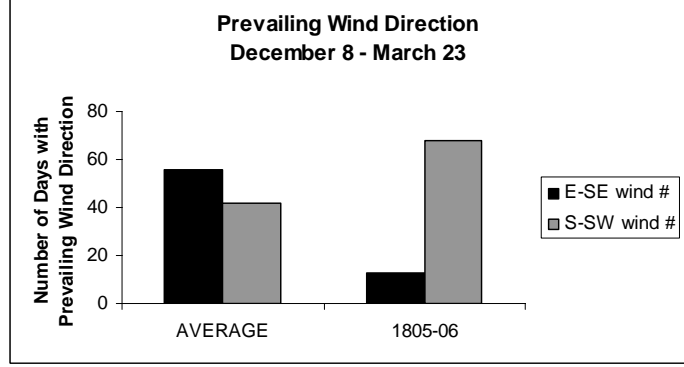
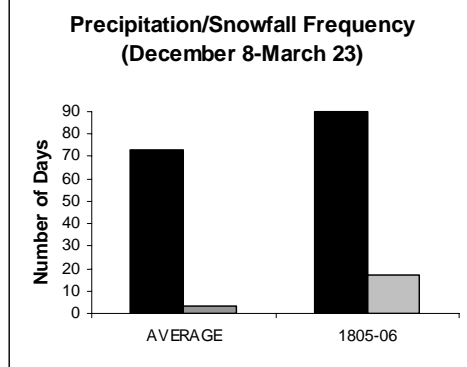


Figure 2. *Left figure:* The number of days of precipitation (black) and snowfall (grey) between December 7 and March 23 for (a) Astoria, Oregon averaged between 1954 and 1999 (left column) and for (b) Fort Clatsop, Oregon for the winter of 1805-1806 (right column). The precipitation numbers include both rain and snow. *Right figure:* The prevailing wind direction between December 8 and March 23 for (a) Astoria, Oregon averaged between 1961 and 2001 and for (b) Fort Clatsop, Oregon for the winter of 1805-1806. Adapted from Nathan (2005)

Lewis and Clark departed Fort Clatsop on March 23rd, 1806. They continued to make daily weather observations on their return trip. At 12 o'clock on September 23rd, 1806 the party arrived to St. Louis and "...were met by all the village and received a hearty welcome from it's inhabitants..." (Moulton 1993).

The Lewis and Clark expedition spanned more than 28 months and traversed more than 8,000 miles of undocumented territory. They recorded in their journals more than 170 plant species and more than 120 animal species that were new to science. They made the first systematic weather observations west of the Mississippi. Combined with hundreds of pages of cartographic, ethnographic, and scientific information, they successfully executed a broad-based, "big science" project that continues to add to our knowledge and spark our imagination more than two-hundred years later. The expedition is etched deep in our nation's psyche, serving as a benchmark for achievement and scientific discovery.

Additional Reading

The reader is referred to Preston (2006) for a comprehensive listing of the weather and climate data of the Lewis and Clark expedition.

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