Lecture 16: The ocean heat transport

Atmosphere, Ocean, Climate Dynamics

EESS 146B/246B
Heat transport in the atmosphere-ocean climate system

- The movement of air in the atmosphere and water in the ocean both act to regulate the Earth’s climate, keeping the temperatures on the Earth from being extreme.
Atmosphere-ocean climate system: an analogy
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• Remove wall to allow airflow.
Atmosphere-ocean climate system:
an analogy
Atmosphere-ocean climate system: an analogy

Pump water through tubes in the floor.
Atmosphere-ocean climate system: an analogy

Pump water through tubes in the floor.
Atmosphere-ocean climate system: an analogy
The ocean heat transport

• Estimating the ocean heat transport from observations.
• Basin to basin variation in heat transport.
• Vertical structure of the heat transport.
Observed incoming and outgoing radiation

- Measurement made at the top of the atmosphere from the Earth Radiation Budget Experiment satellite
Steady state energy balance

\[ 0 = Q_{\text{net}}^{rad} - \nabla \cdot \hat{H} \rightarrow \text{Depth integrated advective heat transport} \]

Meridional heat transport of both atmosphere and ocean

\[
\overline{H}^\lambda = \int_0^{2\pi} \int_{\phi_1}^\phi a^2 \cos \phi Q_{\text{net}}^{rad} d\lambda d\phi \quad \overline{H}^\lambda (\phi_1) = 0
\]

Heat transport is poleward
Estimating the ocean heat transport using the residual method

\[ H_{ocean}^\lambda = H^\lambda - H_{atm}^\lambda \]

• Use atmospheric analyses of velocity and temperature to calculate the total energy transport in the atmosphere and subtract this from the total meridional heat transport.

• Atmosphere: 4 PW
• Ocean 2 PW.

Fig. from Trenberth and Solomon (1994)
While in the Pacific the heat transport is antisymmetric about the Equator, in the Atlantic the heat transport is always northward and is ~0.5 PW at the Equator.
Heat transport by NADW

- The southward transport of the cold NADW results in a northward heat transport.
The vertical structure of ocean heat transport

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Received 18 January 2005; revised 23 March 2005; accepted 29 March 2005; published 17 May 2005.

• Used the MIT GCM (2.8° resolution) run to equilibrium to evaluate the contributions of the surface and abyssal circulation to the oceanic transport of heat.
$\overline{V} = -\frac{\partial \psi}{\partial z}$

$\overline{W} = \frac{\partial \psi}{\partial y}$

(zonal integral)
Evaluating the heat flux

\[ \mathcal{H} = \left( \mathbf{v} + \mathbf{v}_{GM} \right) T - \left( K_{Redi} + \kappa \right) \nabla T. \]

Heat advection by eddy-driven overturning parameterized using the Gent-McWilliams scheme

Diffusivity associated with mesoscale eddies

\[ \mathbf{v}_{res} = \overline{\mathbf{v}} + \overline{\mathbf{v}}_{GM} \]

• Part of the advective heat flux recirculates on a streamline and therefore does not contribute to the net meridional heat transport.

\[ \mathbf{v}_{res} \hat{T} \]

\[ \hat{T}(\psi_{res}) = \frac{\int |\nabla \psi_{res}| T \, dl}{\int |\nabla \psi_{res}| \, dl}. \]

• This is removed to make the vertical structure of the heat transport more clear.
The heat function

\[ \frac{\partial \phi}{\partial z} = \mathcal{H} \cdot \hat{y} - v_{res} \hat{T}(\psi_{res}) \]

\[ \phi|_{z=0} \quad \text{Total meridional heat transport} \]

- Nearly all of the heat transport in the southern hemisphere is confined to upper 500 m.
- 0.4 PW of heat is fluxed by the abyssal circulation in the N. Hemisphere.
- The remaining 1 PW is associated with the surface circulation.
Mass and heat transport in the N. Atlantic

Abyssal circulation contributes 44% of the heat transport.

Horizontal circulation in the gyres transports 0.1 PW.

NADW is responsible for the northward heat transport at the Equator.
Meridional heat transport by the wind-driven gyres

Northward flow of warm water in the western boundary current

Southward flow of cooler water

→ Net heat transport to the north
Increasing the vertical diffusivity in the abyss strengthens the mass transport, but does not affect the heat transport since the gradients in temperature are so weak in the deep ocean.
Implications

• The wind-driven surface circulation dominates the heat transport.
• The heat transport is more sensitive to variations in the wind-driven circulation than the abyssal circulation.
• A decrease in the deep overturning circulation does not imply a significant reduction of the global heat transport.
Parameterization for the eddy-induced transport

- The eddy-induced transport can be represented by a streamfunction $\psi_e$ where
  \[- \Delta \psi_e = \overline{v'h'}\]

- In the ocean interior, the eddy-induced transport associated with *mesoscale* eddies (i.e. with length scales $\sim100$ km) has been successfully parameterized using the so-called Gent-McWilliams scheme:
  \[\psi_e = \kappa_i \overline{S} \quad \kappa_i \text{ eddy diffusivity } \sim 1000 \text{ m}^2/\text{s} \quad \overline{S} \text{ mean slope of isopycnals}\]

- The parameterization breaks down in the mixed layer where isopycnals are nearly vertical and a different class of eddies are found.