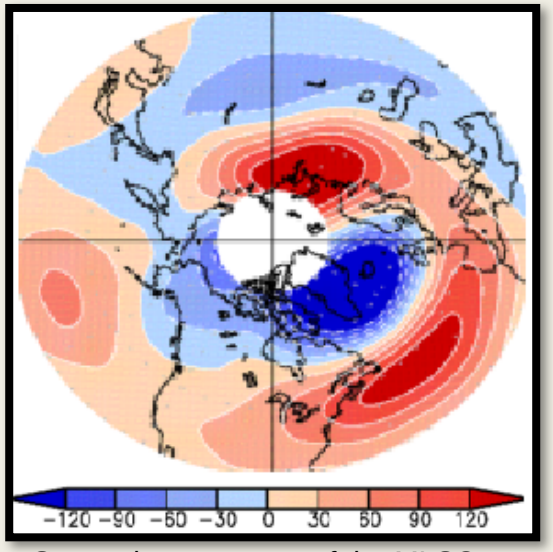
CONNECTING SURFACE WEATHER OVER NORTH AMERICA TO THE MID-LATITUDE SEASONAL OSCILLATION

Zachary H Manthos

Committee: Kathleen Pegion, Cristiana Stan, Paul Dirmeyer

Background

- Walker and Bliss, 1932, first described the North Atlantic Oscillation (NAO), Southern Oscillation (SO), and North Pacific Oscillation (NPO) based off noticeable variations in surface weather
- Atmospheric modes of variability have strong relationships to both temperature and precipitation (Wallace & Gutzler, 1981; Leathers et al., 1991; Diaz et al., 2001; etc.)
- Stan and Krishnamurthy, 2019, found the Mid-Latitude Seasonal Oscillation:
  - *120-Day Oscillation*
  - *Strong correlation with NAO over North Atlantic*
  - *Structure both up stream and down stream of North America*



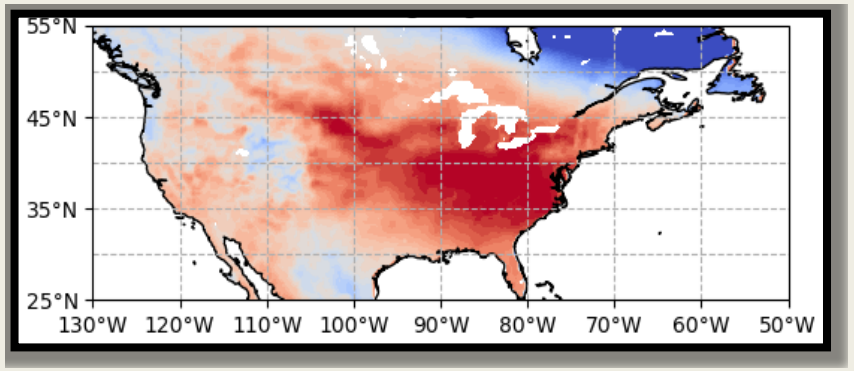
Space-time structure of the MLSO (Fig. 3-A, Stan & Krishnamurthy, 2019)

Objective

- To find variations of temperature and precipitation that are associated to the fluctuation of the Mid-Latitude Seasonal Oscillation (MLSO)
- Does the MLSO affect the frequency and magnitude of temperature anomalies and of precipitation events?
- Does the MLSO interfere with other atmospheric modes?
- Process:
  - *Analyze the MLSO by itself*
  - *Analyze the MLSO in combination with other atmospheric modes, ENSO, NAO, & PNA*

Data

- Domain:
  - *North America: 25N – 55N, 130W – 50W*
- Date Range:
  - *Jan 1st 1997 to Dec 31st 2018*
  - *Daily Data, Start date limited by GPCP data*
- Temperature:
  - *ERA5, ECMWF Reanalysis 5th Gen.*
  - *Daily average 2m surface temp, Land only, Resolution 31km*
- Precipitation:
  - *GPCP, Global Precipitation Climatology Project V1.3 One-Degree Daily*
  - *Daily - mm/day, One degree resolution*
- Geopotential Height (Z500):
  - *ERA-Interim Reanalysis, Daily 500hPa level height*



Domain example, will be explained later

Data

- Indices:
  - *MLSO, Calculated by Stan and Krishnamurthy*
  - *ENSO, Calculated Niño 3.4 index*
    - Based off weekly Optimum Interpolation Sea Surface Temperature dataset
  - *NAO, Obtained from NOAA CPC*
  - *PNA, Obtained from NOAA CPC*

Index	Variable	Region	Method
MLSO	500 hPa height anomalies	30N – 75N	MSSA
ENSO	Sea Surface Temperature	Nino 3.4 5N – 5S 170W – 120W	Standardized Average SST Anomaly
NAO	500 hPa height anomalies	20N – 90N	RPCA
PNA	500 hPa height anomalies	20N – 90N	RPCA

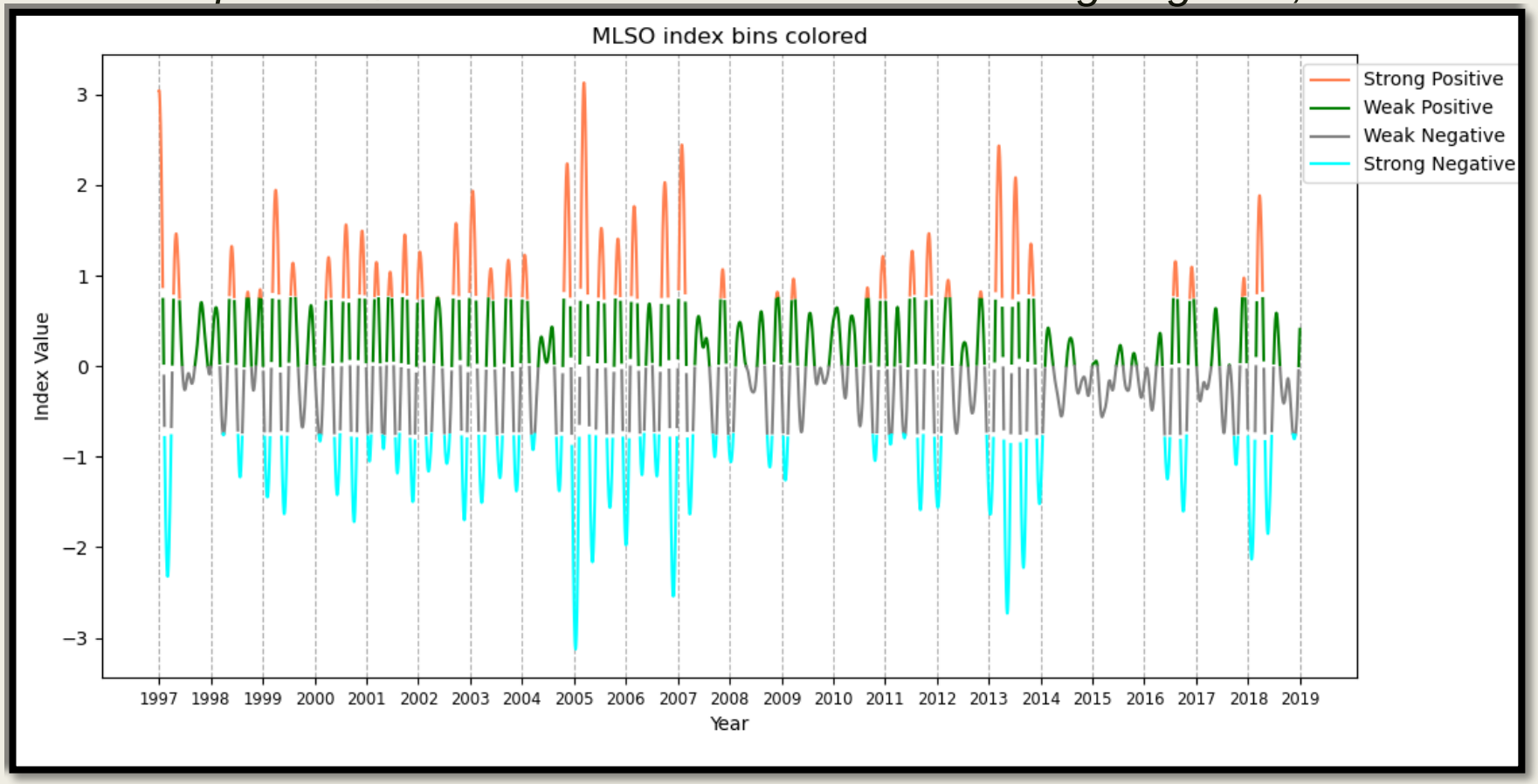
Methods

- Averages: to understand magnitude
  - *Averages of temperature anomalies and precipitation anomalies*
- Ratios: to understand frequency
  - *Warm days/ Cold days and Wet days/ Dry days*
    - Warm = anomaly greater than zero anomaly
    - Wet = greater than 0.01 mm/day nominal value
- Analyses
  - *MLSO alone *tested for significance*
  - *MLSO in combination with ENSO, NAO, or PNA*
- Data selection for each scenario:
  - *Seasons:*
    - Boreal Summer – April - September
    - Boreal Winter – October - March
  - *Bins for the different states of the Oscillations*
  - *Multi-Oscillation – split into in and out of phase*
  - *80 different scenarios, 48 Multi-Oscillation Analyses*

Configurations	Procedure 1: Averages	Procedure 2: Ratios
	MLSO Alone	MLSO Alone
	MLSO + ENSO in and out of phase	MLSO + ENSO in and out of phase
	MLSO + NAO in and out of phase	MLSO + NAO in and out of phase
	MLSO + PNA in and out of phase	MLSO + PNA in and out of phase

Methods

- Bins:
  - *Strong positive, > +0.75*
  - *Weak positive, 0.75 – 0*
  - *Weak negative, 0 – -0.75*
  - *Strong negative, < -0.75*

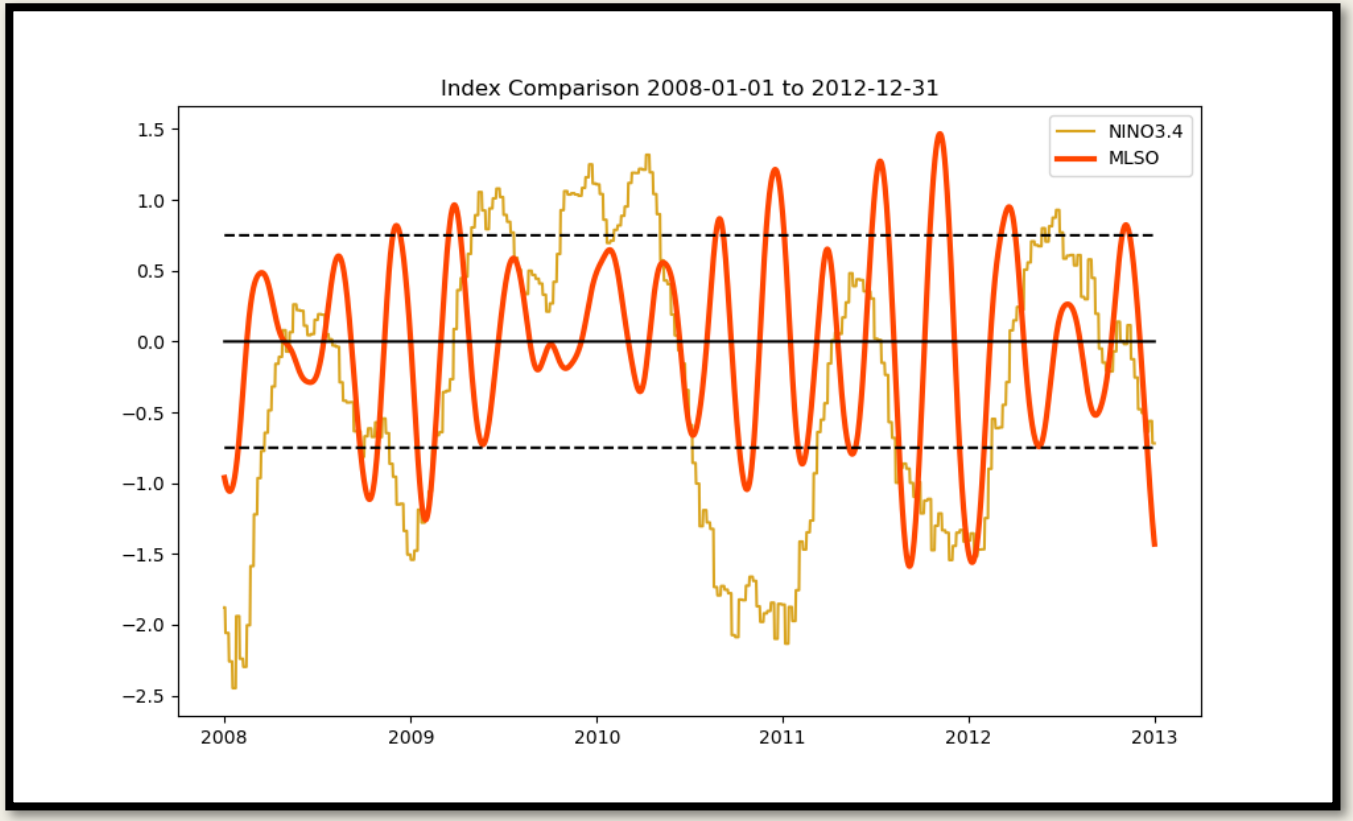


* Areas of decreased amplitude align with El Niño events

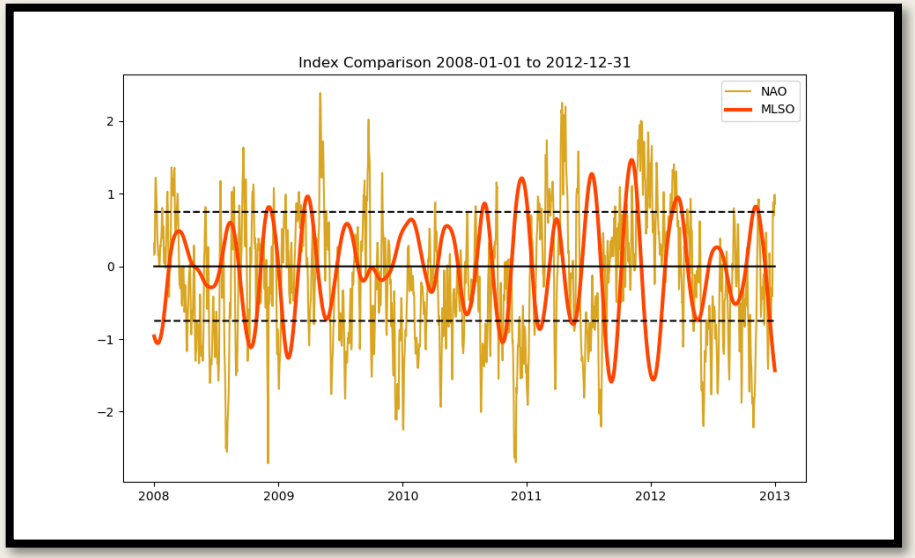
Indices

- Standardized Indices, 2008 - 2013
- NAO and PNA are more variable than the MLSO and ENSO is less variable that MLSO

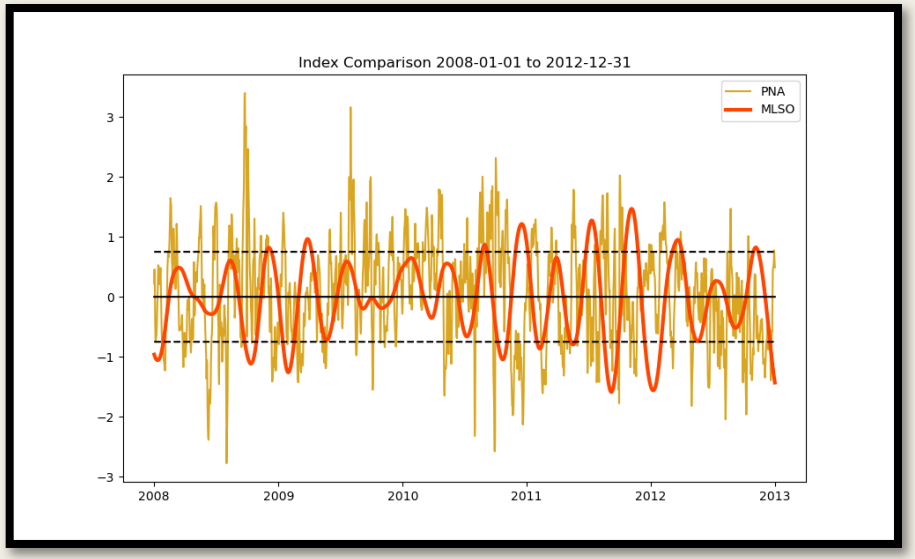
MLSO & ENSO



MLSO & NAO



MLSO & PNA



Methods

- Statistical methods used to determine the significance of the MLSO composites:
  - *Binomial Proportion Test (BPT) - Ratios*
    - Simplified Students t test
  - *Wilcoxon Rank-sum Test (WRS)- Averages*
- BPT & WRS tests used the bin with the highest or lowest ratio or anomaly tested against all the other bins combined

$$A_1 vs A_{234} = \frac{D_2 + D_3 + D_4}{N_2 + N_3 + N_4}$$

Where:

A_1 = Highest Average found in bin 1
A_{234} = Average for bins 2-4
$D_{2\text{-}4}$ = Anomaly values for other bins
$N_{2\text{-}4}$ = Total number of data points in bins 2-4

Methods

- Serial Correlation was addressed with a reduction of DOFs using the e-folding timescale or day-to-day persistence, i.e., memory
- Memory of Temperature: 3.4 Days
- Memory of Precipitation: Less than One Day
- DOF reduction factor = 1/Memory
- Reduction not used in WRS Test

$$Mem = \left[\sum_{i=1}^{22} \frac{-1}{Avg_D(\ln(acor(x_i)))}\right]/22$$

Where:

Mem = Memory in days

Avg_D = Domain Average

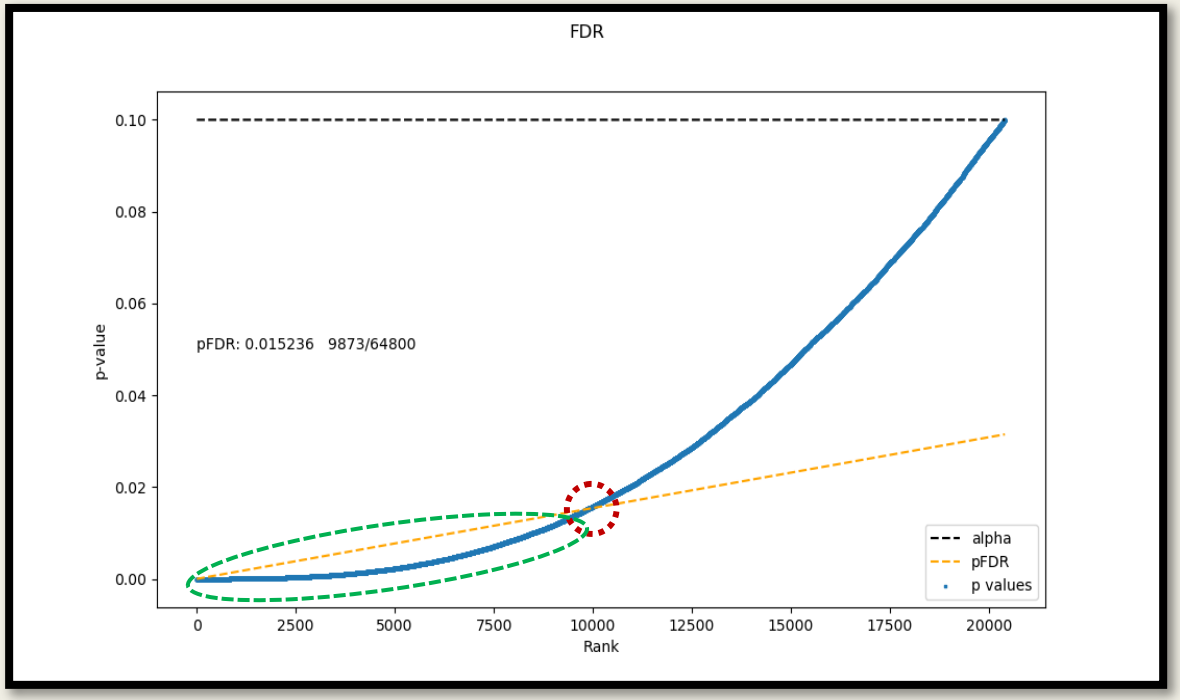
acor = 1-day lagged Auto-Correlation

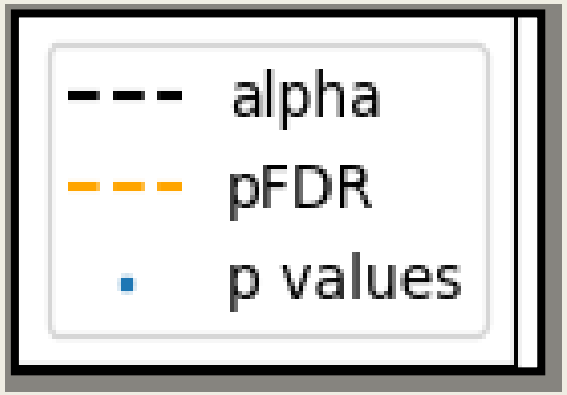
x_i = Temperature anomalies or Precipitation values for 1 year

Methods

- False Discovery Rate Test
  - *Field significance test based off p-values*
  - *Minimizes the expected fraction of nominally significant tests whose null hypotheses are actually true*

$$p_{FDR} = \max_{j=1,\cdots,N} \left\{ p_{(j)} : p_{(j)} \leq \frac{j}{N} \alpha_{global} \right\}$$



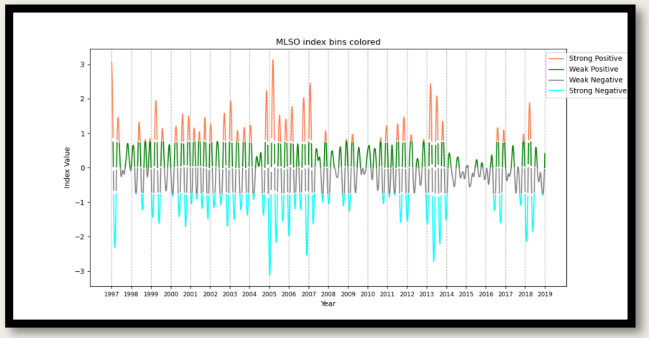


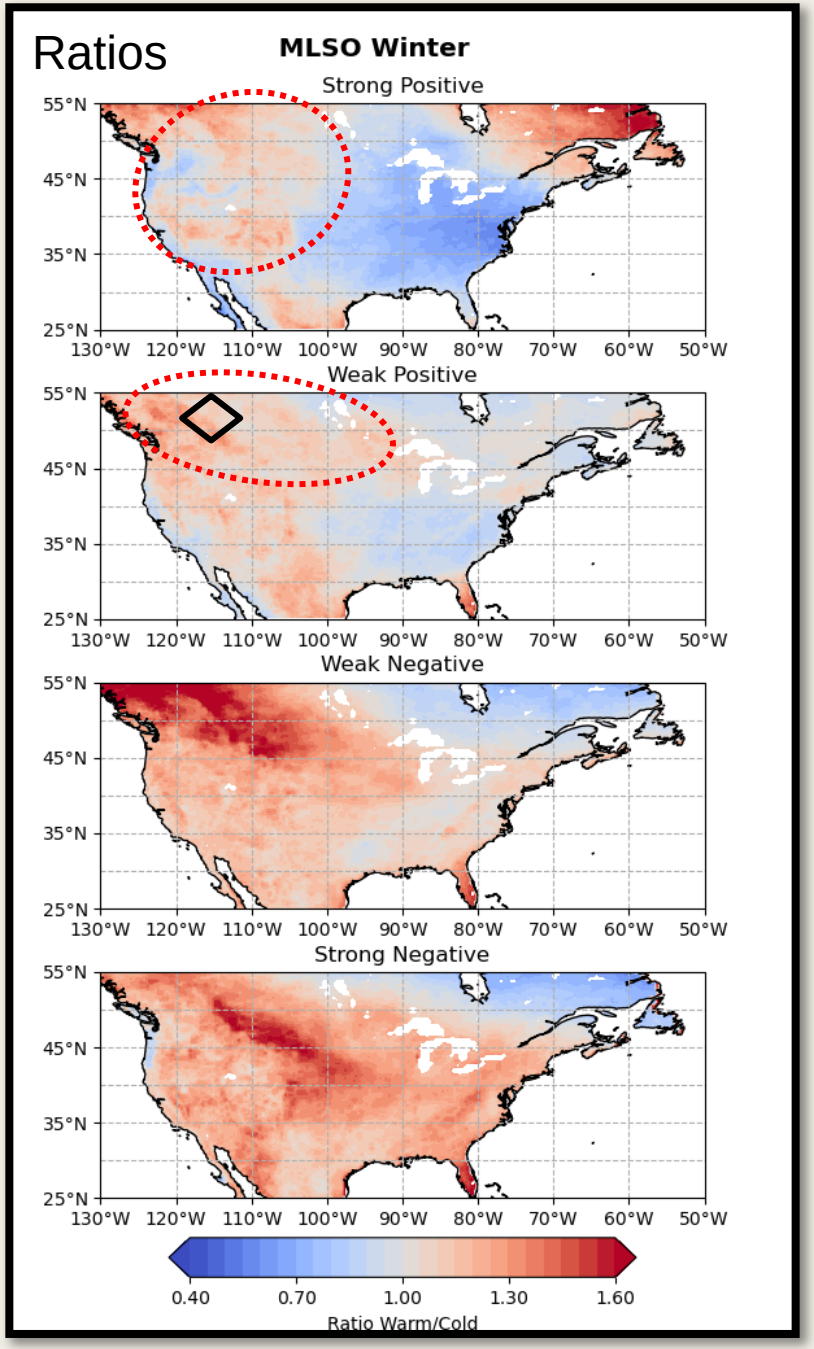
Results

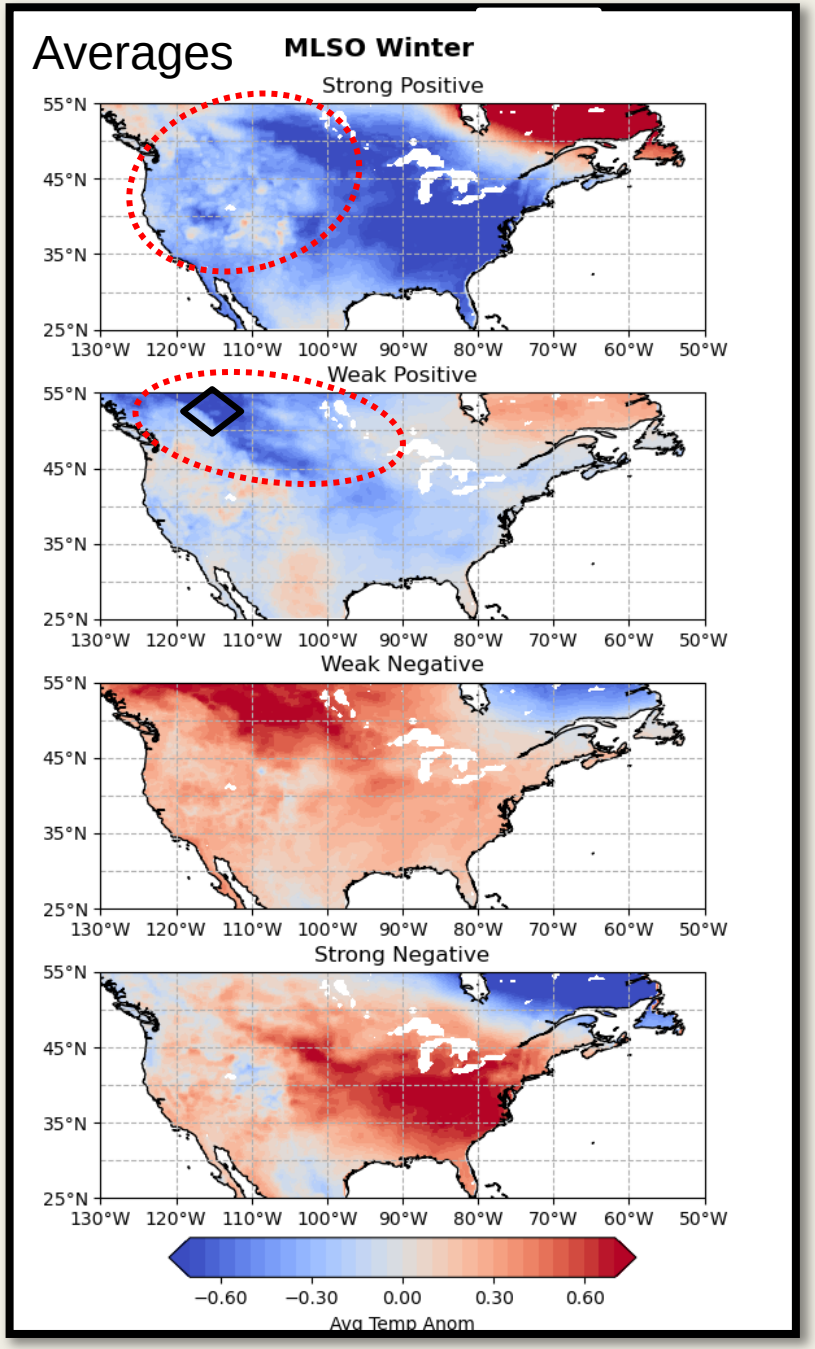
- Methods of description:
  - *MLSO:*
    - Ratios compared to Averages
    - The individual bins compared against each other
    - Statistical Significance
  - *Multi-Oscillation:*
    - Ratios compared to Averages
    - Individual Modes vs. Combination

Results

- MLSO Alone, Boreal Winter
- Right:
  - *Average Temp Anomaly*
  - *Shows Oscillatory Nature of MLSO*
- Left:
  - *Ratios Warm/Cold*
  - *Reveals areas of skewed temperature distribution when compared to the averages (Red Circles)*

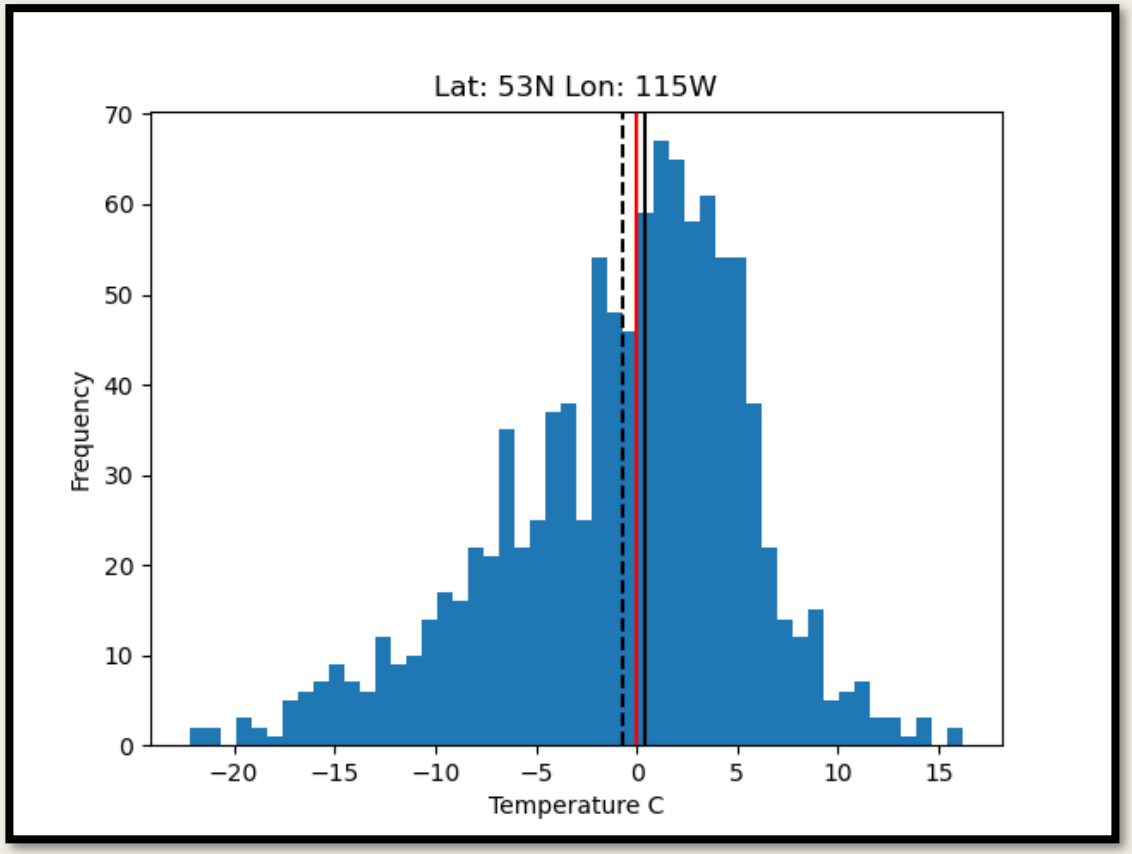






Results

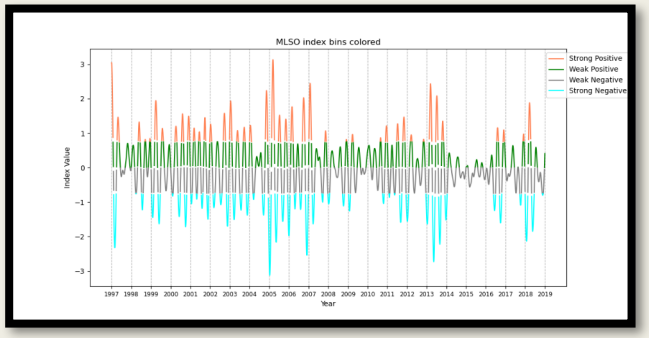
- Histogram of temperature seen in the winter weak positive bin for the MLSO alone

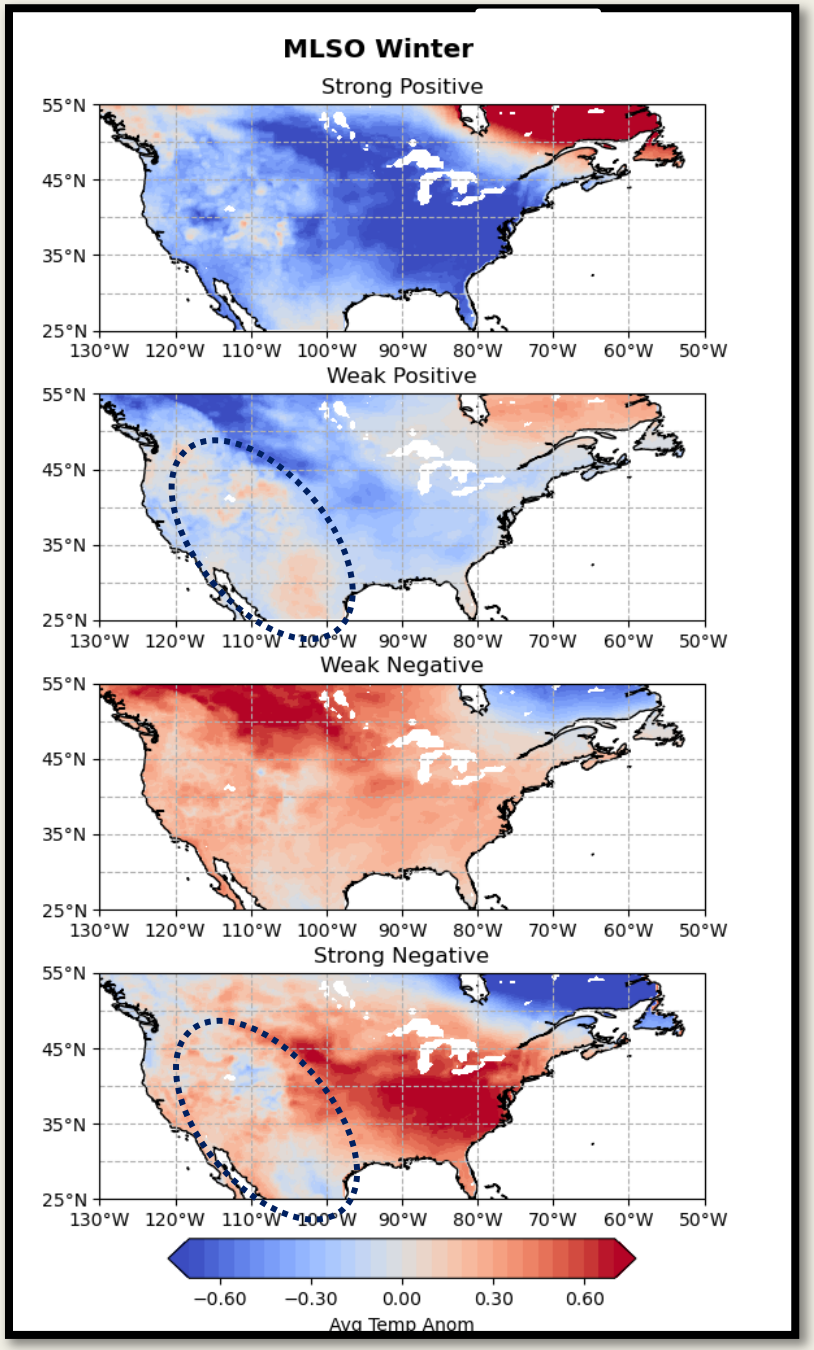


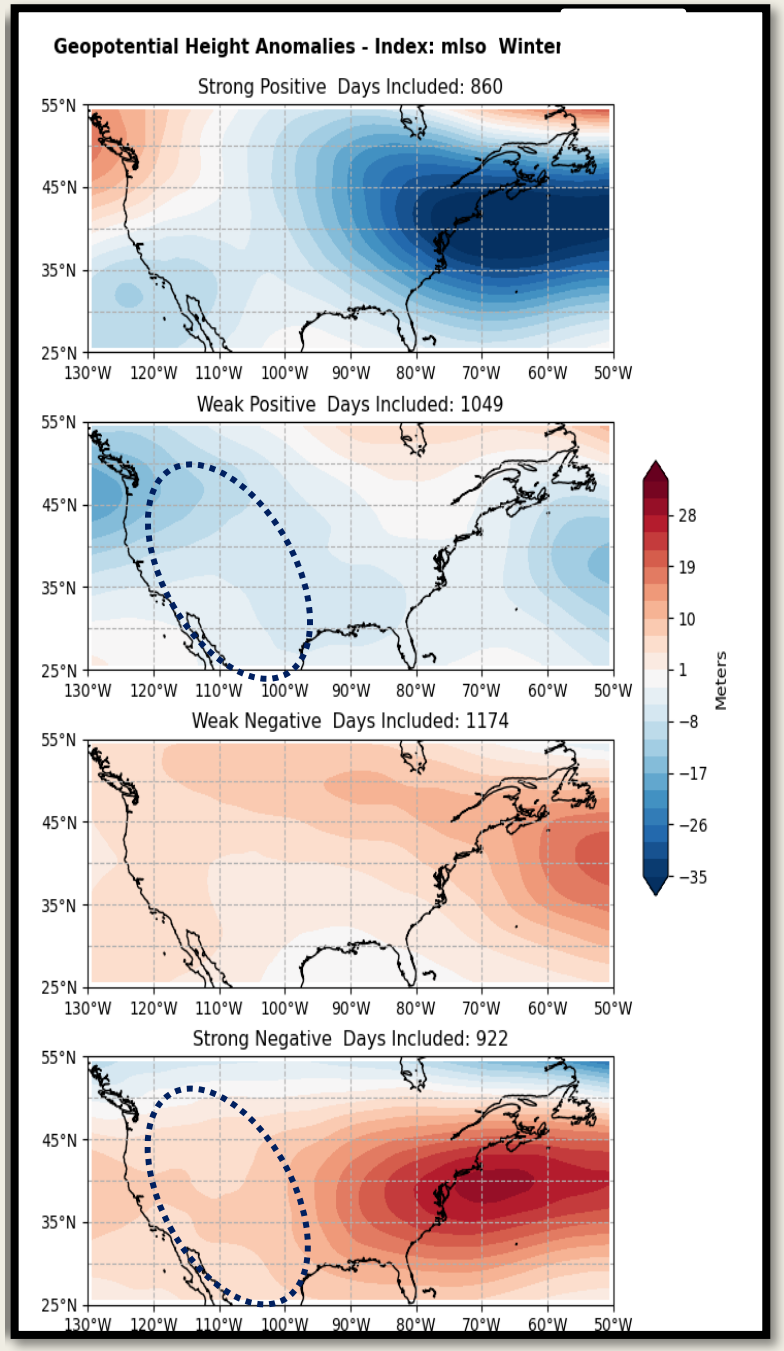
- Red Line = 0
- Dashed Line = Average
- Solid Black Line = Median
- Median used as a proxy for the ratio

Results

- Anomalies over Mexico and The Central Rockies (Blue Circles)
- Asymmetrical Oscillatory Nature
- Most likely due to local topography







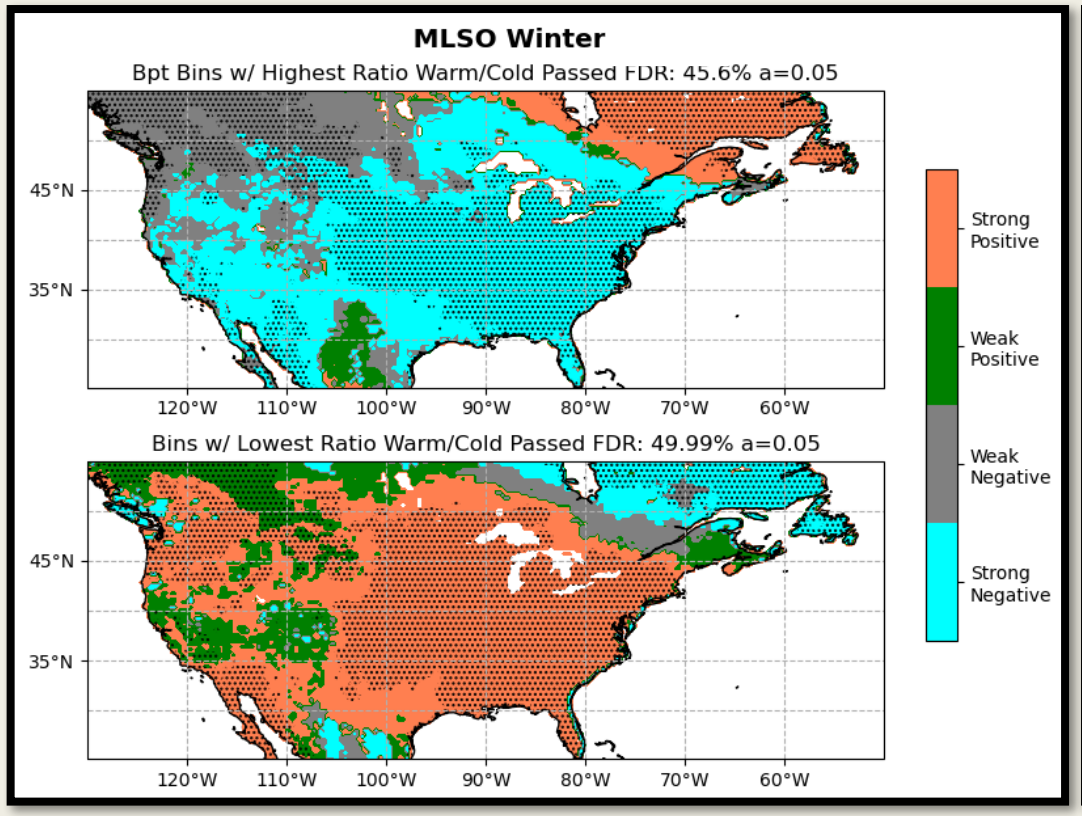
Results

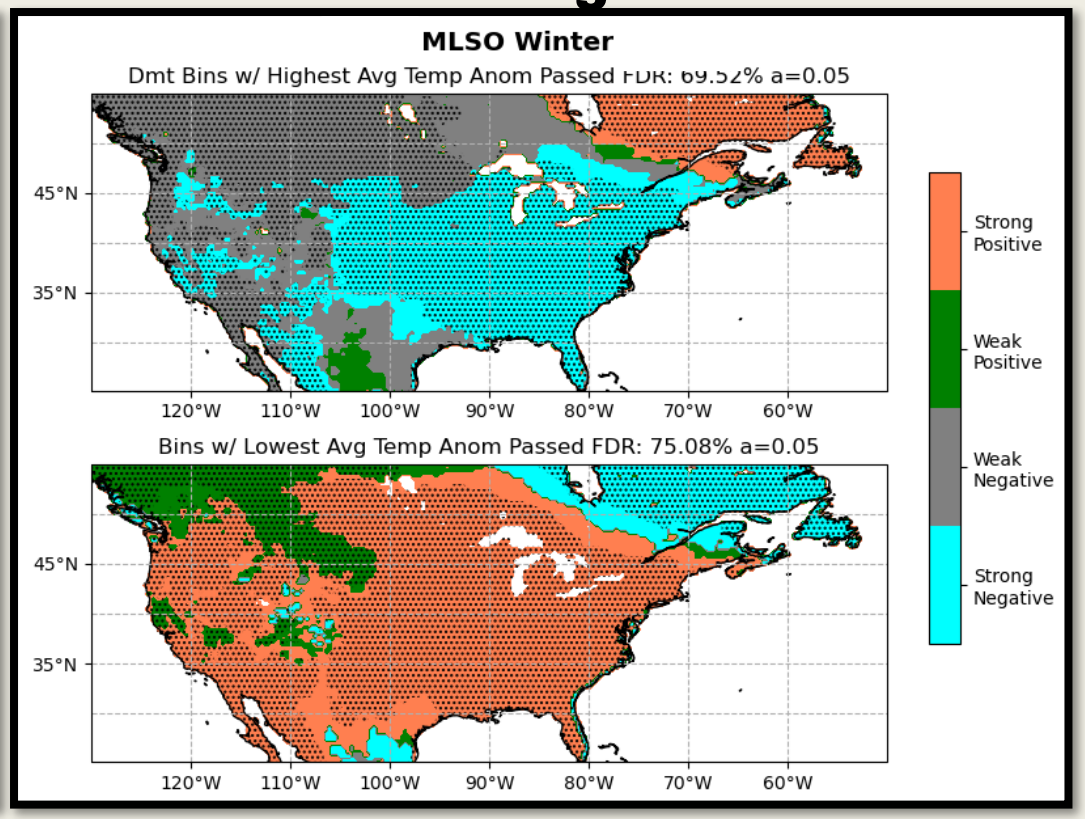
- Corroborates oscillatory nature
- Large areas of same bin hint at a change in the large-scale atmospheric structure
- Stippling shows areas that are significant after FDR test with a = 0.05

Ratios | **Averages**

Highest

Lowest

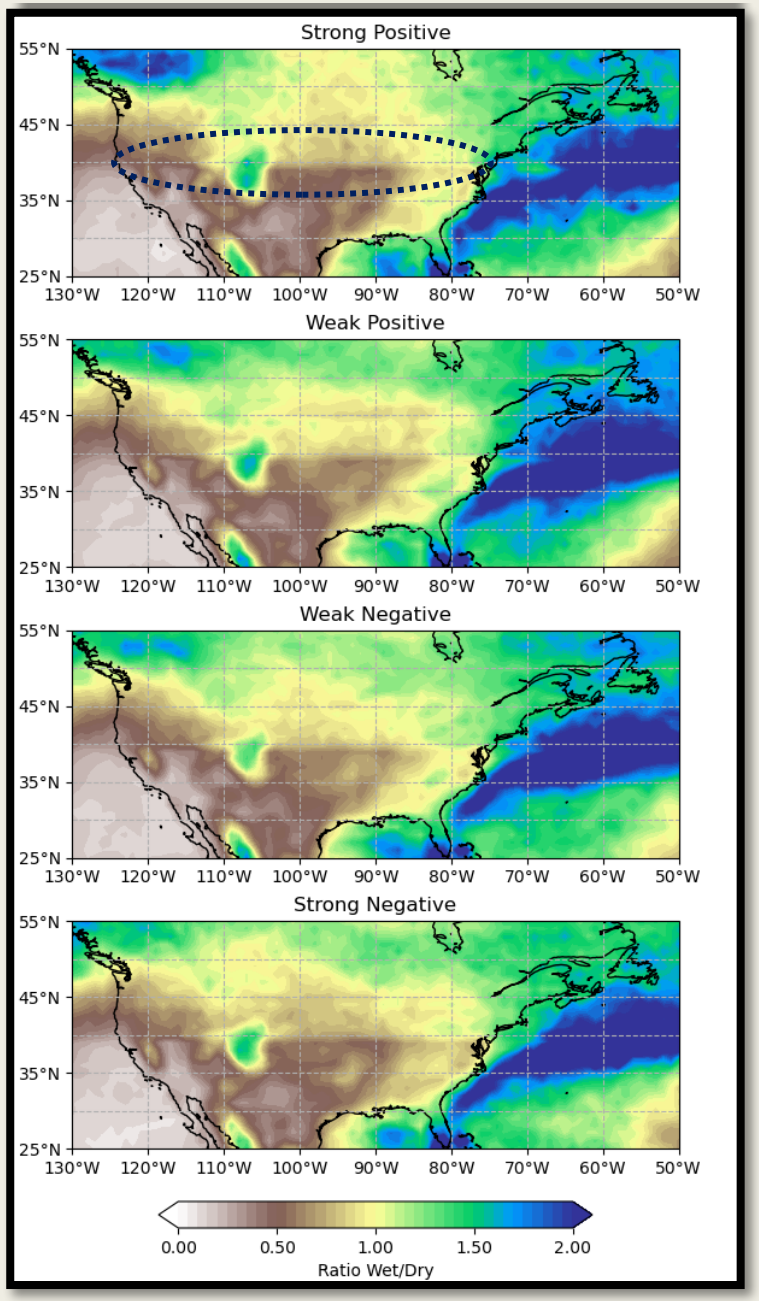


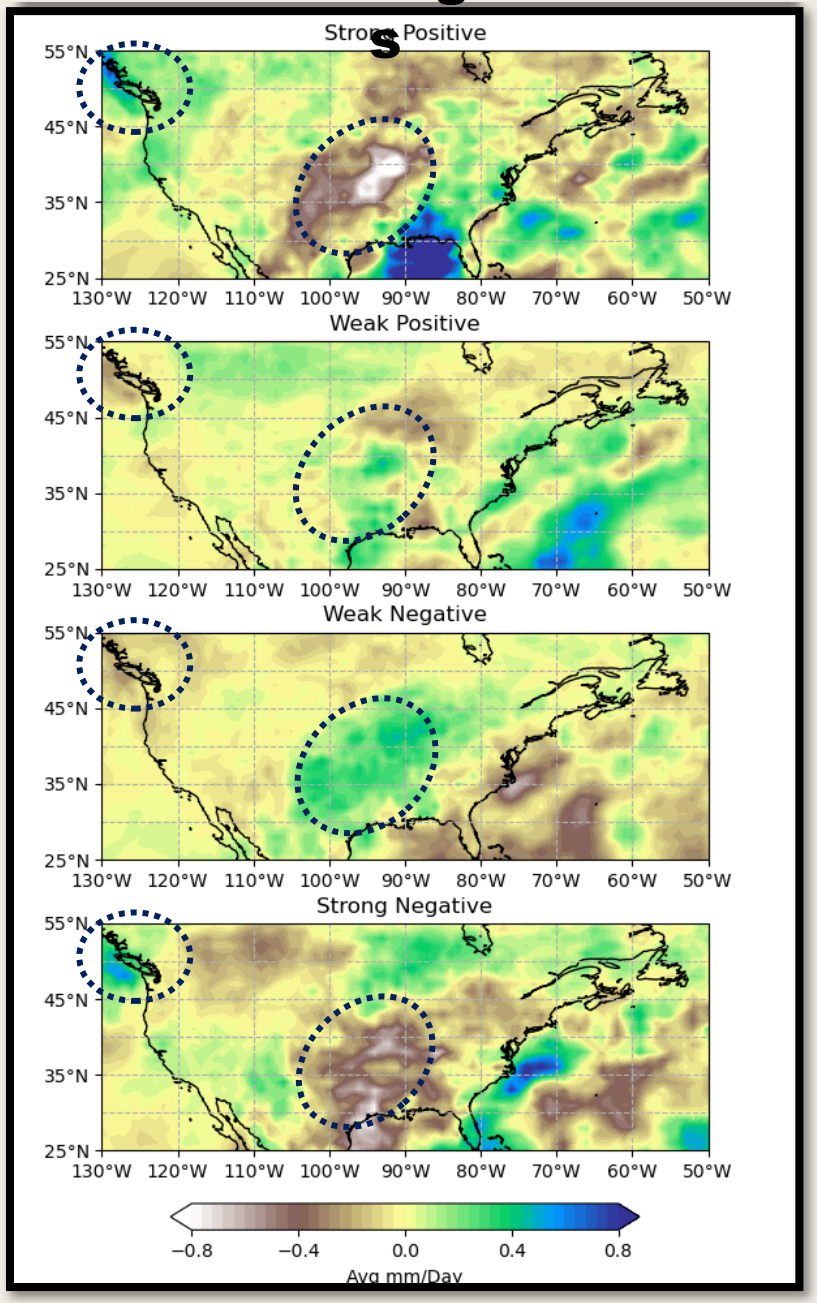


Results

- An Artifact from the GPCP data set is revealed in the Ratios, the flat line along 40N, and it shows the dividing line for the different procedures used to create the dataset
- Ratios for the different bins do not vary much showing that the MLSO has little influence on precipitation frequency
- A few areas in the averages show a magnitude based oscillation

Ratios **MLSO Summer** **Average**s





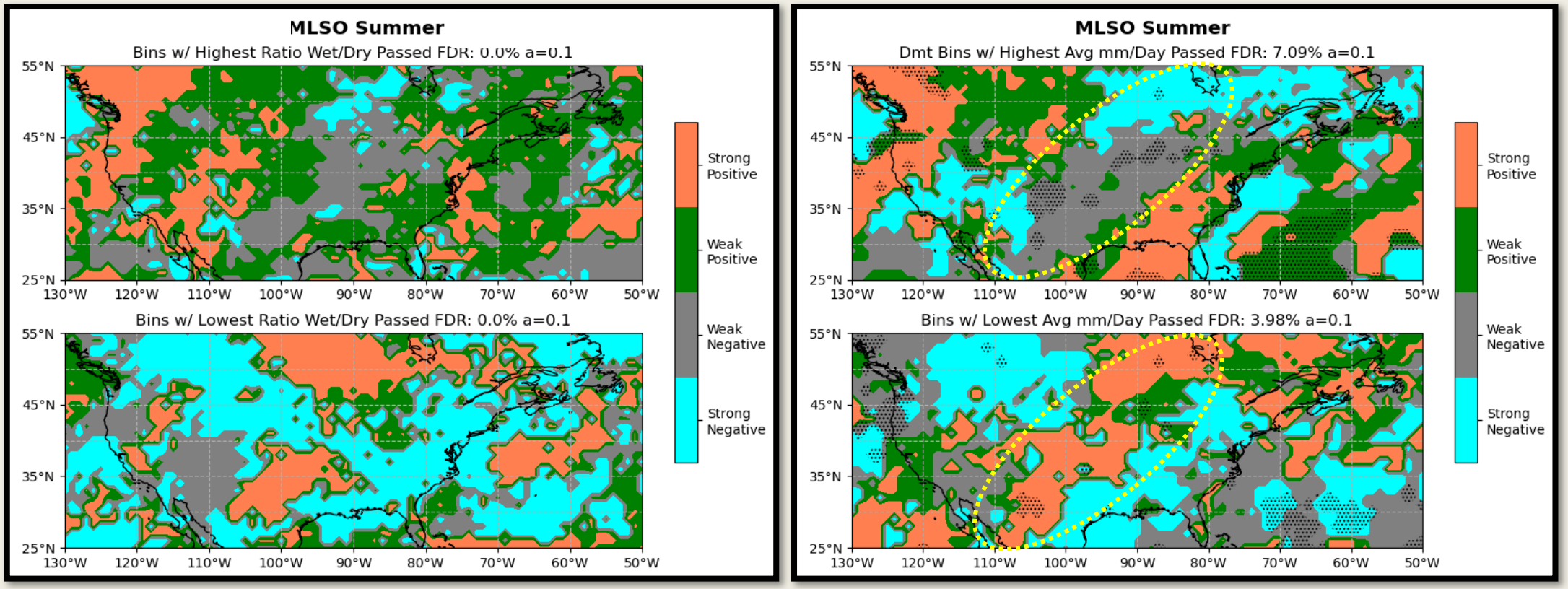
Results

- Analysis of precipitation for the MLSO alone did reveal distinct patterns, for the average anomalies, but little was able to achieve statistical significance
- MLSO may have a connection to the precipitation, an oscillatory nature is hinted at by the switching of bin signs between the highest and lowest values (yellow circles)

Ratios **Averages**

Highest

Lowest

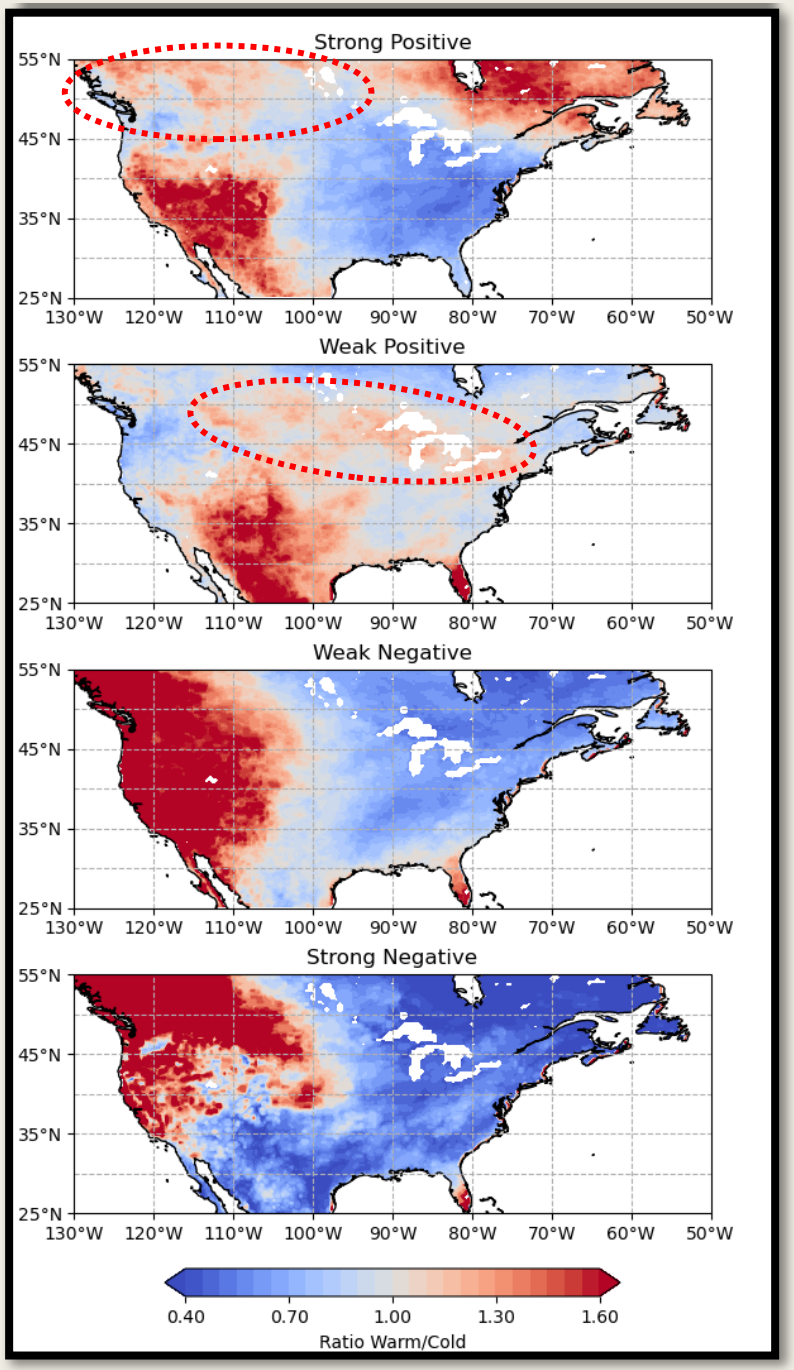


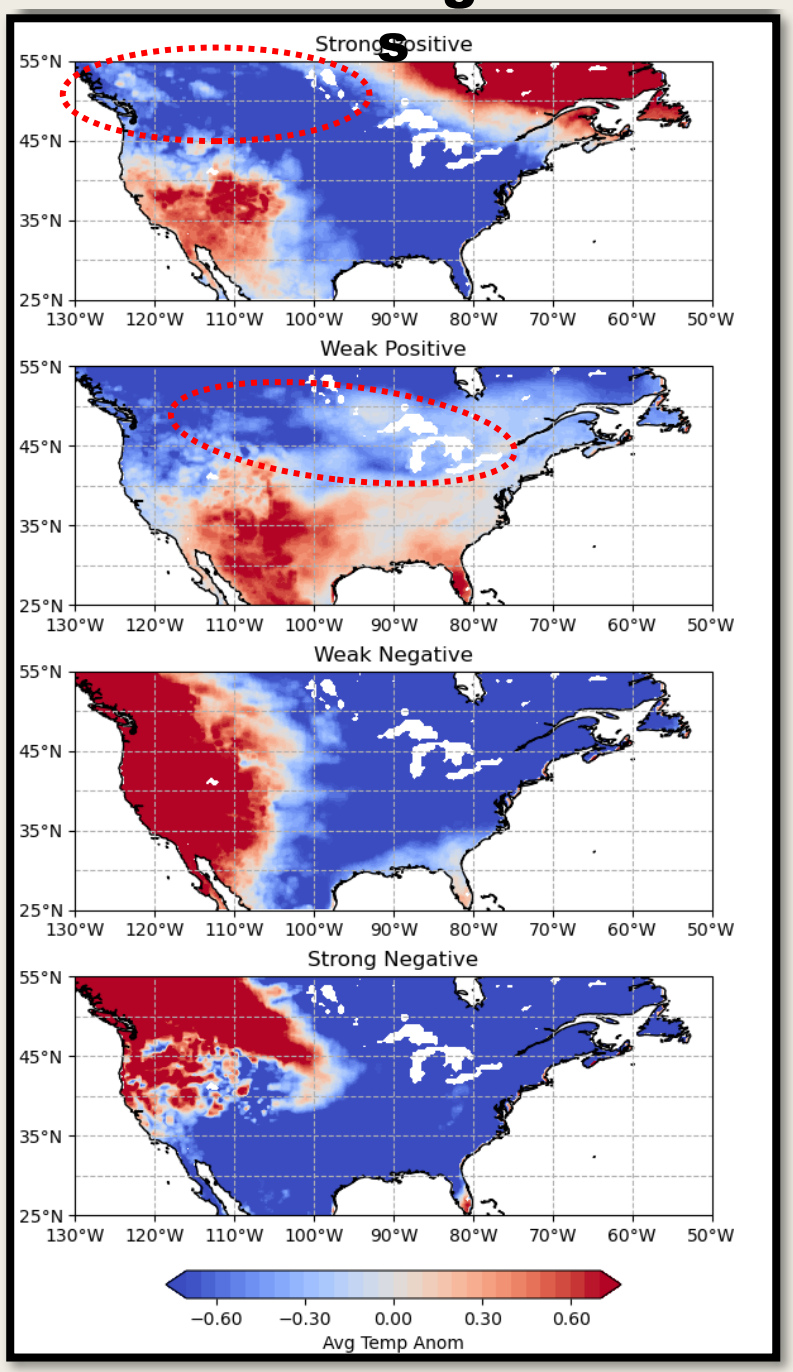
Results

- Multi-Oscillation Analysis: MLSO + ENSO
- Winter, Out of phase

Bin Label on Figures	MLSO Bin	ENSO Bin
Strong Positive (258)	Strong Positive (860)	Strong Negative (1486)
Weak Positive (275)	Weak Positive (1049)	Weak Negative (993)
Weak Negative (298)	Weak Negative (1174)	Weak Positive (878)
Strong Negative (57)	Strong Negative (922)	Strong Positive (648)

- Skewed Distributions over Western Canada in the strong positive bin and much of the US Canada Border in the weak positive bin (Red Circles)





Scenario:

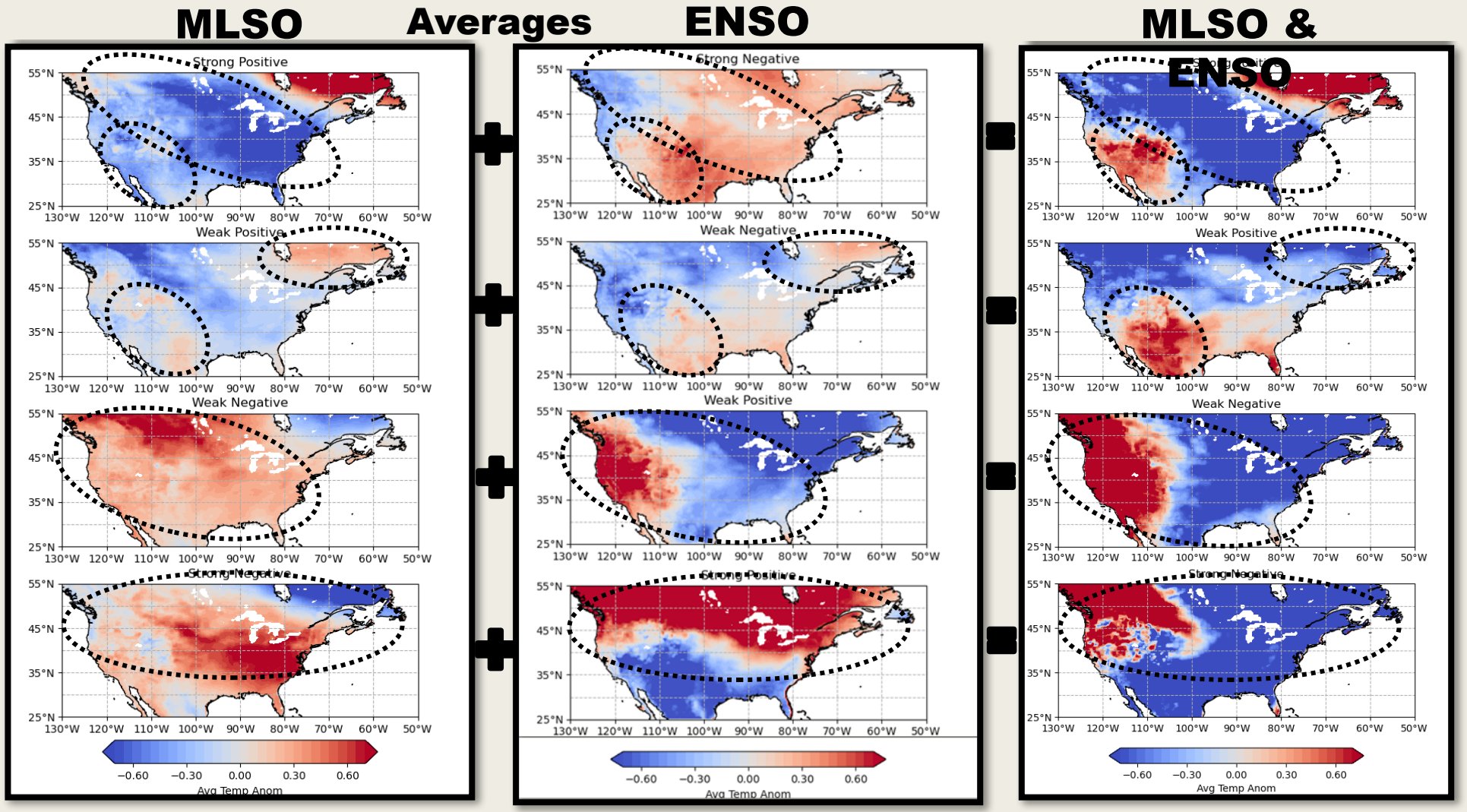
- MLSO & ENSO
- Out of Phase
- Winter

Results

- Comparing MLSO and ENSO to their combination reveals areas where either one dominates, areas of amplification or negation, and the emergence of new patterns

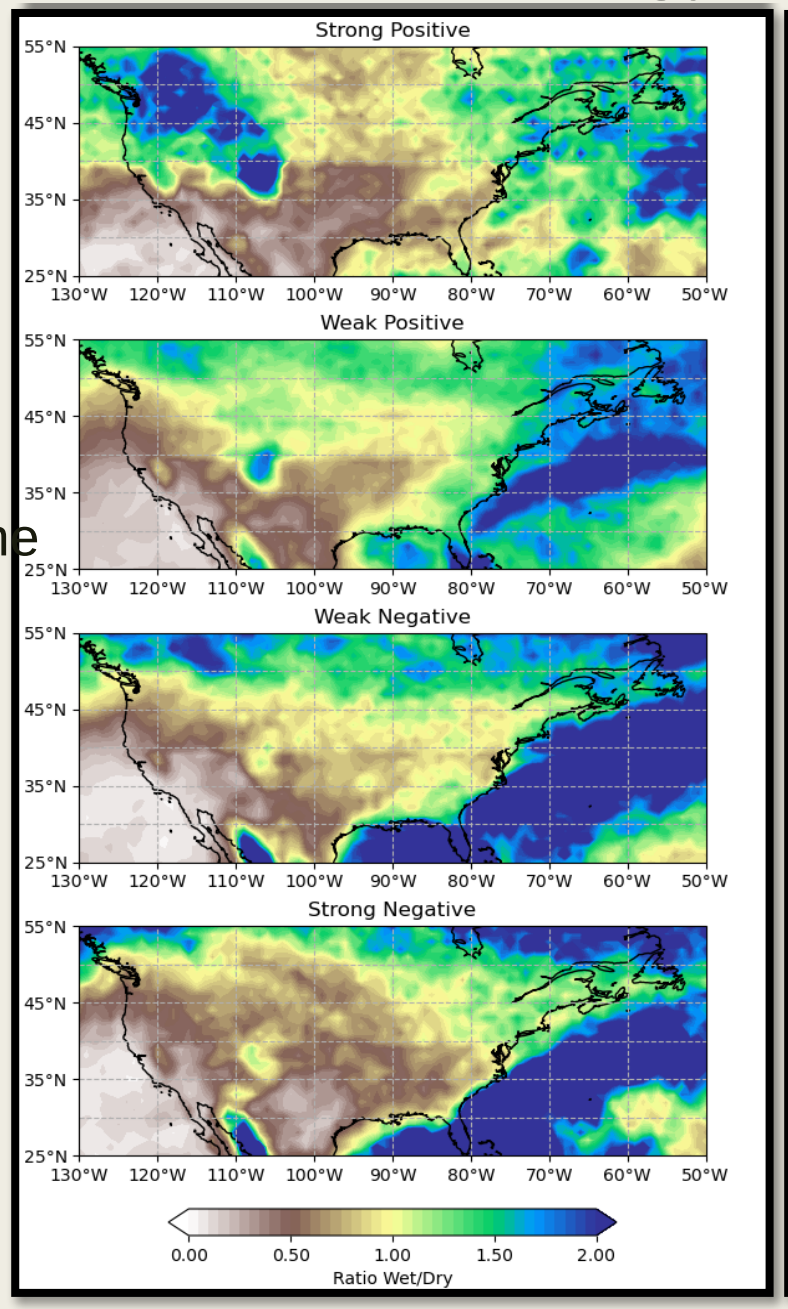
Most Notable features:

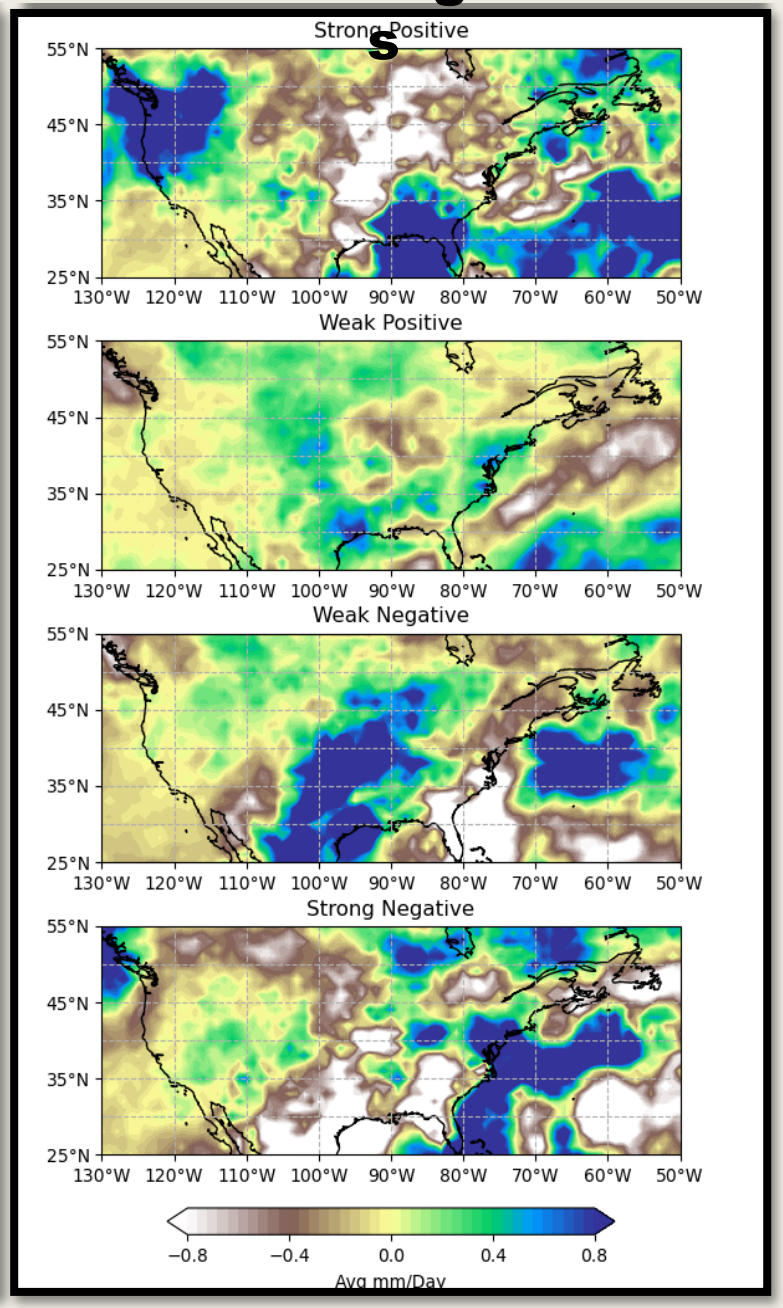
- MLSO Dominance over most of the domain in the Strong positive bin
- ENSO Dominance over most of the domain in the weak negative bin
- Amplification over Western North America in the weak negative bin
- Negation over eastern Canada in the weak positive bin
- Emergence of a new pattern over the Southwest US in the strong positive bin and in the strong negative bin



Results

- Scenario:
  - *MLSO & ENSO*
  - *In Phase*
  - *Summer*
- Combination Influences the frequency of precipitation
- Averages are much more variable than the Ratios



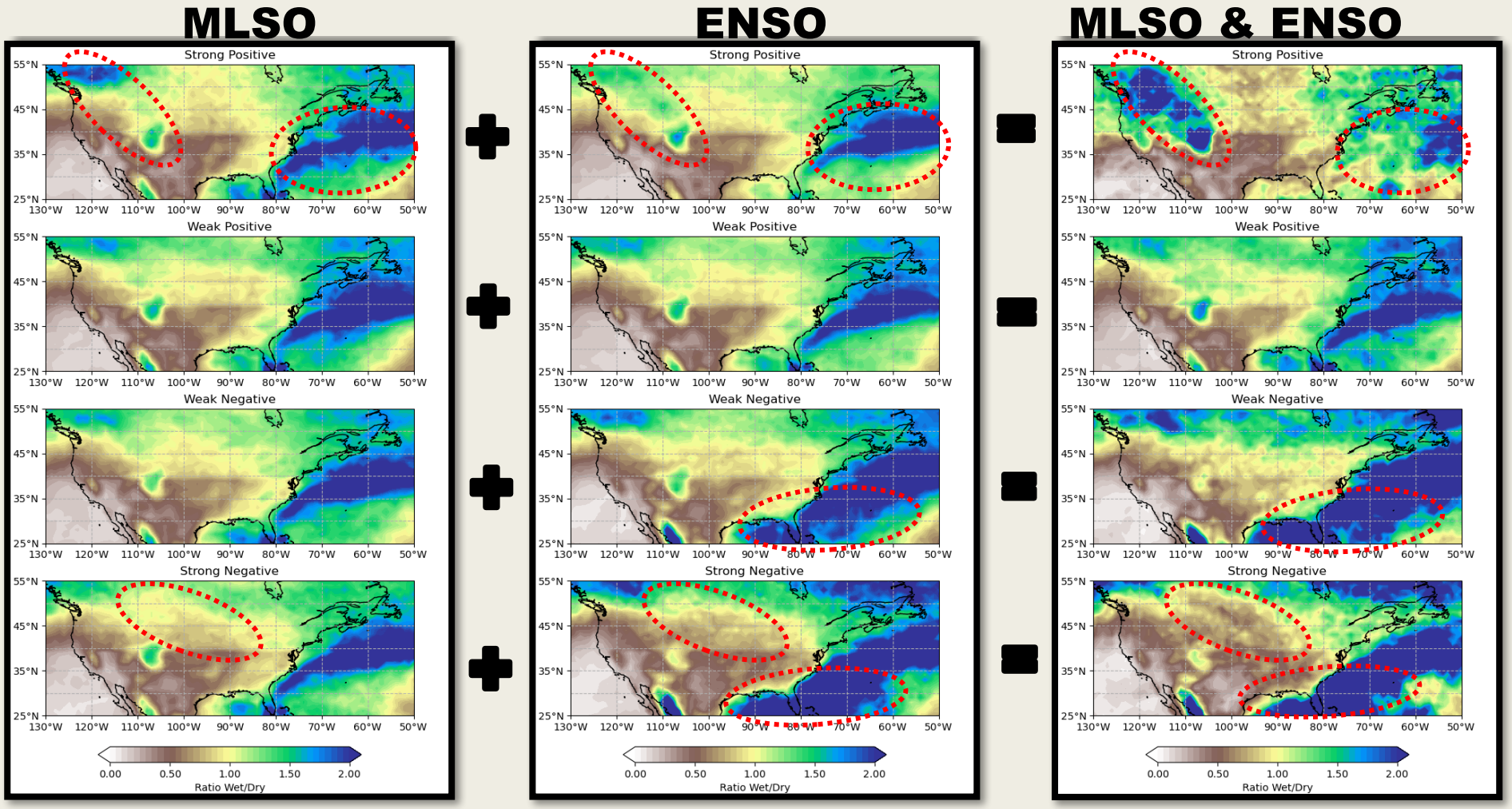


Results

- Precipitation ratios were very consistent throughout the different analyses
  - *Only a few combinations showed areas that had a large deviation from the individual atmospheric modes' patterns*
  - *Only a few showed what could be classified as dominance*

Scenario:

- MLSO & ENSO
- In Phase
- Summer

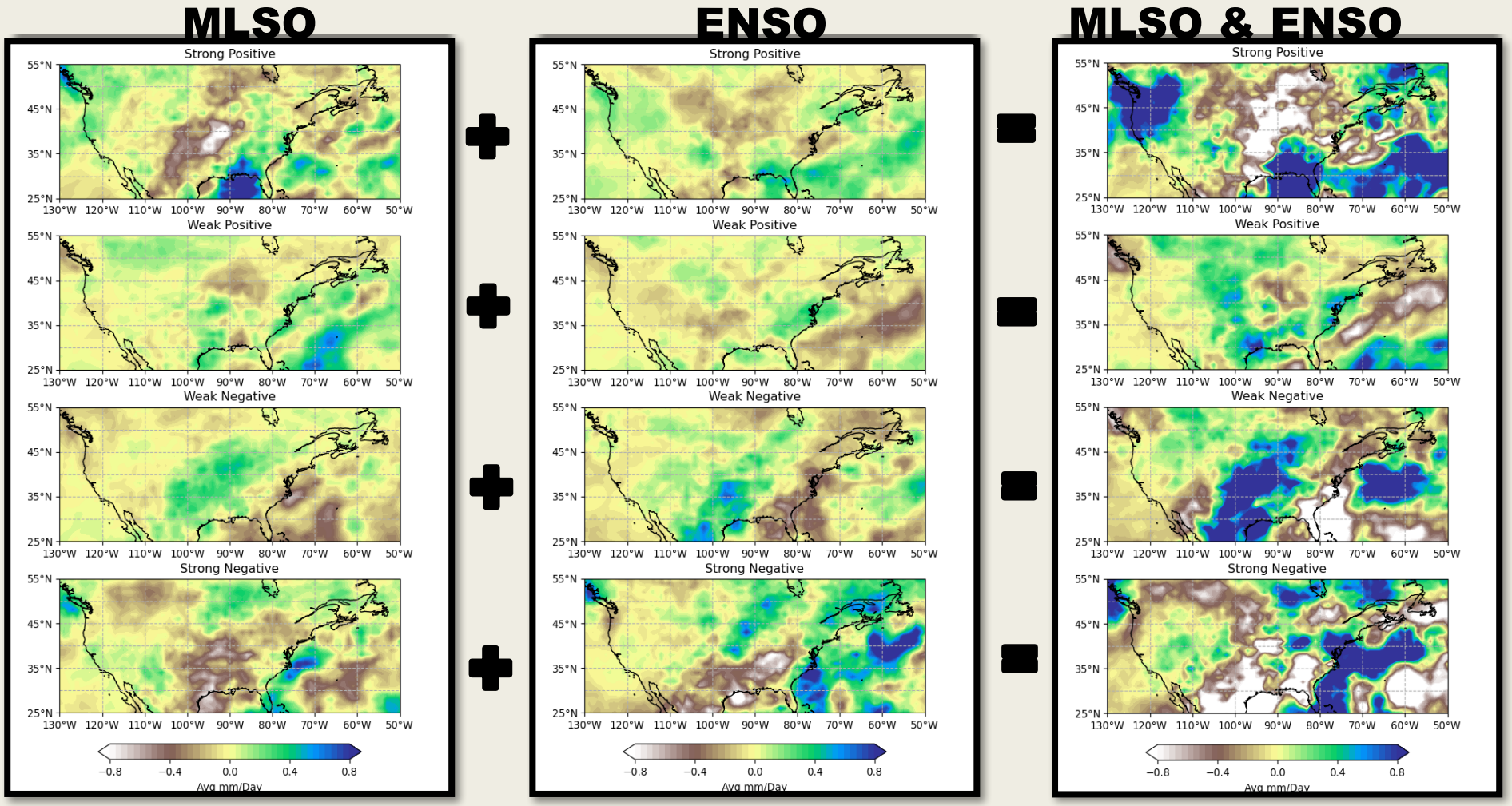


Results

- Precipitation averages were much more chaotic
- They reveal the most notable affects of including the MLSO in the combinations
- MLSO is a complicating factor

Scenario:

- MLSO & ENSO
- In Phase
- Summer



Results

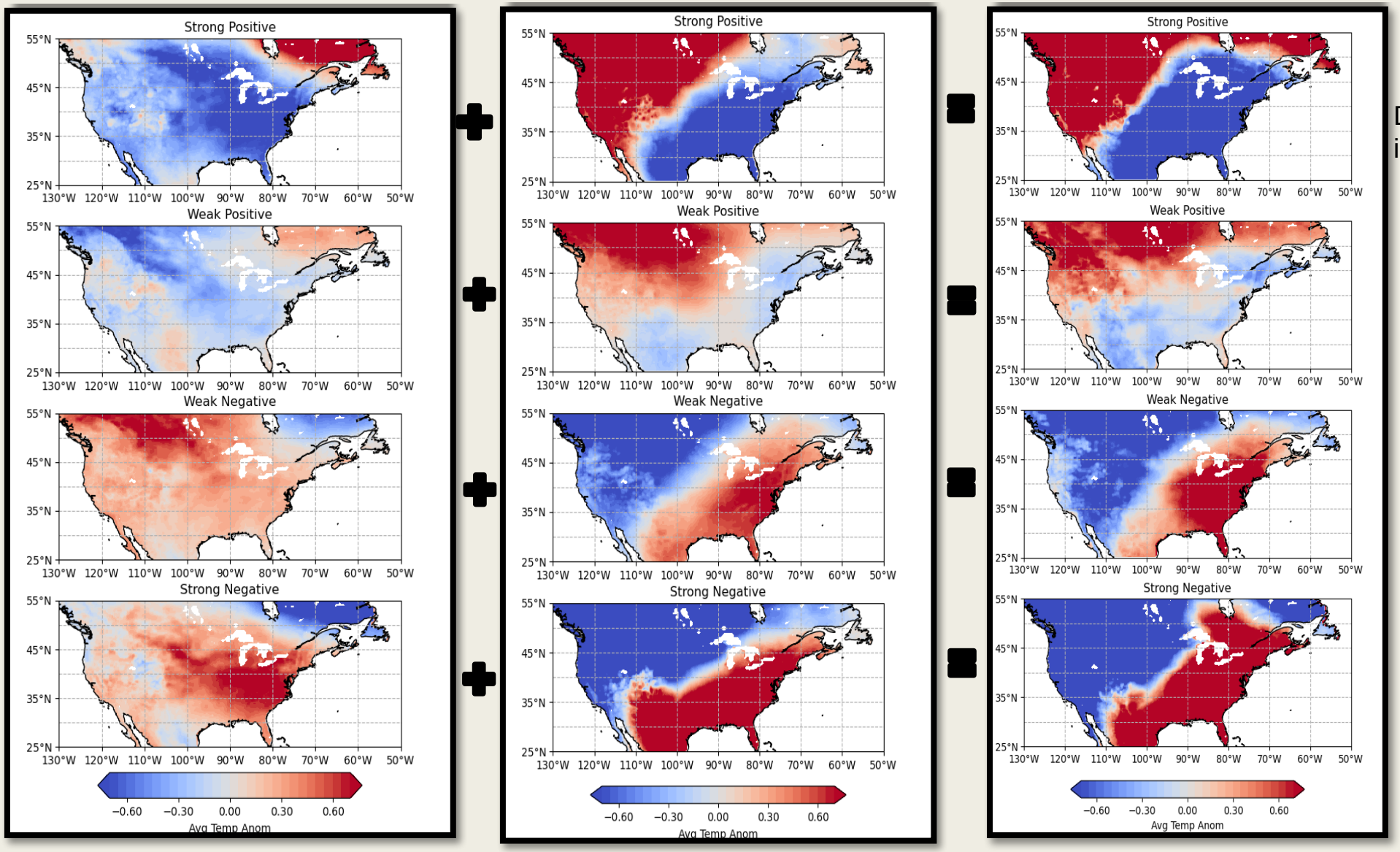
- Temperature Analyses:
  - *NAO and PNA in combination with the MLSO produce similar results, i.e., mixing of patterns, to those seen in the MLSO & ENSO combination*
  - *There is little to no consistency in the method in which the MLSO interacts with the ENSO, NAO, & PNA. Unique patterns arise from all combinations, Qualitatively.*
  - *In the PNA and MLSO combination during winter there is a strong dominance of the PNA patterns*
- Precipitation Analyses:
  - *All combinations produced similar results with widely varying spatial patterns*
  - *PNA dominance is seen again for the combinations during winter*

Results

Scenario:

- MLSO & PNA
- In Phase
- Winter

MLSO **Averages** **PNA** **MLSO &**



Days in Bin

152

405

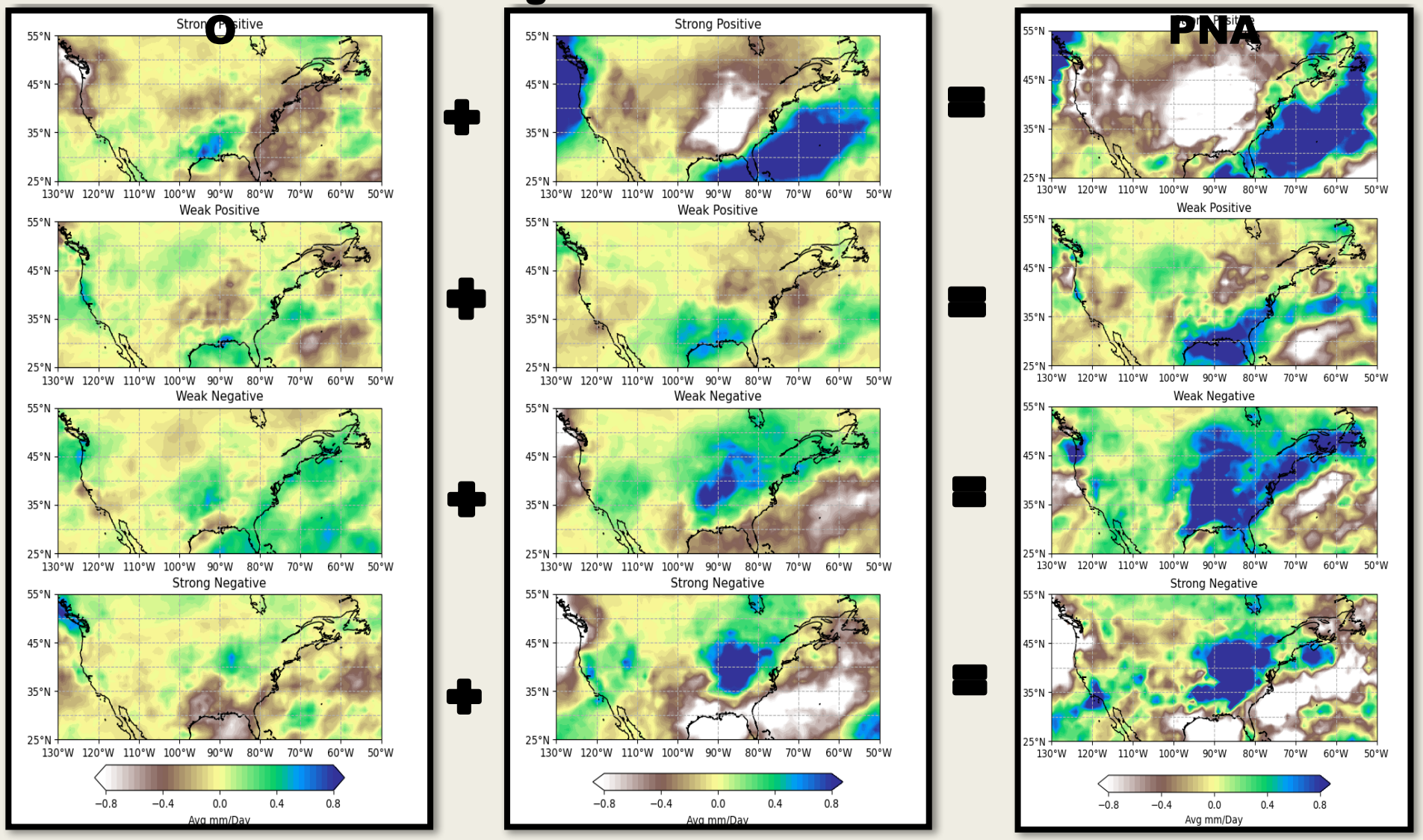
245

116

Results

Scenario:

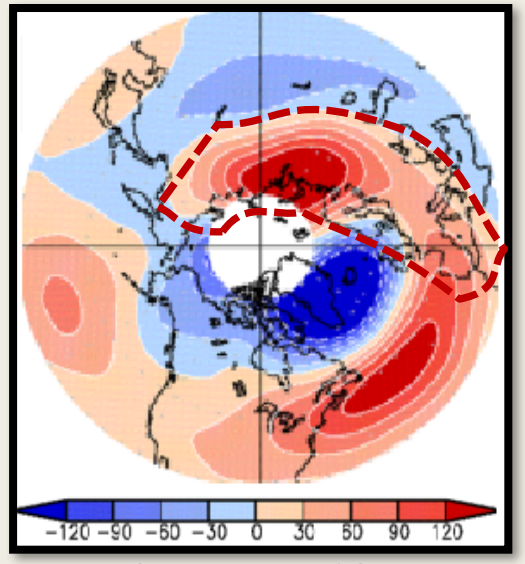
- MLSO & PNA
- In Phase
- Winter



Conclusions

- The MLSO is a statistically important Atmospheric mode for temperature variation over North America for both anomaly averages and frequency of the sign of the anomaly
- Histograms revealed that the MLSO may favor skewed temperature distributions for some areas
- The MLSO causes deviations from what might be expected from ENSO, NAO, and PNA for both temperature and precipitation

- The MLSO is an important factor in the climate system of North America
- It may also be an important factor over Europe and Siberia and warrants investigation

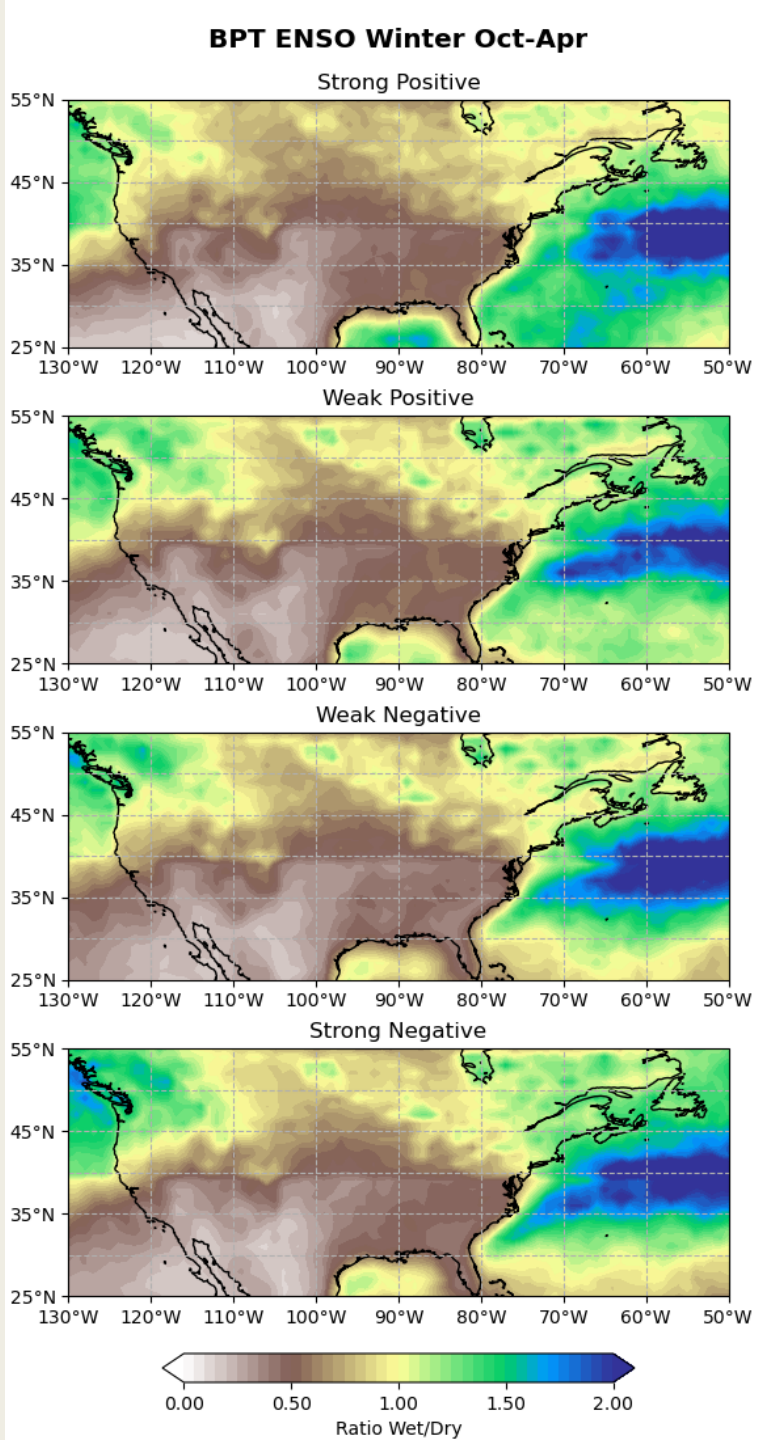


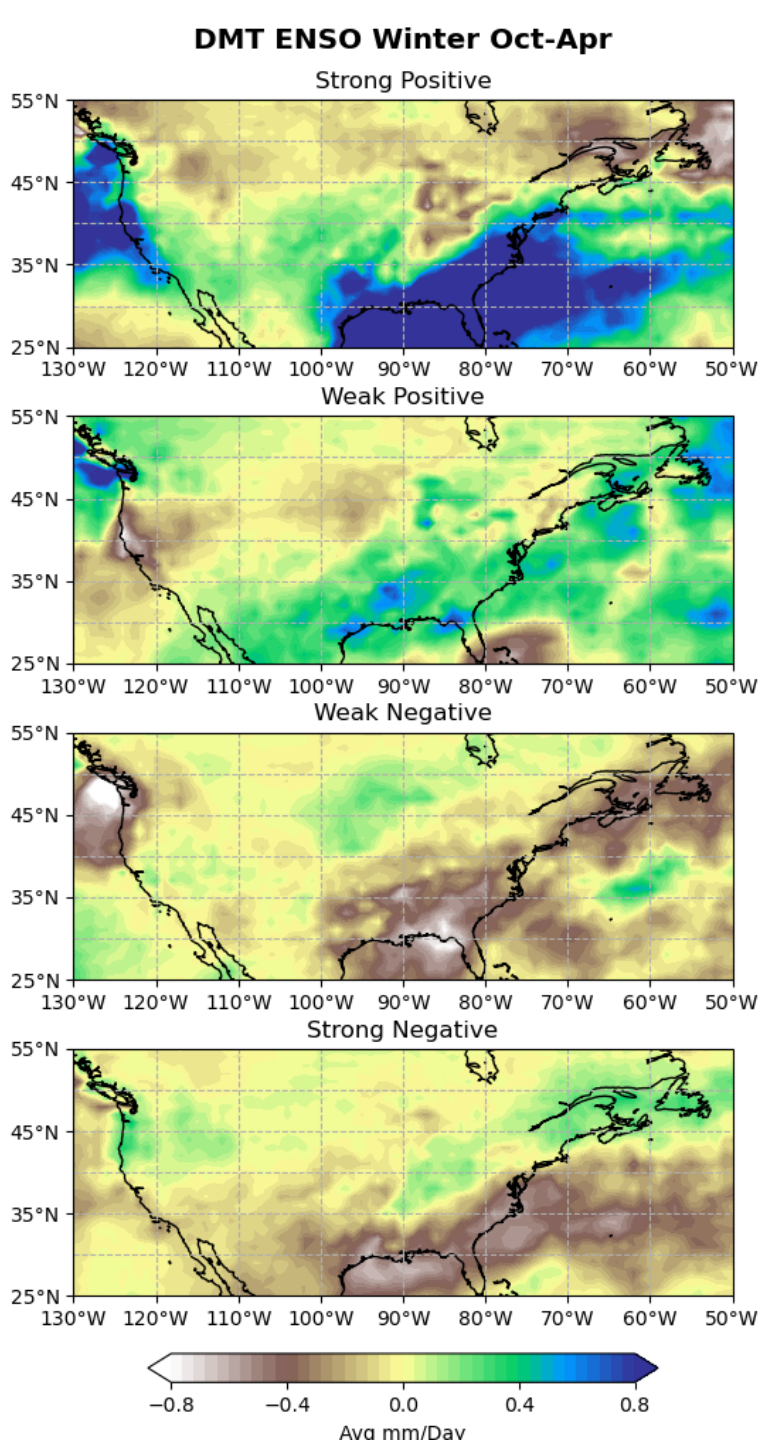
Space-time structure of the MLSO (Fig. 3-A, Stan & Krishnamurthy, 2019)

References

- Diaz, H. F., Hoerling, M. P., & Eischeid, J. K. (2001). ENSO variability, teleconnections and climate change. International Journal of Climatology, 21(15), 1845–1862. https://doi.org/10.1002/joc.631
- Leathers, D. J., Yarnal, B., & Palecki, M. A. (1991). The Pacific/North American Teleconnection Pattern and United States Climate. Part I: Regional Temperature and Precipitation Associations. Journal of Climate, 4(5), 517–528.
- Stan, C., & Krishnamurthy, V. (2019). Intra-seasonal and seasonal variability of the Northern Hemisphere extra-tropics. Climate Dynamics, 53(7–8), 4821–4839. https://doi.org/10.1007/s00382-019-04827-9
- Wallace, J. M., & Gutzler, D. S. (1981). Teleconnections in the Geopotential Height Field during the Northern Hemisphere Winter. Monthly Weather Review, 109(4), 784–812. https://doi.org/10.1175/1520-0493(1981)109<0784:TITGHF>2.0.CO;2

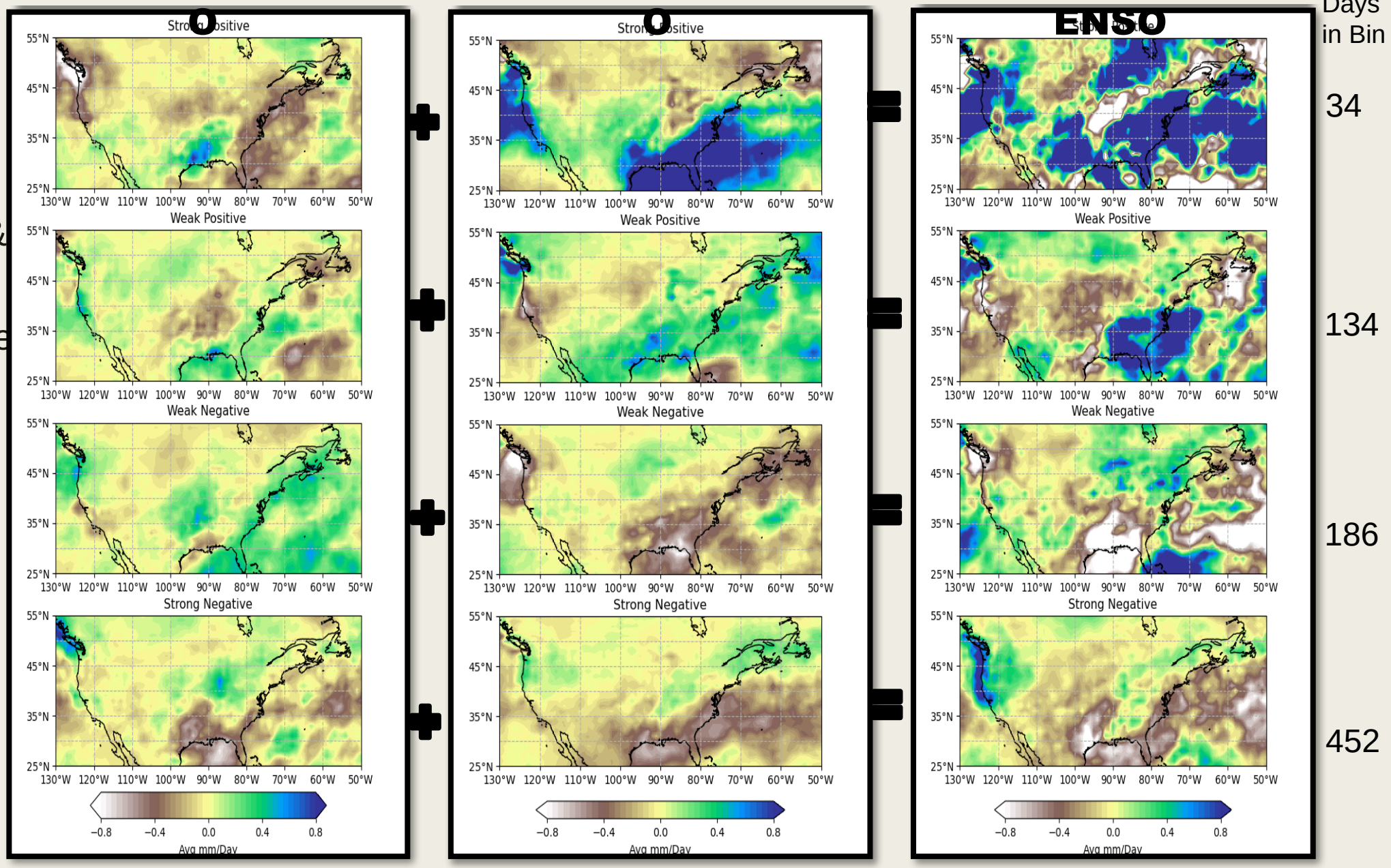
- ENSO
- Winter
- Ratios on Left
- Averages on Right





Scenario:

- MLSO & ENSO
- In Phase
- Winter



Filtering distribution

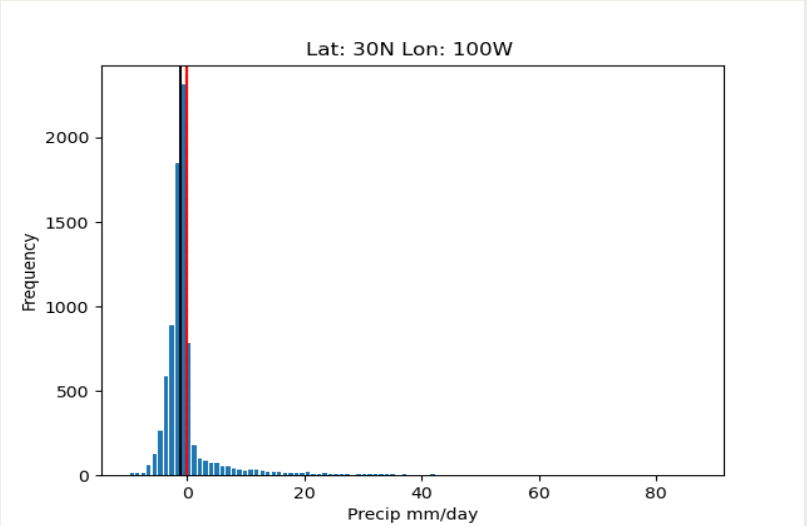
Bins	SUMMER							WINTER						
	MLSO	MLSO + ENSO	MLSO + NAO	MLSO + PNA	MLSO + ENSO Out	MLSO + NAO Out	MLSO + PNA Out	MLSO	MLSO + ENSO	MLSO + NAO	MLSO + PNA	MLSO + Enso Out	MLSO + NAO Out	MLSO + PNA Out
Str. Pos.	556	90	42	123	61	181	105	860	34	96	152	258	202	116
Weak Pos.	1281	521	357	391	260	435	392	1051	134	347	405	276	275	271
Weak Neg.	1433	220	448	387	520	424	543	1177	186	292	245	298	436	460
Str. Neg.	757	122	91	162	88	163	166	922	452	43	116	57	290	214

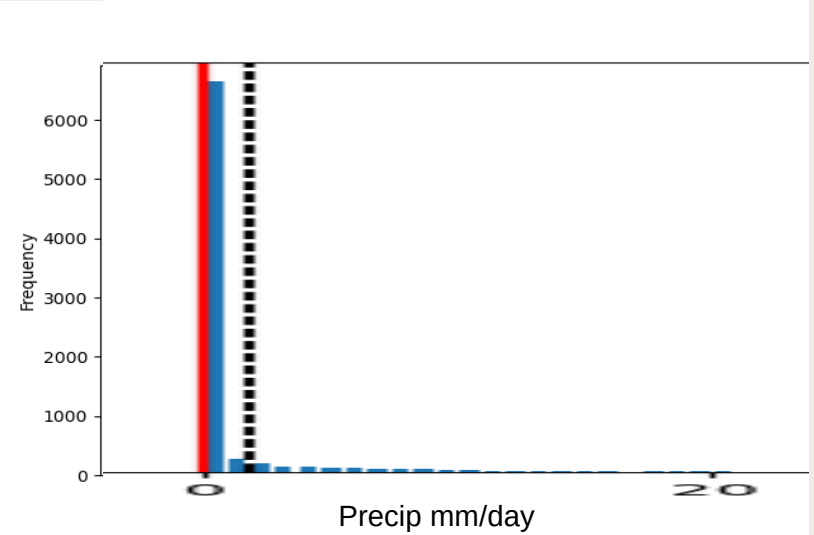
Total data points in Histograms
8038

Histogram of precipitation anomalies

Histogram of precipitation original value

South Central Texas typically dry

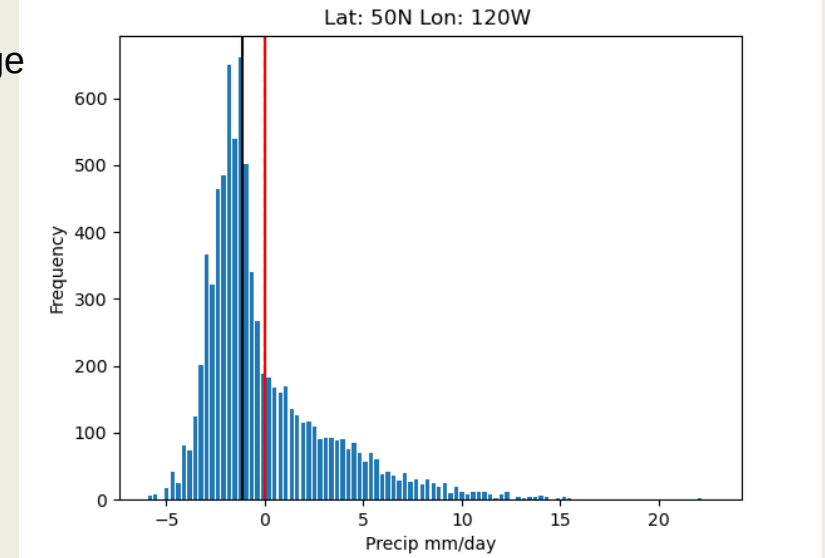


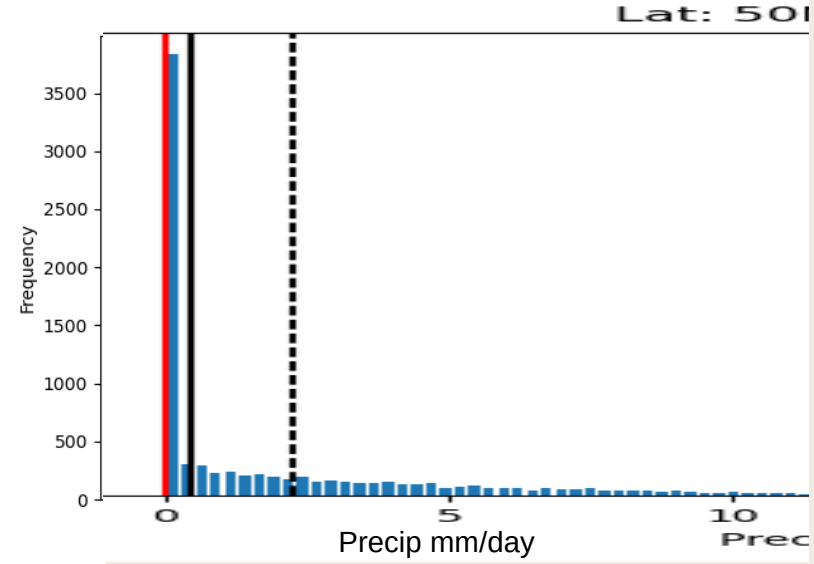


Precipitated on about 19% of days

LINES:
Red = 0
Black = median
Dashed = average

Southern British Columbia typically wet





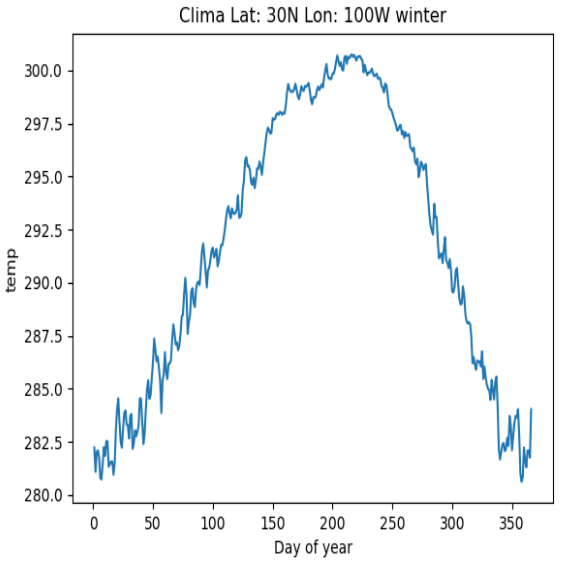
Precipitated on about 53% of days

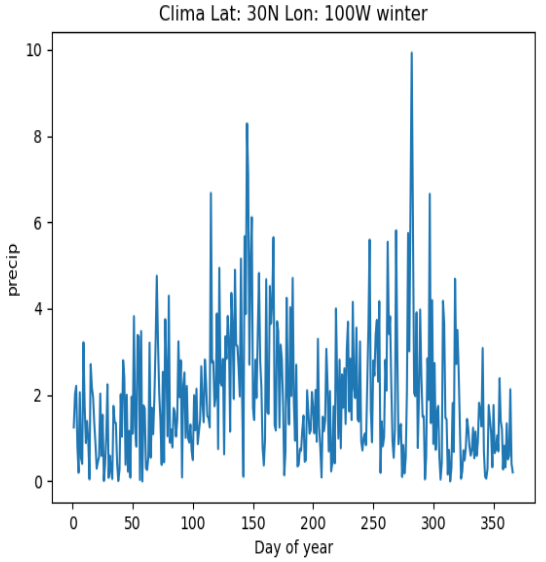
Temperature Climatology
No smoothing

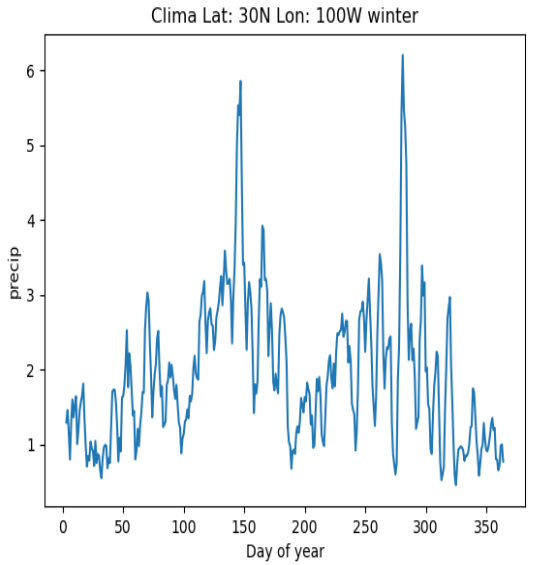
Precipitation Climatology
No smoothing

Precipitation Climatology
5 day rolling average

South Central Texas typically dry







Southern British Columbia typically wet