1. **Wind-driven ocean circulation** *(8 points)*

The **Sverdrup transport** V for the depth-integrated flow is calculated by

$$\rho_0 \beta V = \frac{\partial}{\partial x}\tau_y - \frac{\partial}{\partial y}\tau_x \tag{1}$$

where τ_x and τ_y are the components of the wind stress.

The **Ekman transports** V_E, U_E describe the dynamics in the upper mixed layer:

$$fV_E = -\tau_x/\rho_0 \qquad , \qquad fU_E = \tau_y/\rho_0 \tag{2}$$

where $U_E = \int_{-E}^{0} u dz$ and $V_E = \int_{-E}^{0} v dz$ are the depth-integrated velocities in the thin friction-dominated Ekman layer at the sea surface.

Ekman vertical velocity w_E: Using the continuity equation, the divergence of the Ekman transports leads to a vertical velocity w_E at the bottom of the Ekman layer:

$$w_E = -\int_{-E}^{0} \frac{\partial w}{\partial z} dz = \frac{\partial}{\partial x} U_E + \frac{\partial}{\partial y} V_E = \frac{\partial}{\partial x}\left(\frac{\tau_y}{\rho_0\, f}\right) - \frac{\partial}{\partial y}\left(\frac{\tau_x}{\rho_0\, f}\right) \quad . \tag{3}$$

a) Assume that the windstress is only zonal with

$$\tau_x = -\tau_0 \cos(\pi y/B) \qquad \text{for an ocean basin with } \; 0 < x < L, \; 0 < y < B. \tag{4}$$

Calculate the Sverdrup transport, Ekman transports, and Ekman pumping velocity for this special case.

b) Make a schematic diagram of the windstress, Sverdrup transport, Ekman transports, and Ekman pumping velocity.

c) Using a), at what latitudes y are $|V|$ and $|V_E|$ maximum? Calculate their magnitudes. Take constant $f = 10^{-4}$ s^{-1} and $\beta = 1.8 \cdot 10^{-11}$ m^{-1}s^{-1} and $B = 5000$ km, $\tau_0/\rho_0 = 10^{-4}$ m^{2}s^{-2}.

d) Using the values in b), calculate the maximum of w_E for constant f.

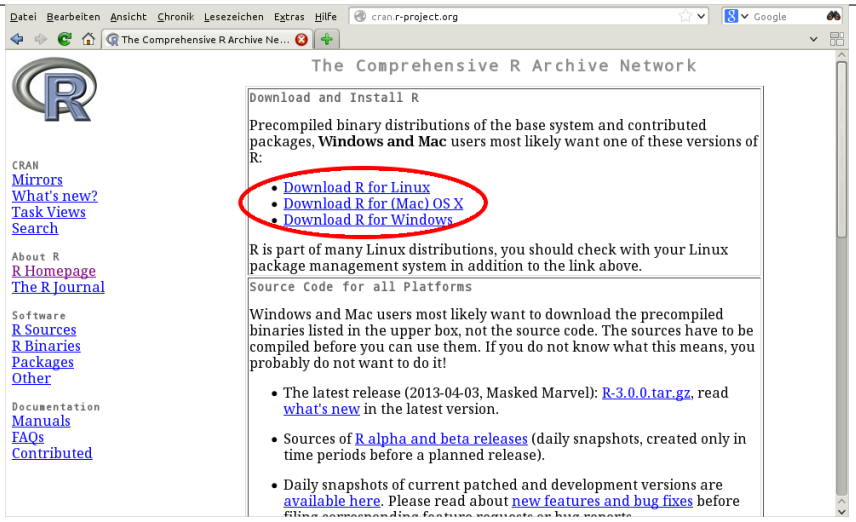

Figure 1: R is available for download from the CRAN webpage: http://cran.r-project.org.

2. **Download and install the R version** for your operating system (for many linux distributions R is also available in the package management system). Furthermore, look at the web page for R studio http://www.rstudio.com/, R studio is a free and open source user interface for R. One particular package is Shiny. This makes it super simple for R users like you to turn analyses into interactive web applications that anyone can use. The latest version of R for Linux, OS X and Windows is freely available on the CRAN webpage: http://cran.r-project.org (Fig. 1).

3. **Short programming questions.** *(4 points)*

   Write down the output for the following R-commands:

   a) `a<-c(0,-5,4,20); mean(a)`

   b) `max(a)-min(a)`

   c) `a*2+c(3,1,-1,0)`

   d) Plot the potential

   ```
   y=-100:100
   x=y/50
   r=1
   z=-r * x^2/2 + r  * x^3/3
   plot(x,z,type='l')
   ```

   and the derivative of z(x)

Notes on submission form of the exercises: *Working in study groups is encouraged, but each student is responsible for his/her own solution. The answers to the questions can be send until the due date (12:00) to Fernanda Matos (Fernanda.Matos@awi.de), Ahmadreza Masoum (Ahmadreza.Masoum@awi.de).*