MAE 578 Term Paper, Update #3 (Theme 3 released)

Theme 3: A simple model for numerical weather prediction

Background

The daily weather predictions we see on TV or read in newspapers are actually based on detailed computer model forecast provided by National Weather Service/National Centers for Environmental Prediction (NWS/NCEP) under National Oceanic and Atmospheric Administration (NOAA). Weather bureaus in other countries around the world also produce their routine numerical weather prediction (NWP). The governing equations used in those NWP models are none other than Navier-Stokes equations (including thermodynamic and continuity equations, etc.) in rotating frame, although they are heavily "parameterized" to accommodate detailed physical processes (e.g., formation of cloud) that cannot be resolved by a fluid dynamical model of moderate spatial resolution. State-of-the-art NWP models retain most terms in the Navier Stokes equations, including non-hydrostatic effects for vertical motion. It also includes equations for water vapor that account for phase change, thereby allowing the prediction of rainfall and snowfall, and so on. An NWP model wasn't always so complicated. When the idea of NWP was first put to test more than a half century ago, very simple dynamical equations were used. The first of such attempts was made by Charney et al. (1950), using a one-level (at 500 mb), barotropic vorticity equation,

$$\frac{d(\zeta + f)}{dt} = -(\zeta + f)D \quad ,$$

where ζ and D are the vorticity and divergence of the horizontal velocity field (cf. HW5 Prob 4 and HW7 Prob 4) and f is Coriolis parameter. This is the equation in our HW7 Prob 4, except that in order to perform numerical integration in time it has to be recast in its Eulerian form; See the key equation, Eq. (5), in Charney et al. (1950). The numerical procedure for the time integration and the set up of boundary and initial conditions are detailed in that paper. To make a 24-hour forecast for North America, Charney et al. had to use one of the biggest computers of the day, ENIAC. Computer technology has advanced so much that the forecast of Charney et al. was recently reenacted by Lynch and Lynch (2008) by re-coding the computer program in Java and running it on a NOKIA cell phone! The following are the key references:

Charney, J. G., R. Fjørtoft, and J. von Neuman, 1950: Numerical integration of the barotropic vorticity equation, *Tellus*, **2**, 237-254

Lynch, P., and O. Lynch, 2008: Forecast by PHONIAC, *Weather*, **63**, 324-326

The project

The main task of this project is to reenact the short-term fluid dynamical prediction of atmospheric circulation at 500 mb for the date(s) in January, 1949, as chosen by Charney et al. (1950). All useful details are in that classic paper. The initial condition(s) - the velocity and/or

geopotential height fields at 500 mb - that are needed to make the forecast are available from the NCEP Reanalysis data set (see note for Theme 2) or, alternatively, from a new data set produced by the 20th Century Reanalysis Project,

http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.html .

The background for this data set can be found in

Compo, G. P., J.S. Whitaker, and P.D. Sardeshmukh, 2006: Feasibility of a 100 year reanalysis using only surface pressure data. *Bulletin of the American Meteorological Society*, **87**, 175-190 .

While the "prediction" made by Charney et al. looks rather crude by today's standard, it did capture a few salient features of the evolution of the 500-mb flow field over a 24-hour period. This is an indication that the equation of absolute vorticity represents not a small part of the dynamics of large-scale circulation at the 500-mb level. (The importance of vorticity dynamics is related to the basic properties of large-scale flows under the influence of stable stratification and planetary rotation. A further improvement would be to upgrade absolute vorticity to "potential vorticity", which we will discuss in class.) In addition to making the forecast, your final report should also include a brief historical survey of NWP and a discussion of the reasons why the equation of absolute vorticity was chosen to make the forecast. It is worth noting that in the 1920s L. F. Richardson had attempted to perform numerical weather prediction using the full set of Navier-Stokes equations but the numerical integration blew up. In the post WWII and pre-1970 era, returning to using simpler "balanced equations" such as the vorticity equation momentarily circumvented the numerical problem. These equations were however not accurate enough to make practically useful predictions. As noted earlier, modern NWP models have restored the full Navier-Stokes equation set.

Please include the key segments of your codes in the report. There is no restriction of the computer language/software to use for this project but a few potential choices are Matlab, Fortran, C, and Java. An example of making a contour plot using Matlab is posted at our course website.