

1. Improbable velocities from conservation of M.

- a. (2 pts) Find M at the starting latitude of 10N if $u=0$ there.
- b. (6 pts) Conserving M, calculate u at these latitudes: 20, 30, 40, 50, 60 N.

2. Arcing path from latitudinal motion. At the start of the course, an imaginary circulation which we labelled as a Hadley cell was drawn whereby the upper level circulation included westerly as well as poleward components. This problem is intended to examine what orientation to draw those circulations. Consider a parcel that moves from 10 N to 30 N with a constant meridional component of velocity that equals 2 m/s. Assume that friction is negligible. The parcel is initially at longitude 0 degrees and has $u=U_0$ zonal velocity.

- a. (4 pts) Write down expressions relating meridional (y) and zonal (x) distance to longitude (λ) and latitude (ϕ). From those formulate definitions of v (northward) and u (eastward) velocity using λ and ϕ .
- b. (6 pts) Derive the general formula for radians of longitude travelled when proceeding from latitude ϕ_S to latitude ϕ_N . The formula should not contain any unsolved integrals. *Hint: use part a to convert between radians and distance and between time and space.*
- c. (2 pts) Use your formula to find the ending longitude when the parcel reaches $\phi_N = 30$ N. Let the initial conditions be $u=0$ at 0 degrees longitude and $\phi_S = 10$ N.

3. Magnitudes of surface heat fluxes. Assume the surface latent heat flux is $LHF=78$ W/m² and the surface sensible heat flux is $SHF=23$ W/m². Note that the heating rate $Q = C_p dT/dt$ and has units W/kg.

- a. (3 pts) Let the SHF heat a boundary layer that is 100 mb thick. Find how rapidly this layer is being heated, expressed in K/day. Hints: P is a force/unit area. Express the heating rate as W/kg then express that result as W/m³.
- b. (4 pts) Find the rate that the LHF is moistening a 1km deep boundary layer. Hint, your answer should be expressed as a local change of mixing ratio (w) where w has units g/kg. Also, let the latent heat of vaporization, $L = 2.4 \times 10^6$ J/kg. Assume that density is approximated by a scale height $H=8$ km as: $\rho(z) = 1.25 \exp(-z/H)$ kg/m³.
- c. (3 pts) Express the LHF in terms of an evaporation rate, E , where E has units of mm of liquid water per day.

NOTE: all homework is to be done by you as an INDIVIDUAL: no 'group' efforts, please. For written answers, please use a word processor, so that penmanship is not an issue. Equations and derivations can be *neatly* hand-written. Full credit requires proper units be included. Any plot must be completely and unambiguously labeled, including title and axes. Show ALL math steps.