OMWG Winter Meeting
February 2, 2021

iHESP
(International Laboratory for High Resolution Earth System Prediction)

An Outsized Role for the Labrador Sea in Low Frequency AMOC Variability

(Does the tail wag the dog in the North Atlantic?)

Stephen Yeager[1,2], Fred Castruccio[1,2], Ping Chang[2,3], Gokhan Danabasoglu[1,2], Elizabeth Maroon[3], Justin Small[1,2], Hong Wang[2,5], Lixin Wu[2,4], Shaoqing Zhang[2,5]

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[2]iHESP, College Station, TX
[3]Texas A&M University, College Station, TX
[3]University of Wisconsin, Madison, WI
[4]Qingdao Pilot National Laboratory for Marine Science and Technology, Qingdao, China
[5]Ocean University of China, Qingdao, China

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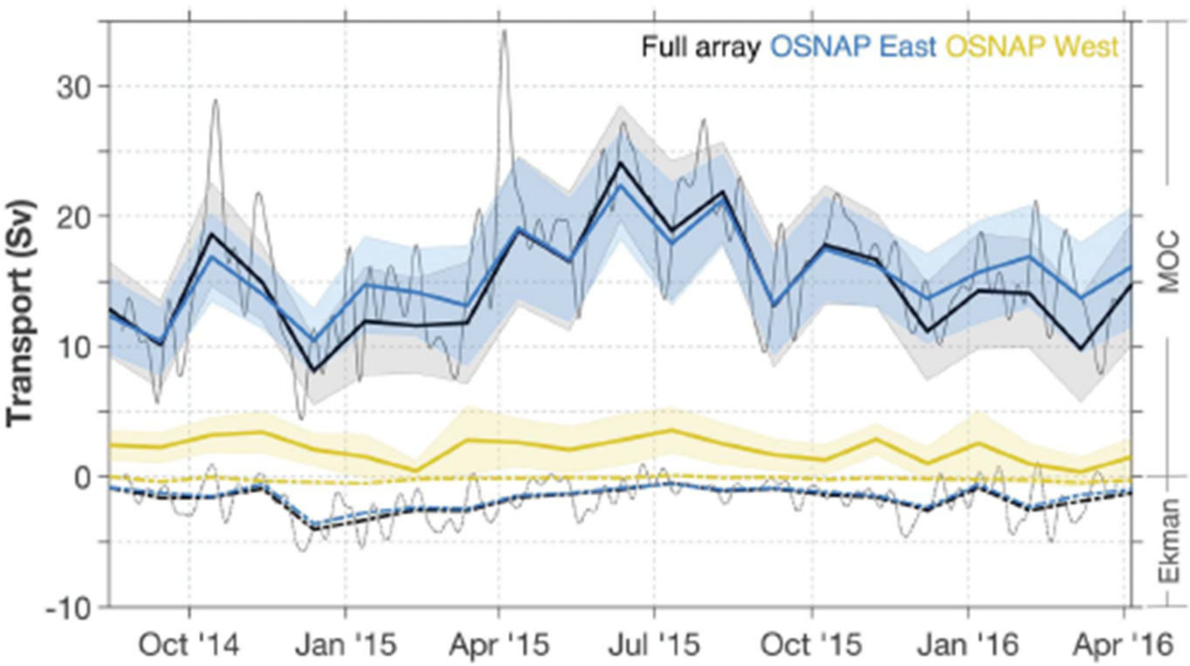
Introduction

- OSNAP data show that the eastern subpolar gyre (SPG) dominates the mean and monthly-interannual variability of AMOC, not the Labrador Sea (Lozier et al., *Science*, 2019).

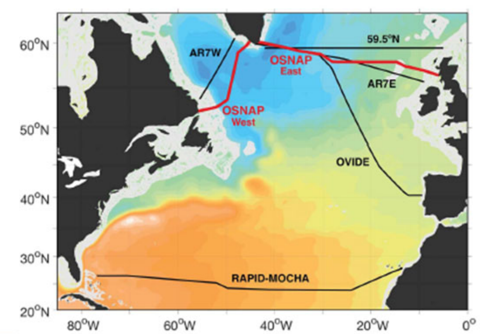


RESEARCH

OCEAN CIRCULATION

A sea change in our view of overturning in the subpolar North Atlantic

M. S. Lozier[1*], F. Li[1*], S. Bacon[2], F. Bahr[3], A. S. Bower[3], S. A. Cunningham[4], M. F. de Jong[5], L. de Steur[5]†, B. deYoung[6], J. Fischer[7], S. F. Gary[4], B. J. W. Greenan[8], N. P. Holliday[2], A. Houk[9], L. Houpert[4], M. E. Inall[4,10], W. E. Johns[9], H. L. Johnson[11], C. Johnson[4], J. Karstensen[7], G. Koman[9], I. A. Le Bras[12], X. Lin[13], N. Mackay[14]‡, D. P. Marshall[15], H. Mercier[16], M. Oltmanns[7], R. S. Pickart[3], A. L. Ramsey[3], D. Rayner[2], F. Straneo[12], V. Thierry[17], D. J. Torres[3], R. G. Williams[18], C. Wilson[14], J. Yang[3], I. Yashayaev[8], J. Zhao[3]§



Introduction

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- Other recent observational work underscores the importance of water mass transformation in the Irminger Sea in the high latitude closure of AMOC(σ) (Chafik & Rossby 2019; Desbruyères et al. 2019; Le Bras et al. 2020; Petit et al. 2020).

"…production of dense water overflow water in Nordic Seas key to the state of the MOC not the Labrador Sea."

Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL082110

Volume, Heat, and Freshwater Divergences in the Subpolar North Atlantic Suggest the Nordic Seas as Key to the State of the Meridional Overturning Circulation

Léon Chafik[1] and T. Rossby[2]

[1]Department of Meteorology and Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden, [2]Graduate School of Oceanography, University of Rhode Island, Kingston, RI, USA

Key Points:
- Great heat loss and production of dense water overflow water in Nordic Seas key to the state of the MOC not the Labrador Sea
- Heat flux convergence greater than climatological estimates of subpolar gyre heat loss
- Subpolar fresh water divergence balanced by freshwater loss from Greenland shelf

Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL091028

Atlantic Deep Water Formation Occurs Primarily in the Iceland Basin and Irminger Sea by Local Buoyancy Forcing

Tillys Petit[1], M. Susan Lozier[1], Simon A. Josey[2], and Stuart A. Cunningham[3]

[1]School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, USA, [2]National Oceanography

Key Points:
- New observations reveal Atlantic Subpolar Gyre deep water is formed primarily in the Irminger and Iceland basins by local buoyancy forcing

"The prevailing hypothesis is that dense waters formed in the Labrador and Nordic Seas are the sources for the AMOC lower limb. However, recent observations reveal that convection in the Labrador Sea contributes minimally to the total overturning of the subpolar gyre."

Introduction

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- Other recent observational work underscores the importance of water mass transformation in the Irminger Sea in the high latitude closure of AMOC($\boldsymbol{\sigma}$) (Chafik & Rossby 2019; Desbruyères et al. 2019; Le Bras et al. 2020; Petit et al. 2020).

- Meanwhile, climate model studies have long emphasized the links between Labrador Sea processes (deep convection; LSW production; LS density) and low-frequency variability (Robson et al. 2016; Ortega et al. 2020) and predictability (Yeager & Robson 2017; Yeager 2020) in the subpolar North Atlantic (SPNA).

Introduction

- How to reconcile?
  - Model bias results in overemphasis on Lab Sea processes (Li et al. 2019; Heuzé 2017)
  - Key LS density signals are not locally forced but are advected in from the eastern SPG (Menary et al. 2020)
  - Surface transformation and ventilation are not co-located (MacGilchrist et al. 2020)
  - The active role of the Labrador Sea is most apparent at longer (decadal) timescales

- Today: new perspective on low-frequency AMOC mechanisms from a long eddy-resolving pre-industrial control simulation

Twin Pre-Industrial Coupled Control Simulations using CESM1.3

JAMES Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2020MS002298

Key Points:
- An unprecedented set of multi-century high-resolution Community Earth System Model (CESM) simulations is described
- High-resolution CESM simulations reveal a potential role of Southern Ocean polynyas in multidecadal climate variability
- High-resolution CESM exhibits significantly improved simulations of extreme events, such as tropical cyclones and atmospheric rivers

An Unprecedented Set of High-Resolution Earth System Simulations for Understanding Multiscale Interactions in Climate Variability and Change

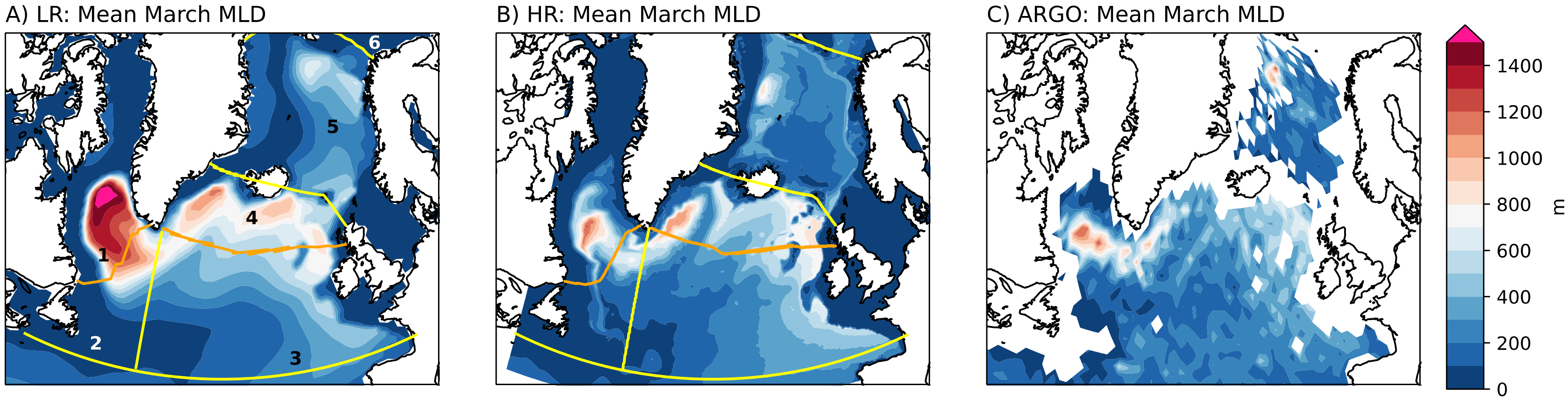
Ping Chang[1,2,3], Shaoqing Zhang[1,4,5], Gokhan Danabasoglu[1,6], Stephen G. Yeager[1,6], Haohuan Fu[1,7,8], Hong Wang[1,4,5], Frederic S. Castruccio[1,6], Yuhu Chen[9], James Edwards[1,6], Dan Fu[1,2], Yinglai Jia[1,5], Lucas C. Laurindo[1,6], Xue Liu[1,2], Nan Rosenbloom[1,6], R. Justin Small[1,6], Gaopeng Xu[1,2], Yunhui Zeng[10], Qiuying Zhang[1,2], Julio Bacmeister[1,6], David A. Bailey[1,6], Xiaohui Duan[8,11], Alice K. DuVivier[1,6], Dapeng Li[1,2], Yuxuan Li[11], Richard Neale[6], Achim Stössel[1,2], Li Wang[10], Yuan Zhuang[10], Allison Baker[1,6], Susan Bates[6], John Dennis[6], Xiliang Diao[1,2], Bolan Gan[1,4,5], Abishek Gopal[1,2], Dongning Jia[9], Zhao Jing[1,4,5], Xiaohui Ma[1,4,5], R. Saravanan[1,3], Warren G. Strand[6], Jian Tao[1,12], Haiyuan Yang[1,4,5], Xiaoqi Wang[1,2], Zhiqiang Wei[9], and Lixin Wu[4,5]

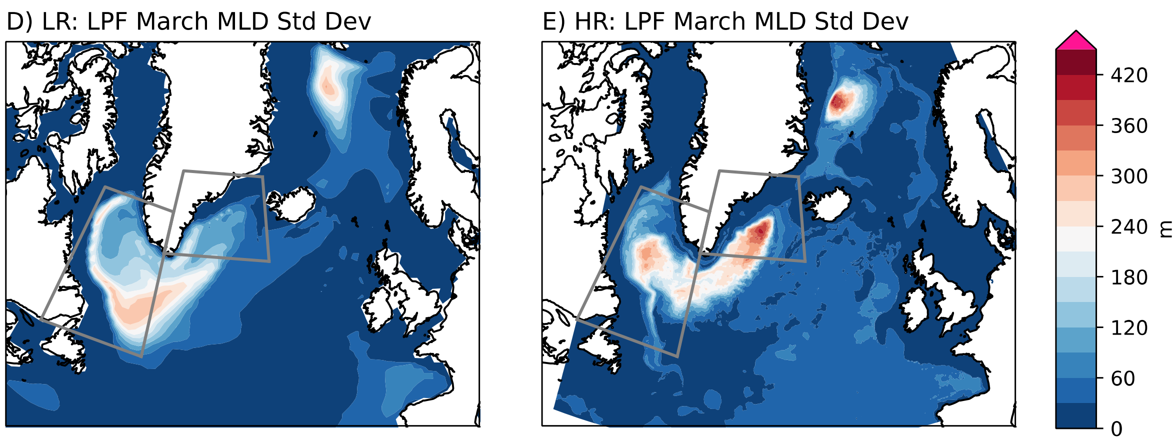
Chang et al. (2020)

- Low Resolution (**LR**): ~1° ocean, atmosphere, sea ice, land
- High Resolution (**HR**): ~0.1° ocean, sea ice; ~0.25° atmosphere, land

- Forcing: Constant Preindustrial (1850)
- Simulation length: 500 years
- Analysis: years 200-500
- Focus: Low-frequency (LF == 10+ year period) variability

Winter Deep Convection



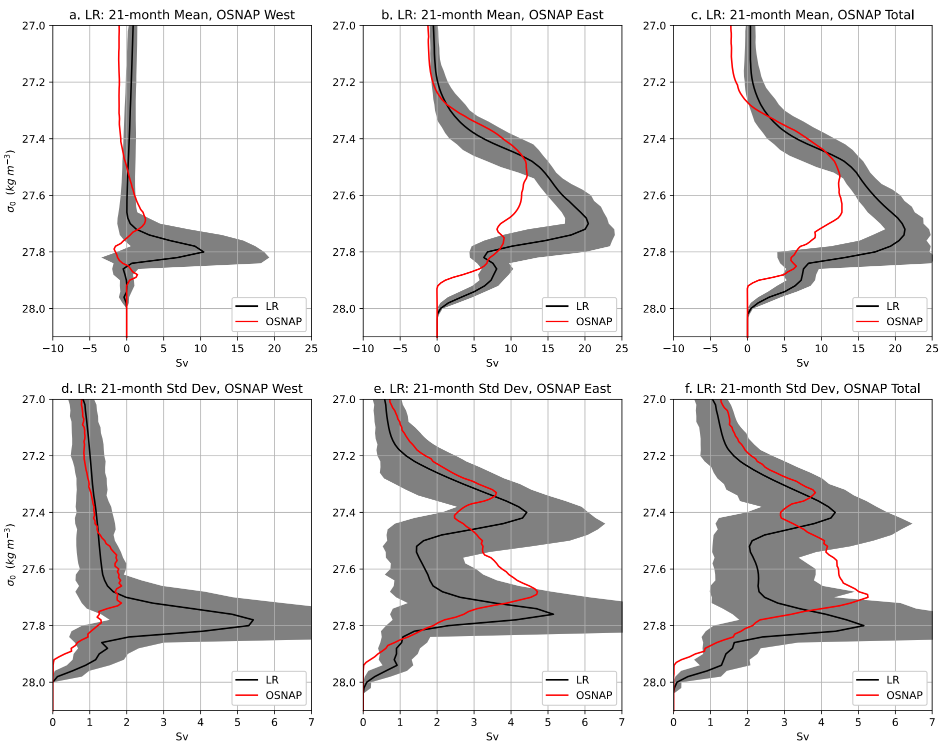


SPNA Regions:

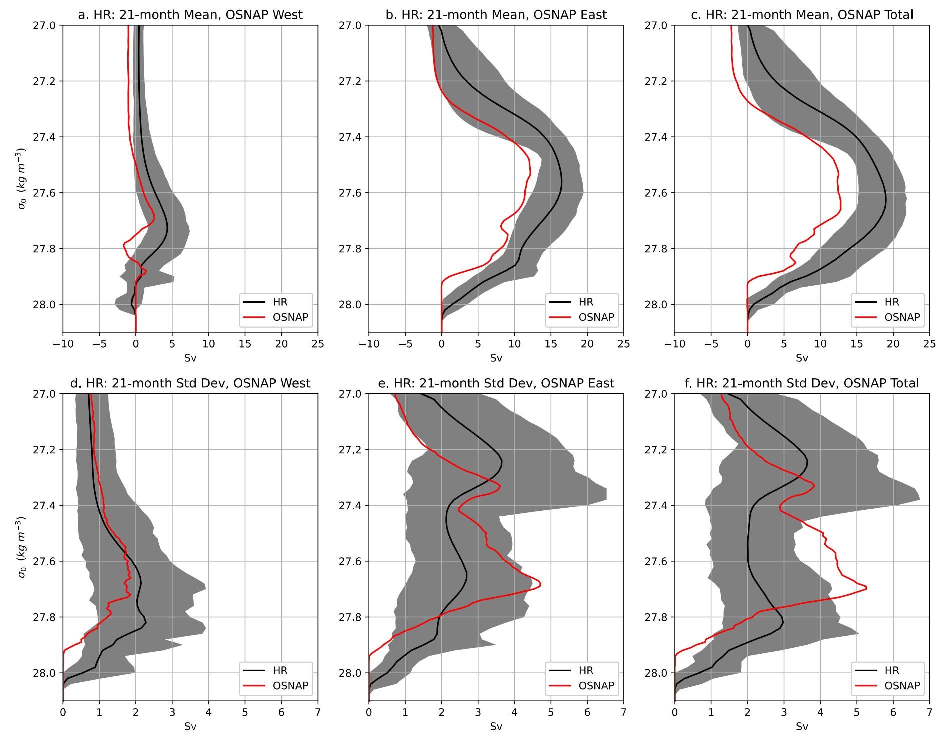
1. Labrador Sea (LAB)
2. Western SPG (SPG-west)
3. Eastern SPG (SPG-east)
4. Irminger Sea & Iceland Basin (IRM)
5. Greenland-Iceland-Norwegian seas (GIN)
6. Arctic (ARC)

OSNAP Overturning

LR:



HR:



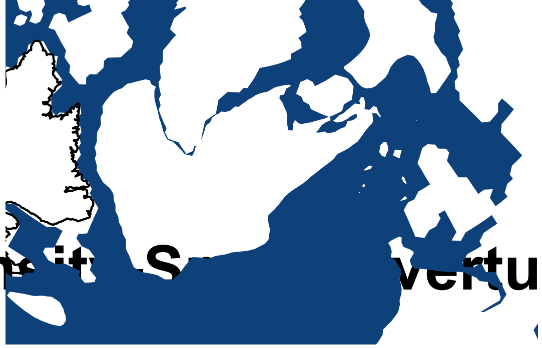
Mean

Std Dev

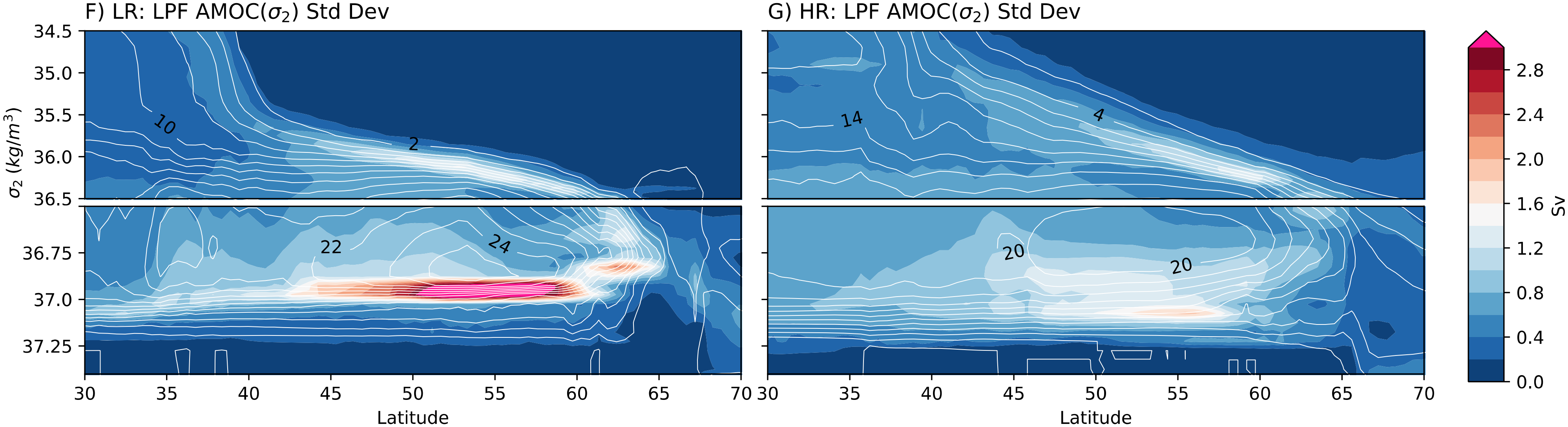
21-month mean & std. dev:

black line (301-year mean)

grey shade (301-year min/max range)



Den... S... verturning

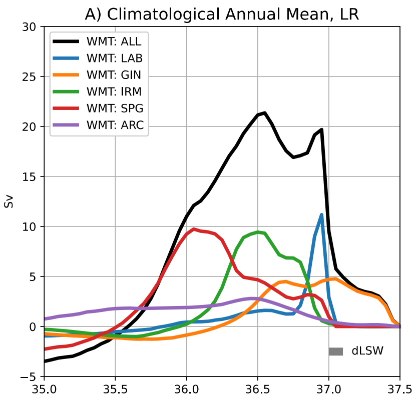


- Maximum LF variance at/near LSW layer
- Secondary band of high LF variance in NAC (will argue this *derives from* LSW variance!)

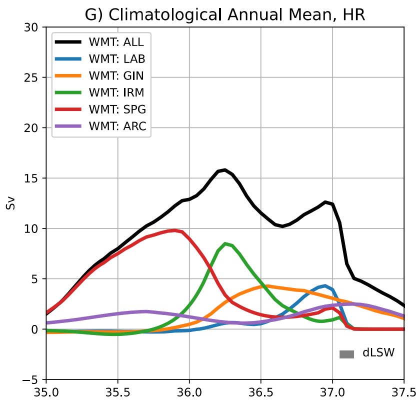
Surface Water Mass Transformation (WMT) and Formation (WMF)

Surface-forced overturning north of 45°N:

LR:



HR:



Surface Density Flux: $$f = -\frac{\alpha}{C_p} Q - \beta \frac{S}{1-S} F$$

Surface WMT: $$WMT(\sigma_2) = \frac{1}{\Delta\sigma_2} \iint f \ dA_{\sigma_2}$$

Surface WMF: $$WMF(\sigma_2) = -\frac{dWMT}{d\sigma_2}$$

Walin (1982); Tziperman (1986); Speer & Tziperman (1992); Speer (1997); Nurser et al. (1999); Marsh (2000); etc.

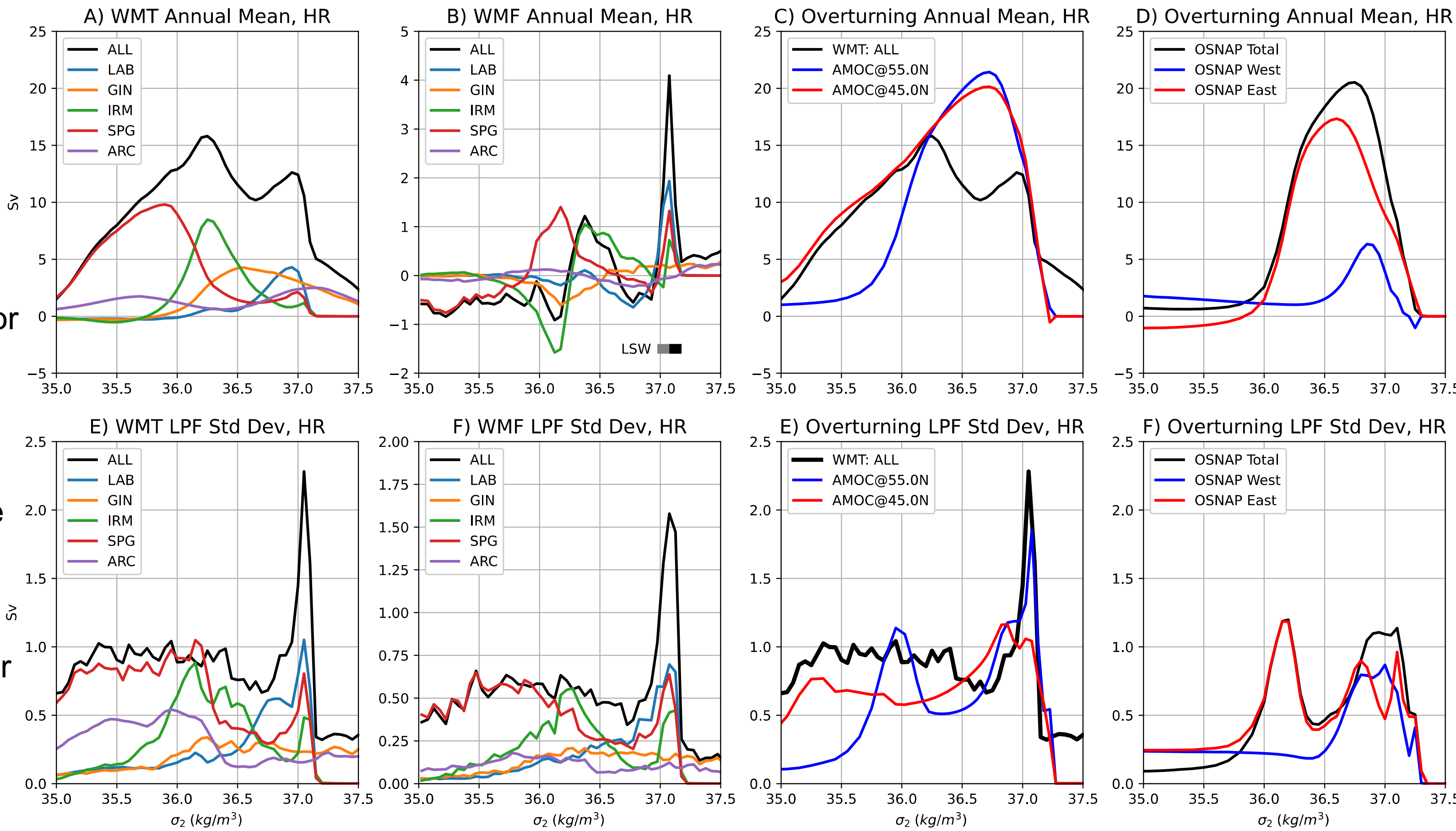
Surface Forced Overturning from HR

LAB plays minor role in mean WMT overall, but large role in transformation into dense NADW & formation of LSW.

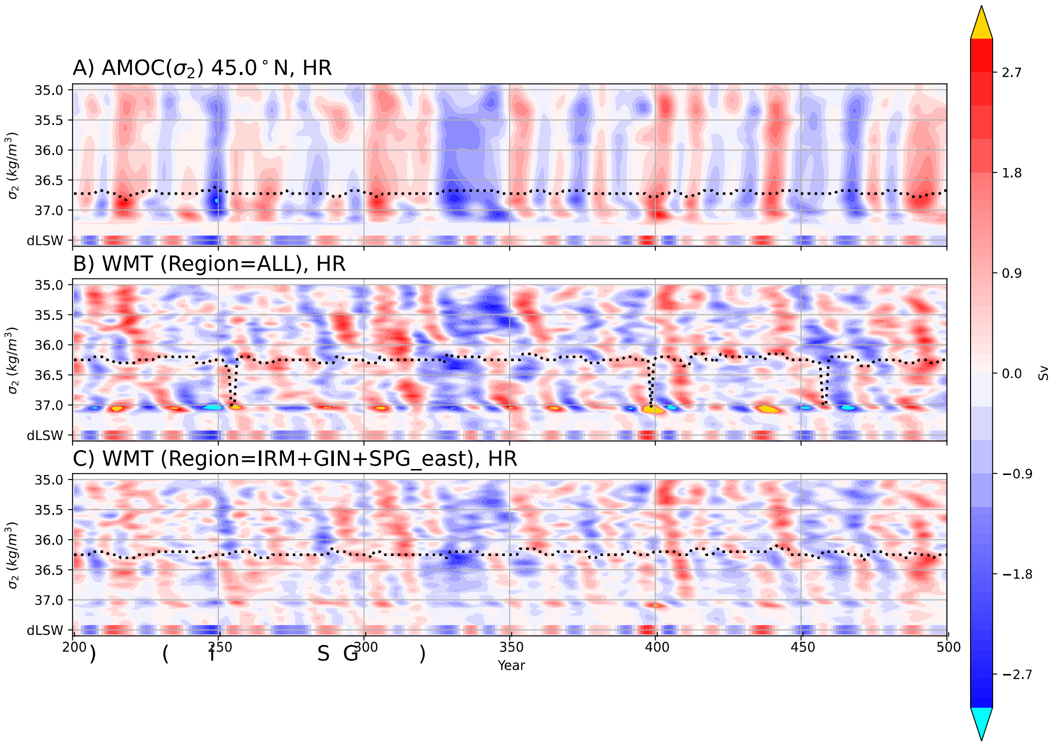
LF variability is maximum in LSW layer, with outsized role for local buoyancy forcing in LAB region

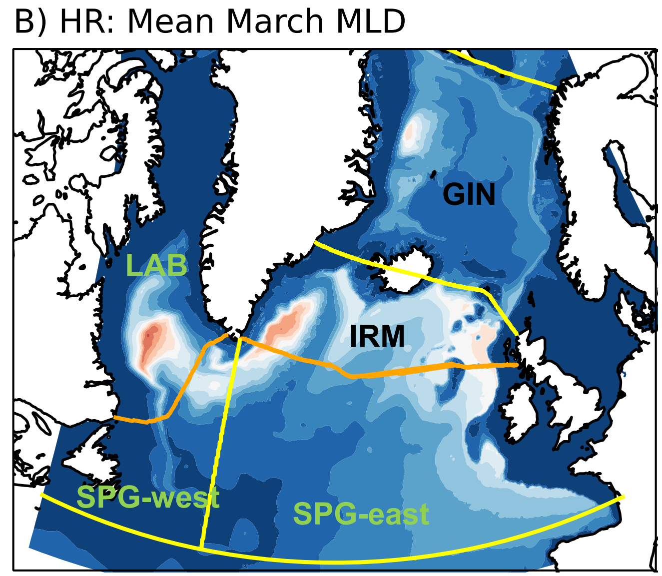
LF variance of deep AMOC(**σ**) is related to anomalous surface transformation/formation of LSW, in particular

OSNAP East/West show similar LF variance in deep limb



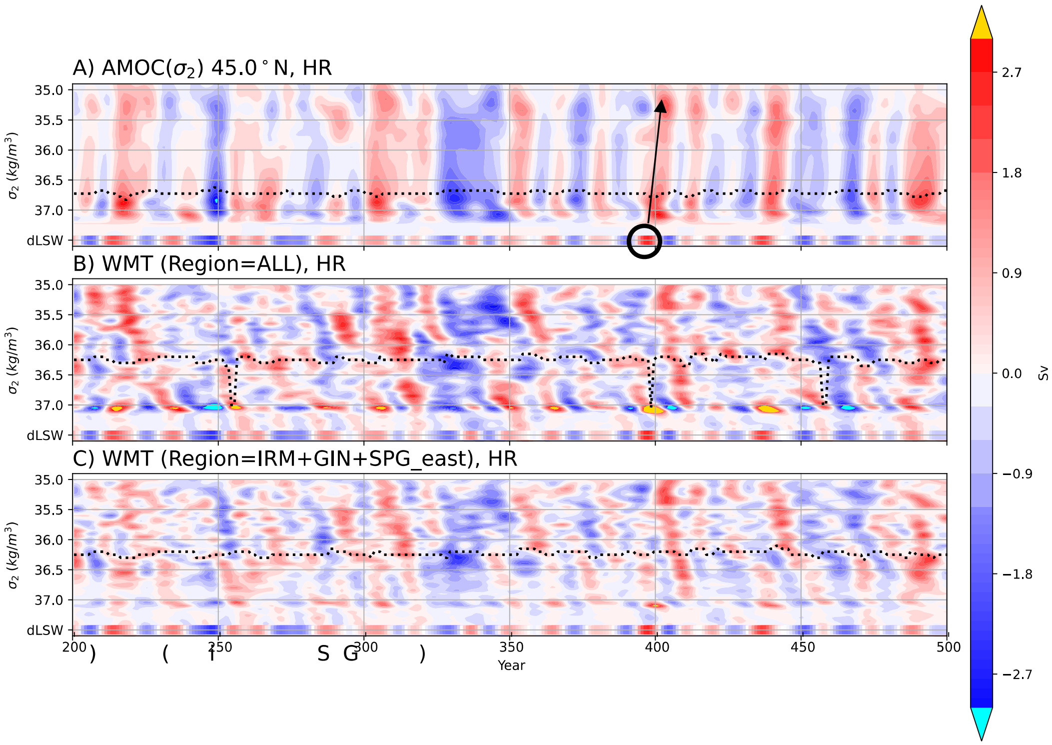
HR: LF Variability



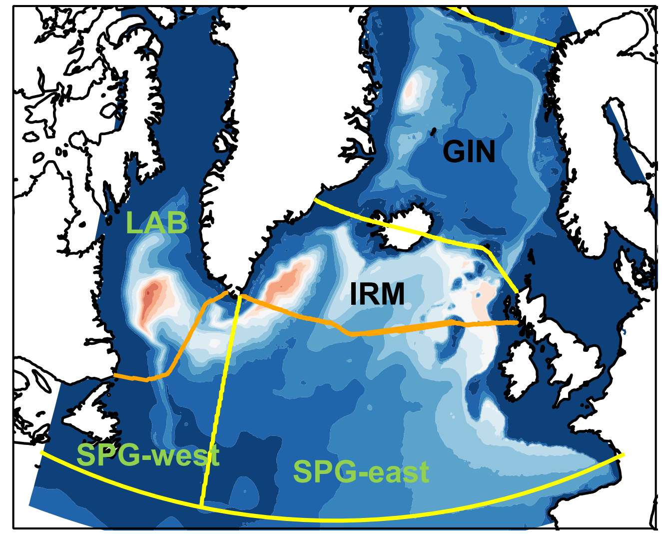


dLSW = anomalous surface WMF in dLSW layer in LAB region
dotted lines = location of streamfunction maximum

HR: LF Variability



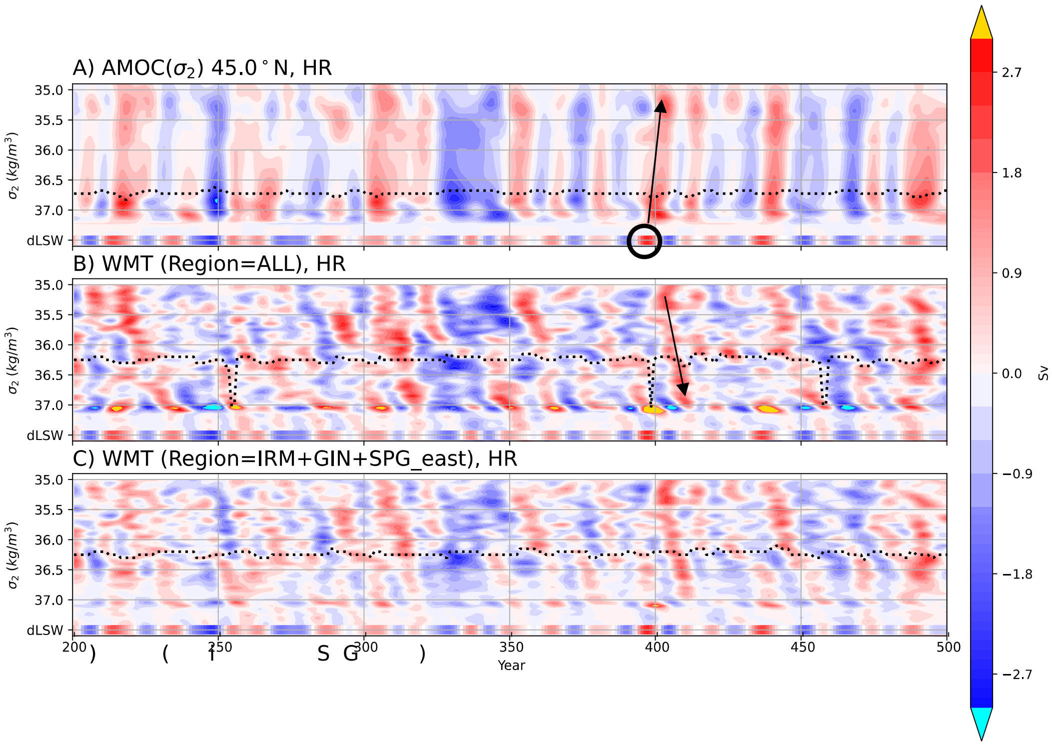
B) HR: Mean March MLD



- Large AMOC($\boldsymbol{\sigma}$) signals emanate from dLSW, propagate ”upward” in density space

dLSW = anomalous surface WMF in dLSW layer in LAB region
dotted lines = location of streamfunction maximum

HR: LF Variability



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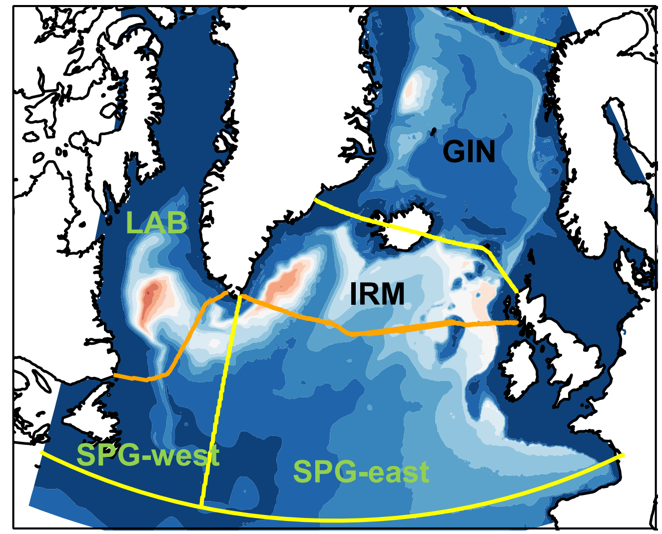

- Large AMOC($\boldsymbol{\sigma}$) signals emanate from dLSW, propagate ”upward” in density space
- Surface WMT in SPNA lags NAC, propagates “downward” in density space (particularly in eastern SPNA)

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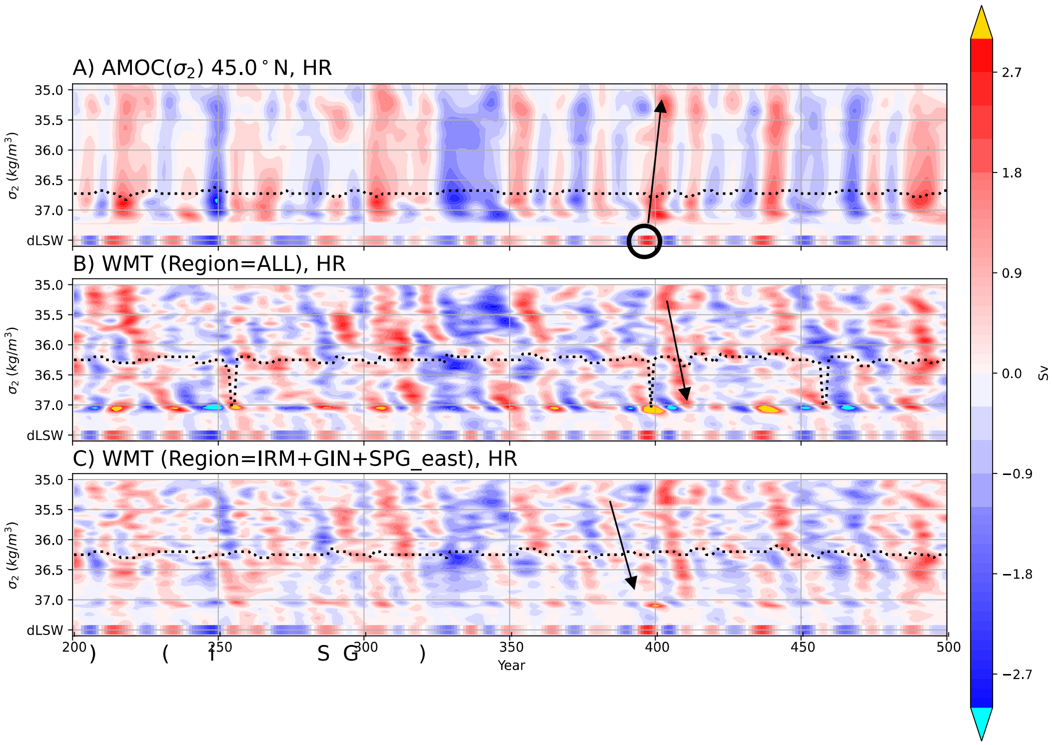
HR: LF Variability



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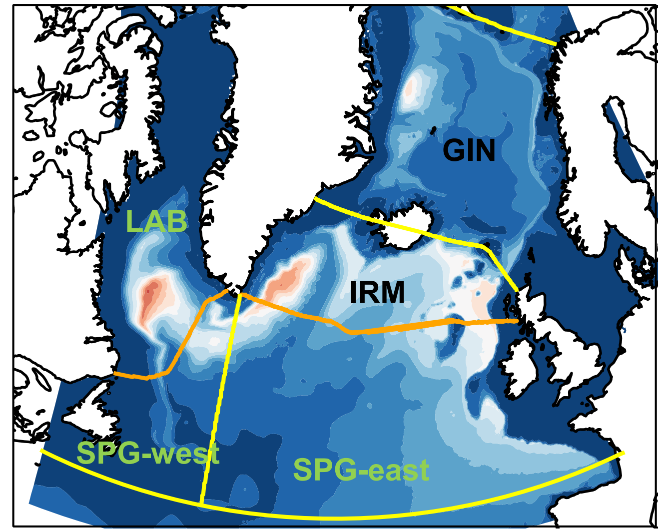
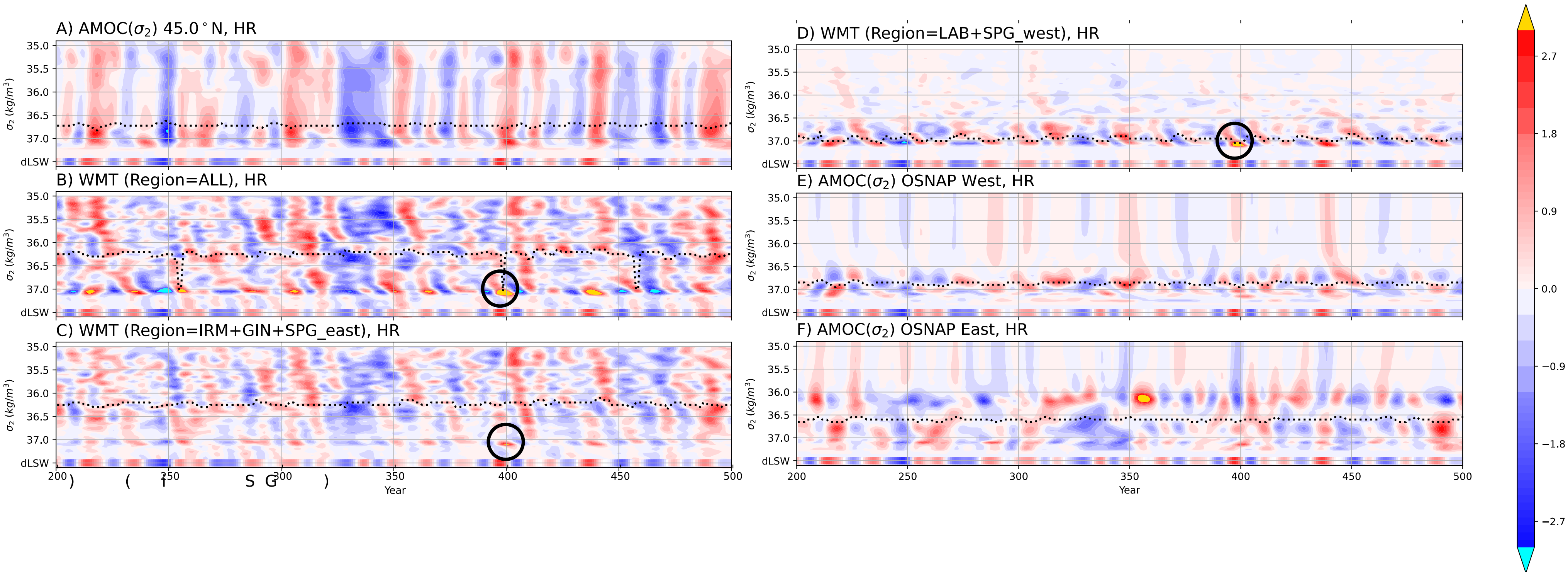


- Large AMOC($\boldsymbol{\sigma}$) signals emanate from dLSW, propagate "upward" in density space
- Surface WMT in SPNA lags NAC, propagates "downward" in density space (particularly in eastern SPNA)
- Evidence that dLSW anomalies themselves are (usually) preconditioned by anomalous transformation in the eastern SPG

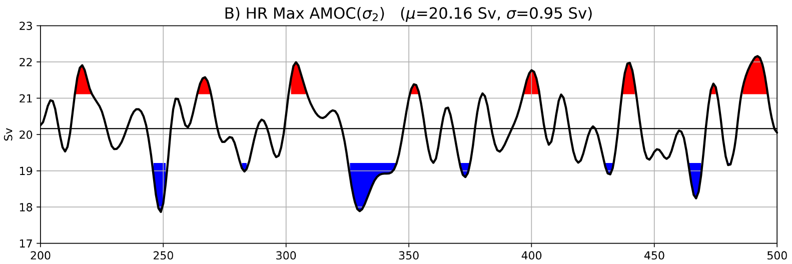
dLSW = anomalous surface WMF in dLSW layer in LAB region
dotted lines = location of streamfunction maximum

HR: LF Variability



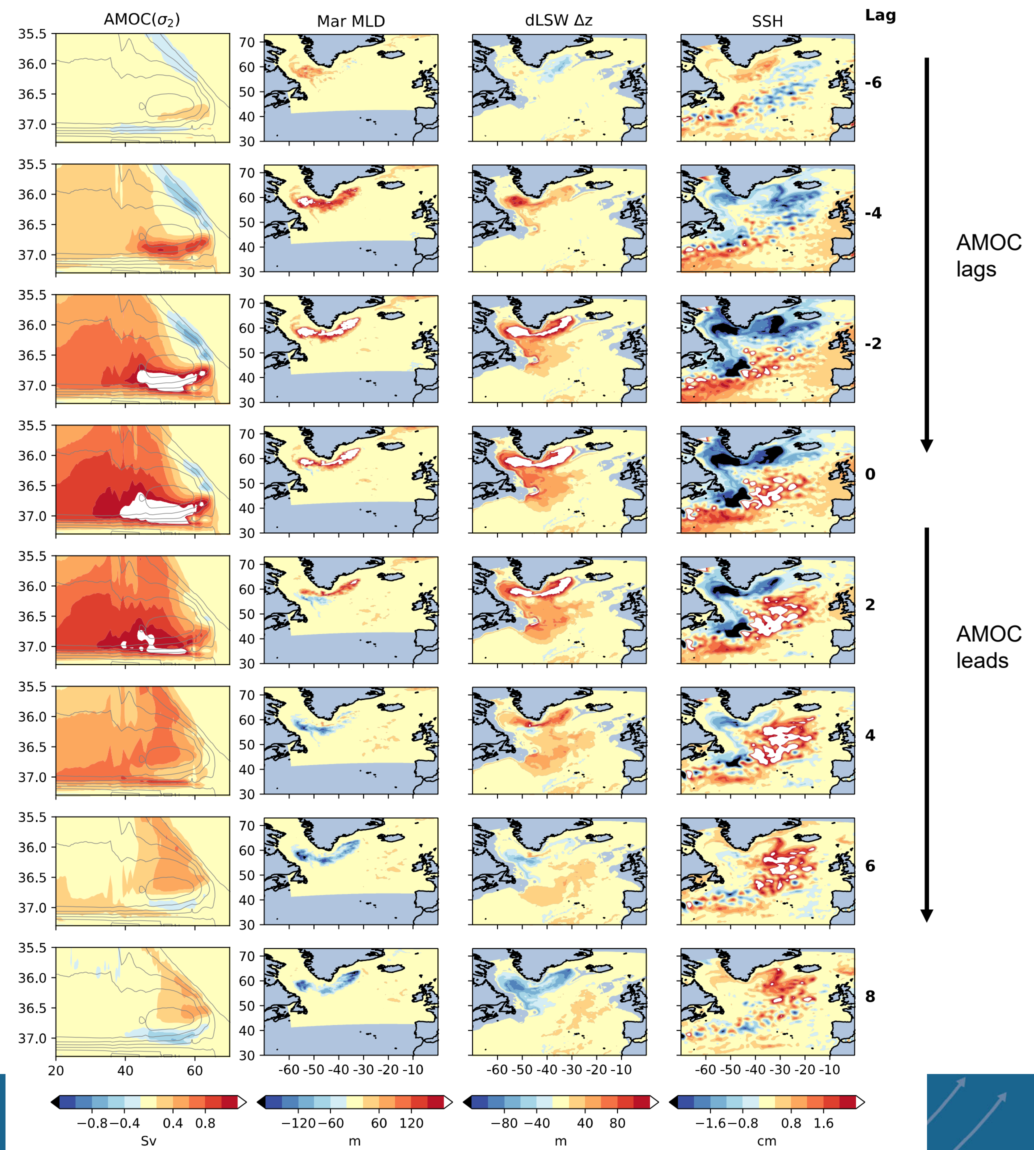
- LAB region does much of the heavy lifting in the critical final stage of transformation into dense LSW

HR AMOC in 4-D



Lag Composites on positive (>1$\boldsymbol{\sigma}$) AMOC($\boldsymbol{\sigma}_2$, 45°N)$_{max}$

Coupling between LF variations in lower/upper limbs of SPNA AMOC arises via ∇SSH' driven by deep LSW thickness anomalies



Conclusions

- A (HR) CESM PI control simulation appears largely compatible with recent work arguing for the dominance of the eastern SPG in the high latitude closure of AMOC($\boldsymbol{\sigma}$) (Lozier et al. 2019; Chafik & Rossby 2019; Desbruyères et al. 2019; Menary et al. 2020; Petit et al. 2020).
  - ➔ In LR, diapycnal transformation in Lab Sea is too strong
  - ➔ Significantly improved realism in HR suggests it can provide plausible low-frequency context for obs

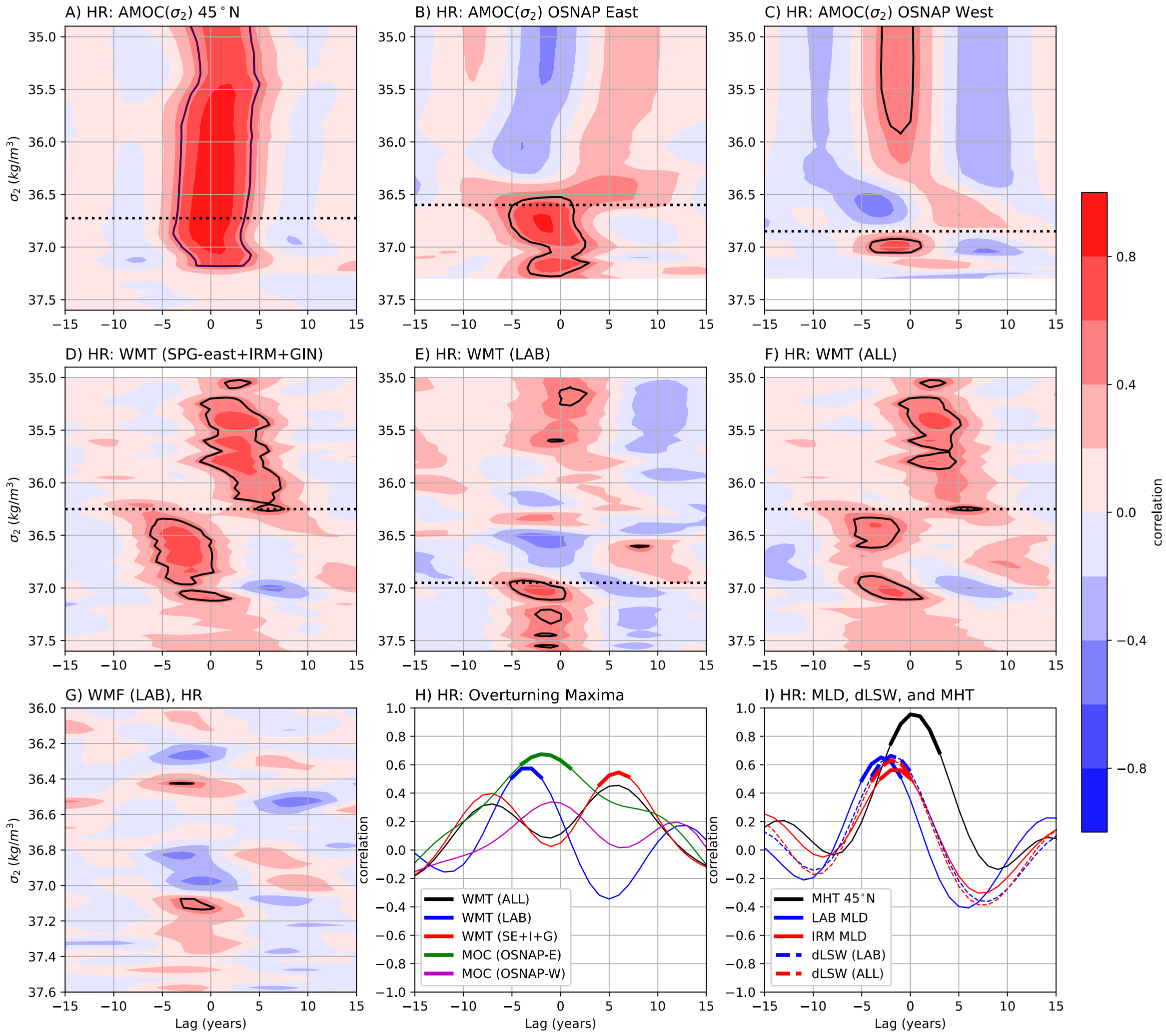
- Despite low mean surface transformation in the Lab Sea, anomalous transformation/formation at the tail end of NADW production (LSW) is implicated as a key pacemaker of low frequency AMOC variability.
  - ➔ Preconditioning in the eastern SPG is important, but local Lab Sea surface transformation is critical element
  - ➔ Evidence of multidecadal gyre mode with AMOC both driving and responding to surface transformation in the eastern SPNA (Menary et al. 2015; Langehaug et al. 2012)
  - ➔ LS metrics appear (at the very least) to be very good indicators of SPNA cumulative transformation

- AMOC($\boldsymbol{\sigma}$) is driven “from below”, with lower/upper limb coupling associated with coherent changes in LSW thickness & SSH.
  - ➔ Highlights role of surface *formation* in AMOC dynamics & N. Atlantic decadal predictability

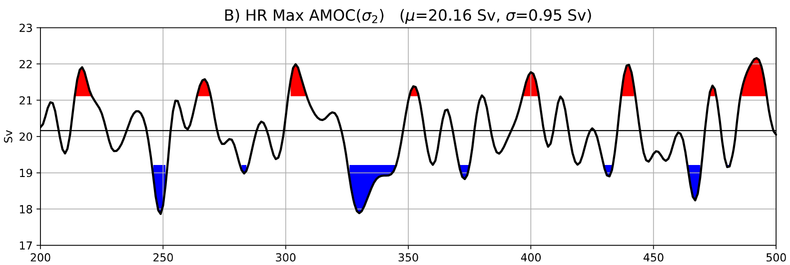
NCAR | UCAR

HR: LF Variability

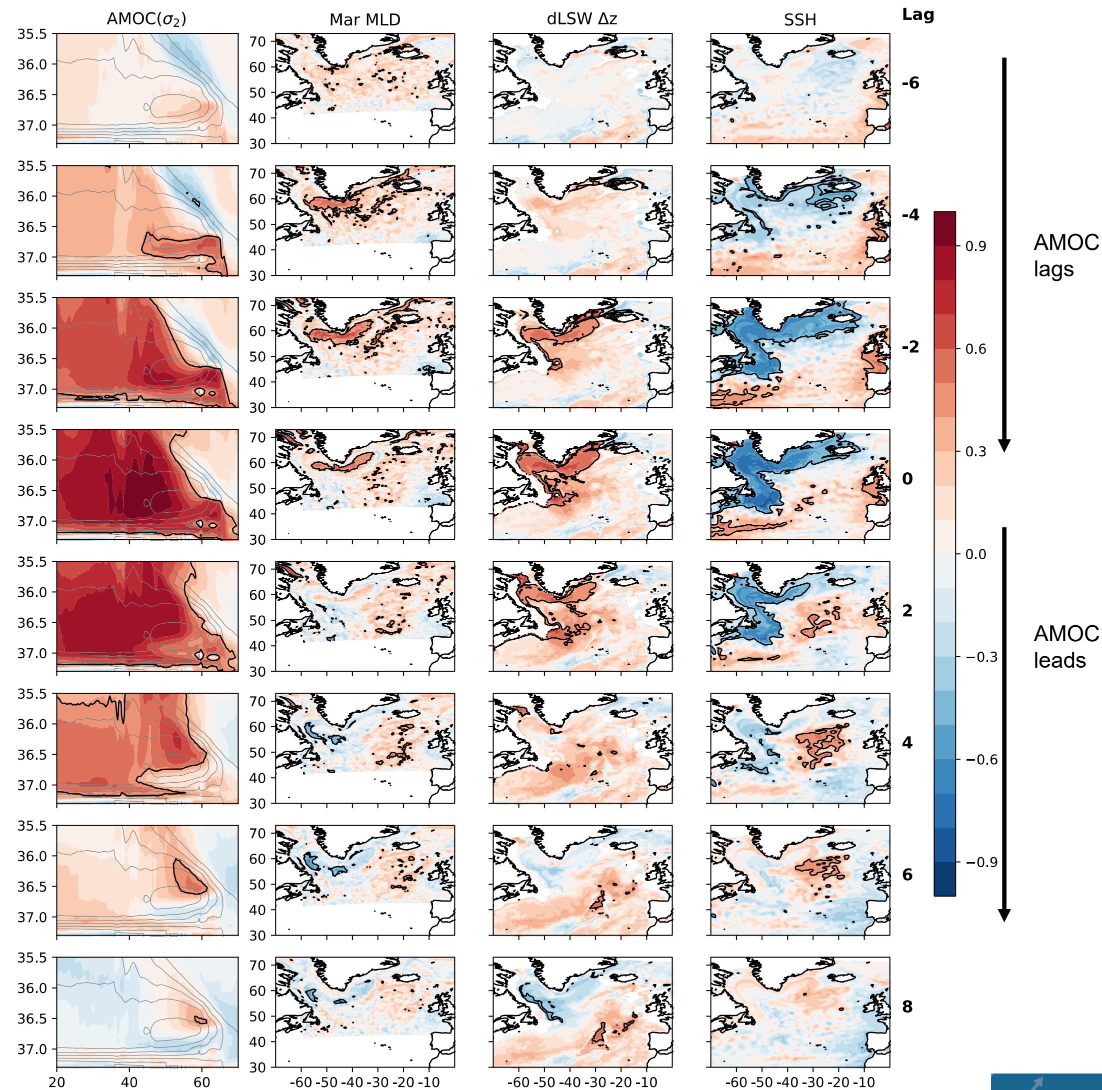
- Lag Correlations with AMOC($\boldsymbol{\sigma}_2$, 45°N)$_{max}$
- Dashed lines = mean location of max overturning



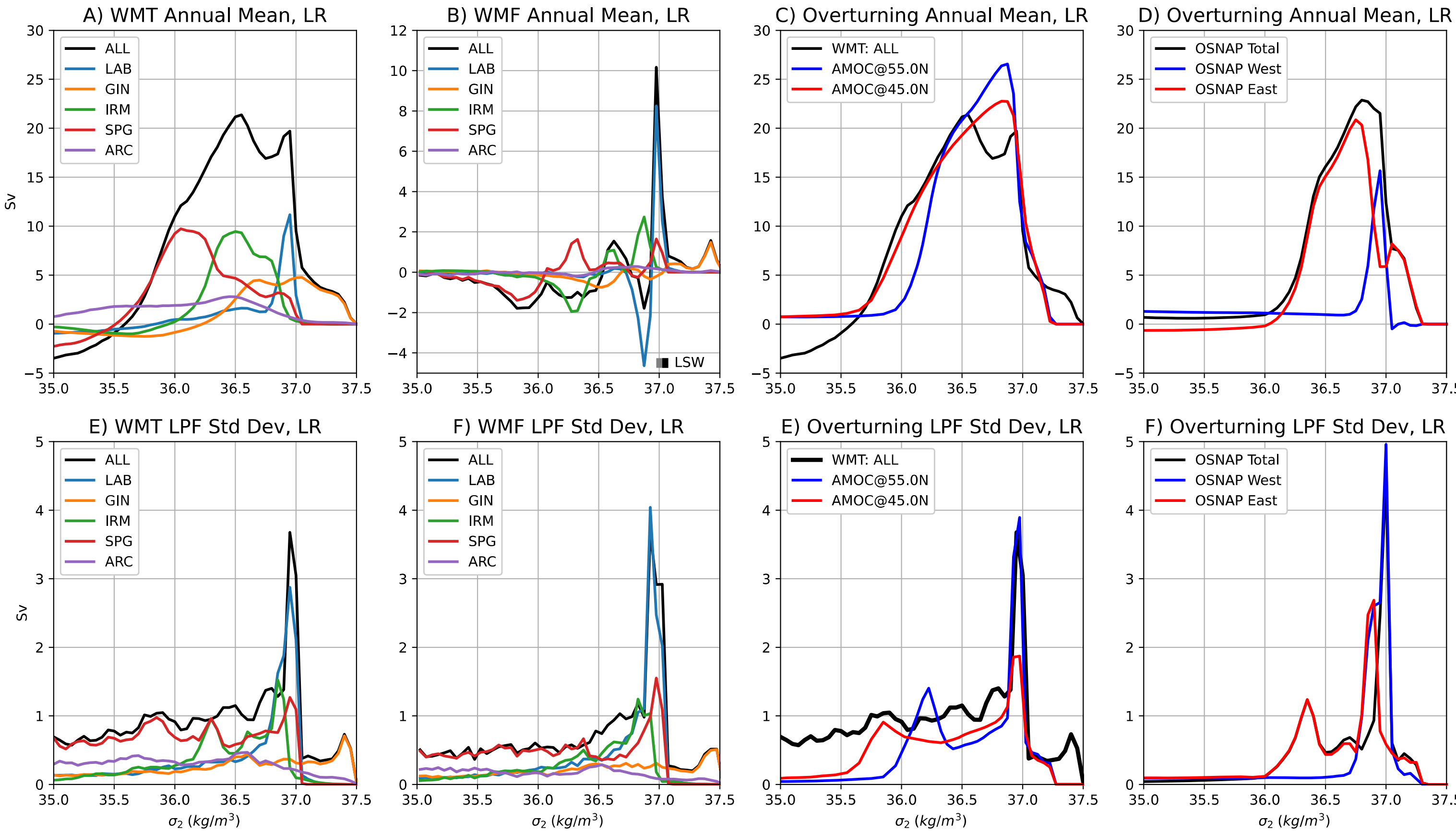
HR AMOC in 4-D



Lag Correlations with AMOC($\boldsymbol{\sigma}_2$, 45°N)$_{max}$

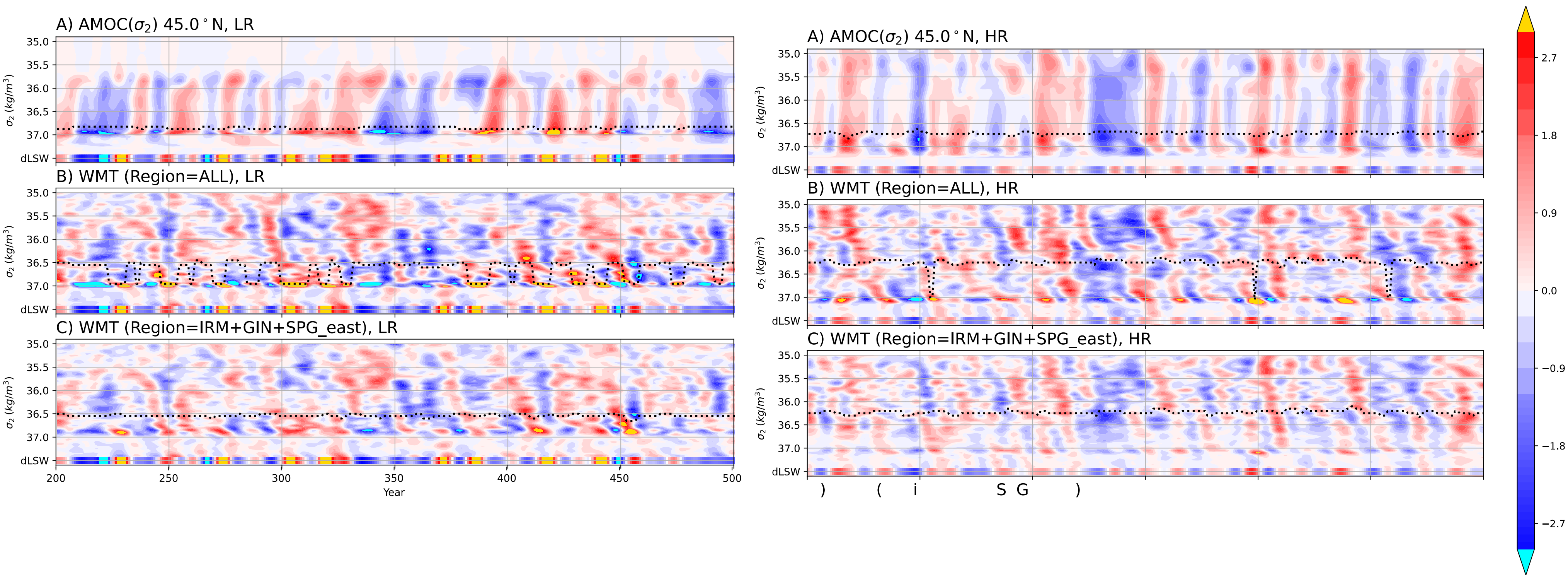


Surface Forced Overturning from LR



NCAR
UCAR

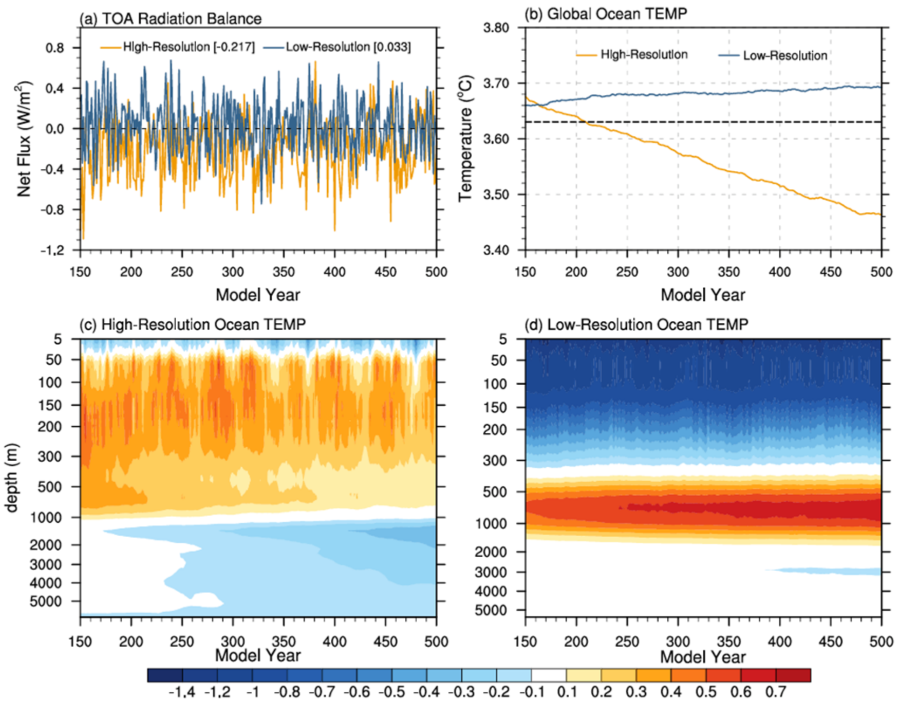
LR: LF Variability



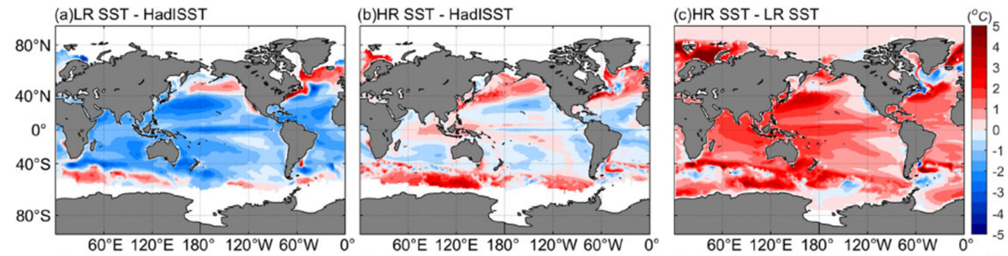
dLSW = anomalous surface WMF in dLSW layer within LAB region

Simulation Overview

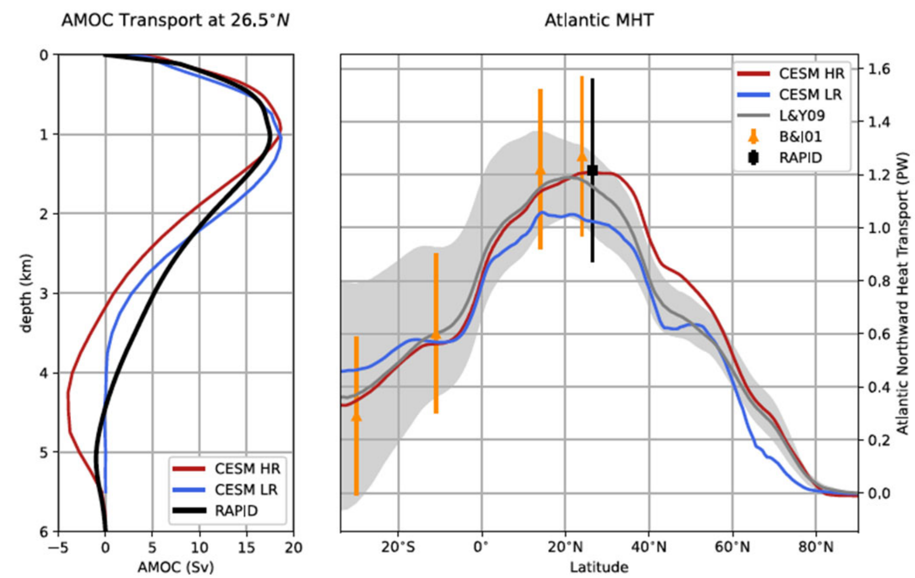
TOA Imbalance & Drift:



SST:*



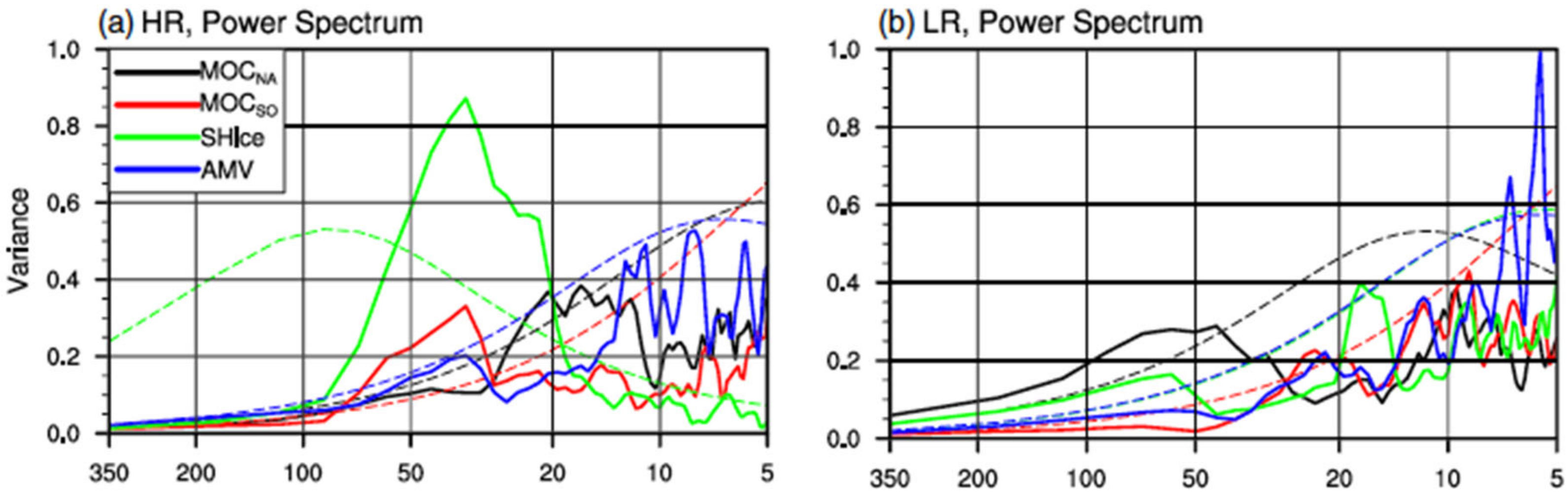
AMOC & AMHT*:*



**Historical/Future Simulations*

Chang et al. (2020)

Is there a link between LSW formation & AMOC timescale?



HR: OMIP2 Simulation

- Color Fill: dLSW thickness
- Contours: low-pass filtered SSH

- High-res equivalent of animation described in Yeager (*Clim Dyn*, 2020)