General circulation of the atmosphere

Assignment 2

Due date: Friday 24 May 2024 (30 marks total)

In this assignment, you will examine the general circulation of the atmosphere using the NCEP/DOE reanalysis (Kanamitsu et al., 2002). This will involve using some computational software to read data from a NetCDF file, calculating various statistics, and constructing plots of the results.

You may use any language/software you like, but I will provide example scripts written in MATLAB and Python to get you started, and I can help you with these languages. MATLAB is available free to students at both Monash University and the University of Melbourne, and it has in-built NetCDF support. You must install external libraries to use NetCDF with Python, and this may not be straightforward if you have never used Python before.

Follow the steps below to complete the assignment. Hand in the plots that you make and any associated explanations. Remember to ensure that the plots can be understood by someone who has not seen the assignment; label all axes, include units and legends, and properly caption the figures.

1. Download the dataset "NCEP2_time_mean.nc" from the course website here: http://singh.sci.monash.edu/GenCirc/data/NCEP2_time_mean.nc.

This dataset was constructed based on the NCEP-DOE reanalysis, and the file above contains time-means of thermodynamic and dynamic variables for all seasons for the years 2008-2017. NetCDF datasets are "self-describing" so you can see information about each variable, including its units, by examining the variable attributes within the file itself. This may be done using MATLAB (see the example script) or using a program such as "NCview".

2. Create contour plots of the following variables:
    a. the zonal-mean temperature as a function of latitude and pressure,
    b. the zonal-mean zonal wind as a function of latitude and pressure,
    c. the zonal-mean potential temperature as a function of latitude and pressure.

Ensure your plots have correct axis labels, units, and captions.

(7 marks)

3. Create a line plot of the zonal-mean 10 m zonal wind as a function of latitude.

(2 marks)

The meridional flux of relative angular momentum by the atmosphere may be written,

$$F_M = R_e \cos\phi \, uv$$

Taking the zonal and temporal mean, this flux can be divided into components associated with the mean winds, stationary eddies, and transient eddies,

$$[\overline{F_M}] = R_e \cos\phi \{[\bar{u}][\bar{v}] + [\bar{u}^*\bar{v}^*] + [\overline{u'v'}]\}.$$

4. Calculate each component of this flux and create a contour plot of each of them as a function of latitude and pressure. *Hint: the data file you are given includes $\overline{uv}$ as one of the variables. Using this, and the time-mean winds ($\bar{u}$ and $\bar{v}$) you can calculate the stationary and transient eddy components.*

(5 marks)

In the class notes, we showed that, in steady state, the momentum flux divergence at a given latitude is balanced by drag on the atmosphere by the Earth. If we neglect form drag, Eq. (5.33) of the notes gives,

$$\frac{1}{R_e \cos\phi} \frac{\partial}{\partial\phi} \left\{ \int_0^{p_s} [\overline{F_M}] \cos\phi \frac{dp}{g} \right\} = R_e \cos\phi\, [\overline{P_s}], \quad (1)$$

where $[\overline{P_s}]$ is the zonal mean surface stress. Assuming that the frictional force on the winds is of the form of a linear drag and that it acts over a boundary layer of pressure thickness Δp_{BL}, we may approximate the zonal-mean stress at the surface as,

$$[\overline{P_s}] = -\frac{1}{\tau_F} [\overline{u_{BL}}] \frac{\Delta p_{BL}}{g}, \quad (2)$$

where u_{BL} is the zonal wind in the boundary layer, and τ_F is the frictional damping timescale. Combining (1) and (2), we may write down an approximate momentum balance of the column as,

$$-\frac{1}{R_e^2 \cos^2\phi} \frac{\partial}{\partial\phi} \left\{ \int_0^{p_s} [\overline{F_M}] \cos\phi \frac{dp}{g} \right\} = \frac{1}{\tau_F} [\overline{u_{BL}}] \frac{\Delta p_{BL}}{g}. \quad (3)$$

5. Calculate an estimate of the left-hand side of (3) from the NCEP data and plot it as a function of latitude. You will need to numerically evaluate the vertical integral and meridional derivative to do this.

(6 marks)

6. On the same graph, plot an estimate of the right-hand side of (3). You may assume the winds at 10 m are representative of u_{BL} and that the boundary layer depth is 50 hPa. Choose a value of τ_F that provides an overall good match between the left and right-hand sides of the equation. What value does this correspond to? Is this a reasonable frictional timescale?

(4 marks)

7. Discuss in a paragraph some of the reasons (practical, numerical, and theoretical) that your estimate of the two sides of (3) do not exactly match. Are there regions in which the agreement is better than others? Speculate as to why this is.

(6 marks)

References:
Kanamitsu, M.; Ebisuzaki, W.; Woollen, J.; Yang, S.; Hnilo, J.; Fiorino, M. & Potter, G. NCEP-DOE AMIP Reanalysis (R-2), *Bull. Amer. Meteor. Soc*, **2002**, *83*, 1631-1643.
(original dataset available for download here:
https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis2.html).