Nonuniform warming of the North Atlantic from 1955-2012

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Outline

1. What is Ocean Heat Content (OHC)?
2. Global changes in OHC
3. North Atlantic OHC and Temperature Changes

What is Ocean Heat Content (OHC)?

The amount of heat stored within the ocean

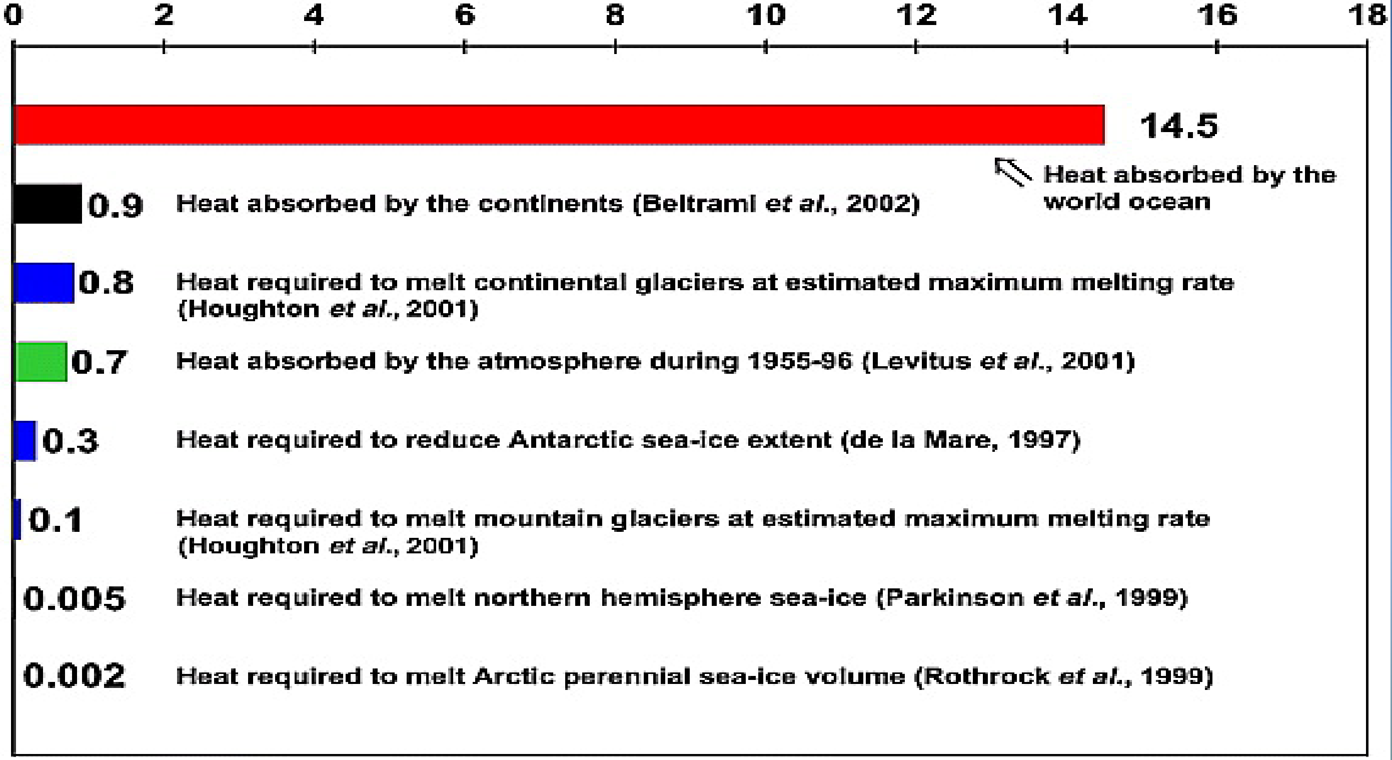
$$OHC = \rho * C_p * \mathrm{SA} \int_{z_1}^{z_2} T(z)(dz)$$

$\rho = Density\ of\ Seawater$
$C_p = Specific\ Heat\ Capacity\ of\ Seawater$
$Z_1 = Upper\ depth\ limit\ (i.e., 0m)$
$Z_2 = Lower\ depth\ limit\ (i.e., 700m)$
$T(z) = Mean\ temperature\ anomaly\ between\ Z_1\ and\ Z_2$
$SA = Surface\ Area$

OHC for our study is "OHC anomaly" as anomaly temperatures (long-term mean removed) are used in the OHC calculation rather than full temperature values

Why is OHC important?

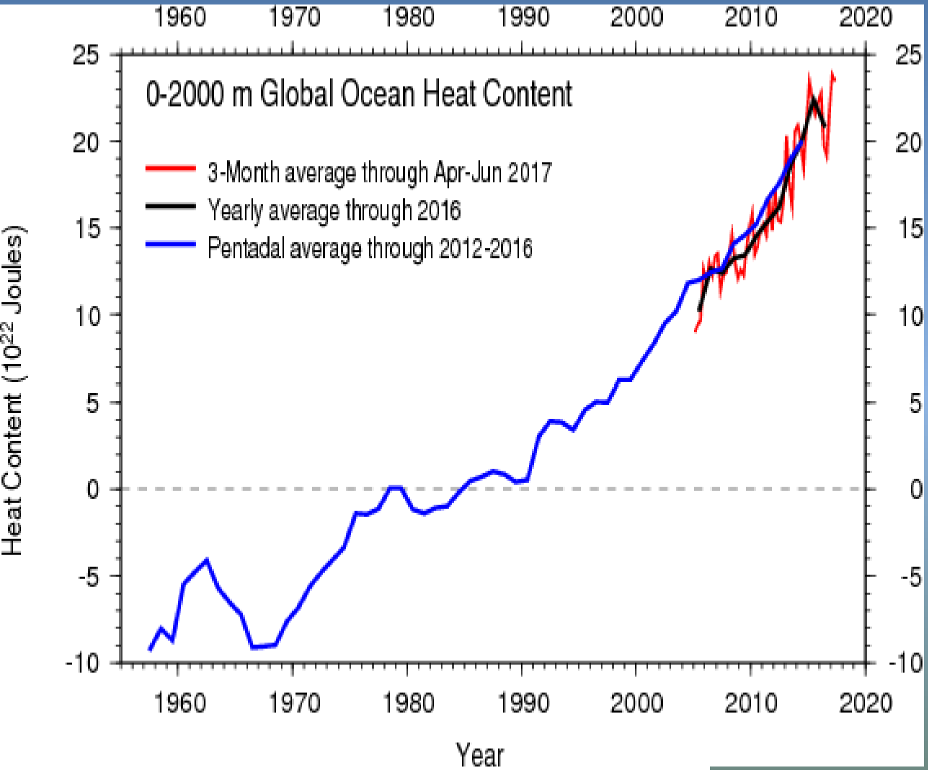
Global OHC



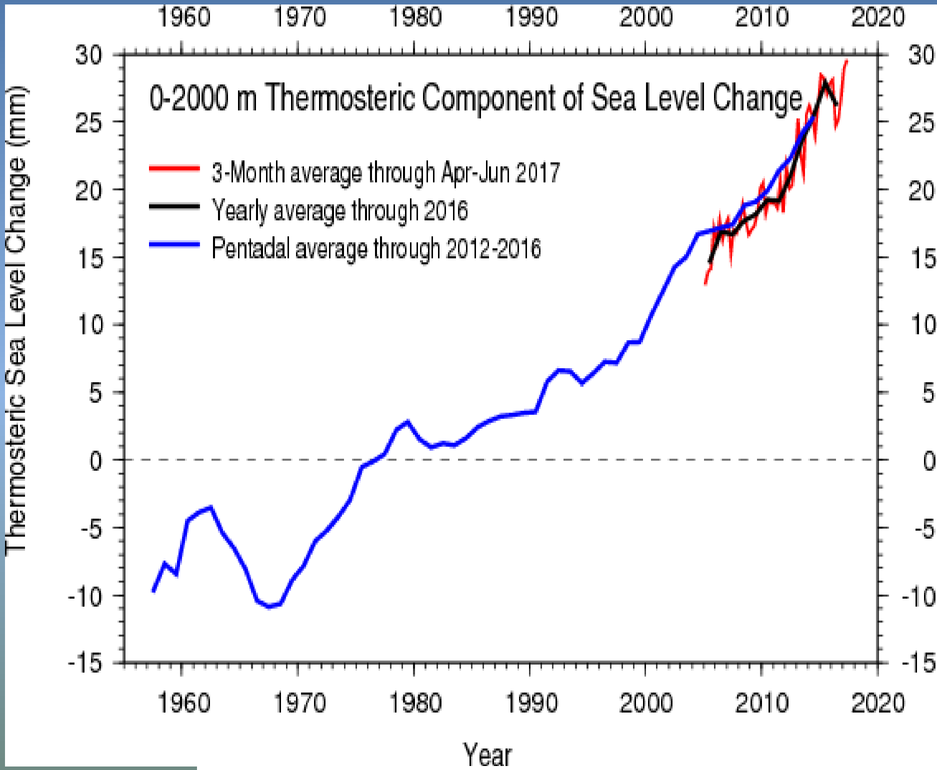
Earth's Heat Balance Estimates (10^{22}J) from Levitus *et al.* (2005)

The ocean is responsible for absorbing over 90% of the excess heat that the Earth System has gained since 1971! (Rhein et al., 2013)

Global OHC



Updated from Levitus et al. (2012)

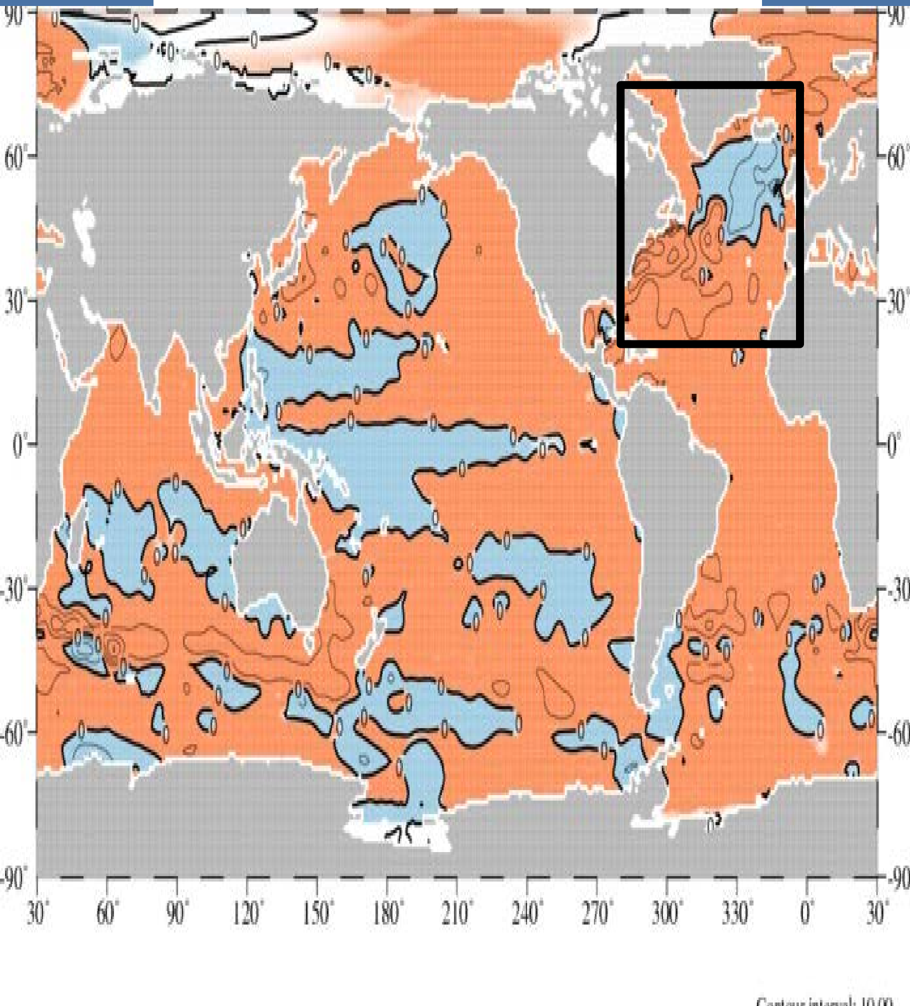


Updated from Antonov et al. (2005)

Source: https://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/

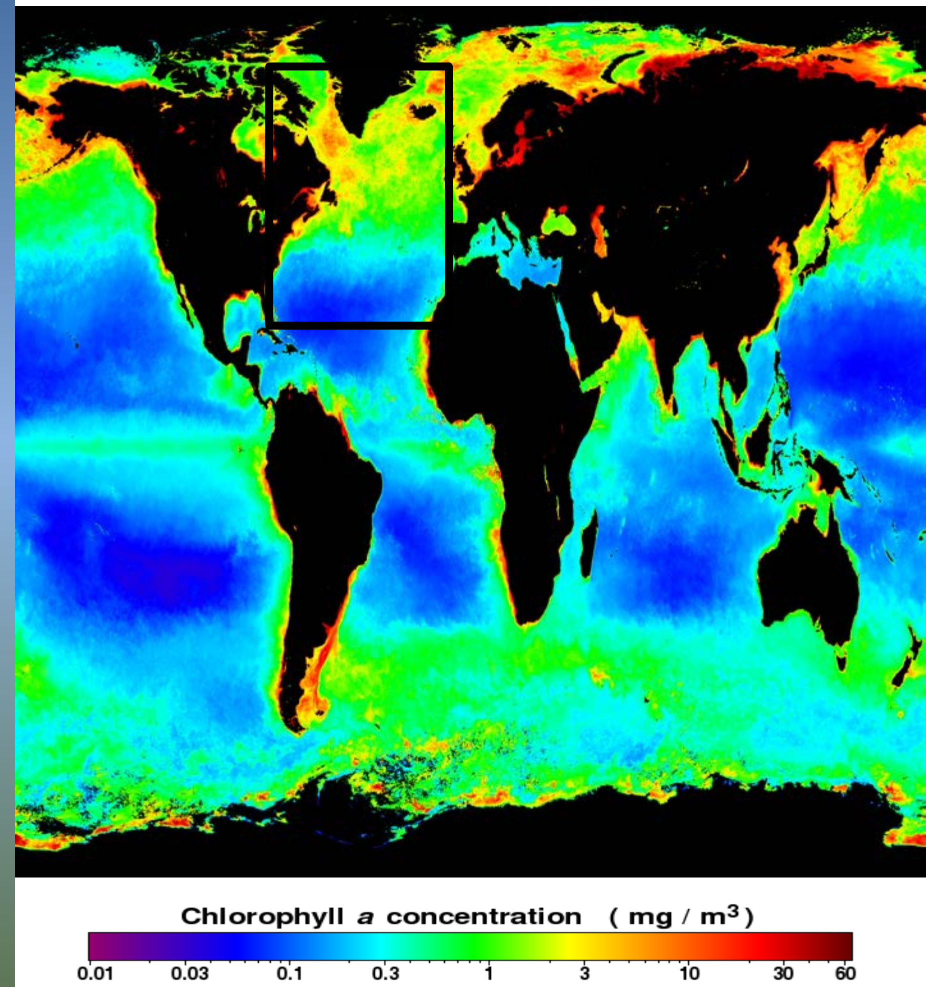
Global OHC and Primary Production

2016 0-2000m OHC ($10^5 J*m^{-3}$)



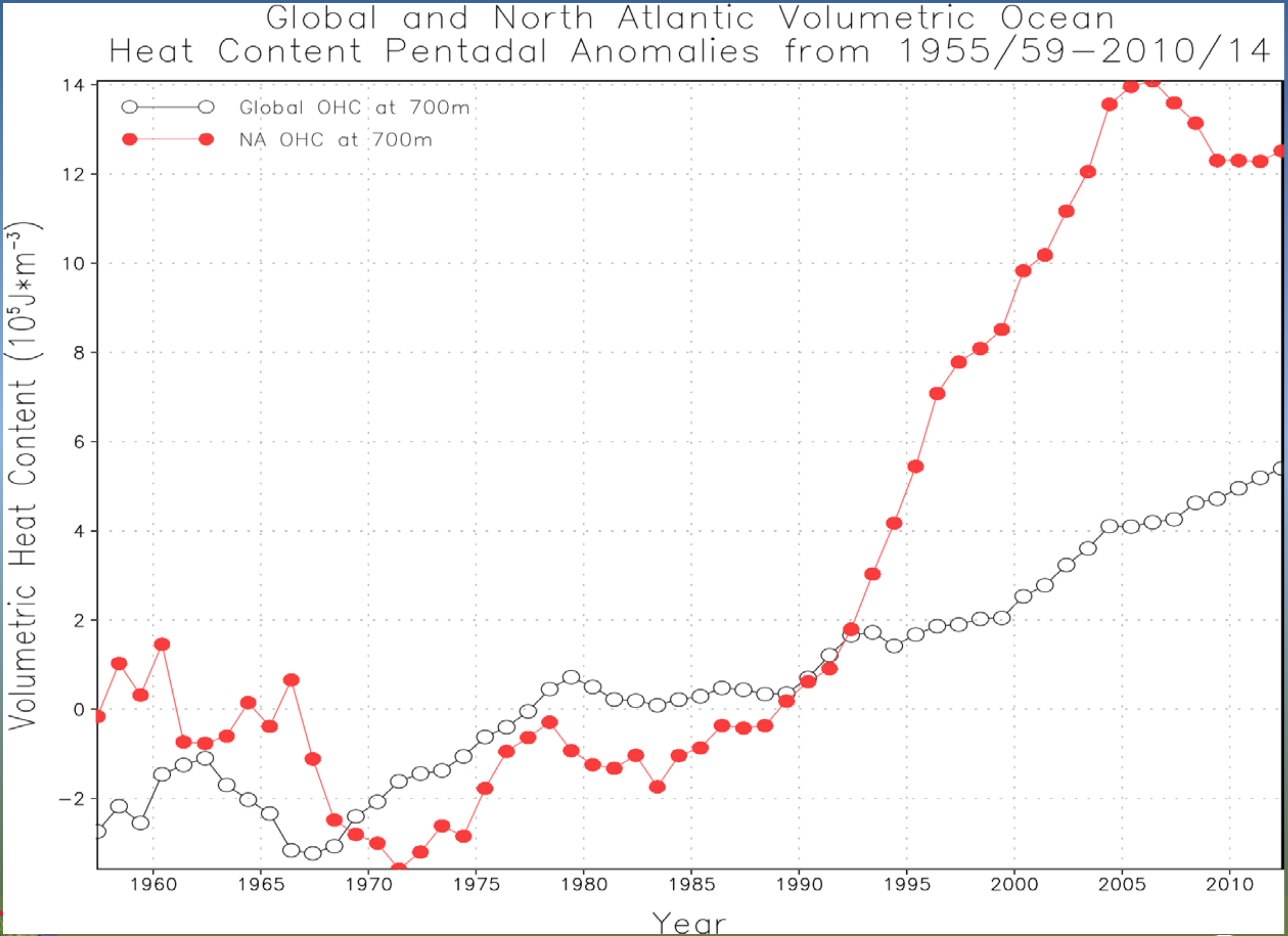
Source: https://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/

Terra MODIS 2016 Chlorophyll-a Concentration



Source: https://oceancolor.gsfc.nasa.gov

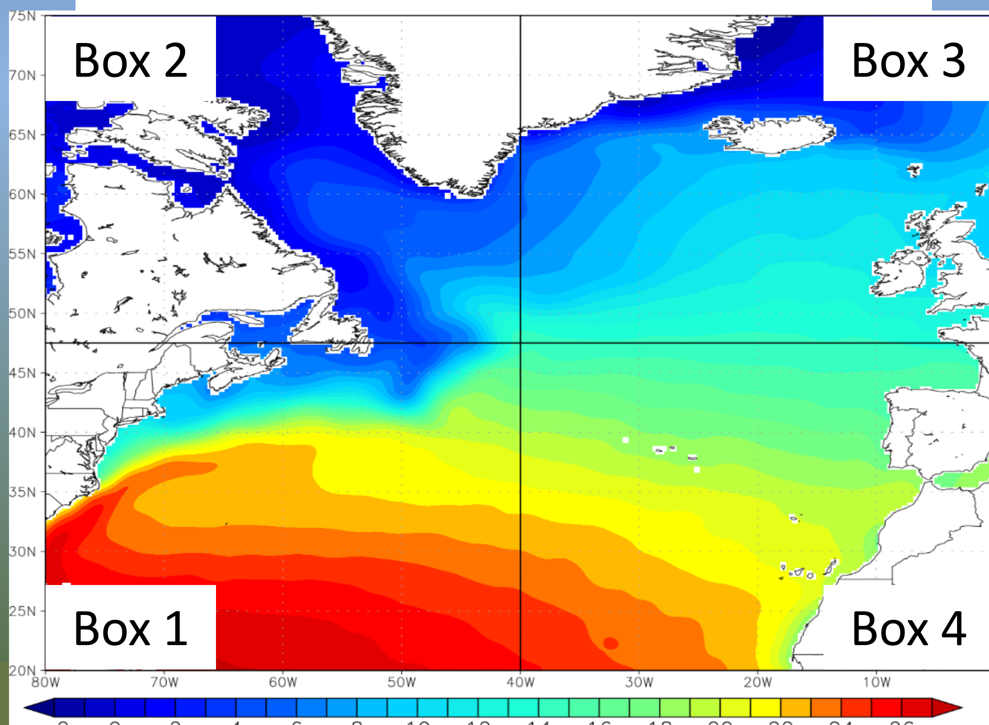
Global and North Atlantic Volumetric OHC



Why study North Atlantic (NA) OHC?

- Highly variable region
- Different regions of the NA exhibited warm and cold OHC anomalies in 2016
- Plays vital role in global thermohaline circulation
- Many marine ecosystems
- Sufficient data coverage allows confident computations of higher-resolution, both horizontally (1/4-degree and higher) and vertically (102 standard depth levels), temperature and OHC fields

1955-2012 10m Temperature Climatology



North Atlantic Circulation

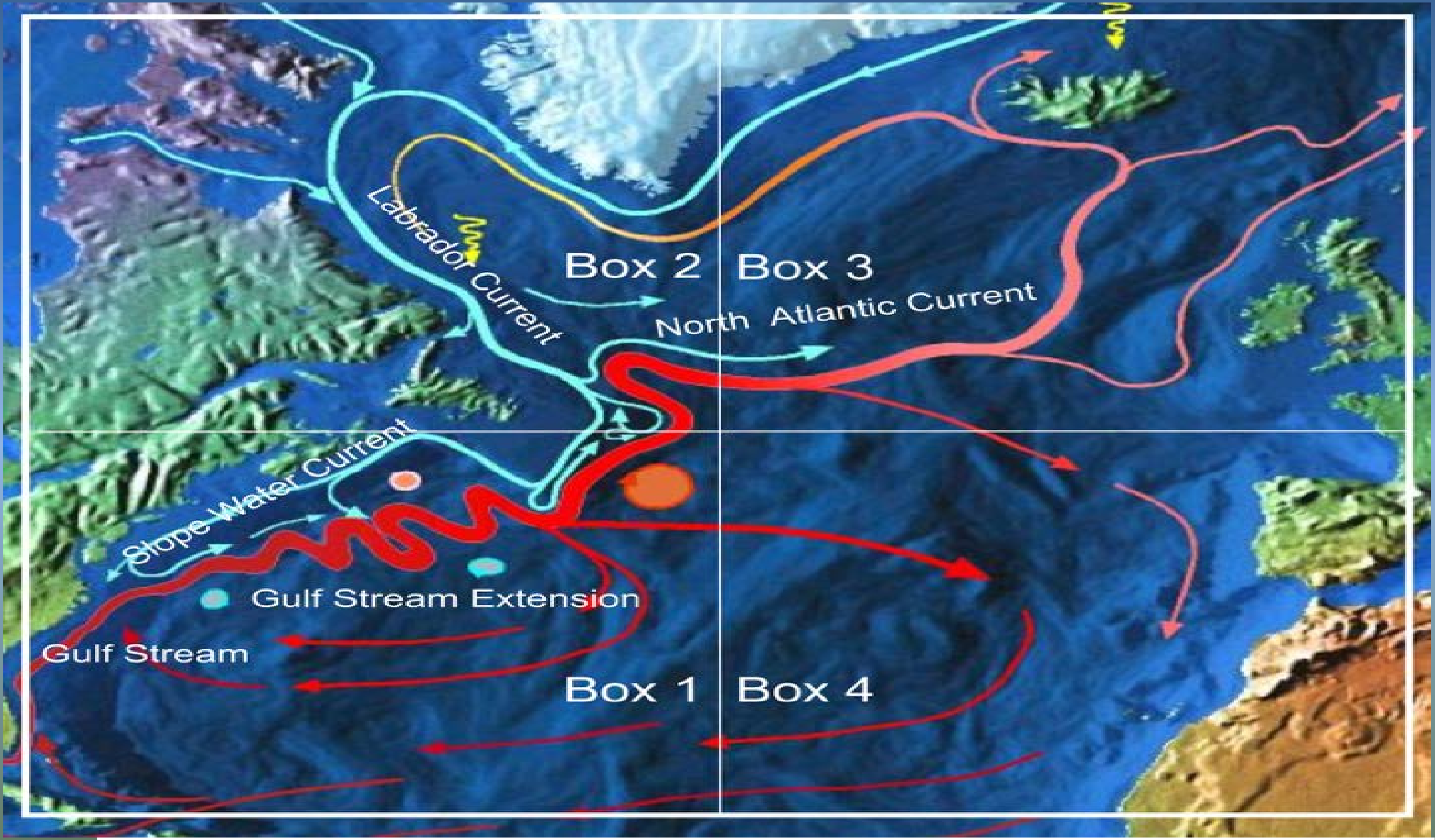
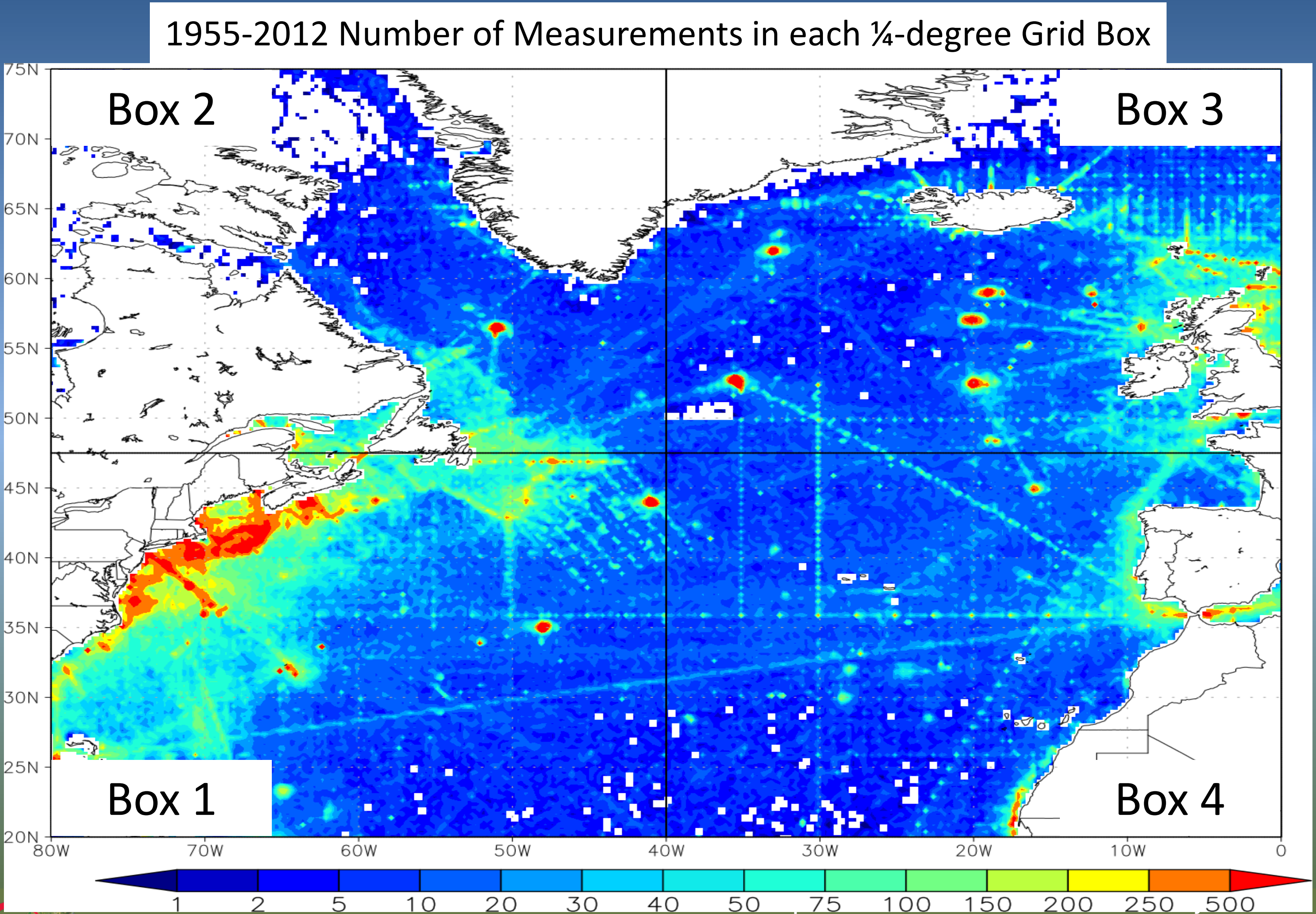


Image courtesy of Igor Yashayaev (http://www2.mar.dfo-mpo.gc.ca/science/ocean/woce/climatology/naclimatology.htm)

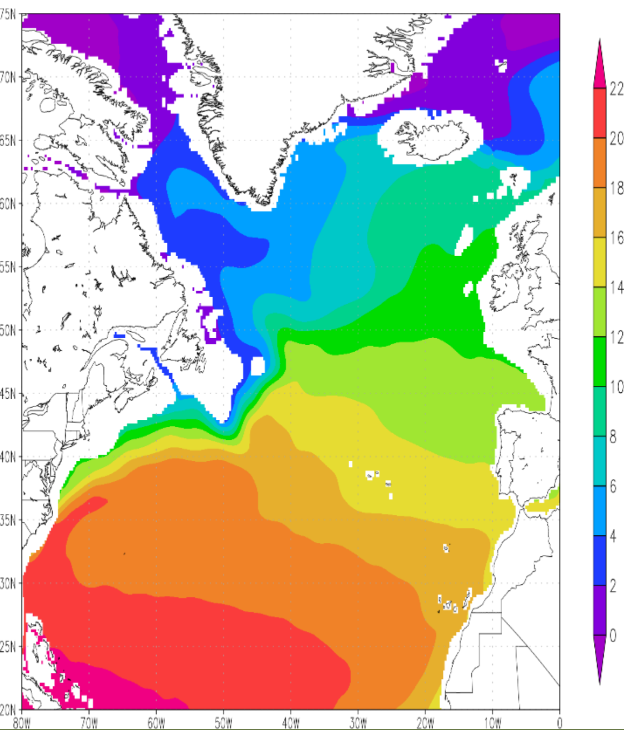
NA Data Coverage



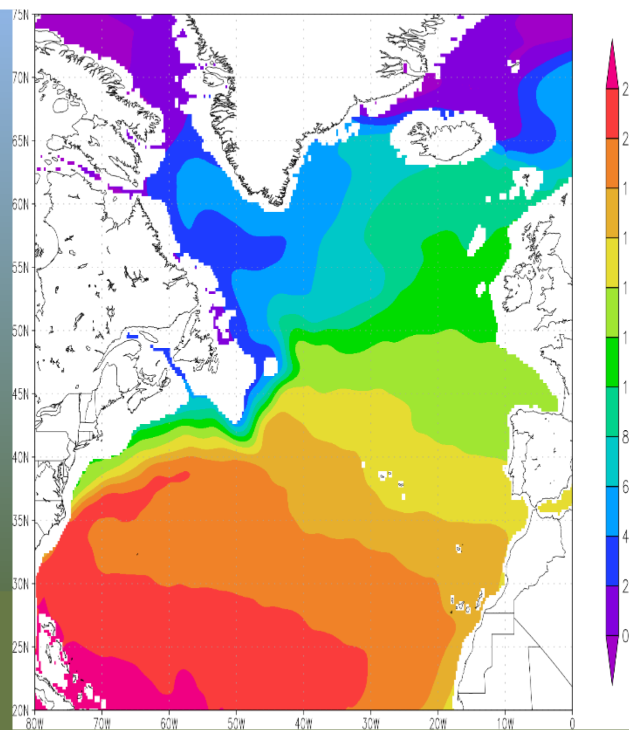
Creation of Temperature & OHC Fields

- Utilized World Ocean Atlas 2013 version 2 (Locarnini et al. 2013) Decadal Temperature Fields
  - Derived from World Ocean Database 2013 (Boyer et al. 2013)
  - Decades: 1955-1964, 1965-1974, 1975-1984
    1985-1994, 1995-2004, 2005-2012
  - Grid Resolution: ¼-Degree, 67 Standard Depth Levels (0-2000m)
  - Created six decadal temperature anomaly fields by subtracting off the six-decade average
  - Computed OHC for 0-300, 0-700, 300-700, and 700-2000m depth layers

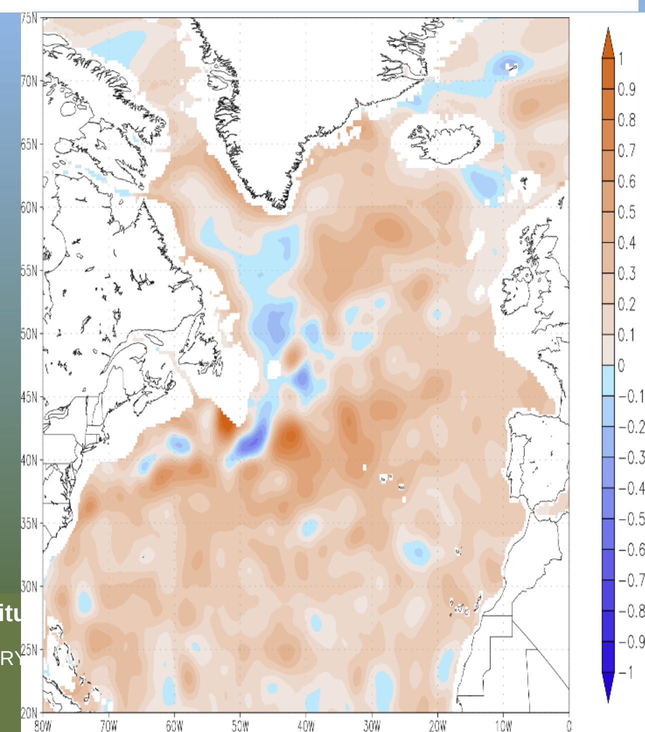
1955-2012 0-300 Mean Temperature



1995-2004 0-300 Mean Temperature

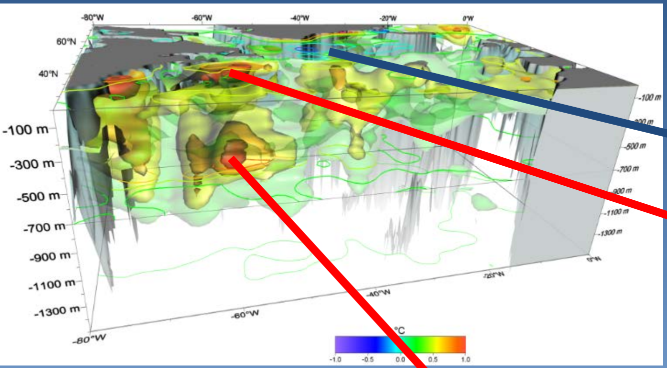


0-300 Mean Temperature Anomaly

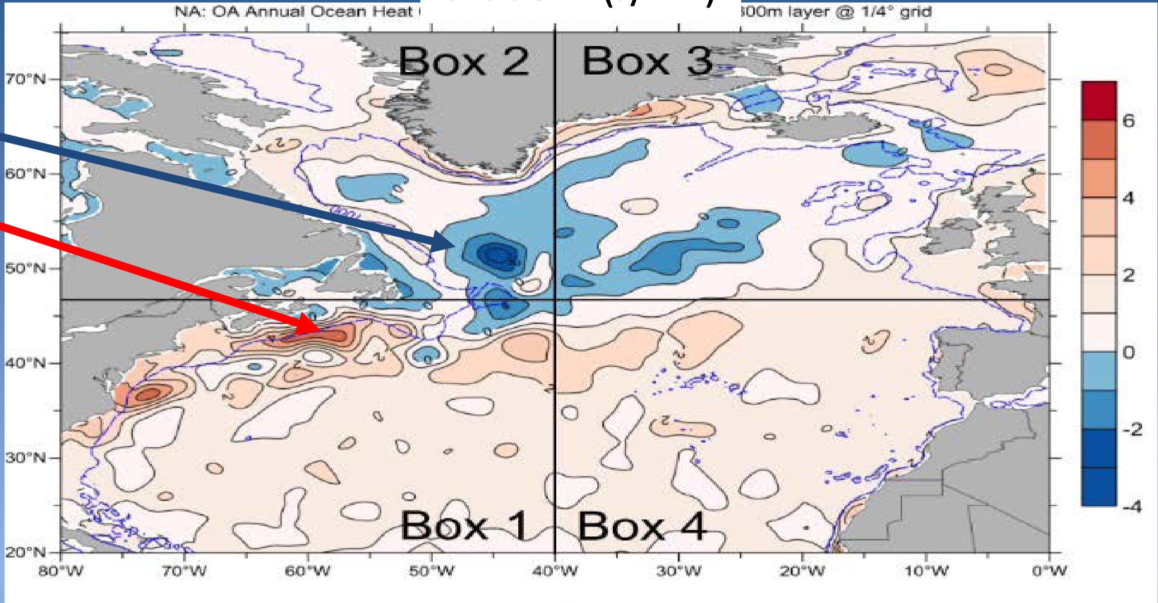


Temperature Difference Between 1985-2012 and 1955-1984

OHC Difference Between 1985-2012 and 1955-1984



0-300m (J/m^3)



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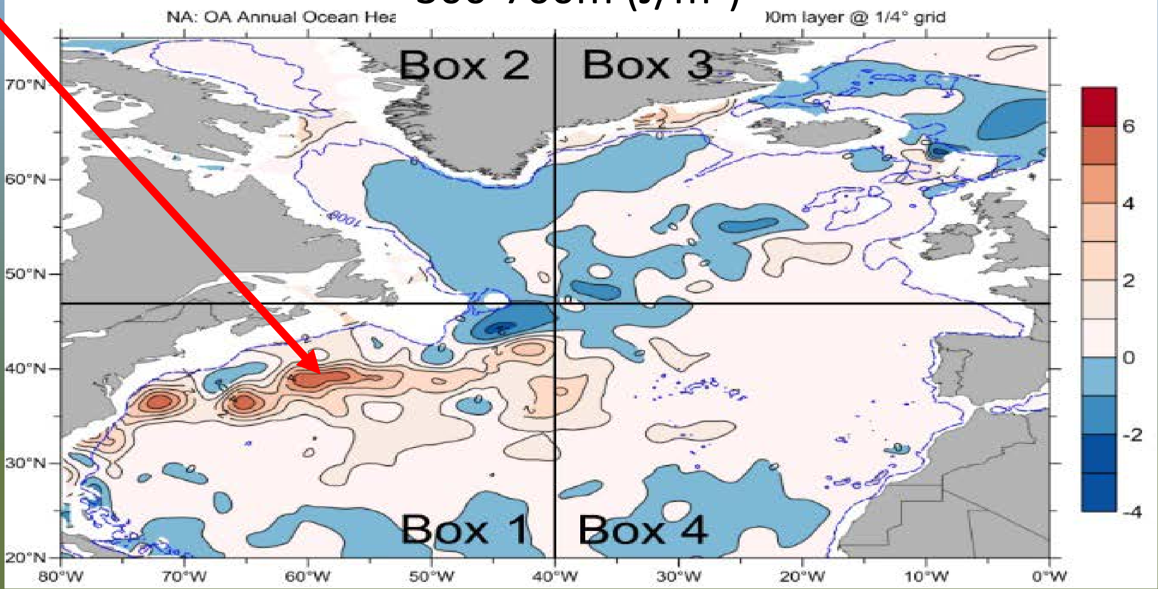
300-700m (J/m^3)



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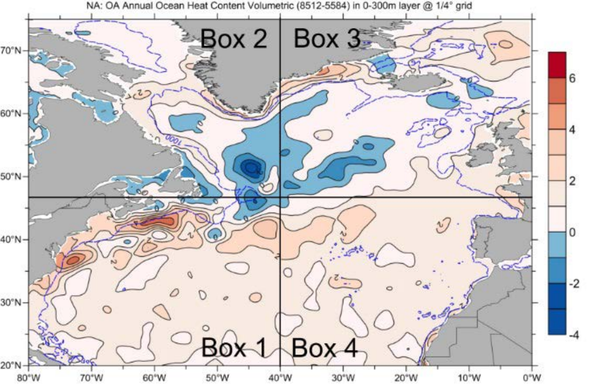
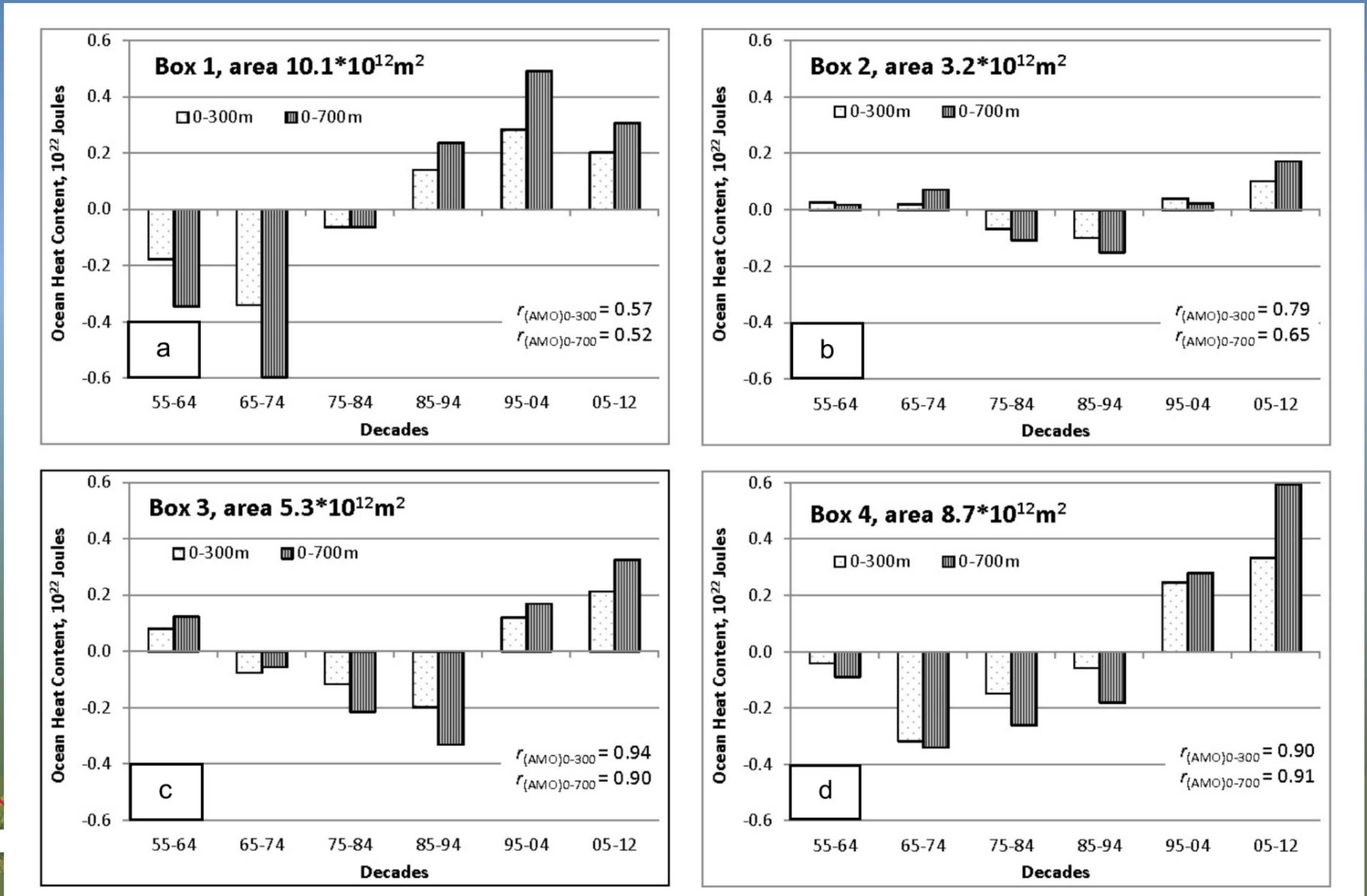
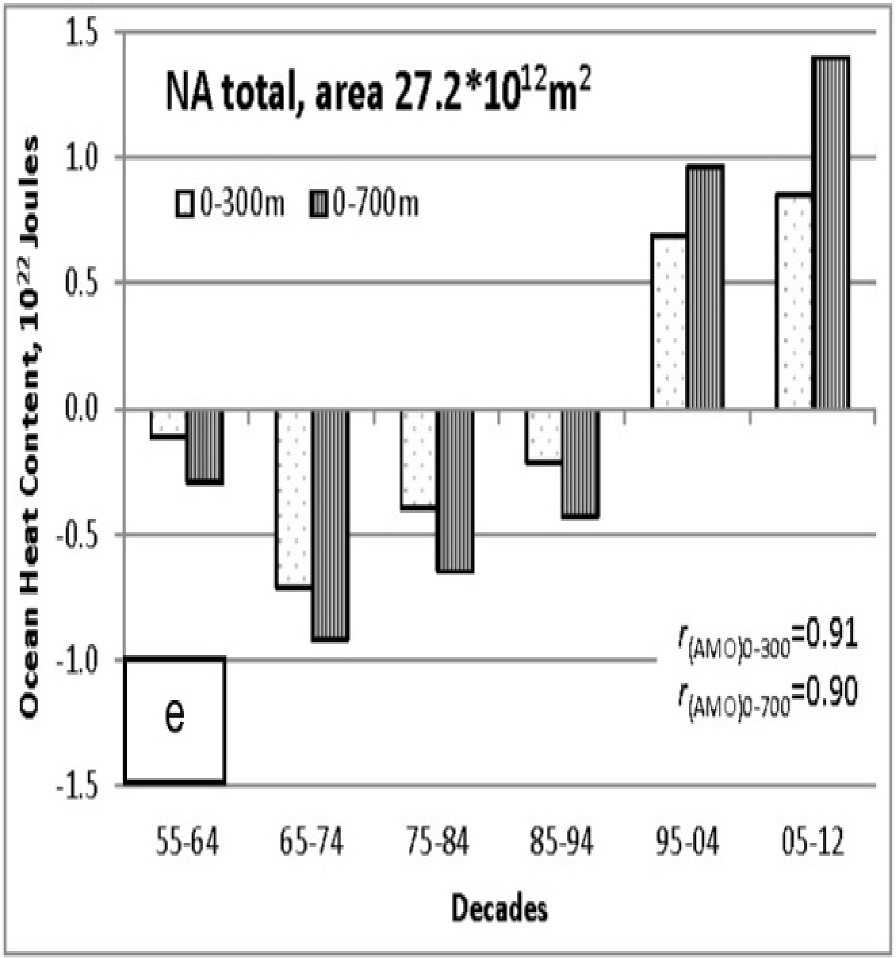
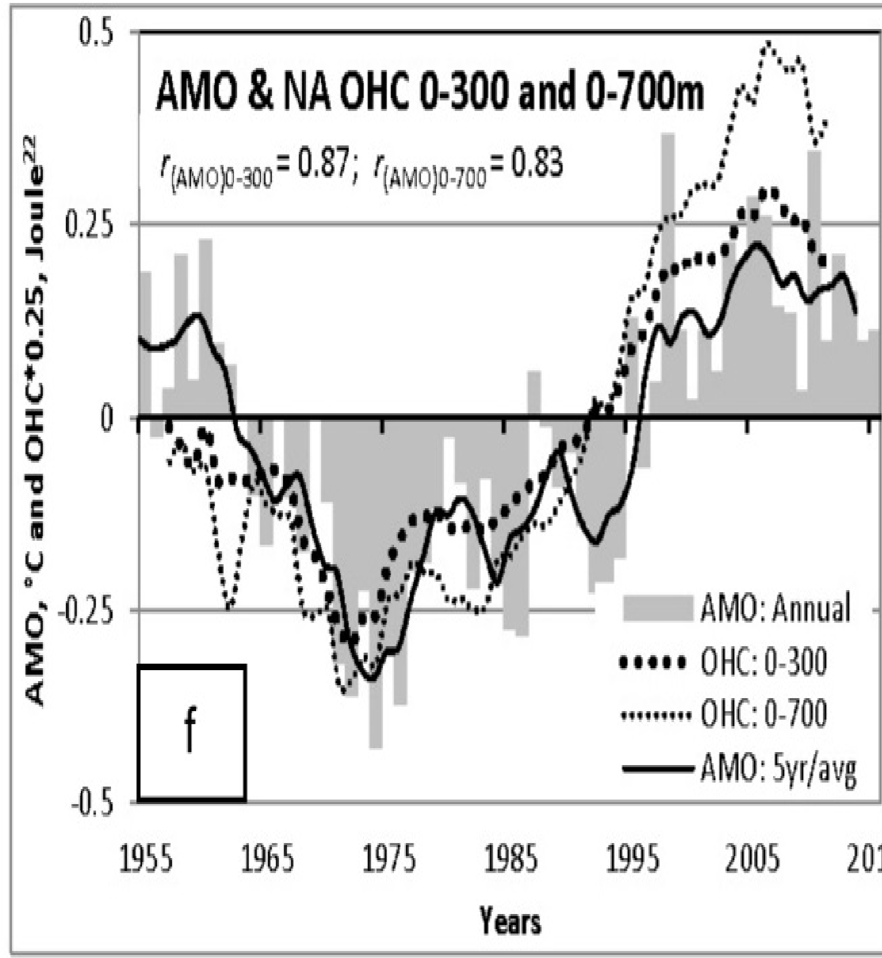


OHC Time Series in NA

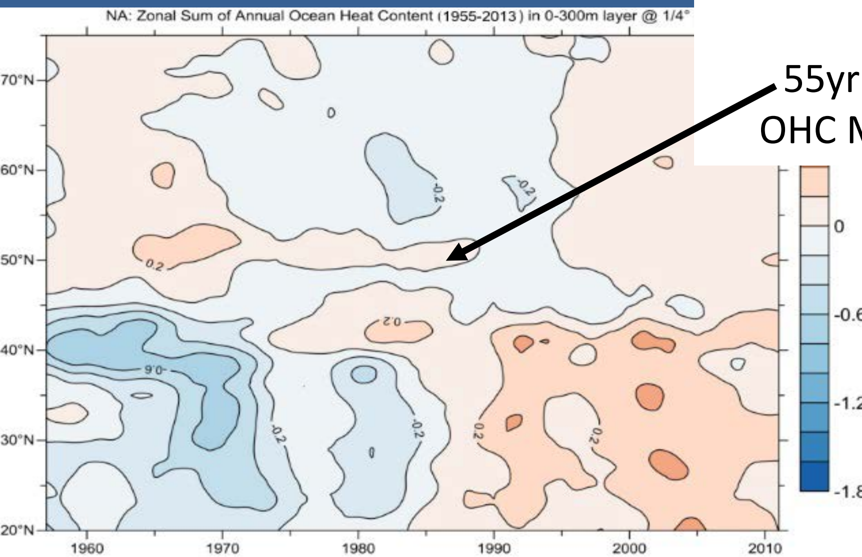


OHC Time Series in NA and Possible Relation to AMO

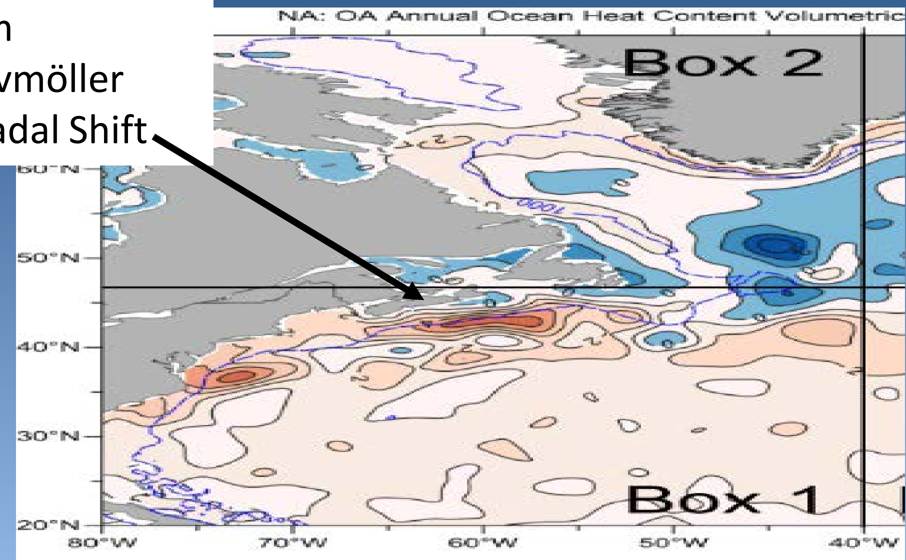


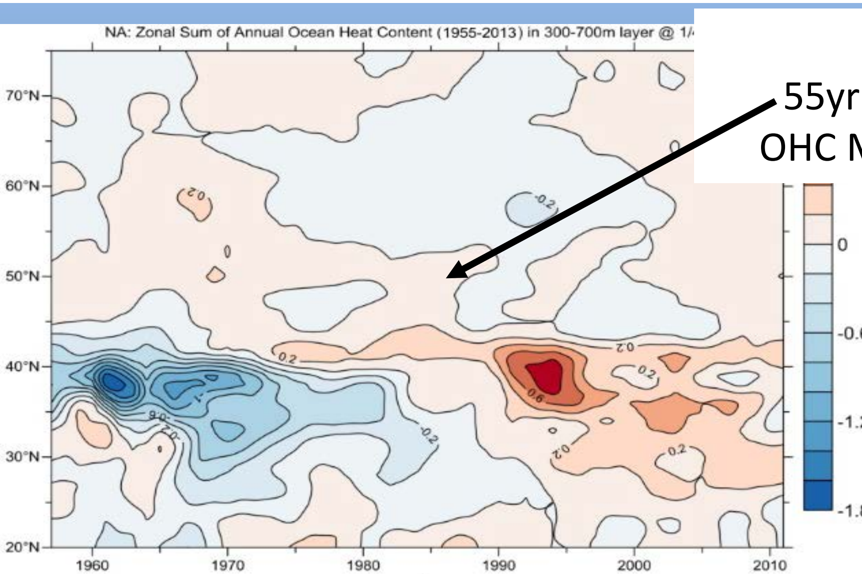


Time Evolution of OHC Changes

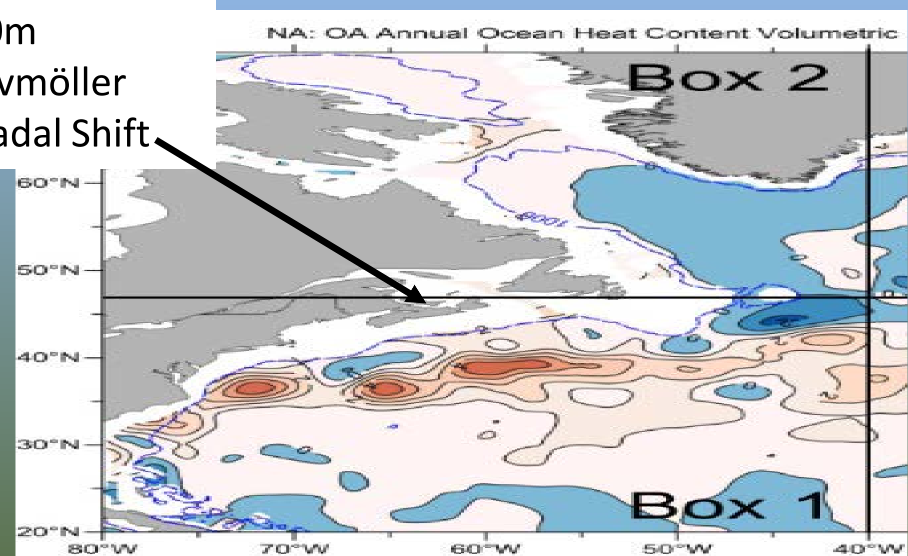


0-300m
55yr OHC Hovmöller
OHC Multidecadal Shift

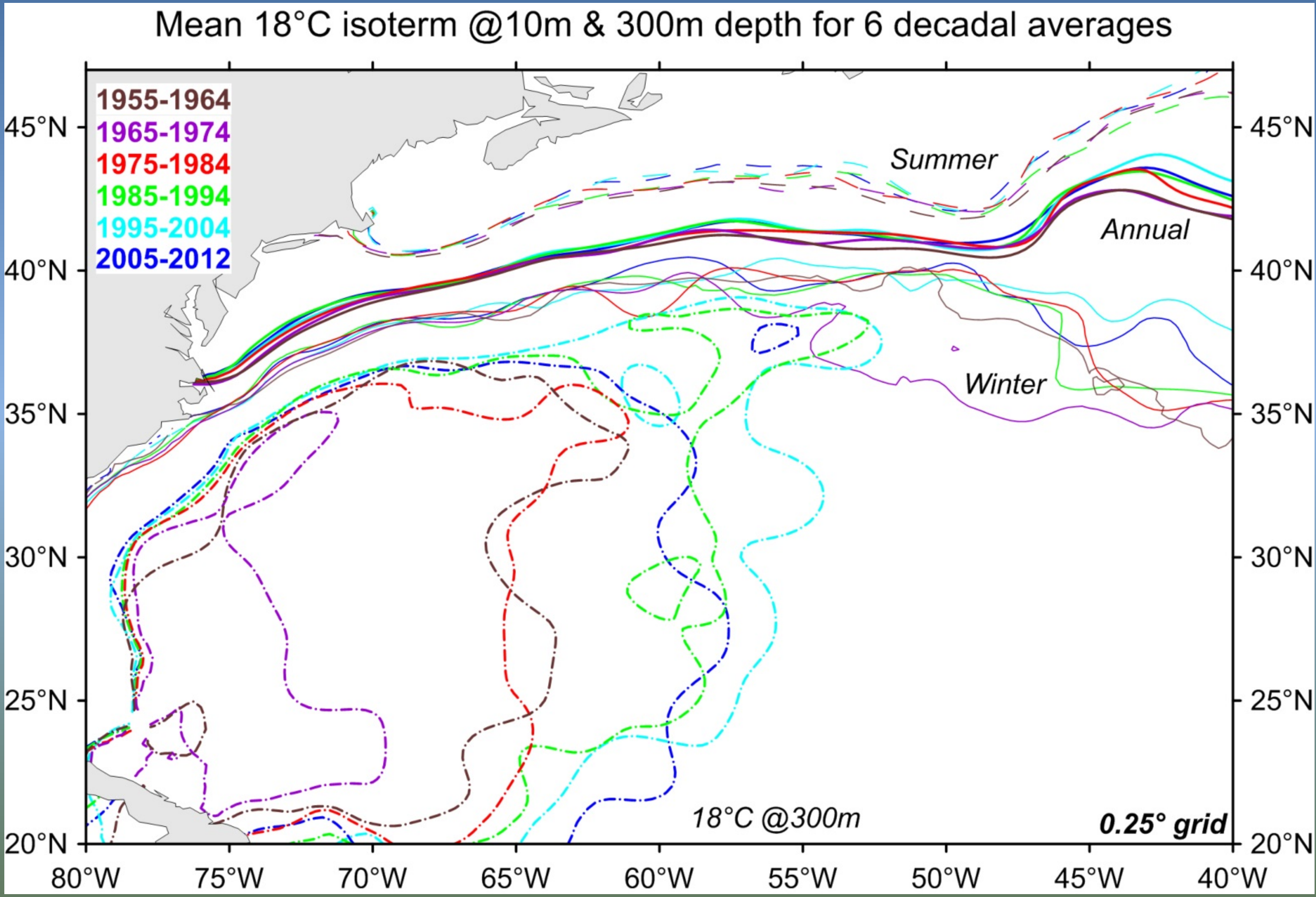




300-700m
55yr OHC Hovmöller
OHC Multidecadal Shift

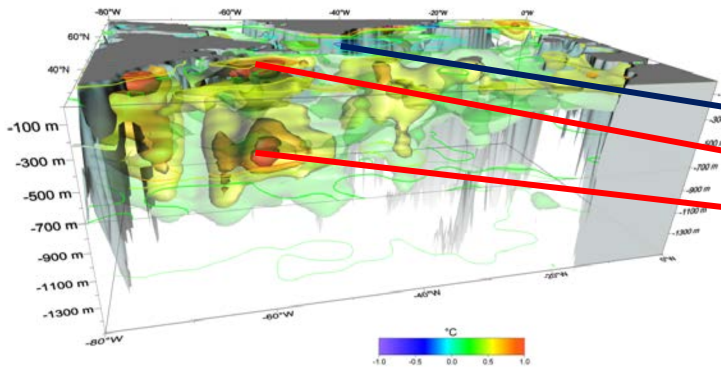


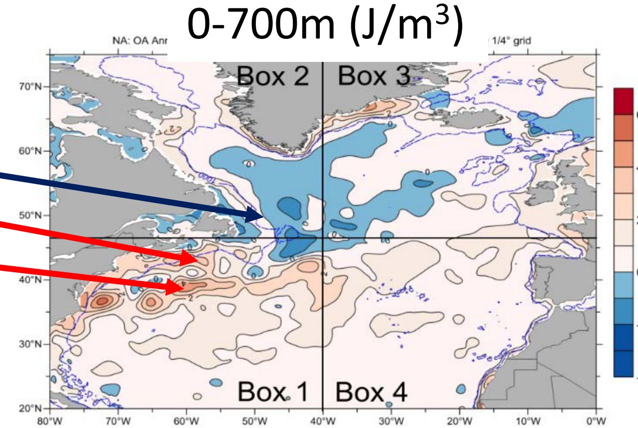
Changes in the Gulf Stream Path?



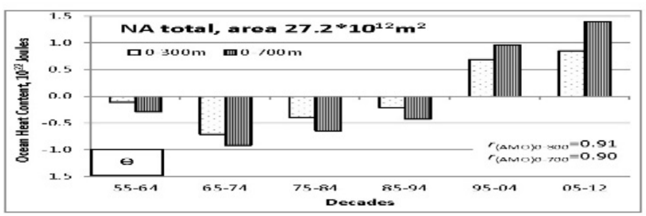
Conclusions

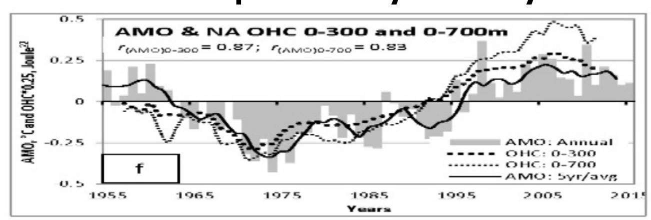
1. North Atlantic warming has been inhomogeneous in both time and space over the 1955-2012 time period.





2. Decadal OHC variability in the North Atlantic is consistent with changes in the AMO. There could be a 60-80 year OHC quasi-cyclicity.





3. Meridional migration of the Gulf Stream does not appear to contribute to the warming near the Gulf Stream path.
   – Contributions from both the heaving of 18°C water near the Gulf Stream path (Huang, 2015) and changes (namely slowing, Bryden et al., 2005; Smeed et al., 2014) of the Atlantic Meridional Overturning Circulation (AMOC) are likely causes.

Acknowledgement

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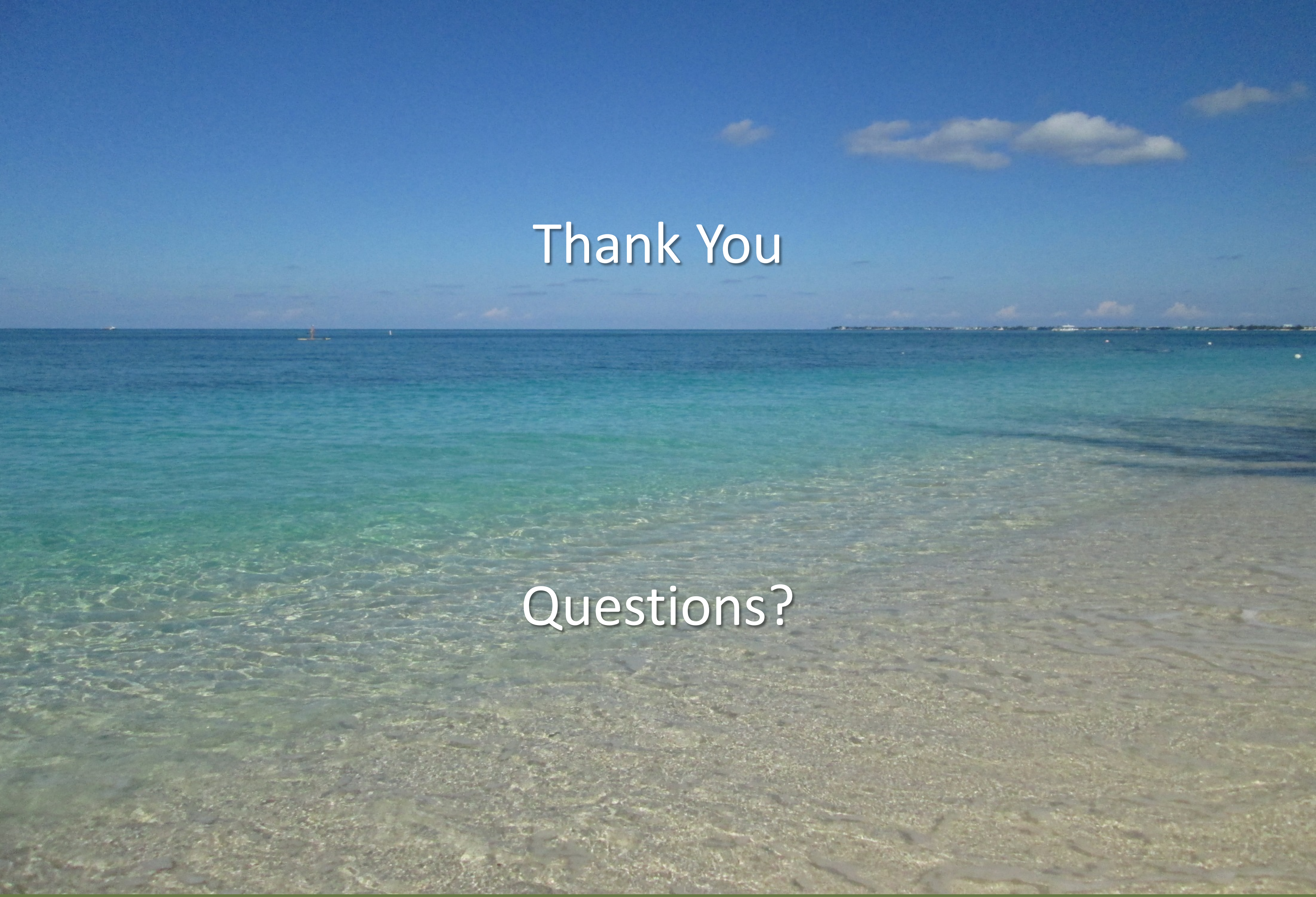

Thank You

Questions?

References

1. Levitus, S., J. I. Antonov, T. P. Boyer, 2005: Warming of the World Ocean, 1955-2003. *Geophys. Res. Lett.* , 32, L02604, doi:10.1029GL021592.
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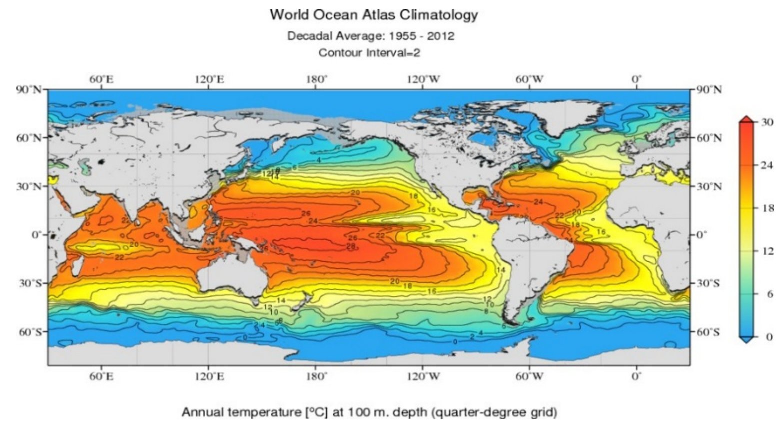
Data

- World Ocean Atlas 2013 (Locarnini et al. 2013)
  - https://www.nodc.noaa.gov/OC5/woa13/



- World Ocean Database 2013 (Boyer et al. 2013)
  - https://www.nodc.noaa.gov/OC5/WOD/pr_wod.html
- Ocean Heat Content
  - https://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/
- Regional Climatologies
  - https://www.nodc.noaa.gov/OC5/regional_climate/

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