Lecture 10: Air-sea fluxes, mixed layer dynamics, and water mass formation

Atmosphere, Ocean, Climate Dynamics

EESS 146B/246B
Review of the wind-driven gyres
The thermohaline circulation

“It seems most sensible to regard the thermohaline circulation as the circulation of temperature and salt.”


• The part of the circulation that transports heat, fresh/salt water, and water masses in general.

**WATER MASS**

A body of water with a common formation history having its origin in a particular region of the ocean. Water masses are identified by their temperature and salinity.
Water masses in the Atlantic

- **Cold, fresh water formed in the S. Ocean**
  - Antarctic Intermediate Water
  - Cool, dense water from the seas around Antarctica
  - Antarctic Bottom Water

- **Cool, salty water from the N. Atlantic Deep Water**
The properties of water masses are most often set in the surface mixed layer by the action of air-sea fluxes of heat, fresh/salt water, and by mixing.
The ocean mixed layer

- Observations of a deep mixed layer south of the Gulf Stream during the late winter
Equations governing the temperature and salinity in the mixed layer

- Temperature and salinity in the mixed layer is modified by:
  - Surface heat fluxes and evaporation and precipitation
  - Entrainment of water from beneath the mixed layer.

- In the absence of currents, T and S follow:
  \[
  \rho_{ref} c_w H \frac{\partial T_{ml}}{\partial t} = -(Q_{net} - Q_{ent})
  \]
  \[
  H \frac{\partial S_{ml}}{\partial t} = S_{ml}(E - P) + F_{ent}^S
  \]

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  - Surface heat fluxes and evaporation and precipitation
  - Entrainment of water from beneath the mixed layer.

- Entrainment velocity dependent on air-sea fluxes that set the strength of turbulence in the ML.

\[
F_{ent}^S = -w_{ent} \Delta S
\]
\[
\frac{Q_{ent}}{\rho_{ref} c_w} = -w_{ent} \Delta T
\]

Entrainment velocity dependent on air-sea fluxes that set the strength of turbulence in the ML.
Surface heat flux

\[ Q_{net} = Q_{SW} + Q_{LW} + Q_S + Q_L \]

- Shortwave radiation → solar radiation
- Longwave radiation → follows the black-body (Stephan-Boltzmann) law.
- Sensible heat associated with the turbulent transfer of heat in the atmospheric boundary layer.

\[ Q_S = \rho_{air} c_P c_S u_{10} (SST - T_{air}) \]

- Latent heat → cooling associated with evaporation → dependent on the turbulent transfer of moisture in the atmospheric boundary layer.

\[ Q_S = \rho_{air} L_e c_L u_{10} (q_\ast (SST) - q_{air}) \]
Heat flux components

Short wave + Long wave

Latent

Sensible

(From Khalay et al. (1996))
Cold air outbreaks

Figure from Bane and Osgood (1989)
Atmospheric forcing of the Gulf Stream during cold air outbreaks

- The large air sea temperature and low humidity of the air resulted in heat fluxes of 1000 W m$^{-2}$.
Zonally averaged heat flux

Heat Flux Components

Ocean Loss

Ocean Gain

Total Heat Flux

Ocean Loss

N-S asymmetry

(From Stewart (2005))
Total heat flux

Net Upward Heat Flux (W/m²)

(From Kalnay et al. (1996).)
Sea surface temperature
What limits the SST in the tropics?

- The specific humidity at saturation is a strong function of SST which for a fixed air humidity causes a rapid increase in cooling by evaporation.
Evaporation minus precipitation
Surface salinity

Surface Salinity (psu)

(Data from Levitus World Ocean Atlas (1994).)
Evaporation and precipitation