Gef 2610
Midterm exam fall 2017
Sample solutions

Probl. 1 Air-Sea fluxes

a) Have total heat flux thru sea surface

$$\sum Q = R_{SW} + R_{LW} + Q_L + Q_S$$

R_{SW} = shortwave radiation, i.e. blackbody radiation from the sun. Some is scattered or absorbed in atmosphere. R_{SW} is a function of latitude, season and time of day

R_{LW} = Longwave radiation, i.e. blackbody radiation from air masses in lower atmosphere minus radiation from sea surface itself. So this can be negative.

Q_L = Latent turbulent heat flux associated with evaporation of surface waters.

$$Q_L \sim \rho_a c_e (e_a - e_w) |\vec{U}|$$

where e_a and e_w are specific humidities of air and water, respectively, and c_e is a transfer coefficient. ρ_a is air density and $\vec{u}$ is the air velocity (at ~10m). Strong winds are typically associated with enhanced turbulence and hence enhanced vertical transfer. Q_L is typically negative (a heat flux out of the ocean)

Q_s = Sensible turbulent heat flux associated with the temperature difference between air and water

$$Q_s = \rho_a C_s (T_a - T_w) |\vec{U}|$$

where T_a and T_w are air and water temperatures and C_s is (another) transfer coefficient.

b) Large wind speeds are typically associated with enhanced turbulence in boundary layers. Enhanced turbulence increases the vertical exchange of heat (and other properties) between ocean surface and lower atmosphere.

c) The evolution of salinity in the upper ocean is primarily set by the addition or removal of fresh water (thru rain, evaporation, rivers, sea ice formation/melt)

Addition of FW reduces salinity while removal of FW increases salinity.

Probl. 2

a) A 'statically stable' water column has light water lying on top of denser waters. Exchanging water parcels vertically will cause the parcels to return to their original position. E.g., a parcel which is moved up will find itself denser (heavier) than its new surrounding and will therefore tend to sink down again.

A 'statically unstable' fluid has heavy water residing on top of light(er) water. Exchanging water parcels vertically in such a fluid will release gravitational potential energy (PE) and enhance the original perturbation/exchange. Eg: a parcel moved up will find itself lighter than its new surroundings and therefore continue to rise. The resulting accellerating motion is called 'vertical convection' - and this will continue until the fluid is stably stratified (with light water on top).

b)

The sketch shows a fluid which is stably stratified vertical (everywhere we look, light waters reside on top of dense waters). Exchanging parcels at A and B will release some PE, and the result is that parcel A will keep rising (it will find itself lighter than its new surrounding) and parcel B will keep sinking (heavier than new surroundings). So a small original perturbation (exchange) is reinforced by the release of PE. So this is a form of 'slanted' (not entirely vertical) convection. The requirement is that the slope of the exchange is smaller than the slope of the isopycnals. (but larger than zero.)

c) The in situ temperature is impacted by pressure. The first law of thermodynamics shows that the temperature of a water parcel may increase when it is compressed, e.g. by being lowered adiabatically (no heat exchange) to greater depths (where the pressure is higher).

When assessing static vertical stability of water columns, i.e. when comparing the densities of water parcels, we need to ignore this pressure effect. We do this by calculating - and comparing - the temp. parcels would have if they had all been raised (or lowered) to some common reference pressure (depth) where the pressure effect on temp would be the same for all of them. This would be their potential temperature.

Problem 3

a) A "CTD" is a Conductivity, Temperature and Depth (pressure) recorder. It measures pressure with a piezoelectric device, temperature with thermisters and the conductivity - the water's ability to conduct electrical currents. Salinity is deduced from conductivity (salt ions increase the conductivity) and temperature.

b) Eulerian current obs. can be gathered from fixed (moored) current meters, either by measuring the rotation speed of propellers or by acoustic doppler shifts (ADCP). ADCPs may also be placed on moving vessels (in which the boat's own velocity needs to be subtracted) Today surface currents may also be measured by radars mounted e.g. along the coast.

LS

b) cont$^{\underline{d}}$

Lagrangian current observations are gathered basically by throwing things in the ocean and observing where these float. Buoyies and drifters are floating instrument platforms that may report their own position, e.g. by satellite links. The velocity field is obtained by differentiating the positions.

c) Satellites that have extremely accurate positioning estimates can measure the height of the sea surface underneath. When the "geoid" (sea surface height variation due to uneven gravitational accelleration) is removed. then geostrophic velocities at the surface are diagnosed from sea surface gradients

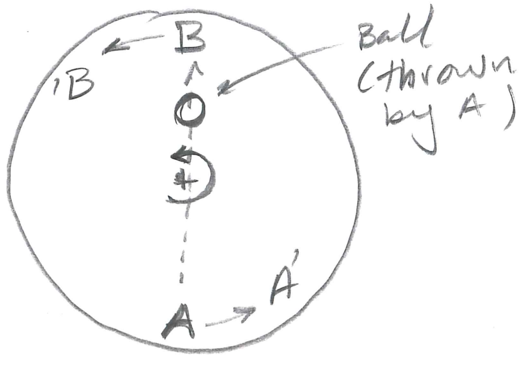
$$U_g(0) = -\frac{g}{f}\frac{\partial \eta}{\partial y}$$

$$V_g(0) = \frac{g}{f}\frac{\partial \eta}{\partial x}$$

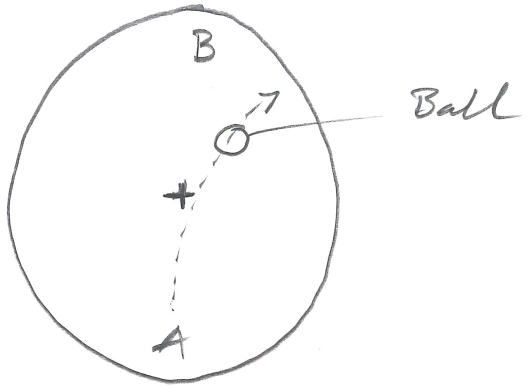
η = sea surf. height.

Probl. 4

a) The coriolis accelleration is an 'aparent accelleration' observed when observing motions in a rotating reference frame. a ball thrown between two friends sitting on a rotating table appears (from the vantage point of the two friends) to move in a curved path. It doesn't! It is instead the two observers who have moved (rotated). For observers A and B sitting on rotating table:



Seen from 'above" in fixed frame



Seen from the rotating frame

b) Geostrophic balance – an approximate balance between the Coriolis acceleration and the pressure gradient in the horizontal momentum equations

x-momentum

$$\frac{\partial u}{\partial t} + \vec{v}\cdot\nabla u \boxed{\underset{\text{Geostroph balance}}{- fv = -\frac{1}{\rho_0}\frac{\partial p}{\partial x}}} + \text{Friction}$$

The balance holds when the time-derivative, the advective terms and friction are small compared to Coriolis. The size of accelerations relative to Coriolis are the Rossby numbers

$$\epsilon_T \equiv \frac{\partial u/\partial t}{fV} \sim \frac{1}{fT} \quad , \quad \epsilon \equiv \frac{\vec{V}\cdot\nabla u}{fV} \sim \frac{U}{fL}$$

When $\epsilon_T \ll 1$, $\epsilon \ll 1$ (and friction is also small) flow is approx. geostrophic.

c) Geostrophic y momentum eq$^{\underline{n}}$

$$fu \sim -\frac{1}{\rho_0}\frac{\partial p}{\partial y} \sim -g\frac{\partial \eta}{\partial y}$$

so

$$u \sim \frac{g}{f}\frac{\partial \eta}{\partial y} \sim \frac{g}{f}\frac{\Delta \eta}{\Delta y}$$

$$\sim \frac{10\,\text{m}\,\text{s}^{-2}}{10^{-4}\,\text{s}^{-1}}\,\frac{0.5\,\text{m}}{10^{4}\,\text{m}} \sim \underline{\underline{5\,\text{cm/s}}}$$