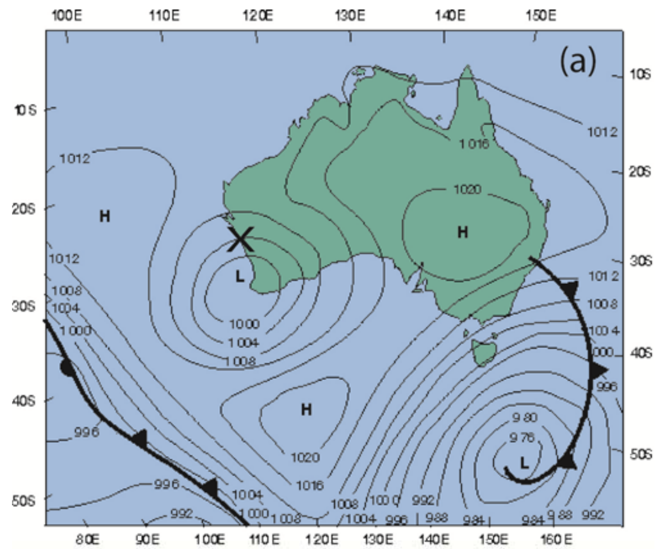
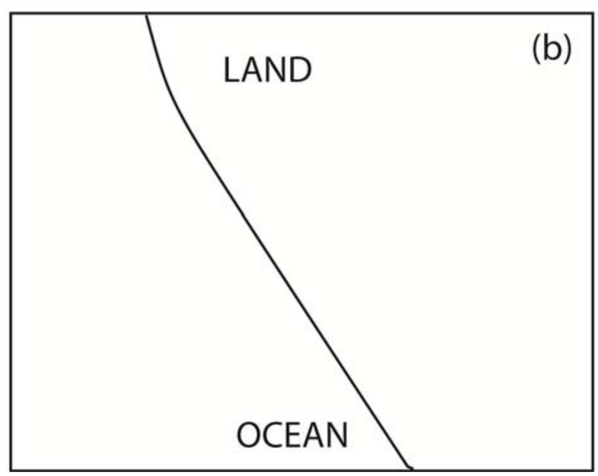
WINDS IN THE BOUNDARY LAYER, VISCOUS FLOWS, and TURBULENCE
Homework assignment

Problems:

1. The PBL flow is driven by large scale atmospheric motions in response to spatial variations in air pressure. Away from the surface in midlatitudes, these large scale flows tend to be in geostrophic balance.





(i) *Use the surface pressure map below to estimate the geostrophic wind vector [U_g,V_g] at the point marked with an* ×. Assume the surface temperature is 15°C.

(ii) Panel (b) shows a close up of the region around the X. Mark on this figure the geostrophic wind arrow you found for the previous section. *What primary effect would the surface type have on the balance of forces associated with the flow in the PBL? How would this balance differ over land and for ocean? Mark on the panel (b) a schematic representation of the force balance over the land and over the ocean.*

(iii) *Draw likely low level wind vectors over the land and over the ocean on panel (b).* Be sure to indicate any differences in both the direction and the magnitude of the wind.

(iv) Using the thermal wind equations, assuming the terms in *dT/dz* are small, with *dT/dx* and *dT/dy* both equal to 1°C per 100 km, *use your surface geostrophic wind vector estimated in (i) to estimate the geostrophic wind vector at the top of a well-mixed boundary layer that is 1.5 km deep.* What might this imply about forced convection in this area? [Hint: consider what the Richardson number might be for this situation]

2. (i) What key property must a fluid have in order for Ekman layers to form? For Ekman layers in the upper ocean, we can ignore horizontal pressure gradients so that the Ekman balance is between the Coriolis force and the viscous (friction) force (see e.g. Equation 7.19 in Arya). For seawater, the kinematic viscosity $\nu = 1.2\times10^{-6}$ m^2 s^{-1}. Calculate the

characteristic parameter of the Ekman flow $a = (f/2\nu)^{1/2}$ at 20°N, where f is the Coriolis parameter. What two aspects of the subsurface currents does a influence?

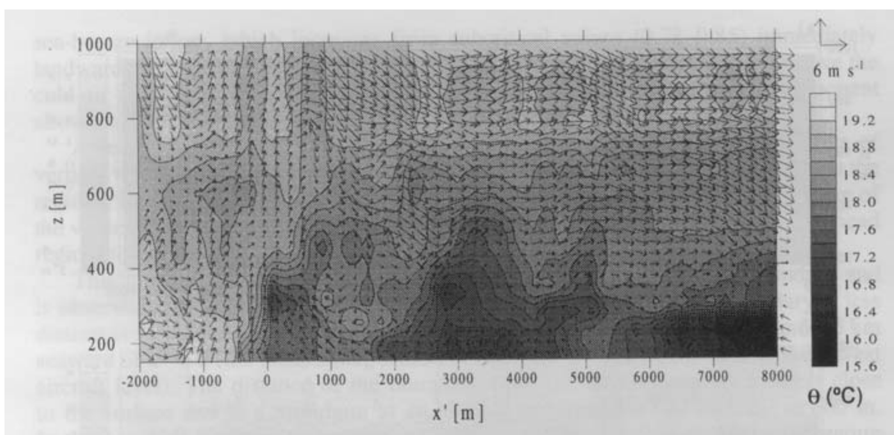
(ii) Off the coast of California in summer, use your meteorological knowledge and resources to describe the direction of the low-level flow. What does this imply about the direction of the upper oceanic Ekman flow?

Imagine an element of ocean immediately adjacent to the coast. Given the near surface flow you deduced above, use mass continuity to determine the likely source of the water flowing into the element. What does this imply about the temperature of the water in this region?

3. Describe the two mechanisms by which turbulence can form in the boundary layer. Include in the description the two basic types of instability. Under which conditions do you expect each of these types of instability to be most important?

4. Given the data in Figures 1 and 2 below estimate the static stability and the wind shear as a function of height. Calculate the Richardson number and attempt to determine which levels, if any, might be unstable. If so, what type of instability you think would dominate? Given what you know about the nature of sea-breezes, do you think that the use of potential temperature rather than virtual potential temperature would be important?

Figure: Cross-section of wind vectors and potential temperature associated with a sea-breeze front propagating from right to left. The surface front is at x′=0. The vertical coordinate is height above the (flat) surface. The measurements were made using a series of flight legs with an instrumented aircraft.



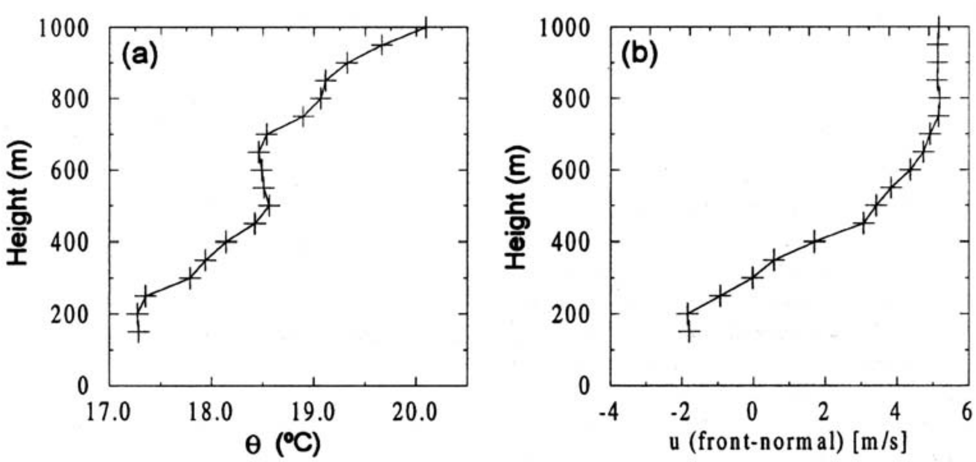


Figure 2: Vertical profiles of potential temperature and front-normal wind speed as a function of height averaged horizontally over the region 0<x′<8 km.

Assuming that any instability would likely lead to turbulence and mixing, what consequences might such mixing have for the sea-breeze front? Consider what mixing does to the buoyancy and to the momentum.

5. Describe how eddy viscosity can be used in place of molecular (kinematic/dynamic) viscosity in the equations of motion. Given that eddy viscosities for even weakly turbulent flows are much greater than the kinematic viscosity for air, what consequences does this have for the depth of the Ekman layers that form in the atmosphere and ocean?