The North Atlantic Sea Surface Height Tripole Impacts the Frequency of Flooding Events Along the U.S. East Coast

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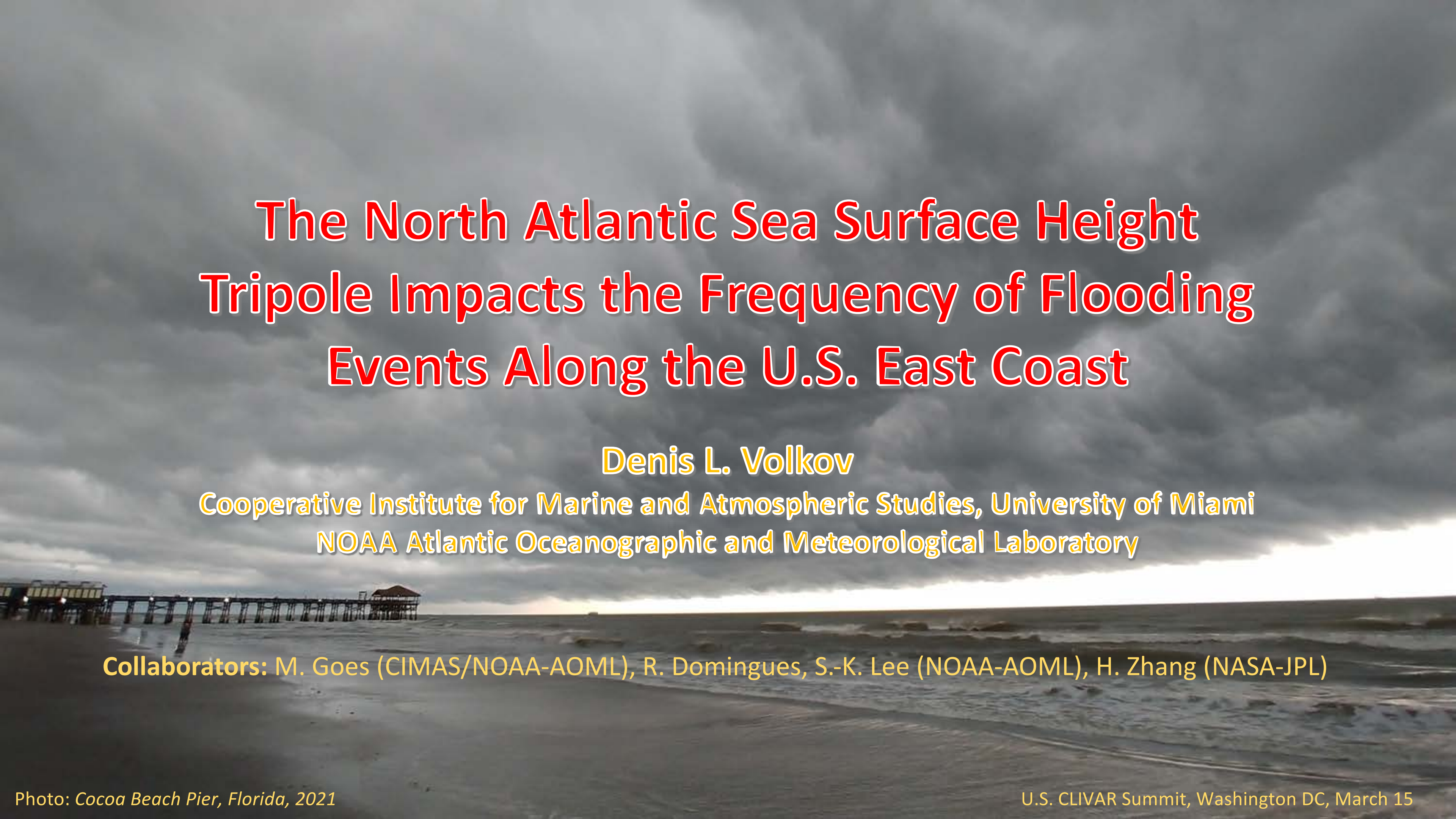
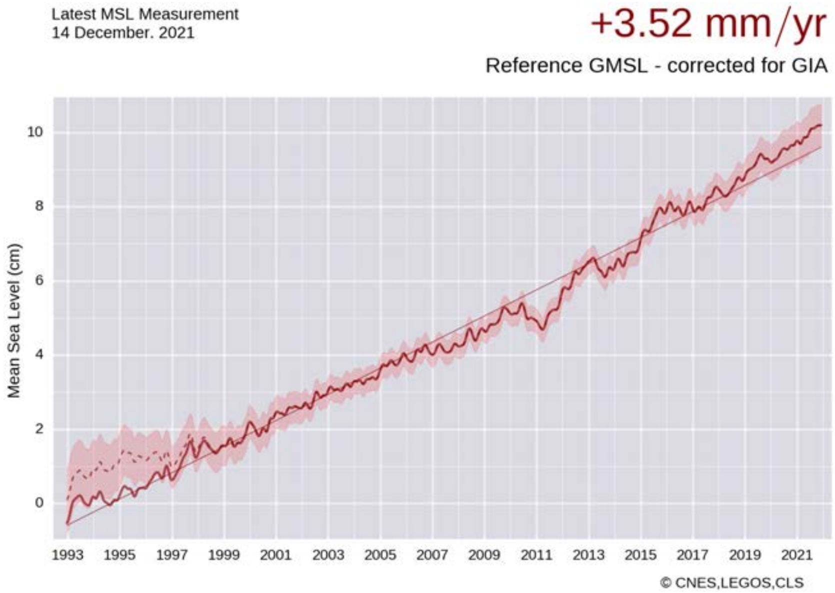
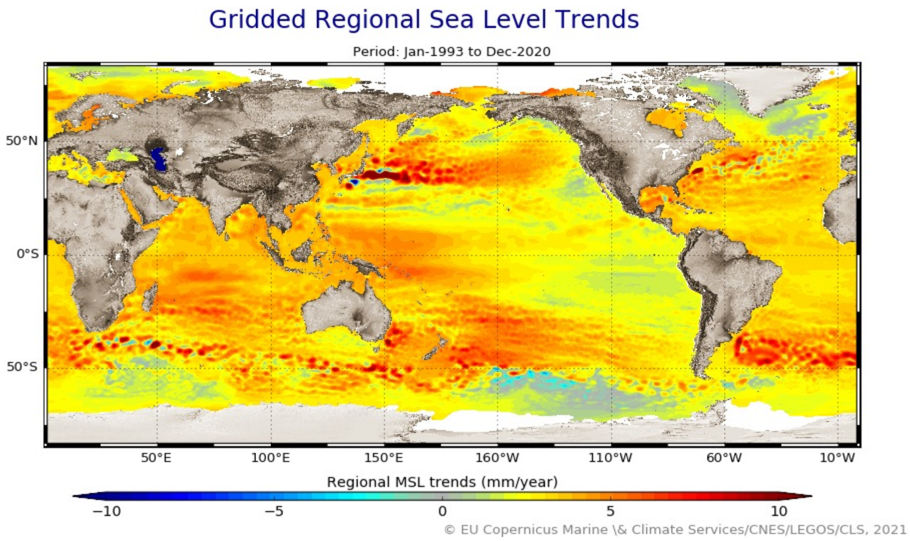


Photo: *Cocoa Beach Pier, Florida, 2021*

U.S. CLIVAR Summit, Washington DC, March 15

1. Global Mean and Regional Sea Level Changes

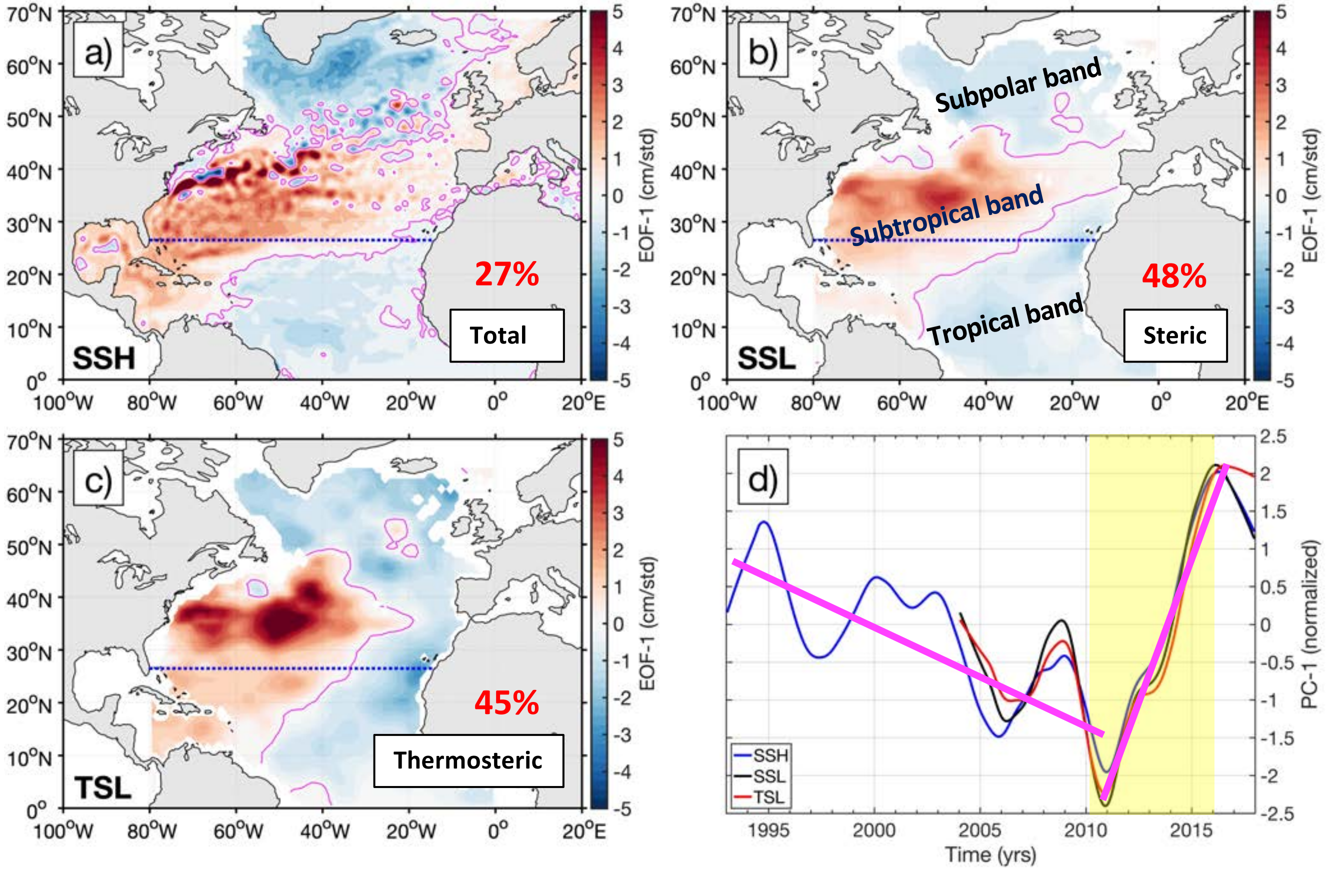




- The global mean sea level (GMSL) is rising due to the melting of glaciers and ice sheets and ocean warming, but ocean and atmosphere dynamics is responsible for the spatial variability of sea level change
- The low-frequency and large-scale regional sea level variability superimposes on the GMSL rise and can lead to increased or decreased rates of coastal sea level change
- What is the large-scale regional sea level variability in the North Atlantic and how does it affect the low-frequency sea level change along the U.S. east coast?

2. The North Atlantic Sea Surface Height Tripole

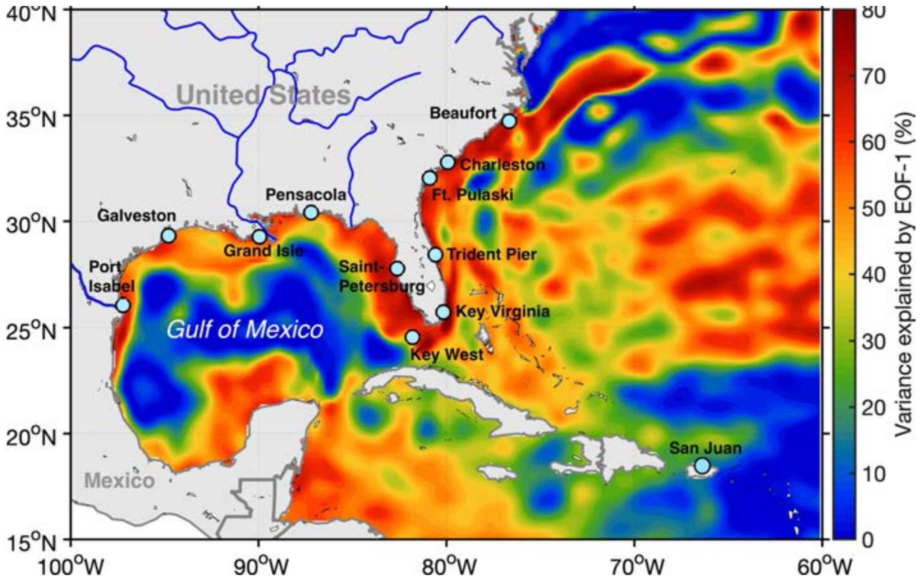
The leading mode (EOF-1) of the interannual sea level variability



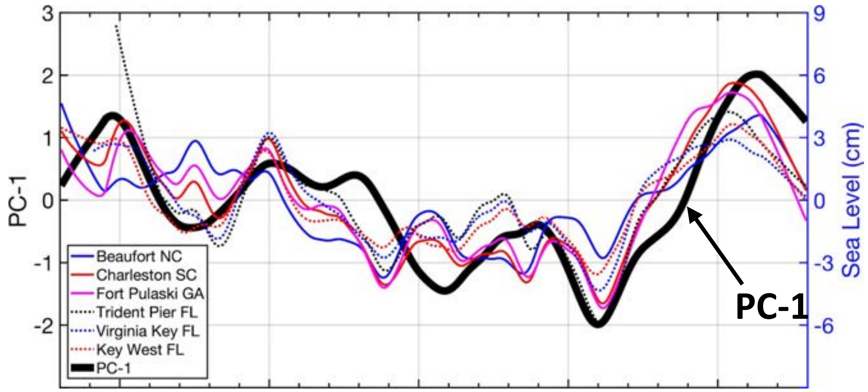
- Interannual dynamic sea level variability in the North Atlantic exhibits a TRIPOLE pattern.
- The North Atlantic SSH tripole is mostly determined by the thermosteric sea level variability → indicates heat content changes
- A decadal lowering of sea level in 1993-2010 followed by a rapid increase of sea level in 2010-2015 occurred in the subtropical band of the TRIPOLE

3. The North Atlantic SSH Tripole and Coastal Sea Level

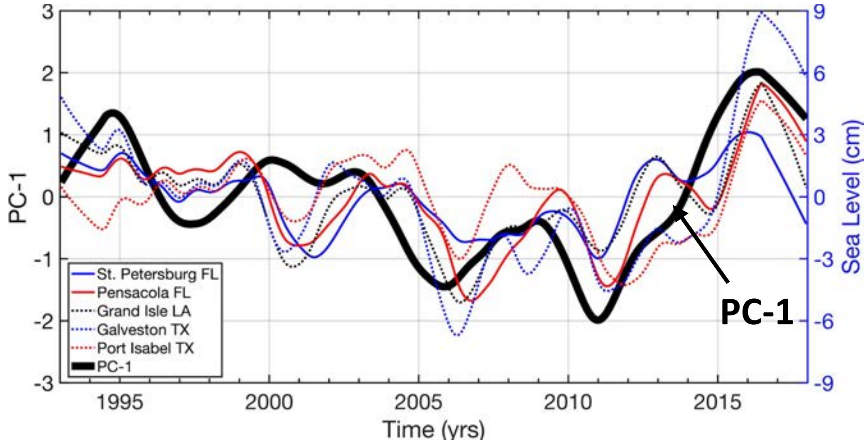
Fraction of the local interannual sea level variance explained by the tripole



PC$_1$ vs Tide Gauge records along the U.S. southeast coast



PC$_1$ vs Tide Gauge records in the Gulf of Mexico

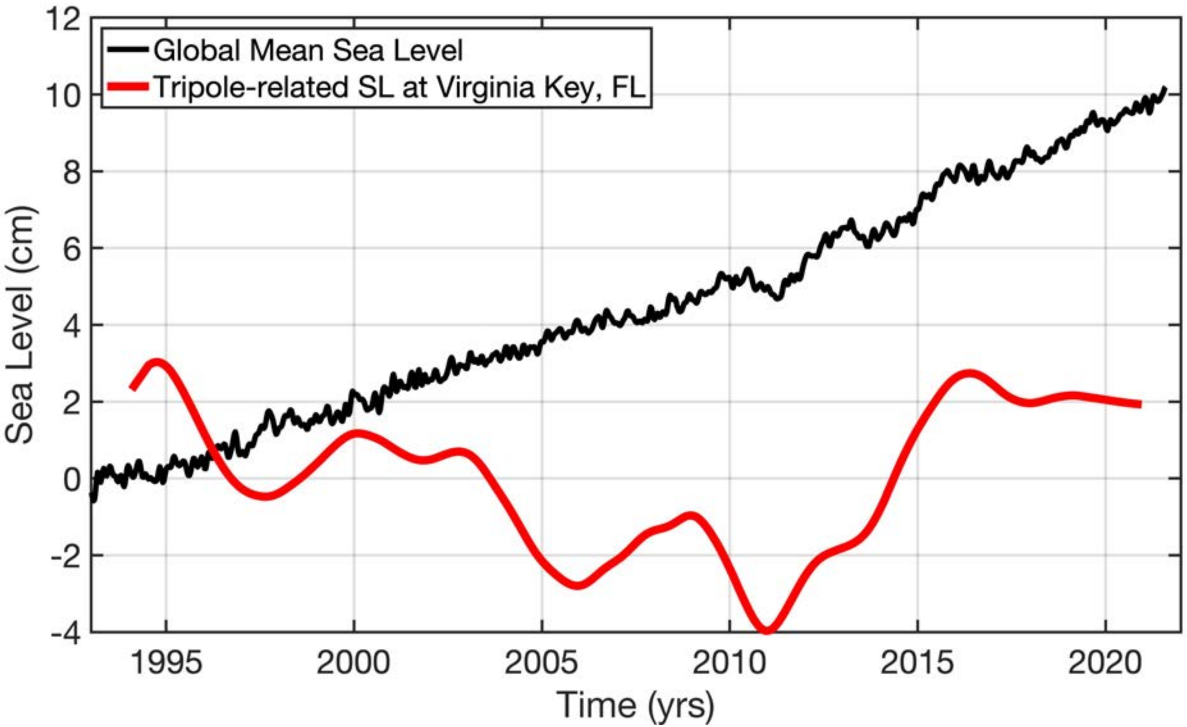


- The NA SSH Tripole explains 60-80% of the local interannual coastal sea level variance south of Cape Hatteras, in the Gulf of Mexico, and in the western Caribbean
- The NA SSH Tripole is correlated with the interannual-to-decadal changes of sea level measured by tide gauges along the U.S. southeast and Gulf coasts

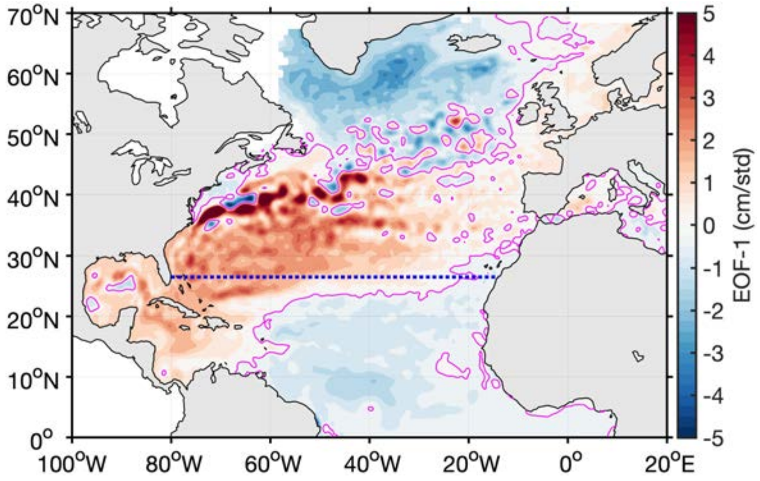
4. The North Atlantic Sea Surface Height Tripole vs GMSL

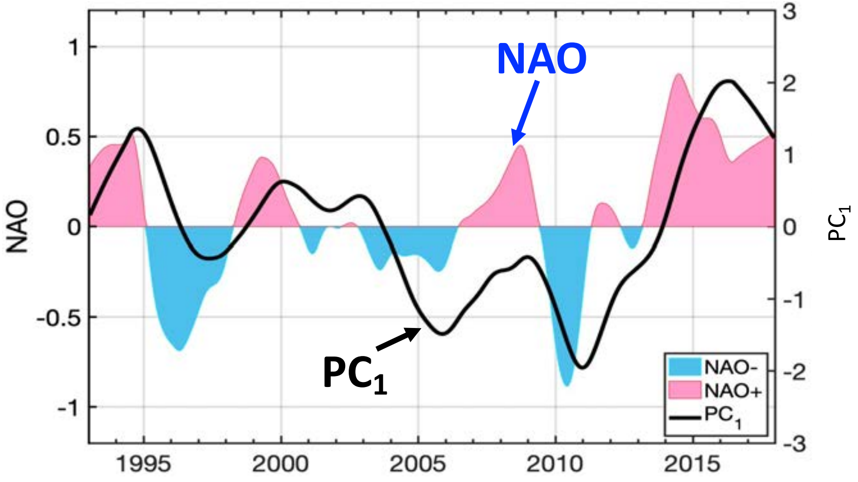
Virginia Key tide gauge, Miami, FL

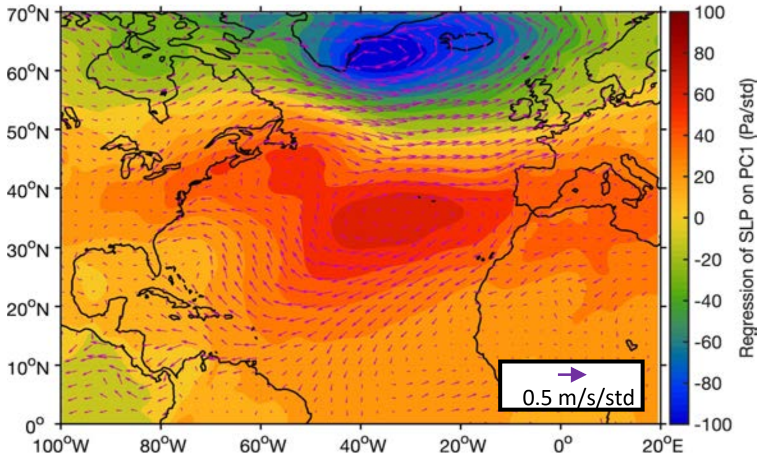
Superimposed on the GMSL rise, the tripole-related sea level changes provide background conditions that can favor coastal inundations



5. Forcing Mechanisms for the North Atlantic SSH Tripole







The NA SSH tripole is related to the low-frequency NAO (r=0.7 at 9-mth time lag) → adjustment of the large-scale horizontal and overturning ocean circulation to variable surface buoyancy and wind forcing

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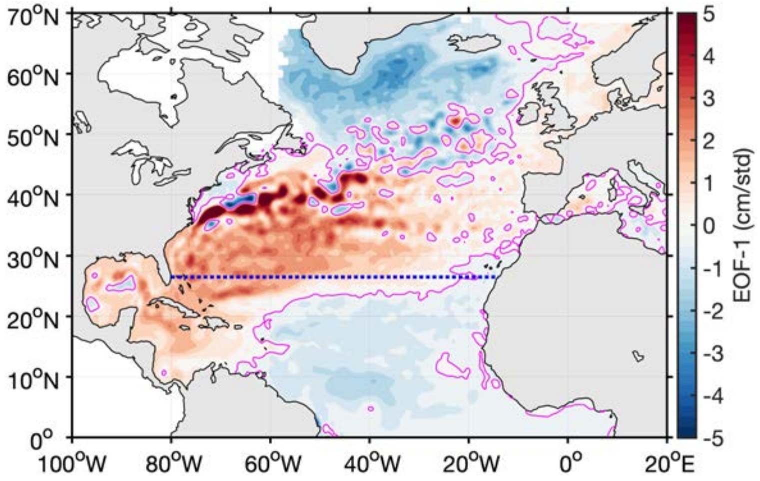
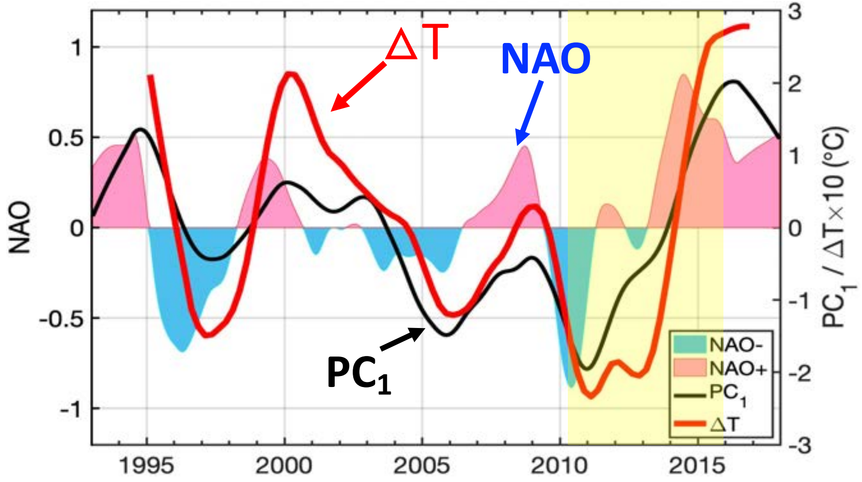
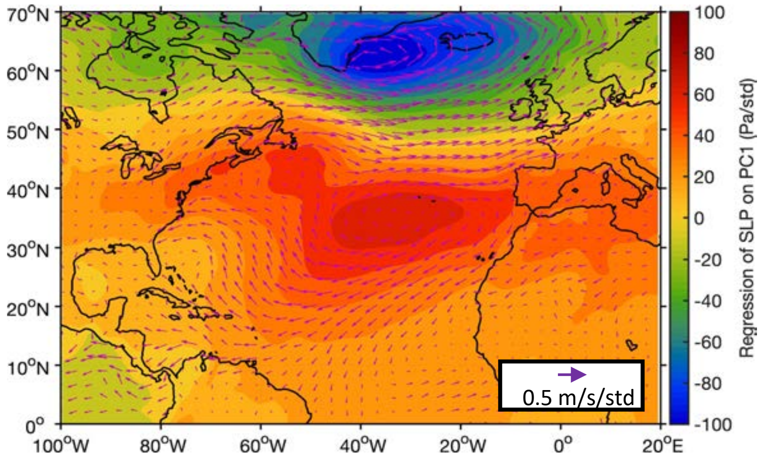
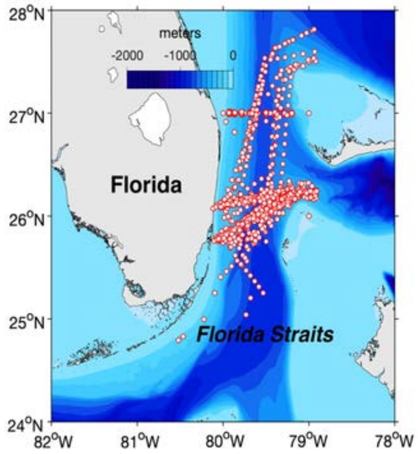






- The NA SSH tripole is correlated with the full-depth temperature in the Florida Straits (no Argo data there!)
- Sea level rise in 2010-2015 along Florida east coast was due to warming (Domingues et al., 2018)



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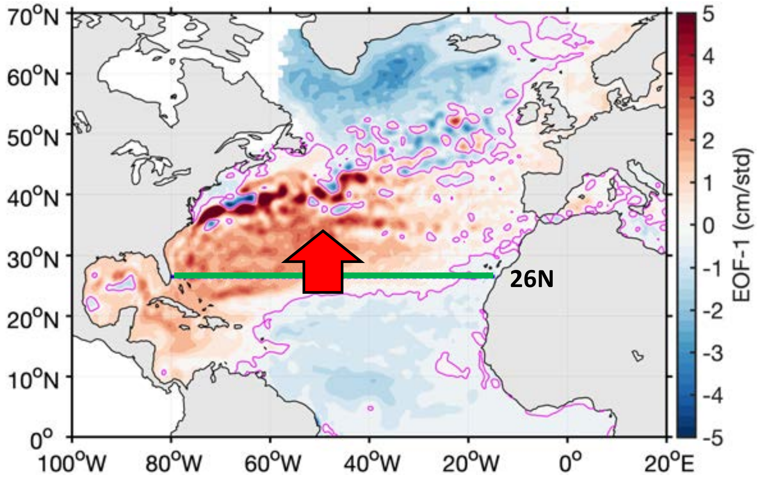
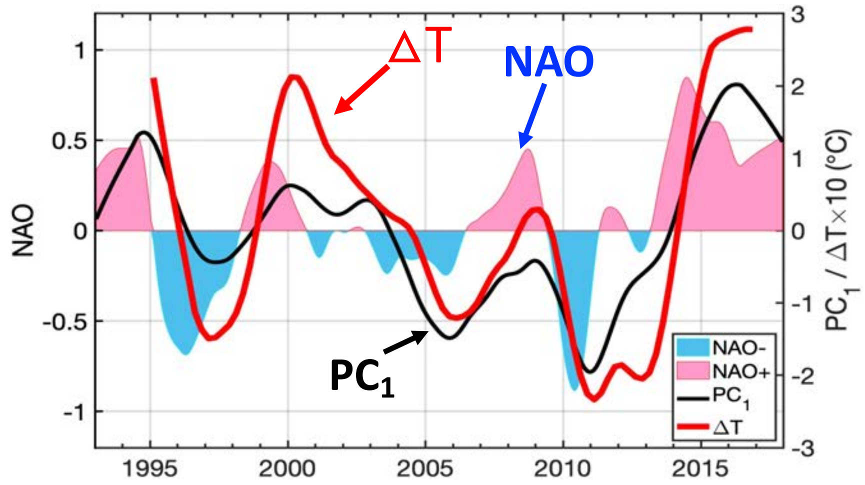
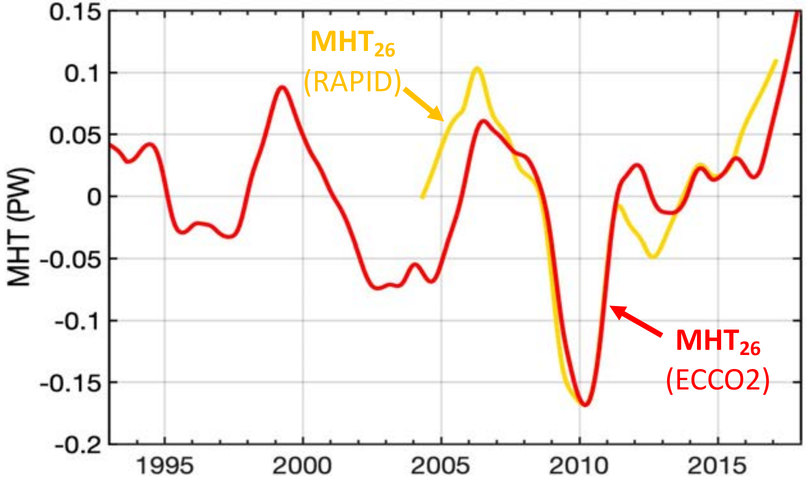
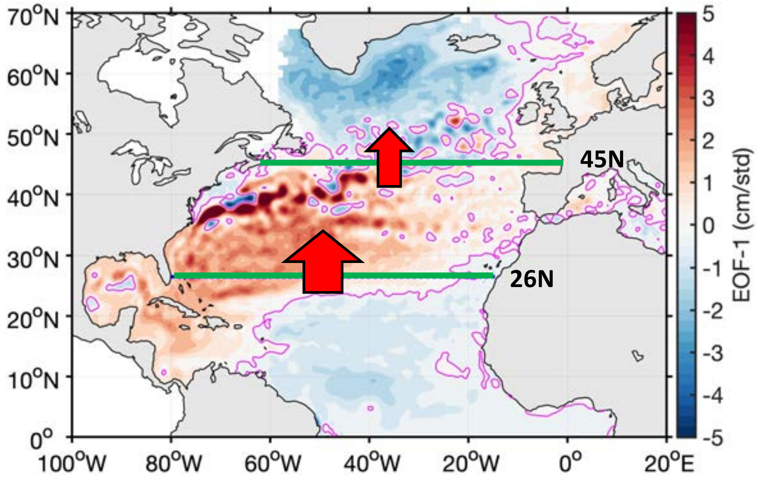


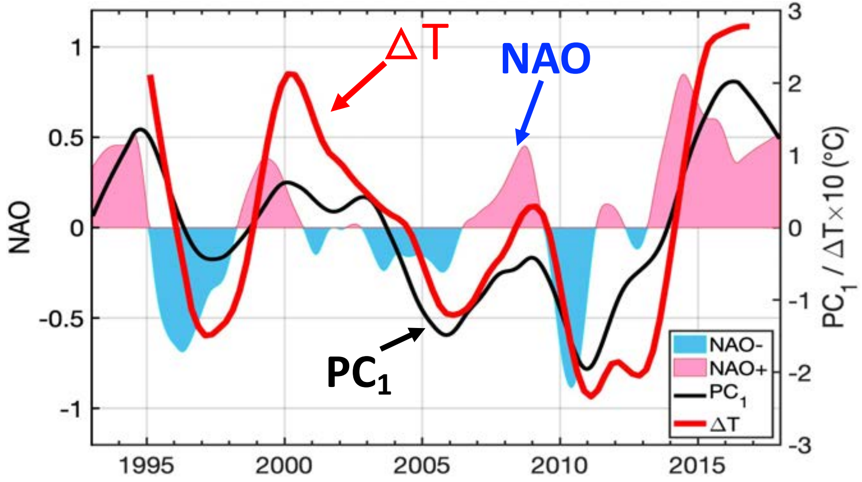
- ECCO2 model realistically reproduces Meridional Heat Transport (MHT) anomalies at 26N → (assumption) can be used for other time periods and at other latitudes

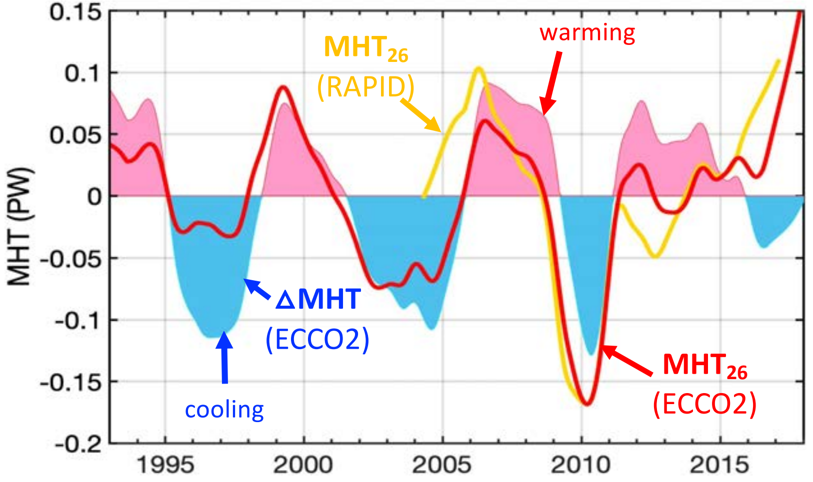




5. Forcing Mechanisms for the North Atlantic SSH Tripole



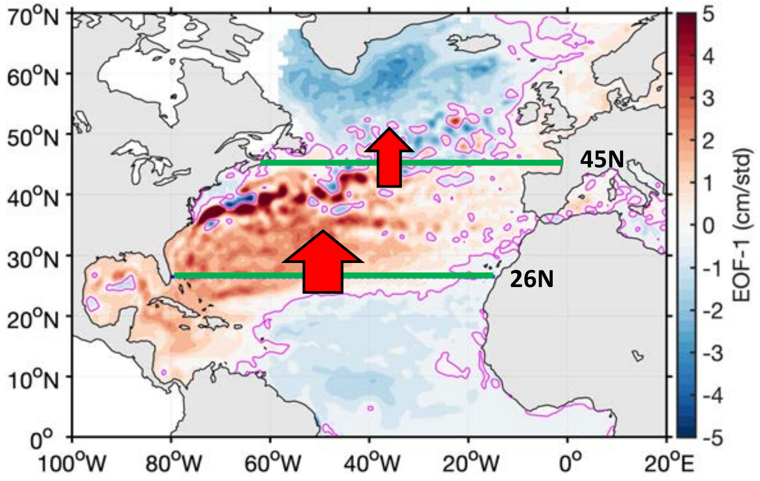


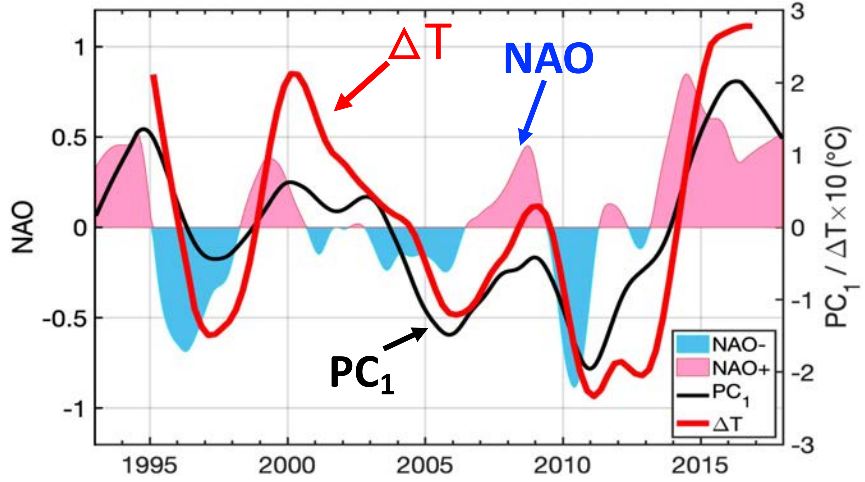


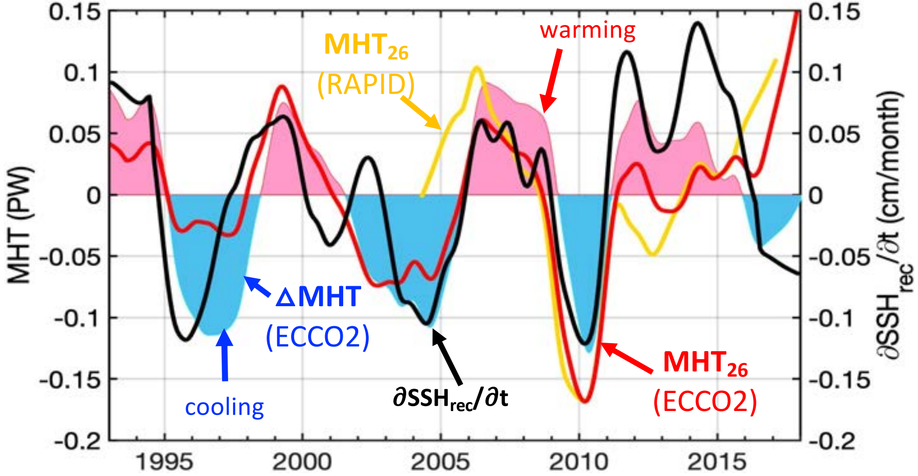
- ECCO2 model realistically reproduces Meridional Heat Transport (MHT) anomalies at 26.5N → (assumption) can be used for other time periods and at other latitudes

- MHT at 26.5N determines the sign of heat divergence between 26-45N

5. Forcing Mechanisms for the North Atlantic SSH Tripole







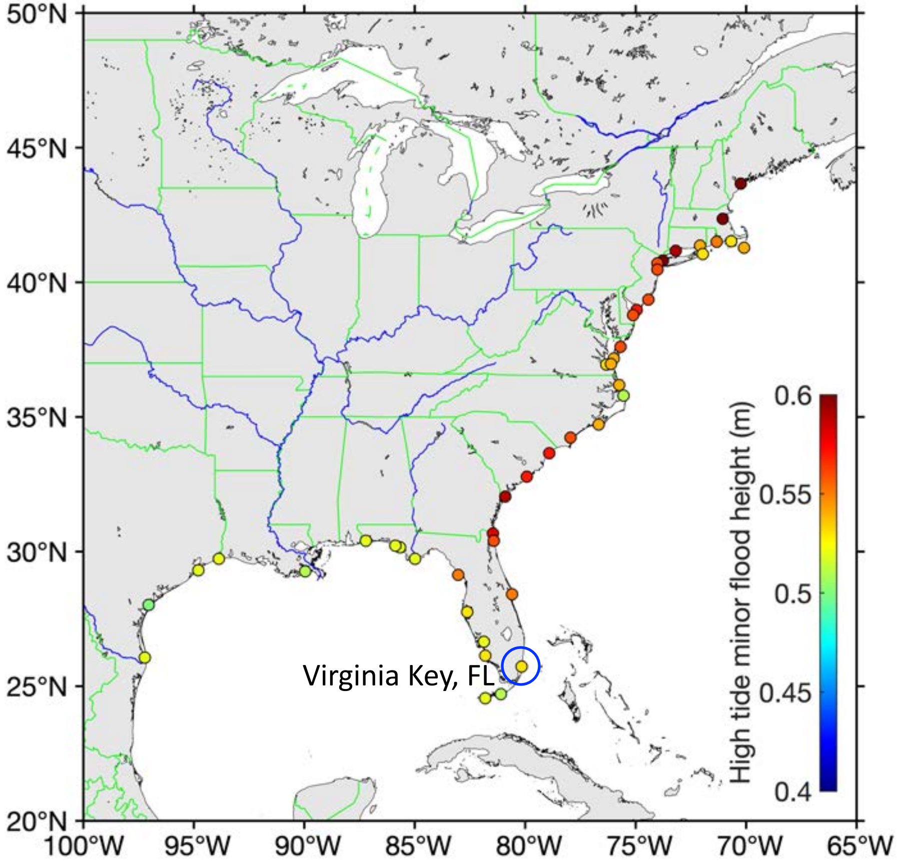
- ECCO2 model realistically reproduces Meridional Heat Transport (MHT) anomalies at 26.5N → (assumption) can be used for other time periods and at other latitudes

- MHT at 26.5N determines the sign of heat divergence between 26.5-45N

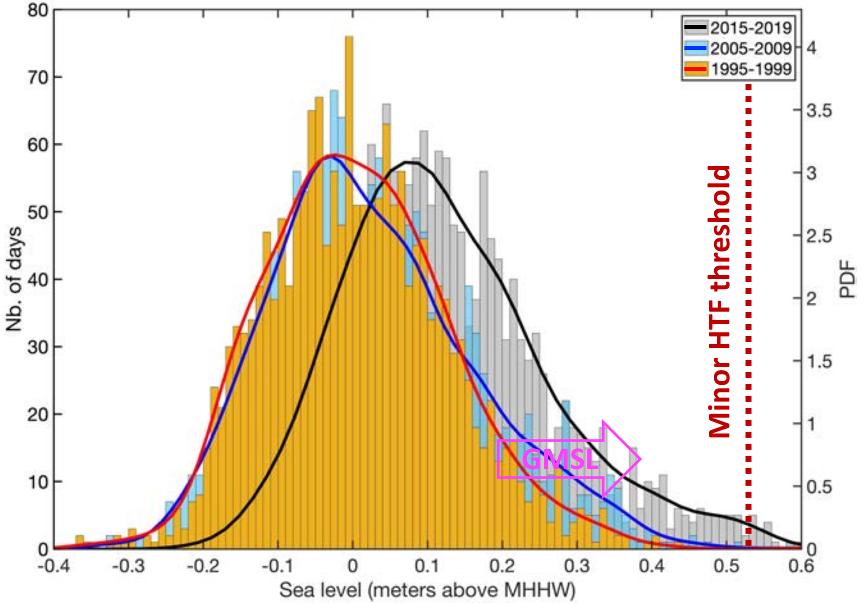
- Sea level changes in the subtropical band of the NA SSH Tripole are largely driven by the MHT divergence

6. Impact of the North Atlantic SSH Tripole on Coastal Inundations

Minor flood thresholds from Sweet et al. (2022)



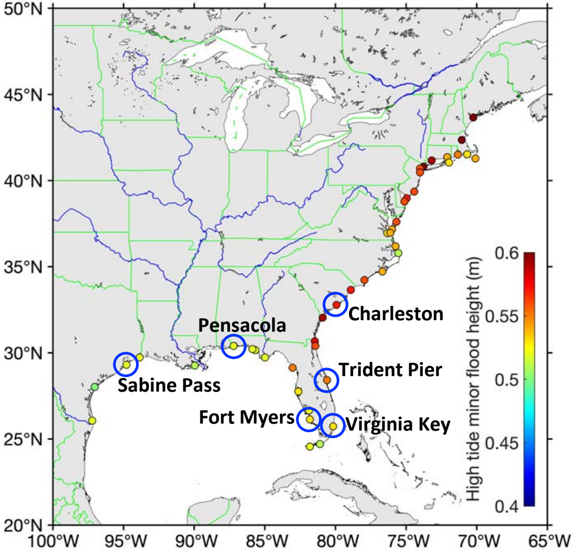
Virginia Key, FL

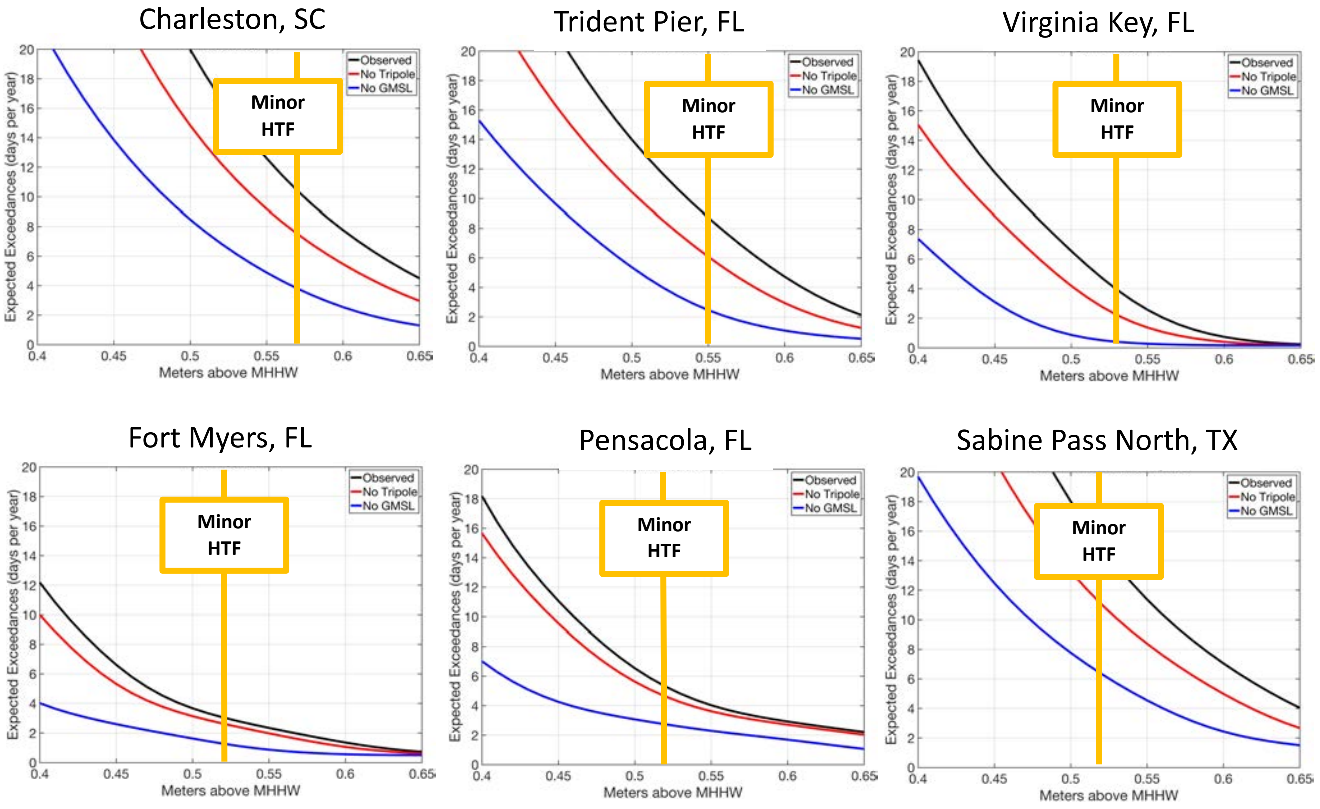


- Because of the GMSL rise, storm surges and high tides are now more likely to exceed flooding thresholds and cause coastal inundations
- Hypothesis: Even a few cm sea level changes due to the NA SSH tripole can become an important factor

6. Impact of the North Atlantic SSH Tripole on Coastal Inundations

Expected exceedances (days/yr) for daily highest water levels in 2015-2020 for: (i) observed, (ii) without the tripole, and (iii) without the GMSL records





In 2015-2020, the NA SSH tripole accounted for 30-50% of flooding events along the U.S. southeast and Gulf coasts relative to what was caused by the GMSL rise alone since 1993

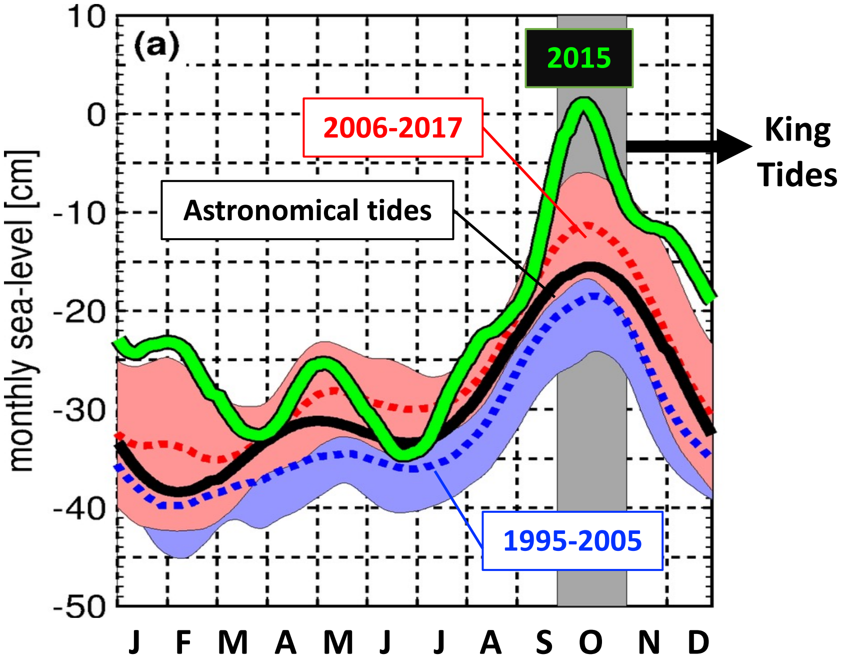
6. Impact of the North Atlantic SSH Tripole on Coastal Inundations

2017 King Tide in Miami Beach

Photo by Grant Rawson (NOAA/AOML)

2015 King Tide in Miami

Monthly Sea-level in Miami

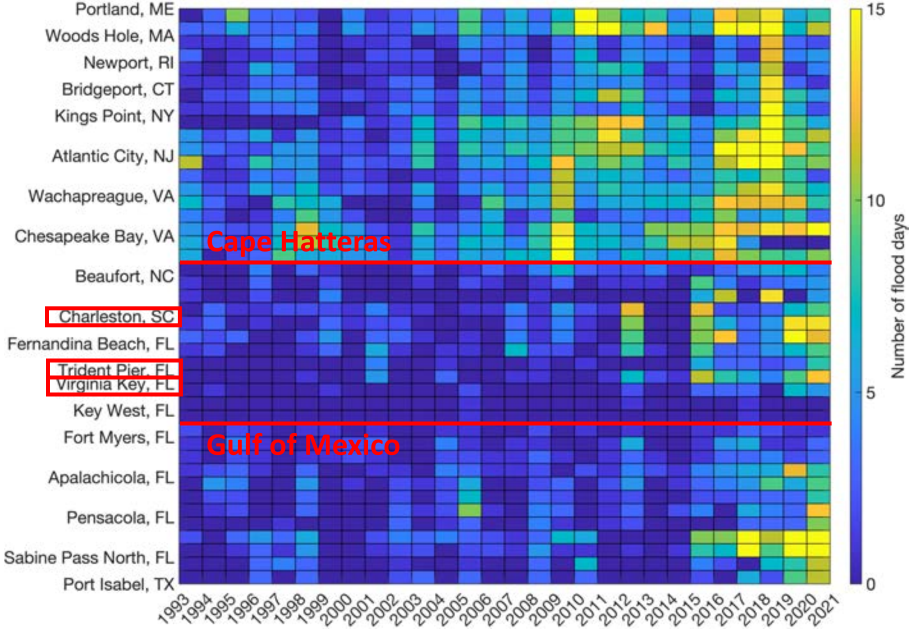


Credits: R. Domingues

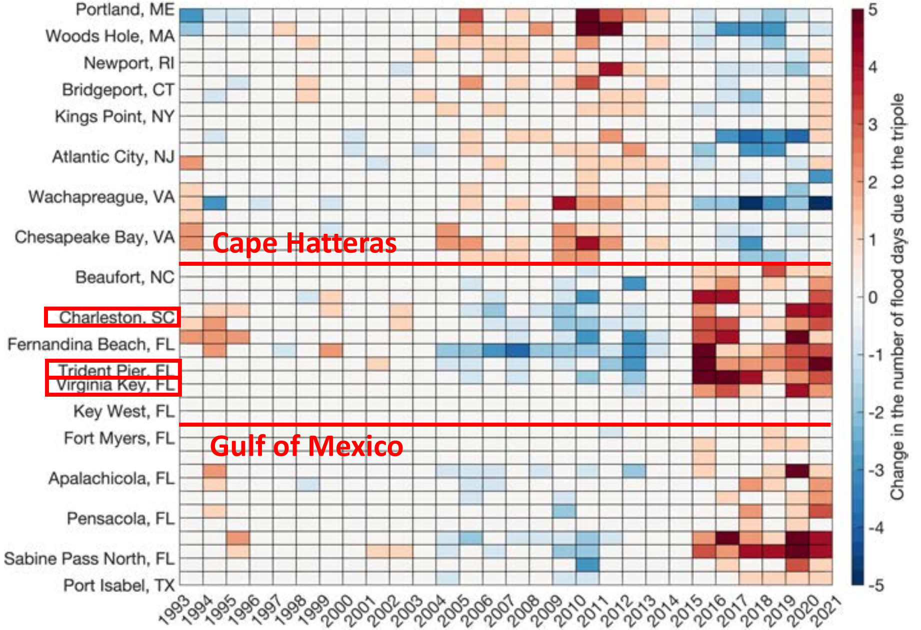
Extremely high 2015 King Tides in Miami were the result of the combined effect of the global mean sea level rise and the North Atlantic SSH Tripole

6. Impact of the North Atlantic SSH Tripole on Coastal Inundations

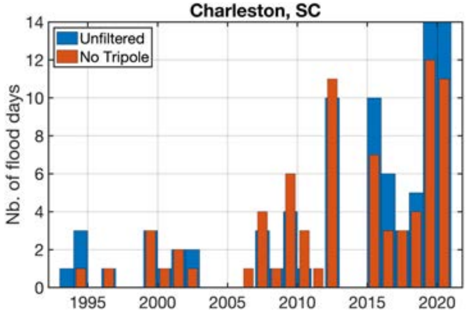
Number of flood days per year

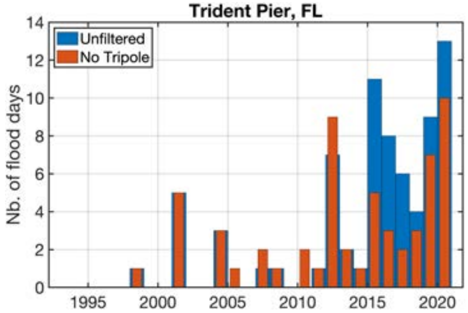


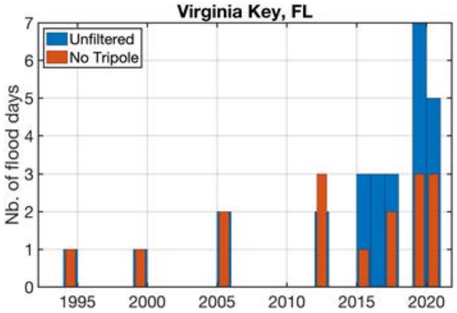
Number of flood days per year due to the tripole



The impact of the NA SSH tripole on the frequency of flooding events has become important since the mid-2000s







7. Summary and Conclusions

- The leading mode of the interannual sea level variability in the NA represents a TRIPOLE pattern partly driven by the AMOC and influenced by the NAO-controlled low-frequency atmospheric circulation

- Due to the GMSL rise, the TRIPOLE has impacted the frequency of flooding events along the U.S. East and Gulf coasts since mid-2000s

- In 2015-2020, the TRIPOLE was responsible for 30-50% increase in the frequency of flooding events south of Cape Hatteras and along the Gulf coast

- To improve the predictability of coastal inundations, it is necessary to account for large-scale SSH variability patterns superimposed on the GMSL

Acknowledgements: This research has been funded by the NOAA Climate Variability and Predictability program (grant number NA20OAR4310407)