Frontier Weather

A Quick Guide to Important Drivers of US Winter Weather Patterns

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KEY TERMS

El Niño: An anomalous warming of the central and eastern equatorial Pacific that occurs every 3-7 years.

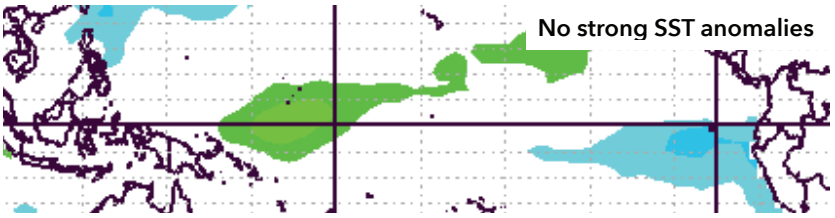
SST: Sea Surface Temperature

Niño 3.4: A region of the Pacific between 5°N – 5°S and 120° – 170°W. SST anomalies in this region are often used to define El Niño.

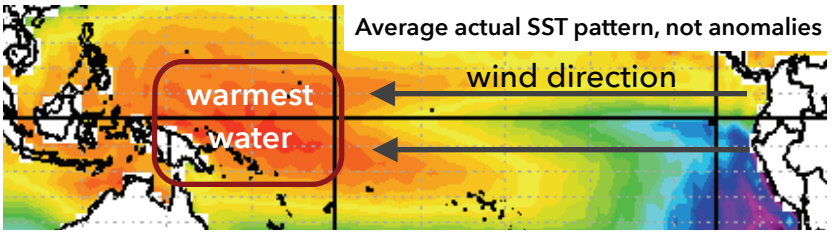
ONI: Oceanic Niño Index, a 3 month average of the Nino 3.4 anomalies.

MEI: Multivariate ENSO Index. A six variable composite index of El Niño.

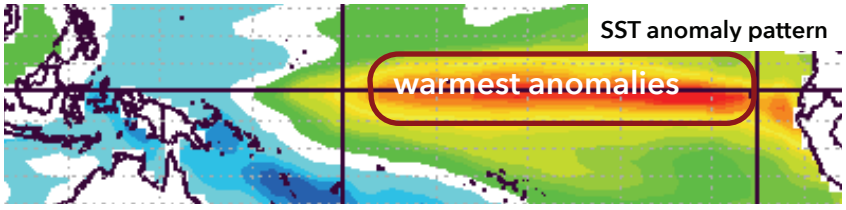
NORMAL YEAR PATTERN



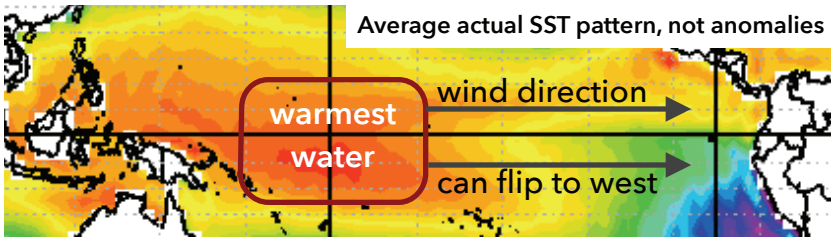
Trade winds blow from east to west, concentrating the warmest water and most of the tropical convection in the western tropical Pacific.



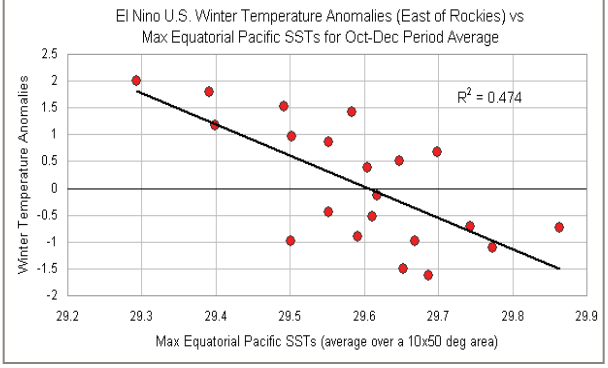
EL NINO YEAR PATTERN



Trade winds slacken or even reverse, allowing warmer water to flow eastward. This shifts tropical convection eastward as well.



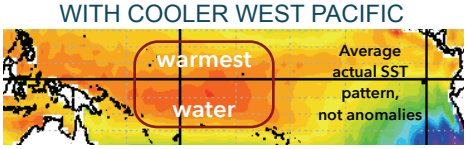
Shifts in tropical convection are what drive global weather pattern changes during El Niño. Tropical convection strength and location is directly tied to the location and intensity of the warmest water temperatures. Warmer peak equatorial water temperatures (not anomalies), tend to produce colder eastern US winters.



El Niño and US Winter Weather

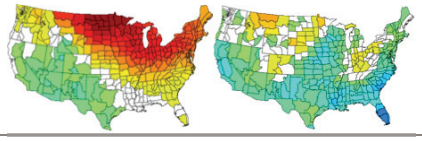
Strong El Niño events have cooler peak water temperatures near the dateline. When warm anomalies are located farther west or when the western tropical Pacific stays warm during El Niño, peak water temperatures are higher, and tropical convection is stronger near and west of the dateline. That in turn promotes a colder eastern US.

STRONG EL NINO YEAR WITH COOLER WEST PACIFIC

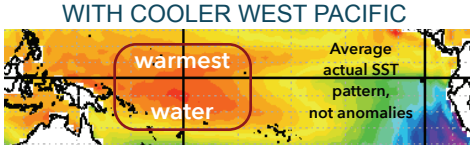


AVERAGE DEC-FEB ANOMALIES

TEMPERATURE PRECIPITATION



MODERATE EL NINO YEAR WITH COOLER WEST PACIFIC



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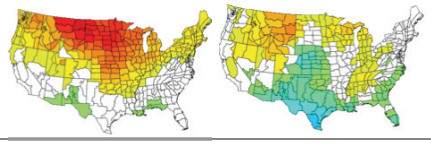
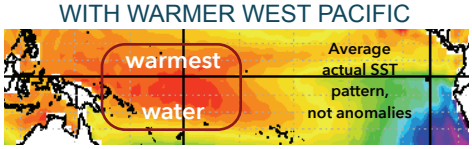
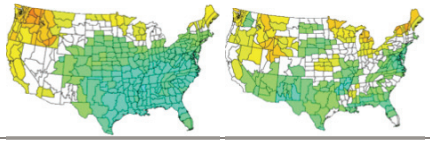


MODERATE EL NINO YEAR WITH WARMER WEST PACIFIC

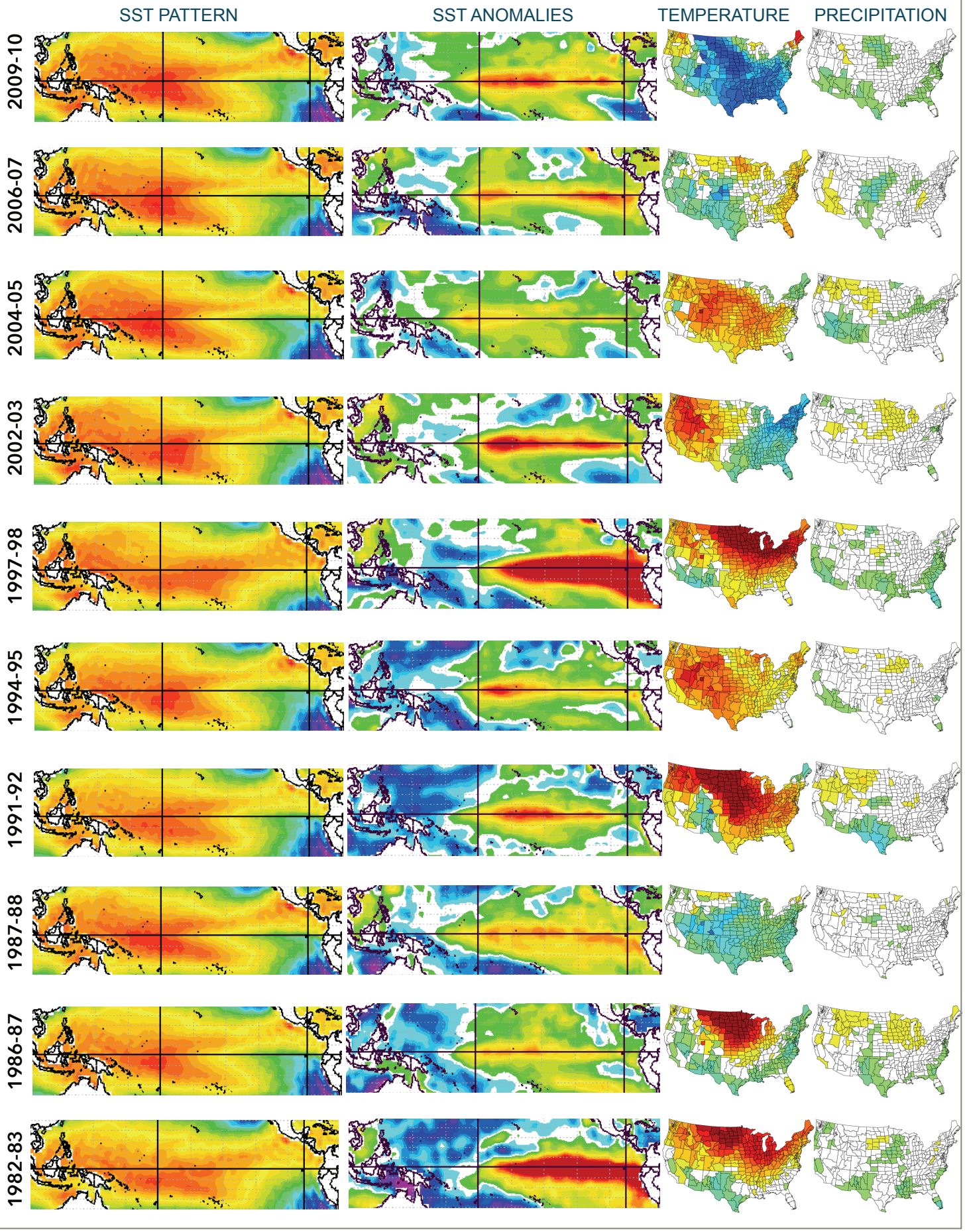


AVERAGE DEC-FEB ANOMALIES

TEMPERATURE PRECIPITATION



RECENT EL NINO YEAR COMPOSITES



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KEY TERMS

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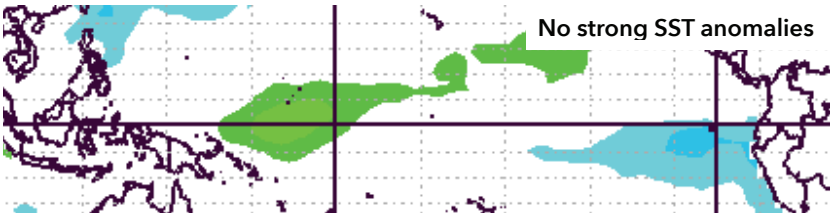
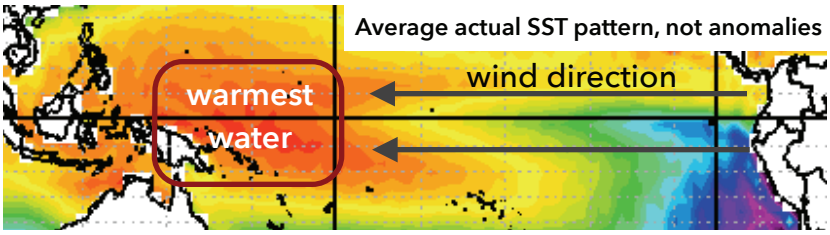
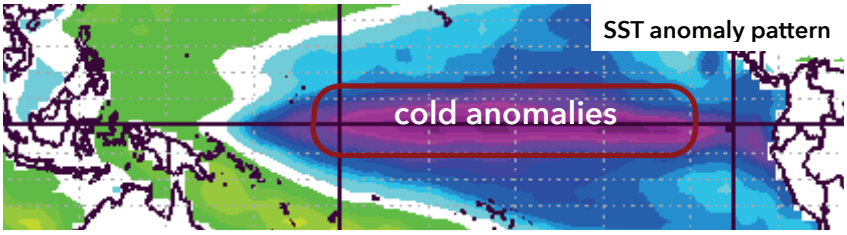


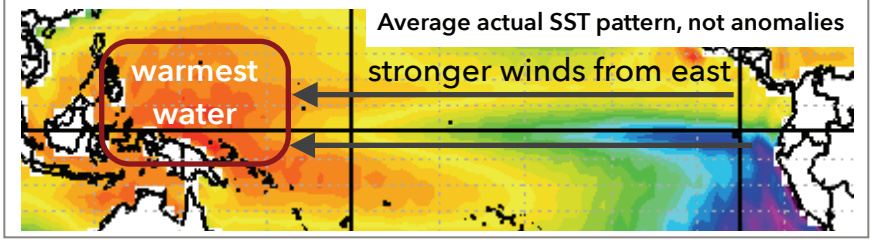
Trade winds blow from east to west, concentrating the warmest water and most of the tropical convection in the western tropical Pacific.



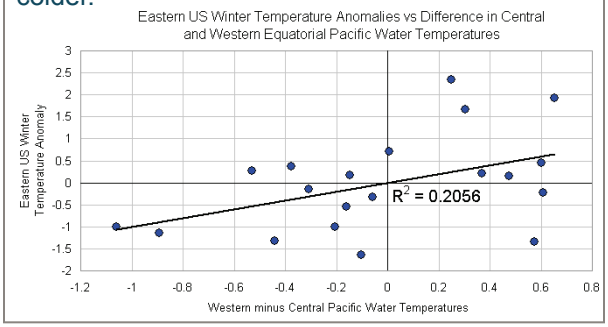
LA NINA YEAR PATTERN



Trade winds strengthen, pushing warmest water farther west than normal while central and eastern Pacific cool significantly.



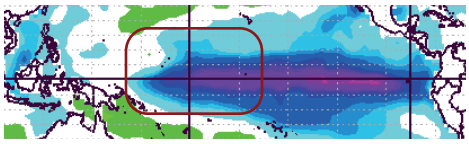
Like during El Niño events, the location and distribution of warm water is also important during La Niña. The plot below shows that the warmer the western equatorial Pacific (west of 140E) is relative to water temperatures near the dateline, the warmer eastern US winters tend to be. When water temperatures are warmer near the dateline versus farther west, winters are colder.



La Niña and US Winter Weather

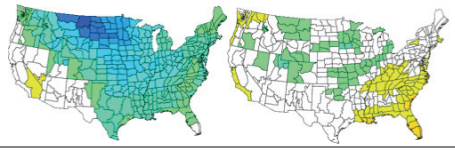
The maps below show SST anomalies for cold, seasonal, and warm La Niña winters. Cold winters during La Niña tend to be associated with weaker cold anomalies near the dateline, while warmer winters have stronger cold anomalies in that region. The seasonal winters also have stronger cold anomalies near the dateline, but colder water farther west helps keep tropical convection farther east than in the milder La Niña winter patterns.

La Nina Pattern with Cold Winters

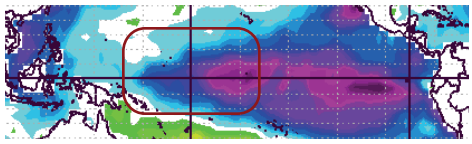


AVERAGE DEC-FEB ANOMALIES

TEMPERATURE PRECIPITATION

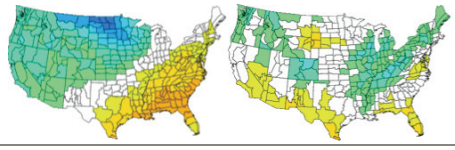


La Nina Pattern with Seasonal Winters

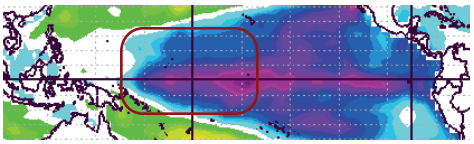


AVERAGE DEC-FEB ANOMALIES

TEMPERATURE PRECIPITATION

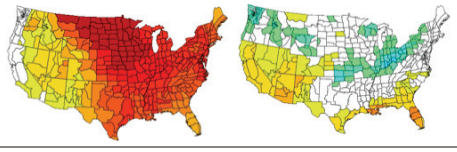


La Nina Pattern with Mild Winters

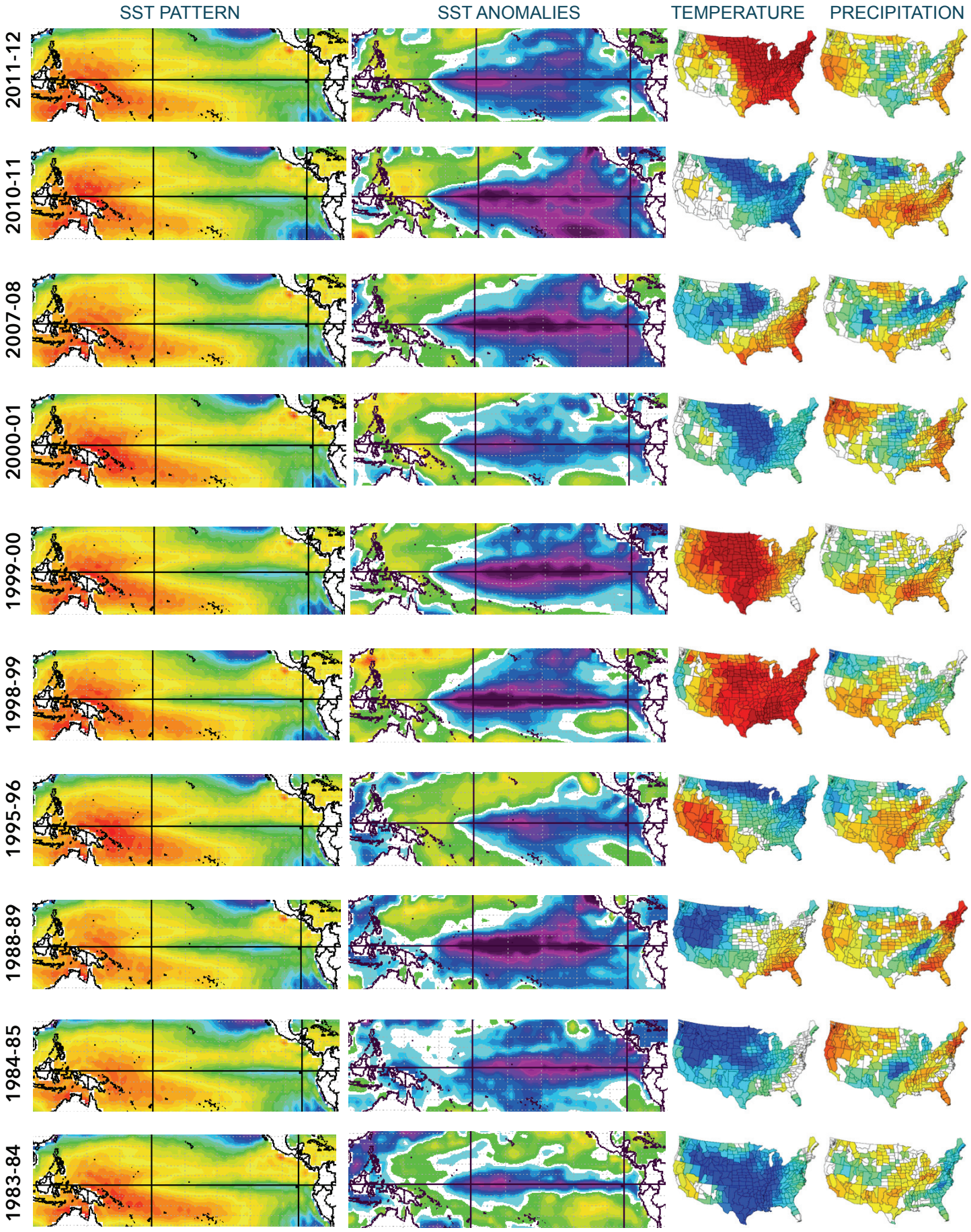


AVERAGE DEC-FEB ANOMALIES

TEMPERATURE PRECIPITATION



RECENT LA NINA YEAR COMPOSITES



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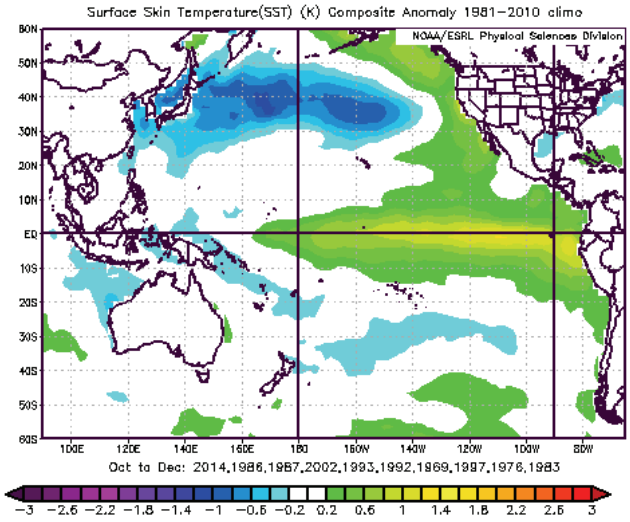
KEY TERMS

PDO: Pacific Decadal Oscillation. An oscillation in mean Pacific SST patterns that vary on a decadal time scale.

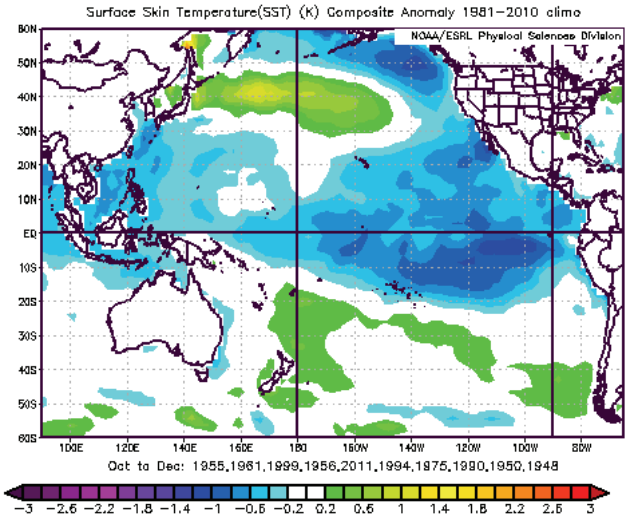
Positive PDO: A pattern of Pacific sea surface temperature anomalies that features colder than normal water from Japan eastward into the central North Pacific, with above normal water temperatures along the West Coast.

Negative PDO: A pattern of Pacific sea surface temperature anomalies that features warmer than normal water from Japan eastward into the central North Pacific, with colder than normal water along the West Coast.

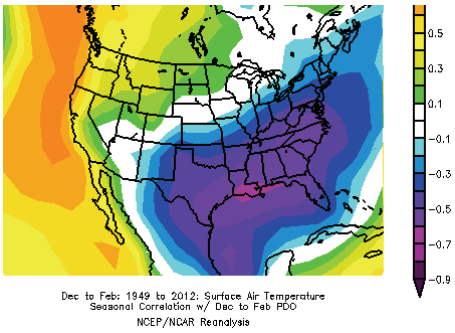
POSITIVE PDO SST ANOMALY PATTERN



NEGATIVE PDO SST ANOMALY PATTERN



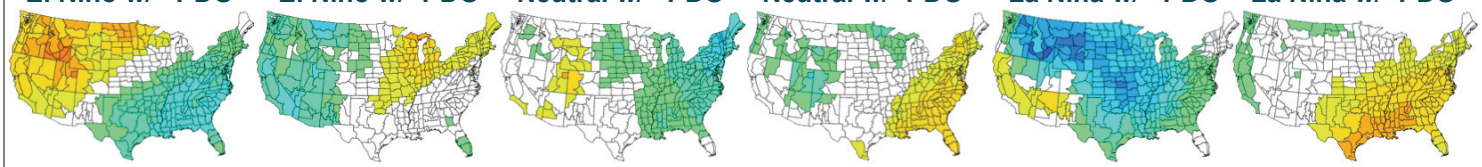
The map below shows correlation values between the PDO index and winter temperatures. Th negative values across the eastern US indicate temperatures tend to be cold when the PDO is positive and warmer when the PDO is negative. Note, however, that the PDO is highly cross-correlated with ENSO and temperature patterns are similar in both.



The PDO and US Winter Weather

The maps below show average winter temperature anomalies across the US for positive and negative PDO phases during El Niño winters, neutral ENSO winters and La Niña winters. A positive PDO regime generally implies that the Pacific is in an El Niño-like base state, and a negative PDO implies that the Pacific is in a La Niña-like base state. El Niño events tend to be more frequent and stronger when the PDO is positive and La Niña events more frequent and stronger when the PDO is negative. ENSO (El Niño/La Niña) and the PDO are linked together though, and both are coupled to the atmospheric pattern, so the PDO phase may be more of an indicator rather than a driver of the overall pattern.

El Niño w/ +PDO | **El Niño w/ -PDO** | **Neutral w/ +PDO** | **Neutral w/ -PDO** | **La Niña w/ +PDO** | **La Niña w/ -PDO**



Temperature Anomaly Key (˚F):

KEY TERMS

MJO: An acronym for **M**adden-**J**ulian **O**scillation

Madden Julian Oscillation: The Madden-Julian Oscillation is a tropical disturbance that propagates eastward around the global tropics with a cycle on the order of 30-60 days. The MJO has wide ranging impacts on the patterns of tropical and extratropical precipitation, atmospheric circulation, and surface temperature around the global tropics and subtropics.

MJO NOTES

The MJO is most active during neutral phases of ENSO (neither El Niño nor La Niña present).

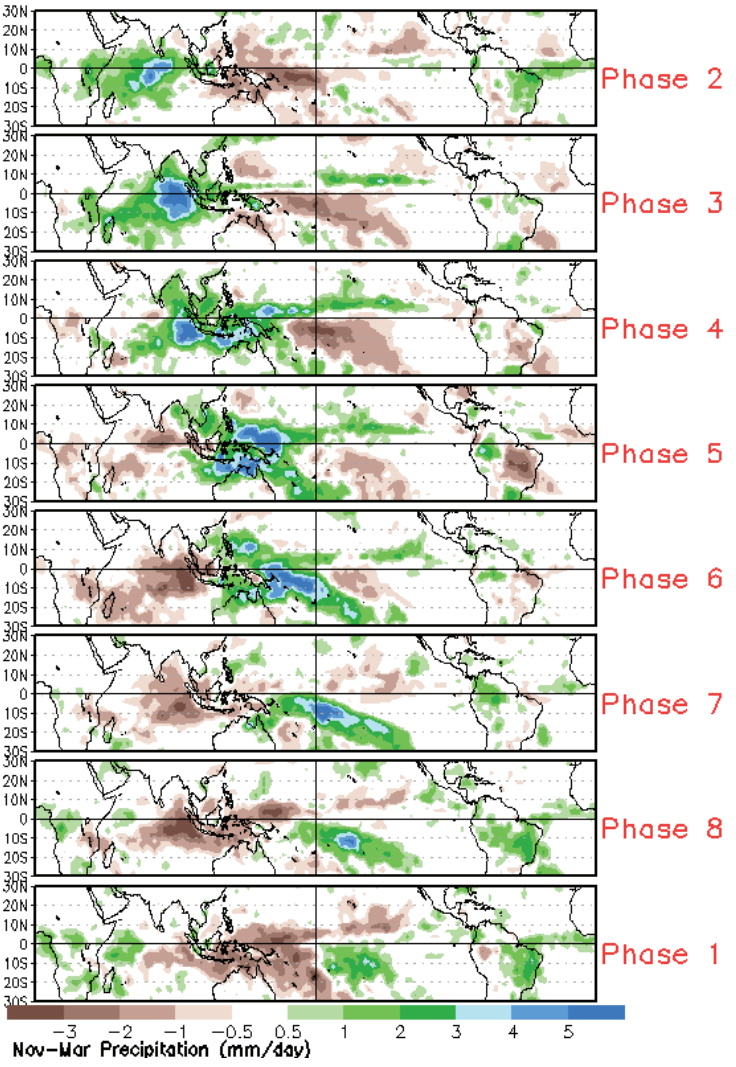
Like ENSO, the MJO modulates global weather patterns by shifting the location of tropical convection. However, instead of slowly shifting convective patterns over the course of months, the MJO does so during the course of weeks.

In the winter season, different phases of the MJO can help produce heavy rainfall events along the West Coast and induce cold outbreaks east of the Rockies.

The MJO can enhance tropical storm development over ocean areas where vertical motion and tropical convection are favored.

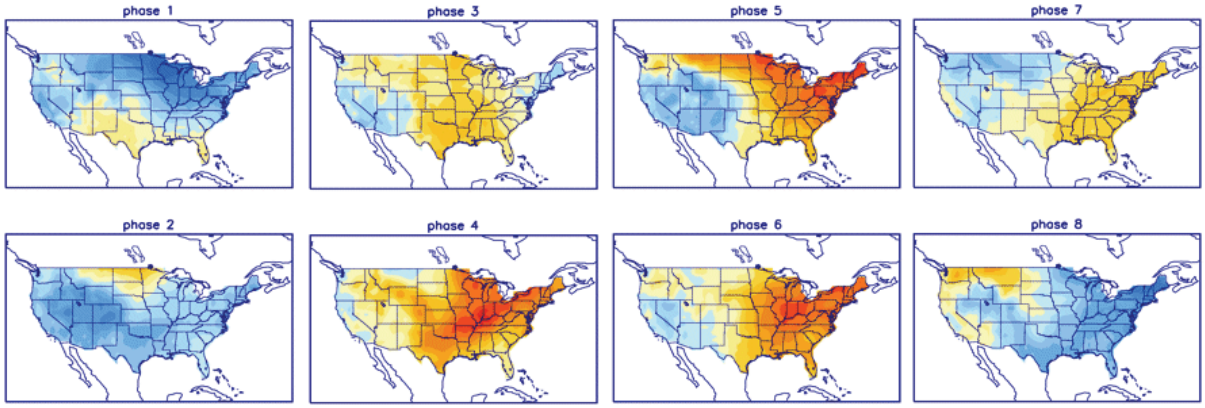
MJO PHASES

The plot below shows phases of the MJO cycle associated with different locations of enhanced tropical convection (green & blue areas).



The MJO (Madden Julian Oscillation) and US Winter Weather

Winter (Dec-Feb) temperature anomaly composites are shown below for the eight phases of the MJO. Blue indicates colder than normal temperatures and yellow/red warmer than normal temperatures.



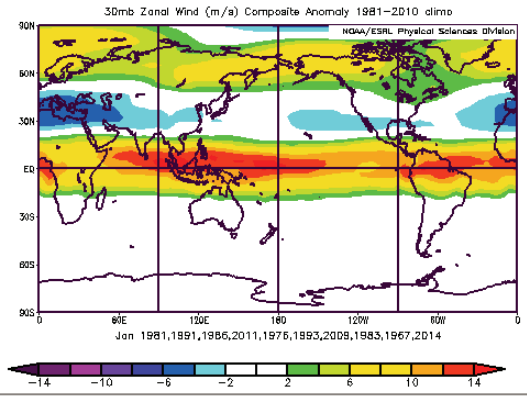
KEY TERMS

QBO: An acronym for **Q**uasi-**B**iennial **O**scillation

Quasi Biennial Oscillation: An oscillation in upper level winds over the equator with a mean period of 28 months. The QBO helps to modulate the strength of the stratospheric polar vortex. When the QBO is positive, it tends to make the polar vortex stronger, trapping more cold air near the pole. When the QBO is negative, it tends to make the polar vortex weaker, making cold intrusions into the US more frequent. However, trends in the QBO are often more important than the actual value.

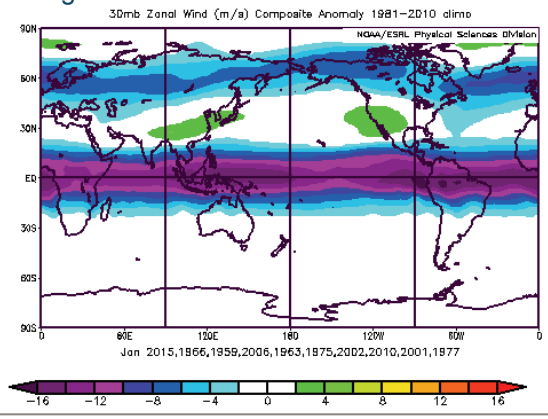
POSITIVE QBO PATTERN

In the positive phase, west-to-east wind flow is stronger over both the equator and high latitudes, promoting a stronger polar vortex. However, as the QBO trends negative it can act to put the brakes on the polar vortex increasing the chances it will break down and turn the US colder.

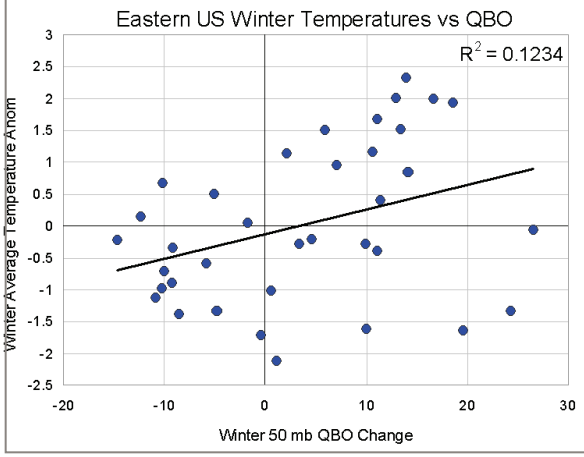


NEGATIVE QBO PATTERN

In the negative phase, wind flow over the equator reverses, and high latitude winds weaken, promoting a weaker polar vortex. However, once the negative phase peaks and begins to weaken, the polar vortex can strengthen, reducing US cold chances.



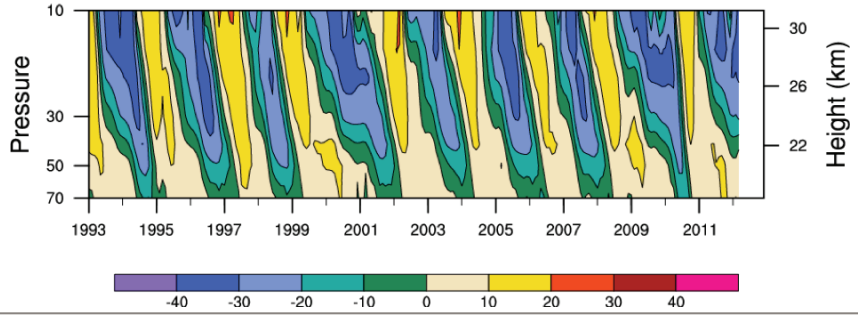
On average, eastern US winter temperature anomalies are more likely to be cold when the QBO falls during winter, and more likely to be warm when it is rising.



The QBO (Quasi-Biennial Oscillation) and US Winter Weather

The changes in wind direction associated with the QBO propagate downward in the atmosphere over time. The phase of the QBO in the lower stratosphere tends to modulate tropical convection in the Pacific as it alters the vertical circulation pattern in the atmosphere. This modulation of tropical convection can influence mid-latitude weather patterns and also influence ENSO phase transitions. The table below looks at eastern US winter temperatures for various QBO trends.

QBO: Zonal Wind



The QBO and Winter Temperatures

50mb QBO	Positive in Dec	Positive Falling	Negative Rising	Negative in Dec
East US Winter Temperature Anomaly	-0.62	-0.48	0.58	0.47
Number Cases	15	13	20	21
%Cold Winters	73%	69%	40%	43%
%Warm Winters	27%	31%	60%	57%
%Cold w/El Nino	75%	75%	20%	20%
%Cold Neutral	100%	60%	44%	100%
%Cold w/La Nina	75%	75%	50%	50%

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KEY TERMS

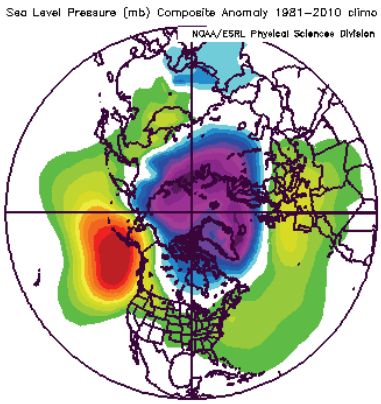
AO: An acronym for Arctic Oscillation

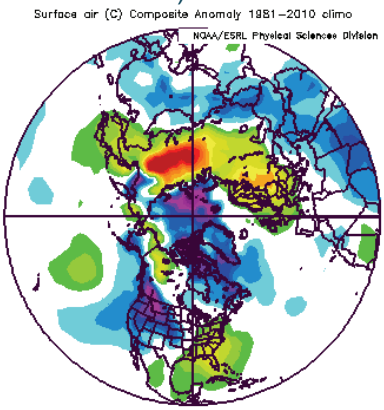
Arctic Oscillation (Also known as the Northern Annular Mode): a variation in the circulation pattern around the Northern Hemisphere from a faster west-to-east flow (positive AO) to one that features more meridional flow, that is flow from north to south and south to north (negative AO). The mid-latitude land areas tend to be colder during a negative AO and warmer during a positive AO phase.

SAI: Snow Advance Index, an index that measures the rate of snow cover growth across a portion of Eurasia that strongly correlates with winter AO phase.

POSITIVE AO PATTERN

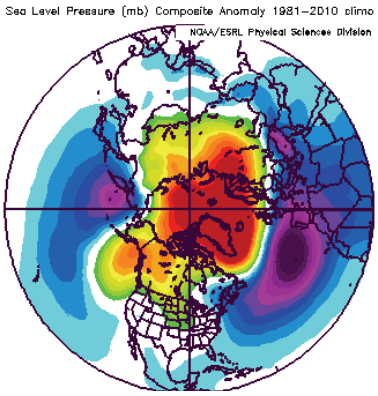
When the AO is positive, surface pressures (below left) are lower than normal (blue) across the Arctic, with colder temperatures (below right) across the Arctic and warmer temperatures across much of Europe, Asia, and eastern areas of the US (yellow/red colors).

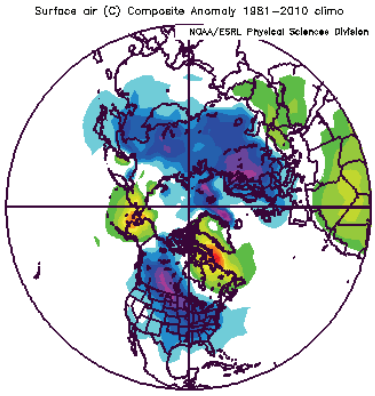




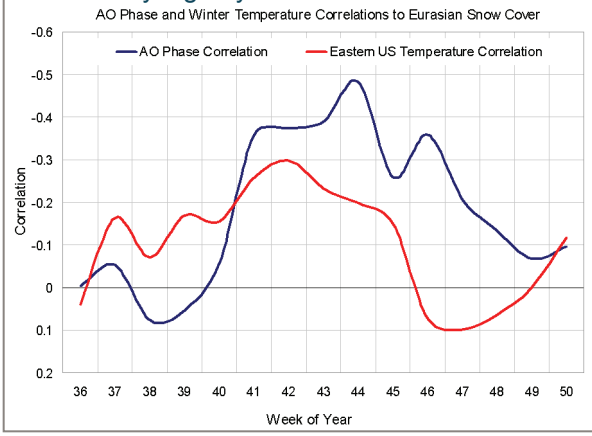
NEGATIVE AO PATTERN

When the AO is negative, surface pressures (below left) are higher than normal (red) across Asia, the Arctic and North America, with colder than normal temperatures (below right) across much of northern Asia, Europe and North America (blue colors).



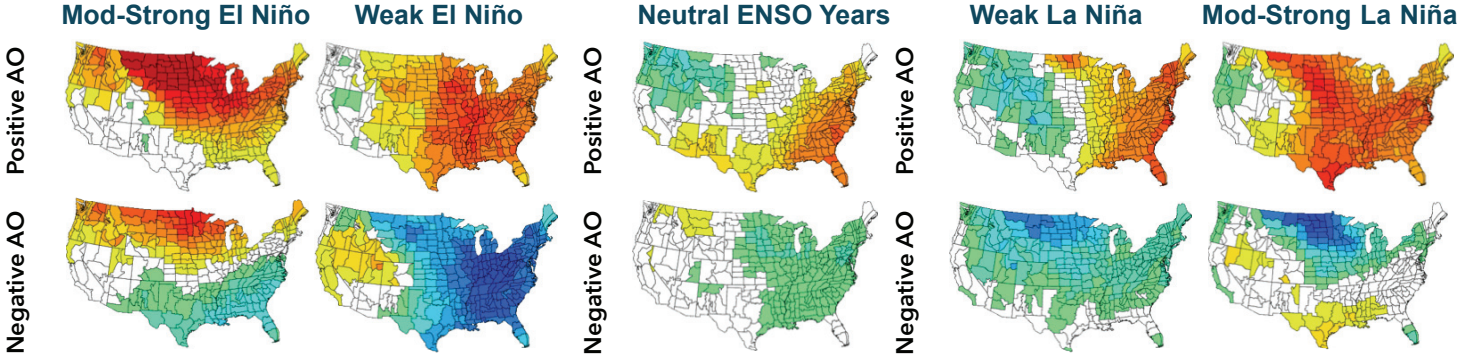


High snow cover extent across Eurasia by late October helps to promote a negative winter AO phase. Eastern US winter temperatures are more likely to be colder if Eurasian snow cover is unusually high by the middle of October.



The Arctic Oscillation and US Winter Weather

The maps below show average winter temperature anomalies across the US for positive and negative AO phases during El Niño winters, neutral ENSO winters and La Niña winters. Regardless of ENSO phase, the eastern half of the US tends to average above normal (yellow and red colors) during winter when the AO is positive, and colder than normal (blue colors) when the AO is negative. However, the location of the strongest anomalies varies based on ENSO phase.



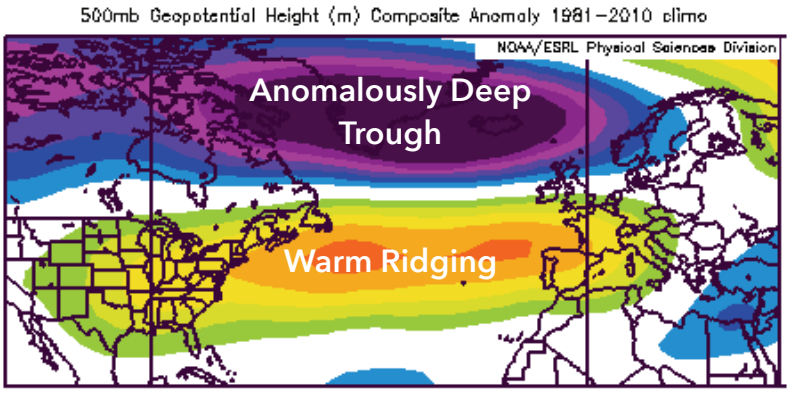
KEY TERMS

NAO: An acronym for **N**orth **A**tlantic **O**scillation

North Atlantic Oscillation: A variation in the pattern across the northern Atlantic that strongly influences weather patterns across eastern North America and western Europe. A positive phase consists of a strong low near Iceland while a negative phase consists of a blocking ridge over Greenland and Iceland. When the blocking ridge is in place, cold air is directed southward into both eastern North America and western Europe. The NAO is usually positive when the AO is positive, but is not always negative when the AO is negative.

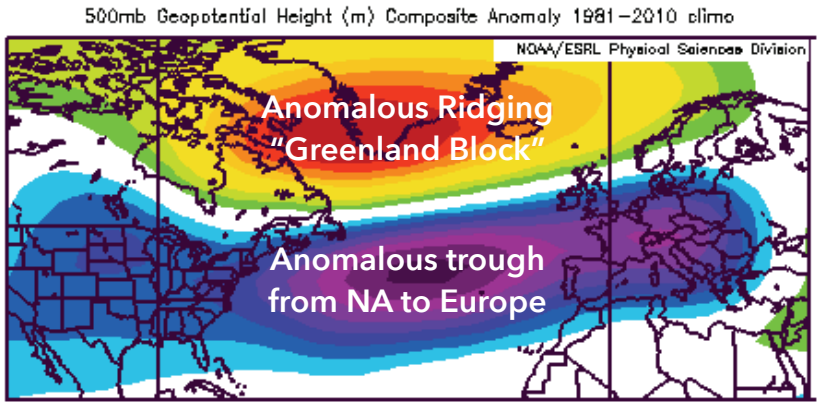
POSITIVE NAO PATTERN

When the NAO is positive, a stronger than normal trough is present over Greenland. This tends to result in colder air sweeping eastward across Canada and into the northern Atlantic, keeping conditions milder from eastern North America to western areas of Europe.

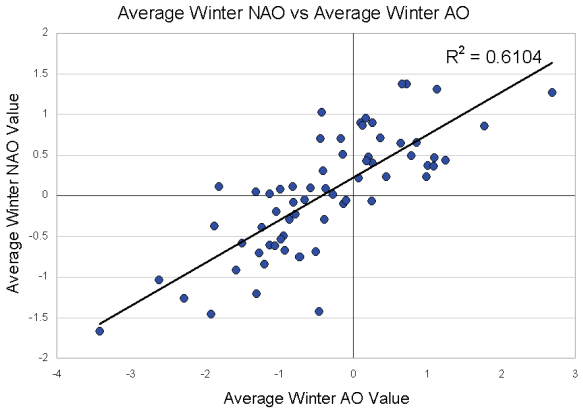


NEGATIVE NAO PATTERN

When the NAO is negative, a blocking ridge builds northward over Greenland (the "Greenland Block"), forcing colder Arctic air southward into both eastern North America and into much of Europe.



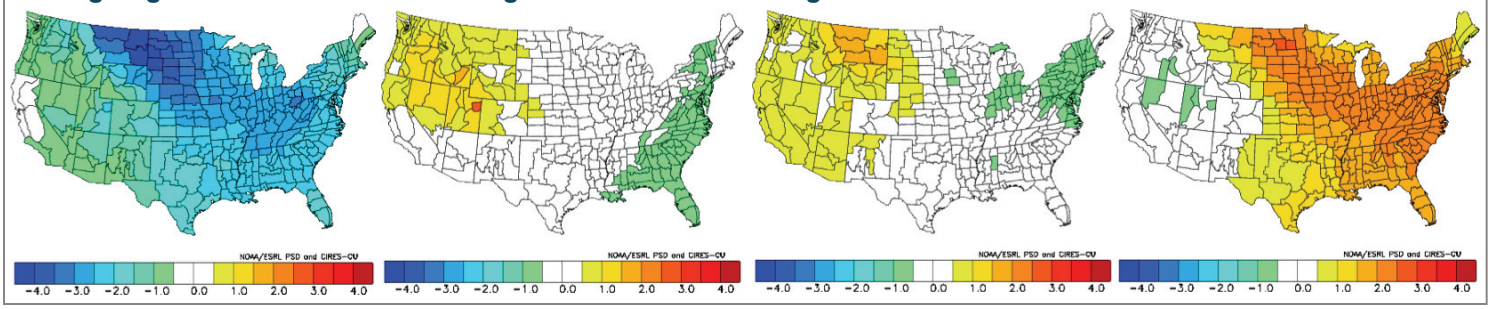
The NAO is highly correlated with the AO and is positive 96% of the time the AO is positive (for the winter average). The stronger the negative AO pattern is during winter, the more likely the NAO will also be negative.



The North Atlantic Oscillation and US Winter Weather

The maps below show average winter temperature anomalies across the US for positive and negative NAO and AO combinations. When the AO and NAO are both strongly negative, the US usually sees a very cold winter. When the AO and NAO are more weakly negative, winters are more variable. This is also the case when the AO is negative and the NAO is positive. In those cases there is only a slight tendency for eastern US cold. When both the AO and NAO are positive, winters tend to average much milder than normal east of the Rockies.

Strong Negative AO & NAO | **Weak Negative AO & NAO** | **Negative AO/Positive NAO** | **Positive AO & NAO**

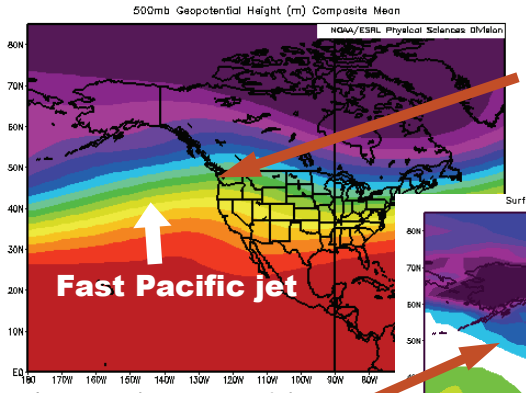


KEY TERMS

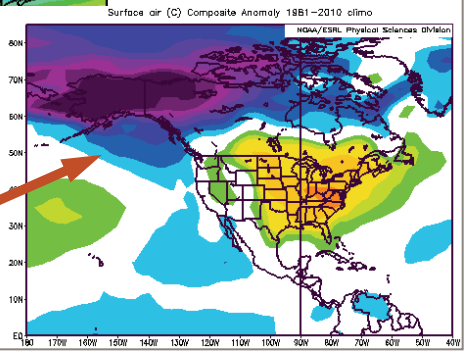
EPO: An acronym for **E**astern **P**acific **O**scillation

Eastern Pacific Oscillation: A variation in the pattern across the northeastern Pacific between an upper level ridge which favors cold air transport into the lower 48, and an upper level trough or zonal (west to east) flow across the northeastern Pacific which promotes a milder pattern across the lower 48 of the US. The EPO is similar to the NAO in the Atlantic with negative phases favoring US cold and positive ones favoring US warmth.

POSITIVE EPO PATTERN

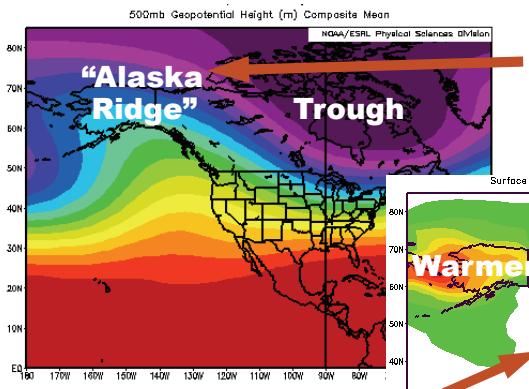


A positive EPO features faster zonal flow, flooding the lower 48 with milder Pacific air.

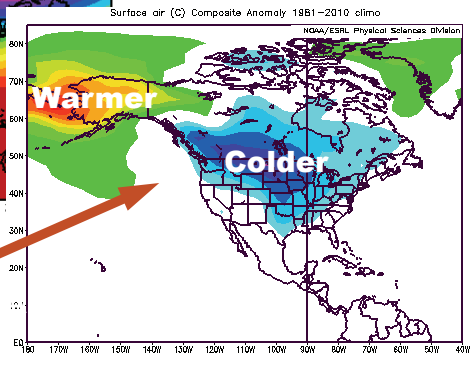


This produces a cold pattern across Alaska and a mild one for the lower 48.

NEGATIVE EPO PATTERN

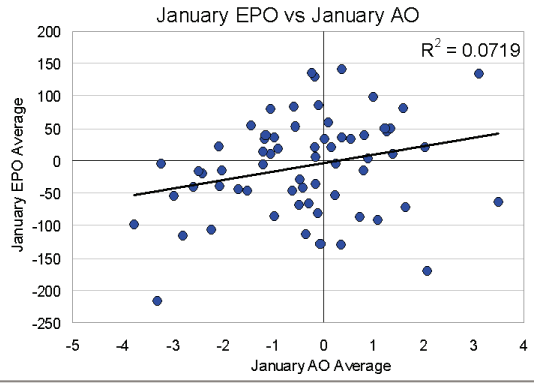


A negative EPO regime features a ridge over Alaska and a trough over eastern N.A.



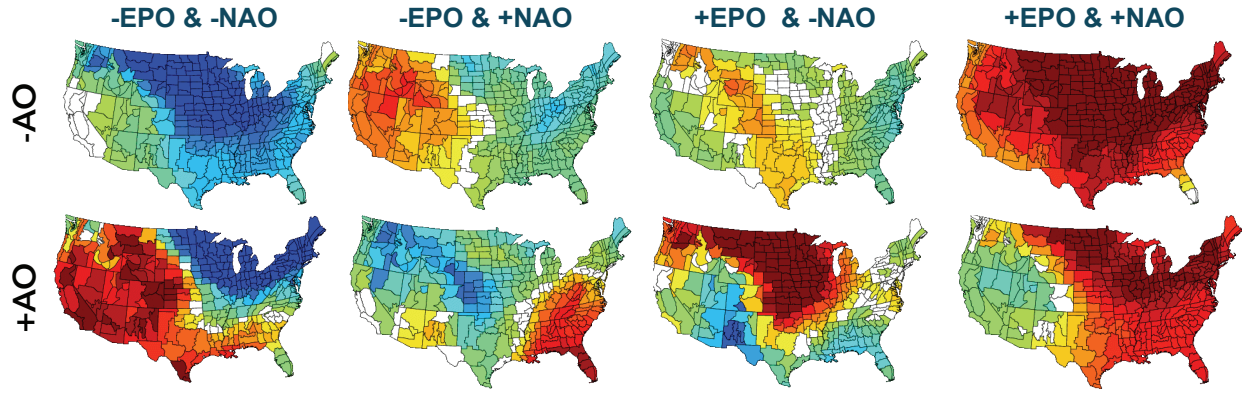
This produces a mild pattern across Alaska and a cold one for the lower 48.

The EPO is only weakly correlated to the phase of the AO as the graph below demonstrates. A strong negative EPO, as was seen during the second half of the 2014-2015 winter, can produce a very cold and snowy pattern even when the AO is positive like it was that winter.



The EPO (Eastern Pacific Oscillation) and US Winter Weather

The maps below show January temperature anomalies for various combinations of the EPO, NAO and AO. Blue shades represent colder than normal temperatures and red shades warmer than normal temperatures.



Here is a list of common El Niño/La Niña related weather acronyms and their definitions.

ENSO

ENSO is an abbreviation for El Niño-Southern Oscillation, the broad term describing the equatorial Pacific oscillation that includes El Niño, La Niña and the Southern Oscillation.

El Niño

A phase of ENSO that is associated with an anomalous warming of the central and eastern equatorial Pacific Ocean. Tropical convection normally over the western Pacific shifts eastward in response to the warming water of the central and eastern equatorial Pacific, resulting in global weather pattern changes. An El Niño event generally occurs every 3 to 7 years.

La Niña

A phase of ENSO that is associated with an anomalous cooling of surface ocean waters in the central and eastern tropical Pacific. Tropical convection normally over the western Pacific shifts farther west than usual, influencing global weather patterns.

MEI

MEI is the multivariate ENSO index. It is a method used to characterize the intensity of an El Niño Southern Oscillation (ENSO) event. The MEI is generally regarded as the most comprehensive measurement of ENSO since it incorporates six variables into the index, versus a single atmospheric or ocean temperature measurement like other indices.

Niño 3.4

The average SST (sea surface temperature) anomaly over a region of the Pacific between 5°N – 5°S and 120°W – 170°W that is commonly used as an ENSO index. Ocean temperature anomalies in that region greater than 0.5°C above normal are indicative of El Niño conditions and temperature anomalies more than 0.5°C below normal are indicative of La Niña conditions.

PDO

The Pacific Decadal Oscillation, a pattern of climate variation similar to ENSO though on a timescale of decades and not seasons. It is characterized by SST anomalies of one sign in the north-central Pacific and SST anomalies of another sign to the north and east near the Aleutians and the Gulf of Alaska. PDO "events" persist for 20-to-30 years, while typical ENSO events persisted for 6 to 18 months. The influences of the PDO are most visible in the North Pacific/North American sector, and less so in the tropics, the opposite of ENSO. El Niño regimes tend to be stronger and more frequent during long-term positive phases of the PDO, while La Niñas are shorter in duration and less frequent. The opposite is true during long-term negative phases of the PDO. A long-term positive PDO essentially represents the shifting of the Pacific basin into an El Niño-like base state, whereas a long-term negative PDO represents the shifting of the Pacific basin into a La Niña-like base state. Note that the PDO index varies on a monthly and yearly basis, so the index will at times be positive during a long-term negative phase and vice-versa. The PDO index is frequently positive when El Niño conditions are present and frequently negative when La Niña is present, though not in every instance.

SOI

The Southern Oscillation Index (SOI) is a measure of the atmospheric pressure difference between sea level pressures at Darwin, Australia, and Tahiti, although other stations have sometimes been used. Large negative values of the SOI are associated with El Niño and large

positive values associated with La Niña. The SOI index, being a simple measure of pressure differences, is highly variable, much more so than other indices such as ocean temperatures. So, the SOI will at times be positive during El Niño events and negative during La Niña events. As such, a multi-week running average of the SOI can provide a better indicator of overall ENSO conditions.

SST

An acronym for Sea Surface Temperature. Most SST maps and data are reported in degrees Celsius.

Here are some other weather and climate oscillation acronyms:

AO

Arctic Oscillation - the Arctic Oscillation is a pattern in which atmospheric pressure at polar and middle latitudes fluctuates between negative and positive phases. The negative phase brings higher-than-normal pressure over the polar region and lower-than-normal pressure at about 45 degrees north latitude. The negative phase allows cold air to plunge into the central and eastern United States and western Europe. The positive phase brings the opposite conditions, steering ocean storms farther north and bringing wetter weather to Alaska, Scotland and Scandinavia and drier conditions to areas such as California, Spain and the Middle East.

AMO

The Atlantic Multidecadal Oscillation is a series of quasi-periodic (not completely regular) variations, each lasting several decades, in sea surface temperatures (SSTs) across the North Atlantic. Observations of this pattern go back 150 years. A positive phase of the AMO is associated with above average water temperatures across the northern half of the Atlantic basin and increased tropical activity, while a negative phase of the AMO is associated with cooler water temperatures and decreased tropical activity.

EPO

The Eastern Pacific Oscillation, a dipole pattern similar to the NAO in the Atlantic, but located in the eastern Pacific. A negative EPO regime corresponds to ridging over the northeastern Pacific, and a positive EPO regime corresponds with a trough in the same location. The negative phase corresponds to widespread cooling over central and eastern North America and the positive phase to warming. Most major cold waves in winter are associated with a negative phase of the EPO.

MJO

Madden-Julian Oscillation, a global scale oscillation in tropical rainfall and vertical motion in the atmosphere that varies greatly in strength with a full cycle frequently lasting between 30-60 days. The MJO significantly affects circulation patterns in the tropics and subtropics and also jet stream patterns over the Pacific and North America. The MJO also modulates hurricane activity in the Pacific and Atlantic Oceans resulting in periods of enhanced and suppressed activity depending on the phase of the MJO wave over a given ocean basin.

NAO

North Atlantic Oscillation - the NAO is a large-scale fluctuation in atmospheric pressure between the subtropical high pressure system located near the Azores in the Atlantic Ocean and the sub-

polar low pressure system near Iceland and is quantified in the NAO Index. The surface pressure drives surface winds and wintertime storms from west to east across the North Atlantic affecting climate from New England to western Europe as far eastward as central Siberia and eastern Mediterranean and southward to West Africa.

PNA

The Pacific North American teleconnection pattern. The negative phase features a western U.S. trough and eastern U.S. ridge resulting in below normal temperatures across the western U.S. and above normal temperatures across the eastern U.S. The positive phase consists of a western U.S. ridge and eastern U.S. trough, which favors colder than normal temperatures across the eastern half of the country and above normal temperatures across the western U.S.

QBO

The Quasi-Biennial Oscillation (QBO) is a measure of the oscillation in wind direction about 15 miles up (generally where atmospheric pressure is between 10 and 100 mb) around the equator. These winds reverse direction (oscillate) roughly every other year (quasi-biennially) between easterly (negative-phase QBO) and westerly (positive-phase QBO).

WPO

The Western Pacific Oscillation. During winter and spring, the pattern consists of a north-south dipole of anomalies, with one center located over the Kamchatka Peninsula and another broad center of opposite sign covering portions of southeastern Asia and the western subtropical North Pacific. Like the EPO, the negative phase favors colder weather across the eastern portions of North America. However, on average, the westward extent of cold is greater during a negative WPO compared to a negative EPO. At times, the WPO and EPO will be in phase, both being negative or positive at the same time.