Extreme Sea Level Rise Event Linked to 2009-10 AMOC Downturn

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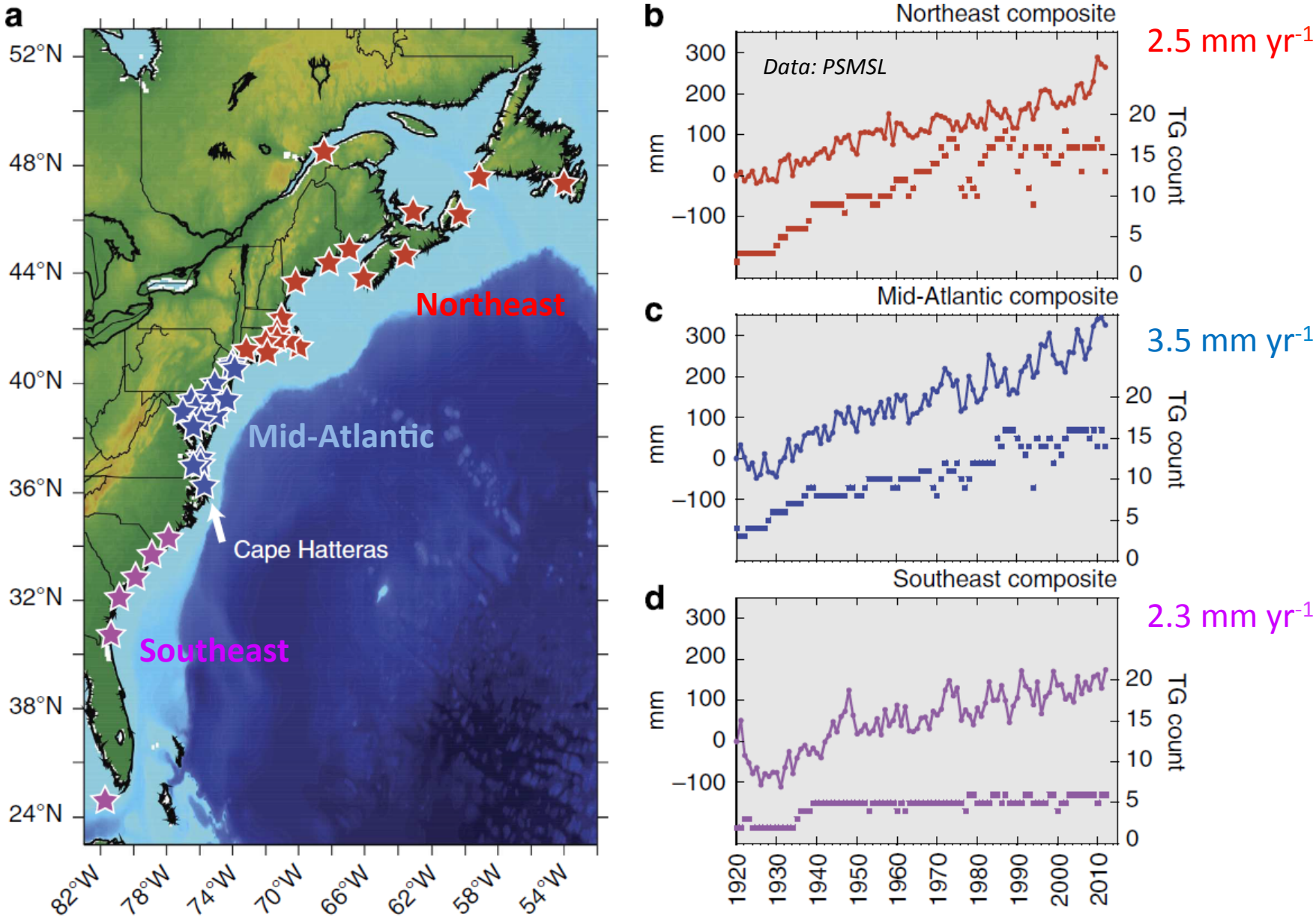
U.S. East Coast – Hotspot of SLR



Goddard et al., Nat. Comm., 2015

2009-10 Northeast Extreme Event

- **Yearly sea level change**

  SLR(t) = [SL(t+1)-SL(t-1)] / 2 ;

  t=1921, 1922, …., 2011

- **Northeast regime**

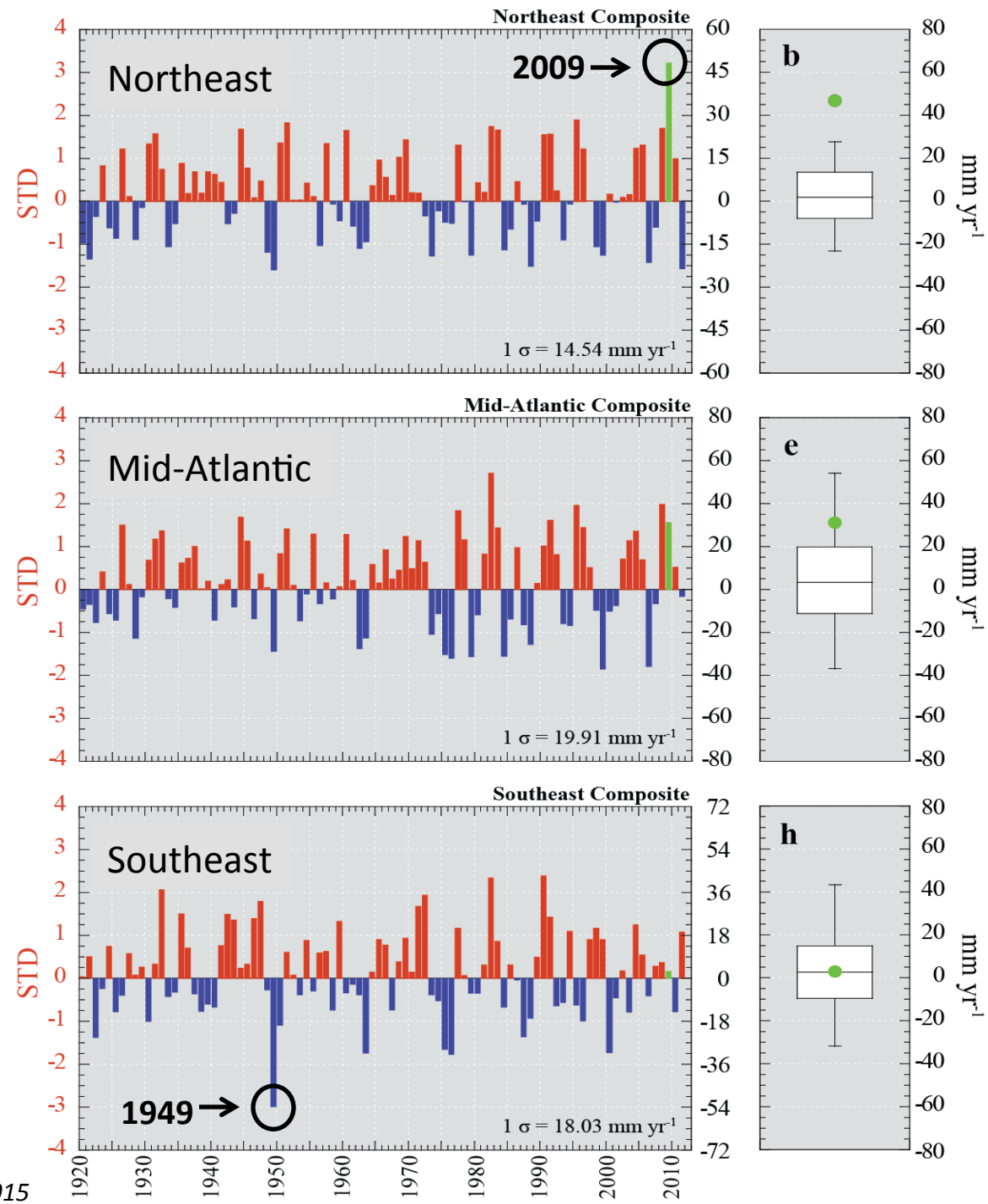
  2009 rate > 3σ

  Probability (1-in-850 year)

  On average, sea level jumped by about 100 mm during 2008-10.

- **Southeast regime**

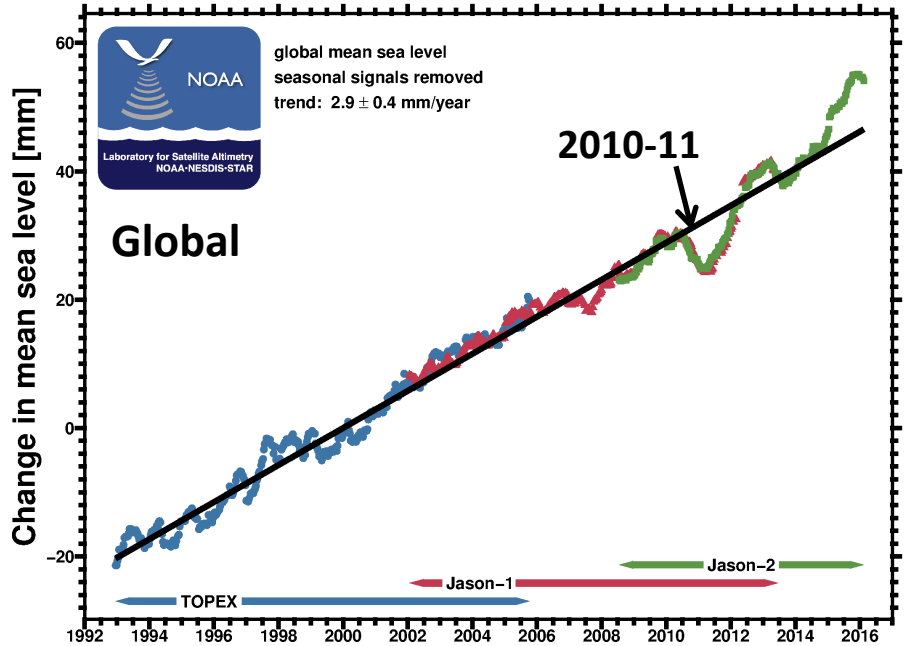
  Extreme event in 1949 ~ 3σ

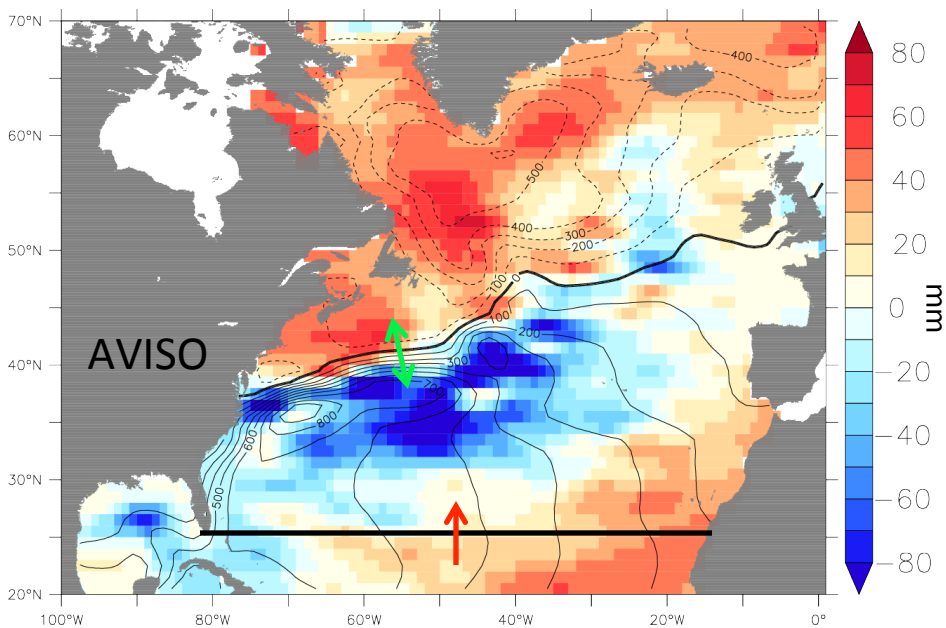


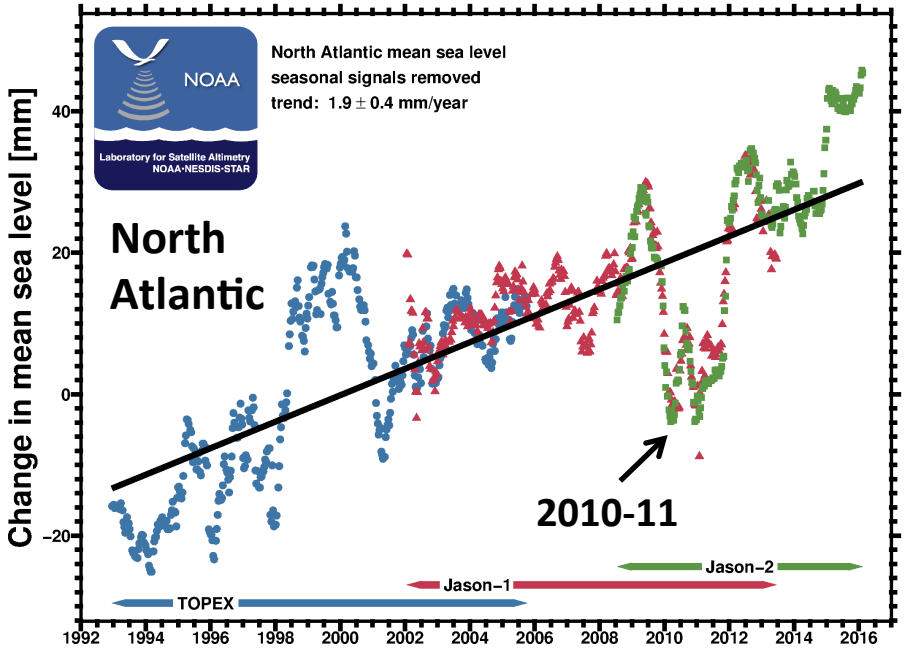
Goddard et al., Nat. Comm., 2015

Large-Scale Context

- The 2009-10 extreme SLR event on the northeast coast occurred during a short period of global and regional sea level fall.
- 2010-11 global sea level drop – La Niña
- 2010-11 North Atlantic sea level drop – reduced northward heat transport and cooling of the subtropical gyre (Cunningham et al., *GRL*, 2014)

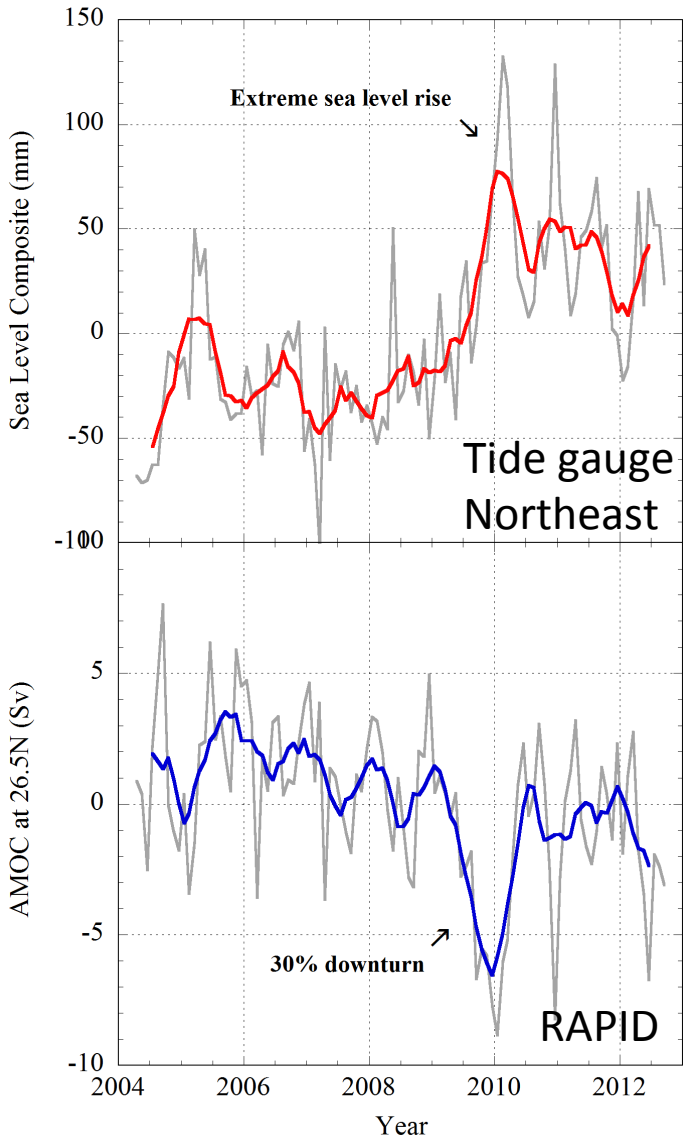




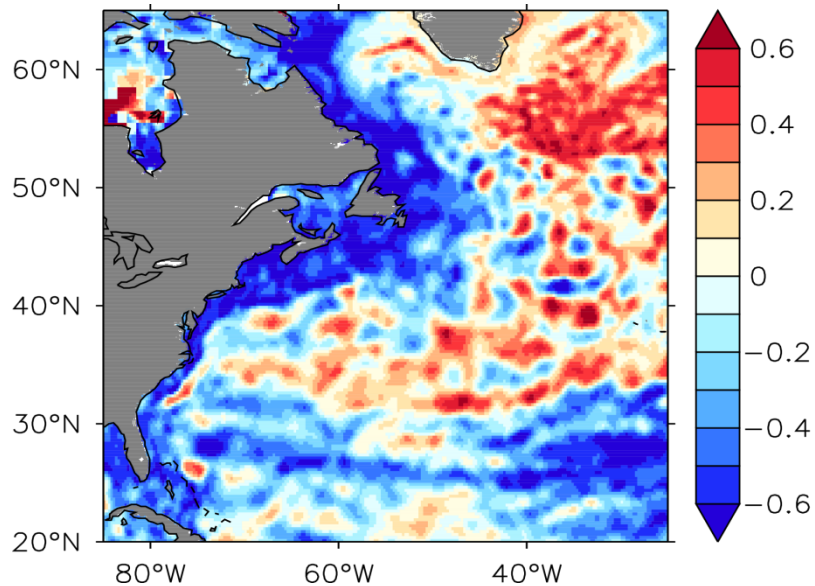


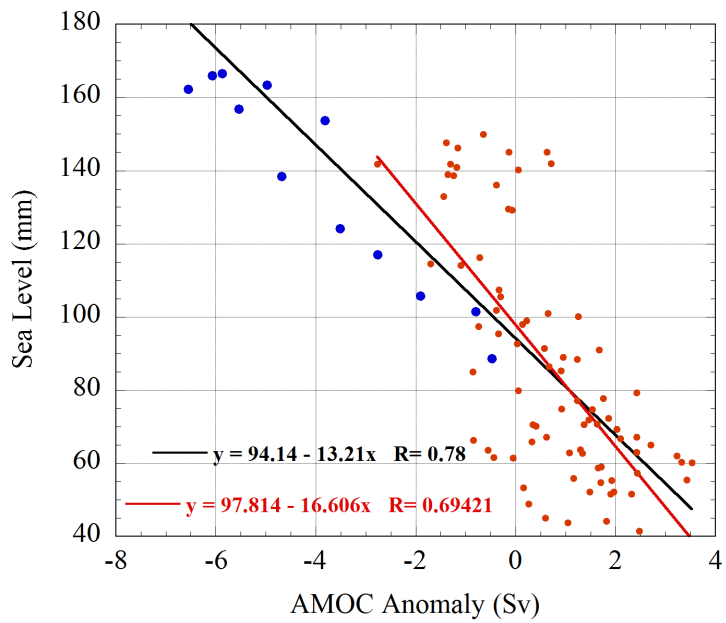
2010 dynamic sea level anomalies relative to long-term mean

Role of AMOC



RAPID & AVISO



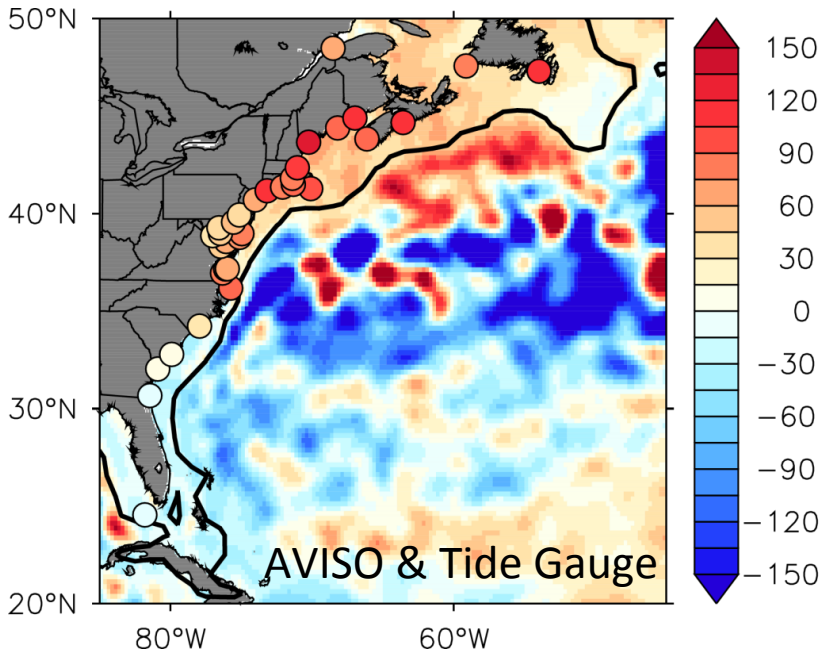


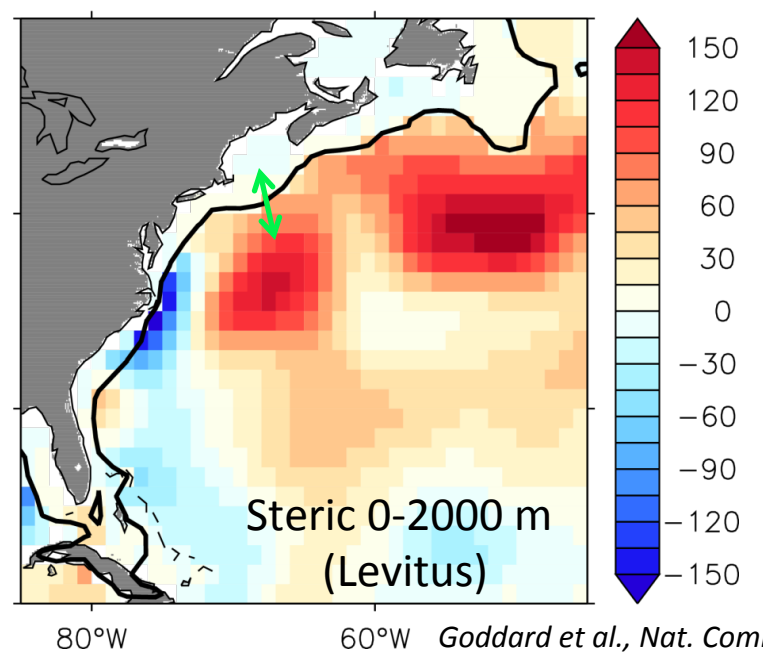
The AMOC and Northeast sea level composite are well correlated during 2004-2012.

The regression suggests a 13-17 mm Sv^{-1} relationship.

Goddard et al., Nat. Comm., 2015

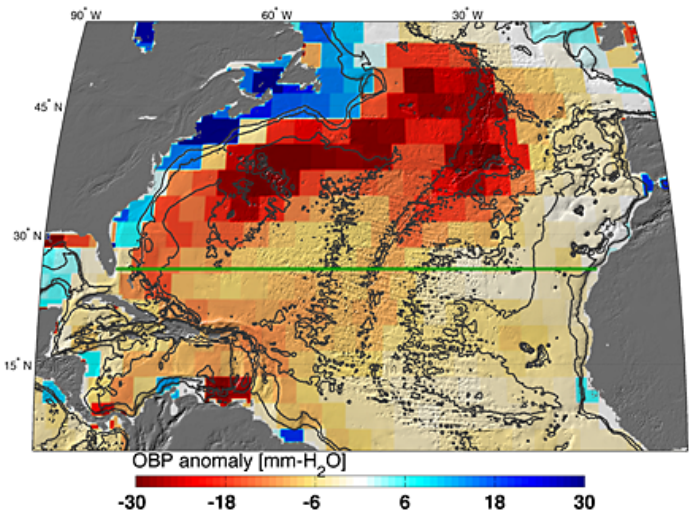
Physical Processes





Goddard et al., Nat. Comm., 2015

- The altimetry and tide gauge data are generally consistent in the 2009-10 extreme event, but the magnitudes differ.
- Ocean temperature and salinity data indicate steric SLR southeast of the shelf break.
- Yin et al., Nat. Geo., 2009



Ocean bottom Pressure

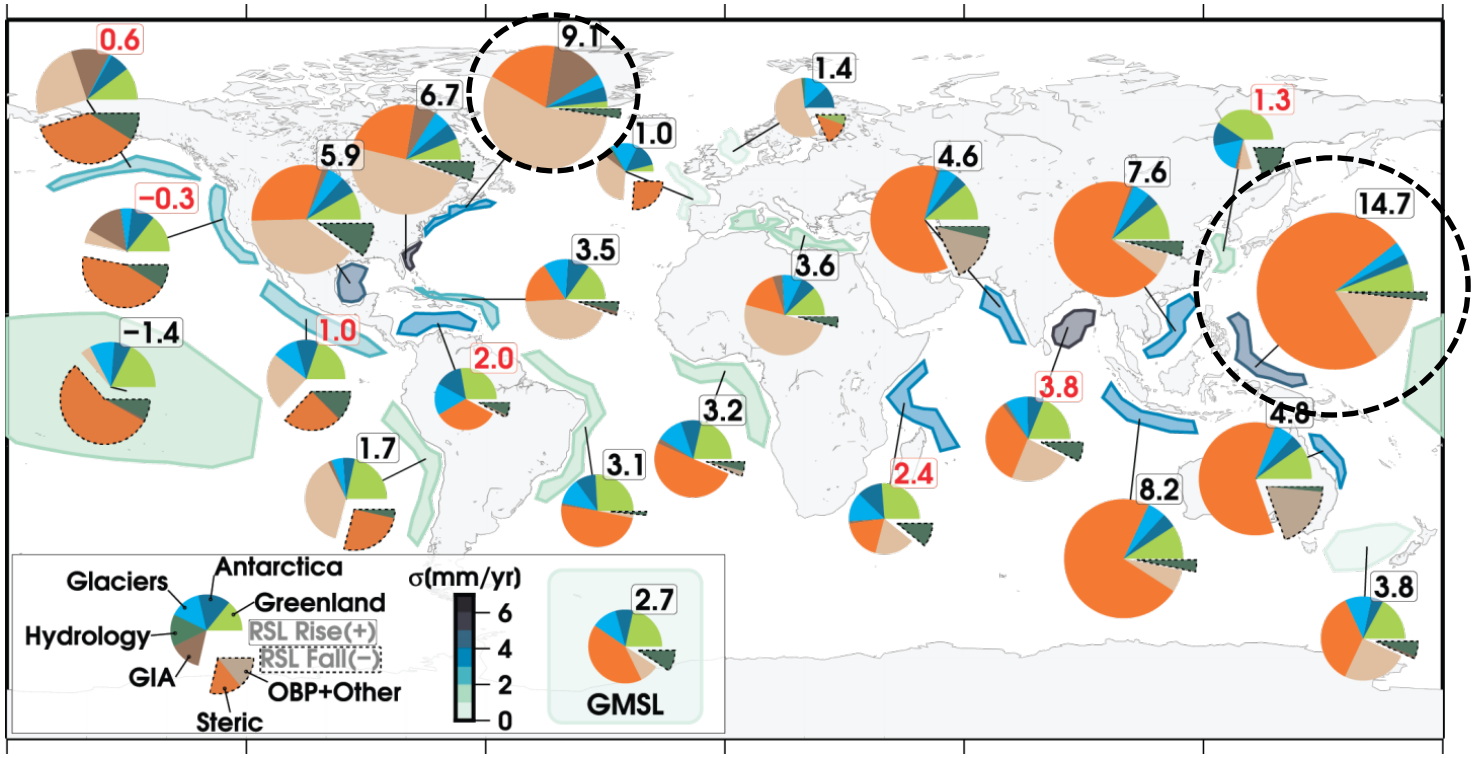
GRACE data

Landerer et al., GRL, 2015

Rietbroek et al., *PNAS*, 2016

Relative SLR ($mm\ yr^{-1}$) in coastal zones during 2002-2014

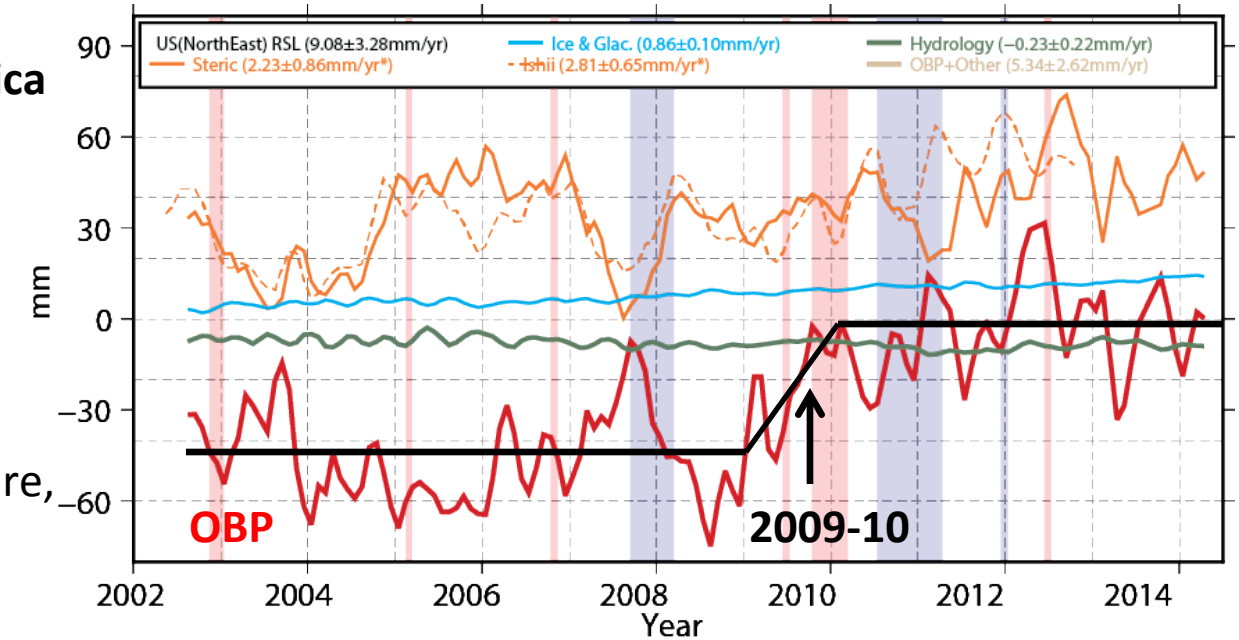
Based on satellite altimetry gravimetry



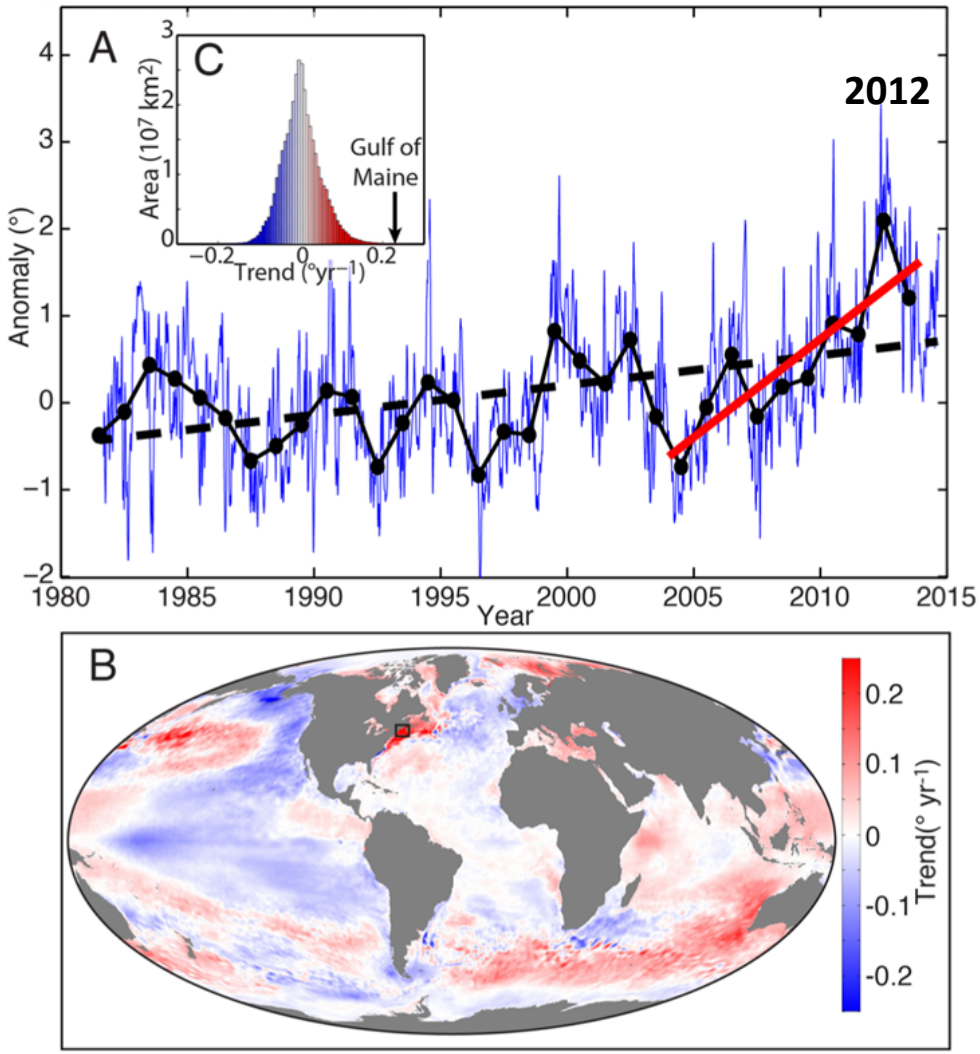
Northeast Coast of North America

The nearby shelf region experienced some of the fastest SLR during 2002-2014.

Most of the SLR is due to the increase in ocean bottom pressure, especially during 2009-10.



Thermosteric Effect

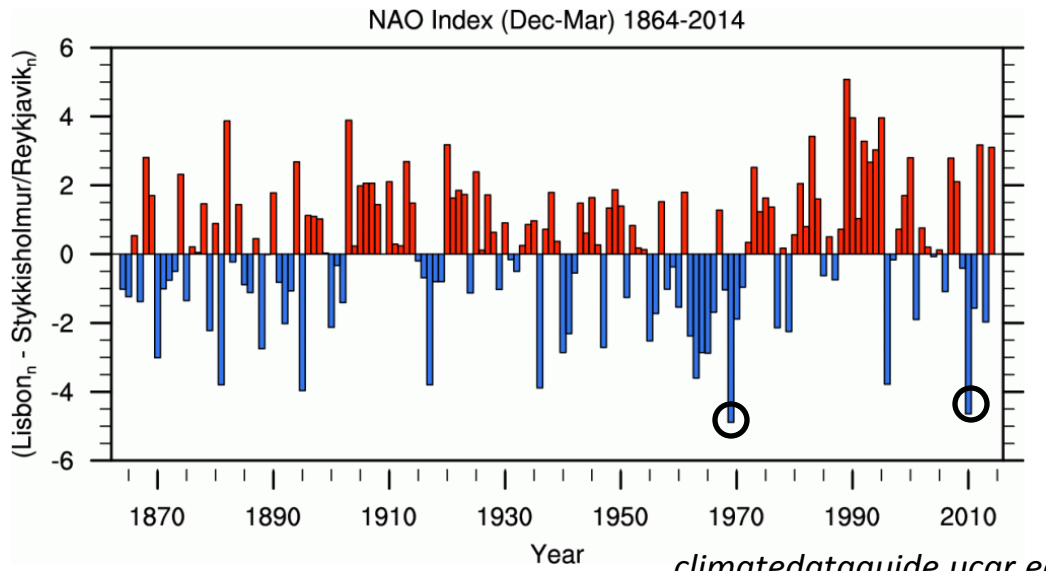


- The northeast coast and nearby oceans experienced some of the fastest warming (Pershing et al., 2015; Saba et al., 2016)
- Ocean heat wave in 2012
- The ocean warming could contribute to SLR through the thermosteric effect.

Pershing et al., Science, 2015

Role of NAO

- A significant negative NAO occurred in 2009-10.
- The northeasterly wind anomalies during 2009-10 could generate onshore Ekman transport.
- The lower atmospheric pressure can further enhance the magnitude through the inverse barometer effect.



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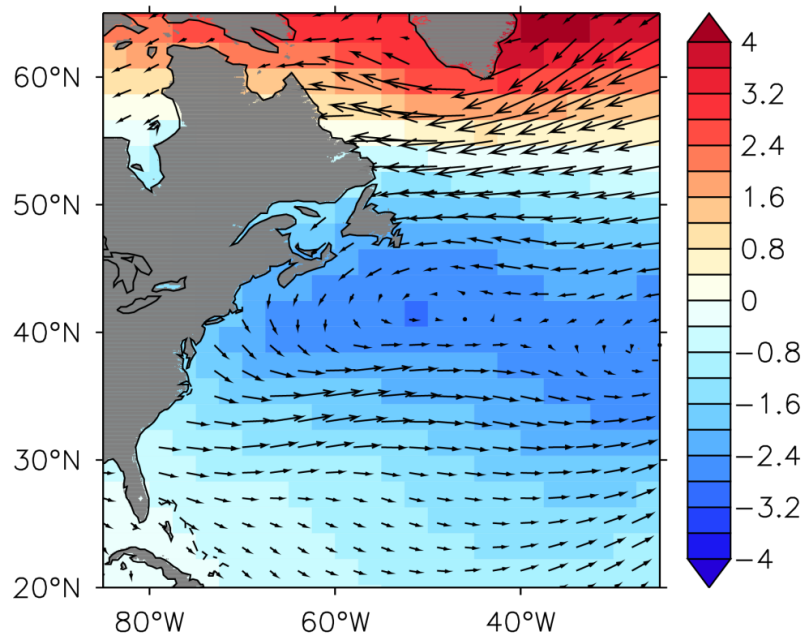

GFDL 50-year reanalysis → 6.000E−02

Goddard et al., Nat. Comm., 2015

Recent Work

- AMOC + NAO (Goddard et al., 2015)
- North/south and onshore/offshore shift the Gulf Stream (Ezer, 2015; …)
- Wind stress (Andres et al., 2013; …)
- Inverse barometer (Piecuch and Ponte, 2015; …)
- Ocean warming (Saba et al., 2016; …)
- Bottom pressure change (Landerer et al., 2015; …)
- Influence of NAO on AMOC (Zhao et al., 2014; …)
- Influence of AMOC on NAO (Bryden et al., 2014; …)
- Other factors

Conclusions

- Long-term tide gauge records show an extreme (>3σ or 1-in-850 year) sea-level rise event during 2009–10 along the Northeast Coast of North America.
- This extreme event is a combined effect of two factors: an observed 30% downturn of the AMOC and a significant negative NAO index.
- The relative contribution of each factor is still under investigation and in debate.
- Regression analysis indicates a 13-17 mm Sv^{-1} relationship between AMOC slowdown and the northeast coast SLR.
- The extreme event suggests that the 2009-10 AMOC downturn is unusual.