The Impact of Cold-air Outbreaks on Labrador Sea Deep Convection and the AMOC

Who M. Kim (whokim@tamu.edu) and Ping Chang

Department of Oceanography, Texas A&M University

Introduction

Cold-air outbreak storms (CAOs) are shown to have significant influence on Labrador Sea (LS) deep convection[1], which provides a major source water for the AMOC. While the AMOC is thought to decrease during the late 20th century, due to increased surface buoyancy in the subpolar North Atlantic in response to global warming, recent ocean simulations show rather stable AMOC, or even an upward trend in AMOC[2]. Meanwhile, it has been also shown that the North Atlantic storm track has been strengthened and shifted northward[3] during the late 20th century. We conjecture that the increased CAOs may compensate the surface buoyancy increase in the subpolar North Atlantic, thus cause the stable (or upward) AMOC trend. In this study, we test this hypothesis within in the framework of a forced ocean/ice model by suppressing and/or enhancing identified CAOs in the LS.

Heat Flux Event Analysis

CAOs can be identified by extreme heat flux events[4]. Using the daily NCEP/NCAR reanalysis data, heat flux (latent plus sensible) event days are defined in the LS where the winter (JFM) mean heat flux is most intense, and mixed layer depth (MLD) simulated in our control simulation is greatest (Fig. 1). As in the previous study[4], which focused on the North Atlantic mode water region, the extreme heat flux events, which only comprise 16% of the total winter period, explain most of total heat flux variability in this region (r ~ 0.9).

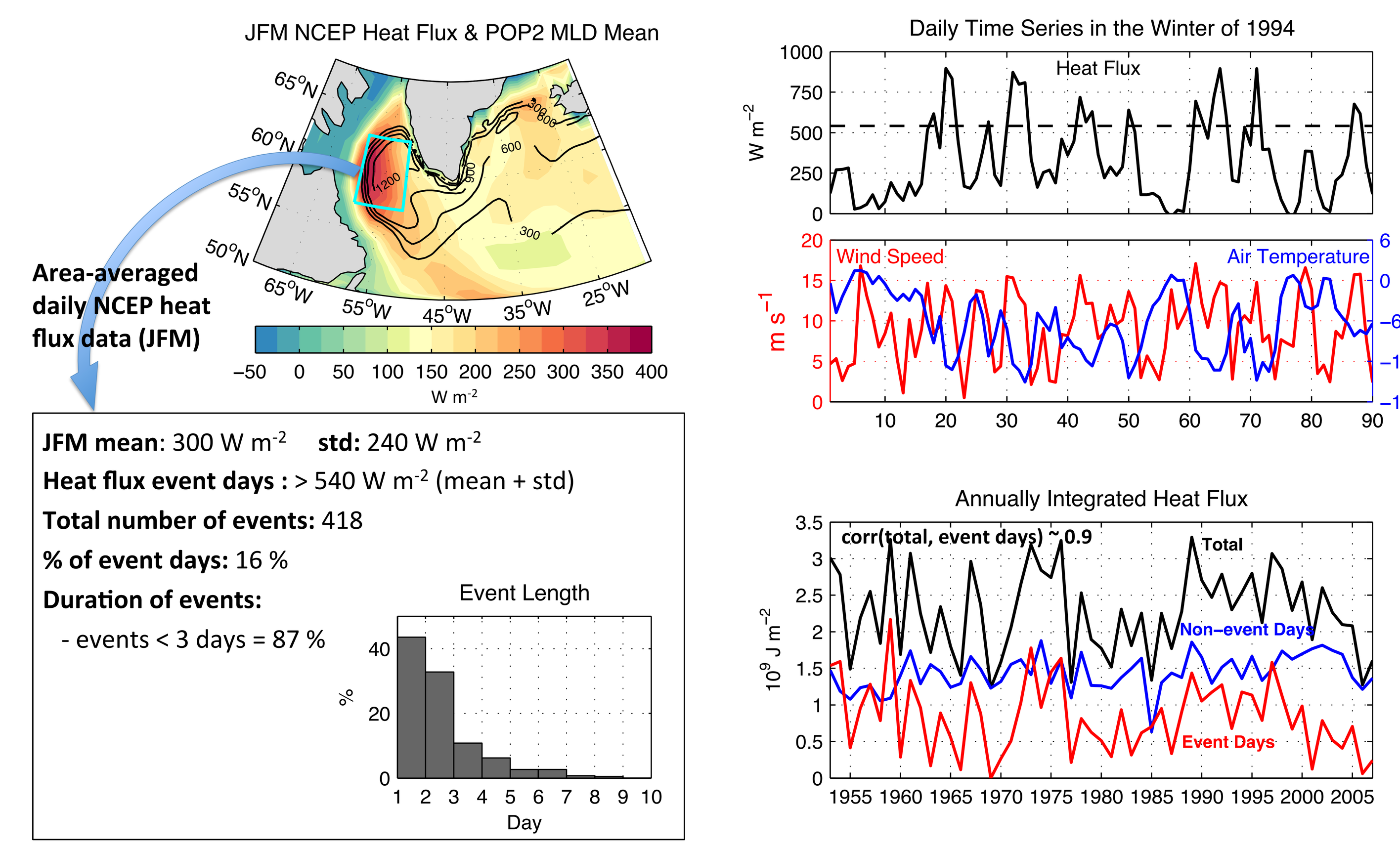
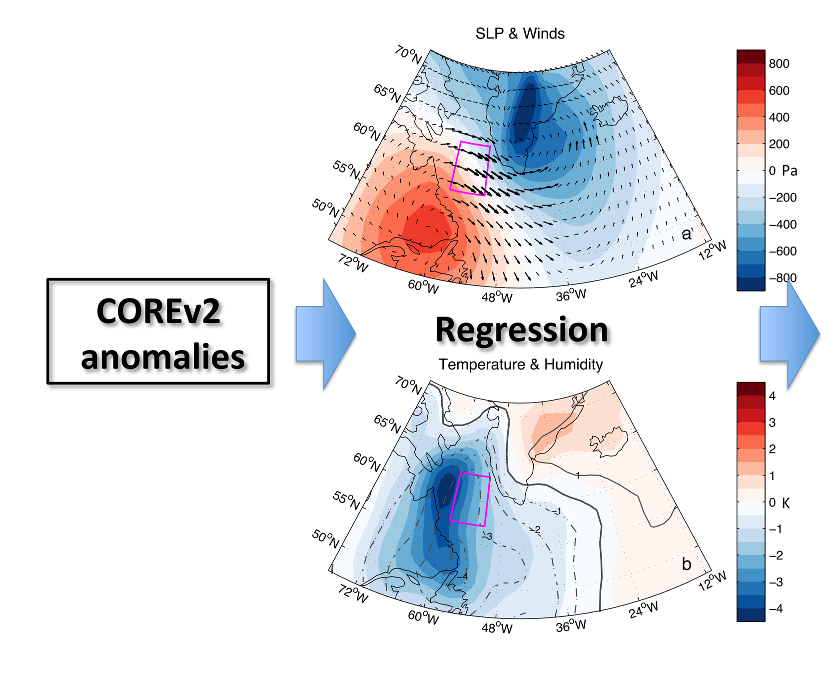


Fig. 1. (a) Winter Mean combined latent and sensible heat fluxes from the NCEP/NCAR reanalysis (color), and MLD simulated in the control simulation. (b) Daily time series (winter 1994) of the NCEP/NCAR combined heat fluxes, wind speed, and 2 m air-temperature averaged over the region indicated by the box in (a). The Threshold used to define the heat flux events is indicated by the dashed line. (c) The annual heat flux time series of total (black), event days (red), and non-event days (blue) integrated during winter.

Synthetic Forcing

For the heat flux event days, the CAO composites for winds, air temperature, and humidity (C_U) have been constructed from the low-pass filtered (< 11 days) COREv2 dataset (Fig. 2), which shows winter storm pattern associated with heat flux events in the LS. Then, the synthetic atmospheric forcing that either suppresses or enhances CAOs is obtained by regressing anomalies of each COREv2 variable (U') on the corresponding composite as below. The power spectrum of the regression coefficients (r) shows the high-frequent nature of CAOs (Fig. 3).



$$U'(t,x,y) = r(t)\times C_U(x,y) + R_U(t,x,y)$$

Regression Coefficent; Residual

Synthetic Forcing

$$U_s(t,x,y) = \bar{U}(x,y) + \beta r(t) C_U(x,y) + \alpha R_U(t,x,y)$$

COREv2 Mean

$\beta = 0$ for suppressed CAO case, NST

$\sqrt{2}$ for enhanced CAO case, 2ST (doubled variance)

$$\alpha = \sqrt{\frac{[\sigma^2(U')] - [\sigma^2(\beta r C_U)]}{[\sigma^2(R_U)]}}$$

For winds only to make domain-averaged (46ºN-73ºN, 79ºW-26ºE) variance same as in original COREv2

Fig. 2. (a) heat flux event day composite of 11-day high-pass filtered COREv2 sea level pressure (color) and 10m winds (vector). The large (small) vectors indicate wind speed greater (smaller) than 4 (2) m s^{-1}. (b) As in r(a), but for 10 m air-temperature (color) and specific humidity in 10^4 kg kg^{-1} (contour).

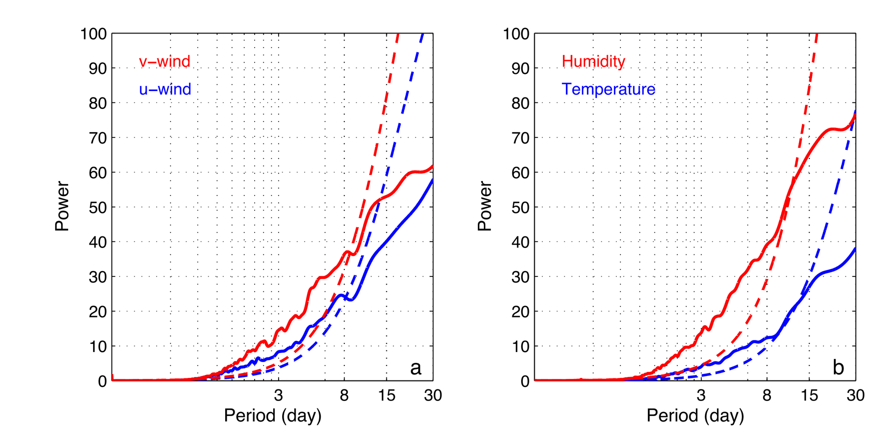


Fig. 3. Power spectrum of the correlation coefficients using Welch's method with a 128 (days) wide Hamming window. The dashed lines indicate 95% confidence level based on each AR1 spectrum.

Experiments

Control simulation (CTL): POP2/CICE4 is forced by the 60-year long interannually varying COREv2 dataset (14 cycles).

Synthetic Forcing Simulations: 4 synthetic forcing simulations have been conducted as follows. Each simulation is run for 3 forcing cycle (180 years).

	U_{10}	T_{10}	q_{10}
NST_W	X	-	-
$2ST_W$	O	-	-
NST_A	X	X	X
$2ST_A$	O	O	O

Results

Heat Flux Difference: Altering the CAOs causes substantial changes in the combined heat fluxes in the western LS off the ice edge.

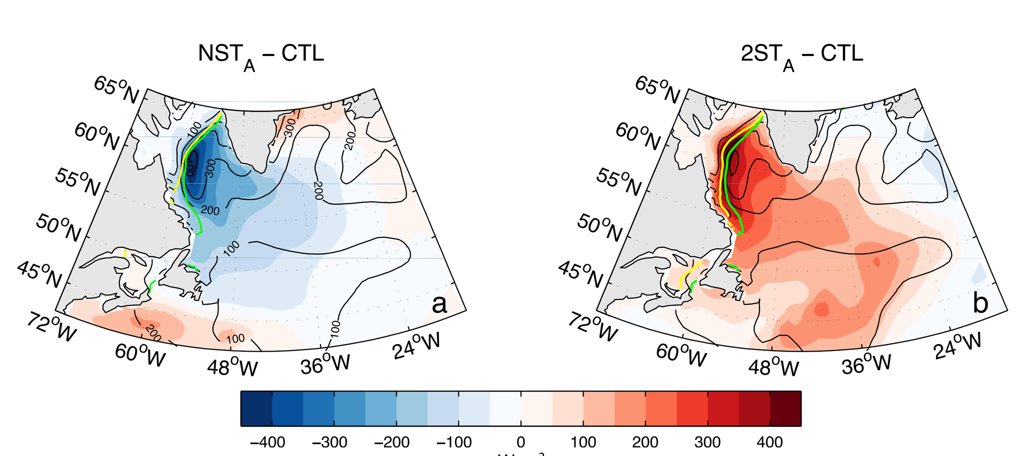


Fig. 4. Winter mean surface heat flux differences between synthetic forcing experiments and CTL. The winter mean heat fluxes in CTL are indicated by contour line. Also, the ice edge (15%) in CTL (green) and each synthetic forcing experiment (yellow) is shown.

MLD response: As a result, MLD suffers significant changes. In particular, the LS MLD is almost absent in NST_A, indicating that deep convection is suppressed.

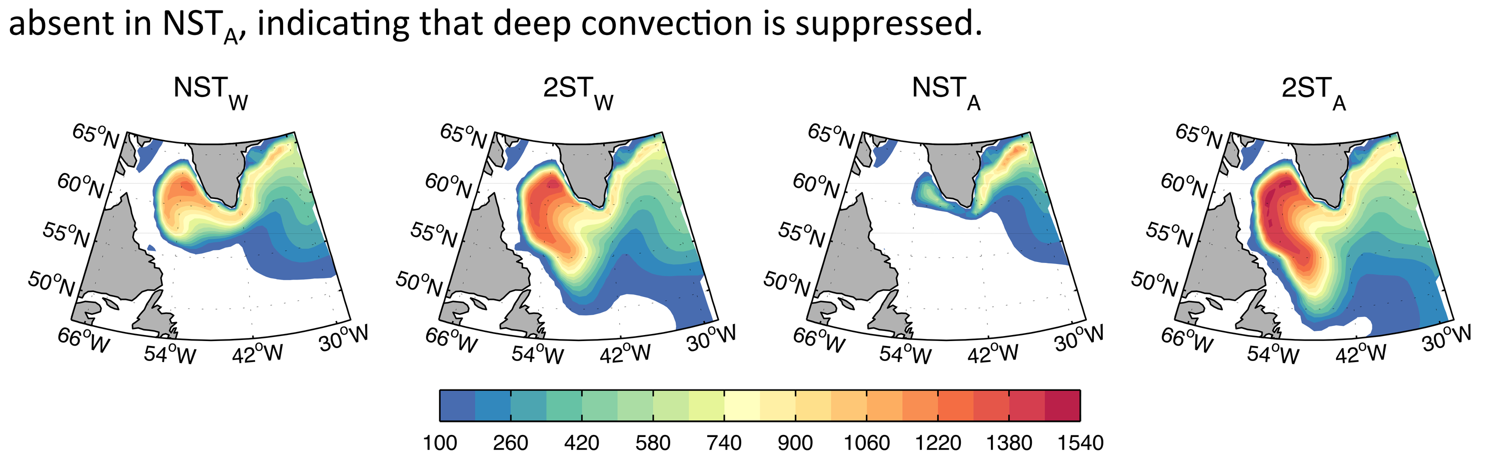


Fig. 5. Winter mean MLD in the LS and Irminger Sea in each synthetic forcing simulation.

Results Continued

Changes in AMOC: Consistent with surface heat flux forcing, AMOC changes up to 8 Sv (33%). In addition, the AMOC time series reveals that an upward trend in CTL (0.67 Sv/decade) is almost halved in NST_A (0.38 Sv/decade).

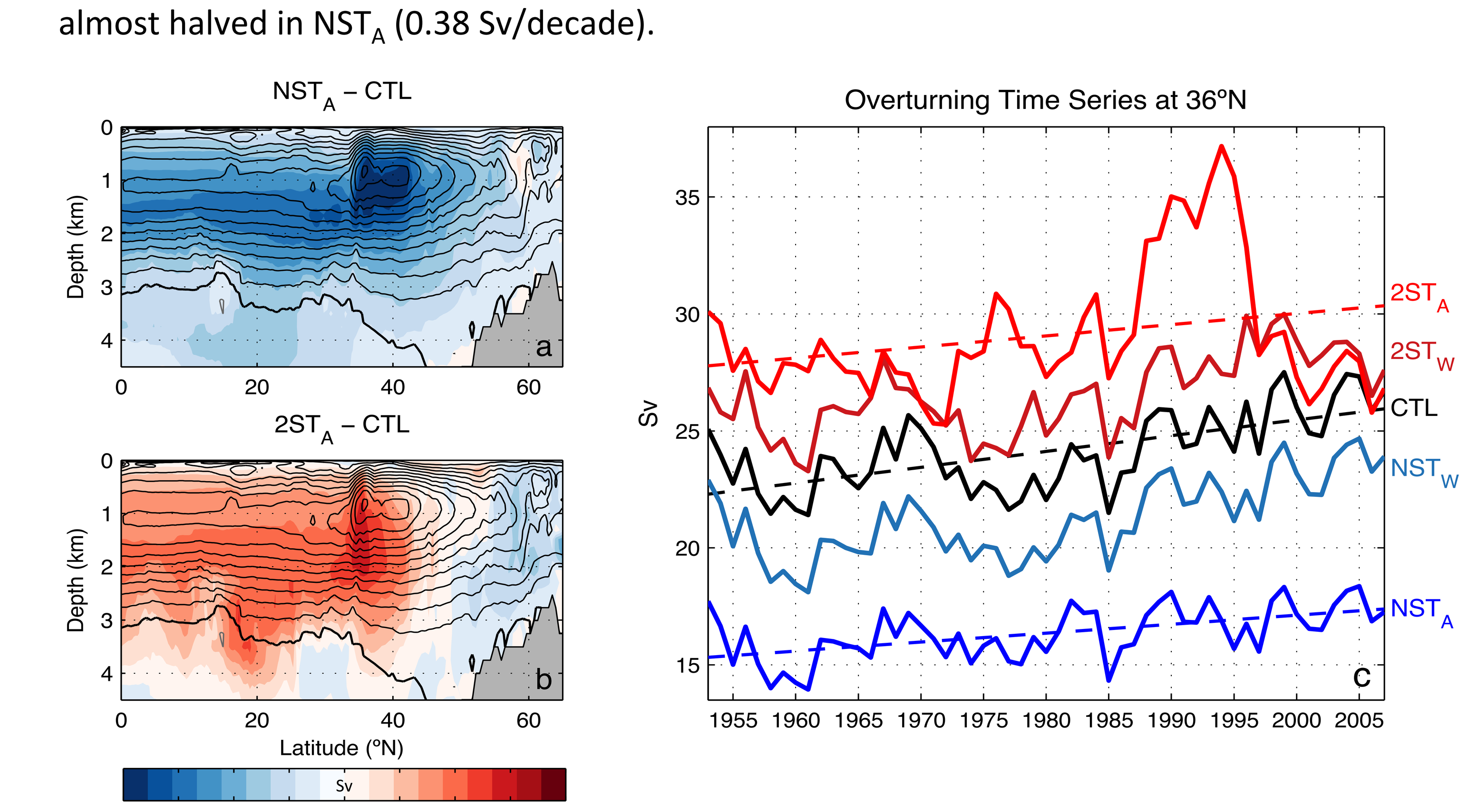


Fig. 6. (a) & (b) Mean AMOC streamfunction differences (color) between synthetic forcing experiments and CTL. The mean AMOC streamfunction in CTL is also contoured in 2 Sv interval. (c) the annual time series of the maximum overturning at 36ºN in all simulations. The dashed lines denote linear trends.

Heat Flux trends: The changes in AMOC trends appears to result from changes in heat flux trends. As shown below (Fig . 7), a strong trend in the western LS in CTL weakens when wind variability associated with CAOs is removed, and disappears when temperature and humidity variability is additionally removed.

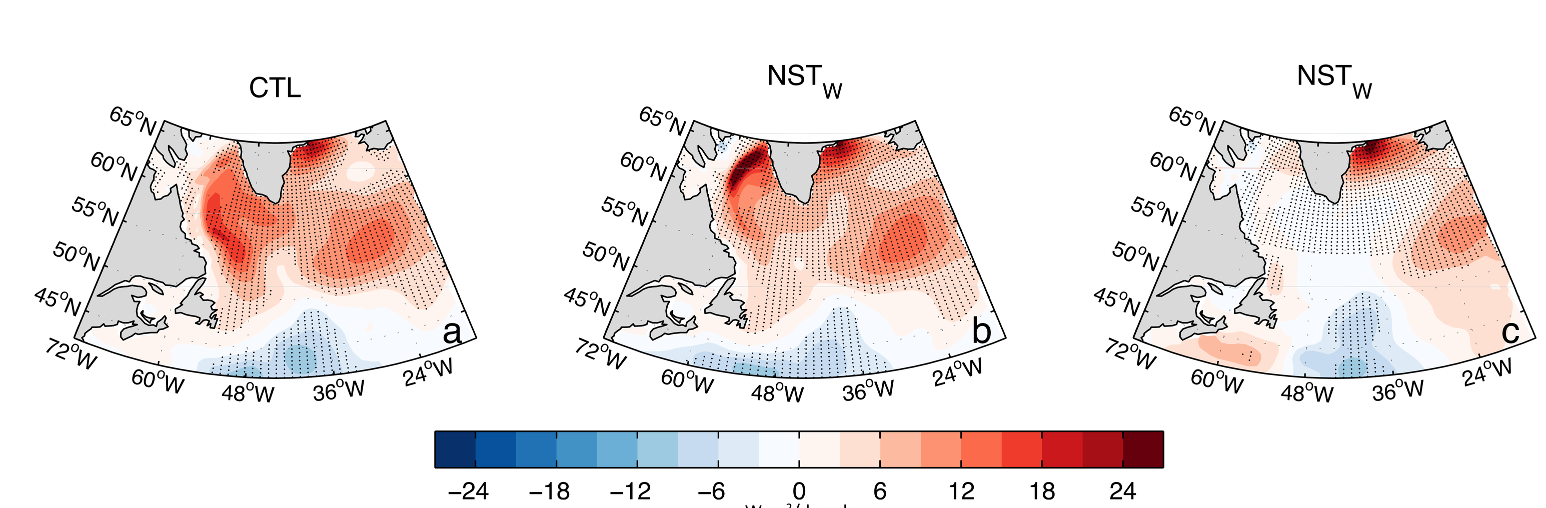


Fig. 7. Linear trends in the surface heat fluxes. Statistically significant trends are denoted by dots.

Conclusions

- The heat flux event analysis reveals the high-frequent nature of CAOs, which decisively control the total heat flux variability in the LS.
- Suppressing (enhancing) the variability of atmospheric fields associated with CAOs substantially decreases (increases) Labrador Sea deep convection activities via reduced (strengthened) turbulent heat fluxes.
- This leads not only to a mean AMOC reduction (intensification) of about 33%, but also to a decrease of the upward trend in CTL substantially for the suppressed case.
- The reduced trend in the AMOC appears to result from weakened heat flux trends in the LS.
- These results suggest that the strengthened, northward shifted storm track during the 20th century may have contributed to long-term changes in AMOC strength.

References

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