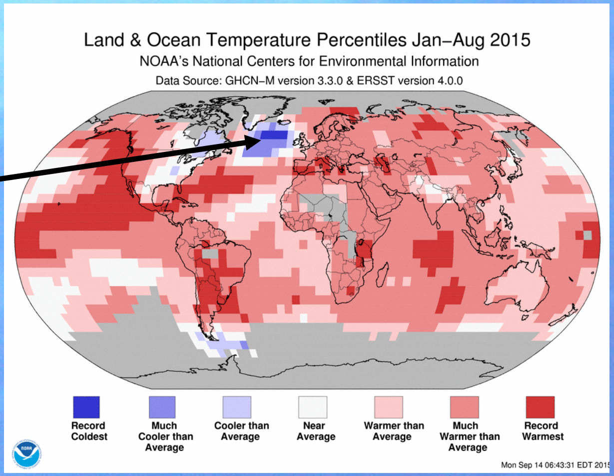
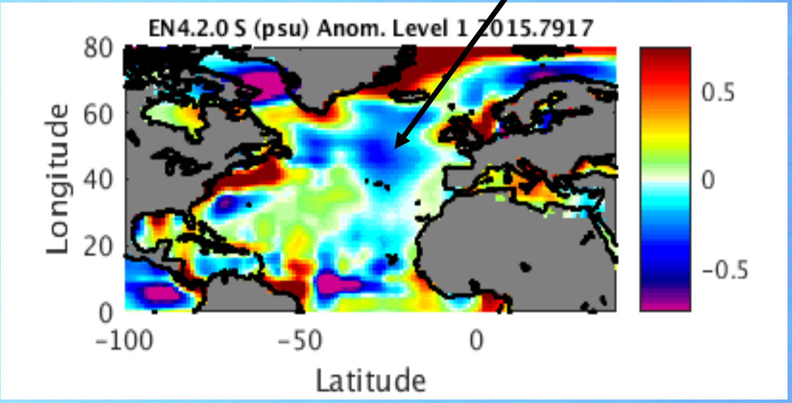
Changing Air-Sea Freshwater Fluxes and Ocean Salinity: From Wet gets Wetter to the Big Fresh Blob

<u>Outline:</u>

- Background
- Changing Air-Sea Freshwater Fluxes
- Subpolar Gyre: The 2015 Cold Anomaly (aka the Big Blue Blob, BBB)
- Corresponding Salinity Changes …the Big Fresh Blob



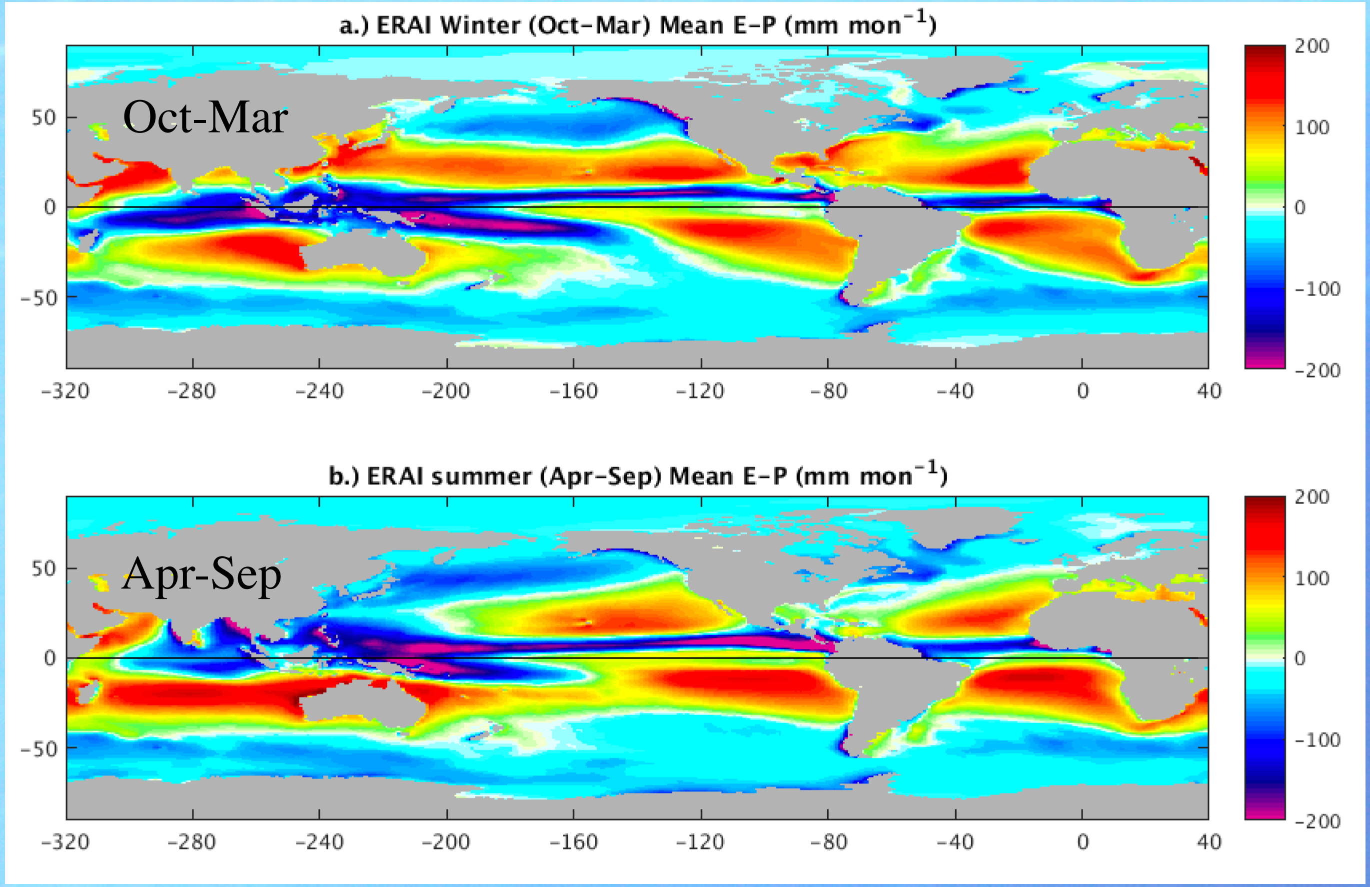


ESA Atlantic from Space, NOC, Jan 23-25th 2019,
Simon Josey & Jeremy Grist

ACSIS

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

Background: Air-Sea Freshwater Flux



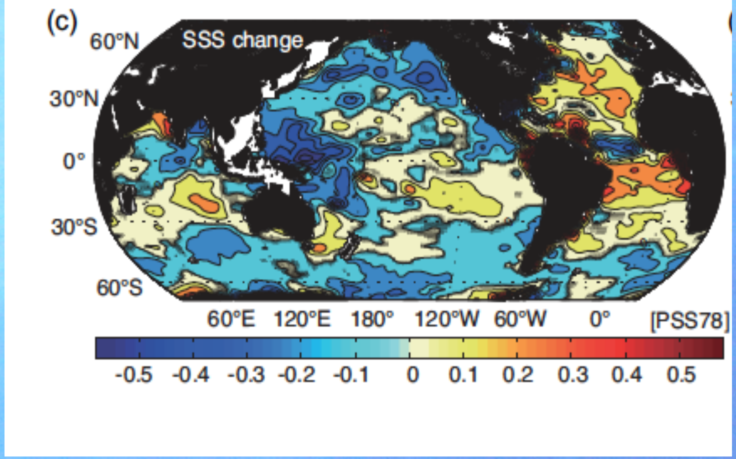
ERA-Interim Climatological Evaporation − Precipitation (E-P)

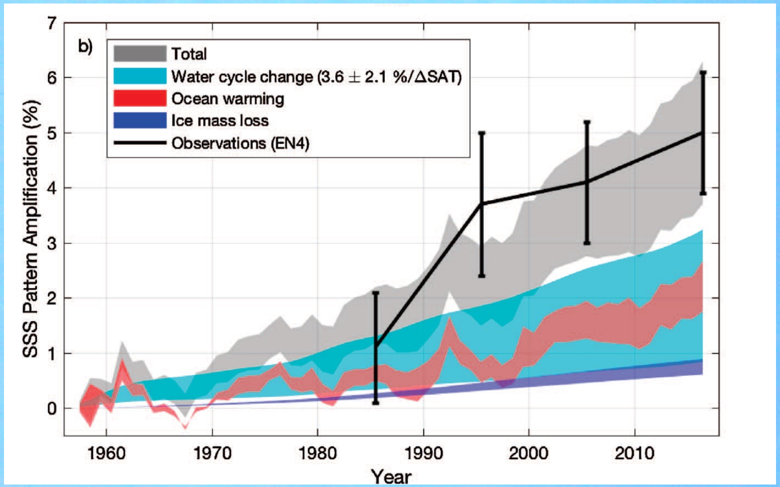
Surface flux review: Josey, S. A., S. Gulev and L. Yu, 2013: Exchanges through the ocean surface, in G. Siedler, J. Church, W. J. Gould and S. Griffies (eds): Ocean Circulation and Climate - Observing and Modelling the Global Ocean, Elsevier, 42 pp.

What's Driving Multidecadal Salinity Trends?

Fresh gets fresher···

SSS change (1950-2008, Durack and Wijffels, 2010).





Sources of surface salinity pattern amplification identified (Zika et al., 2018).

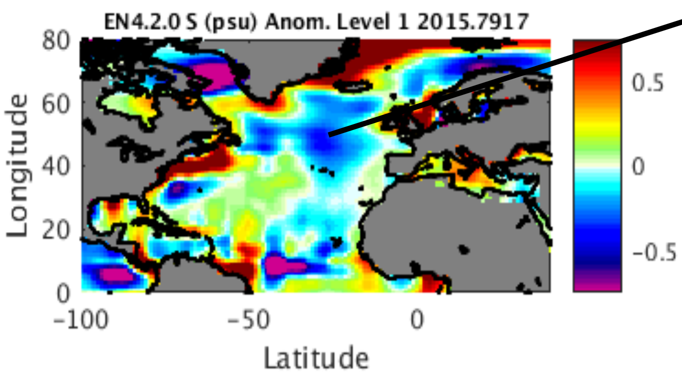
Approximately 40% by water cycle amplification, 45% by ocean warming (due to MLD reduction) and 15% by ice mass loss.

Zika, J., N. Skliris, A. T. Blaker, R. Marsh, A. J. G. Nurser and S. A Josey 2018: Improved estimates of water cycle change from ocean salinity: the key role of ocean warming, Env. Res. Lett., 13,7,doi: 10.1088/1748-9326/aace42.

A Major Freshwater Anomaly in the Subpolar Gyre…

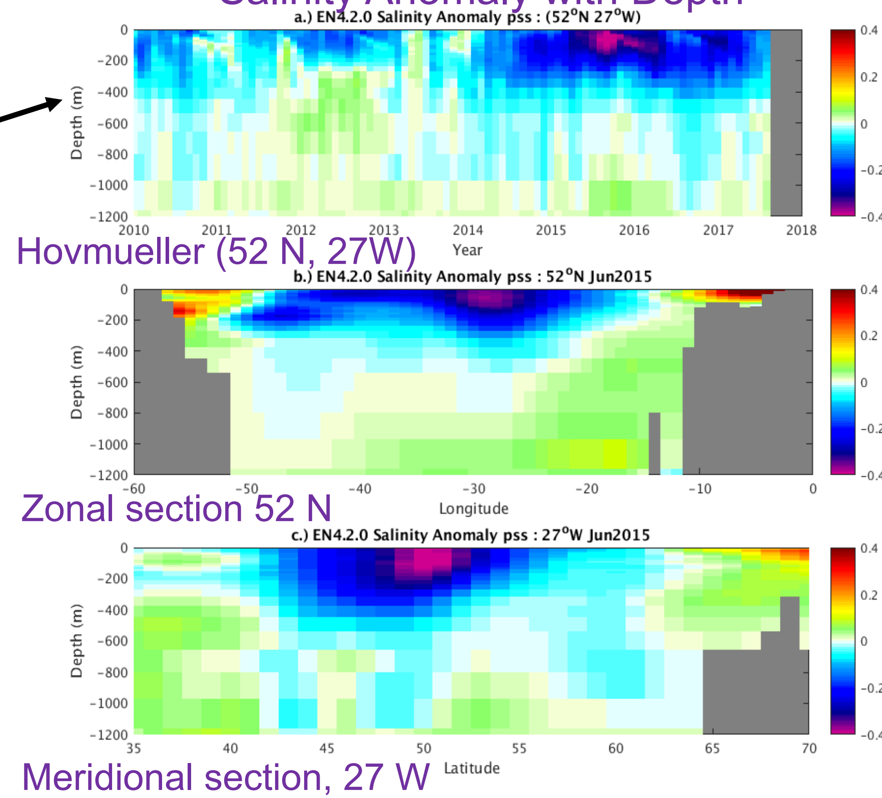
- Evidence for a anomalously fresh conditions in the North Atlantic subpolar gyre over past few years…

In situ observations (EN4)



SSS Anomaly Sep 2015

Salinity Anomaly with Depth



- Is the freshwater anomaly a response to circulation changes? What role do changes in E-P play?

- To what extent is it related to the 2015 Atlantic Cold Anomaly (Big Blue Blob)?

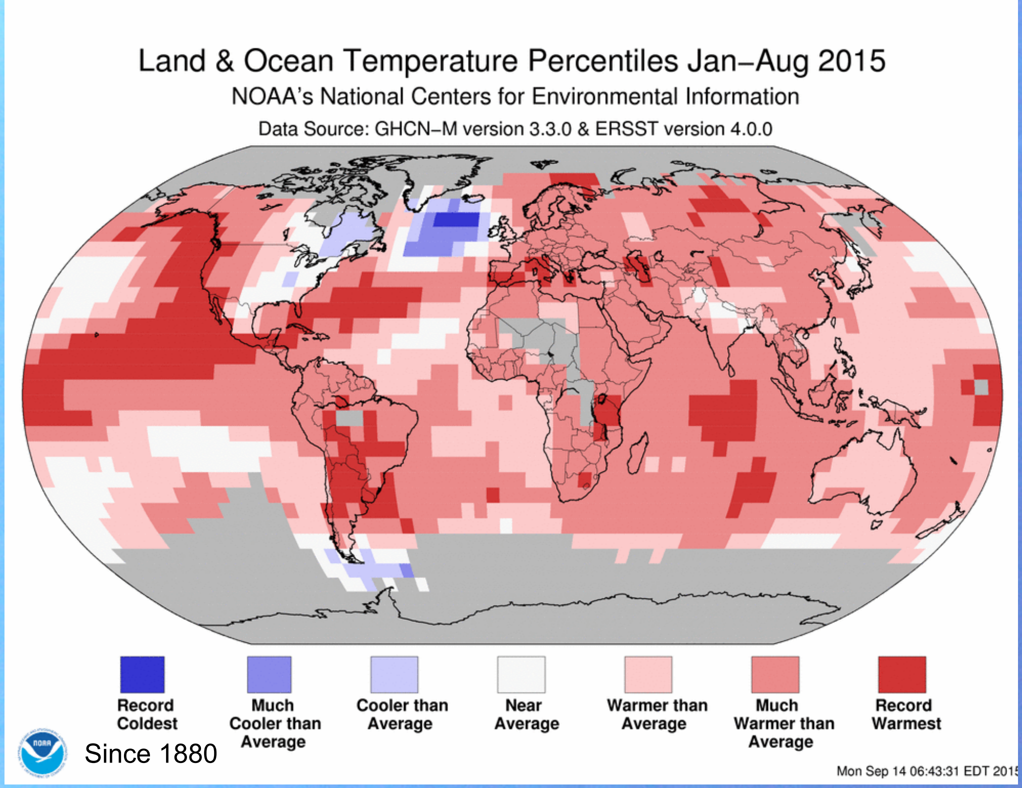
The North Atlantic 2015 Cold Anomaly (aka the Big Blue Blob)

- The cold anomaly first came to widespread attention as the ‘Big Blue Blob’ a region of record low SST in the North-East Atlantic.

- Generated headlines (e.g. Washington Post) as the rest of the globe is warming.

- Is this a sign of Atlantic Meridional Overturning Circulation (AMOC) decline?

- Or can it be explained by extreme heat loss over the preceding 2 winters?



Why Do We Care About the Cold Anomaly?

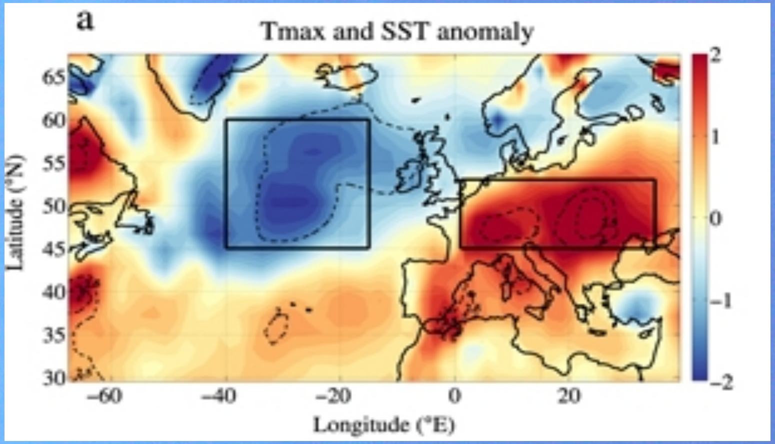
- **North Atlantic variability.** Potentially significant influence on estimates of Atlantic decadal timescale OHC trends.

- **Advection vs. Surface Forcing.** Influences efforts to determine the relative contributions of advective and surface forced signals to OHC variability (Roberts et al., 2017; Piecuch et al., 2017).

- **Re-emergence processes.** Cold ocean surface anomaly may be capped by summer restratification and re-emerge the following autumn/winter. 2014-15 events provide ideal opportunity to study processes involved in re-emergence.

- **Winter Impact**. Re-emergent SST signal may impact atmospheric state and modify European climate (Grist et al., 2018). Important for seasonal forecasting.

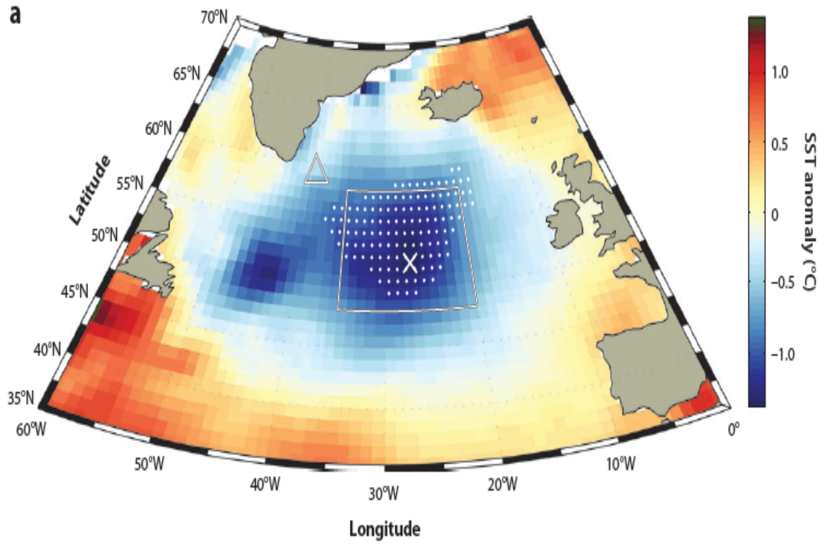
- **Summer Impacts.** Cold surface anomalies in late spring may favour development of European summer heat waves (Duchez, Frajka-Williams, Josey, Evans, Grist, Marsh, McCarthy, Sinha, Berry and Hirschi, Env. Res. Lett. 2016)



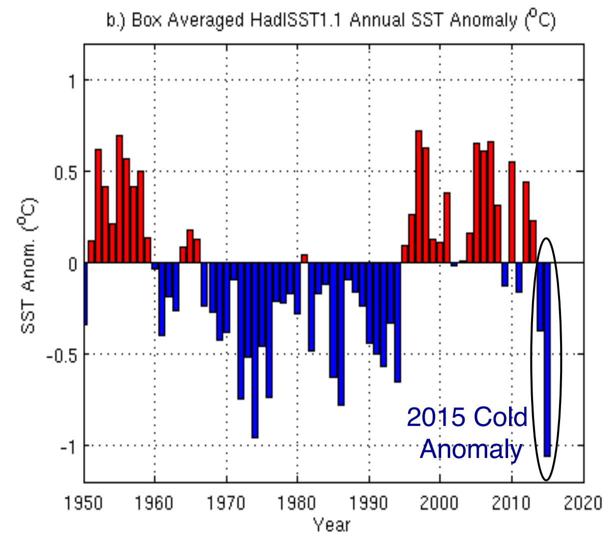
2015 JJA SST anomalies (over the ocean) and maximum 2 m air temperature anomalies (over land) in °C.

- **AMOC Decline.** Are we seeing a sign of a reduction in the Atlantic Meridional Overturning Circulation?

The Cold Anomaly in Context



Observed (HadISST1.1) – SST 2015
Annually Averaged Anomaly



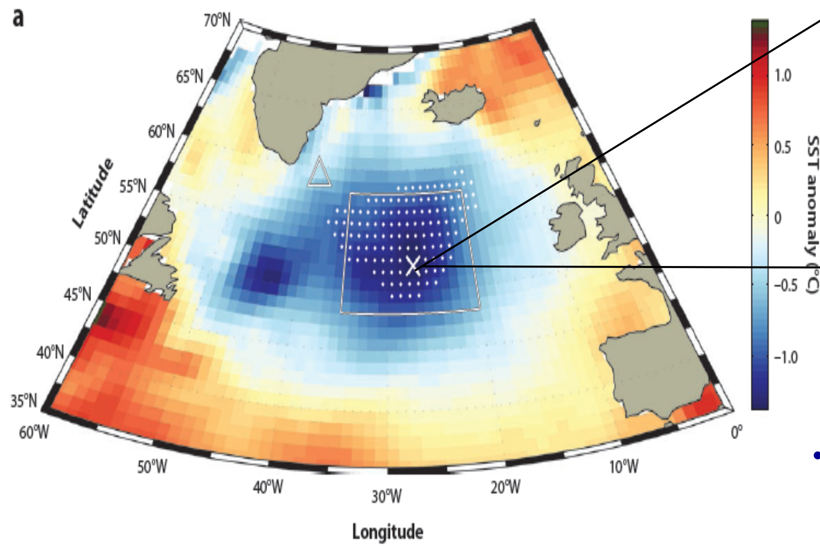
Observed (HadISST1.1) – Annual Averaged
Anomaly Time Series

Josey, S. A., J. J.-M. Hirschi, B. Sinha, Duchez, A., J. P. Grist and R. Marsh, 2018: The Recent Atlantic Cold Anomaly: Causes, Consequences and Related Phenomena, Annual Reviews of Marine Science.

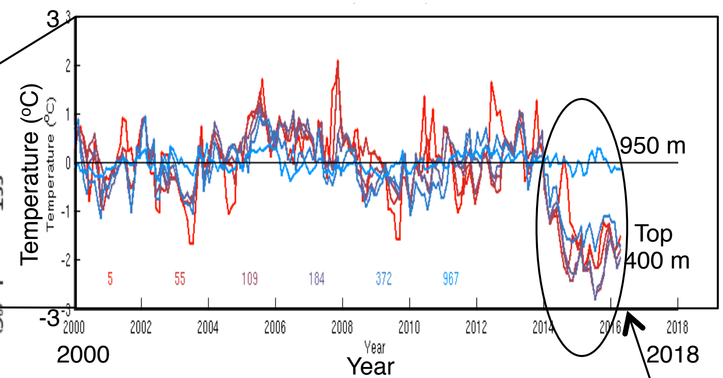
- Timescale is a key issue – evidence for some cooling in past decade (Robson et al., 2016) and the past century (Rahmstorf et al., 2015).

- However, intense cooling signal and record breaking surface temperatures have developed in the 2 years since winter 2013-14. Not dealing with decadal or centennial variability.

The Cold Anomaly in Context



Observed (HadISST1.1) – SST 2015
Annually Averaged Anomaly



Observed (EN4) – Potential Temperature Anomaly (52N, 27 W)

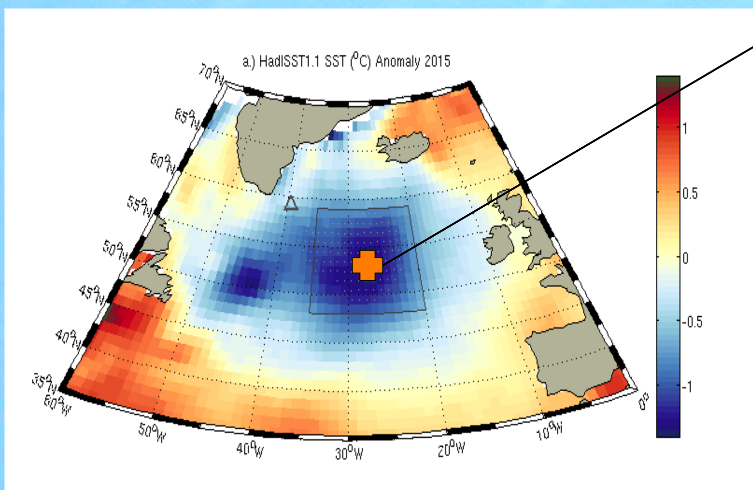
- Time series at various depths in cold anomaly centre show strong short-term (2-3 years) cooling in blob centre.
- Important when considering decadal trends.

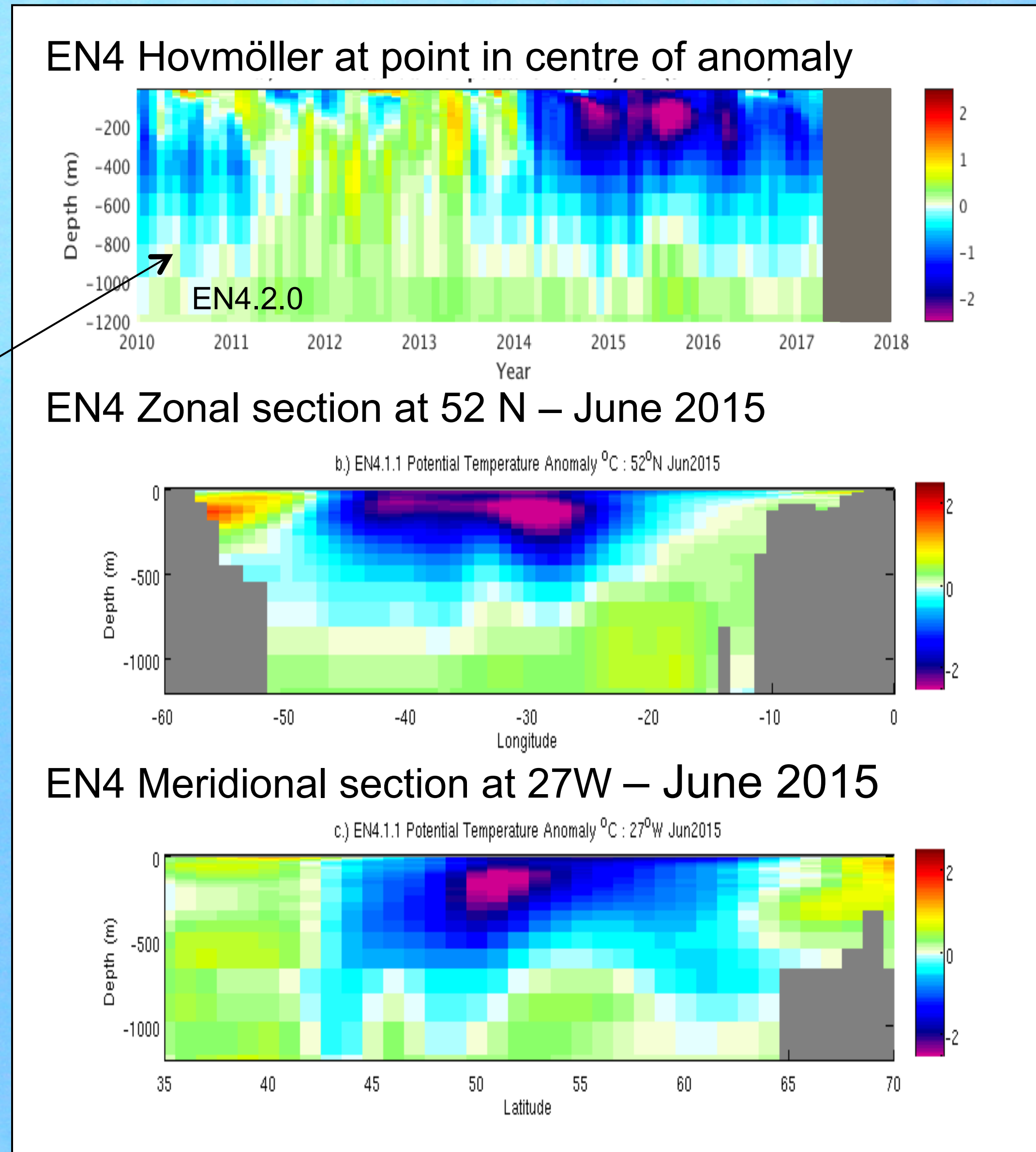
Josey, S. A., J. J.-M. Hirschi, B. Sinha, Duchez, A., J. P. Grist and R. Marsh, 2018: The Recent Atlantic Cold Anomaly: Causes, Consequences and Related Phenomena, Annual Reviews of Marine Science.

- Timescale is a key issue – evidence for some cooling in past decade (Robson et al., 2016) and the past century (Rahmstorf et al., 2015).
- However, intense cooling signal and record breaking surface temperatures have developed in the 2 years since winter 2013-14. Not dealing with decadal or centennial variability.

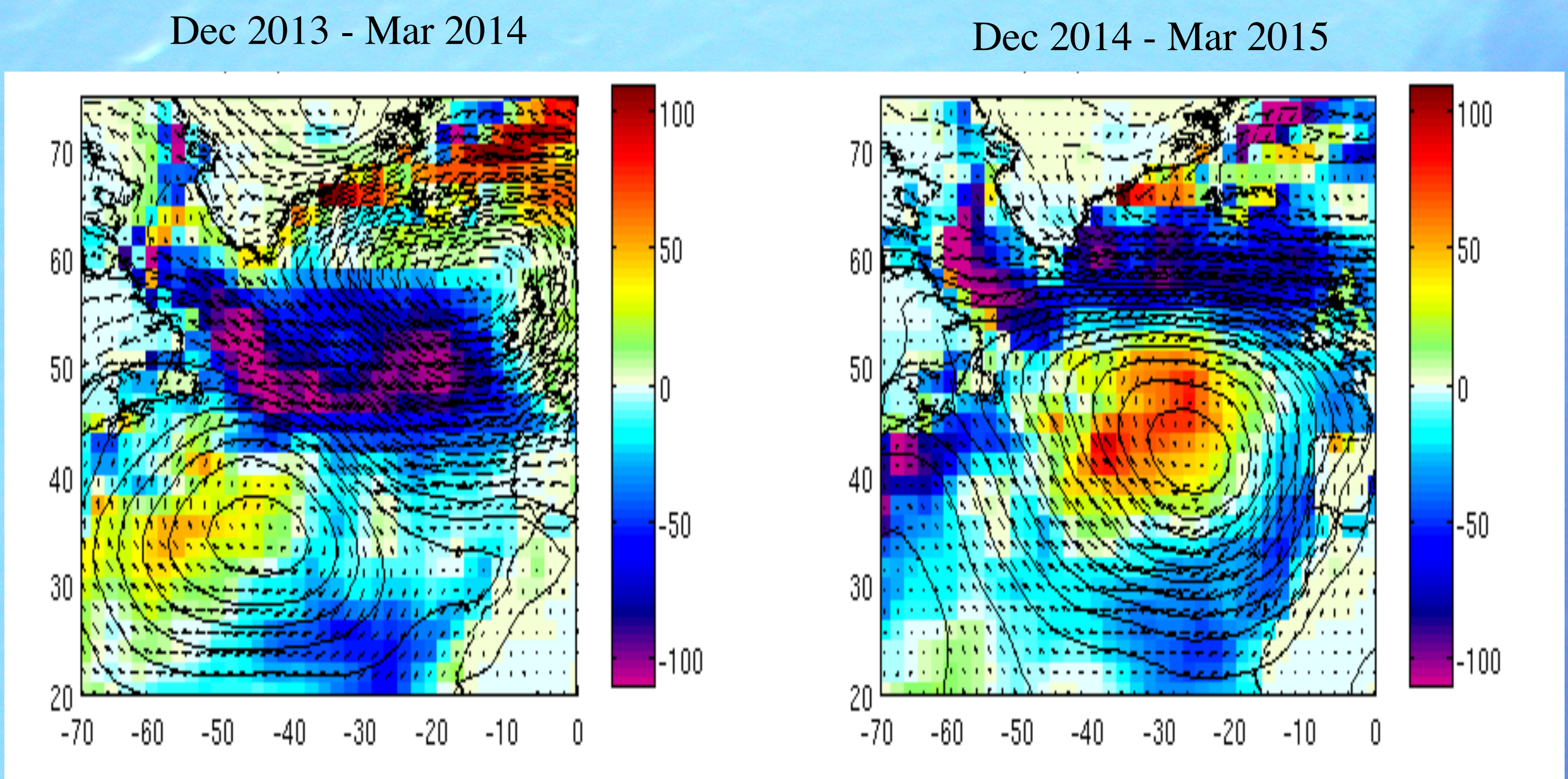
EN4 analysis: Observed Variation with Depth – 2015 Average

- In addition to SST signal, cold anomaly extends to about 500m depth.





Causes : Extreme Winter Heat Loss

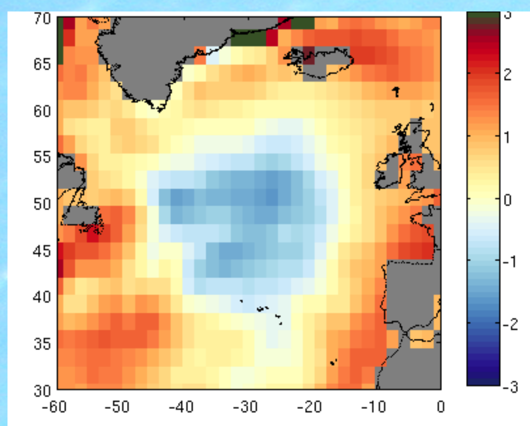


NCEP/NCAR Winter Net Heat Flux Anomaly (W m^{-2})

- Successive winters 2013-14 and 2014-15 were two of the most extreme on record in the past 50 years.
- Most intense heat loss in 2014-15 (NAO dominated) displaced northwards relative to 2013-14 (EAP dominated).

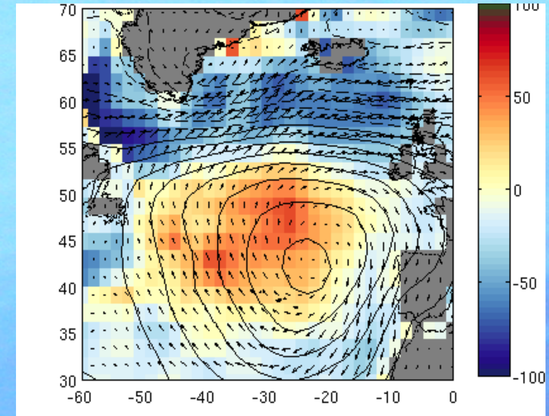
Anomalous Winter Heat Loss Can Explain Much of the Blob....

Initial condition: Nov14 SST'



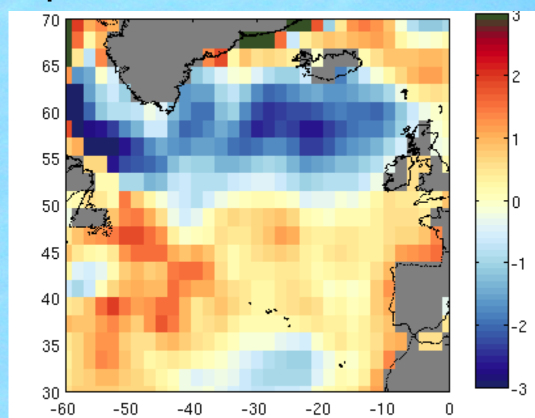
+

Subsequent forcing: Dec14-May15 Net Heat (Wm^{-2})



=

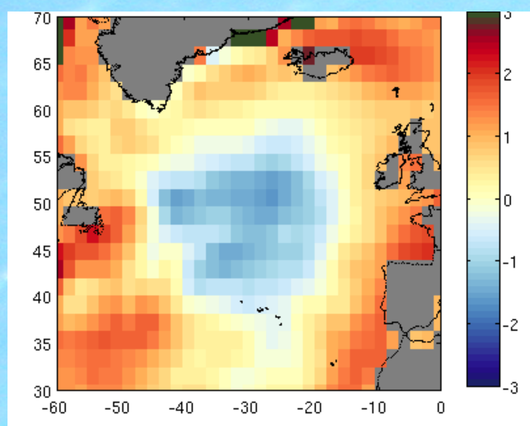
Implied 'blob': Jun15 SST'



- Implied SST anomaly determined by applying Dec-May 2015 heat flux anomaly over mixed layer and adding to initial condition field (Nov 2014 SST anomaly).
- Volumetric analysis of water above 27.6 kg m^{-3} isopycnal shows surface heat loss accounts for 0.7 GJ m^{-2} of total change in ocean heat content of 1.1 GJ m^{-2} from Jan-Jun 2013 to Jan-Jun 2015. Details: Duchez, Frajka-Williams, Josey, Evans, Grist, Marsh, McCarthy, Sinha, Berry and Hirschi, 2016: Env. Res. Lett..

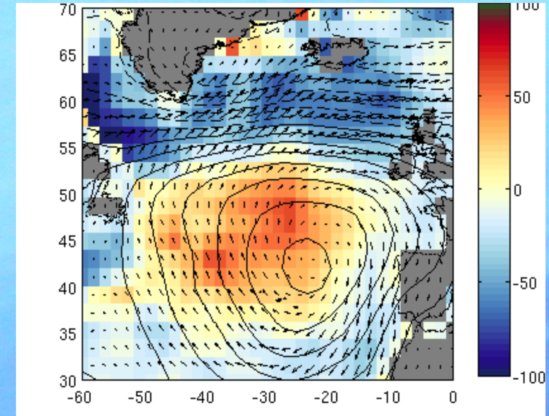
Anomalous Winter Heat Loss Can Explain Much of the Blob….

Initial condition: Nov14 SST’



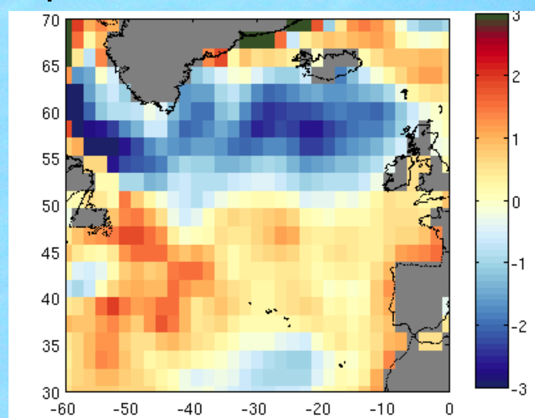
+

Subsequent forcing: Dec14-May15 Net Heat (Wm^{-2})

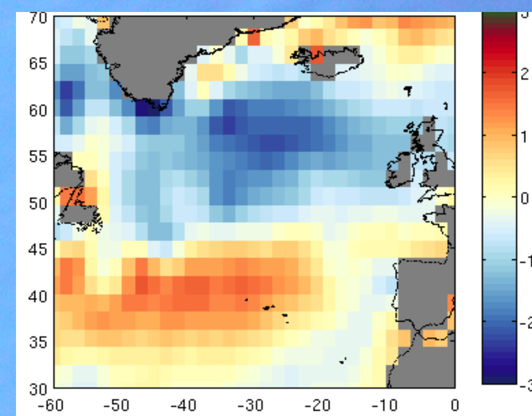


=

Implied ‘blob’: Jun15 SST’



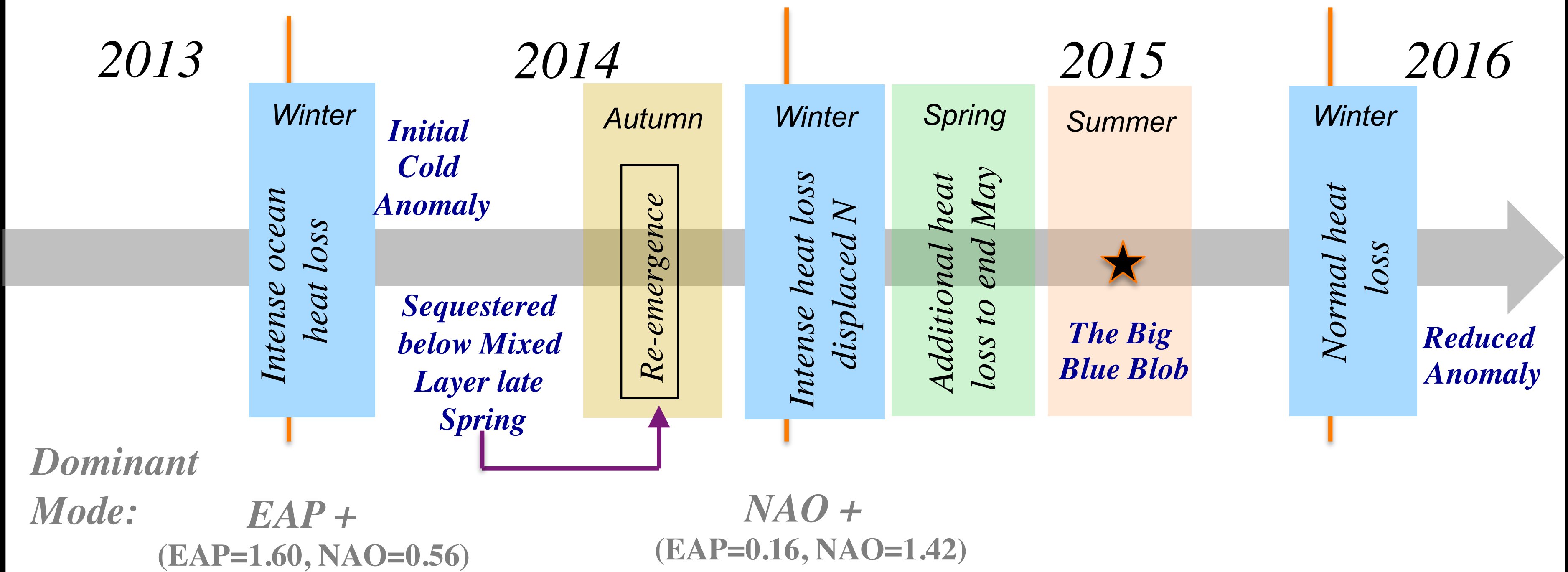
Observed ‘blob’: Jun15 SST’



- Implied SST anomaly determined by applying Dec-May 2015 heat flux anomaly over mixed layer and adding to initial condition field (Nov 2014 SST anomaly).

- Volumetric analysis of water above 27.6 kg m^{-3} isopycnal shows surface heat loss accounts for 0.7 GJ m^{-2} of total change in ocean heat content of 1.1 GJ m^{-2} from Jan-Jun 2013 to Jan-Jun 2015. Details: Duchez, Frajka-Williams, Josey, Evans, Grist, Marsh, McCarthy, Sinha, Berry and Hirschi, 2016: Env. Res. Lett..

Overview of Surface Forcing and the Recent Cold Anomaly

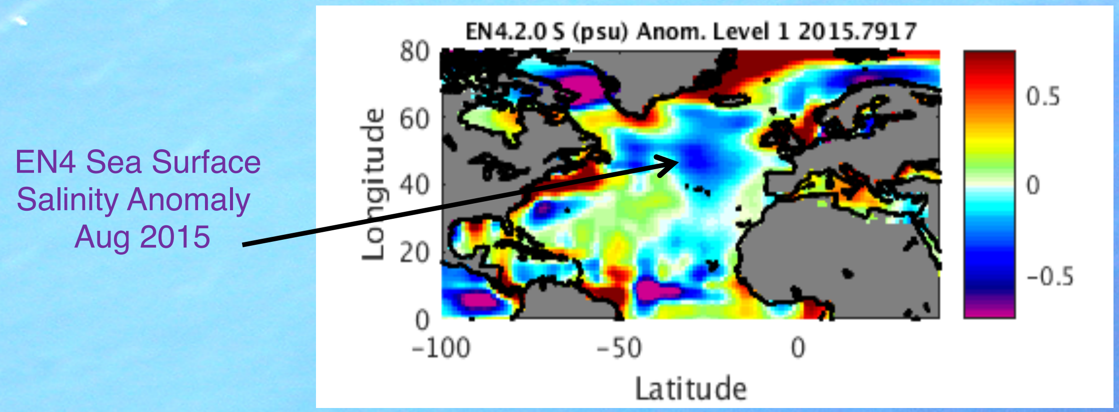


Josey, S. A., J. J.-M. Hirschi, B. Sinha, Duchez, A., J. P. Grist and R. Marsh, 2018: The Recent Atlantic Cold Anomaly: Causes, Consequences and Related Phenomena, Annual Reviews of Marine Science.

Connecting the Fresh and Cold Anomalies

<u>ESA Funded Pilot Study (Josey, Martin, Grist - 3months)</u>

- Preliminary analysis of in situ observation based ocean salinity fields indicate that the cold anomaly is accompanied by ocean freshening.



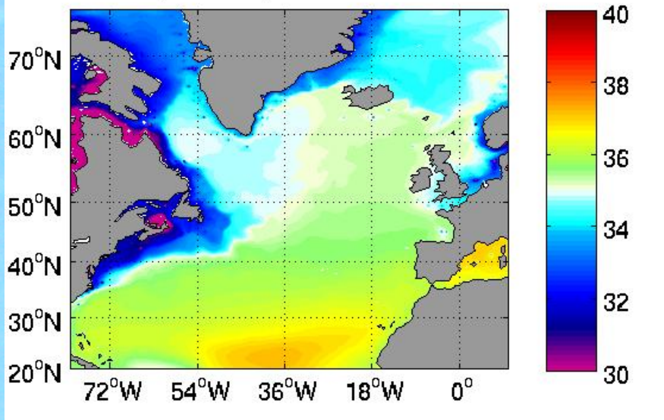
- Pilot study : Use new ESA CCI Salinity fields with other data sources (Argo, hydrographic sections) and models to investigate processes responsible for generating the salinity anomaly and its relationship to to changing ocean circulation.

- Models to include high resolution forced ocean simulations of the current and earlier decades (1/12^o NEMO) and state of the art coupled ocean-atmosphere models (1/12^o NEMO, 25 km atmosphere).

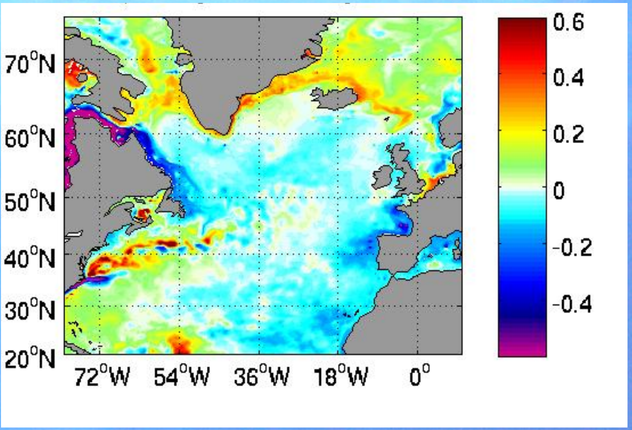
Confronting Coupled Models with ESA CCI Salinity Fields

Preliminary analysis of sea surface salinity variability in state of the art coupled ocean-atmosphere model (1/12° NEMO, 25 km atmosphere) run at NOC.

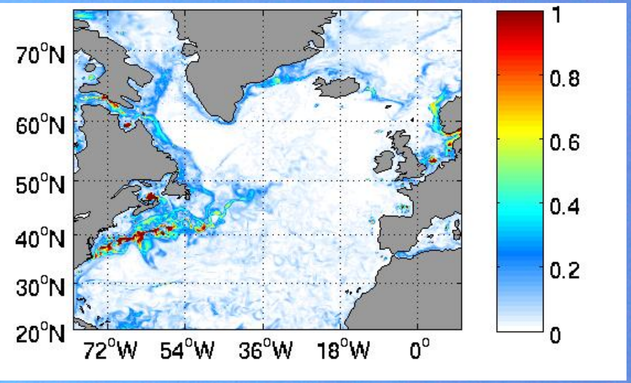
Model Mean Sea Surface Salinity (SSS)



Change in SSS over last Decade of Model Run

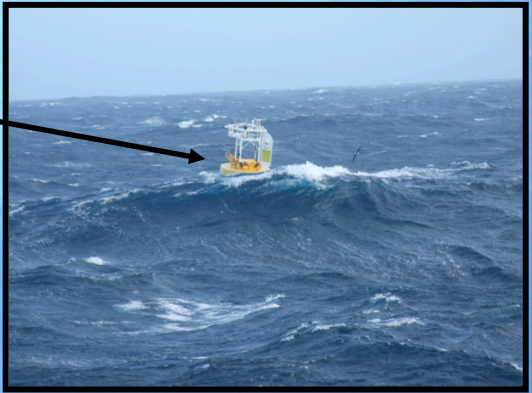


Model Variability in SSS at Daily Timescales

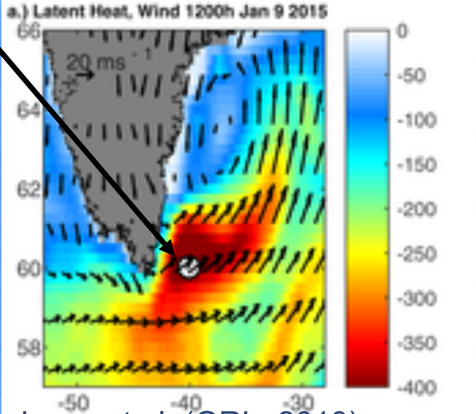


- Next step: Evaluation of Model SSS Variability against ESA CCI (Collaboration with Boutin, Reul)

Wind Jet Forcing of Extreme Heat Loss in Irminger Sea Deep Convection Region



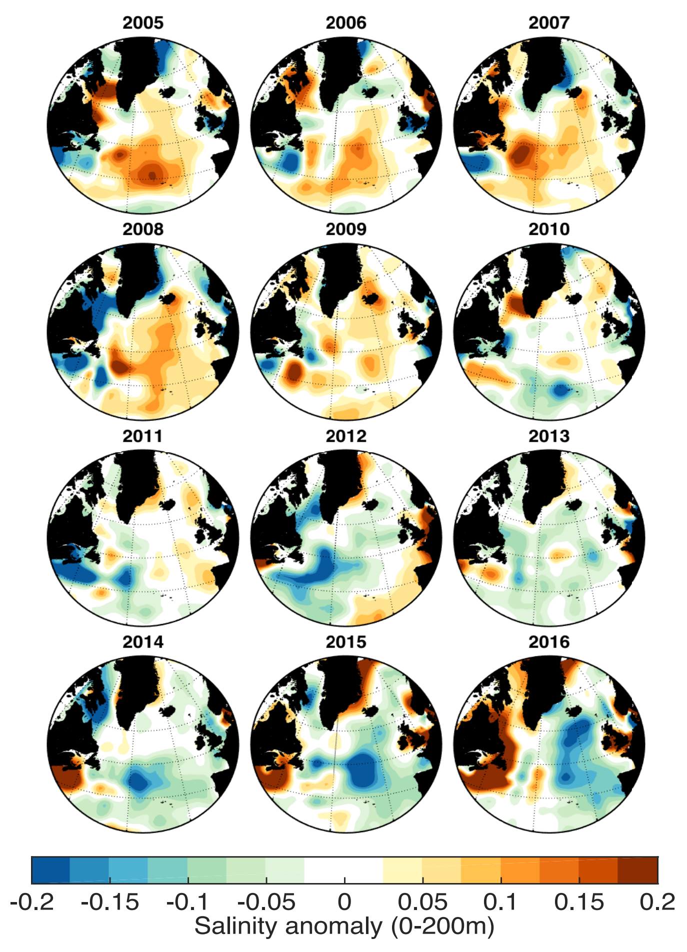
- First Surface Flux Mooring observations from the Irminger Sea have revealed Greenland Tip Jet impacts (Josey et al., 2019).
- Extreme heat loss during strong Tip Jet conditions (latent 400 Wm^{-2} , net 800 Wm^{-2}).
- Tip jets favoured by the North Atlantic Oscillation (first mode of atmospheric variability) but suppressed by the second mode (East Atlantic Pattern).
- More complex picture for atmospheric influence on Irminger Sea deep convection than previously thought).
- Potential for further insights using ESA winds, SST and SSS.

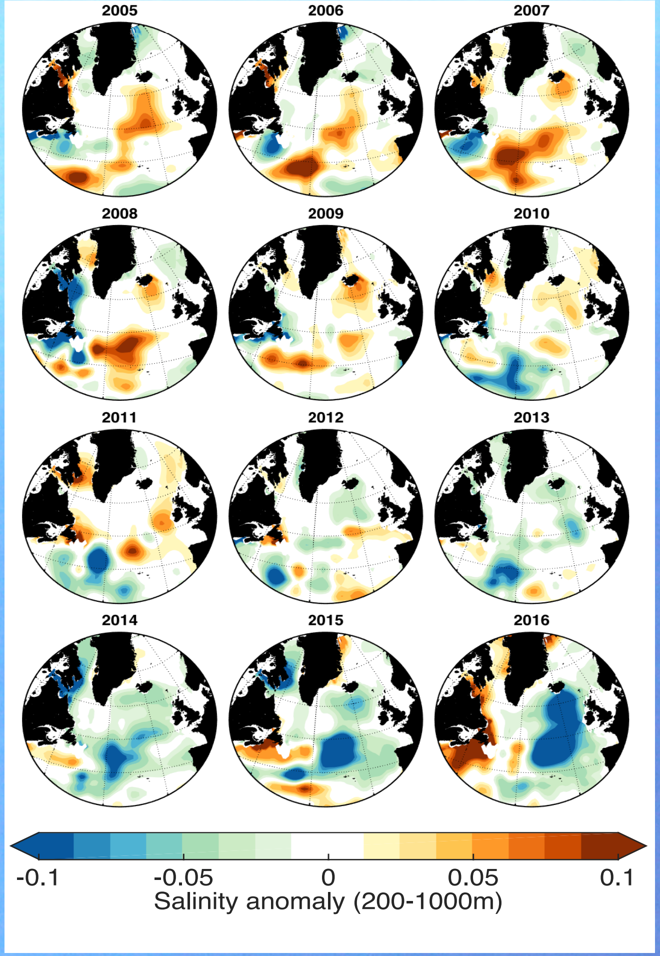


Josey et al. (GRL, 2019)

Josey, S. A., M. F. de Jong, M. Oltmanns, G. K. Moore and R. A. Weller, 2019: Extreme Variability in Irminger Sea Winter Heat Loss Revealed by Ocean Observatories Initiative Mooring and the ERA5 Reanalysis, Geophys. Res. Lett., https://doi.org/10.1029/2018GL080956

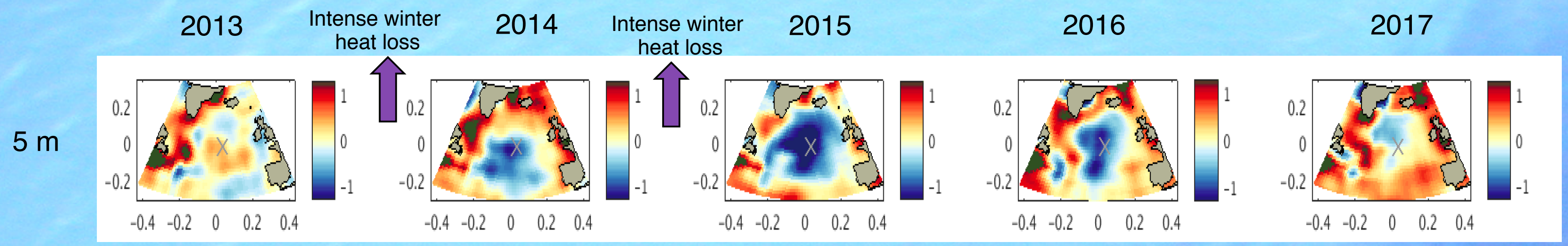
Holliday et al. (2018) – Basin Scale Variability





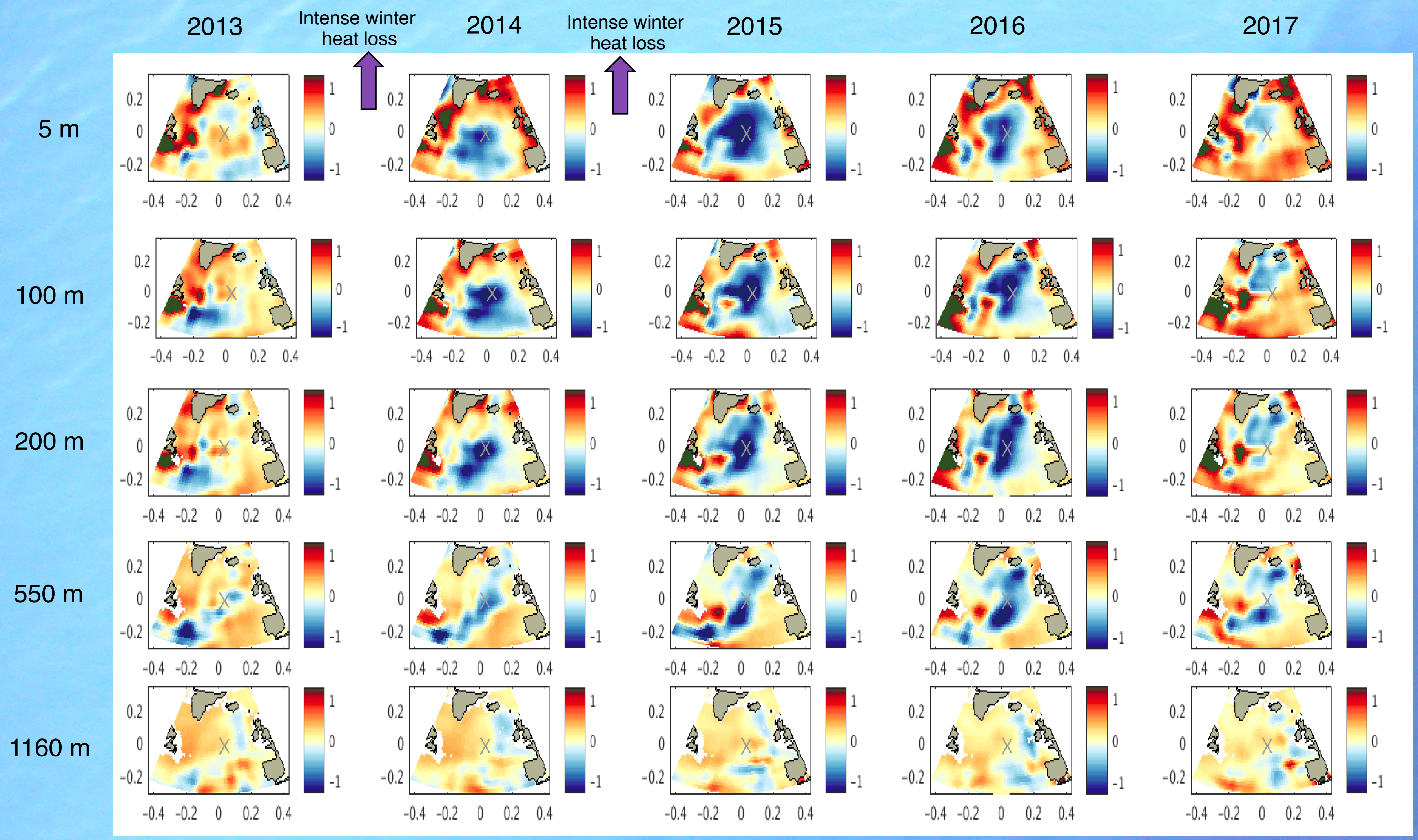
- Very strong signal evident in eastern gyre by 2016. Causes under investigation.
- Likely ocean circulation driven rather than surface forced (as preliminary ERAI and NCEP E-P calculations indicate surface freshwater flux contribution relatively small, Holliday et al., 2018, in prep.).

Development and Persistence at Annual Timescales



- EN 4.1.2 observation based maps of ocean temperature anomaly relative to 1981-2010 showing development, persistence and erosion of the cold subpolar gyre feature.

Development and Persistence at Annual Timescales

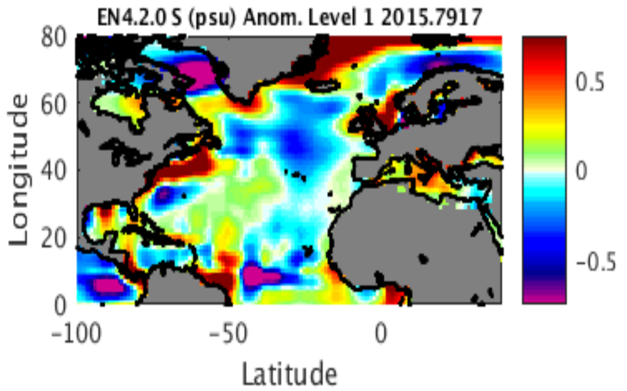


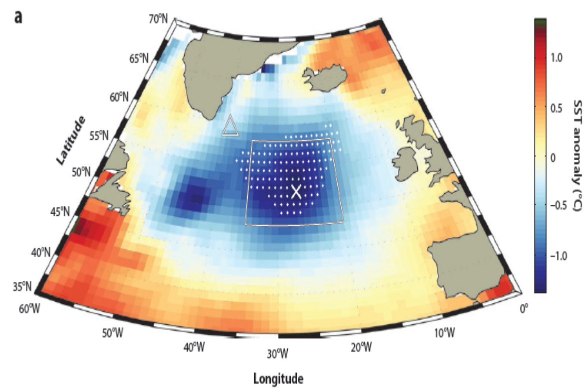
- EN 4.1.2 observation based maps of ocean temperature anomaly relative to 1981-2010 showing development, persistence and erosion of the cold subpolar gyre feature.

Summary

- Strong freshwater anomaly evident in North Atlantic subpolar gyre in recent years.
- Causes under investigation, including use of ESA CCI SSS fields.

EN4 Sea Surface Salinity Anomaly Aug 2015





Observed (HadISST1.1) – SST 2015
Annually Averaged Anomaly

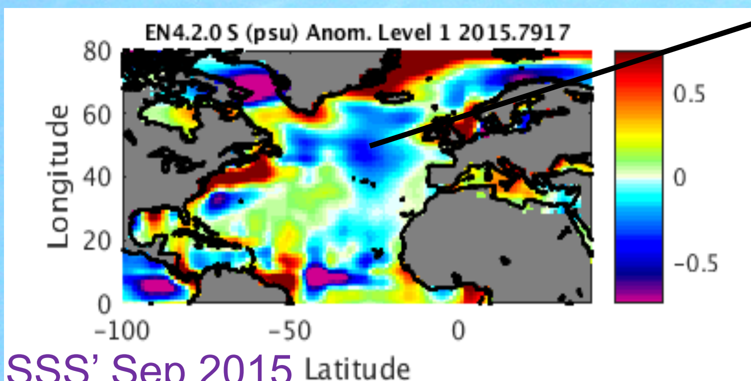
- 2015 cold anomaly causes and consequences reviewed (Josey et al., 2018). Largely a surface forced event resulting from two exceptionally severe heat loss winters
- Open question … How closely related are the driving processes for the heat and freshwater content anomalies?

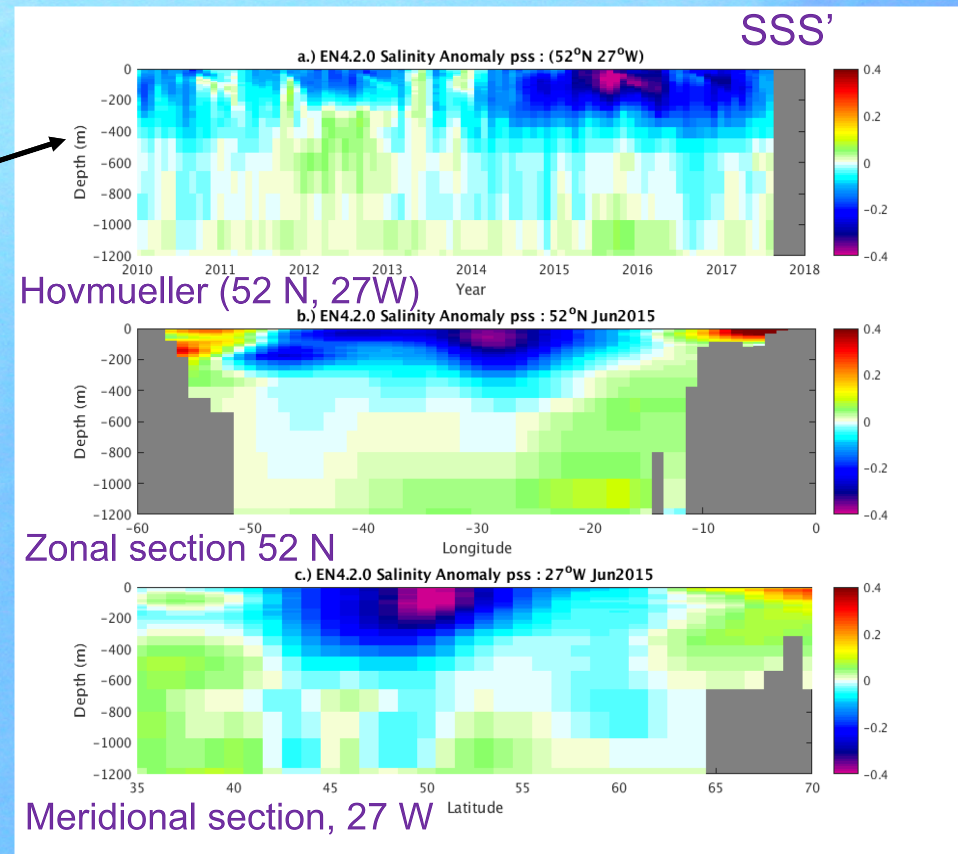
Josey, S. A., J. J.-M. Hirschi, B. Sinha, Duchez, A., J. P. Grist and R. Marsh, 2018: The Recent Atlantic Cold Anomaly: Causes, Consequences and Related Phenomena, Annual Reviews of Marine Science.

The Subpolar Gyre Freshwater Anomaly

- Evidence for a anomalously fresh conditions in the North Atlantic subpolar gyre over past few years…

Observations (EN4)

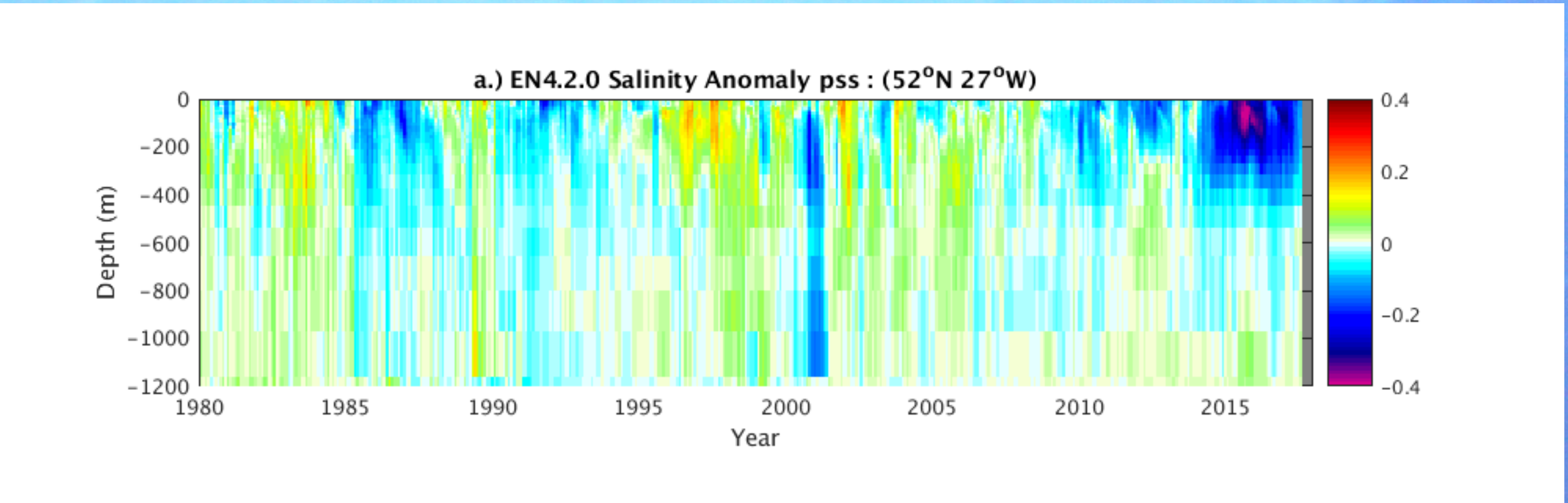




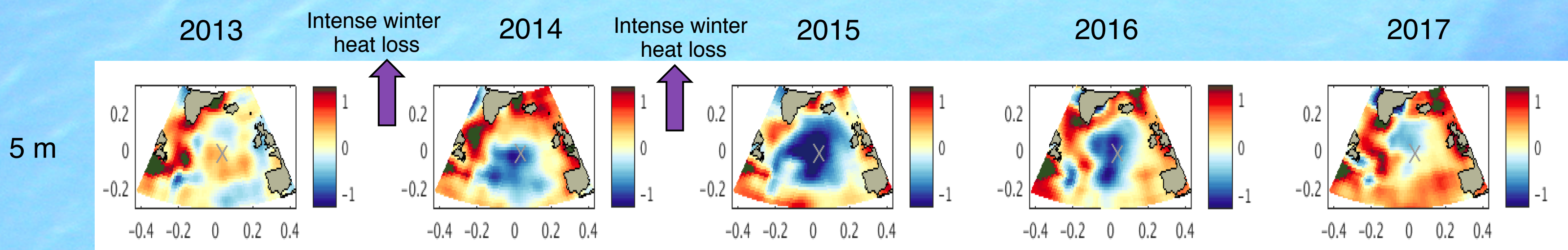
- Is the freshwater anomaly a response to circulation changes? What role do changes in E-P play?

- To what extent is it related to the 2015 Atlantic Cold Anomaly (Big Blue Blob)?

Long Term Context…

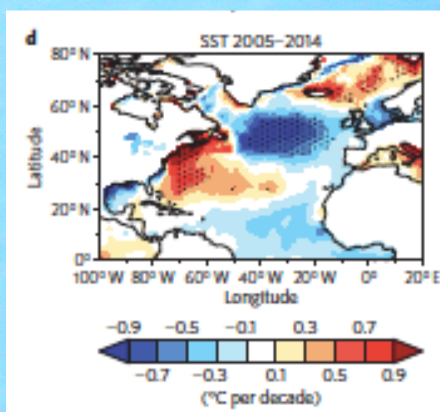


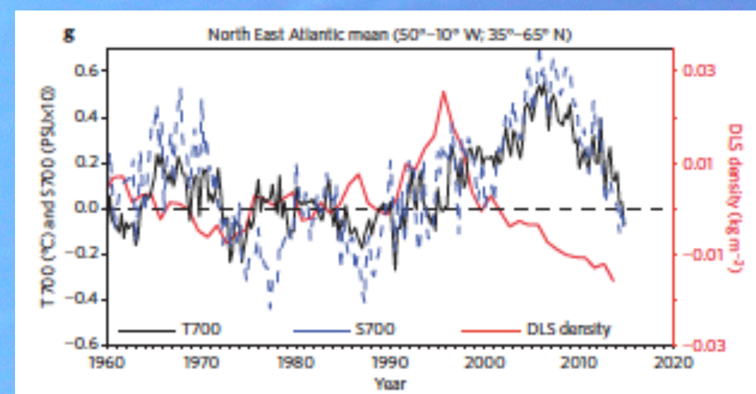
The Interannual to Interdecadal Transition



- How do we relate the potential for extreme variability at 2-3 year timescales to decadal timescale subpolar gyre changes?

Robson et al. (2016):

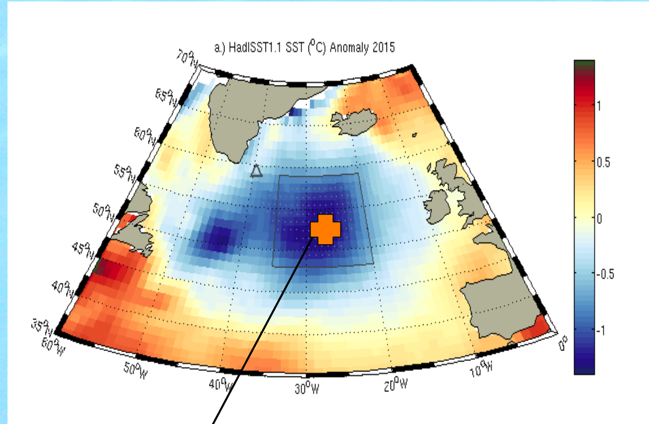




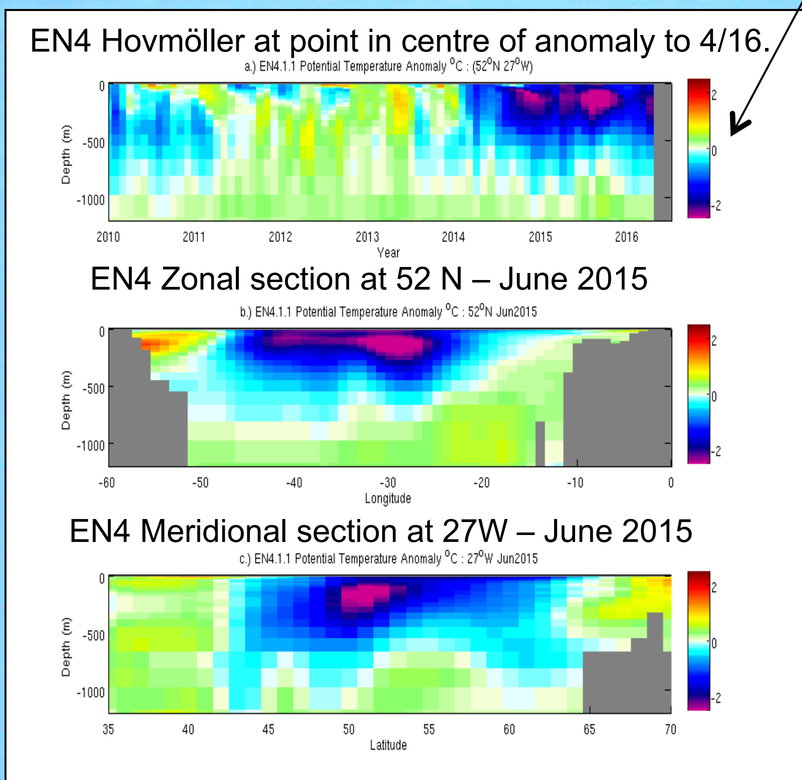
- What drivers do I-A and I-D variability have in common? Is it a simple transition from surface forced to circulation forced change with increasing timescale? Regional dependence: Is circulation more important in east / surface forcing in the west (Robson et al., 2018)?

- How does this relate to Atlantic Multidecadal Variability (Sutton et al., 2017)? Do different states of AMV favour increased frequency of extreme heat loss at interannual timescales?

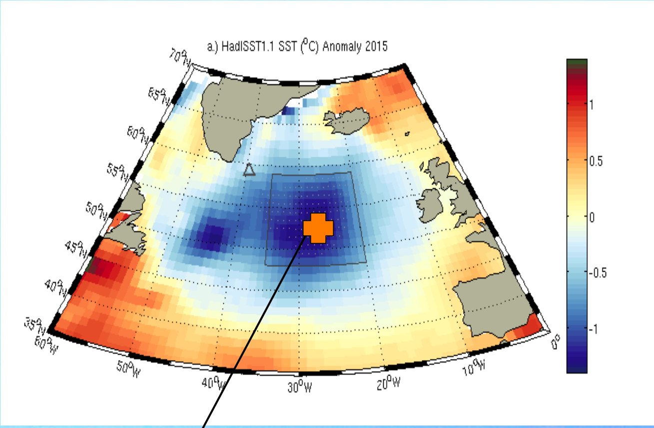
What's Left of the Cold Anomaly Now?



June 2015 sections

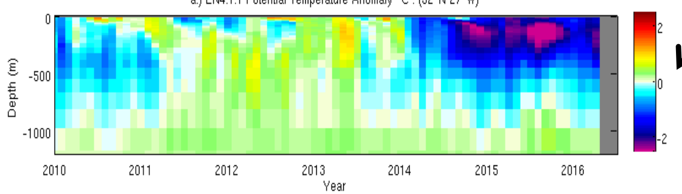


What’s Left of the Cold Anomaly Now?

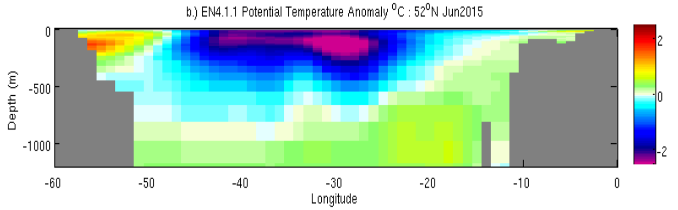


June 2015 sections

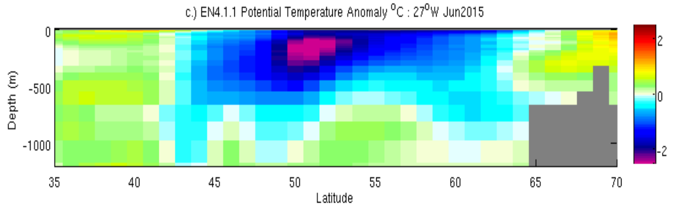
EN4 Hovmöller at point in centre of anomaly to 4/16.



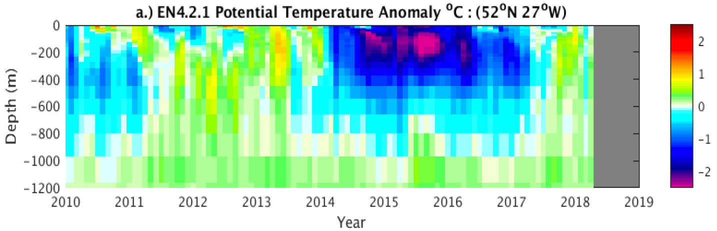
EN4 Zonal section at 52 N – June 2015



EN4 Meridional section at 27W – June 2015



Updated Hovmöller to 4/18.



Corresponding April 2018 sections