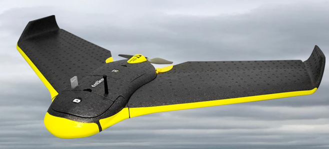
# SUBMARINE GROUNDWATER DISCHARGE IN COASTAL NORTH CAROLINA, USA



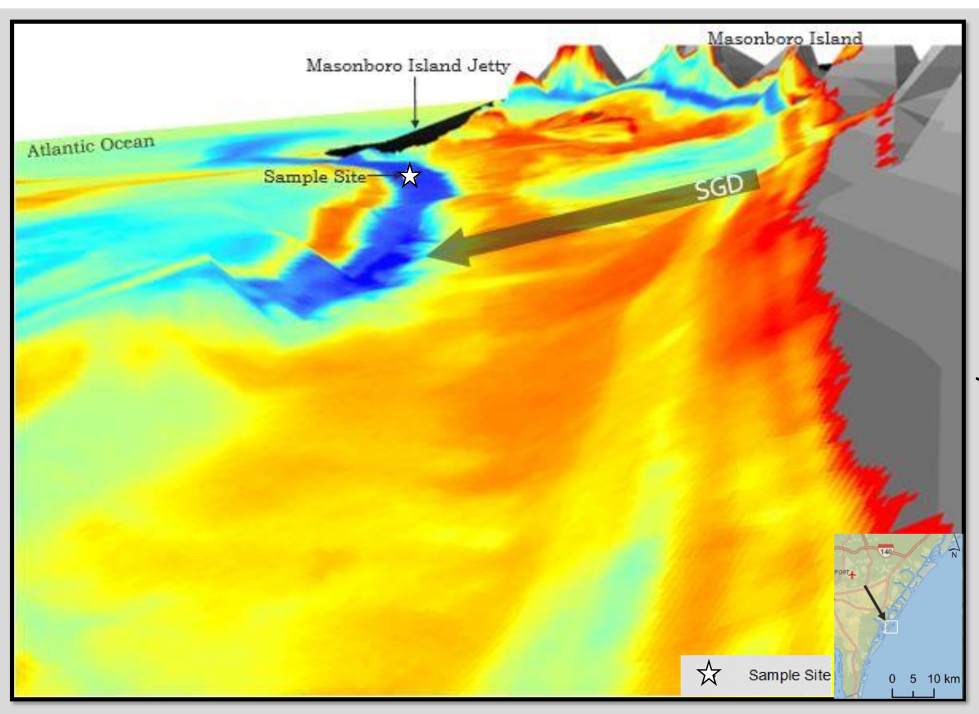
**Moore, Raymond; Ghoneim, Eman; Wells, Dave; Zamora, Peter**

**Department of Earth and Ocean Sciences, University of North Carolina Wilmington**

## Abstract

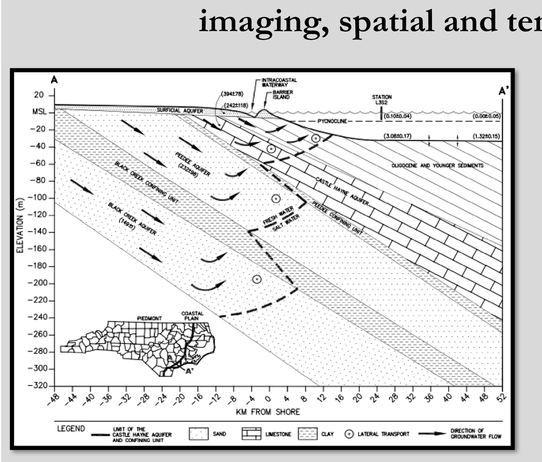
Submarine groundwater discharge (SGD), the direct discharge of groundwater from coastal aquifers to the ocean, is an important fresh water and dissolved nutrient source in Onslow Bay, NC. Hence, mapping SGD hotspots and hot moments is important to better understand their impacts to coastal waters. Here we applied innovative geospatial analysis techniques using thermal infrared (TIR) data from a multispectral satellite and a senseFly eBee Plus fixed wing Unmanned aerial system (UAS) equipped with multiple sensors to map SGD anomalies, with high accuracy over a vast areal extent. In-situ radon, temperature, salinity, and global positioning coordinates were measured during the survey for data validation. Relative to commonly used chemical tracing techniques, utilizing geospatial analysis of TIR and multispectral data enables a more cost-efficient, spatially-accurate, and time-efficient method for monitoring SGD. Masonboro Barrier Island and Bald Head Island Creek were selected as testing sites in this study. Survey results from Masonboro Barrier Island revealed cooler sea surface temperature anomalies adjacent to the wider section of the barrier island where more groundwater can potentially accumulate and discharge along the island shoreline. Survey results from Bald Head Island Creek revealed cooler water in the headwaters compared to the creek mouth due to topography and hydrologic gradient. High $^{222}Rn$ concentrations in seawater adjacent to this site confirms the presence of SGD at these sites. The daily mean groundwater discharge at the specified sample point within a tidal cycle at Masonboro Island and Bald Head Island Creek were estimated to be 0.8962 m day$^{-1}$ and 0.6097 m day$^{-1}$, respectively. The adopted approach demonstrates the utility of UAS-TIR systems in mapping SGD hotspots and potentially hot moments in coastal areas such as barrier islands.

## Why Quantify SGD?

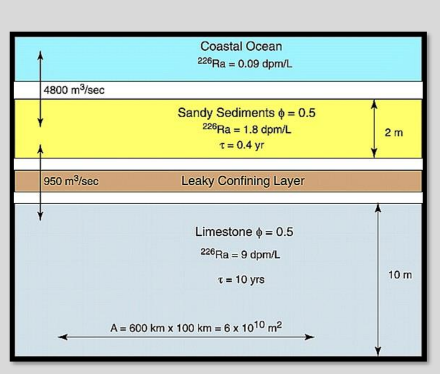



*Off-Nadir view of Masonboro Island UAS-TIR Survey region appended to a spatial interpolation produced using continuous topographic RTK survey points below the water surface to enable hydrologic gradient and SGD flux to be modeled*

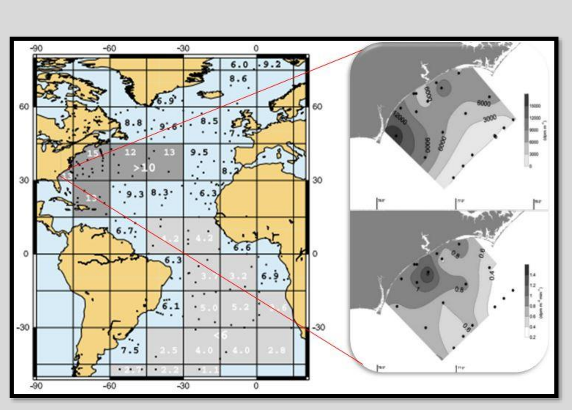
**Groundwater discharge along North Carolinas coasts is predominantly colder than ambient ocean water and, because a significant proportion of the discharge is fresh, it floats buoyantly on the ocean surface. This allows high resolution UAS-TIR imaging methods to be implemented to observe SGD mixing characteristics. Prior to UAS-TIR imaging, spatial and temporal ambiguity made SGD difficult to evaluate [1].**



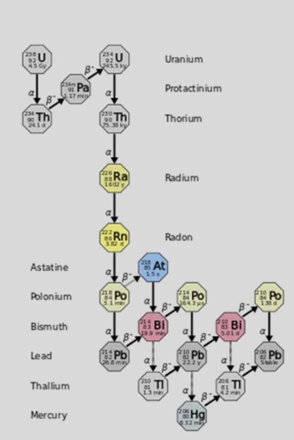
**Geology:** *Stratigraphic cross section of geology, aquifers and SGD flow in study region [5]*




**Radium Transport:** *Transfer of fluids from the limestone aquifer comprising the continental shelf enriches the pore waters of overlying sandy sediments in radium and may release radium continuously or episodically [4]*

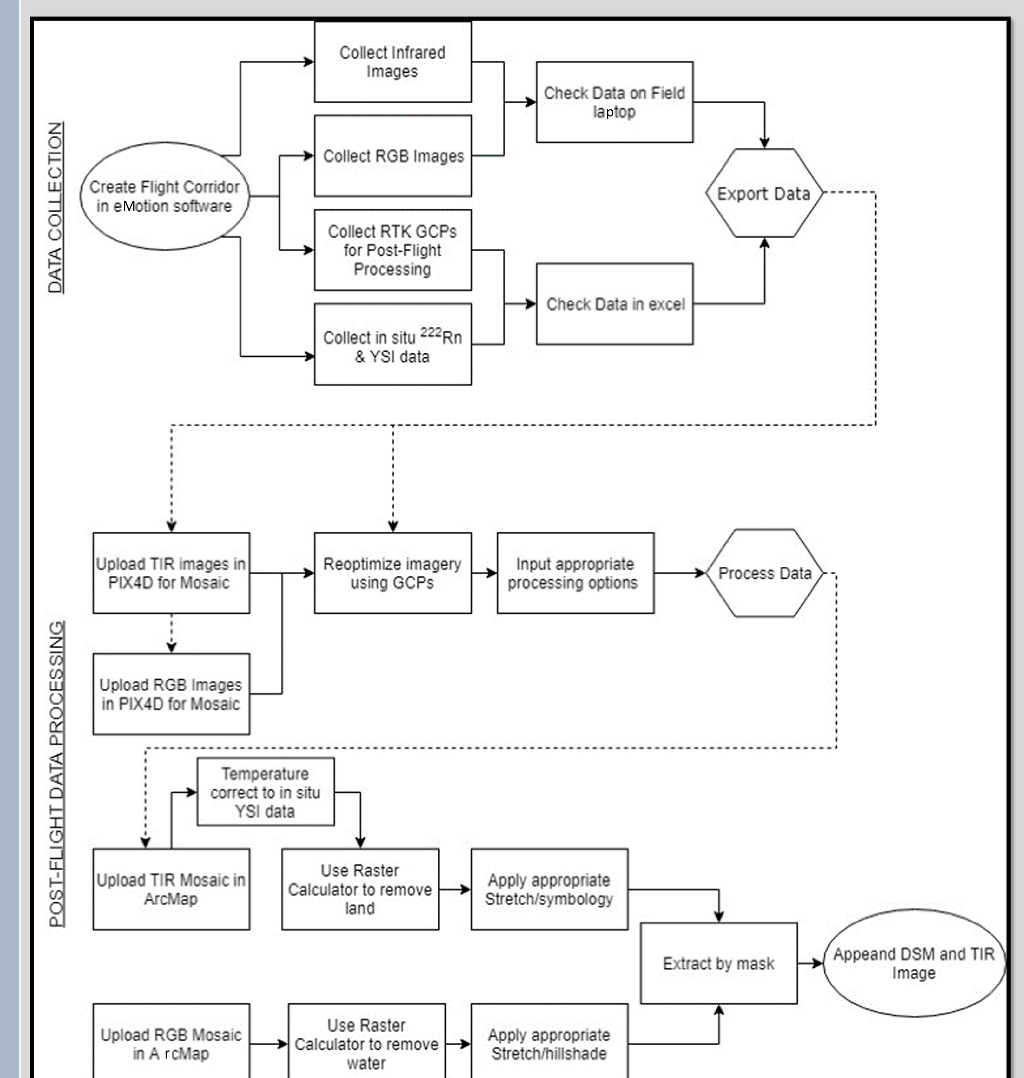


**Previous Measurements:** Tracer methods suggest *the annual SGD flux into the South Atlantic Bight is three times greater than the river flux. Nutrients delivered to the coastal zone via SGD exceed those delivered by local river run-off [4,5]*




**$^{222}$Rn Decay Chain:** $^{226}$Ra emanation from sediments to $^{222}$Rn, *note short half-life of 3.82 days for $^{222}$Rn*

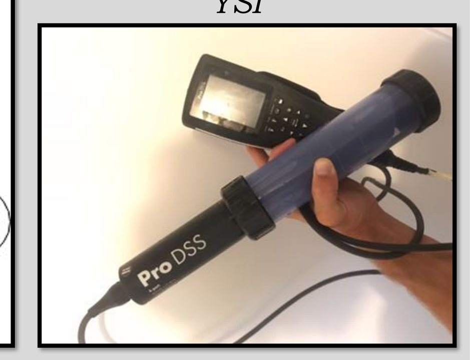
## Methodology




*Monitoring Vessel*

*RAD-7 Aqua*

*YSI*



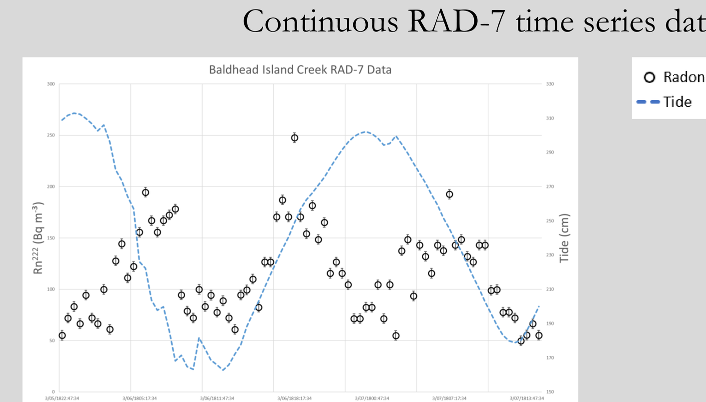
**UAS-TIR Data Collection and Image Processing:**
Accurate orthomosaics (maps) of UAS-TIR data at prominent SGD plumes were produced using an eBee professional drone equipped with a high-resolution senseFly thermoMap sensor, capable of detecting 0.1°C at approximately 14 cm/pixel. Multiple flights were required to image the entire region of interest because UAS battery life. FAA regulations require all flights to be below an altitude of 122 meters.

**Radon Time Series Measurements:**
Upon collecting UAS-TIR imaging data, in-situ water conductivity, temperature, and depth were recorded with a YSI. Measurements were logged continuously and autonomously on thirty-minute intervals over multiple tidal cycles. Measurements are recorded within the SGD plume to ground-truth the SST measurements recorded by the UAS-TIR imagery. The RAD-7 Aqua circulates seawater from an intake valve from the sample site into an air-water exchanger by a peristaltic pump, enabling positively charged isotopes to be released into a closed air loop that is attracted to a ground potential semiconductor in the RAD-7 where it can be measured.

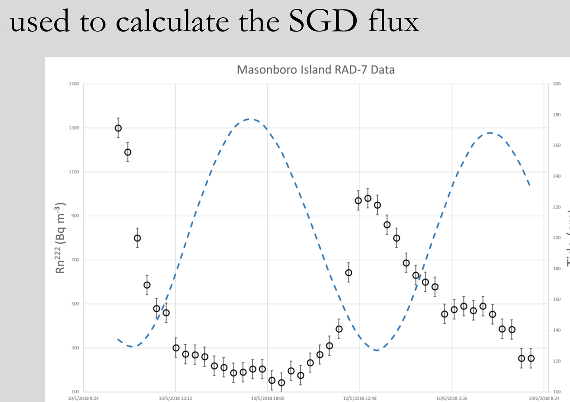
**Radon Mass Balance Model:**
Calculations for converting $^{222}$Rn volume measurements into groundwater seepage flux require in-situ data such as: continuous measurements of $^{222}$Rn activities (Bq m$^{-3}$ ) in the coastal water column, water depth, water, and air temperatures, wind speed, and atmospheric $^{222}$Rn concentrations. Atmospheric evasion is accounted for using an air coefficient. Tidal range is accounted for by adding tidal values before multiplying the air coefficient by the corrected radon inventory times and the water depth to convert to Bq m$^{-2}$. Finally, convert to flux by dividing by the pore water equilibration sample value.

## Geochemical Tracer Results

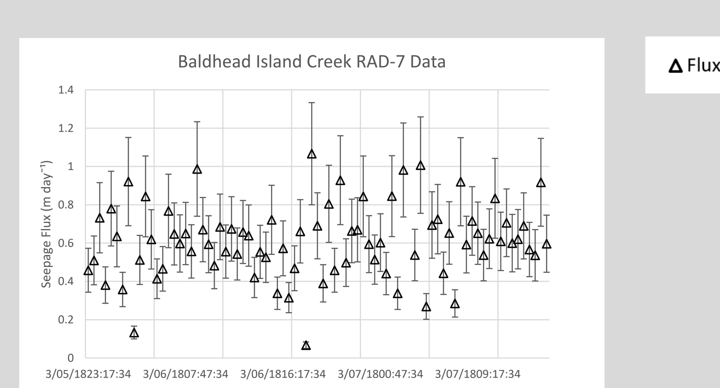
Time series $^{222}$Rn sampling, a standard radon emanation technique:
Continuous RAD-7 time series data used to calculate the SGD flux



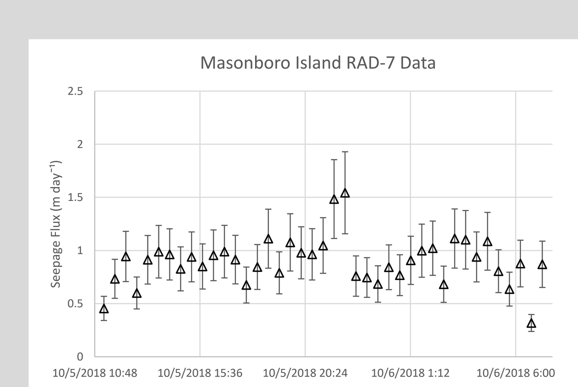

*Total $^{222}$Rn from March 5, 2018 error bars indicate the Standard error.*




*Total $^{222}$Rn from October 5, 2018 error bars indicate the Standard error.*



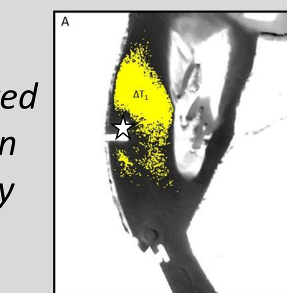

*Estimated seepage rates over the experimental period based on the radon model and using a pore water radon concentration of 1000 Bq m$^{-3}$ . Error bars above and below the SGD estimates (open triangles) represent ±25% uncertainties.*

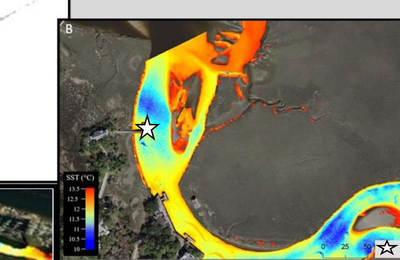


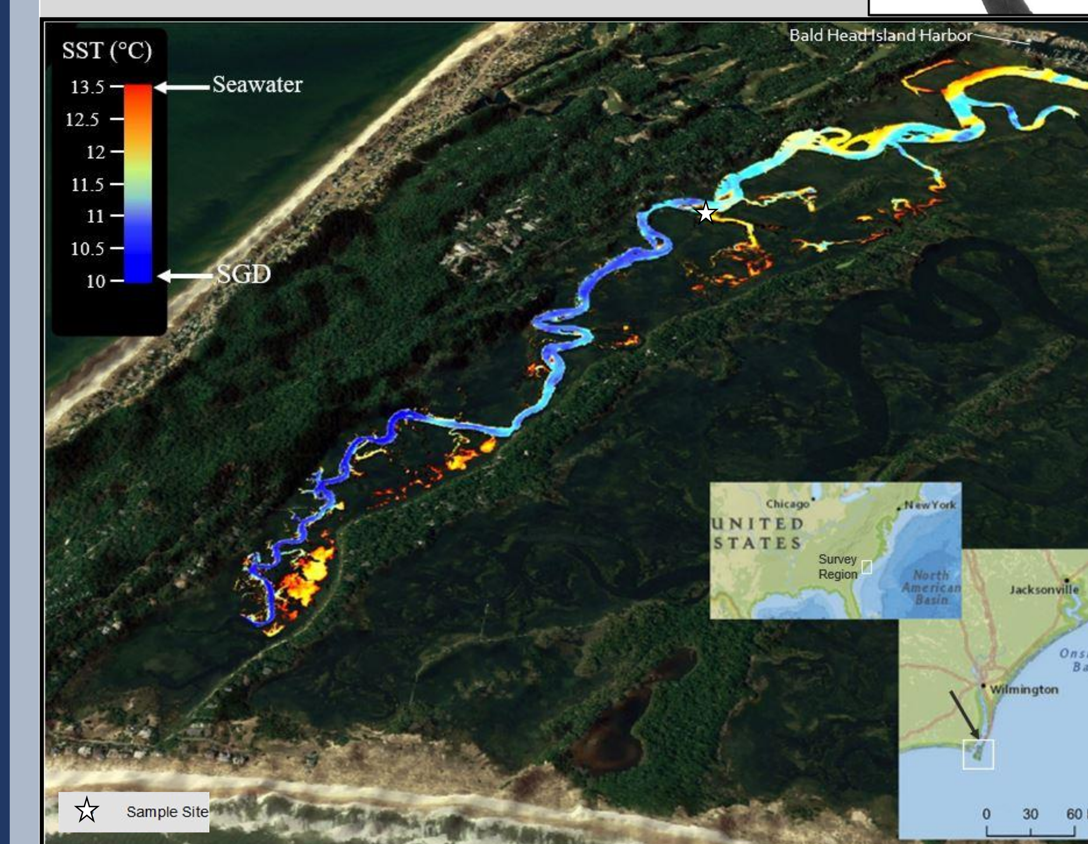

*Estimated seepage rates over the experimental period based on the radon model and using a pore water radon concentration of 1000 Bq m$^{-3}$ . Error bars above and below the SGD estimates (open triangles) represent ±25% uncertainties.*

## Barrier Island Thermal infrared (TIR)

*Off-Nadir view of Bald Head Tidal Creek UAS-TIR survey region appended to a vertically exaggerated DEM to represent a greater hydrologic gradient in the headwaters vs the creek mouth which directly corresponds with a higher SGD flux*

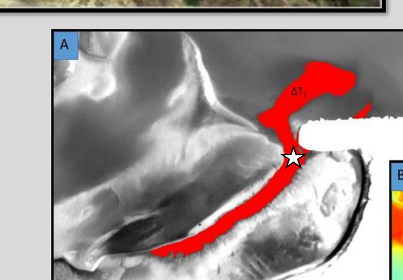


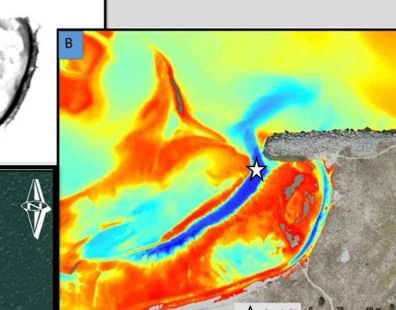


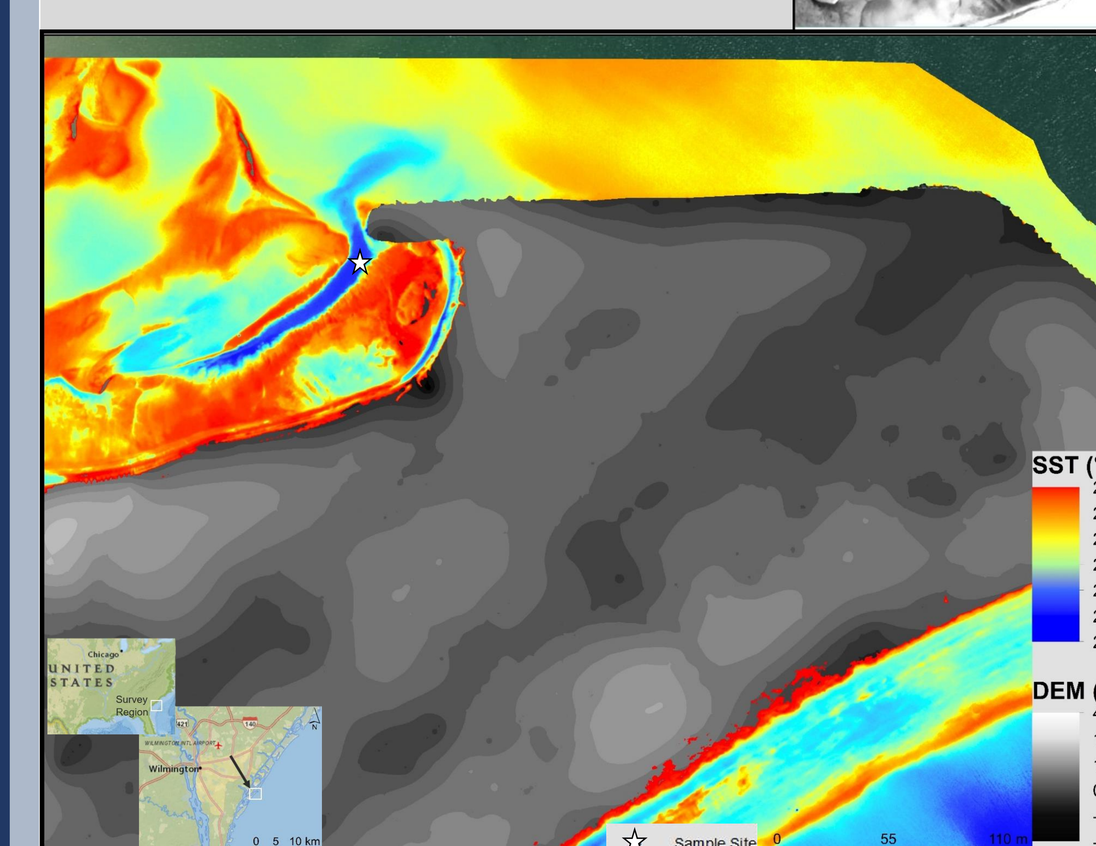



*Bald Head Island Tidal Creek clipped section showing SST plume at Radon time series sampling location. A) Displays the ΔT1 contour surface area represented by the yellow region. B) Displays the clipped section of Bald Head Island Tidal creek above the Radon Monitoring station as well as the SST.*

*Nadir View of Masonboro Island UAS-TIR survey region overlain on DEM to enable correlation with hydrologic gradient and SGD plume*








*Masonboro Barrier Island showing SST plume at Radon time series sampling location. A) Displays the $\Delta T_1$ contour surface area represented by the red region. B) Displays the Masonboro Barrier Island SGD plume above the Radon Monitoring station as well as the SST.*

## Conclusions

- Observed SGD fluxes have an inverse relationship with tidal stage and SGD contributes to an overall decrease in salinity and pH.
- The larger ΔT1 contour surface plume area at the Masonboro Island survey site of 2,315.739 m² responded with a mean discharge volume at the sample point of 0.8962 m day$^{-1}$.
- The ΔT1 contour surface plume area at the Bald Head Island Creek study site of 1,391.31 m² yields lower mean discharge volume at of 0.6097 m day $^{-1}$.
- The resulting Bald Head Island sample area mean discharge contribution is qA = 0.0281 m day -1.
- The resulting Masonboro Island sample area mean discharge contribution is qA = 0.0496 m day -1. This discharge value can be interpreted as the contribution to the daily tidal variation resulting from SGD.

## References

[1]Burnet, W., Aggarwal, P., Aureli, A., Bokuniewicz, H., and Cable, J., 2006, Quantifying submarine groundwater discharge in the coastal zone via multiple methods: Science Total Environment, v. 367, p. 498–543, doi:10.1016
[2]Kelly, J., Glenn, C., and Lucey, P., 2013, High-resolution aerial infrared mapping of groundwater discharge to the coastal ocean: Limnology and Oceanography, v. 11, p. 262–277, doi:10.4319/lom.2013.11.262.
[3]Kennedy, J., 2016, Coupling aircraft and unmanned aerial vehicle remote sensing with simultaneous in-situ coastal measurements to monitor the dynamics of submarine groundwater discharge: University of Hawaii at Manoa
[4]McCoy, C., Corbett, D., Cable, J., and Spruill, R., 2007, Hydrogeological characterization of southeast coastal plain aquifers and groundwater discharge to Onslow Bay, North Carolina (USA): Journal of Hydrology, v. 339, p. 159–171.
[5]Moore, W.S., Krest, J., Taylor, G., Roggenstein, E., Joye, S., Lee, R., 2002, Thermal evidence of water exchange trough a coastal aquifer: implications for nutrient fluxes: Geophysical Research Letters, v. 29, p. 49–51.

-Contact email: Rcmoore291@gmail.com