MAE578 Term Paper, Update #2 (Theme 2 released)

Theme 2: Geostrophic and thermal wind balance: Theory and observation

The second half of our course will focus on the dynamics of large-scale fluid flows under the influence of Earth's rotation (Coriolis effect). Analyzing the governing equation of fluid motion in a rotating frame, in Chapter 7 we find that large-scale flows approximately follow the so-called "geostrophic balance" (Eq. 7-3, 7-4, or 7-8 in M&P textbook) that connects velocity to pressure (or height), or the "thermal wind balance" (Eq. 7-18 or 7-24) that connects velocity to temperature. Using these balance relations, one would be able to deduce the velocity field from temperature or pressure/height field, and vice versa. For instance, using the geostrophic approximation, one can use the pressure or height field in a "weather map" to visualize the anticipated flow pattern (i.e., velocity field). Given the importance of these balance relations, the purpose of this project is to analyze observational data to determine how accurately these relations hold for the real atmosphere. In the final report, it is mandatory that you *quantify* the error incurred by the geostrophic and thermal wind approximation as a function of latitude (tropics vs. mid- and high latitudes), height (near surface vs. upper troposphere), and the spatial (horizontal) and temporal scales of atmospheric motion.

For example, in *p*-coordinate, the thermal wind relation can be expressed as (cf. Eq. 7-24)

$$\frac{\partial \boldsymbol{v}}{\partial \ln(p)} \approx -\frac{R}{f}\boldsymbol{k}\times\nabla T \quad .$$

For our purpose, we can re-cast the relation as

$$\frac{\partial \boldsymbol{v}}{\partial \ln(p)} = -\frac{R}{f}\boldsymbol{k}\times\nabla T + Residue \quad .$$

Your goal is to quantify how big the residue is, for instance in terms of percentage of either of the two major terms in the balance relation. Please also do the same for the geostrophic approximation.

For the "observational data" we may use the NCEP or ECMWF (ERA) "reanalysis". They have a global coverage and a 6-hourly temporal resolution. (The raw meteorological observations are spatially and temporally inhomogeneous. They have been interpolated and quality-checked in the construction of the re-analysis data sets.) For most of our purposes, an analysis of the monthly mean data (readily available from the online data portal, see below) might be useful enough, although you are still encouraged to look at the daily data to explore the dependence of the errors on the temporal scale of atmospheric motion. Beware that the reanalysis data is archived in pressure coordinate. All relevant formulas have to be written in pressure coordinate before they are used for the calculations. (Alternatively, you can use the formulas in z-coordinate but transform all of the observational data also to z-coordinate.)

Unlike Theme 1, the major ingredient of the final report for this project should be the quantitative calculations, presented in figures and tables. The methodology and the formulas you use for the calculations should also be described. Computer codes, if any, can be included in an appendix. Please be specific about how the calculations are done. For example, if you construct your figures by

analyzing the NCEP reanalysis monthly-mean data for the 500 mb level from January 2005, please say so. In addition to the main calculations, a discussion (~ 3-4 pages) on how the errors vary with latitude, height, and spatial/temporal scales is also essential.

Some background for the data can be found in

Kalnay, E., et al., 1996: The NCEP/NCAR reanalysis project, *Bulletin of the American Meteorological Society*, **77**, 437-470

Uppala et al., 2005: The ERA-40 re-analysis, *Quarterly Journal of the Royal Meteorological Society*, **131**, 2961-3012

The relevant data are archived at several websites with public access. For example:

www.esrl.noaa.gov (NOAA Earth Systems Research Lab)
Data Access & Plotting
Reanalysis Datasets
Climate Research Data
Interactive Plotting & Analysis

This website is very user-friendly. It allows users to assemble their own composite of a specific field for a given time period and/or for selected vertical (pressure) levels. The data are archived in pressure coordinate. One can choose to make a plot or download the data. A short tutorial will be given in class. Those who choose to write the term paper on this subject may also contact the instructor (use office hours) for further technical assistance. Another useful website is

iridl.ldeo.columbia.edu (IRI/LDEO Climaet Data Library, Columbia University).

This is the web site used by the authors of our textbook to produce the figures for the observed climate. It is less user-friendly but has more tools for performing basic mathematical operations on the data.

Important: When processing the observational data, you might encounter various technical problems such as those related to data format and the input/out interface for Matlab (or Fortran, C, etc.) Each of them will take time to resolve. This is not a trivial task. **Please start as early as possible and talk to the instructor for technical assistance if needed.** We have plenty of office hours to work on it. If you cannot make it to Tuesday's office hours, email the instructor to make appointments.