Improvements in Estimating Upper Ocean Heat Content in the North Atlantic Ocean with the NOAA Next-Generation Enterprise Ocean Heat Content Algorithm

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Overview

Motivation: Improve tropical storm prediction at NOAA — Particularly rapid intensification and weakening

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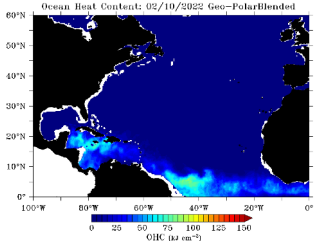

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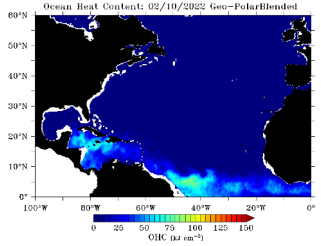
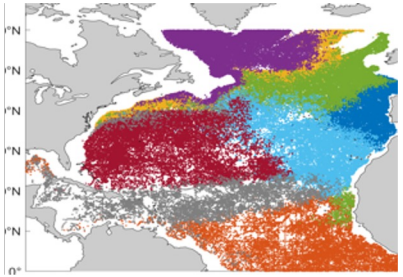


Method: Use a variety of modern techniques including the Geostrophic Empirical Mode (GEM) and AI/ML to:

1) Quality control Θ & S profiles

2) Identify hydrographic regimes

3) Construct lookup tables



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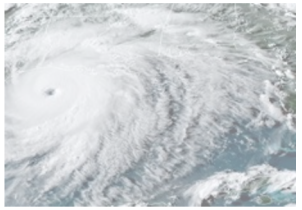

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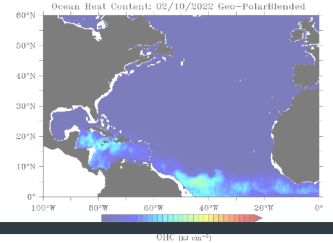

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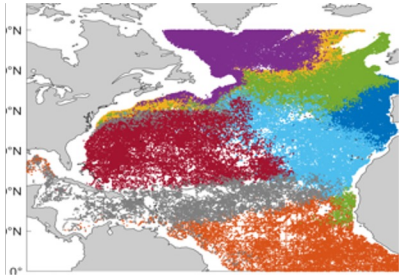
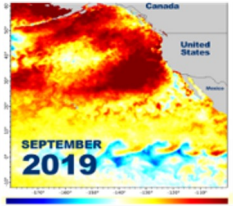
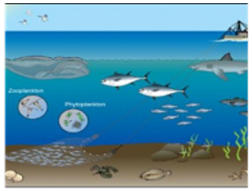


Many applications for Ocean Heat Content across forecasting, monitoring, and planning domains

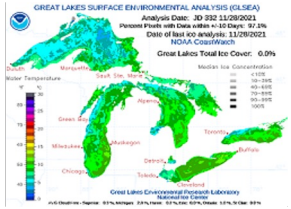
HURRICANE INTENSITY



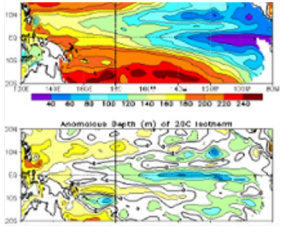
MARINE HEATWAVES



ECOSYSTEM MANAGEMENT (EBFM)

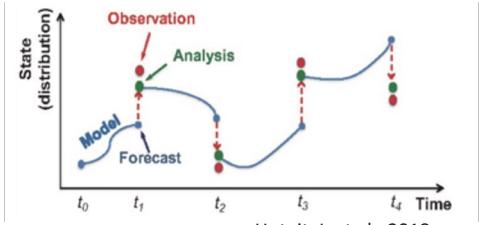


ICE EXTENT FORECASTING



METRICS
(A SUBSTITUTE FOR REANALYSES)

PLANNING RESILIENT COASTAL INFRASTRUCTURE



Hoteit, I. et al., 2018

DATA ASSIMILATION

INFORMING RISK ESTIMATES

-Citation for “Data Assimilation” picture: Hoteit, I. et al., 2018: Data assimilation in oceanography: Current status and new directions. In “New Frontiers in Operation Oceanography”, doi:10.17125/gov2018.ch17.

What is the **Next Generation Enterprise Ocean Heat Content** (NGE OHC) Product?

A statistically robust, observationally-based daily estimate of ocean thermohaline conditions ($\Theta(z)$, $S(z)$) to ~1800 m, with a focus on high accuracy in the upper ocean.

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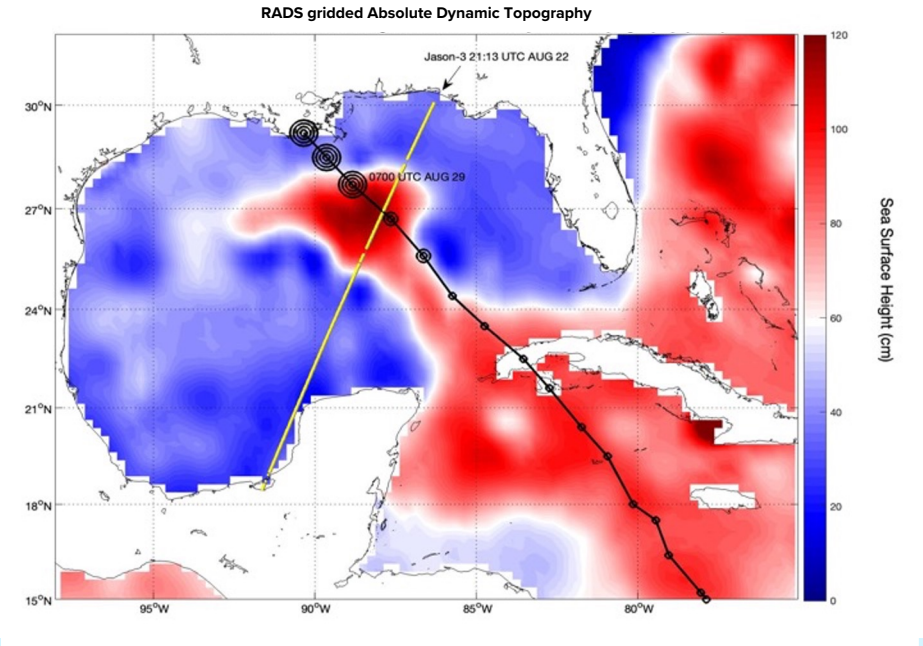
Case study (Hurricane Ida): 2021-08-29 – category 4 at landfall



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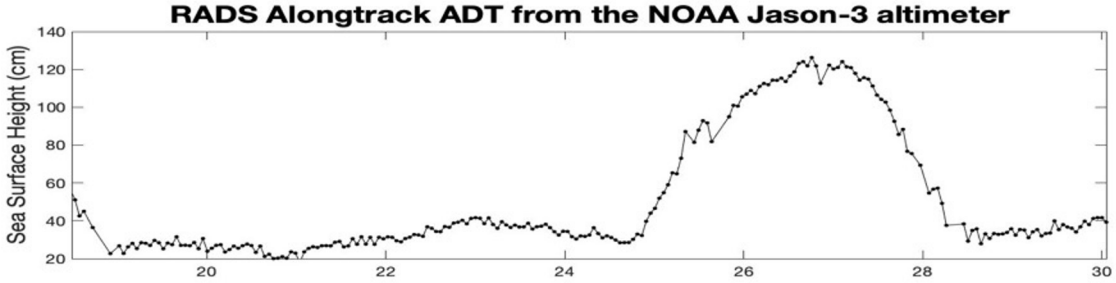

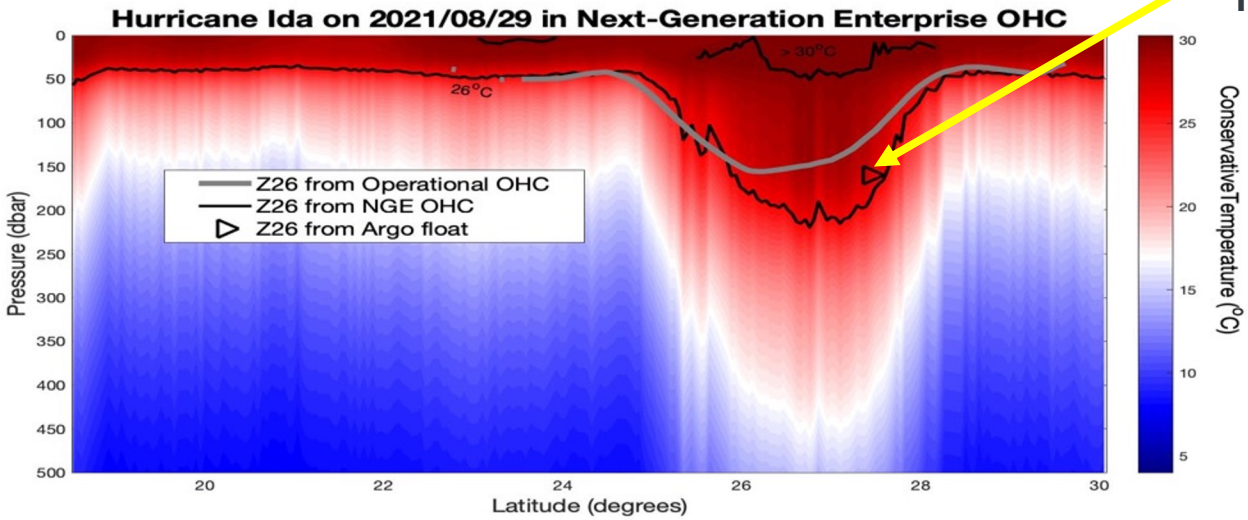

Argo float measurement

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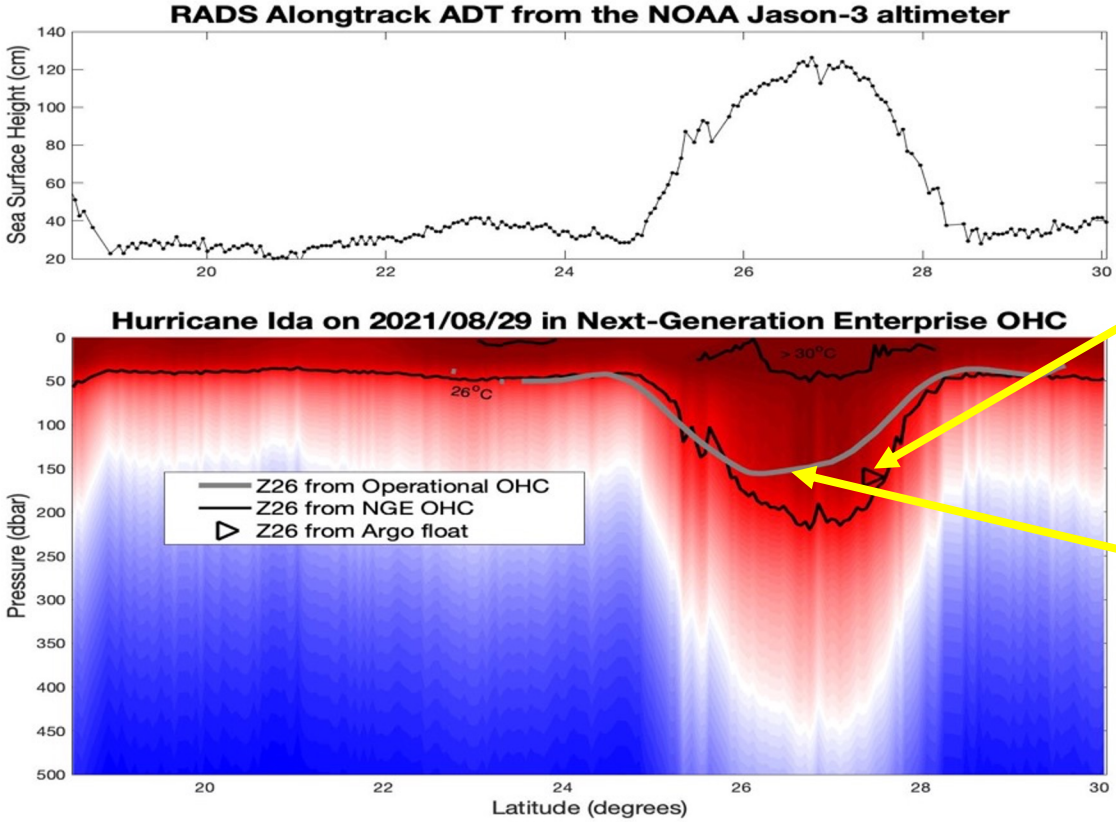

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Current operational product (Z_{20}, Z_{26}, Mixed Layer Depth (MLD) only)

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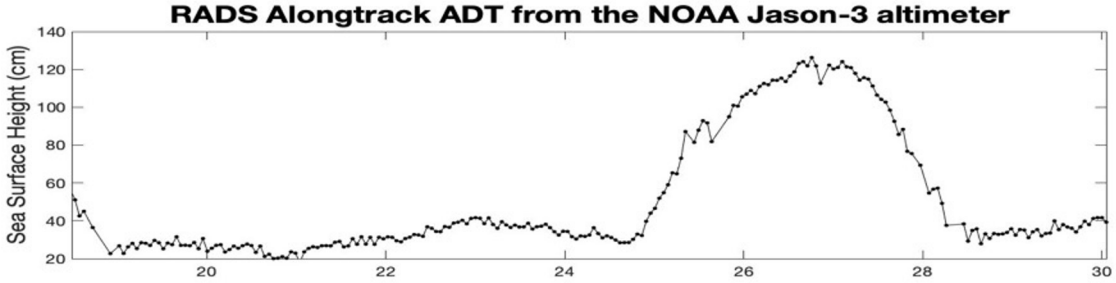

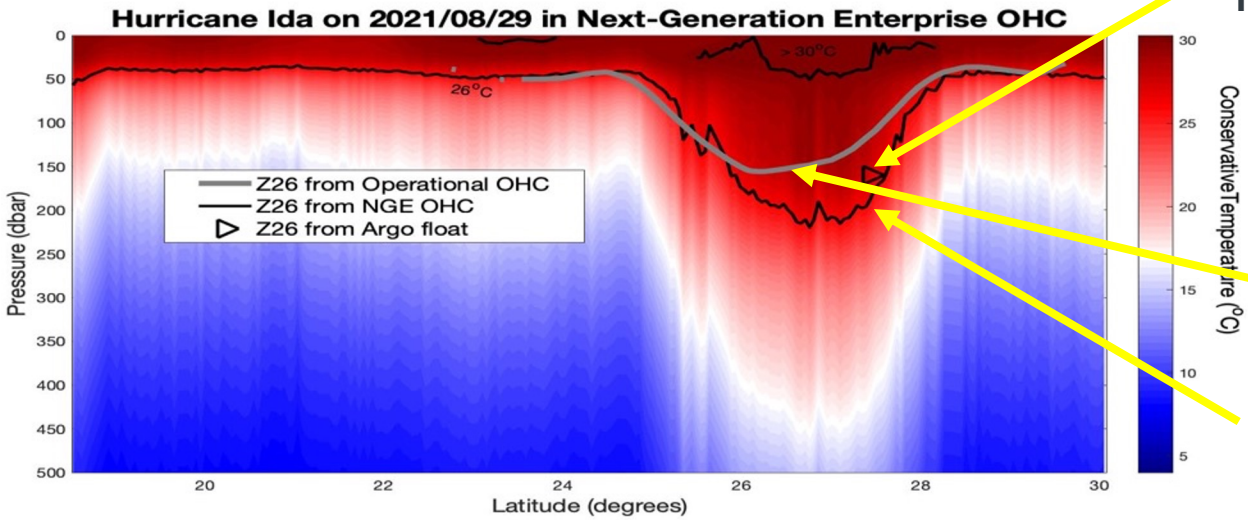

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Derived from the 2 dbar NGE OHC

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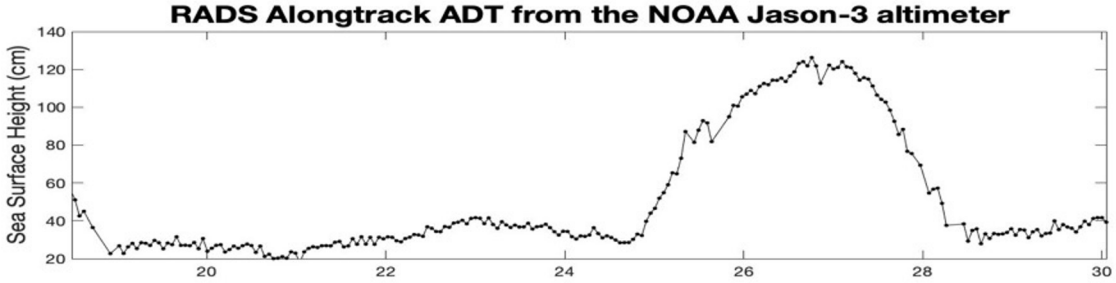

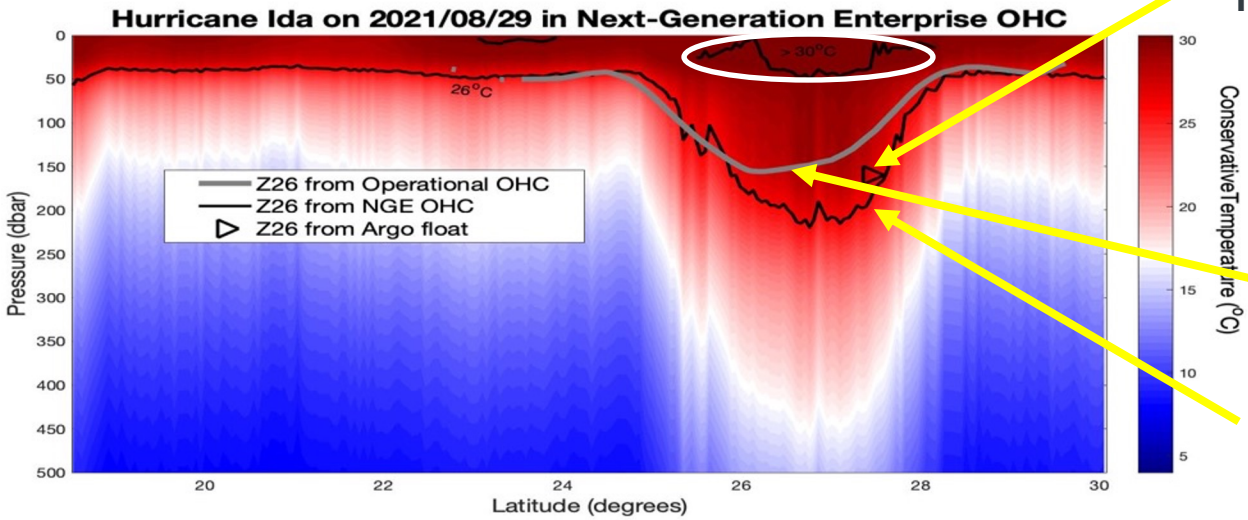

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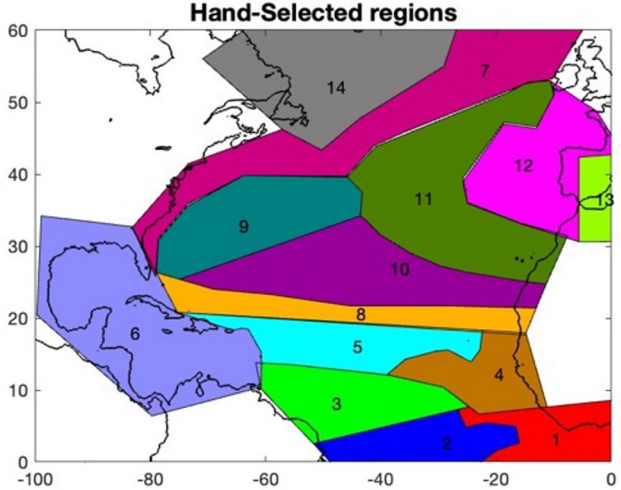
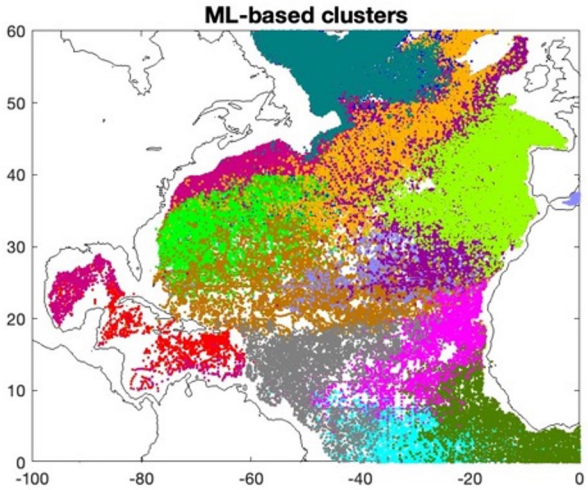
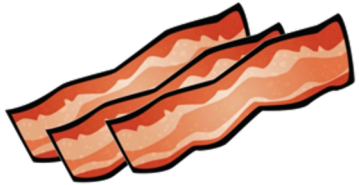
How does the NGE OHC Work?
Uses the *BLT method*
(a meaty sandwich with trimmings)

Byrne
Lavin
Trossman

Collect a large database of ocean profile data. Apply a method to divide it up into hydrographically (dynamically) similar regions:







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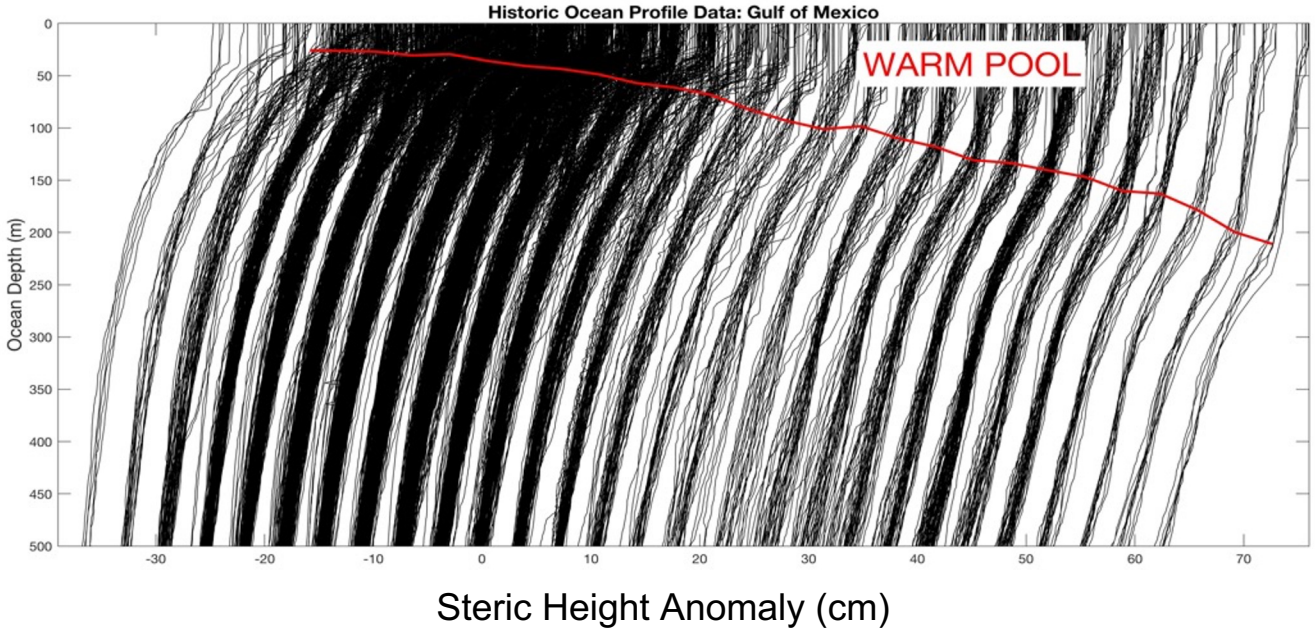
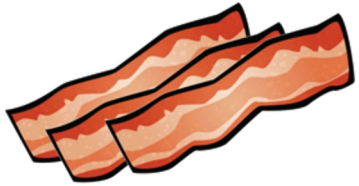


Tropical Cyclone Heat Potential (TCHP) is the amount of energy above the red line (26°C isotherm)

Collect a large database of ocean profile data. Organize it with respect to a parameter of interest, in our case **Steric Height Anomaly (SHA)**



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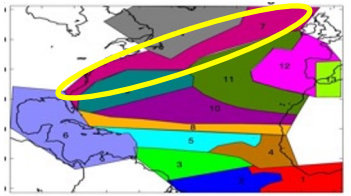
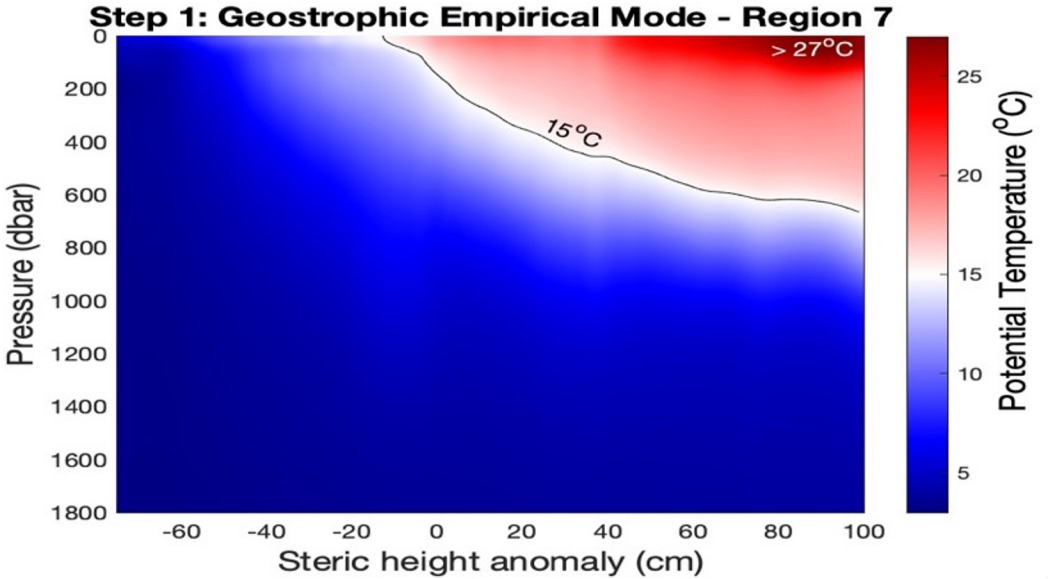
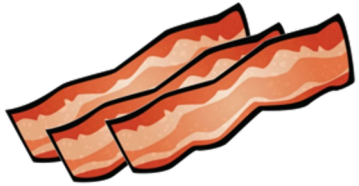




For each region/cluster, create a lookup table based on ocean profile data



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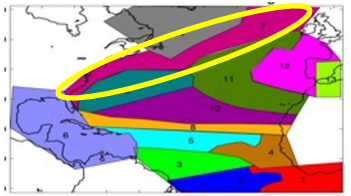
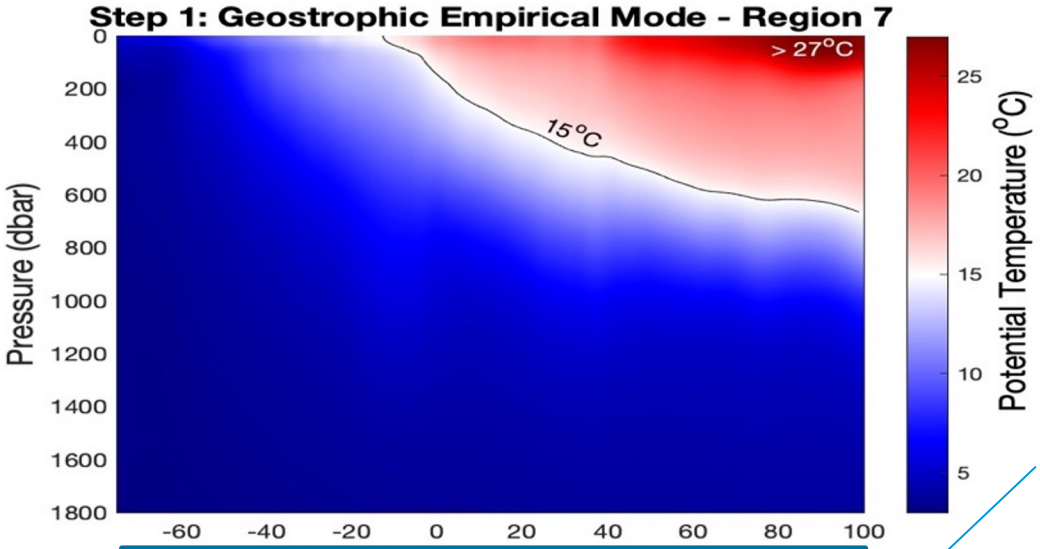




Missing signal of steric variability > 1800 dbar.

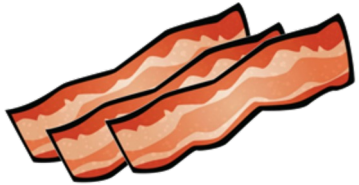
Using coincident ocean profile and Absolute Dynamic Topography (ADT) data, we map ADT to steric height at our chosen reference level (a linear fit is usually fine):

M*ADT + B = SHA

Correlated variability below the reference level adds to the slope. Uncorrelated variability adds to the noise.

Typical value of M: 1.03

(B depends only on how we referenced steric height.)



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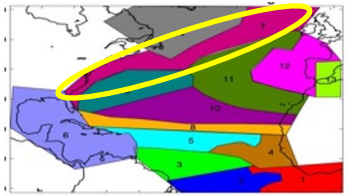
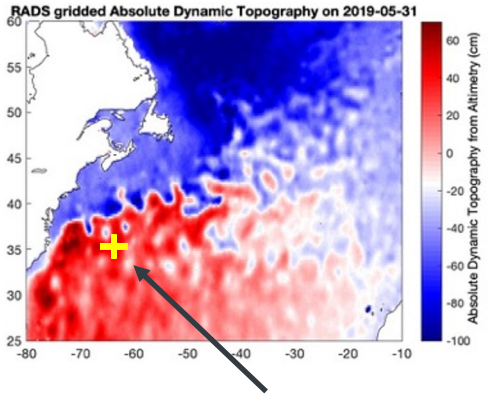
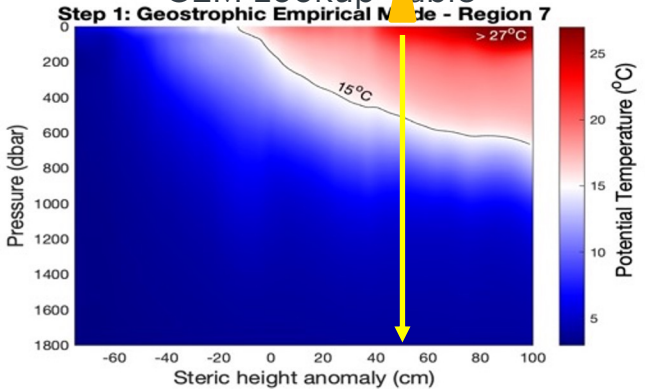


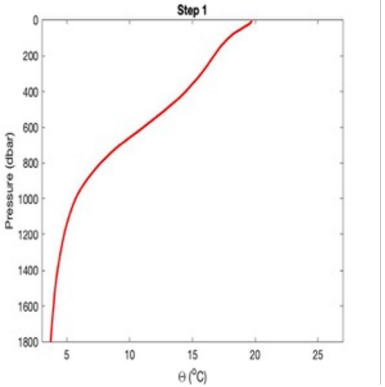
Absolute Dynamic Topography – from the Radar Altimeter Database System (RADS)



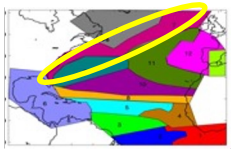
Sample location: 36°N, 65°W

GEM Lookup Table

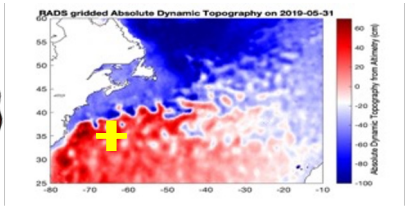


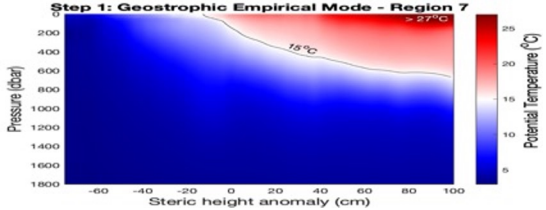


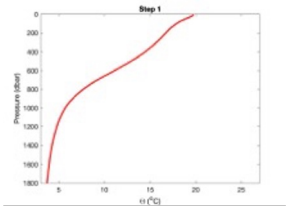
GEM is the meat of the algorithm



ADT

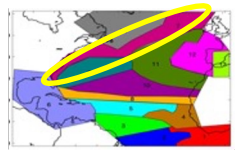






Goal: A set of lookup tables for each region


? … now fit residuals



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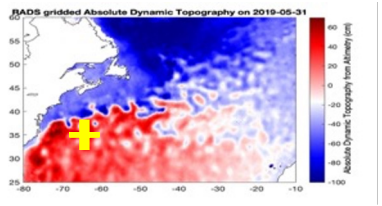
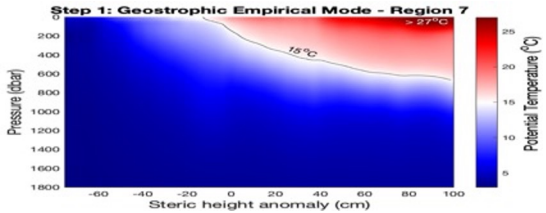
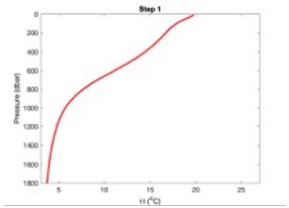
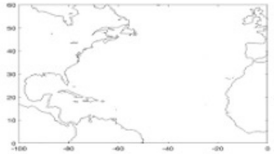
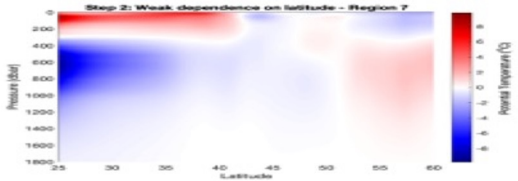


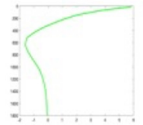




Latitude







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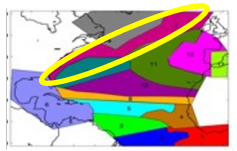

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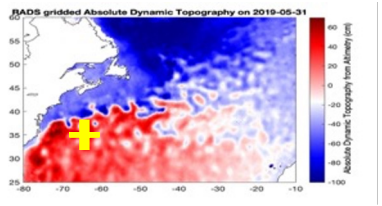

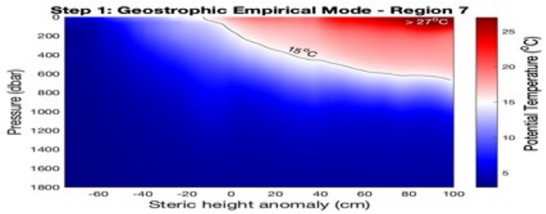

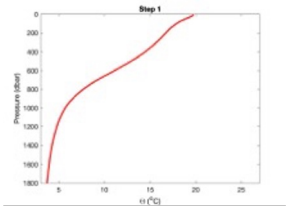

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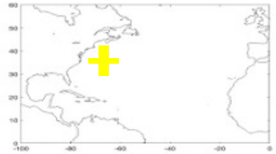
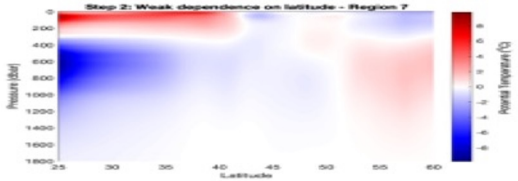
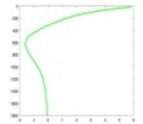
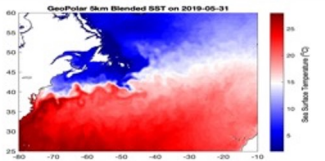
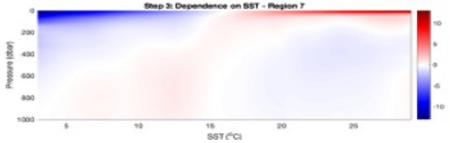


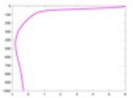




Sea Surface Temperature – from NOAA's 5 km GeoPolar blended SST

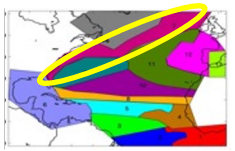




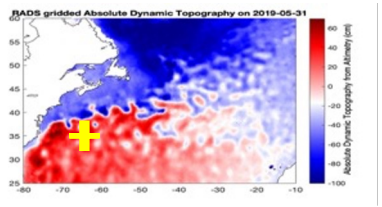


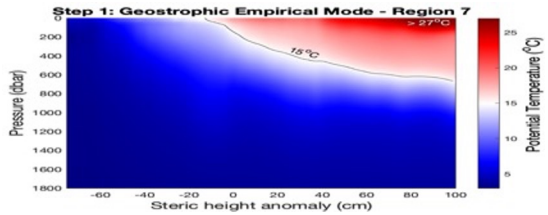
Goal: A set of lookup tables for each region

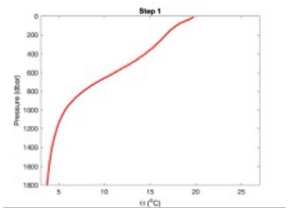

? … now fit residuals



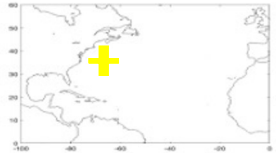
ADT

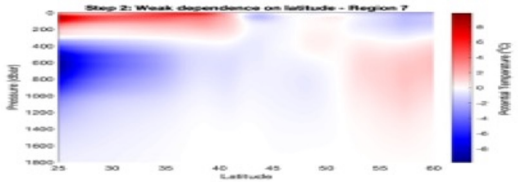


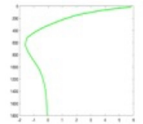




Latitude







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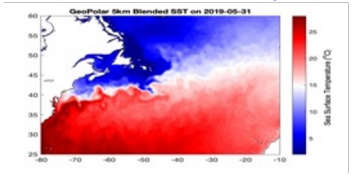
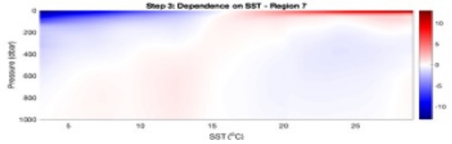
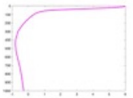
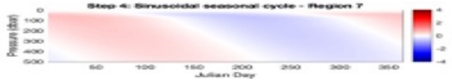






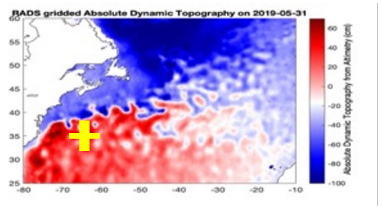
Julian Day

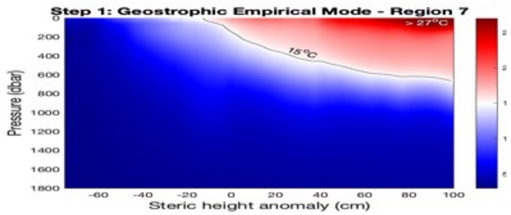


Goal: A set of lookup tables for each region

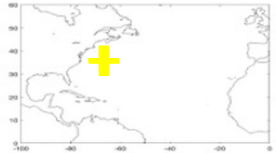

? … now fit residuals

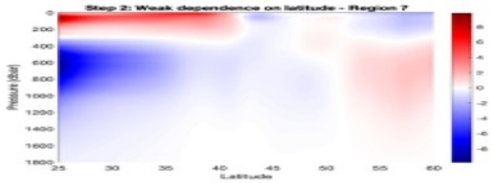
ADT

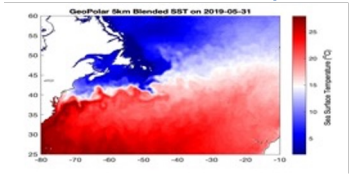


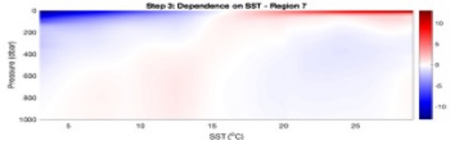
Latitude



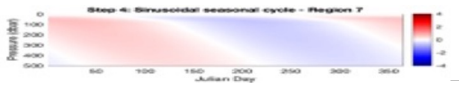


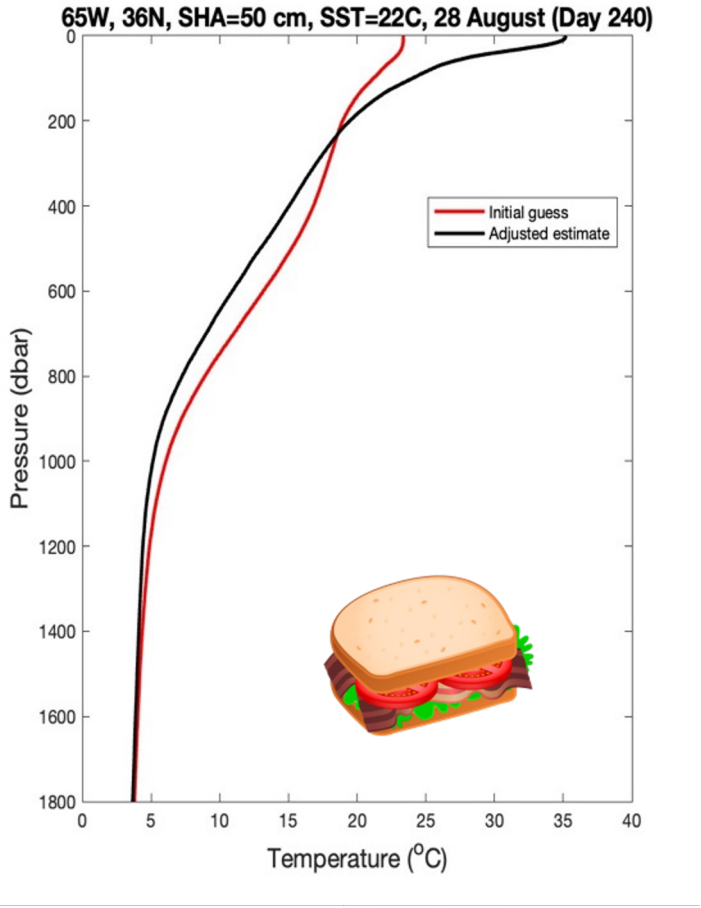
Sea Surface Temperature – from NOAA's 5 km GeoPolar blended SST





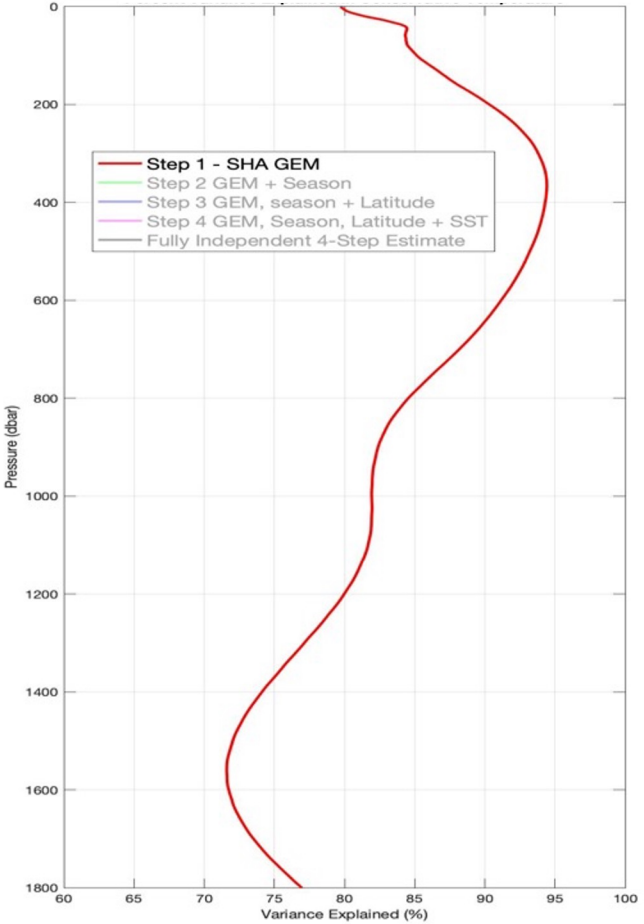
Julian Day



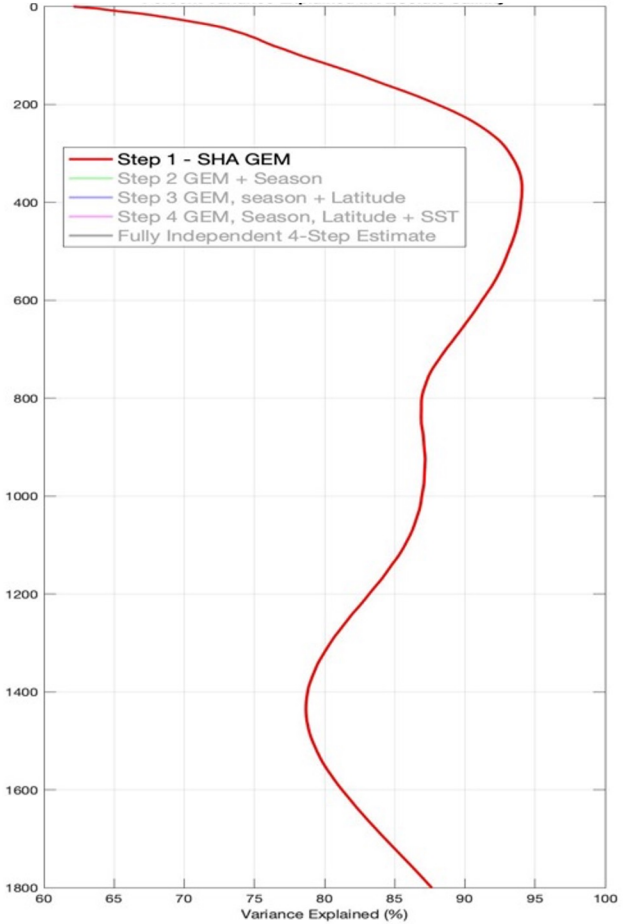


Goal: A set of lookup tables for each region

Conservative temperature (variance explained)

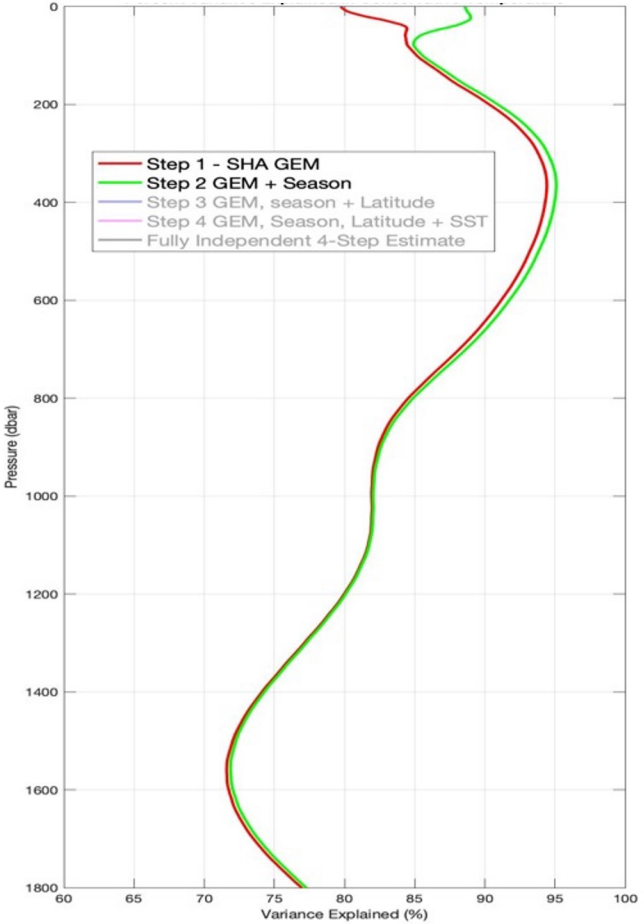


Absolute salinity (variance explained)



How well do the NGE OHC profiles represent ocean conditions?

Conservative temperature (variance explained)



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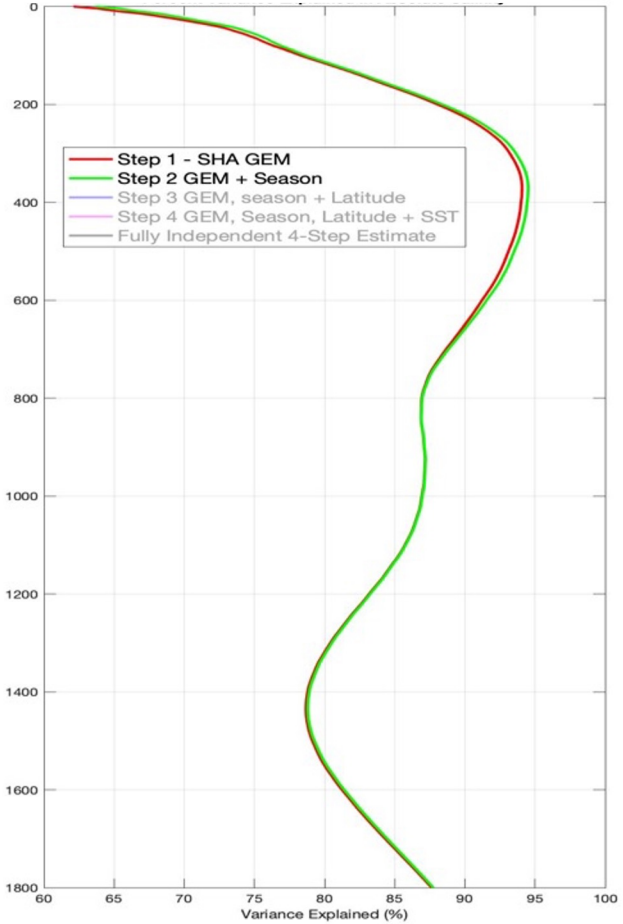

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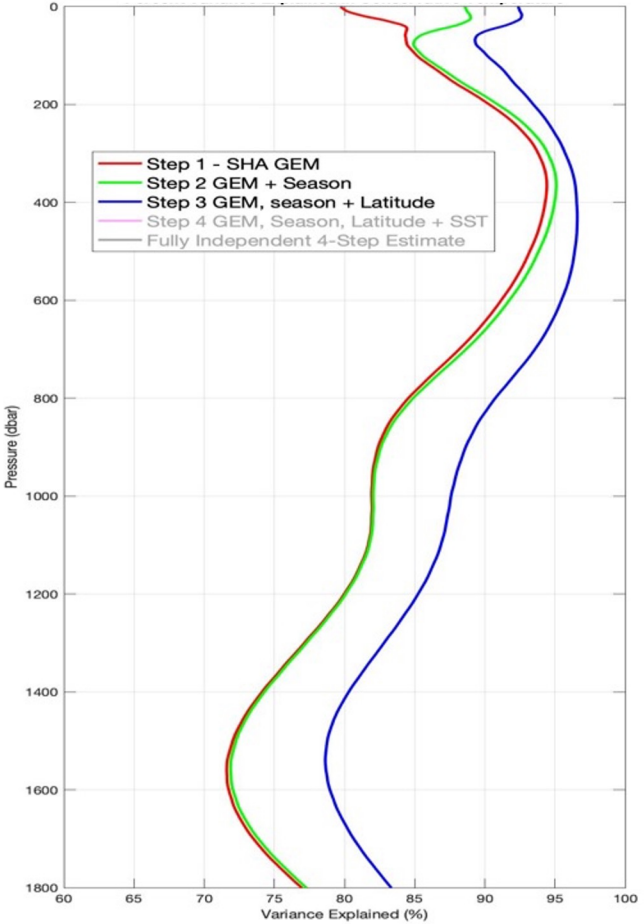

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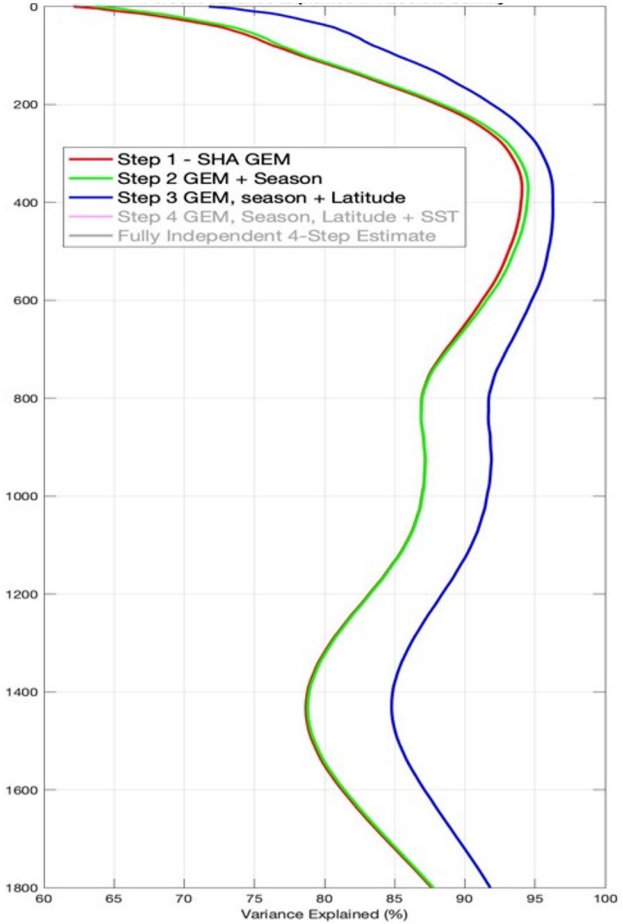

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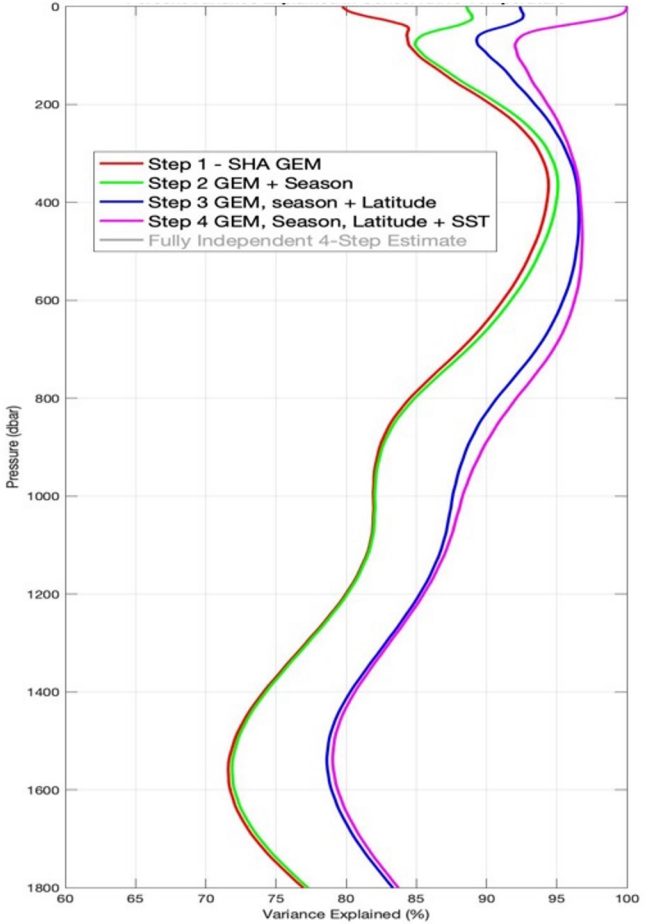
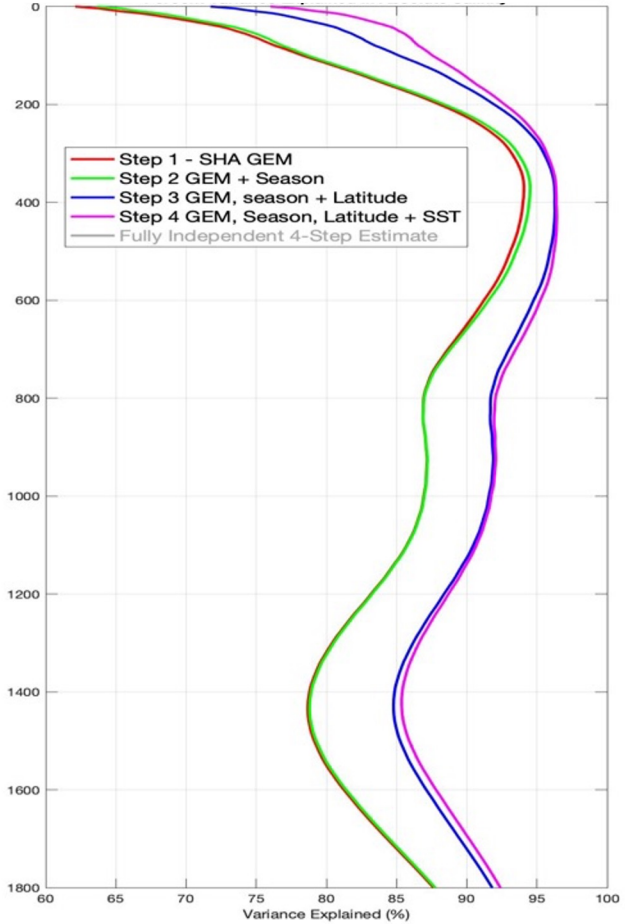
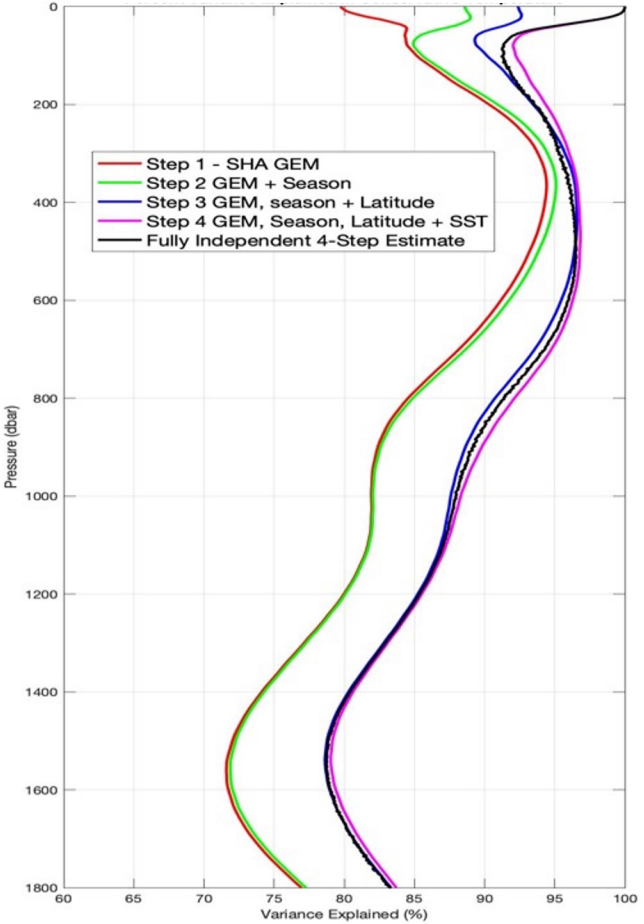


Absolute salinity (variance explained)



How well do the NGE OHC profiles represent ocean conditions?

Conservative temperature (variance explained)



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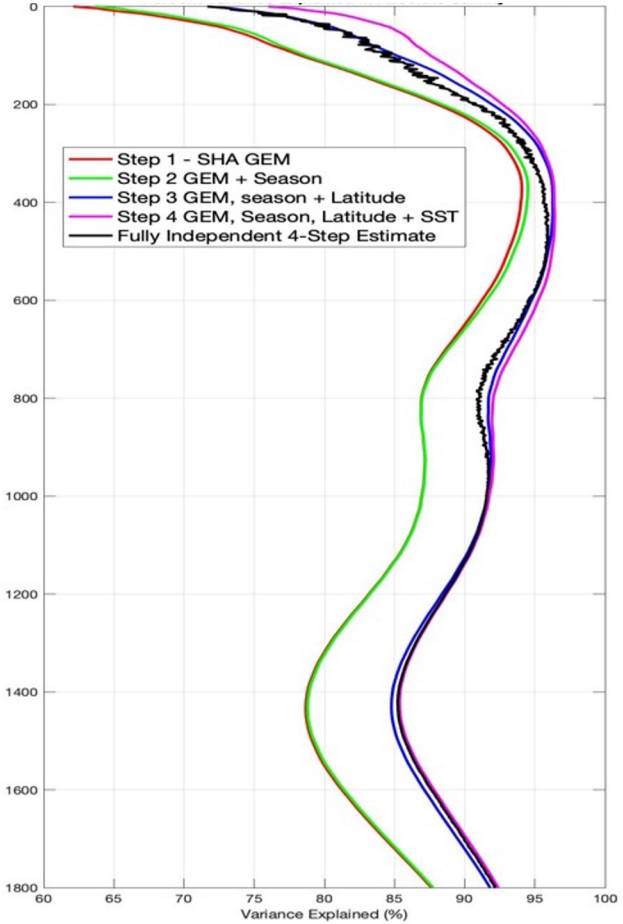

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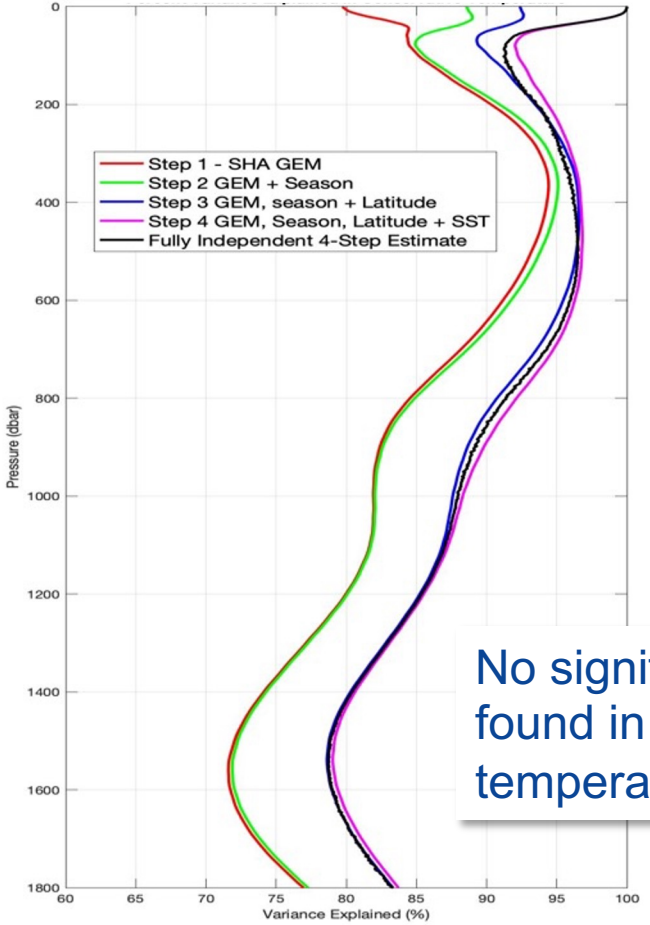

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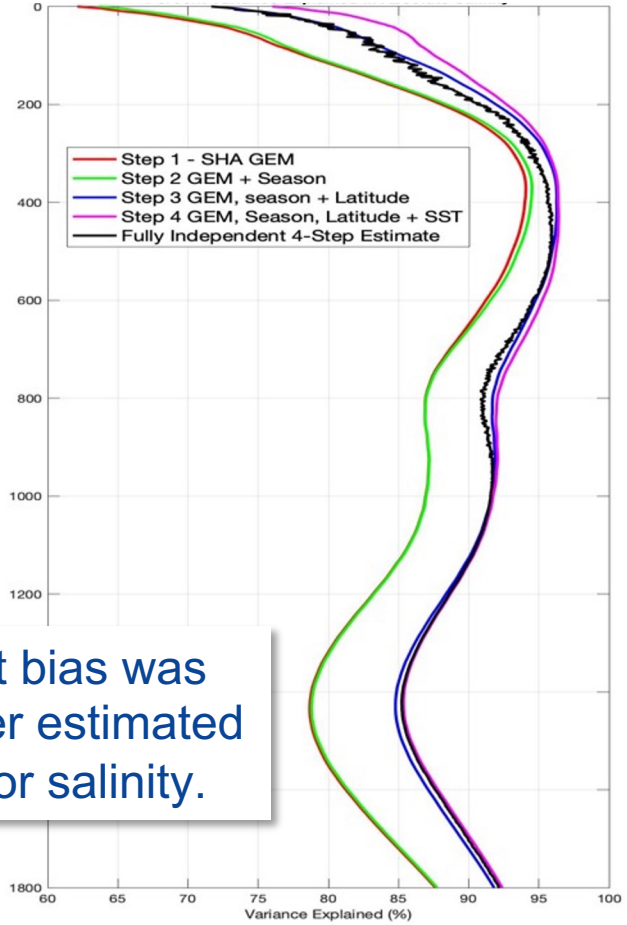


No significant bias was found in either estimated temperature or salinity.

How well do the NGE OHC profiles represent ocean conditions?

Summary and Conclusions

Adaptable algorithms are needed for a warming world

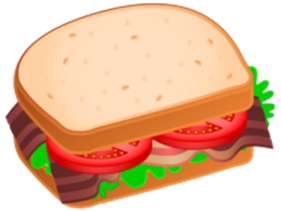
- Dynamically based NGE OHC better captures extremes
- Use of ML/AI allows for input of new profiles and annual updates to lookup tables
- Based on satellite inputs: RADS ADT & NOAA GeoPolar blended SST
- Good depth resolution in T/S allows OHC (TCHP) & MLD estimates and other metrics to be derived

Coming in 2023

- Finalize selection of (ML/AI) methods for clusters & residual lookup tables
- Daily ¼ degree gridded T(z), S(z) fields for the North Atlantic
- Daily 7-km along-track fields using RADS ADT: Jason-3, CryoSat-2, Sentinel-6 MF, Sentinel-3A,-3B, SARAL

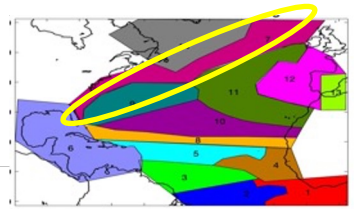
Future Work

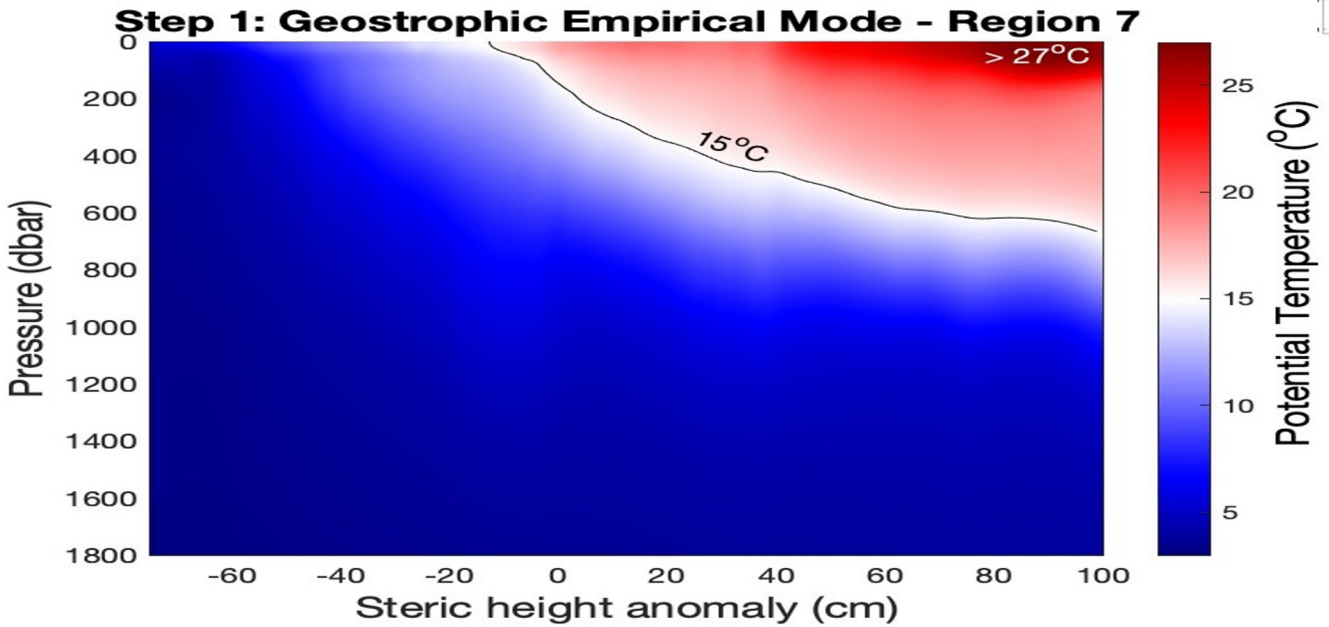
- Expansions: Global Open Ocean; Coastal Zone (< 1800 dbar)
- Error Estimates



BACKUP SLIDES

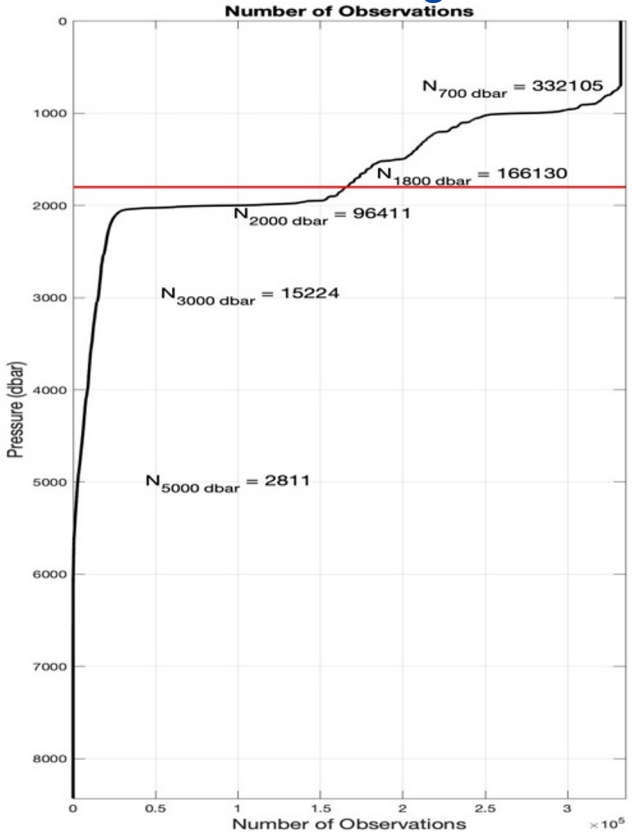
How does the NGE OHC Work?

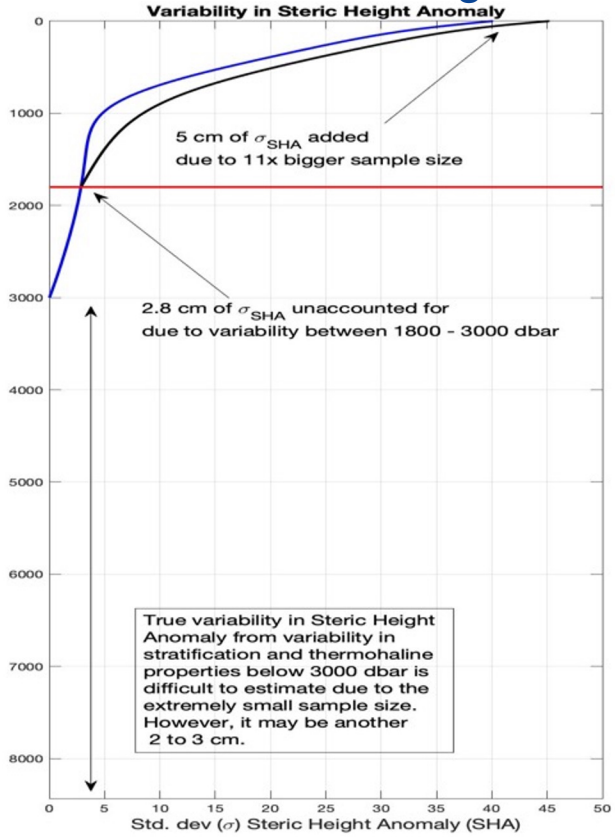




All variability that has a predictable sea surface height expression has been removed. **Anything left is density-compensated within the water column.**

The selected reference level is a trade-off between including more profiles, and including more of the water column steric height variability.

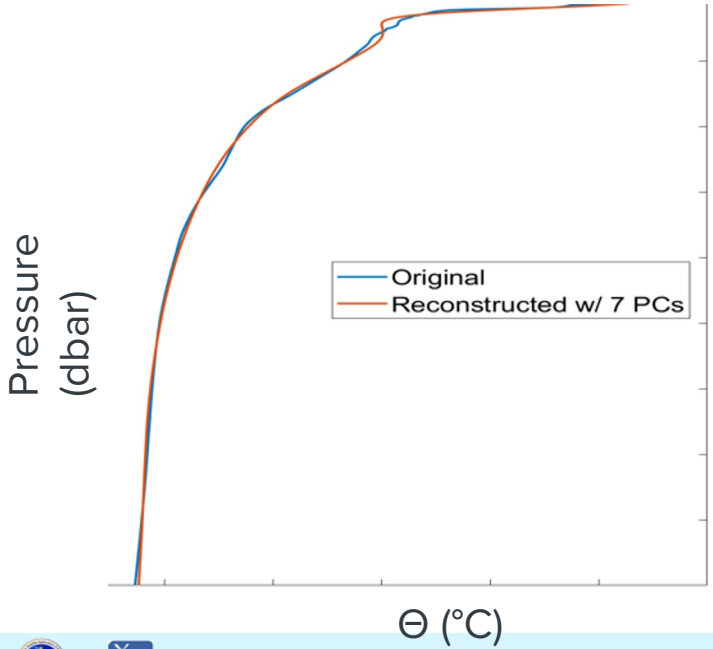


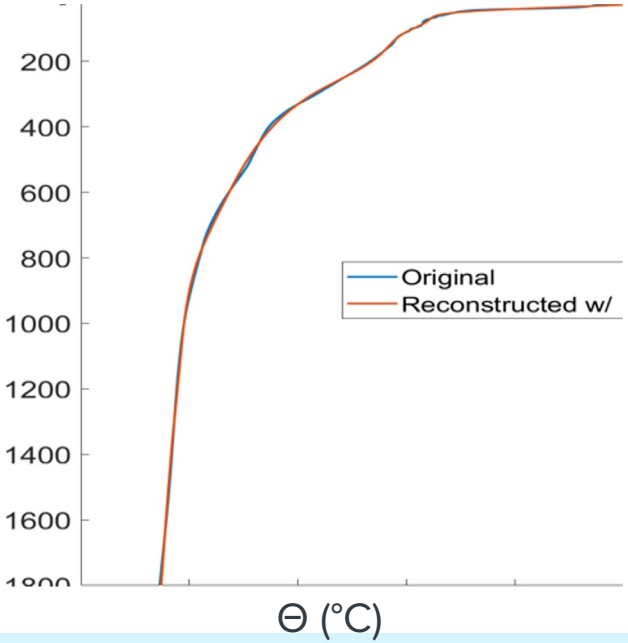


Principal components can provide a simplified representation of each Θ profile

2 dbar levels from 0–1800 dbar
(901 total “variables” per profile)

7 or 12 PCs (“variables”) per profile
7 PCs = 99.95% variance explained
12 PCs = 99.99% variance explained





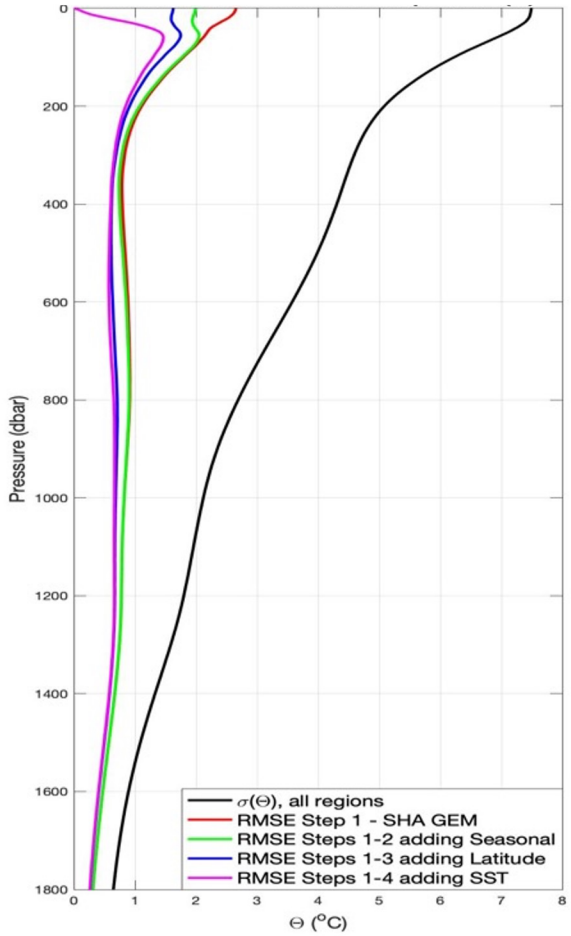
Focus on Hurricanes

- A tropical cyclone making landfall in the USA causes on average ~$19.2 billion in damage.
- There have been more category 4 and 5 landfalls between 2017 – 2021 than from 1963 – 2016 and these storms collectively did $353 billion damage to the USA through 2020.
- The over-ocean intensification of tropical storms can bring stronger winds and greater rainfall to land areas, making them even more dangerous and costly. This effect was seen in Hurricane Katrina, which went on to cause a record $161 billion in damage.
- Of the nine strongest tropical storms to hit the continental USA, only one was hurricane strength more than 72 hours before landfall.
- In 2021, Hurricane Ida brought a 3 m storm surge, left 1.5 million people without electricity, produced up to 432 mm of rain, and increased in strength by 105 kmh in its last 24 hours prior to landfall.
- Hurricane Ian ….

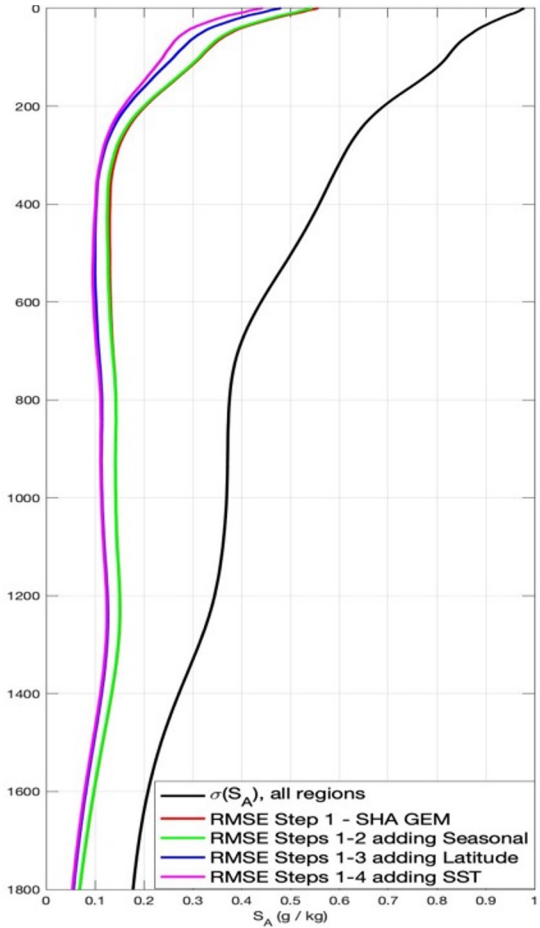
New York Times,
August 30, 2021

Emanuel, K.A. 2021 *update to data originally published in*: Emanuel, K.A. 2007. Environmental factors affecting tropical cyclone power dissipation. *J. Climate* **20**(22):5497–5509.

Conservative temperature (RMSE)



Absolute salinity (RMSE)



How well do the NGE OHC profiles represent ocean conditions?

Case Study: Hurricane Fiona

A collaboration between NESDIS/STAR/SOCD and OAR/AOML/HRD

HAFS_S, New NESDIS OHC, and ocean observations

Tues. 27 Sep 18:00z

Forecast peak wind

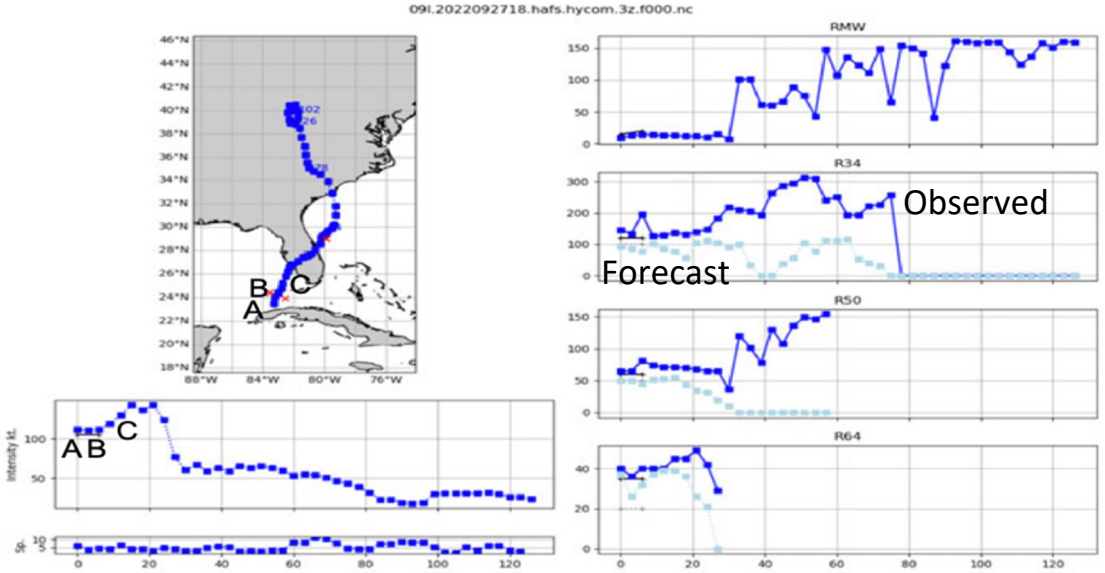
143 kn

Forward speed slow

~5 m/s

34 kn wind field radius

120-150 nm



Case Study: Hurricane Fiona

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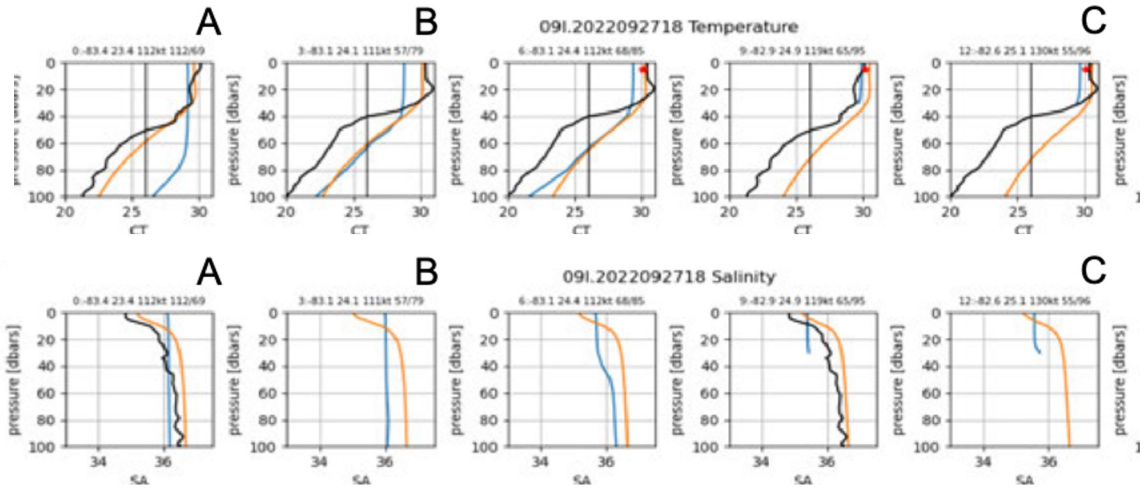
HAFS_S

Argo

NGE OHC

* NDBC



Objectives of the NOAA Next Generation Enterprise Ocean Heat Content (NGE OHC) Algorithm

- Using primarily satellite altimetry as input, provide 4-Dimensional (spatial, depth, temporally resolved) estimates of ocean heat and salt
- Provide ¼° global coverage, and high resolution (7 – 10 km) where & when needed.
- Be able to use input from many (and new) satellites without requiring modification or recalibration.
- Exhibit accuracy and fidelity in extreme environmental conditions, e.g., anomalously high heat content.
- Adaptable – be able to be updated in the face of a warming ocean. Updating uses advanced computational techniques (AI/ML) to be as routine and automated as possible.