Sensitivity of Strong Extratropical Cyclones to Large-Scale Climate Variability in the Contiguous United States

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Introduction

Extratropical cyclones are a substantial contributor to mid-latitude climate variability, especially during the winter months, and also contribute widely to weather and climate impacts. Cyclone characteristics, such as spatial distribution and intensity, exhibit dependence on the large-scale circulation, primarily through displacement of large-scale circulation features, such as the jet stream. The relationship between cyclone characteristics and individual modes of large-scale climate variability has been investigated in previous studies, but interactions between modes have been largely ignored. The goal of this project is to quantify relationships between modes of climate variability, and their interactions, and characteristics of strong cyclones in the United States. Using sea-level pressure data, gridded at 2.5° × 2.5° (NCEP/NCAR Reanalysis data), cyclones intensity, frequency, and spatial distribution are investigated using a cyclone definition that combines the requirement for low pressure (1000 mb or lower) and positive vorticity. The modes of climate variability considered include El Niño Southern Oscillation (ENSO), the Pacific North American (PNA) mode, and the Arctic Oscillation (AO). This poster focus on establishing cyclone composites for negative, neutral, and positive phases of ENSO, PNA, and AO. Additional work will examine cyclone variability in the context of interactions between modes of large-scale climate variability.

Literature Review

ENSO is a coupled atmospheric-ocean oscillation having a 3-7 year period. The warm (positive) phase is called El Niño, while the cold (negative) phase is called La Niña. El Niño is associated with the warming of the ocean current near the equator off the South American coast; La Niña is associated with colder water conditions in eastern equatorial Pacific. ENSO impacts cyclone variability primarily through jet stream displacement.

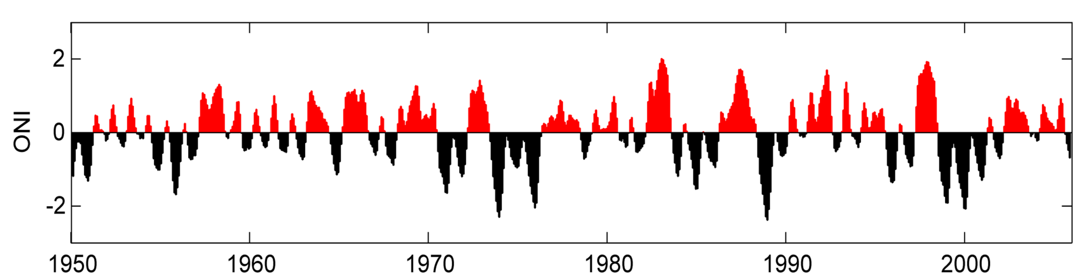

Figure 1. Oceanic Niño index. Warm (positive) phase in red, cool (negative) phase in black (Schoof and Pryor 2014).

The PNA is an oscillation characterized by variations in geopotential height over the Pacific Ocean and across North America having a 1-4 year period. The PNA pattern represents the Rossby flow across North America. The positive phase features an amplified ridge over western North America and an amplified trough over eastern North America, the negative phase is associated with a weakening of the mid-latitude ridge-trough pair, forcing zonal flow. In the mid-latitudes, PNA effects on cyclones mirror ENSO effects.

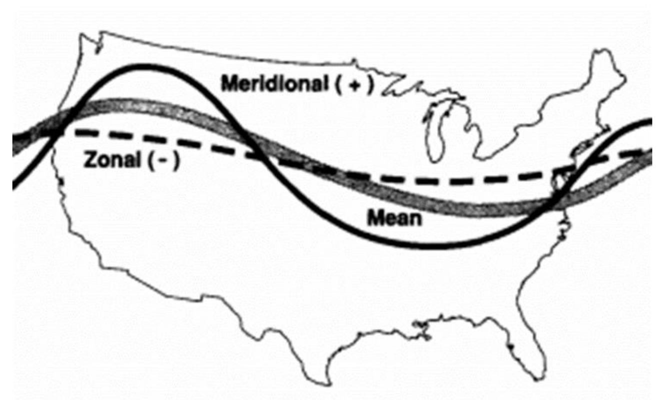

Figure 2. The Pacific North American Pattern. Positive phase shown by the thin, black line; negative phase by the thick, grey line (Leathers et al. 1991).

The AO is an oscillation defined by pressure anomalies between the mid-latitudes and the Arctic Basin with a 6-12 month period. The positive phase is associated with higher pressure in the mid-latitudes which strengthens the circumpolar vortex; negative phase is associated with higher pressure at the North Pole and lower pressure in the mid-latitudes which weakens the circumpolar vortex. The pressure anomalies affect cyclone tracks. The AO is sensitive to topography.

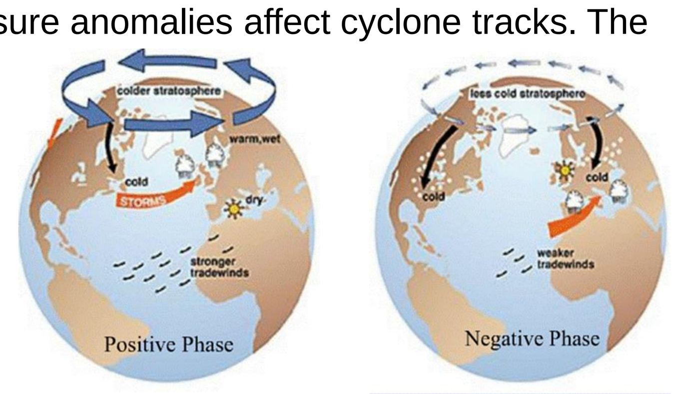

Figure 3. The Arctic Oscillation. Positive phase shows a stronger circumpolar vortex; negative shows weaker (NOAA 2014).

Results: Frequency and Intensity

Cyclones are identified using two requirements: a pressure threshold of 1000 mb and positive vorticity. Vorticity was calculated using the method described in Dessouky and Jenkinson (1975) and applied in Schoof (2004), which estimates geostrophic vorticity using sea level pressure data.

Frequencies and intensities are quantified by examining cyclone occurrences at each grid point. Maps of climatological mean frequency and intensity are intuitive, with higher mean frequency at high latitude and in the lee of Rocky Mountains and greatest intensity in the northeast.

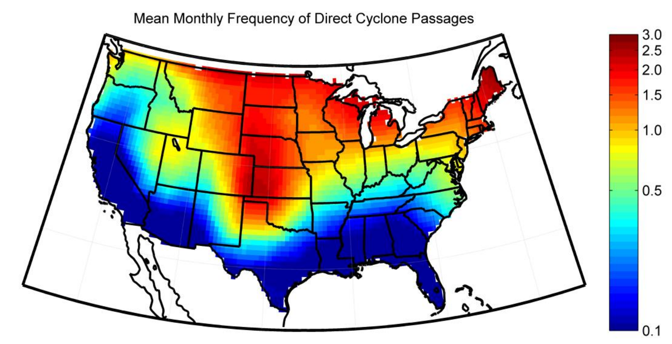

Figure 4. Mean cyclone frequency

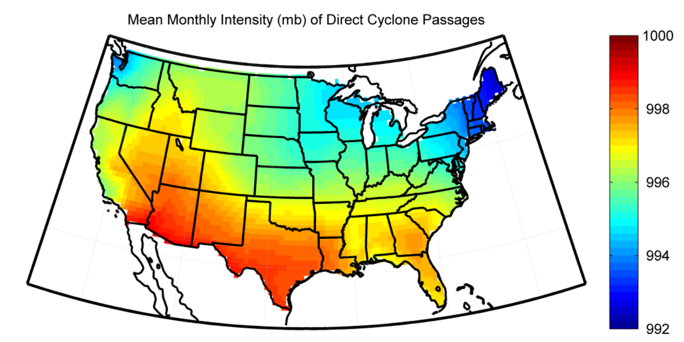

Figure 5. Mean cyclone intensity (mb)

Results: Frequency and Large-Scale Modes

Each of the large-scale modes of climate variability are associated with variations in cyclone frequency in some US regions. The negative phase of the AO is associated with above average cyclone frequency in the NW and NE USA and below average cyclone frequency in the northern Great Plains (Figure 6). ENSO and PNA exhibit very similar composites for cyclone frequency with generally symmetric patterns indicating greater frequency of lee cyclones during the negative phase and lesser frequency of lee cyclones during the positive phase (Figure 7 and Figure 8). For all three modes, the neutral phase is associated with cyclone frequency that don't differ substantially from climatology.

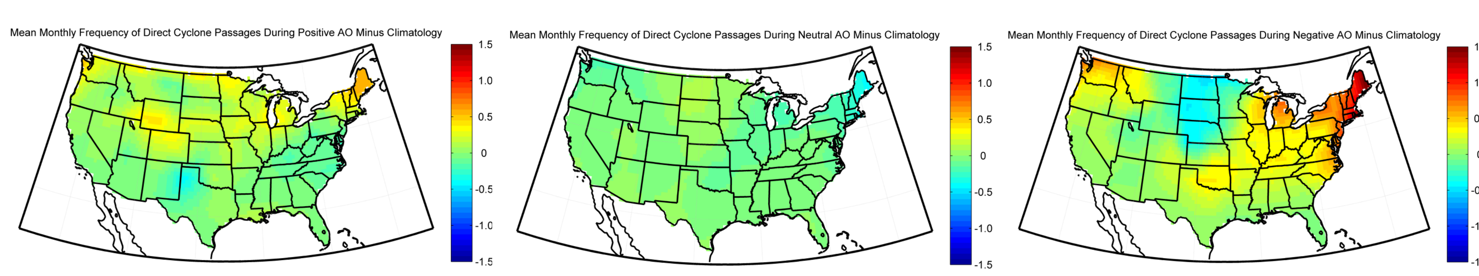

Figure 6. Monthly mean cyclone frequency by AO phase

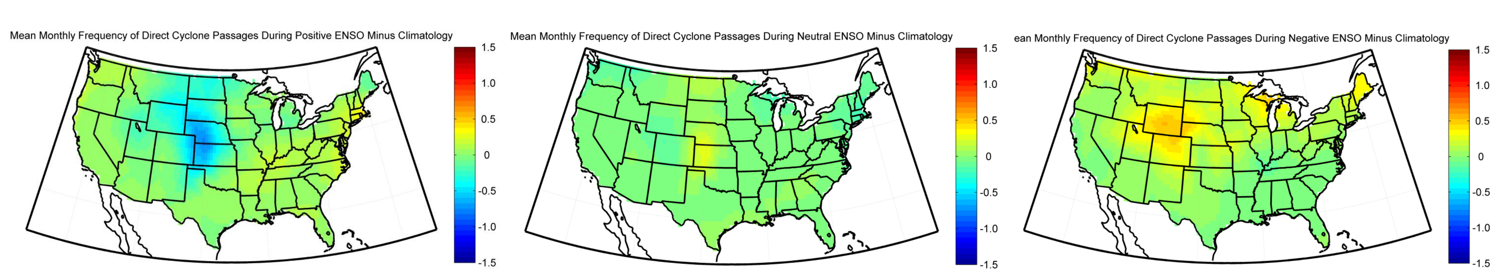

Figure 7. Monthly mean cyclone frequency by ENSO phase

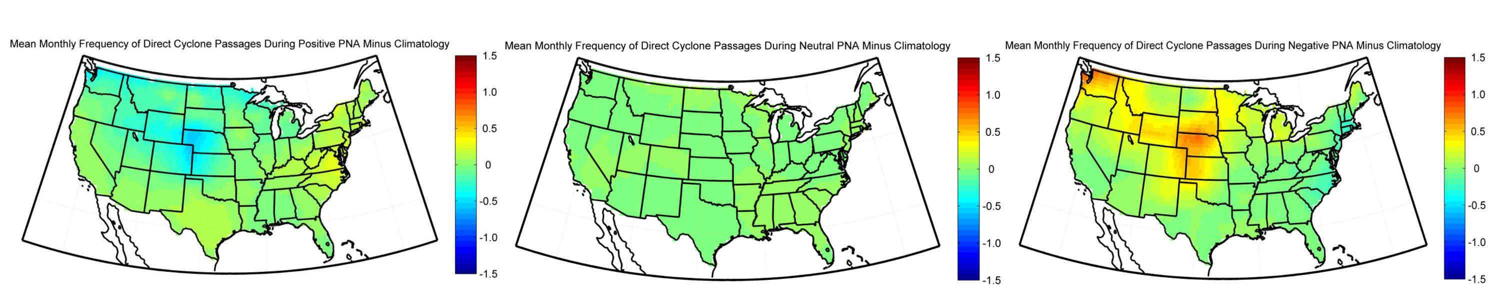

Figure 8. Monthly mean cyclone frequency by PNA phase

Results: Intensity and Large-Scale Modes

Climatological mean intensity (Figure 5) is characterized by stronger cyclones in the north and weaker cyclones in the south, with the strongest cyclones affecting the Northeast region. Positive AO is associated with stronger cyclones in the eastern US, while negative AO is associated with stronger cyclones in the upper Midwest (Figure 9). ENSO (Figure 10) and PNA (Figure 11) once again show similar signals and a roughly symmetric response of cyclone intensity to positive and negative phases. Eastern US cyclones tend to be stronger under negative ENSO/PNA and weaker under positive ENSO/PNA. Interestingly, the neutral phases of all three modes are associated with average or above-average cyclone intensity over most of the US.

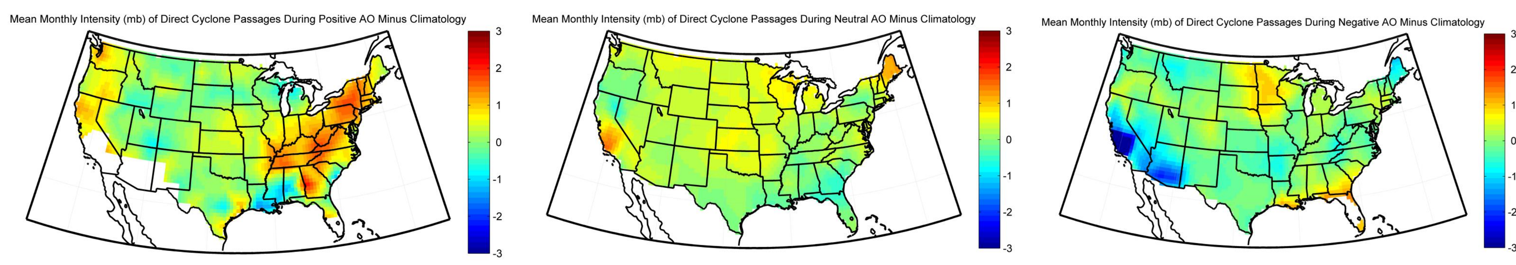

Figure 9. Monthly mean cyclone intensity by AO phase

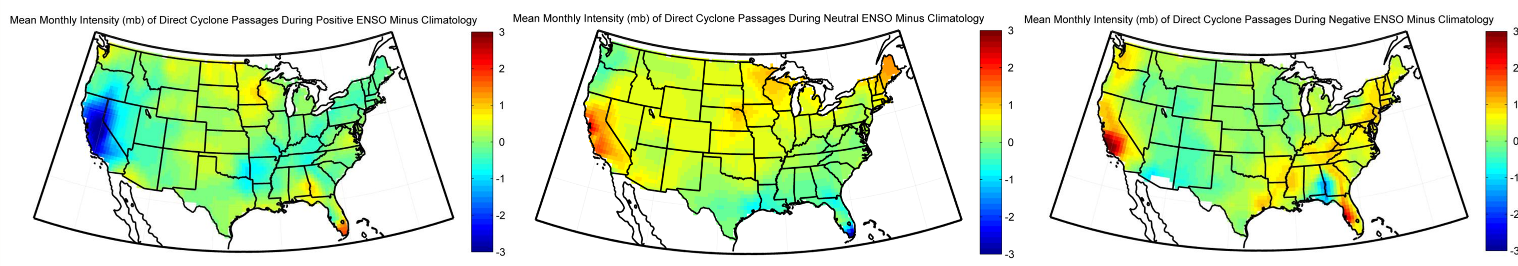

Figure 10. Monthly mean cyclone intensity by ENSO phase

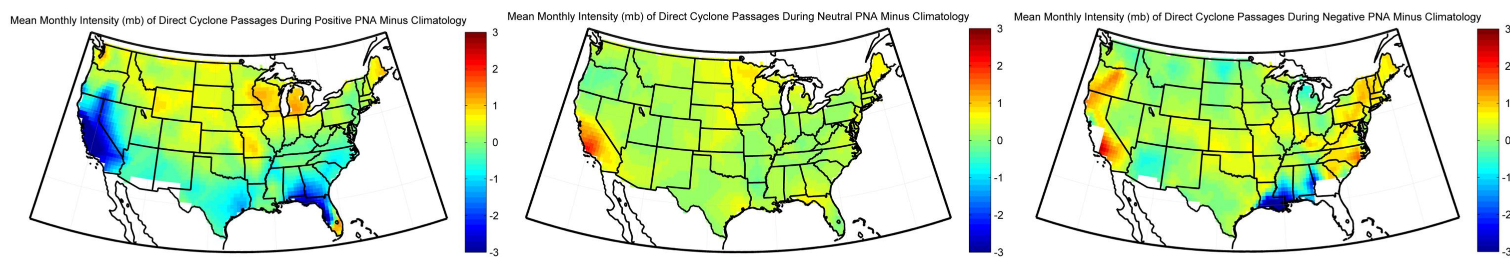

Figure 11. Monthly mean cyclone intensity by PNA phase

The maps presented here represent simple composites based on the phases of the large-scale modes. The relationships presented will next be tested for statistical significance before examination of the modes in a coupled framework as described in the literature review. It is anticipated that the findings will be of utility for seasonal forecasting and evaluation of cyclone climatologies generated by climate models.

References

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