Motivation
- Observations indicate Atlantic SSTs exhibit significant low-frequency variability (Broecker, 1964; Kushnir, 1994; Ting et al., 2009).
- Large-scale changes in ocean heat transport due to changes in the AMOC (Kushnir, 1994, et al. and gyre circulations. Not available due to missing data).
- This document provides a comprehensive overview of the factors influencing ocean heat transport and the role of the AMOC.

Question
What are the relative roles of atmospheric forcing and ocean dynamics in setting upper-ocean heat variability in the North Atlantic?

ECCO version 4 state estimate (1992-2010)
- MITgcm least squares fit to observations using adjoint (Wunsch, 2009, 2009)
- fit adjusted by adjusting initial conditions, forcing, and model parameters.
- well suited to understand UOHC variability because it satisfies equations of motion and preserves properties exactly (Wunsch and Heimbach, in press).
- Atmospheric forcing ERA-Interim
- Ocean data:
  - In-situ: Argo, CTD, XBTs, mooring arrays
  - Satellite: AVHRR & AMSR SST, altimetry
- Model Details (G.-F)
  - New global grid (LCCO3) includes Arctic, 50 vertical levels with partial cells
  - Nominal 1° resolution with telescop resolution to 1/3° near Equator
  - State of the art dynamic/thermodynamics sea-ice model
  - Nonlinear free surface + real freshwater fluxes

Comparison to observations
Temperature Misfits
- Temperature misfits for (left) “first-guess” solution and (right) optimized ECCO v4 solution at 100 m depth for all-in-situ data (Argo, CTD, XBT, SeaDi) averaged over 1992-2010. Misfits are calculated as the sample mean for each grid cell at t = T0 where T0 are the observational profiles and T are the corresponding profiles from the model.

Comparison of observed and ECCO v4 SST variability
- SST Observations: EOF 1
- SST Observations: EOF 2
- ECCO SST-EOF 1
- ECCO SST-EOF 2
- PC timeseries of Atlantic SST
- Powerspectra

Upper-ocean heat content variability
Heat Content integrated over maximum climatological mixed layer depth (D)
- Measure of heat contained in “active” ocean layers
- Implicitly accounts for reemergence of SST anomalies (Brierley et al., 2003; Cesslone and Frankignoul, 2002; Buckley et al., sub.)
- Define: $H = \rho C_p \int T \; d z$

Maximum Climatological mixed layer depth (D)
To right:
- (a) The first two PC time series of monthly H anomalies (seasonal cycle removed) over the North Atlantic and (b) their respective power spectra.

Heat content budgets
- Variance of monthly anomalies (seasonal cycle removed) of terms in the $H$ budget:
  1. tendency $\Delta H$
  2. advective $\theta$ divergence $\sigma_{\theta}$ (c) air-sea heat flux $\sigma_{\theta}$ and (d) diffusive $\sigma_{\theta}$

Dynamics of Advection heat transport convergences
- $\text{not standard}$
- $\text{not standard}$
- $\text{not standard}$
- $\text{not standard}$
- $\text{not standard}$

Maps showing the fraction of the variance of $H$ explained by
- $\text{not standard}$
- $\text{not standard}$
- $\text{not standard}$
- $\text{not standard}$
- $\text{not standard}$

Conclusions
- Heat content integrated over the climatological mixed layer depth H is a useful measure of upper-ocean heat content.
- Both advection & air-sea heat fluxes play a role in variability in $H$, the tendency of $H$.
- Approximating the advection heat transport contribution as the sum of $\text{Ekman}$ & $\text{geostrophic}$ convergences is successful over most of subropical and subpolar gyres.
- Exceptions: boundary regions of subpolar gyre, Mann Eddy region
- Over the interior of the subropical and subpolar gyres >70% of the variance of H can be explained by local air-sea heat flux + Ekman transport variability.
- Geostrophic convergence plays a role along Gulf Stream Path.
- Importance of various terms in variance of $H$ depends on timescale.
- Subpolar gyre: local forcing dominates on all timescales.
- Gulf Stream: local forcing dominates for periods less than 6 months; geostrophic convergences increasingly important on longer timescales.
- Subpolar gyre: local forcing dominates for periods less than 1 year; geostrophic transports, baroclinic transports, and diffusion play a role on longer timescales.
- Temporally integrated budgets emphasize terms important in H variability.
- Subpolar gyre: majority of H variance explained by local forcing
- Gulf Stream region: geostrophic transports important, anti-correlated with air-sea heat fluxes $H$ variability is forced by geostrophic convergences & ramped by air-sea fluxes.

References