An Atmospheric-Terrestrial Teleconnection Study for Lake Sinkhole Dry-Down Events in Tallahassee, Florida

Carolyn Emerson, Dr. Ming Ye, Kyle Compare

Department of Earth, Ocean, & Atmospheric Science

Background

Lake Sinkhole Dry-Down Event: Natural and periodic decrease of lake-level from a lake-bed sinkhole draining into the aquifer (FDEP)

- In Tallahassee, there are 5 sinkhole lakes
- Occurrence of a sinkhole can be influenced by groundwater level fluctuations, with increasing sinkhole occurrence being related to lower groundwater elevation (Wilson & Beck, 1992; Aurit et al., 2013)
- Fluctuations of groundwater level can be influence by precipitation, with more precipitation leading to rising groundwater levels in the long-term (Kotchoni et al., 2018; Lucon et al., 2020)

El Niño Southern Oscillation (ENSO): Climate teleconnection pattern caused by the fluctuation of sea surface temperatures in the eastern equatorial Pacific, which holds significant influence over weather patterns thousands of kilometers away (NCEI)

- Intensity/amount of precipitation can be influenced by the phase of ENSO. In Florida, increased wintertime precipitation is often seen with an El Nino phase compared to a La Nina phase (Goly & Teegavarapu, 2014)

- The above referenced papers studies this connection on regional/state scales
- This research aims to take these results and verify them on a smaller spatial scale
- This research also aims to further the connection between ENSO and groundwater fluctuations to include its impact on sinkhole occurrence

Data

- **ENSO**: *Nino-3.4 index* measures the sea surface temperature anomalies along the equatorial Pacific from the dateline to the South American coast (GCOS WG-SP)

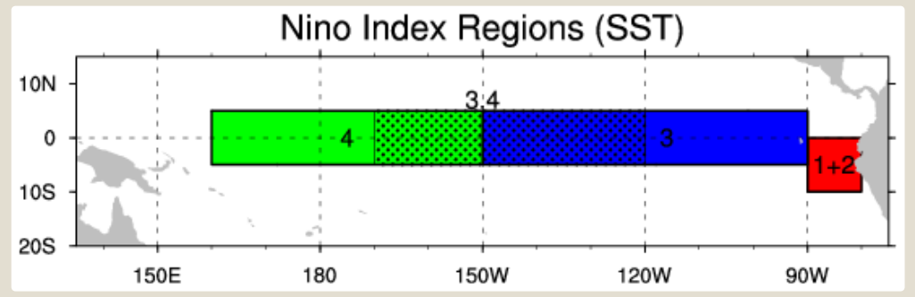

Figure 1: Location along the equatorial Pacific where temperature anomalies are measured for ENSO

- **Precipitation**: *Total monthly precipitation* collected from Tallahassee Regional Airport (Florida Climate Center). *Extreme monthly precipitation* used *RX1*, which is an index describing the maximum 1-day precipitation for a given month (Donat et al., 2013)

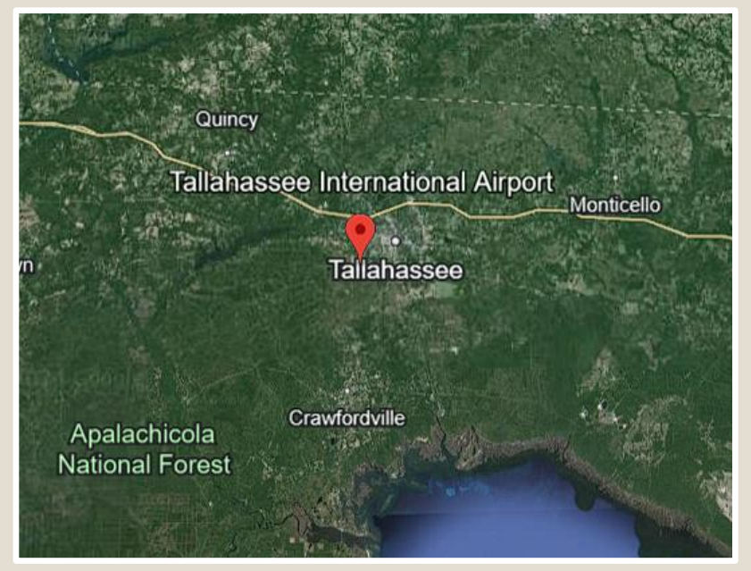

Figure 2: Geographical location of the weather station where precipitation data is recorded

- **Groundwater**: Used groundwater elevation from several Tallahassee wells to obtain a larger temporal range; Fluctuations in groundwater level are similar across all wells although the specific elevation is different.
- **Sinkholes**: Obtained timeline of lake sinkhole events from (Lammers, 2021) which obtains it from archived newspaper reports

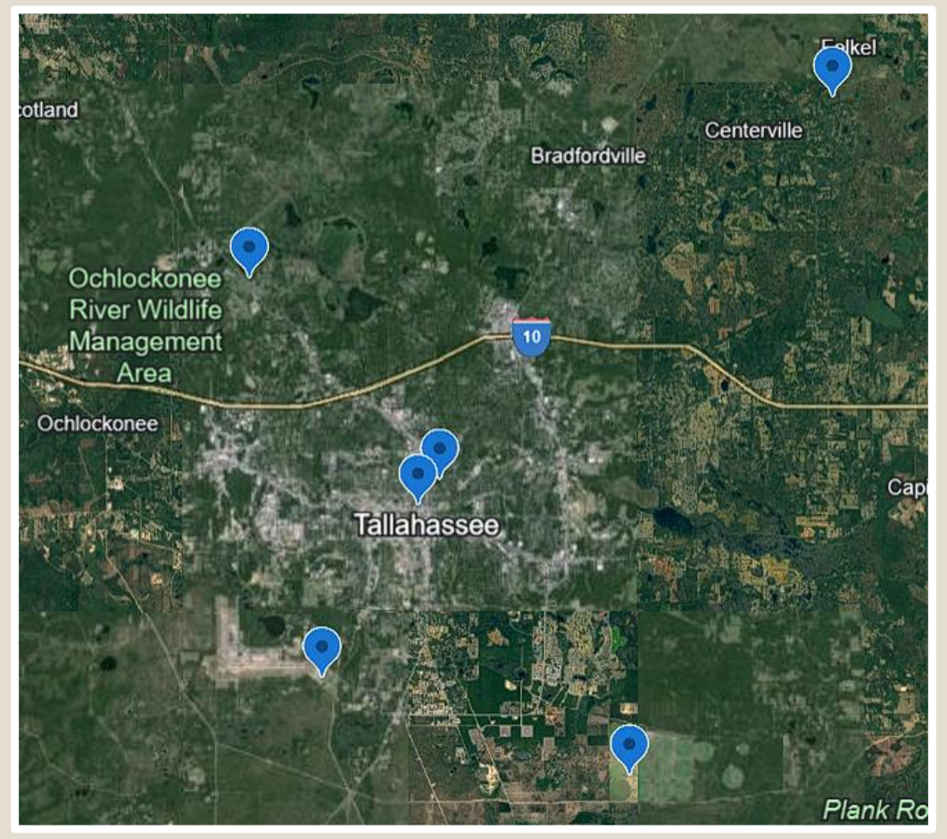

Figure 3: Geographical location of the 6 groundwater wells

Results

Precipitation

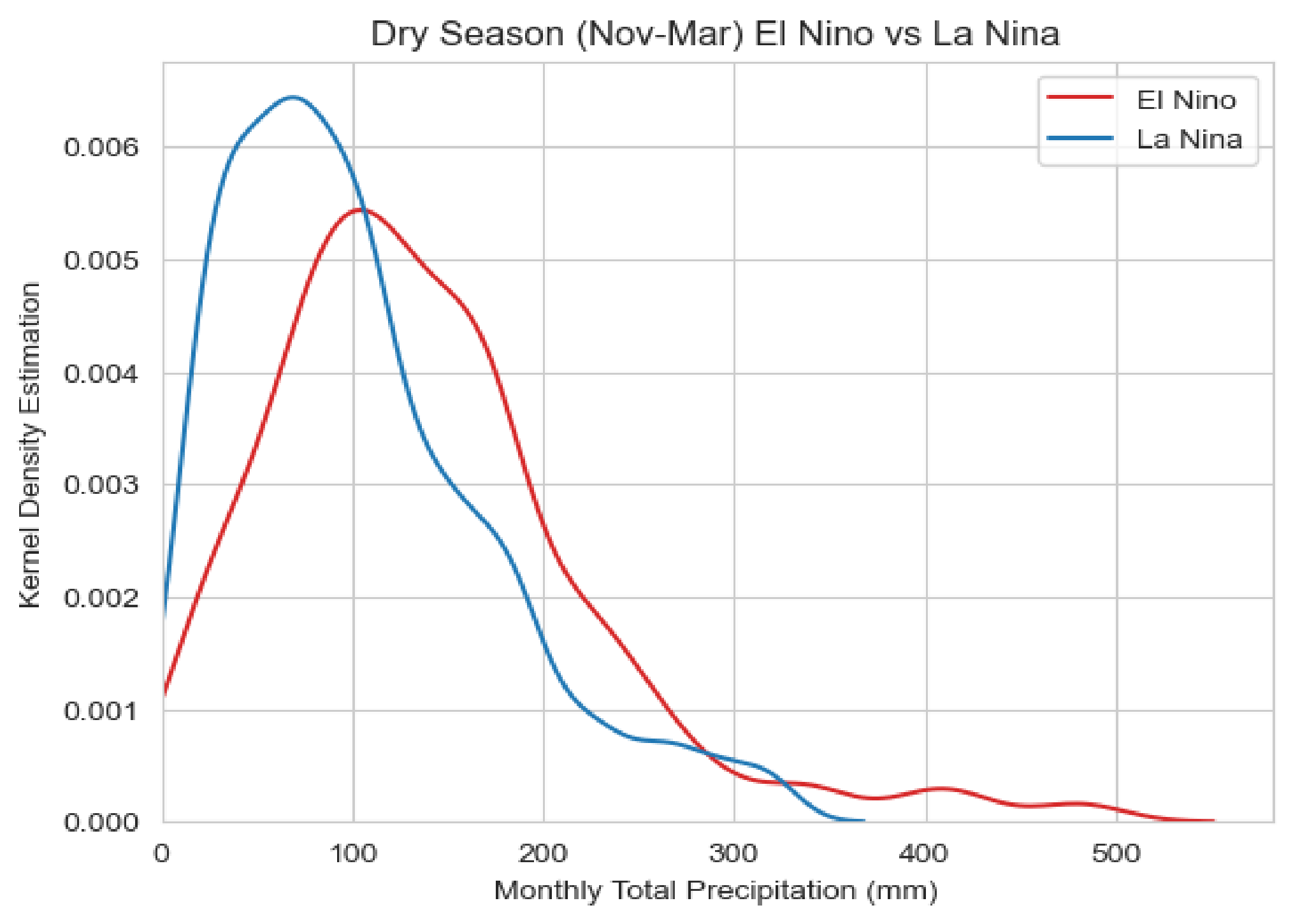

Figure 4: Kernel density functions of the monthly total precipitation during the dry season (November through March) for all El Nino and La Nina months. The most notable trend is the approximate 25 mm difference in peaks between the El Nino function and the La Nina function. This trend was not present while looking at wet season months.

	El Nino – La Nina Difference (mm)	P-value
Dry Season	17.77	2.66e-5
Wet Season	2.59	0.66
Total	3.33	0.43

Table 1: The difference in averaged RX1 extreme precipitation across the dry season, wet season, and total year between the phases of ENSO (El Nino – La Nina) and their respective P-values showing the significance

Groundwater

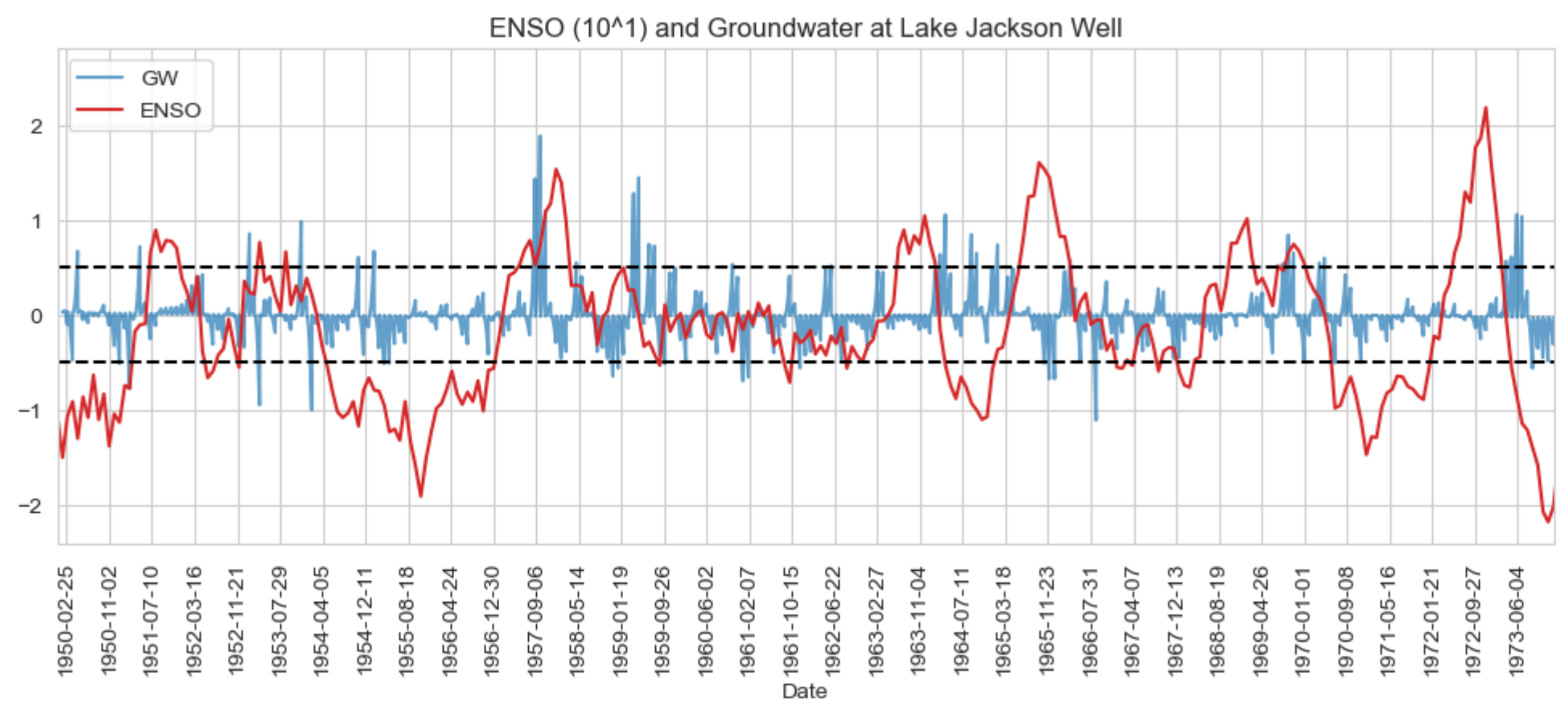

Figure 5: ENSO (amplified by a scale of 10 to more accurately visually compare trends) plotted next to the normalized departures of groundwater elevation at the Lake Jackson well in Northwest Tallahassee. The dashed lines represent the thresholds for an El Nino or La Nina episode. When ENSO anomaly exceeds 0.5 deg C, that is an El Nino phase; When ENSO anomaly exceeds -0.5 deg C, that is a La Nina phase.

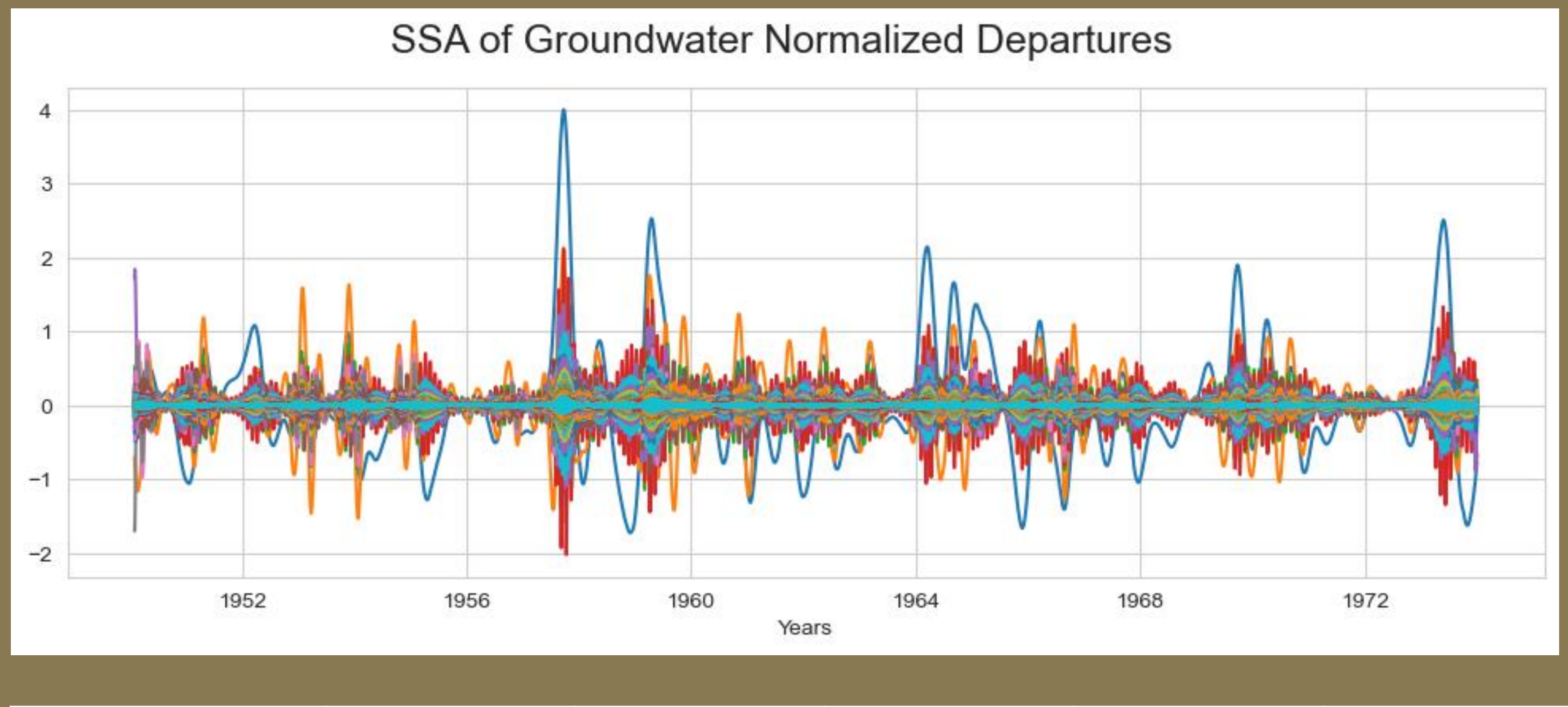

Figure 6: Reconstructed components (RCs) resulting from singular spectrum analysis (SSA) of the groundwater elevation normalized departures time series. RCs are the "building blocks" of the original time series, whereas they represent the different oscillatory periods and noise. The sum of the RCs equals the original time series. Each different colored line represents a different RC.

Time Period (years)	1	3	5	7	9	10	15	20
Percent Variance (%)	61.29%	58.43%	82.49%	71.36%	107.27%	126.71%	112.67%	104.52%

Table 2: Percent variance is calculated as the ratio of the filtered reconstructed components' variance according to each time period's time scale to the totaled variances of the filtered RCs of the normalized departure groundwater elevation time series. The percent variance appears to peak at a 5-7 time period. The values above 100% with time periods of 9 years or greater are likely due to the successful filtering out of frequencies that are not on an ENSO-like time scale.

Methods

- **ENSO and Precipitation:** Followed procedures of Goly & Teegavarapu (2014) by analyzing the significance of the difference in *precipitation totals and extremes* between El Niño and La Niña months
  - *Totals*: *Kernel density functions*, used to identify a difference in the total precipitation occurring between ENSO phases
  - *Extremes*: Used *Lilliefors* and *Jarque Bera* tests on RX1 dataset to verify normality of both datasets (Lilliefors, 1967; Jarque & Bera, 1987). If the variance of a dataset were said to be significant different, then the *Satterthwaite's modified t-test* was used, if they were not then the *two-sample t test* was used to test the significance of the difference (Satterthwaite, 1946)
- **ENSO and Groundwater**: Followed procedures of Kuss & Gurdak (2014) to pre-process the groundwater elevation time series to remove noise and long-term anthropogenic signals.
  - Singular Spectrum Analysis (SSA) was utilized to decompose and recompose the data to create reconstructed components (RCs) that represent the different frequencies, oscillatory modes, and noise of the original time series.
  - These RCs are tested against a red noise null hypothesis and filtered to only include those components on the same time scale as ENSO (2-7 years).
  - Percent variances are calculated according to different time scales to determine how much of the groundwater departure variances is a result of ENSO-like cycles

Conclusions

ENSO and Precipitation:

- Found significant difference in precipitation totals/extremes between phases of ENSO in Tallahassee, FL
  - Verifies the results of Goly and Teegavarapu (2014) on a smaller spatial scale.

ENSO and Groundwater:

- Found a peak of explained percent variance at a period of 5 years, which is within the range of ENSO-like cycles
  - Suggests 82.49% of the variance is seen can be attributed to 5-year cycles
- Periods above 9 years have explained percent variances above 100%, which just suggests that the filtering was successful in excluding components with frequencies beyond ENSO-like cycles

References

Aurit, M. D., Peterson, R. O., & Blanford, J. I. (2013). A GIS analysis of the relationship between sinkholes, dry-well complaints and groundwater pumping for frost-freeze protection of winter strawberry production in Florida. PLoS ONE, 8(1). https://doi.org/10.1371/journal.pone.0053832

Donat, M. G., et al. (2013), Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset, J. Geophys. Res. Atmos., 118, 2098–2118, doi:10.1002/jgrd.50150

Florida Climate Center (n.d.). Climate Data Access Tools - Florida Climate Center. https://climatecenter.fsu.edu/climate-data-access-tools/downloadable-data

Florida Department of Environmental Protection. (n.d.). Lake Jackson Dry Downs: Frequently Asked Questions [PDF]. Retrieved from https://floridadep.gov/sites/default/files/Lake-Jackson-Dry-Downs-FAQ_0.pdf

Global Climate Observing System Working Group on Surface Pressure (GCOS WG-SP). (n.d.), Niño 3.4 SST Index - NOAA Physical Sciences Laboratory. https://psl.noaa.gov/gcos_wgsp/Timeseries/Nino34/

Goly, A., and Teegavarapu, R. S. V. (2014), Individual and coupled influences of AMO and ENSO on regional precipitation characteristics and extremes, Water Resour. Res., 50, 4686–4709, doi:10.1002/2013WR014540.

Jarque, C. M., and A. K. Bera (1987), A test for normality of observations and regression residuals, Int. Stat. Rev., 55(2), 163–172.

Kotchoni, D. O. V., Vouillamoz, J., Lawson, F. M. A., Adjomayi, P. A., Boukari, M., & Taylor, R. G. (2018). Relationships between rainfall and groundwater recharge in seasonally humid Benin: a comparative analysis of long-term hydrographs in sedimentary and crystalline aquifers. Hydrogeology Journal, 27(2), 447–457. https://doi.org/10.1007/s10040-018-1806-2

Kuss, A. J. M., & Gurdak, J. J. (2014). Groundwater level response in U.S. principal aquifers to ENSO, NAO, PDO, and AMO. Journal of Hydrology, 519, 1939–1952. https://doi.org/10.1016/j.jhydrol.2014.09.069

Lammers, Jonathan (June 2021). History and Chronology of Lake Draining Episodes: Leon and Jefferson Counties, Florida.

Lilliefors, H. W. (1967), On the Kolmogorov-Smirnov test for normality with mean and variance unknown, J. Am. Stat. Assoc., 62, 399–402.

Lucon, T. N., Costa, A. T., Galvão, P., Leite, M. G. P., Madeira, T. J. A., & Nogueira, L. B. (2020). Recharge sources and hydraulic communication of karst aquifer, São Miguel watershed, MG, Brazil. Journal of South American Earth Sciences, 100, 102591. https://doi.org/10.1016/j.jsames.2020.102591

National Centers for Environmental Information (n.d.). El Niño/Southern Oscillation (ENSO) | National Centers for Environmental Information (NCEI). https://www.ncei.noaa.gov/access/monitoring/enso/

Satterthwaite, F. E. (1946), An approximate distribution of estimates of variance components, Biom. Bull., 2, 110–114.

Wilson, W. L., & Beck, B. F. (1992). Hydrogeologic Factors Affecting New Sinkhole Development in the Orlando Area, Florida. Ground Water, 30(6), 918–930. https://doi.org/10.1111/j.1745-6584.1992.tb01575.