On the Long-term AMOC Changes during the 20th Century: Some Preliminary Results of CESM-LE, CCSM4 and forced POP2 simulations

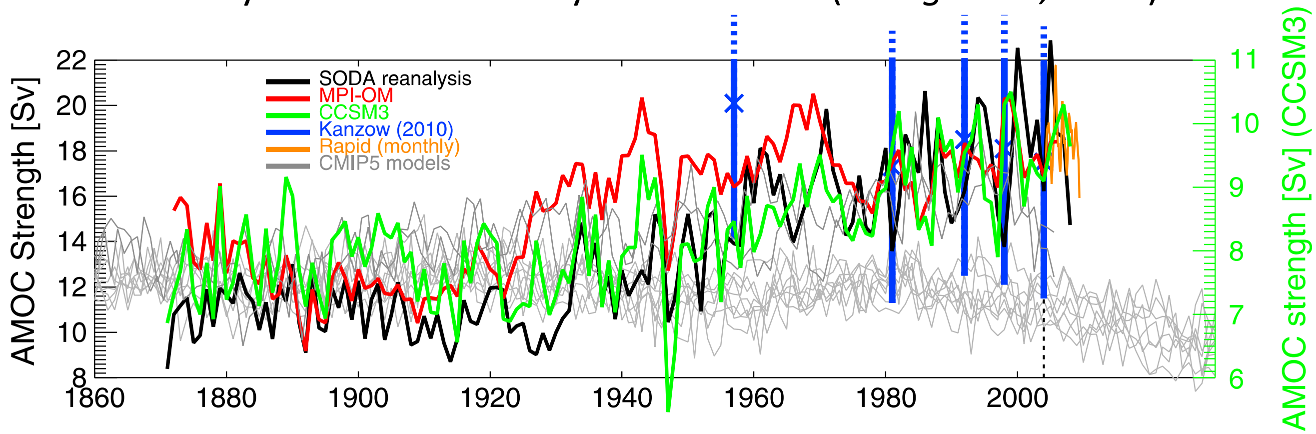
Who M. Kim *(whokim@tamu.edu)*

Texas A&M University

Collaborators: Ping Chang (TAMU), Steve Yeager and Gokhan Danabasoglu (NCAR)

Inconsistency between coupled and forced simulations

- While most of coupled simulations show a steady or deceasing AMOC, forced ocean simulations consistently exhibit an **overall increasing AMOC** during the 20C, whether they are forced with
  - NCEP-based (*Boning et al., 2006; Yeager & Danabasoglu, 2014*); ERA40-based (*Brodeau et al., 2010*); 20C reanalyses (*Menary et al., 2013*)
  - Whether they are constrained by observations (*Wang et al., 2010*)



Menary et al. (2013)

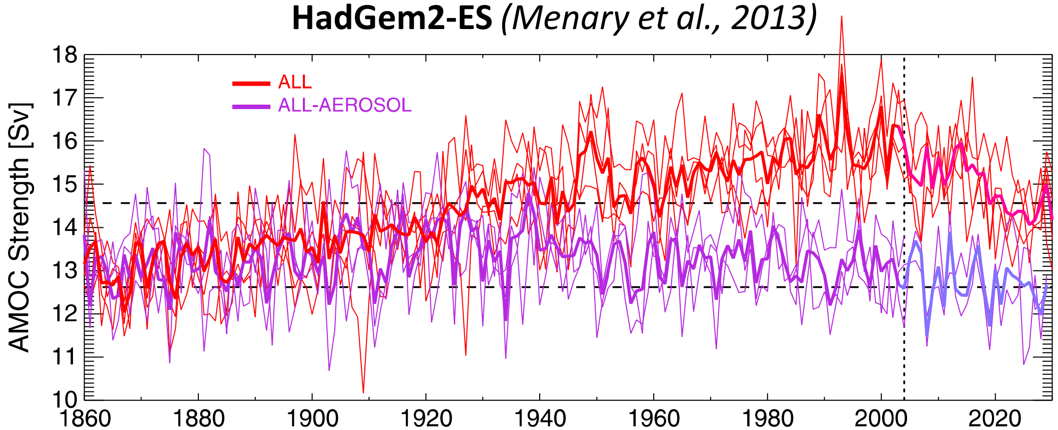
- Inferences from observations (AMOC fingerprint) also suggest an increase in AMOC during the 20C
  - SST difference between the north and south North Atlantic (Latif et al. 2006)
  - Meridional density difference (Wang et al. 2010)

→ **Suggesting that AMOC has been strengthened, rather than decreased, during the 20C**

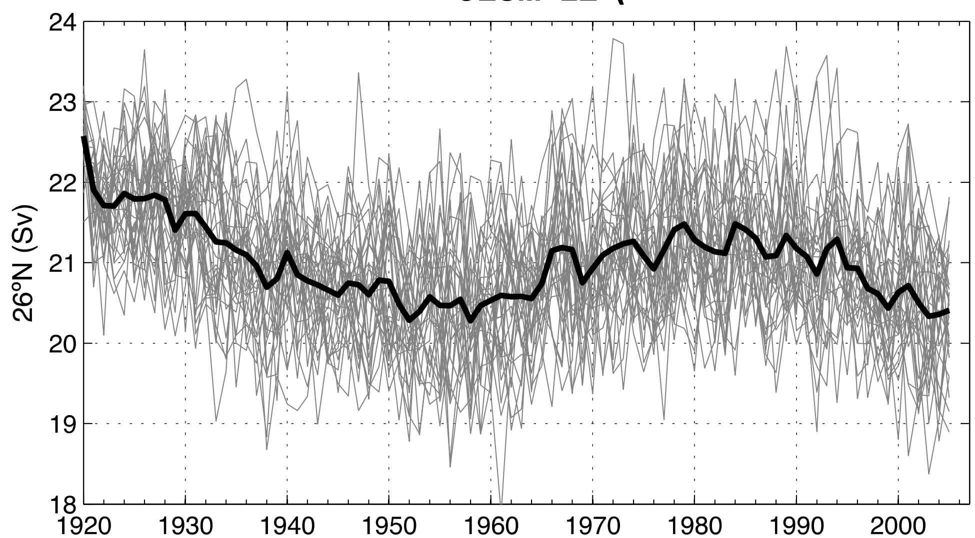
Externally Forced AMOC Changes

- Some coupled models show an "externally forced" upward trend in the AMOC

HadGem2-ES *(Menary et al., 2013)*



CESM–LE (30 Ensemble members)

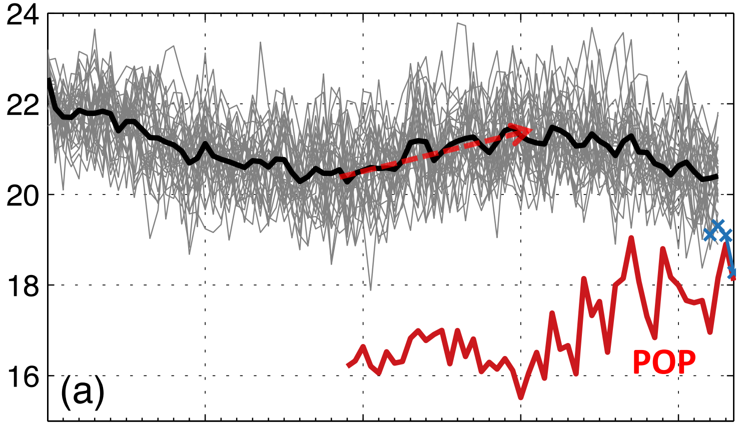


Questions/Models

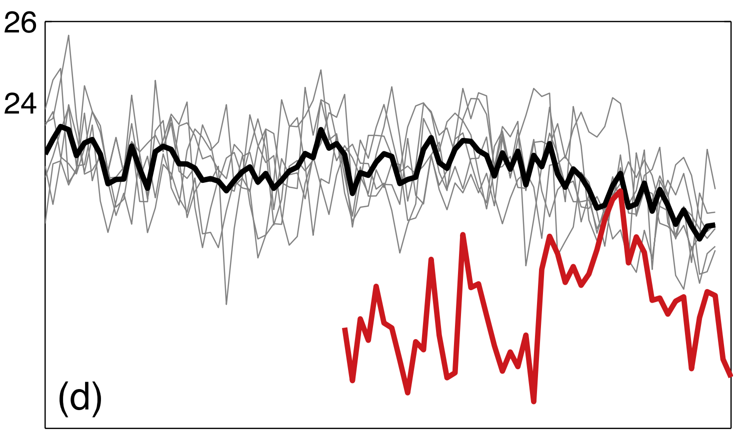
- Disparity in long-term AMOC changes raises questions
  - Does the increasing AMOC trend in the forced ocean simulations (and likely in nature) involve external forcing?
  - What are the dominant dynamical processes responsible for the long-term AMOC changes?
- To address these questions, we analyzed and compared:
  1) *CORE-II-forced POP2 hindcast simulation (POP)*
  2) *CESM Large Ensemble (CESM-LE) simulations (30)*

     : Allowing for statistical assessment of how the AMOC changes in forced simulation lies within its forced plus internal variations of the AMOC
  3) *CCSM4* (6)
  - All simulations use the same ocean model (POP2), making the comparison particularly instructive

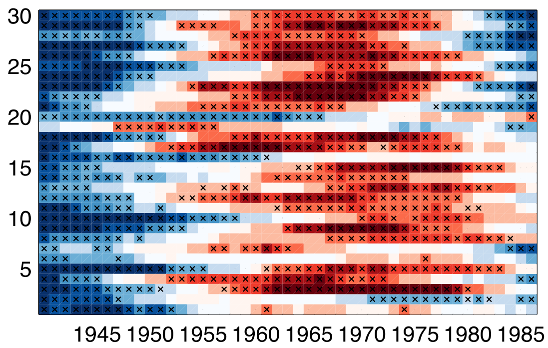
AMOC Time Series



RAPID



Internal Vs. Forced AMOC trend



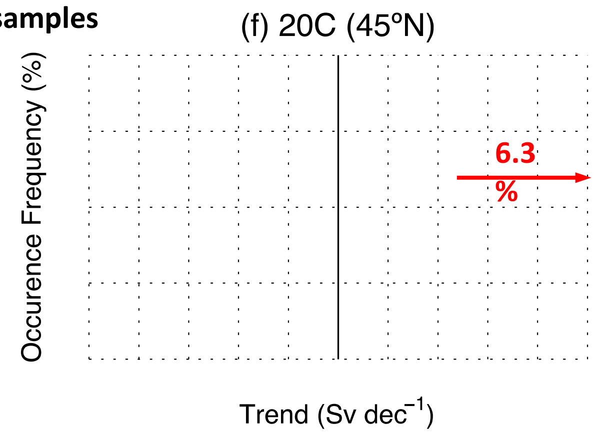
1072 samples

1.9 %

3.6 %

1410 samples

5.4 %



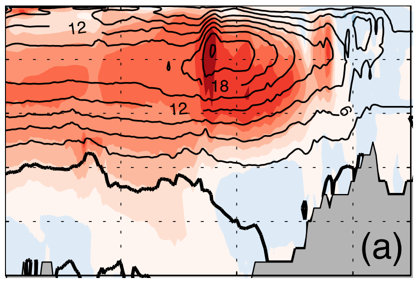
6.3 %

*** CESM AMOC trends using a sliding 40-yr window, normalized to the mean 40-yr POP AMOC trends**

*** Shading: range of the 40-yr POP AMOC trends (mean ± 1 std)**

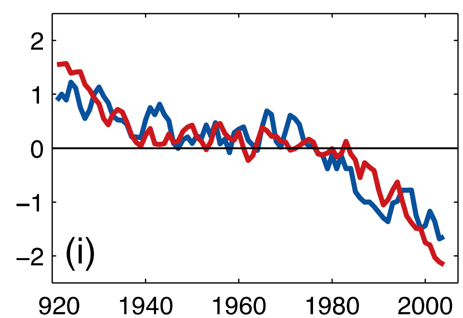
Link between AMOC and Convection

First SVD* modes between AMOC and Mar MLD in the subpolar NA



Sv

m



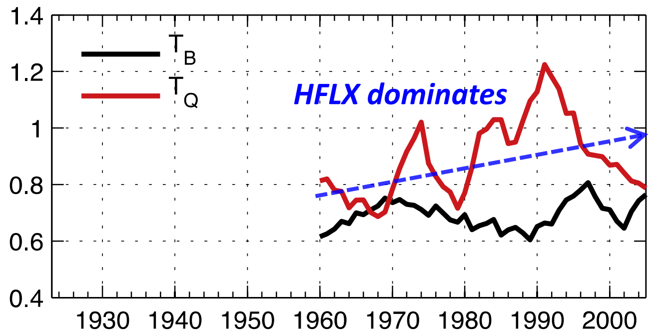
* SVD for CESM-LE and CCSM4 is computed from the time series extended by merging all ensemble members into a single matrix, and the time series here is the ensemble mean.

Imposed buoyancy Vs. winter HFLX in the interior Lab Sea

***T_B*: due to imposed buoyancy (Nov.) that should be eroded for convection (> 700m)**

T_Q: temperature that can be lowered by HFLX averaged over 700m

POP



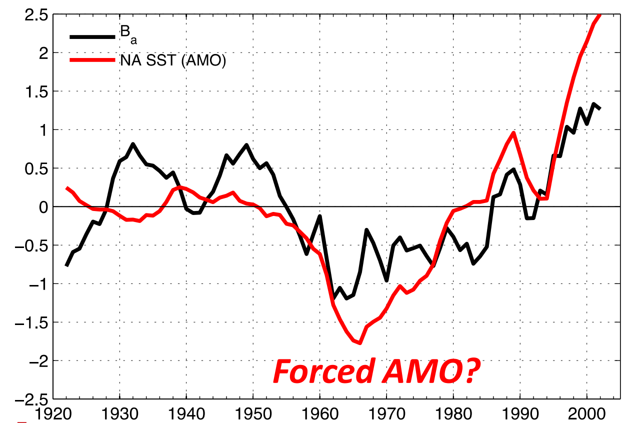
T_Q > T_B

T_B > T_Q

CESM-LE

HFLX: positive trend

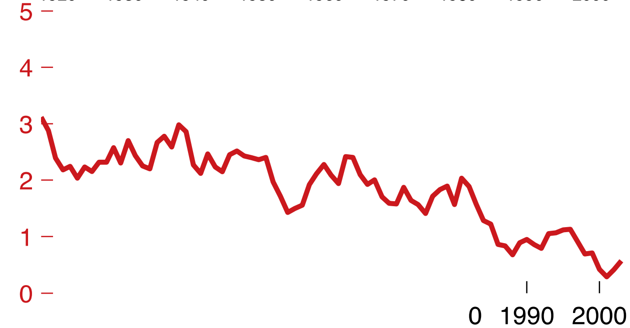
buoy: multidecadal variability



MLD anomaly wrt 700 m

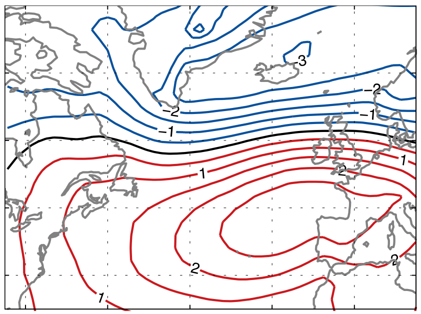
CCSM4

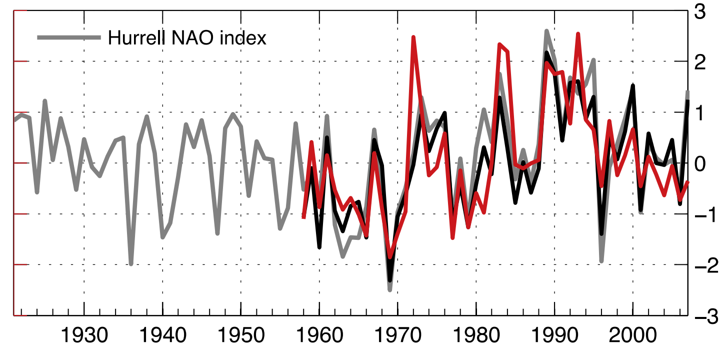
HFLX and buoy equally contribute

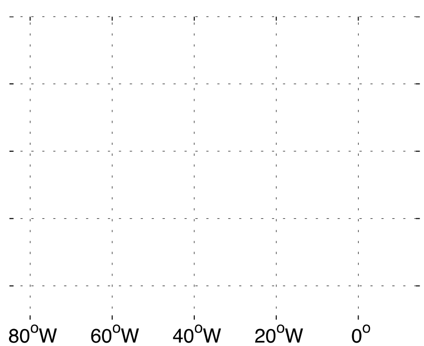


Link between NAO and HFLX

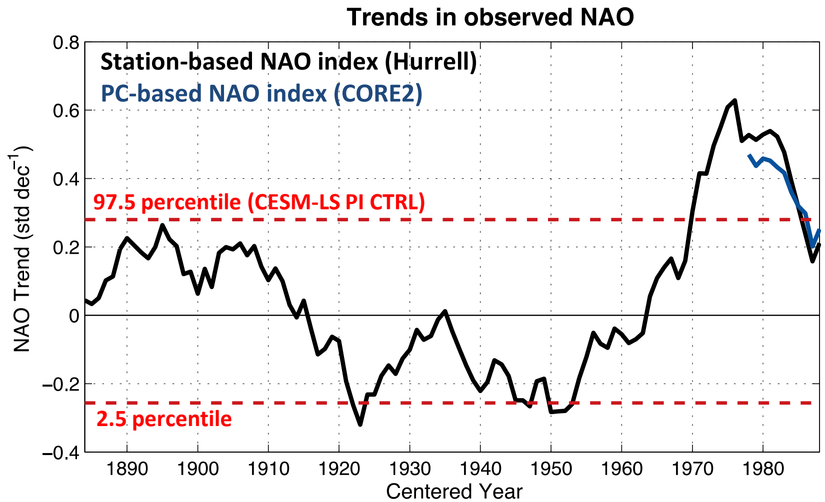
(CORE-II)







Internal Vs. Forced NAO trend



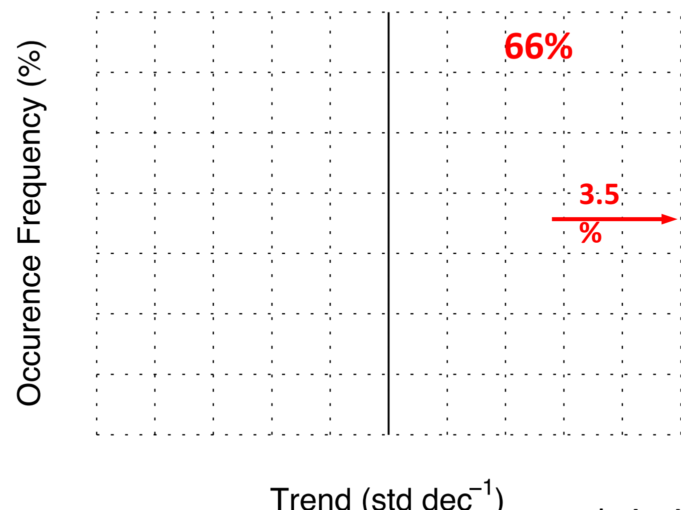
CESM-LE NAO Moving Trends

(1070 samples)

49%

2.5 %

20C (1380 samples)

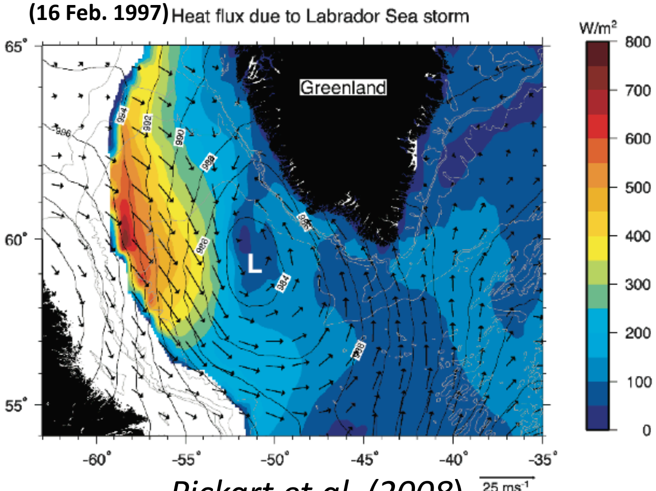


*** Shading: range of the 40-yr CORE2 NAO trends (mean ± 1 std)**

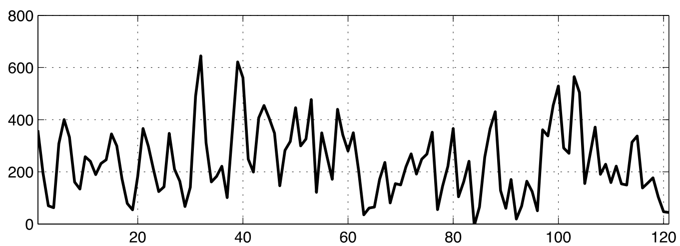
Storm-induced HFLX

HFLX event days: > 90th percentile of all DJFM daily records, averaged over the Lab. Sea (~ 500 and 580 W m^{-2} in POP and CESM-LE)

(16 Feb. 1997) Heat flux due to Labrador Sea storm

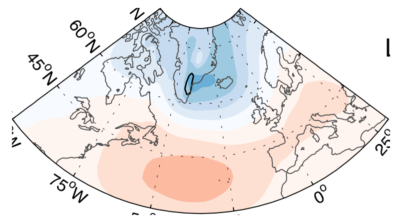


Pickart et al. (2008)



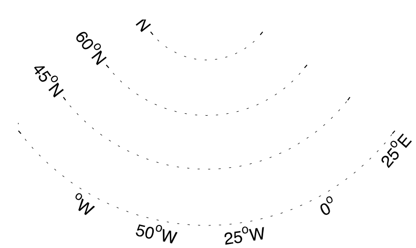
Event-day SLP Composite

(CORE-II)

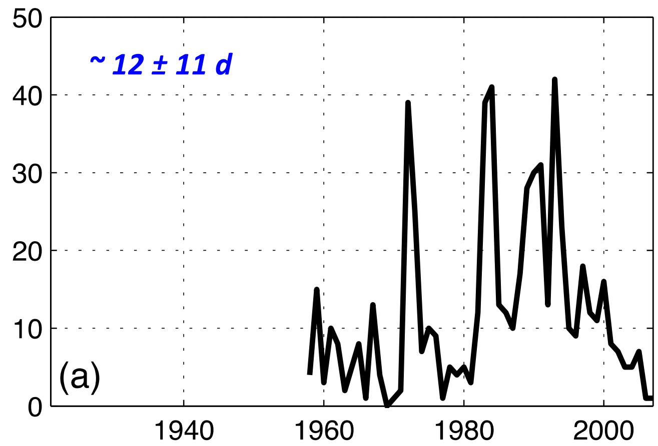


✓ Synoptic storms set up the strong pressure gradient

hPa



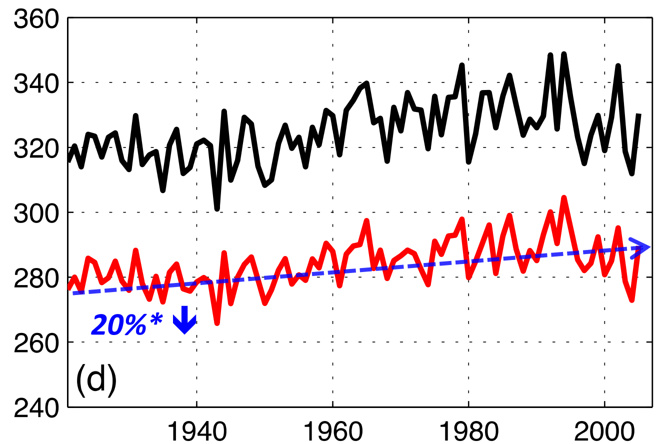
Storm-induced HFLX



~ 12 ± 6
d

30%

30%*



✓ But, trends are still significant (even at higher confidence level in POP, 94% → 99%)

Summary

- An “externally forced” increase in AMOC (as a part of multidecal oscillation) found in CESM-LE 20C simulations
- However, the timing of the increase is not consistent with that in POP
- This increase is associated with
  - 1) surface HFLX increase associated with a “externally forced” positive trend in NAO, as in POP (also likely in nature), the timing of which is also not consistent with observations
  - 2) a buoyancy decrease as a part of forced large scale SST (density) changes (forced AMO-like variability)
- Statistical analysis suggests that chances that AMOC and NAO trends in CESM-LE equal or exceed those of POP (and CORE2) increase with external forcing
- Suggesting a possibility that the upward AMOC trend in POP (also likely in nature) is *partially* driven by external forcing (embedded within the natural variability)
- Storm-induced HFLX over the Lab. Sea accounts for up to 30% in high winter-mean HFLX years and shows an increasing trend during the 20C in both POP and CESM-LE
- But, appears to contribute little to the overall HFLX trend