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Hydrology, P357

A Climatology of Precipitation 'Whiplash' in the United States 1891-2015

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About me/my research group

1. WHAT IS 'WHIPLASH', AND WHY IS IT IMPORTANT?

Variability is a basic state of being. Periods of boom and bust, famine and plenty are part of the natural condition. **However, when these transitions occur irregularly, dramatically, and frequently, the hazards associated with them may increase. High variability, particularly in opposing extremes, is of concern to decision-makers in a changing climate because it suggests a decline in predictability, as well as the prospect of conflicting management decisions** (e.g., Mullens and McPherson 2019, Dilling and Berggren 2014).

This study examines high monthly variability in precipitation. Whiplash is defined as a difference in accumulation between onset and end month of <=25th percentile to >=75th percentile (Dry-Wet), or vice versa (Wet-Dry), with percentiles based on a 1981-2010 climatology.

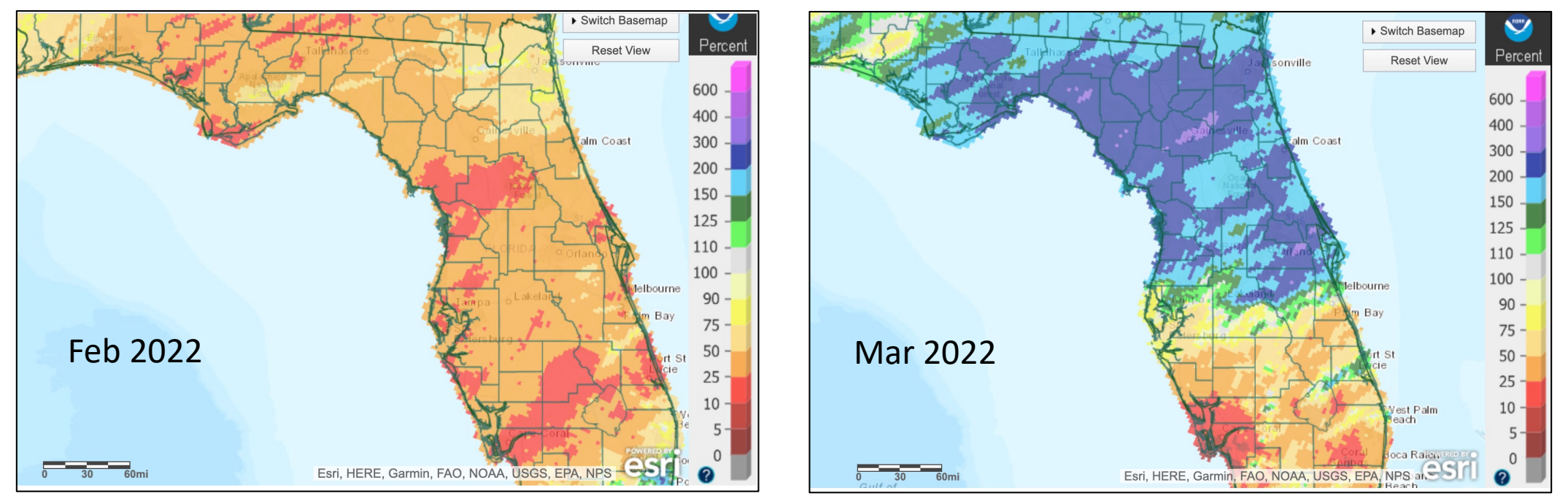


Figure 1: Example of a recent Dry-Wet whiplash event in Florida Image sourced from https://water.weather.gov/ahps/

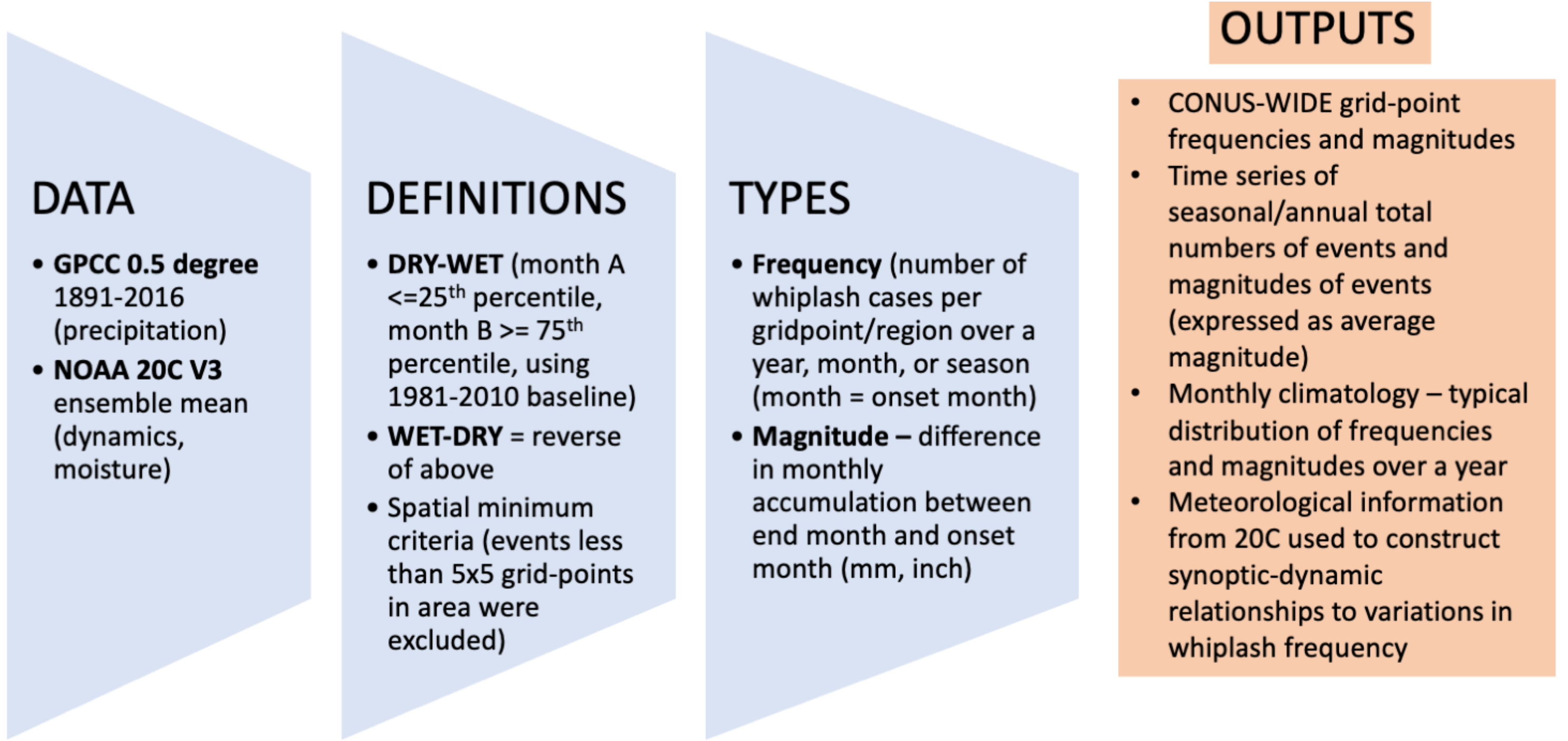
Research questions include the following:

- What are the geospatial frequencies and magnitudes of whiplash events across CONUS, and what is their seasonality (if any)?
- Are there any specific trends in whiplash frequency and/or magnitudes?
- How are whiplash events driven by the large-scale environment? What are their meteorological and climatological drivers?
- Could whiplash events be predictable at seasonal-sub-seasonal timescales?

2. DATA & METHODS

Data selection was driven by both resolution, and record-length. In order to have a large sample of whiplash cases to test some of the research questions above, century-scale data was needed.

Domain – CONUS United States, separated into seven lat/lon box subdomains based on the National Climate Assessment sub-regions (NCA 2018).



DATA

- **GPCC 0.5 degree** 1891-2016 (precipitation)
- **NOAA 20C V3** ensemble mean (dynamics, moisture)

DEFINITIONS

- **DRY-WET** (month A <=25th percentile, month B >= 75th percentile, using 1981-2010 baseline)
- **WET-DRY** = reverse of above
- Spatial minimum criteria (events less than 5x5 grid-points in area were excluded)

TYPES

- **Frequency** (number of whiplash cases per gridpoint/region over a year, month, or season (month = onset month)
- **Magnitude –** difference in monthly accumulation between end month and onset month (mm, inch)

OUTPUTS

- CONUS-WIDE grid-point frequencies and magnitudes
- Time series of seasonal/annual total numbers of events and magnitudes of events (expressed as average magnitude)
- Monthly climatology – typical distribution of frequencies and magnitudes over a year
- Meteorological information from 20C used to construct synoptic-dynamic relationships to variations in whiplash frequency

NOAA 20C version 3 - (Slivinski et al. 2019). Ensemble mean used.; Global Precipitation Climatology Project (GPCC) (Schneider et al. 2017). Overlapping years = 1891-2015.

Caveats

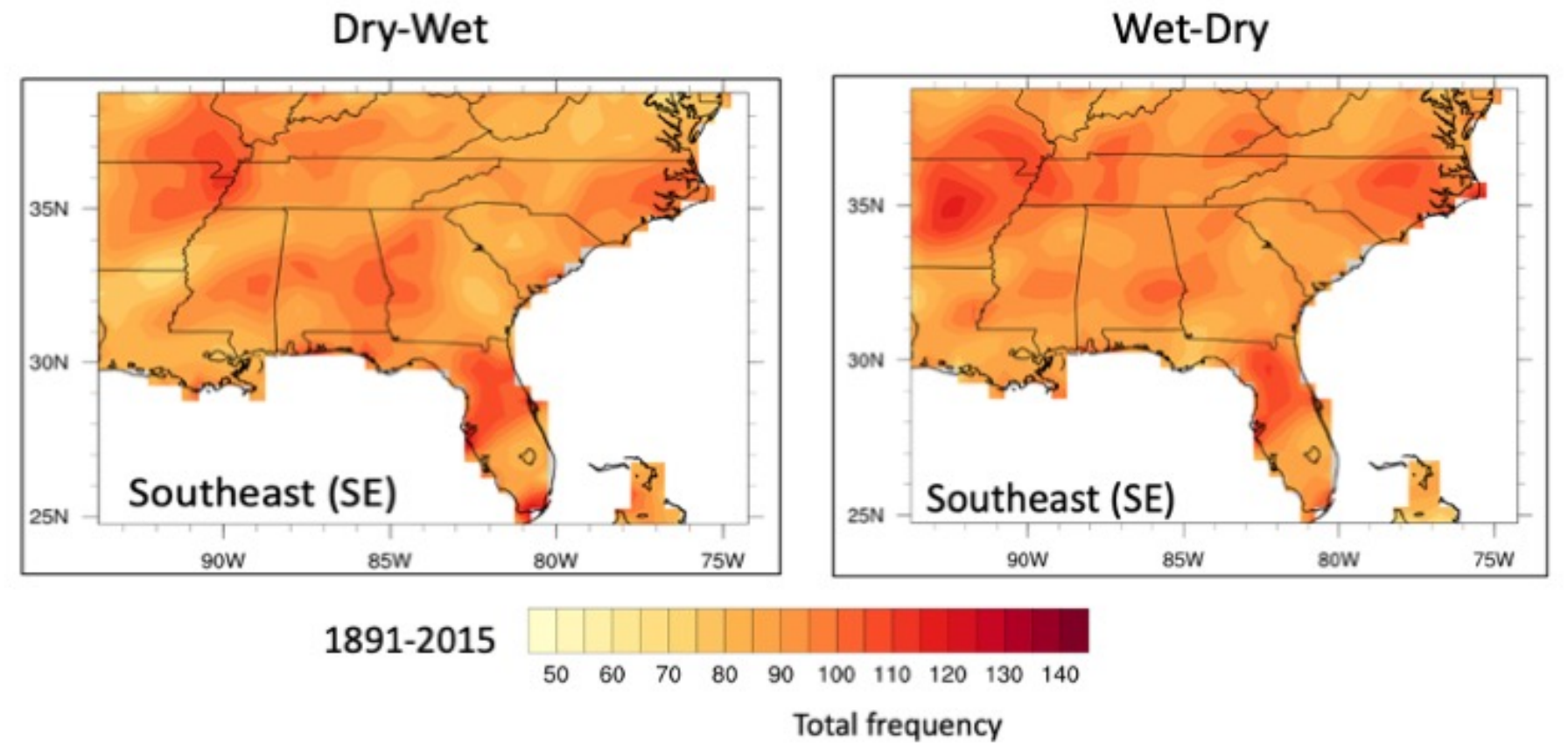
Doesn't rain-gauge -based data change over time? Yes. Gauge-records have generally increased with time, and so long-term trends should be interpreted with caution.

How is this definition of whiplash linked to societal and/or environmental impacts? This is unclear. Further work aims to investigate the frequency of water-related hazards (drought, flood) during periods of heightened whiplash variability. Current work suggests that parts of the country exhibit links between pluvial years and higher whiplash, particularly those in the west. Moreover, in the southwest, whiplash events are linked to the onset and cessation of the North American monsoon.

Are there limitations to this definition of whiplash? Yes! Month-to-month variability may be less impactful than seasonal or interannual whiplash, another aspect which will be examined. We also examined the frequency of whiplash events within 6-month warm/cool seasons and annually, identifying that most years with high (low) whiplash were due to a large (small) spatial extent of whiplash. This is due to our definitions of whiplash frequencies being based on spatially accumulated statistics over each sub-region.

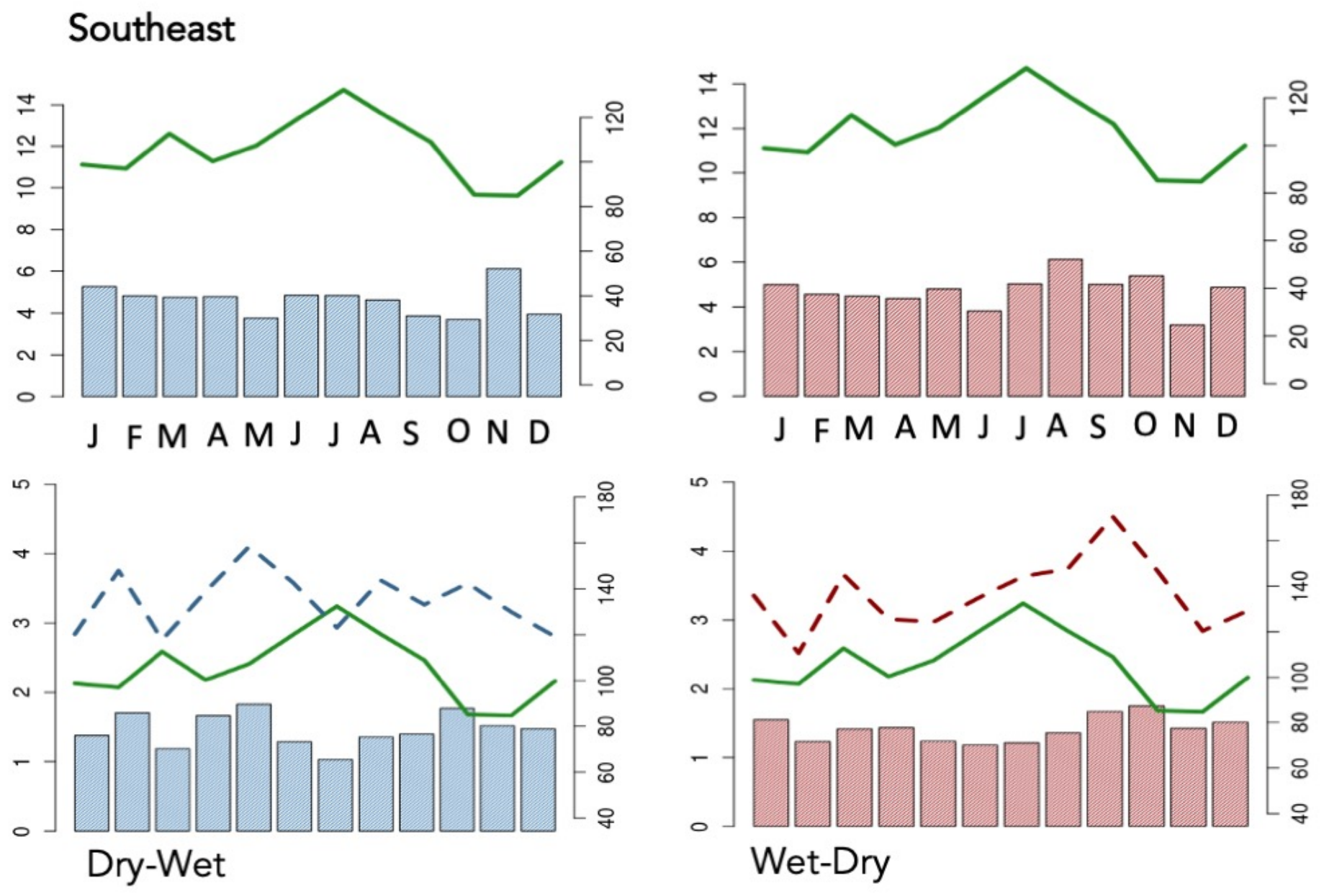
3. SEASONAL AND INTERANNUAL CLIMATOLOGY

The results below are examples for the US Southeast. Although results have been obtained for all sub-domains, there is too much to put on a single poster!

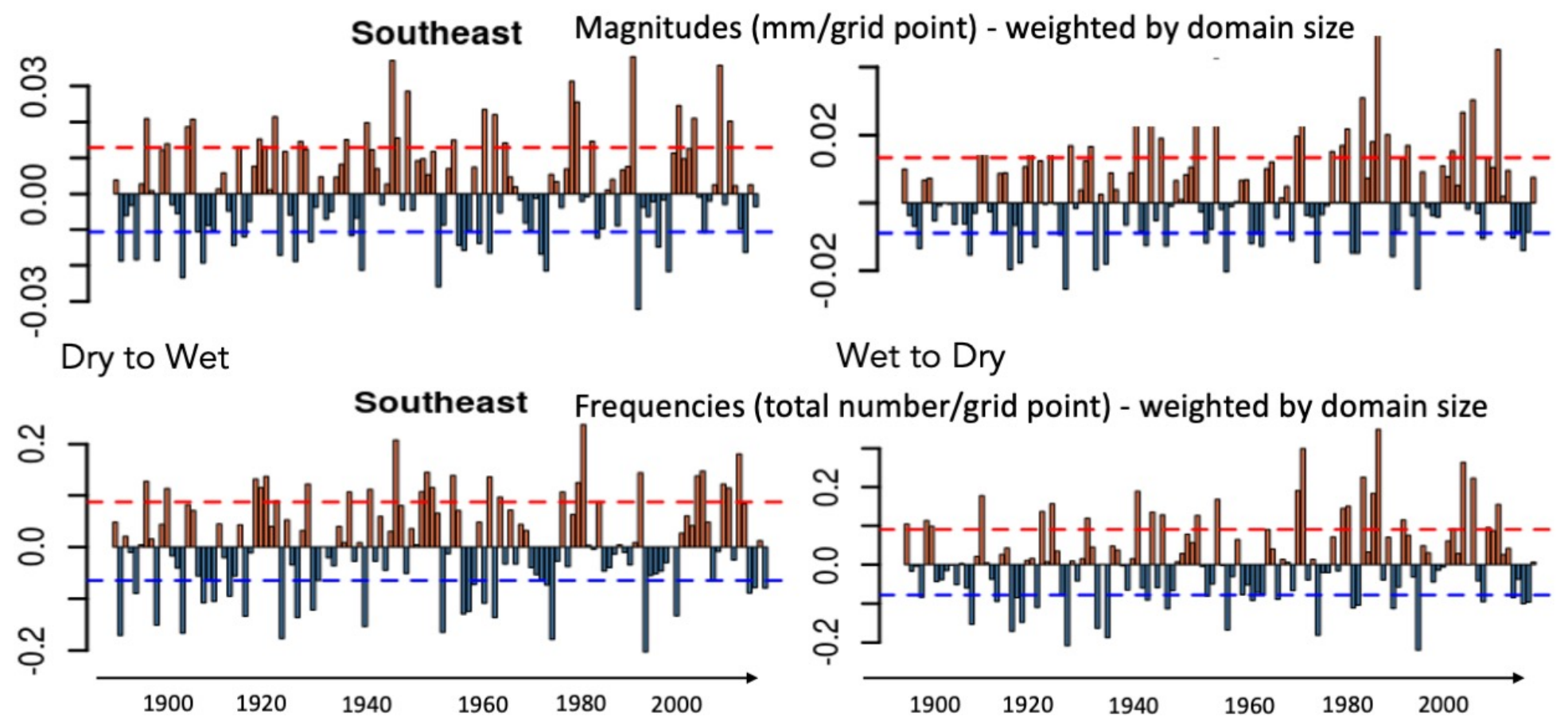


TOTAL FREQUENCY. Figure 2 (left) shows the Southeast US domain, including the total number of whiplash events by grid-point – summed over the entire record. There is sub-regional variability, with higher frequencies located in some coastal zones (e.g., FL, NC), and the northern sections of the lower Mississippi valley. Nonetheless, in general, there is no clear geographic variability and total number of events are similar across the area.

SEASONALITY. Figure 3 (right) shows the total domain-averaged recorded frequencies of whiplash events by the *starting or onset month* of the whiplash event (bars, top), with monthly averaged precipitation shown in mm by the green line and right-hand y-axis. Similarly. The bottom two plots show the magnitudes, expressed as a *fraction of the onset month's average precipitation* in the bars, while the dotted lines show the absolute precipitation difference between onset and end month (mm, right hand y-axis), with the mean monthly precipitation once again shown in green.



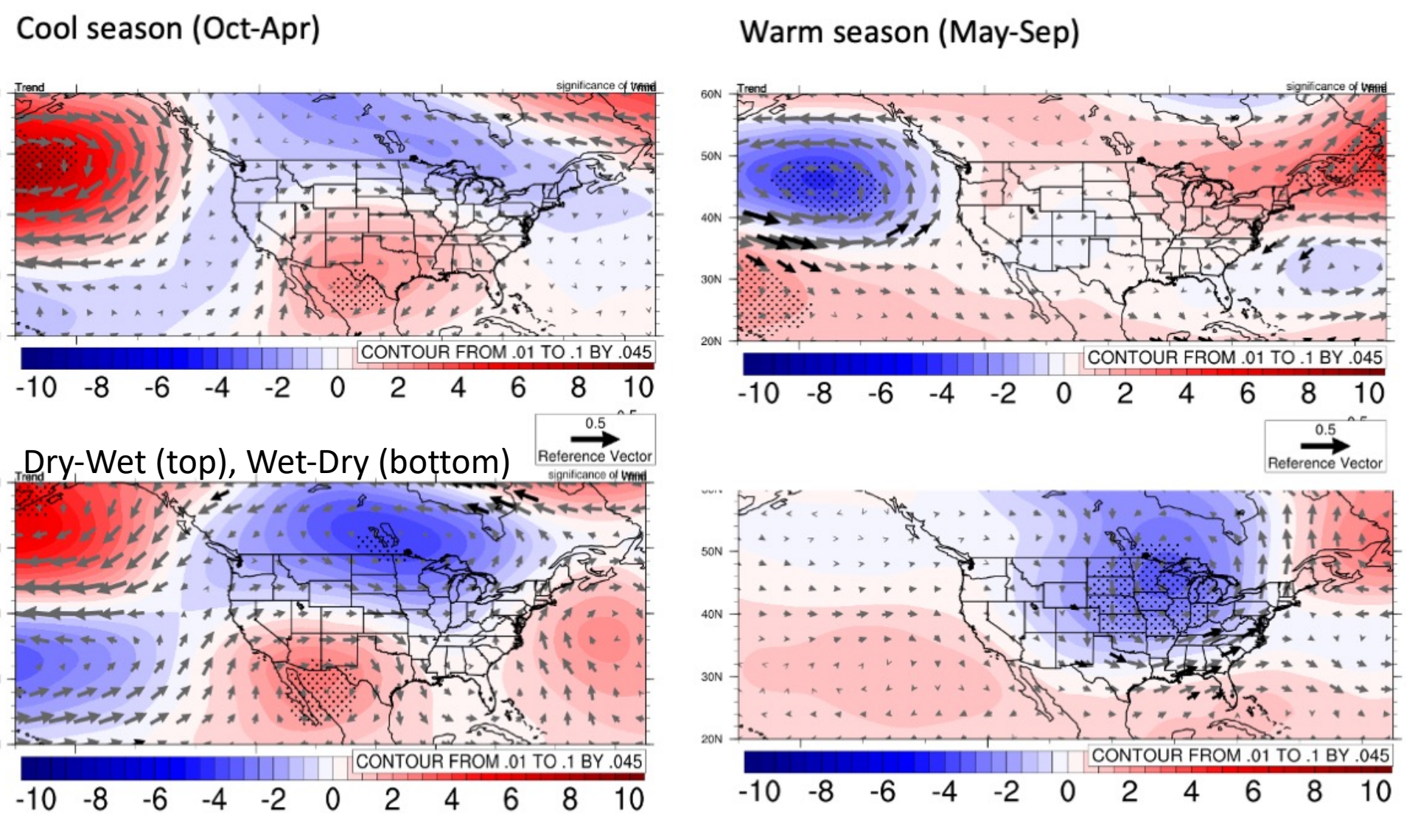
The key points from this figure suggest that when averaging over the whole domain there is little month-to-month trend in terms of whiplash frequency, and such events can occur throughout the year. ***Magnitude does demonstrate some seasonality***, including peak dry-wet transitions during spring, and the opposite during fall. It is expected that these relate to variability in sea breeze onset and cessation as well as tropical cyclone activity in the summer and fall.



ANNUAL TIME SERIES. Figure 4 (left). High interannual variability in whiplash frequency and magnitudes are apparent. There is a *possible* increasing trend for wet to dry whiplash events, which can be seen in magnitude in particular. Nonetheless, given data limitations, this finding requires further analysis.
The region shows a weak, yet significant, positive association (r=0.28) between wet-dry and dry-wet whiplash frequencies, suggesting that the occurrence of one type also predisposes the other type – presumably related to the synoptic-dynamic conditions that produce these events.

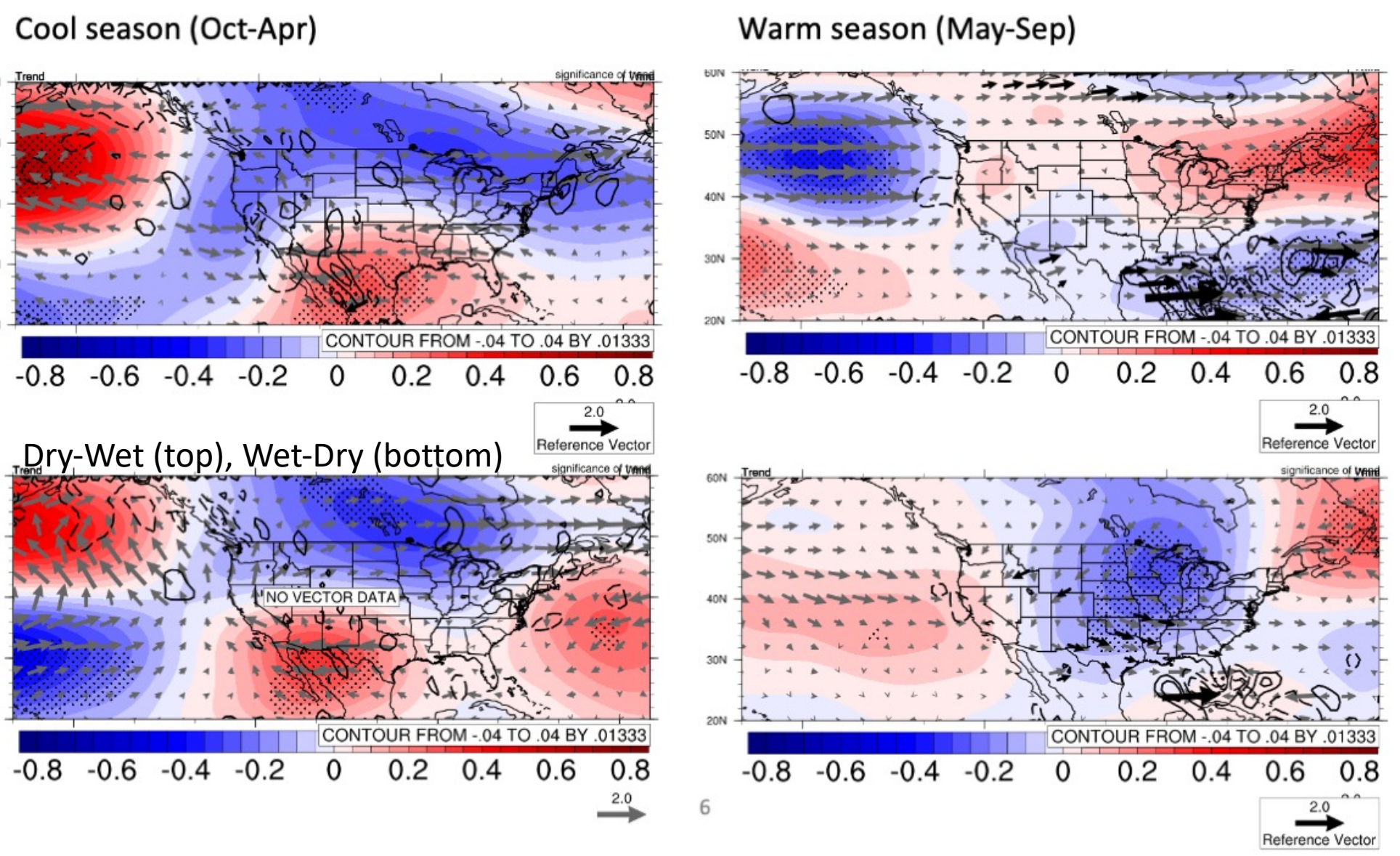
4. SYNOPTIC PATTERNS

Let's explore the dynamics of whiplash events in the southeast



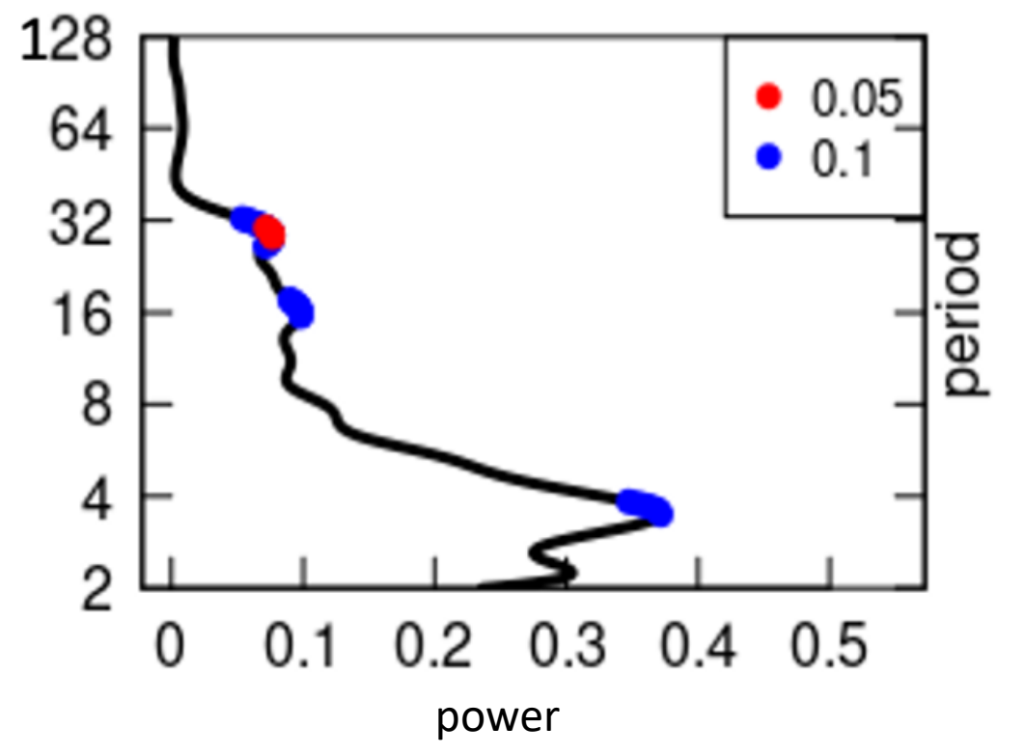
Stippling shows significance at the p<0.1 level. Black wind vectors also highlight significance to the same level

500 mb GEOPOTENTIAL HEIGHT AND 700 mb VECTOR WIND REGRESSION ONTO WHIPLASH frequency TIME SERIES. Figure 5 (left)
This linear regression (using standardized anomaly data) can identify synoptic patterns that are commonly associated with high/low whiplash frequencies. Results are show for warm and cool seasons, and for both whiplash types.
Cool season – Higher frequencies of both whiplash types **reveal a La Nina-type pattern**, with North Pacific anticyclone and ridging anomalies over the south. Wind vector anomalies are largely insignificant.
Warm season – Notably, the regressed patterns between whiplash types **are different**. For dry-wet, dominant features are remote to the region, including troughing over the north Pacific, while for wet-dry, an enhanced trough over the eastern US is evident, in addition to enhanced winds rounding the trough. This pattern is reminiscent of an enhanced sea-breeze termination pattern



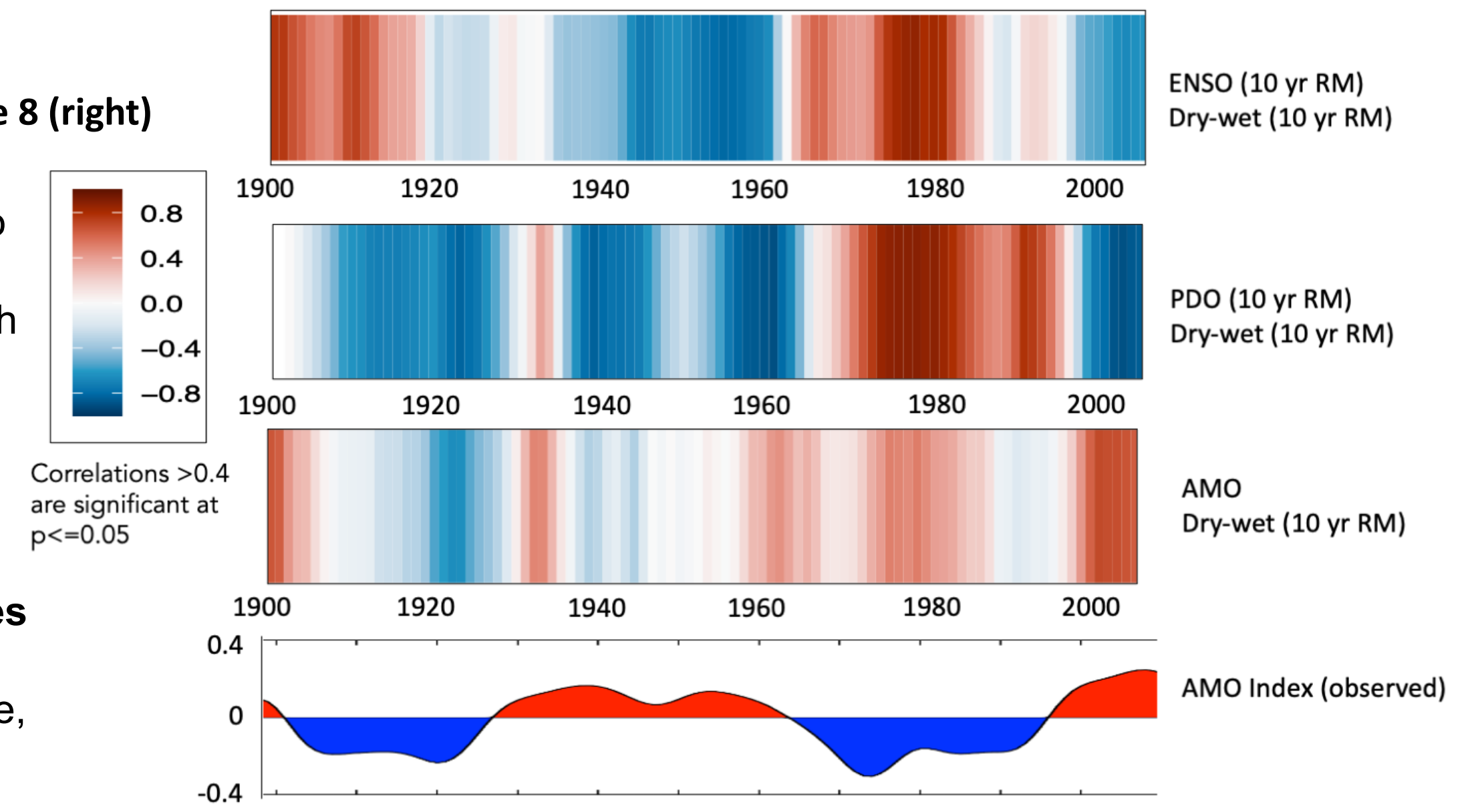
500 mb ZONAL anomaly GEOPOTENTIAL HEIGHT AND ROSSBY WAVE ACTIVITY FLUX (WAF) REGRESSION. Figure 6 (left). WAF is calculated based on Plumb (1985). Geopotential height is filtered to as ~7-day interval using a Lanczos filter. The height regressions are as before, only magnitudes adjusted due to the zonal anomaly.
Zones of eastward WAF anomalies – progressive flow, upstream amplification possible. The reverse is true for westward anomalies.
WAF anomalies are not significant during the cool season. **However, there are notable anomalies focused on the SE region during the warm season.** Dry-wet shows enhanced convergence (possibly Rossby wave breaking) particularly over the northern Gulf and subtropical Atlantic. Wet-dry shows a mixed bag of convergence over interior SE and divergence (possible wave generation) to the south.

5. LINKS WITH NATURAL VARIABILITY

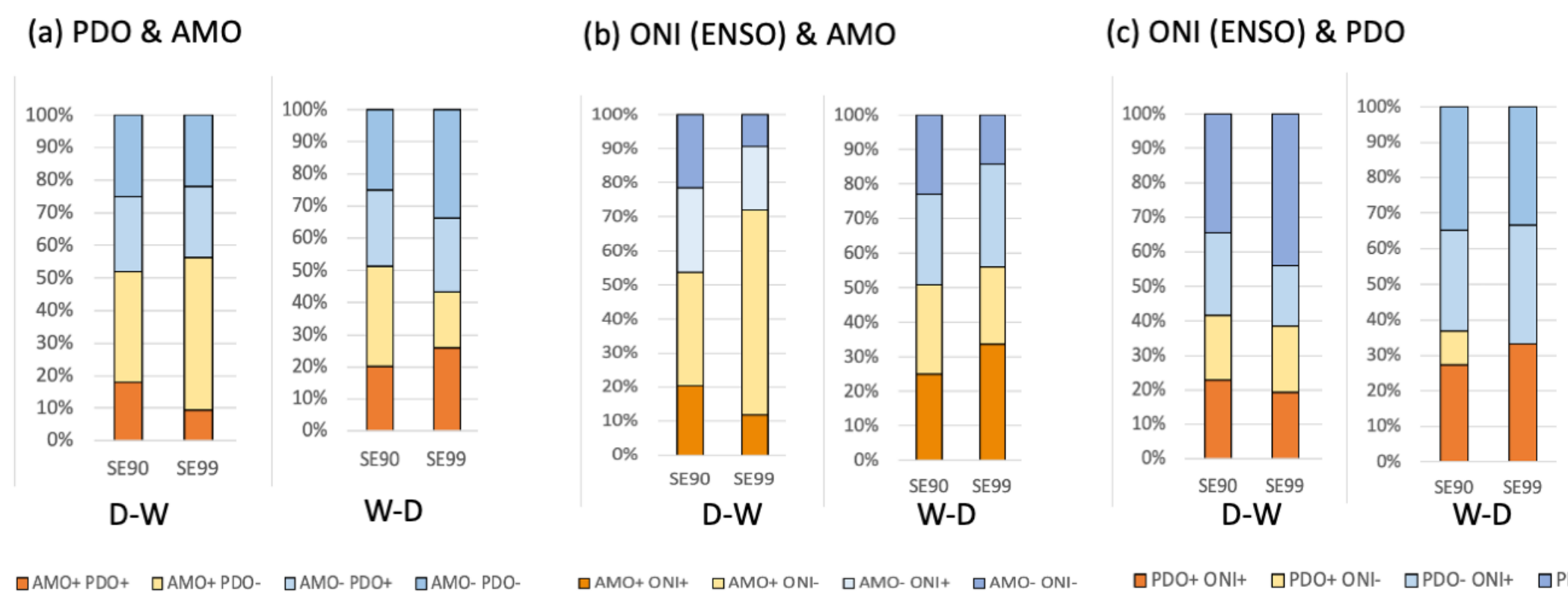


WAVELET ANALYSIS OF DRY-WET WHIPLASH. Figure 7 (left). Wavelet analysis can help to identify slower-moving cyclical variability in a high-frequency time series. When applied to frequency in this case, there is significant power in the ~4 and 16-32-year ranges, which implicates planetary variability. We explore relationships with a few Pacific-North American teleconnections that vary over these timescales. The data used for these teleconnections (AMO, NINO3.4, and PDO) were obtained from UCAR [1], NOAA PSL [2], NCEI [3] respectively.

RUNNING CORRELATIONS WITH TELECONNECTIONS. Figure 8 (right)
Here, a 10-year running average is applied to both whiplash data, and ENSO and PDO time series prior to applying a 20-year running correction, in order to evaluate slower-moving relationships between whiplash and natural variability. Both ENSO and PDO (in the latter half of the record) show cyclically-varying correlations with dry-wet whiplash. **These variations are strongly inversely (r~ -0.75) correlated to the Atlantic Multidecadal Oscillation (AMO). Higher whiplash frequencies are linked to opposing phases of these teleconnections (e.g., AMO+, ENSO-).** However, when evaluating whiplash against AMO alone, there is little consistency in the correlation over time.



Correlations >0.4 are significant at p<=0.05



LINKS TO HIGH MAGNITUDE VARIABILITY. Figure 9 (left) (1950-2015 only)

The figure shows the % of top-magnitude whiplash events linked to various compound teleconnection regimes. Here, ONI [4] is used in place of Nino 3.4

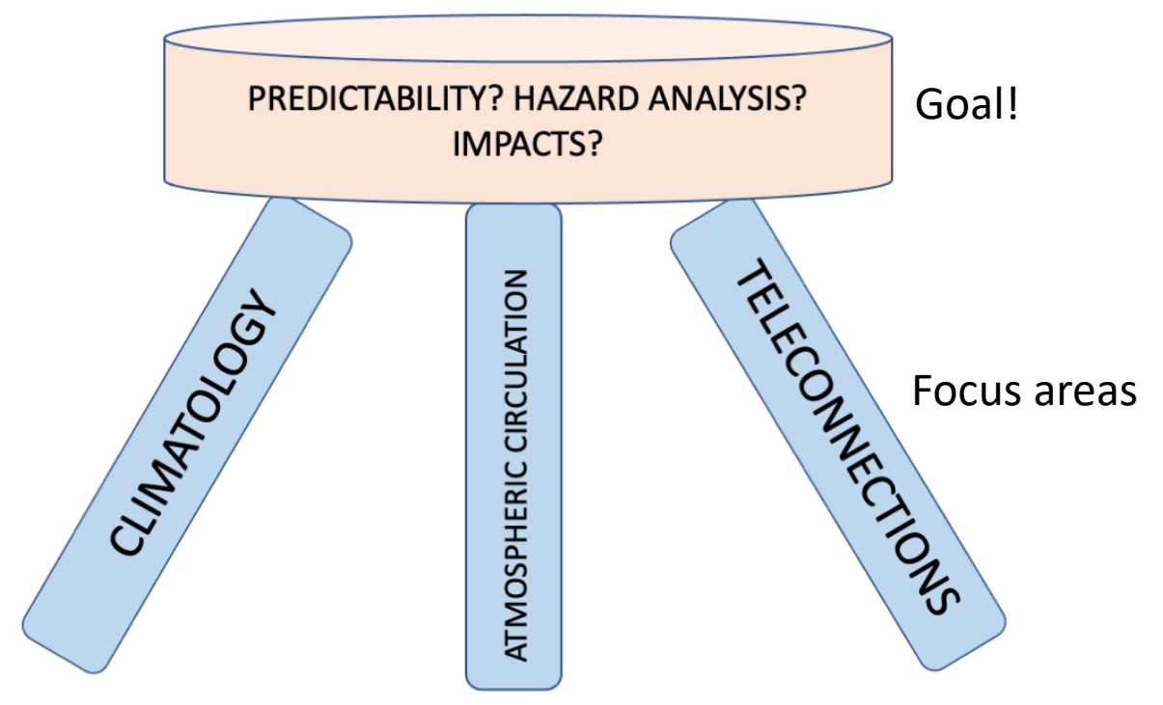
Key results from this figure reveal a propensity for higher-magnitude events in dry-wet (D-W) whiplash to be linked to opposing phases of the AMO and ENSO & PDO) as revealed above, particularly when AMO is in its positive (warm) phase which may relate to the quality of available moisture when SSTs are warmer. This finding is not apparent for wet-dry whiplash. Compound PDO and ENSO indicates for both whiplash types that negative phases of PDO predispose to higher-magnitude events, as well as in-phase PDO and ENSO, especially for wet-dry transitions.

6. KEY FINDINGS AND FUTURE WORK

This work has developed a region-based spatial, temporal, and synoptic climatology of dry-wet and wet-dry whiplash events over CONUS using 125 years of data. The results are demonstrated here for the southeast US using techniques applied to all CONUS subdomains.

Key takeaways for the southeast US:

- **Whiplash frequencies show little seasonality; however, the magnitudes of these whiplash events show a tendency to peak during the spring (dry-wet) and fall (wet-dry),** highlighting that existing transition seasons in this region are susceptible to higher-magnitude variability depending on the timing of key synoptic processes (e.g., movement and and intensity of the North American Subtropical High, frequency of tropical systems…)
- **Synoptic patterns** that contribute to spatially extensive and/or higher whiplash frequency are similar during the **cool season**, **pointing to the role of La Nina,** while during the **warm season, the role of anomalous Rossby wave generation and dissipation** appear to play a key role.
- **STRONG link between the AMO and ENSO phases on whiplash frequencies** during the cool season, where more whiplash events occur when **AMO and ENSO are out of phase**.
- As shown by the graphic on the right, this work is part of a larger study to evaluate the predictability, hazards, and trends in whiplash events, and those elements are the focus for the next stage of research.



PREDICTABILITY? HAZARD ANALYSIS? IMPACTS?
Goal!
CLIMATOLOGY
ATMOSPHERIC CIRCULATION
TELECONNECTIONS
Focus areas

References

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Schneider et al (2017): Evaluating the Hydrological Cycle over Land Using the Newly-Corrected Precipitation Climatology from the Global Precipitation Climatology Centre (GPCC). Atmosphere 8(3), 52; doi:10.3390/ atmos8030052

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Data Links

[1] AMO source data: https://climatedataguide.ucar.edu/sites/default/files/2022-03/amo_monthly.txt

[2] ENSO source data: https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/nino34.long.data

[3] PDO source data: https://www.ncei.noaa.gov/access/monitoring/pdo/

[4] ONI source data (1950+)
https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php