What drives upper ocean heat content variability?

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Salinity Trends within the Upper Layers of the Subpolar North Atlantic

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Really good at working with ECCO!
Recent global-warming hiatus tied to equatorial Pacific surface cooling
Yu Konicek & Shang-Ping Xie

Geophysical Research Letters

Surface warming hiatus caused by increased heat uptake across multiple ocean basins

19601, University of Southampton, Southampton, UK; National Oceanography Centre, Southampton, UK; Southampton Centre for Knudsen scale Molecular Physics, Southampton, UK.

Recent intensification of wind-driven circulation in the Pacific and the ongoing warming hiatus
Matthew H. England, Shaye McGreggor, Paul Spence, Gerald A. Meehl, Askel Tomassen, Wenju Cai, Alex Sen Gupta, Michael J. McPhaden, Ariana Punshud, and Agus Santoso

Pacific origin of the abrupt increase in Indian Ocean heat content during the warming hiatus
Sang-Ki Lee, Wimon Parkh, Molly O. Baringer, Arnold L. Gordon, Bruce Huber, and Yanjun Liu

Global Warming

Recent hiatus caused by decadal shift in Indo-Pacific heating
Veronica Nieves, Josiah K. Willis, William C. Patzert
Hiатусы и Блобы

MARINE SCIENCE

‘The Blob’ invades Pacific, flummoxing climate experts

Persistent mass of warm water is reshuffling ocean currents, marine ecosystems, and inland weather
Hiatuses and Blobs

Contrasting modes of internal variability

“Hiatus”

atmosphere cools

upper ocean warms

atmosphere

surface ocean

deep ocean

“Blob”

atmosphere cools

upper ocean warms

atmosphere

surface ocean

deep ocean
What drives upper ocean heat content variability?

- What is the relative role of air-sea forcing vs. internal ocean processes?
- “Advection of anomalies” vs. “anomalous advection”?
- How does the balance of terms depend on the spatial and temporal aggregation scale?
Heat Budget

❖ ECCO is well suited for answering these questions because it has a closed heat budget with detailed diagnostic capability
❖ ECCOv4 even adjusts mixing coefficients

\[
\frac{\partial s^*\theta}{\partial t} = -\nabla_h \cdot (s^*\theta \mathbf{u}_{res}) - \frac{\partial}{\partial z} (\theta w_{res}) + s^* F_\theta + s^* D_\theta
\]
Comparison to Piecuch et al. (2017)

- Calculate full diagnostic budget
- Integrate spatially over SPNA
- Integrate cumulatively over time
- Detrend
- Remove seasonal cycle

Anomaly Budget

\[
\frac{\partial \theta'}{\partial t} = F'_{surf} - \nabla_h \cdot (\bar{u}'_h \theta') - \nabla_h \cdot (u'_h \bar{\theta}') - \frac{\partial}{\partial z} (w' \bar{\theta}') - \frac{\partial}{\partial z} (w' \bar{\theta}') - \nabla \cdot (u' \theta' - \bar{u}' \bar{\theta}') - \nabla \cdot F'_d + R
\]

- \( \bar{\theta}'^m, \bar{u}'^m \): Monthly mean climatology
- \( \theta', u' \): Monthly anomalies
- Surface forcing
- Anomalous horizontal advection of mean
- Anomalous vertical advection of mean
- Mean horizontal advection of anomalies
- Nonlinear advection
- Diffusion
- Residual
Example Timeseries

North Atlantic: 17 W, 45 N
Example Timeseries

North Atlantic: 17 W, 45 N
Regression Analysis

What are the dominant terms in any particular timeseries?

\[
\frac{\partial \theta'}{\partial t} = F'_{\text{surf}} - \nabla_h \cdot (u'_h \bar{\theta}^m_h) - \nabla_h \cdot (\bar{u}_h^m \theta') - \frac{\partial}{\partial z} (w'^m_h \theta') - \frac{\partial}{\partial z} (\bar{w}^m \theta') - \nabla \cdot (u' \theta' - \bar{u}' \theta') - \nabla \cdot F_{\text{diff}} + R
\]

Think of this as:

\[
y(t) = x_1(t) + x_2(t) + \ldots + x_n(t)
\]

\[
r_1 = \frac{\int_{t_0}^{t_1} x_1(t)y(t)dt}{\int_{t_0}^{t_1} y(t)y(t)dt} \quad r_2 = \frac{\int_{t_0}^{t_1} x_2(t)y(t)dt}{\int_{t_0}^{t_1} y(t)y(t)dt} \quad \text{etc.}
\]

\[
r_1 + r_2 + \ldots + r_n = 1
\]
Regression Analysis
Regression Maps
Regression Analysis

Temporal Averaging: 1_month | Integration Depth: 300m

- $F'_\text{surf}$
- $-\nabla_h \cdot (u'_h \bar{\theta}^m)$
- $-\nabla_h \cdot (\bar{u}'_h \theta')$
- $-\partial_z (w' \bar{\theta}^m)$
- $-\partial_z (\bar{w}^m \theta')$
- $-\nabla \cdot (u' \theta' - \bar{u}' \bar{\theta}')$
- $-\nabla \cdot \mathbf{F}_{\text{diff}}$
- $R$
How does the budget change as we integrate over deeper depths?
Temporal Scale Dependence

How does the budget change as we average over longer time intervals?
Spatial Scale Dependence

How does the budget change as we aggregate over larger spatial regions?

1 degree

9 degrees
Conclusions

- Low latitudes: anomalous advection is the sole driver of OHC variability
- Anomalous vertical advection damps variability (diminishes with depth)
- **Forcing** becomes more important as you move to higher latitudes
- Picture is remarkably **insensitive to scale**