Mid-latitude Atmospheric Variability

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Contents

1 Introduction, Purpose and Scope

The purpose of this note is to provide an overview of the salient features of the variability of the atmosphere in the mid-latitude regions, and to describe the main factors influencing this variability. Some of the basic concepts are mentioned without the mathematical framework; these are provided in references. The scope is intended to cover the mechanistics of the variability while the actual historical records are available through the weather service web sites.

For this purpose the mid-latitudes are loosely defined as those between about 23 deg North/South to about 66 deg North/South (Tropics of Cancer and Capricorn to Arctic/Antarctic circles). They therefore include much of the sub-tropical high pressure belts and the mid-latitude storm tracks. Reference to a climatological atlas shows that climate regimes include mediterranean, marine west coast (dry and wet), humid subtropical and continental (dry and humid). The mid-latitudes are characterised by pronounced annual cycle of weather types, perhaps more so in the northern hemisphere (NH) because of the dominance of land over ocean compared to the southern hemisphere (SH).

Although this note concerns the atmosphere, the reader is encouraged to refer to the talk I gave on the oceans, their currents and thermal structure, which have a very strong influence on the mid-latitude climates.

2 Dynamics of mid-latitudes

It is often instructive to consider the morphology and evolution of the structure of the atmosphere in a typical annual cycle without the constraint of fixed geo-coordinates. In this regard the equatorward bound for the mid-latitudes are the descending arms of the Hadley cell, which are characterised by the sub-tropical high pressure belts. Hence the lower latitudes climates are typically dry throughout the year with two notable exceptions: i) the monsoons (especially in the NH) and ii) tropical cyclones after they have developed in the tropics and have moved poleward (in the Atlantic and Pacific basins).

The sub-tropical anticyclonic belts move poleward with the sun in the summer (with a lag), so the summer season tends to be more influenced by these high pressures belts. At the same time the storm tracks also tend to follow the sun and move more poleward in the summer and more equatorward in the winter.

As a result of the global-scale thermal distribution and the rotation of the near-spherical Earth - there is a tendency for the air to move from west to east in the mid-latitudes over much of the depth of the troposphere. As described by the thermal wind balance [ref], these air motions tend to be concentrated in narrow regions in the free troposphere called the jet-streams, which are typically wavey in nature see figure 1. It is important to note that in many cases the polar and sub-tropical jet may not be distinguishable, and they are certainly not uniform around the globe. It is the jet stream that tends to steer the extra-tropical cyclones.

A more realistic representation of the flow in the free-troposphere is by the gradient of the geopotential height for example in figure 2. In this type of figure much detail of the thermal structure of the atmosphere is shown. The wind flows parallel to the contours of geopential height (in the free troposphere) and its strength is proportional to the gradient. It also flows with cold air to the left and warm air to the right. In figure 2, the wavenumber is approximately 5 (5 waves around the globe).

3 Details of the mechanisms.

Referring to figure 2, because the air through the depth of the troposphere tends to be warmer toward the equator, a given geopotential surface is higher nearer the equator than nearer the pole. Such surfaces tend to slope down toward the pole, it is this gradient that sets up the thermal wind - and hence the jet stream (to first approximation). Further, the distance between any two geopotential surfaces gives a measure of the mean temperature between them.

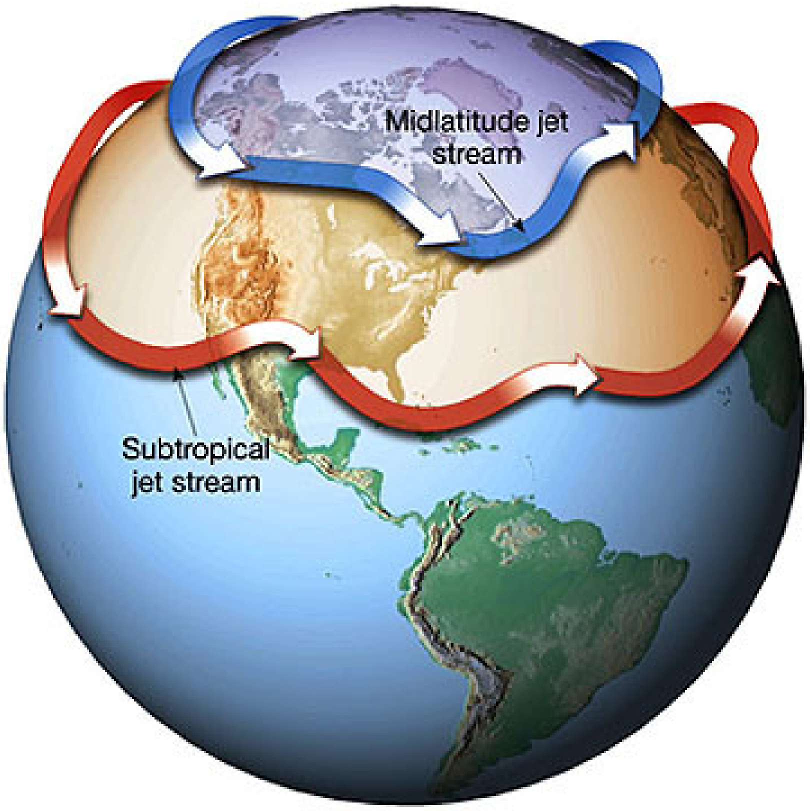


Figure 1: Schematic of mid-latitude jet streams. CAUTION: don't take too literaly!

It is easy to see, as is often the case, that the thickesses (temperature) of layers in the troposphere vary in the horizontal (lat/long) direction, resulting in a rotation of the wind with height - so called vertical shear of the horizontal geostrophic wind. Such an atmospheric structure is called baroclinic, and is hydrodyamically unstable under certain (many) conditions (when the Rossby number is small enough). When this happens the zonal flow is characterized by meridional departures resulting in the familiar Rossby wave structure in the flow. It is along the jet stream in regions favoured for instability that result in the growth of extra-tropical cyclones. See figure 3.

Amongst the many processes that take place during the life cycle of an extra-tropical cyclone, one of the main is that it transports heat poleward, see figure 4. In summary: the baroclinic eddy converts potential energy (P.E.) from the horizontal thermal field into kinetic energy (K.E.) and works to reduce those thermal gradients, and they are associated with thermal advection.

For completeness, another situation gives rise to hydrodynamic instabil-

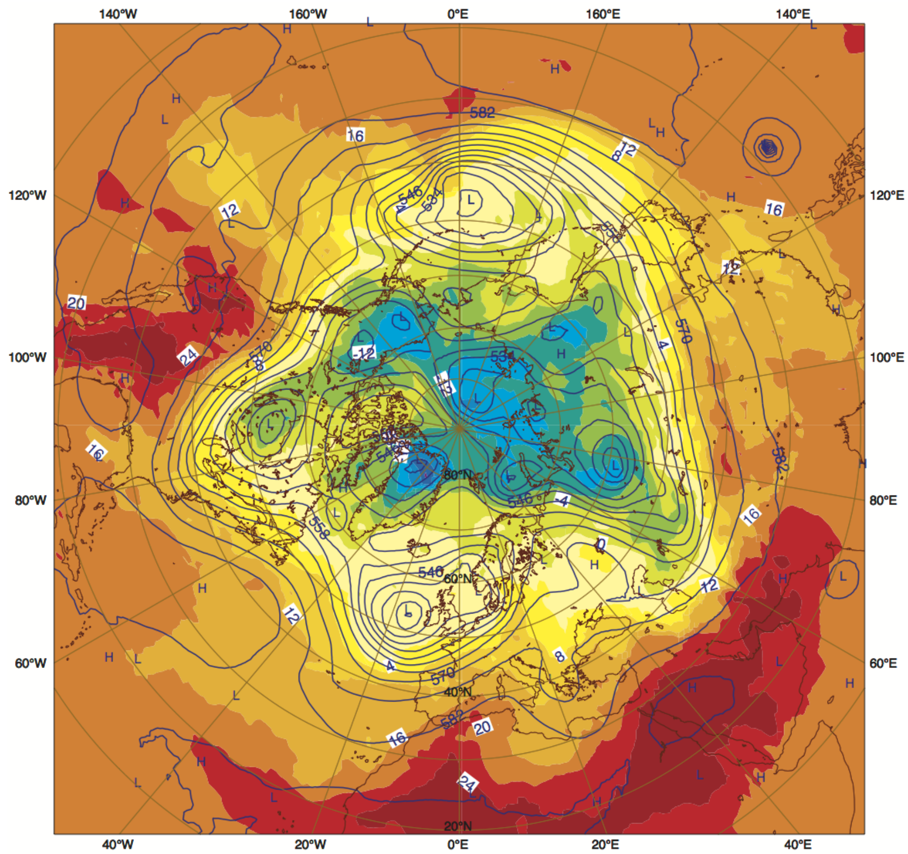


Figure 2: Wednesday 8 October 2014 00UTC: 850 hPa Temperature / 500 hPa Geopotential

ity in the case of a barotropic atmosphere, in which the geostrophic wind only varies horizontally (horizontal shear). In this atmosphere the winds (geopotential height surfaces) are parallel to the pressure surfaces. See for example this map of barotropic flow., which is also shown below. The growing barotropic wave extracts K.E. from the mean flow and through the conservation of potential vorticity, tends to create curvature in the flow. http://www.meteo.mcgill.ca/wxlab/ATOC-546/notes/lesson09.thermal_advection/03100812_cmc0500.gif

4 Variability

The key point to note is that in the mid-latitudes the mean flow tends to be mostly zonal with (Rossby) waves that create meridional flow. The amplitude and wavelength of the waves varies with time. The phase speed of the waves

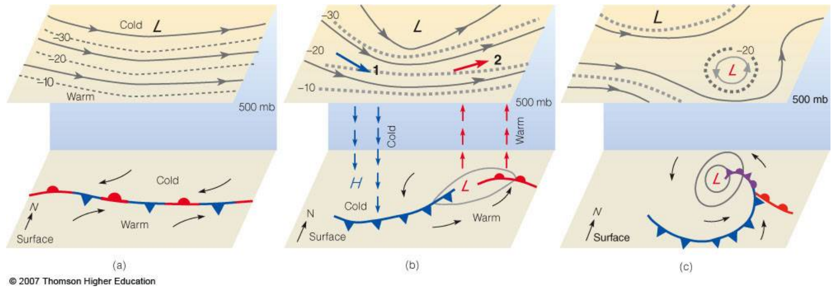


Figure 3:

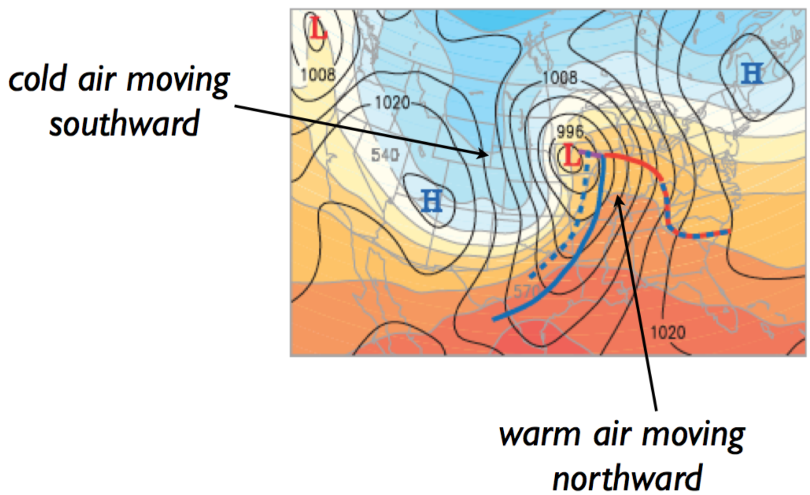


Figure 4: Typical developing baroclinic wave with surface low pressure.

also varies (such that in general air parcels flow through the wave and the wave propogates and changes). The waves are associated with extra-tropical cyclones, and the trough of the wave is associated with polar air being advected equatorward and the leading ridge with sub-tropical air being advected poleward, as illustrated in figure 4. The details of the air masses, the phase of the wave and the prescence and development of a storm system will all determine the weather experienced at a given location as the system passes through.

It is interesting to note the climatology of the storm tracks that result from regions of hydrodynamic instability as described above. See figure 5 for example:

Note that, especially in the N.H. cyclogenesis is favoured in the western ocean basins - because of the land/ocean contrast. This is an important factor in the characteristics of the circumpolar flow as often the phase and wavelength of the Rossby waves is influenced by orography and land distribution.

This notion leads to the important charactersitic of the Rossby wave mor-

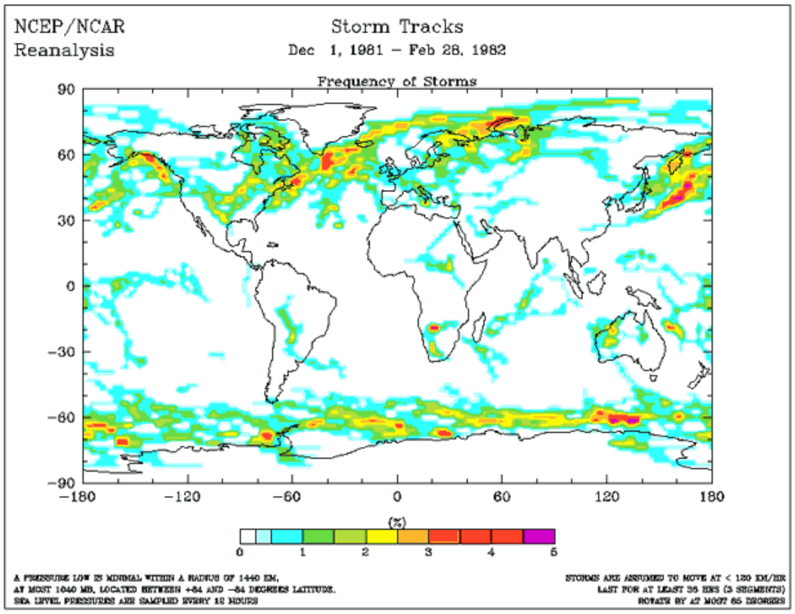


Figure 5: Frequency of extra-tropical storms NH winter 1981/82.

phology and that is to do with phase propogation and the fact that they are dispersive. The phase speed of Rossby waves is inversely related to the horizontal wavenumber (long waves travel faster). You can see then for a fixed location there would tend to be higher rate of cycling between air masses and weather types.

It is also the case that the wave structure at any one time results from the previous state of the atmosphere and from underlying forcing patterns. These forcings may be due to land/ocean heating contrast and oceanic temperature patterns. A common example is the forcing due to flow across the Rocky mountain chain, and the tendency to form a trough leeward of the range. Although it is beyond this discussion, it is often the case that a stationary pattern can be set up, which lasts for several days or longer. You can see then for a fixed location there would tend to be a persistent weather pattern. Recent examples come to mind: i). the exceptional warm period in the mid-west USA mid-March 2012, due to persistent trough in the jet stream over the Rockies. http://www.crh.noaa.gov/Image/lot/cliplot/KORD2012plot.png ii). The persistent NW flow in to the central and eastern USA during winter 2013/14, which has been suggested due to the warm pool anomaly in the north east Pacific ocean. See also: http://www.cpc.noaa.gov/products/precip/CWlink/MJO/block.shtml.

5 Other teleconnection processes.

So apart from the normal internal variability (whatever that means) of the steering winds and planetary waves that encircle the mid-latitudes, there are many investigations into what other variability might be associated with them. Ofcourse, there's the usual annual cycle, which is characterised by a migration poleward in summer and equatorward in winter, with associated active phases (spring and atumumn). What else might alter the regions and strength of cyclogenesis and the storm tracks. Much recent research has been looking at the possible effects due to global warming. Two relevant modes of variability we'll mention here are the north annular mode (NAM) and the ENSO.

- North Annular Mode (NAM)
  This refers to the oscillation of the mean flow pattern and pressure patterns associated with the circumpolar flow around the north pole. (A similar oscillation has been reported around the south pole, SAM). Precise definitions vary between authors. Attempts are made to distinguish between the NAM, also know as the Arctic Oscillation (AO), the North Atlantic Oscillation (NAO) and the Pacific North Anomaly (PNA). It is not unreasonable to expect that anomalies from the mean state for the circumpolar flow might manifest separately over the north Pacific and north Atlantic basins. The NAO is illustrated in figure 6, 7 and 8, and see http://www.cpc.noaa.gov/products/precip/CWlink/pna/month_nao_index.shtml.

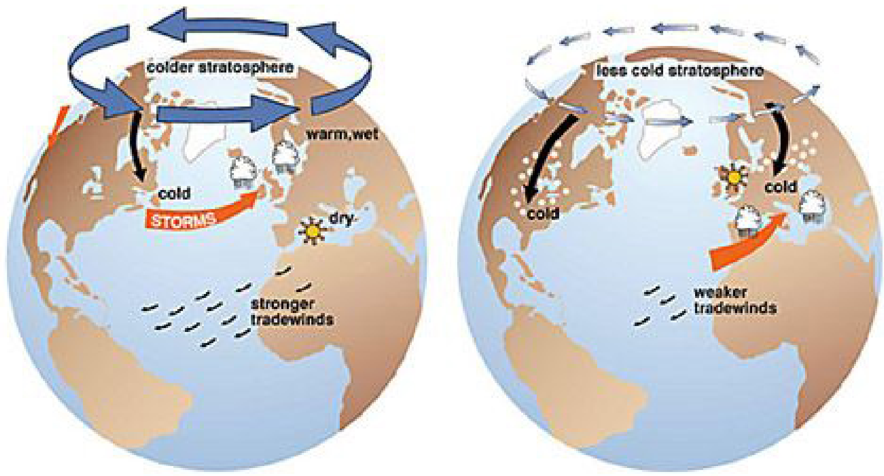


Figure 6: Schematic of the Arctic Oscillation

In summary, the positive phase of the NAO in NH winter tends to result in warmer wetter western Europe as the storm tracks pass further north than compared to the negative phase of the NAO, during which greater outbreaks of cold polar continental air occur.

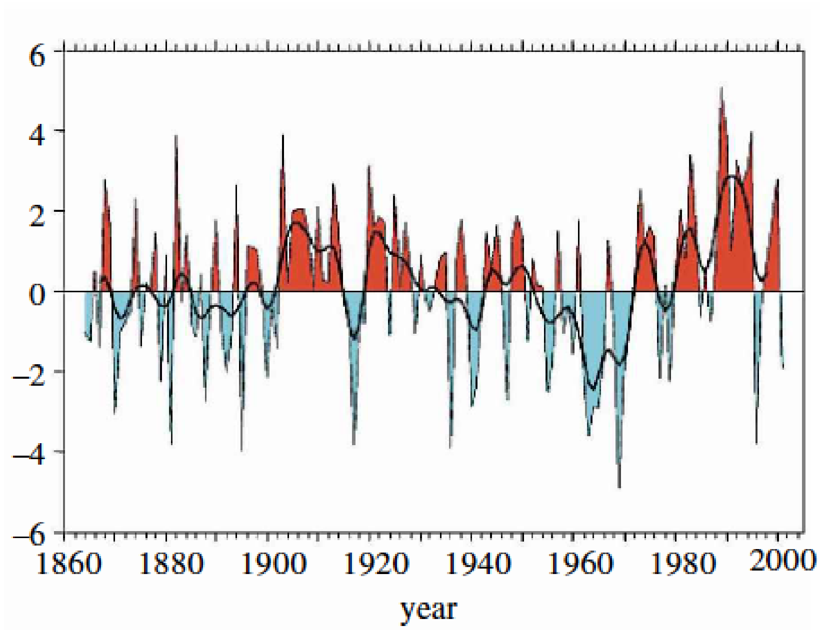


Figure 7: Time series of the noarth Atlantic Oscillation

In the case of the PNA The positive phase is associated with above average temperatures over western Canada and western United States, and below-average temperatures across the south-central and southeastern U.S. The PNA tends to have little impact on surface temperature variability over North America during summer. See figure 9, and see http://www.cpc.noaa.gov/data/teledoc/pna_ts.shtml.

- ENSO
  The El Nino Southern Oscillation (ENSO) of the Pacific ocean is very familiar to you - let's just say that during the positive phase the center of gravity of the warm pool of water around the equator moves east. With this, the center of precipitation moves east. It should not be surprising to expect that as a result of this significant shift in diabatic heating (sensible and letent heat from ocean to atmosphere) that there will be significant regional changes in weather patterns. The teleconnection patterns are illustrated in the following two figures 10 and 11 , each for different seasons.

  More relevant to our discussion of mid-latitude storm tracks and effect in North America, these effects are illustrated in the figure 12:

  Note that in the positive phase the main jet stream carries increased moisture to the western USA, and the tendency in winter is to draw colder air into the mid- and eastern USA. In the negative phase, the main jet tends to be weaker and travel further north, with the tendency to draw up the

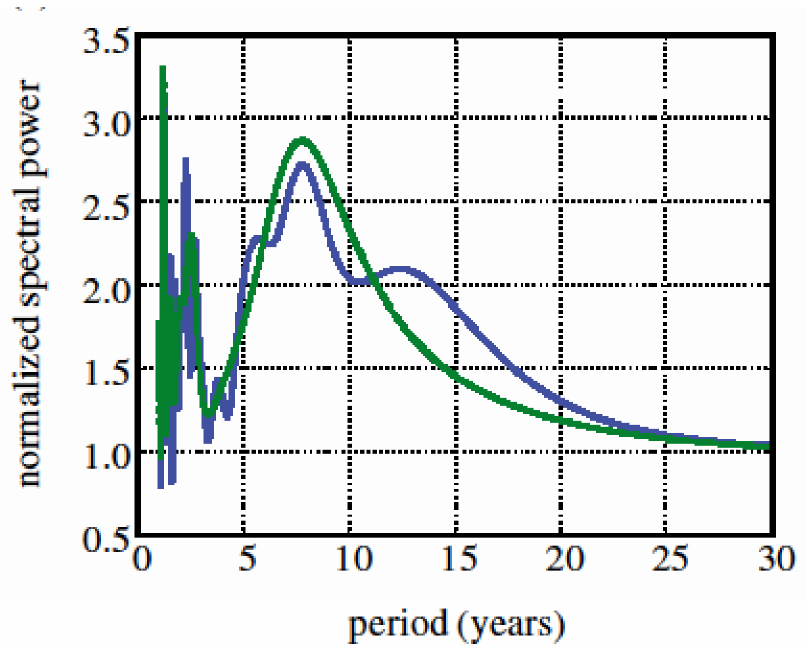


Figure 8: Power spectral density of the NAO

sub-tropical anti-cyclone in the the west and central USA. The northern branch of the jet tends to draw cooler air into the north west American continent.

It is interesting to note that during the winter 2013/14 a warm anomaly persisted in the NW pacific ocean (not directly connected to the El Nino), which tended to deflect the northern branch of the jet over it and then draw polar air into the central and eastern USA. Since the ocean tends to have a long memory, that atmospheric flow pattern persisted for an extended period resulting in unusually cold winter 2013/14 in central eastern USA, at the same time keeping the SW USA warm and dry.

6 Conclusions

In this note we have covered some of the major underlying processes that influence weather and climate in the mid-latitudes and what drives the variability on timescales of a few days to a few years. When we consider the climate in any one region of the mid-latitudes it is essential to understand what weather types dominate them - such as the deserts, the mediterranean, the moist western marine regions and so forth.

The principal mode of variability in any one of these regions is the annual cycle, and secondly the rotation of the Rossby waves and the regions of cyclogenesis. The patterns of weather are always changing, but over a sufficiently long period of time, typically taken to be 30 years, much of the variability averages out.

When you consider anomalies - that is departures from the climatological mean for a particular location or region, it tends be be correlated to the persistence of a given Rossby wave pattern, the amplitude and the timing. An example already cited is the persistence of NW flow into the central/eastern USA during winter 2013/14, which permitted the displacement of polar air relatively far south. You can look at the historical record and see how other extreme events related to persistence of these flow patterns and what time of year they occured.

7 Appendix

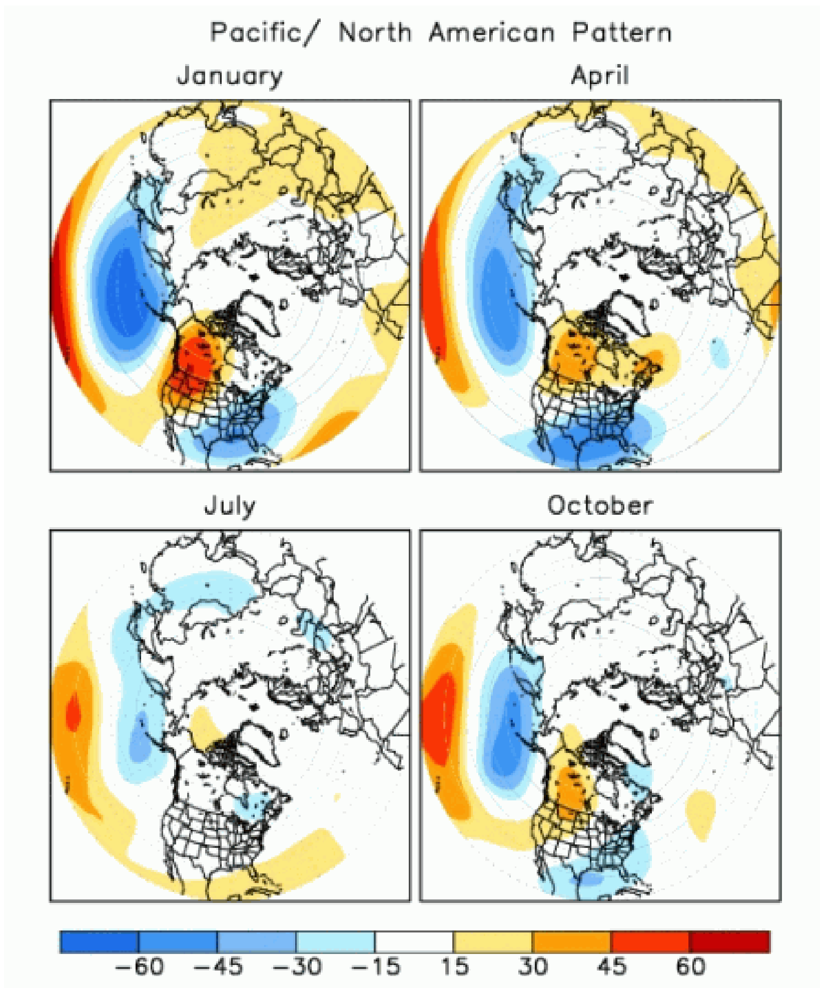
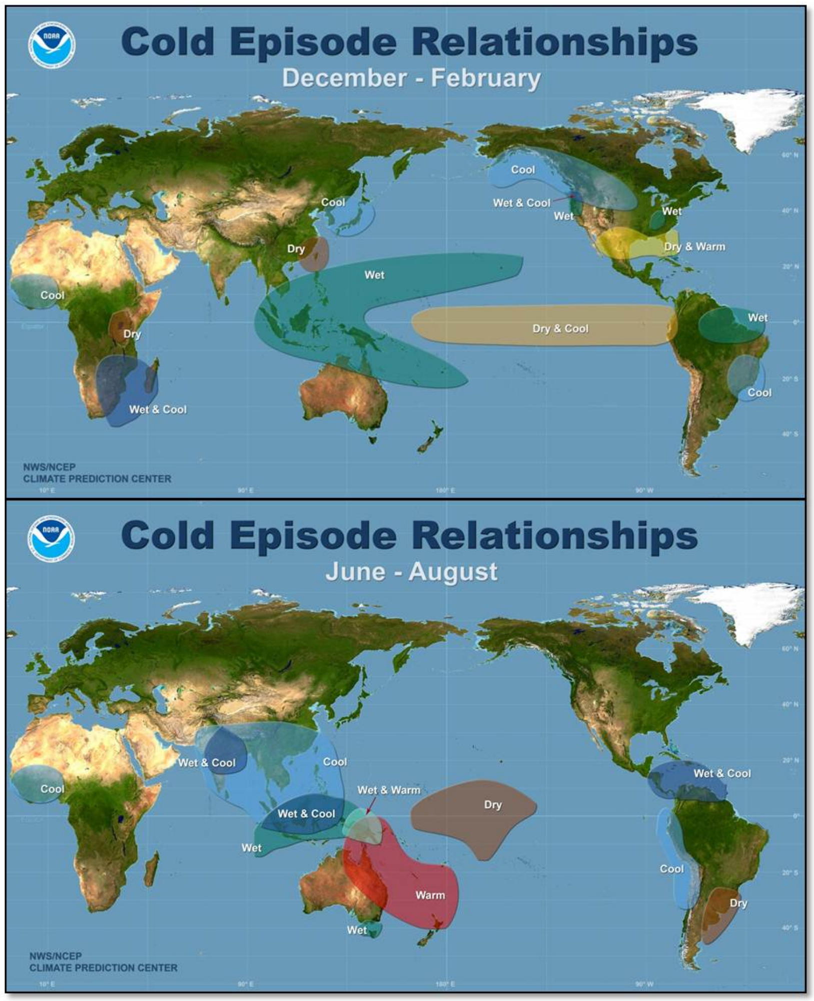


Figure 9: correlation plot of monthly height anomalies



High Resolution Images can be found at:
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENSO/ENSO-Global-Impacts/

Figure 10: ENSO in cold phase.

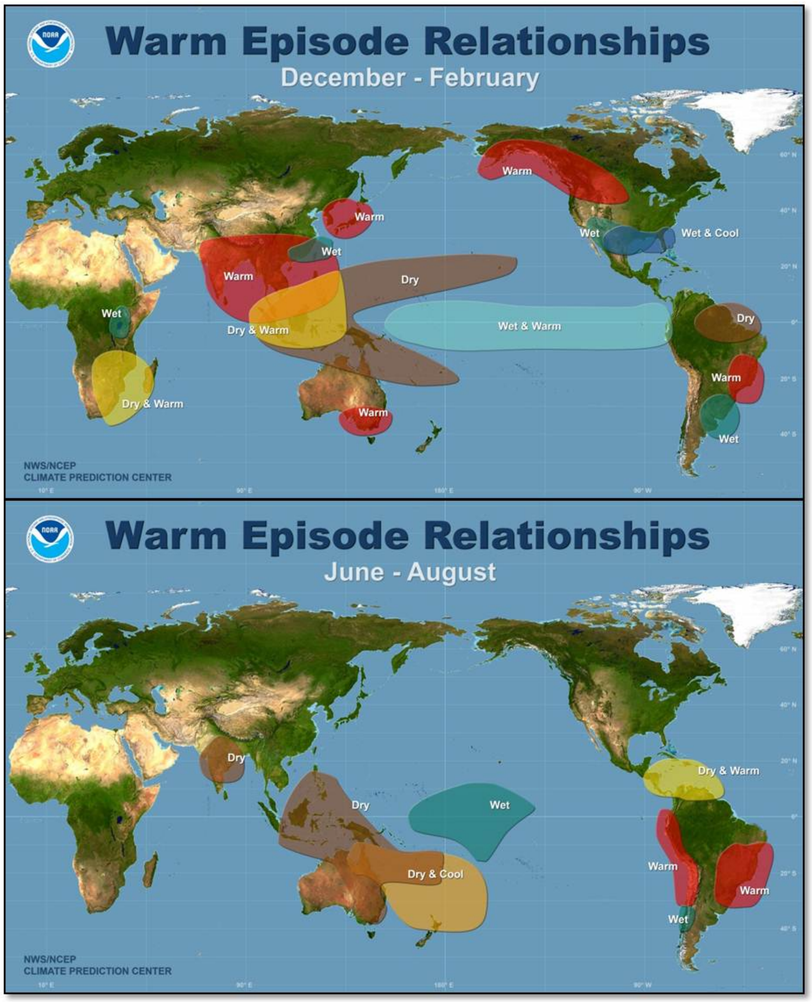


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Figure 11: ENSO in warm phase.

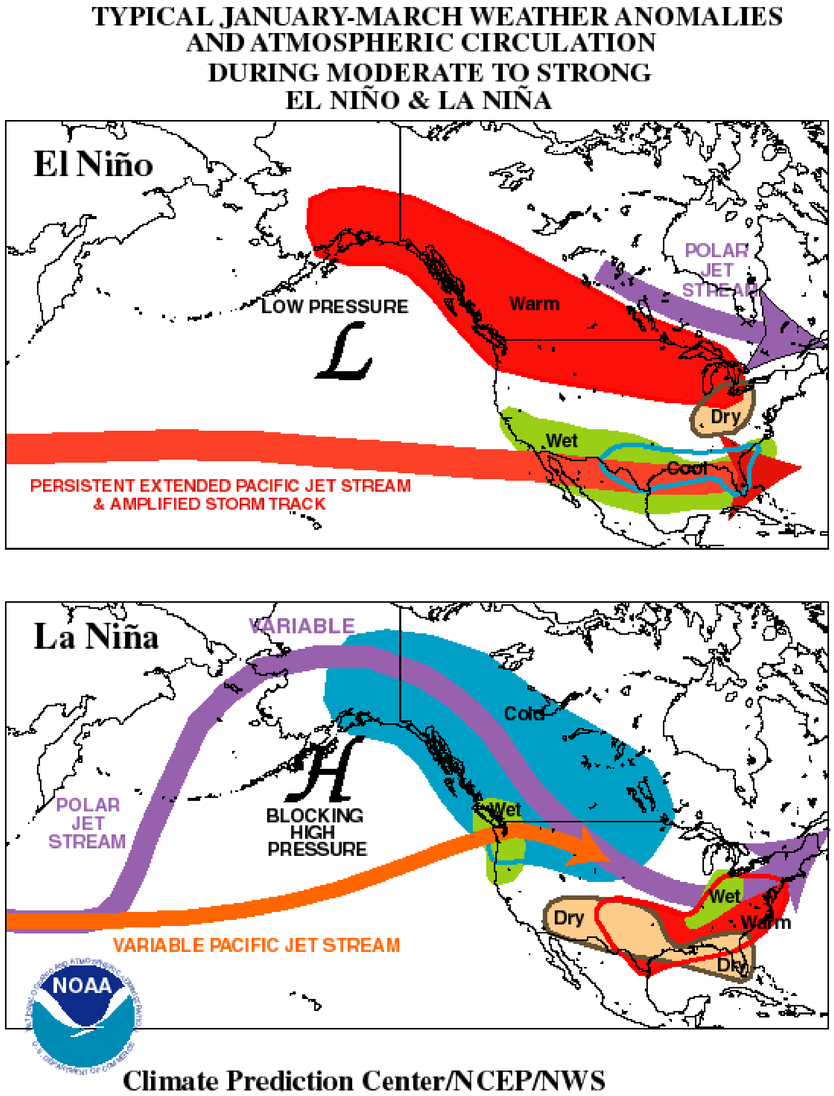
TYPICAL JANUARY-MARCH WEATHER ANOMALIES
AND ATMOSPHERIC CIRCULATION
DURING MODERATE TO STRONG
EL NIÑO & LA NIÑA
El Niño
POLAR JET STREAM
LOW PRESSURE
L
Warm
Dry
Wet
Cool
PERSISTENT EXTENDED PACIFIC JET STREAM
& AMPLIFIED STORM TRACK
La Niña
VARIABLE
Cold
POLAR JET STREAM
H
BLOCKING HIGH PRESSURE
Wet
Wet
Dry
Warm
Dry
VARIABLE PACIFIC JET STREAM
NOAA
Climate Prediction Center/NCEP/NWS

Figure 12: