Global Climate Patterns and Their Impacts on North American Weather

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Introduction

This article provides a broad overview of various climate patterns and their impacts on weather in North America. The most well-known and widely studied climate pattern is the El Niño – Southern Oscillation (ENSO). Climate patterns are characterized by irregular cyclical variations in oceanic or atmospheric circulations. Oscillations in sea-level pressure and SSTs influence atmospheric circulation patterns. As these patterns shift and change, they affect weather around the world. Rigorous statistical analyses identify teleconnections (or relationships) that cover large geographical regions, over both the oceans and land.

Hemispheric and global-scale climate patterns have been studied for over a century[1]. Climate patterns emerge from naturally reoccurring variations in either the atmospheric circulation or SSTs, or reflect the interplay between the atmosphere and SSTs. Large differences in pressure create strong pressure gradients, which cause the winds to blow quickly and steer the direction of weather systems. Cloudiness, rain, snow, and/or thunderstorms are associated with low-pressure systems due to rising air motions and atmospheric instability. Clear skies are associated with high-pressure systems due to sinking air and less instability. Sea

surface temperatures (SSTs) interact with the air above the sea surface, and in turn, influence and are influenced by sea level pressure. In the tropics, warm SSTs are associated with low-pressure because the warm, moist air above the surface of the ocean rises, eventually cools and condenses into clouds, which then can cause precipitation. Conversely, cool SSTs are associated with high-pressure because cooler air is denser and sinks, which inhibits the rising motion needed for cloud formation and weather.

The five climate patterns discussed in this article are either well known or they influence the weather of North America. The climate patterns are presented in order of decreasing influence on the western U.S.: El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Madden-Julian Oscillation (MJO), Pacific-North American Pattern (PNA), and North Atlantic Oscillation (NAO)/Arctic Oscillation (AO)

(Figure 1a).

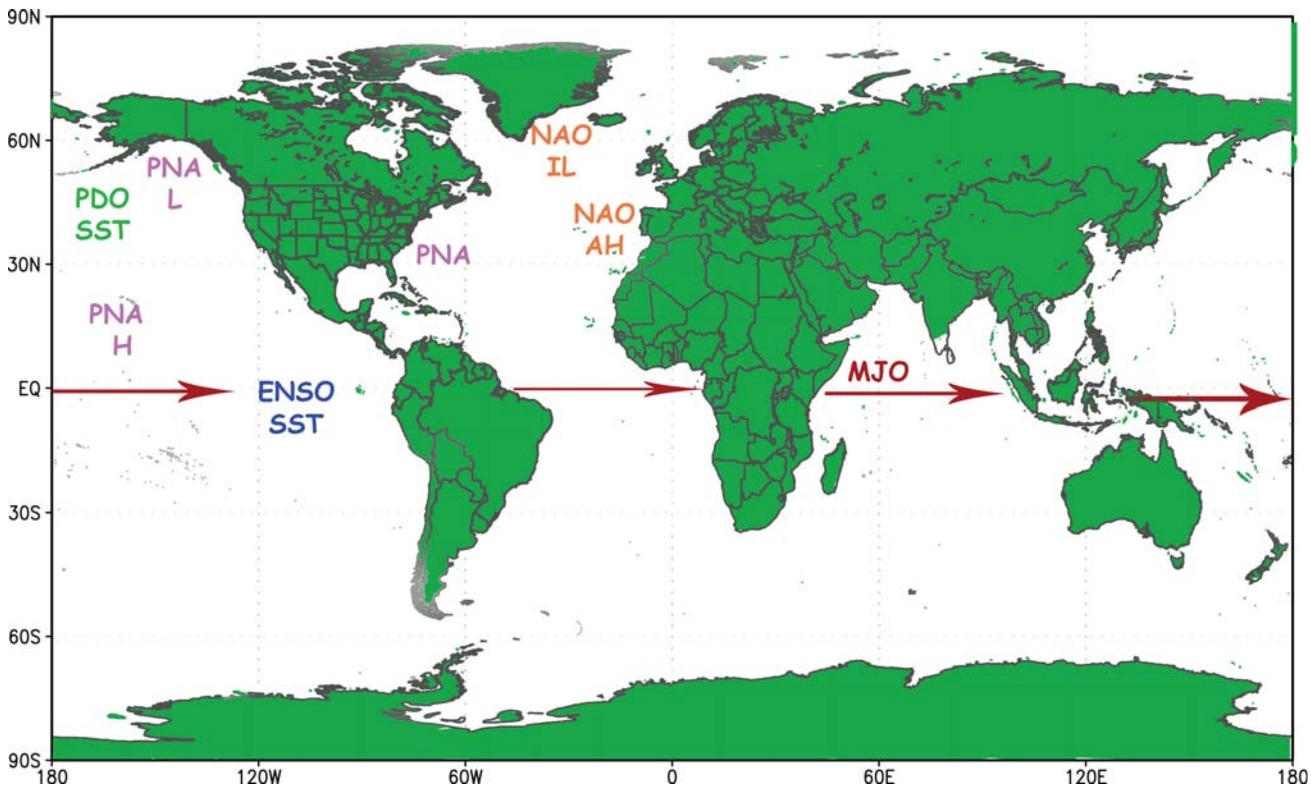

Figure 1a. Locations of the five climate patterns: the El Niño Southern Oscillation (ENSO) reflects SST along the equatorial Pacific Ocean. The Pacific Decadal Oscillation (PDO) reflects SST in the northern Pacific Ocean. The Madden-Julian Oscillation (MJO) reflects a repeating pattern of high and low-pressure systems that moves eastward along the equator. The Pacific-North American Pattern (PNA) reflects pressure differences between a high-pressure system near the Hawaiian Islands and a low-pressure system near Alaska's Aleutian Islands. The North Atlantic Oscillation (NAO)/Arctic Oscillation (AO) reflects pressure differences between the Icelandic Low (IL) and the Azores High (AH).

[1] For a definitive book chapter on climate patterns, see Barry and Carleton (2001).

El Niño Southern Oscillation

The most studied and well-known climate pattern is the El Niño Southern Oscillation (ENSO), which reflects the combined variations of SSTs and the atmospheric circulation in the eastern equatorial Pacific Ocean (Figure 1a). During ENSO-neutral conditions, trade winds over the central and western Pacific blow warm surface water towards the west, causing the sea surface to be warmer in the western Pacific than in the east. During the ENSO-positive or El Niño phase, the trade winds weaken or even reverse, causing warmer than average SSTs in the central and/or eastern Pacific. During the ENSO-negative or La Niña phase, the trade winds strengthen beyond the neutral phase, and the sea surface is cooler than average in the equatorial Pacific (Figure 1b). El Niño and La Niña usually occur every 3-7 years and persist 6-18 months.

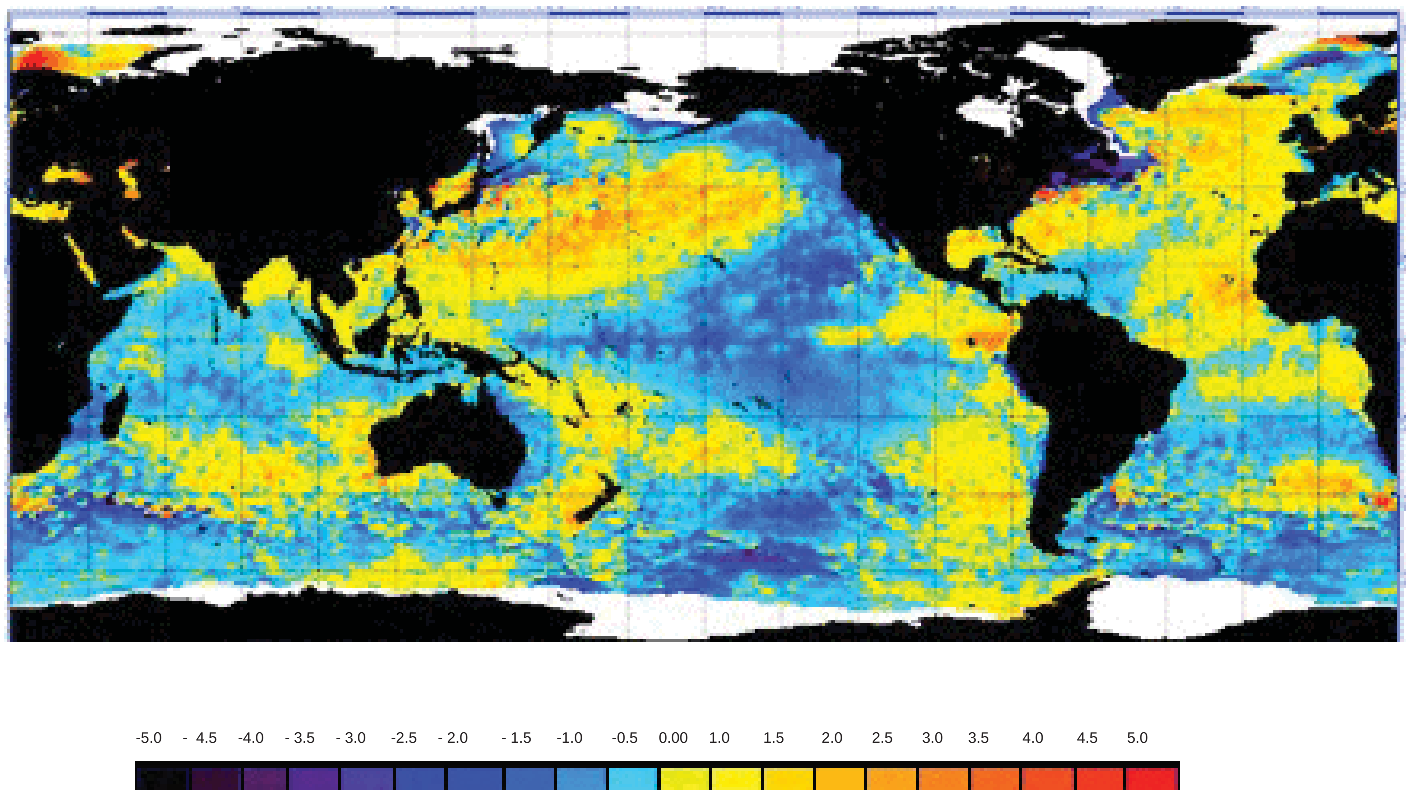

Figure 1b. NOAA/NESDIS 50 KM Global Analysis: SST Anomaly (Degrees C) as of April 3, 2008. Cooler than average SST in the equatorial Pacific indicate a La Niña event. Source: National Climatic Data Center (http://www.ncdc.noaa.gov/oa/climate/elnino/elnino.html)

ENSO is the most important source of year-to-year climate variability over the tropical Pacific Ocean, and it affects weather conditions around the globe. These impacts are fairly reliable, so scientists have been monitoring and predicting ENSO over the past two decades thanks to technological advances in oceanic and atmospheric monitoring. During El Niño events, winters in North America tend to be warmer than average in the north and wetter than average in the south. The IMW region is in an area that does not show a distinct anomaly due toduring El Niño (CPC, 2005a). During La Niña events, winters in the northwestern U.S. tend to be colder and wetter than average, and winters in the southwestern U.S. tend to be dryer and warmer than average (Goodrich, 2007). The changes in storm tracks and weather events associated with ENSO can also influence other climate patterns. However, the teleconnections between ENSO and the other patterns are not as well understood as ENSO itself.

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) reflects decadal changes in SSTs in the northern or "extra-tropical" Pacific Ocean (Mantua, 2001; Goodrich, 2007; Figure 1a). When the PDO is positive, the SSTs in the northern Pacific Ocean are colder than average, and when the PDO is negative, the SSTs in the northern Pacific Ocean are warmer than average[2] (Figure 1c). PDO events generally persist for 30 – 50 years.

Whether or not the PDO is independent of ENSO is a controversial topic. However, it is known that the relationship between ENSO and PDO can act to cancel out or reinforce the teleconnections of each other. For example, when El Niño and the negative PDO are in phase, meaning there are warmer than average SSTs in both the equatorial and northern Pacific Ocean, winter

[2] Note that this is opposite of ENSO, where the positive reflects warm SST, and vice versa.

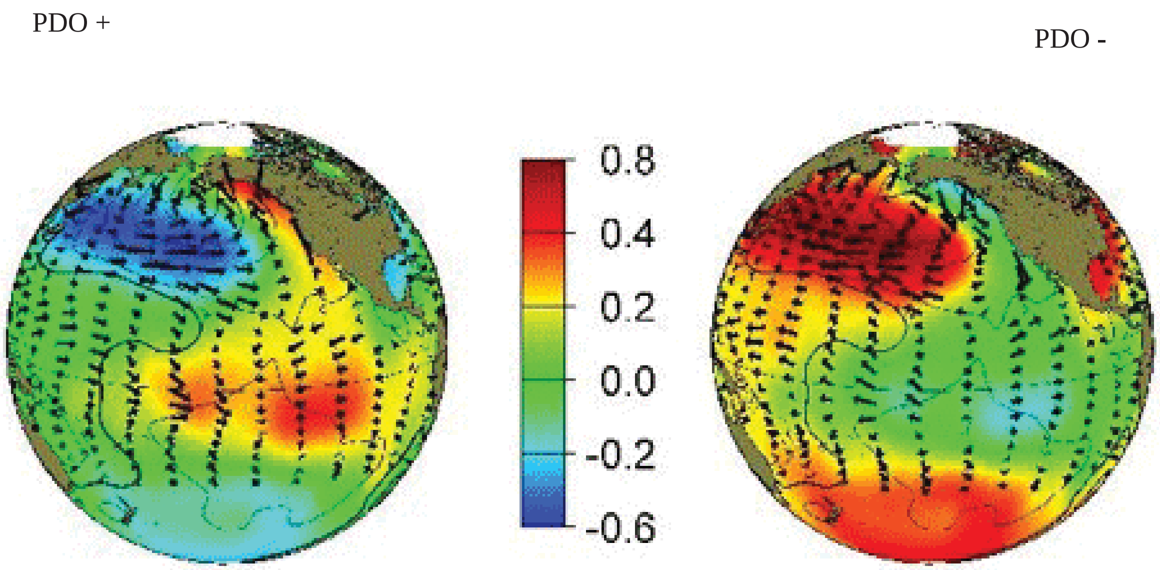

Figure 1c. Differences in SST during positive and negative phases of PDO. The positive phase of the PDO (colder than average SST in the northern Pacific) is on the left, the negative phase (warmer than average temperatures in the northern Pacific) on the right (Mantua, 2001). The scale shows the temperature above or below average in ºC.

precipitation tends to be above average in the southwestern United States and portions of the IMW region. When La Niña and the positive PDO are in phase, and SSTs in the Pacific are below average, winter precipitation tends to be below average in the southwestern United States, including parts of Utah. Finally, during a negative PDO event and a neutral ENSO, winter precipitation is above average for most of the west (Goodrich, 2007).

Madden-Julian Oscillation

The Madden-Julian Oscillation (MJO) is a pattern of suppressed and enhanced rainfall that shifts eastward in the tropics. Anomalous rainfall becomes evident initially over the western Indian Ocean, moves eastward into the equatorial Pacific Ocean, and then into the western hemisphere where the anomalous rainfall pattern becomes less apparent (Figure 1a). A complete revolution around the equator takes about 30 to 60 days (Barry and Carleton, 2001; Figure 1d).

The MJO can “cross paths” with ENSO in the equatorial Pacific Ocean, where regions of enhanced or suppressed precipitation can be amplified or reduced depending on the location of the MJO. The strength of the MJO varies year-to-year and some of this variability is linked to ENSO. The MJO is often strong during weak La Niña years or during ENSO-neutral years. The MJO is often weak or absent during strong El Niño years (CPC, 2002).

The MJO is not as well understood as other climate patterns, so its impacts on the United States are not well defined. Under special circumstances, in the winter, enhanced equatorial precipitation associated with the MJO can be correlated to enhanced precipitation along the west coast of the United States. As areas of enhanced equatorial precipitation move east, areas of enhanced precipitation in the United States move south (CPC, 2002). For example, if the maximum equatorial precipitation is at 120°E, MJO-related rainfall could occur in western Washington. When the maximum equatorial precipitation is at 140°E, MJO-related rainfall could occur in northwestern California. A future focus page in the IMW Climate Summary will discuss the MJO in further detail.

Pacific-North American Pattern

The Pacific-North American Pattern (PNA) is defined by a teleconnection of large-scale pressure anomalies that arc from the Hawaiian Islands, through the North Pacific Ocean and Canada, and then to the Southeastern United States (Figure 1a). The PNA is positive when the Pacific and Southeastern U.S. pressure anomalies are negative and when the Hawaiian and Canadian pressure anomalies are positive. The opposite is true during the negative phase of the PNA. The PNA is highly variable and can change phase within a week, but can also persist for longer periods (up to months).

The PNA can be influenced by ENSO, even though they are distinct climate patterns (Straus and Shukla, 2002). During El Niño, the PNA tends to be in the positive phase, and during La Niña, the PNA tends to be in the negative phase (CPC, 2005b). In the western U.S., a positive PNA circulation is generally associated with warm, dry conditions, and a negative PNA circulation is generally associated with cold, wet conditions. (Woodhouse, 2002).

North Atlantic Oscillation/Arctic Oscillation

The North Atlantic Oscillation (NAO) reflects the difference in sea-level pressure between the Icelandic Low (IL), a permanent polar low-pressure system over Iceland, and the he Azores High (AH), a permanent subtropical high-pressure system over the Azores (Figure 1d). When the pressure difference is large, this is considered a high index year, or NAO+. When the pressure difference is small, it is considered a low index year, or NAO-. Like the PNA, the NAO can change phases frequently, but there are persistent periods where it can stay in the same phase. While the NAO is a regional pattern of climate variability over the Atlantic Ocean, many scientists see it as part of the larger, hemispheric pattern called the Arctic Oscillation (AO; Thompson and Wallace, 2000). The NAO/AO has a strong influence on the weather in Western Europe and a weaker influence on the weather in eastern North America. Like several other climate oscillations mentioned above, the NOA/AO impacts can overlap with ENSO. When NAO+ occurs at the same time as a strong El Niño, winters are warmer than average over much of the United States, including over the IMW region (Hurrell et al., 2003).

Conclusion

Climate variations in the oceanic and atmospheric circulation can impact the weather in distant locations. Climate scientists study the teleconnections between climate and regional weather patterns in order to better understand the global climate system and improve short and long-term forecasts. For example, NOAA Climate Prediction Center has improved the skill of seasonal temperature and precipitation forecasts by incorporating ENSO information. Scientists hope that these forecasts will continue to improve for the IMW region as they gain a better understanding of other oscillations like MJO. For more information about the current conditions of climate oscillations and links to new research, see On the Web box.

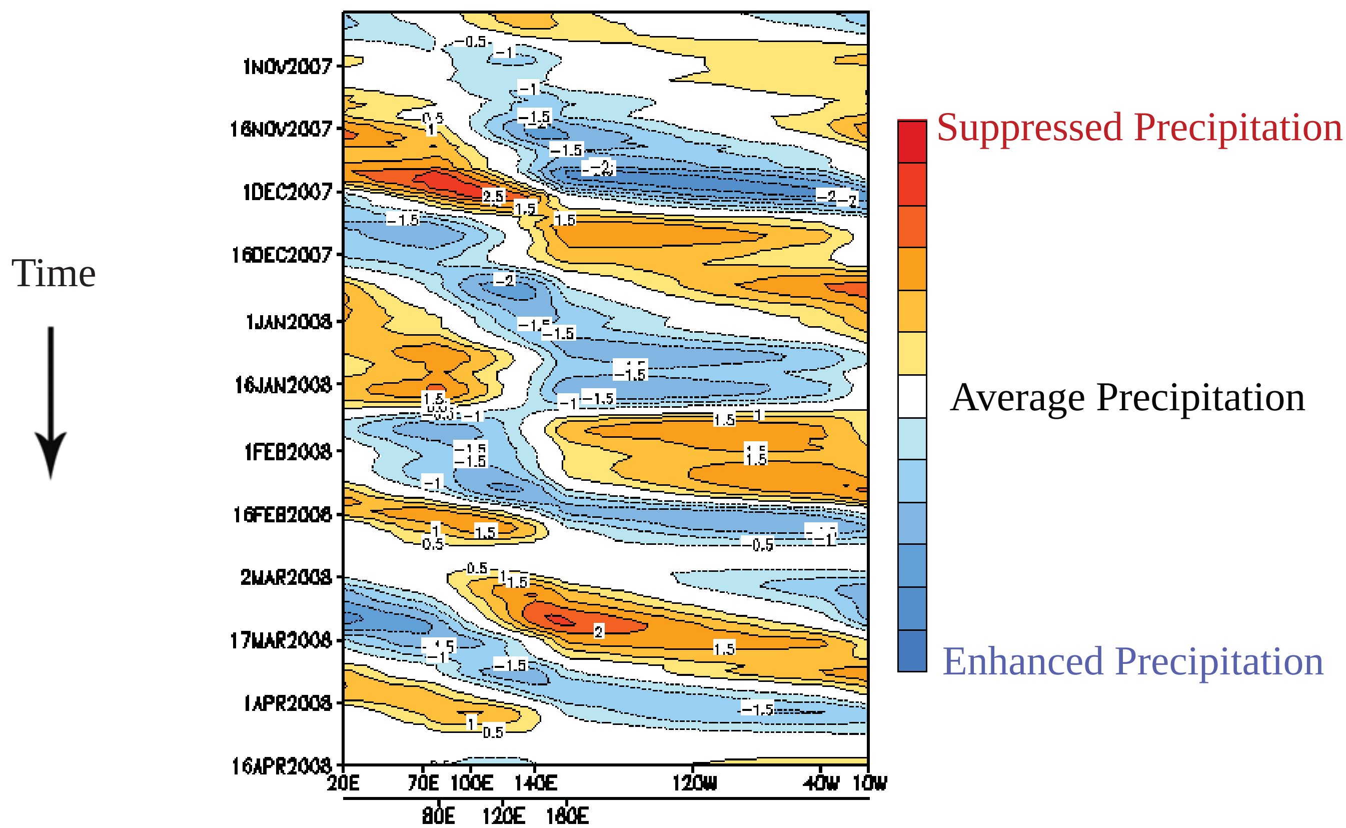

Figure 1d. The MJO Index is computed daily and identifies areas of enhanced or suppressed equatorial precipitation. The MJO Indices – blueish colors represent enhanced precipitation, reddish colors represent suppressed precipitation. The horizontal axis is longitude, and the vertical axis is time. For any given location, precipitation anomalies switch from being suppressed to being enhanced about every 10-30 days, and they move eastward through time. Source: NOAA Climate Prediction Center (http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_mjo_index/mjo_index.html

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On the Web

For a general discussion about climate oscillations and teleconnections, see:
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/teleconnections.shtml

For more information about the climate oscillations in this article, use the following links:

- ENSO: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml
- PDO: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/ca-pdo.cfm
- MJO: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjo.shtml
- PNA: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/pna.shtml
- NAO: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml