# Mapping 2023 Groundwater Stress Zones in Coastal Lowland Aquifers Using Downscaled GRACE Satellite Data

**Md Nasrat Jahan[1,2], Lance D Yarbrough[1,2], Greg Easson[3], Zahra Ghaffari[1,2], Hakan Yasarer[4]**

[1] Department of Geology & Geological Engineering, University of Mississippi
[2] Mississippi Mineral Resources Institute, University of Mississippi
[3]Office of Research and Sponsored Programs, University of Mississippi
[4]Department of Civil Engineering, The University of Mississippi, University

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# Introduction

- The Coastal Lowlands aquifer system **ranks fourth** in the nation as a source of groundwater for public supply and **fifth** as a source of private domestic supply, providing about one billion gallons per day for this use (Barlow and Belitz, 2016).
- According to National Water Census: Regional Groundwater Availability Studies (U.S. Geological Survey, 2022), heavy withdrawals from the aquifer system in some areas have resulted in **saltwater encroachment** and **land subsidence**.
- **Land surface subsidence** in the **Houston-Galveston region, Texas** due to the excessive withdrawal of groundwater
- **Subsidence** and **saline water intrusion** in **Baton Rouge, Louisiana** and **Mobil, Alabama**

# Location of the Study Area

The total area of **2,77,534** square kilometers in the Gulf of Mexico Coastal Plain includes the coastal area of **Texas, Louisiana, Mississippi,** and part of **Alabama**, **Florida** states of the United States of America.

# Objectives

- Apply a **Random Forest Model** to downscale the GRACE satellite data into **4 km** spatial resolution
- Identify the **potential groundwater stress zone** using the downscaled GRACE Mascon data of 2023
- Validate the potential groundwater stress zone using the available **groundwater level data** of the study area

# What is GRACE/GRACE-FO

- GRACE mission by **NASA and the German Aerospace Center,** which launched on March 17, 2002, and ended in October 2017. GRACE-FO launched on May 21, 2018
- Its primary mission goal is to continue the tracking of **Earth's mass movements and changes**, in particular those **related to water**
- It can detect gravitational differences on the planet's surface equivalent to that of a **300-km disk of water only one centimeter thick**.
- Each monthly GRACE-FO Tellus grid represents the **surface mass deviation** for that month relative to a **baseline temporal average (2005-2010)**.
- The units of the data are **Liquid Water Equivalent Thickness** in **meter or centimeter**

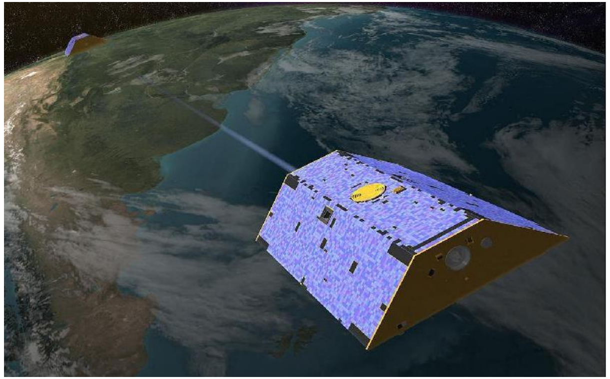

Illustration of the GRACE twin satellites in orbit (NASA image credit).

# What is Random Forest Model (RFM)

The **Random Forest** model is an ensemble machine learning algorithm that combines multiple decision trees to improve accuracy and reduce overfitting. It works by:

Step 1: Select **random samples** from a given data or training set.

Step 2: This algorithm will construct an **individual decision tree** for each set of training data.

Step 3: **Aggregate** the decisions of the individual trees through averaging.

Step 4: Finally, designate the prediction result with **the highest vote** as the conclusive prediction result

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# Data

| Variables | Source | Spatial Resolution |
|---|---|---|
| GRACE/GRACE-FO | JPL | ~ 111 km (Represent the 333 km) |
| Root zone soil moisture (RZSM) | GLDAS | ~ 28 km |
| Plant canopy surface water (CNWAT) | GLDAS | ~ 28 km |
| Snow depth water equivalent (SWE) | GLDAS | ~ 28 km |
| Mean Temperature | PRISM | 4 km |
| Total Precipitation | PRISM | 4 km |
| NDVI | MODIS | 1 km |
| Evapotranspiration (ET) | MODIS | 500 m |
| DEM | SRTM | 30 m |
| Slope (Generated from DEM) | SRTM | 30 m |
| Soil Type | FAO/UNESCO | Vector data |
| Lithology | Esri | 250 m |
| Ground-based measurement | USGS/TWDB/GSAL | Groundwater Table point data |

# Data Preprocessing

1. **Download** all the data

2. **Reproject** all the data into UTM Zone 16N NAD 1983 projection (EPSG:26916)

3. **Clip** all the data

4. Prepare the **Monthly Anomaly** of Mean Temperature, Total Precipitation, NDVI, ET, RZSM, CNWAT & SWE

5. **Resample** all the data into 4 km spatial resolution

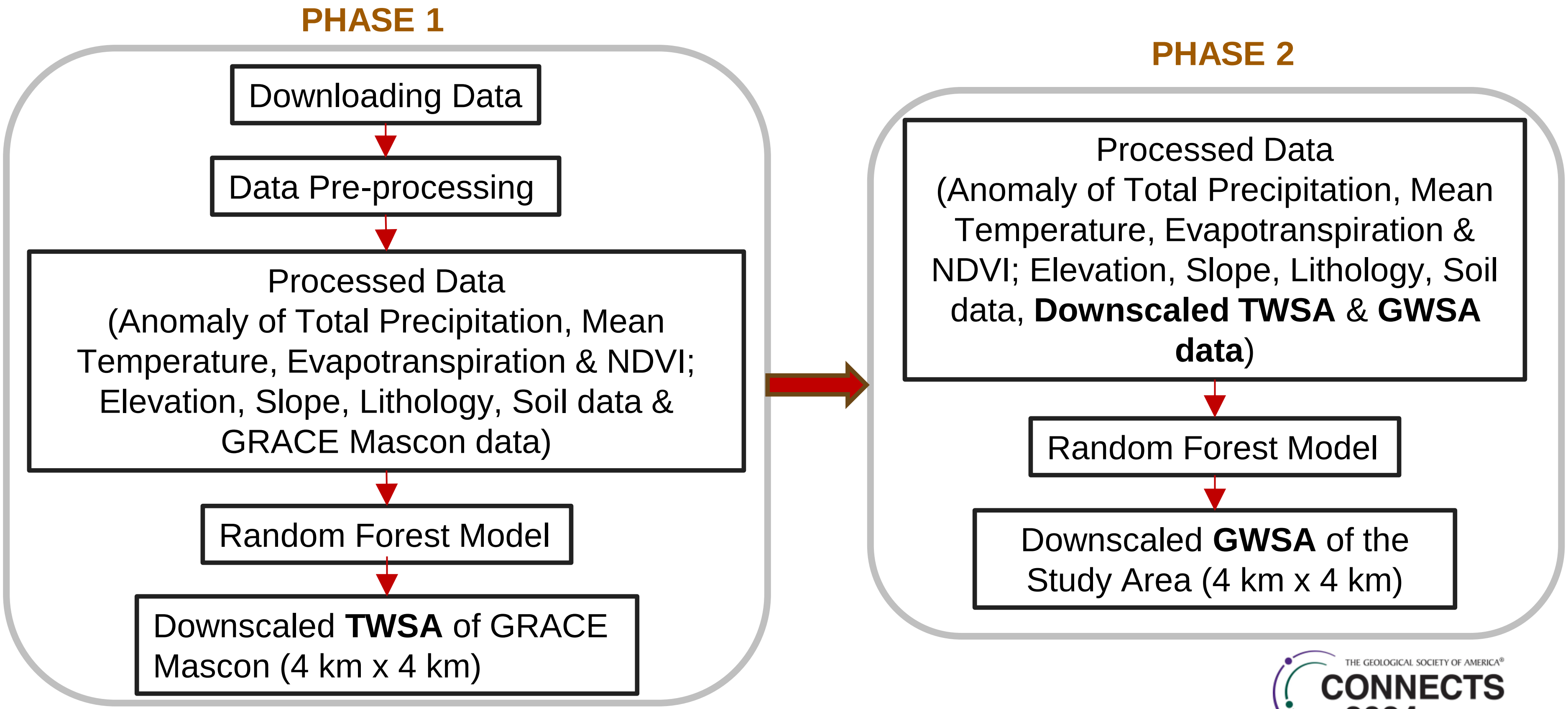
6. Prepare the **Monthly Anomaly of Groundwater Storage Anomaly (GWSA)**

**[GWSA = TWSA – (RZSM + CNWAT + SWE)]**

7. Create **Fishnet** layers (4km x 4 km) and **integrate** Data values into the Fishnets

8. **Mask** the Fishnet layer with the surface waterbody layer of the study area

# Methods Flowchart

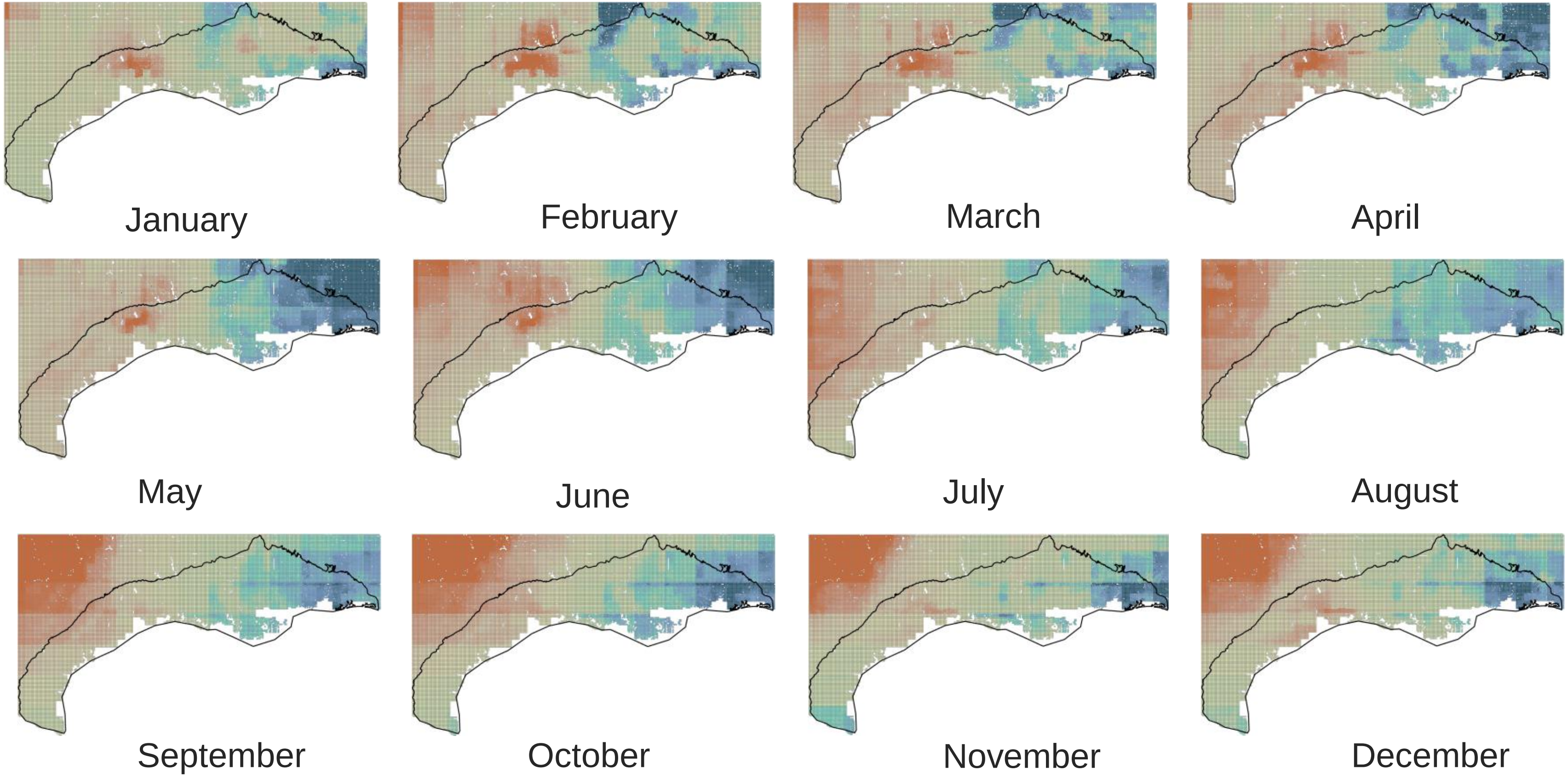


# Important Variables

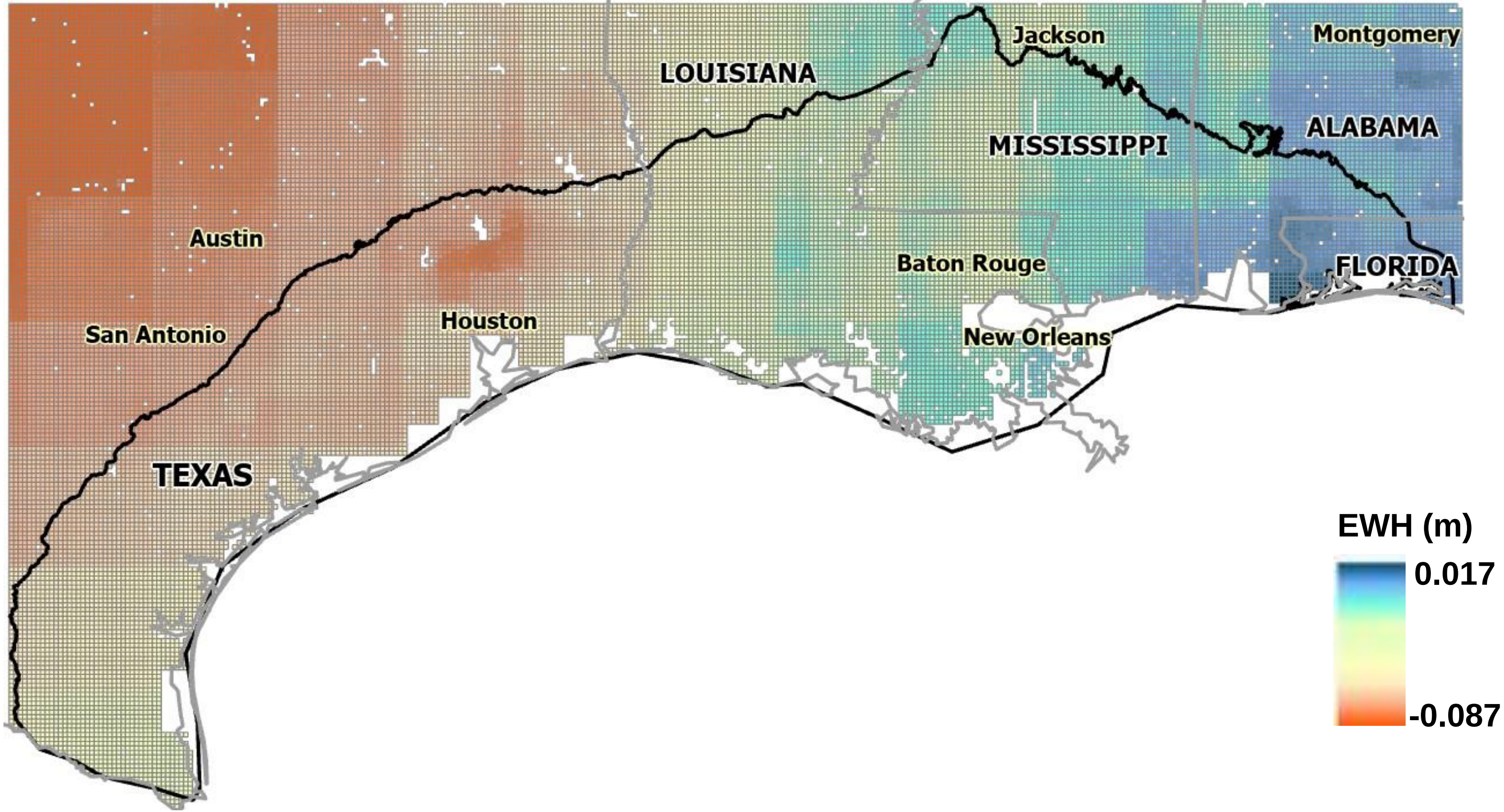
| Variables | Rank of Importance |
|---|---|
| Predicted TWSA / Soil Type | 1 |
| Mean Temperature / Total Precipitation | 2 |
| DEM | 3 |
| Evapotranspiration | 4 |
| NDVI | 5 |
| Slope | 6 |
| Lithology | 7 |

# Statistical Matrix of RF Model

| Downscaled GWSA | Training Data | | | Validation Data | | |
|---|---|---|---|---|---|---|
| | R-Squared | p value | RMS Error | R-Squared | p value | RMS Error |
| January | 0.971 | 0.000 | 0.003 | 0.842 | 0.000 | 0.007 |
| February | 0.979 | 0.000 | 0.004 | 0.889 | 0.000 | 0.009 |
| March | 0.980 | 0.000 | 0.004 | 0.896 | 0.000 | 0.008 |
| April | 0.987 | 0.000 | 0.003 | 0.934 | 0.000 | 0.007 |
| May | 0.993 | 0.000 | 0.004 | 0.966 | 0.000 | 0.008 |
| June | 0.996 | 0.000 | 0.002 | 0.981 | 0.000 | 0.005 |
| July | 0.996 | 0.000 | 0.002 | 0.981 | 0.000 | 0.005 |
| August | 0.995 | 0.000 | 0.003 | 0.980 | 0.000 | 0.006 |
| September | 0.996 | 0.000 | 0.003 | 0.980 | 0.000 | 0.007 |
| October | 0.996 | 0.000 | 0.003 | 0.980 | 0.000 | 0.007 |
| November | 0.987 | 0.000 | 0.003 | 0.946 | 0.000 | 0.006 |
| December | 0.991 | 0.000 | 0.002 | 0.957 | 0.000 | 0.005 |




# Downscaled Monthly GRACE-FO 2023




# Downscaled GRACE-FO 2023

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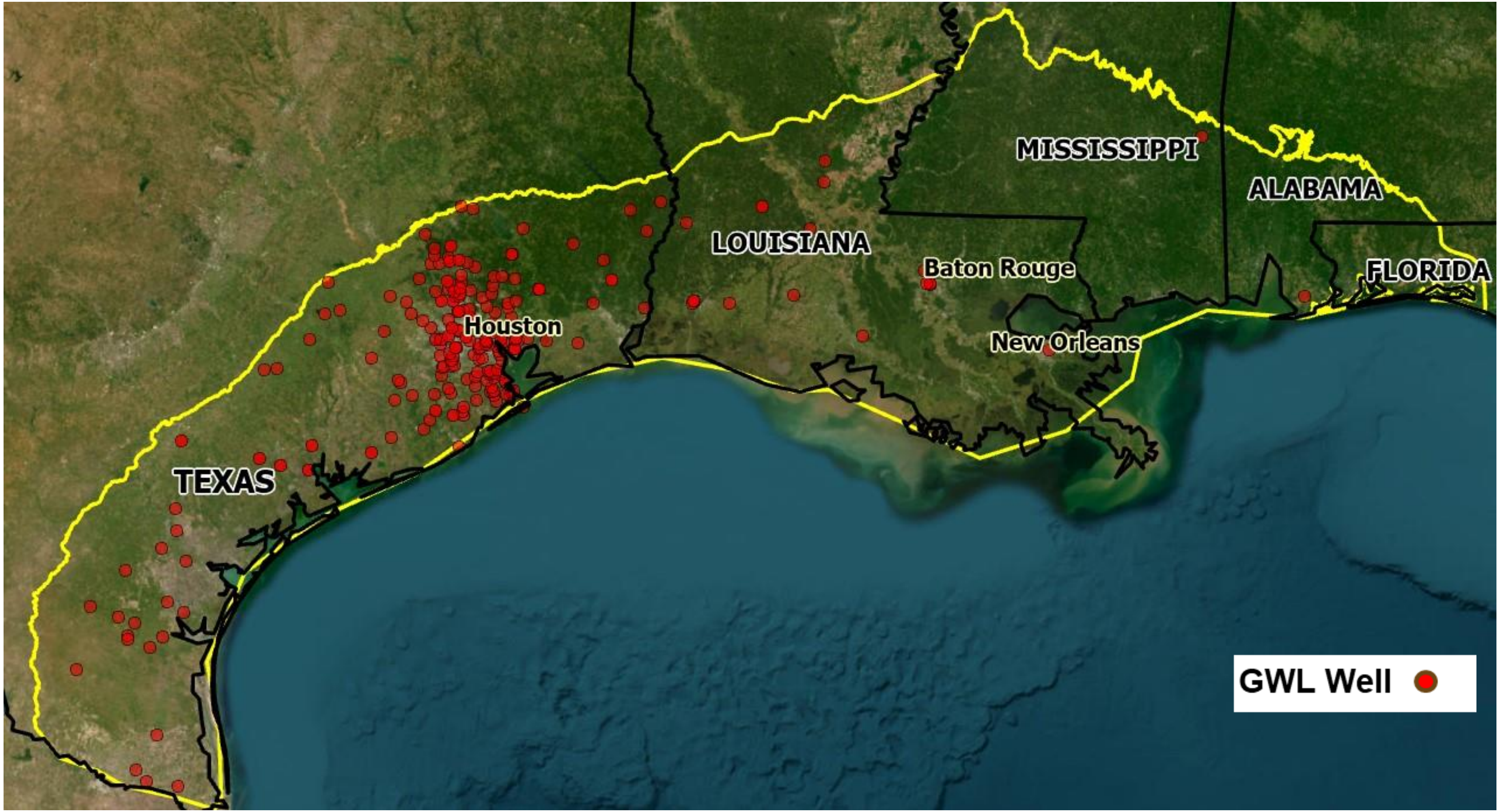


# Location of Groundwater Level (GWL) Monitoring Well

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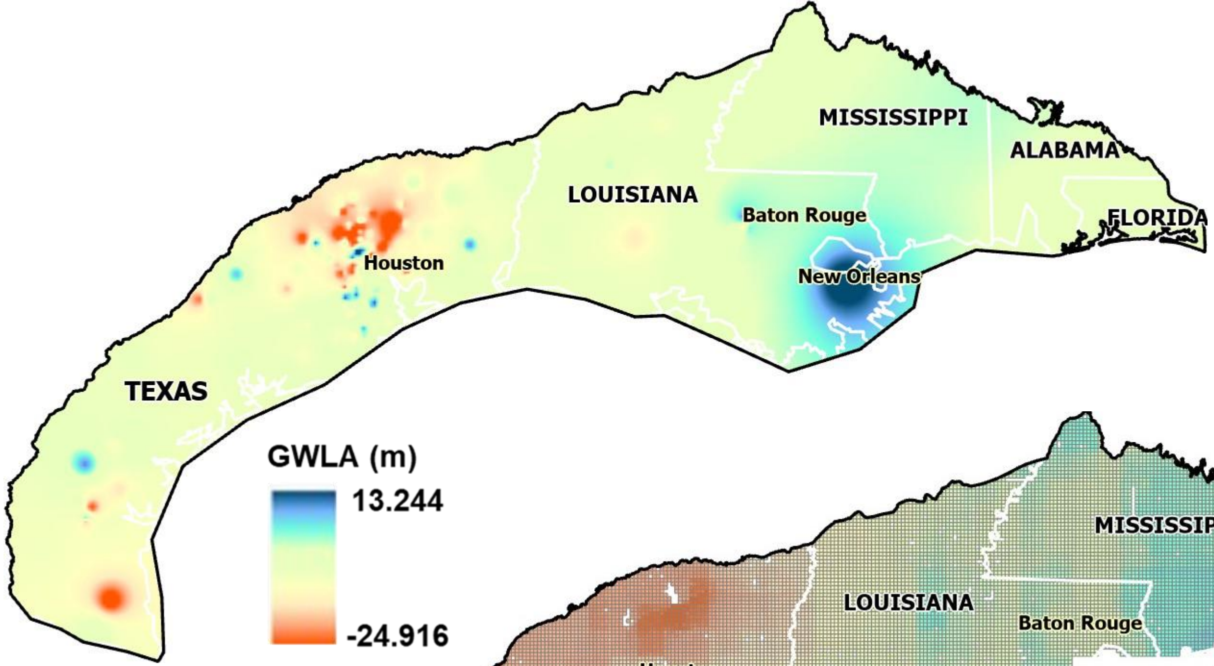
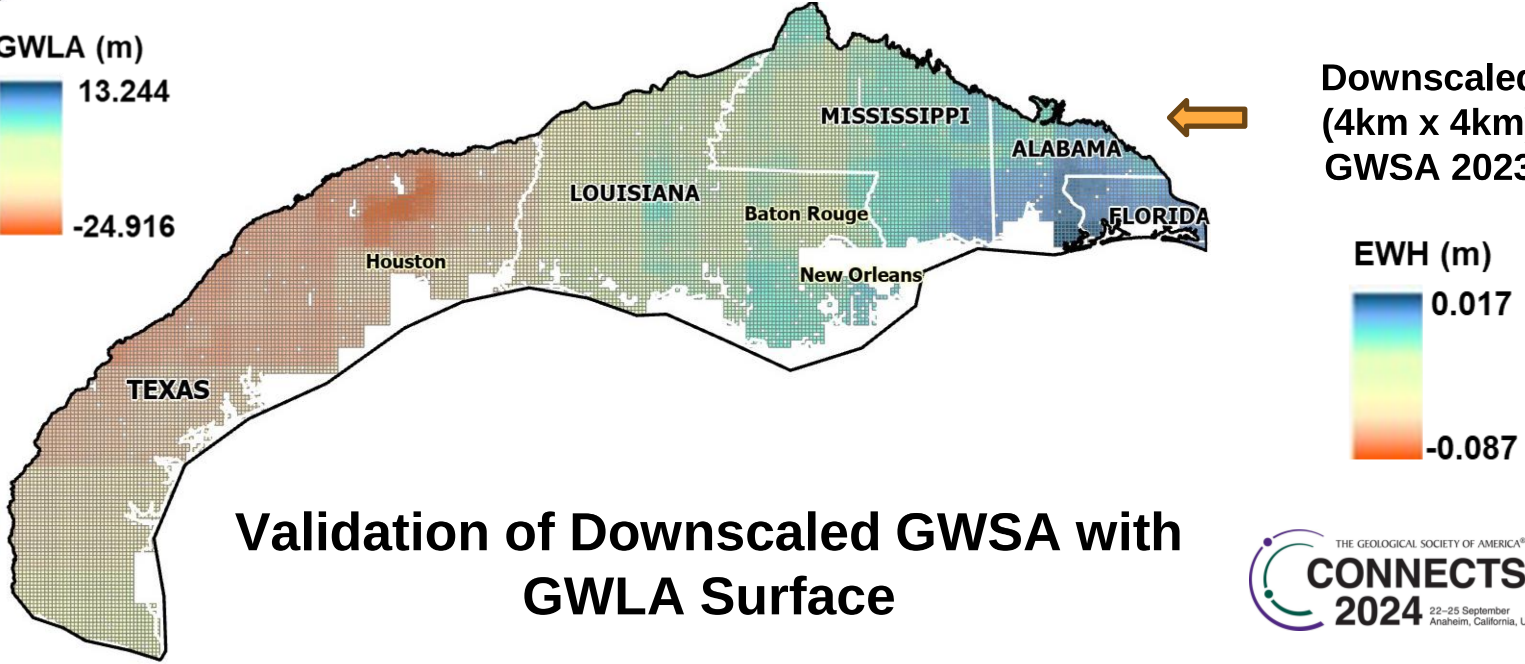
# Validation of Downscaled GWSA with GWLA Surface




Groundwater Level Anomaly (GWLA) Surface (4 km x 4km) 2023




Downscaled (4km x 4km) GWSA 2023

# Conclusions

- The validating data $R^2$ for each model of the downscaled monthly GWS anomaly map of 2023 ranges from **0.84 to 0.98**.
- The validating data RMS error for each model of the downscaled monthly GWS anomaly map of 2023 ranges from **0.005 to 0.009**.
- The downscaled GWSA from GRACE-FO 2023, produced using the Random Forest Model, shows an **approximately similar declining trend** in groundwater levels (GWL) compared to the GWLA surface derived from GWL data.

# Future Work

- In the future, **Random Forest**, **Artificial Neural Network (ANN)**, and **Deep Learning models** will be applied to the time series datasets (2003-2023) of GRACE/GRACE-FO to generate **downscaled GWSA maps (2003-2023)**.
- An attempt will be made to **assess the characteristics** of downscaled GWSA data (2003-2023) from GRACE/GRACE-FO to identify **zones of saline water intrusion**.

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# Thank You