MAE598 Fall 2012 HW4

The level of difficulty of this assignment is "**D**". Any useful answers (even partial answers) you provide will earn you bonuses for the semester. You have the option of expanding this assignment and use it as the final report. In that case, the discussion will have to be thorough.

Background: Hydrostatic vs. non-hydrostatic model

In our discussion on the governing equations used in numerical weather and climate prediction, it was noted that most (if not all) of the numerical models used in real applications today are either hydrostatic or fully non-hydrostatic. The latter allows acoustic waves in the system which significantly reduces the required time step size, Δt, for the numerical integration. This is one of the reasons that the "climate" models used for long-term integration are almost exclusively hydrostatic. (The NCAR global atmospheric model that we will use in class belongs to this class.) At the same time, many regional models for short-term weather prediction (e.g., the WRF model to be used in class) are moving towards fully non-hydrostatic.

The hydrostatic and fully non-hydrostatic versions of the "primitive equations" are at the two ends of the spectrum in terms of the level of complexity of the model. In the history of the development of atmospheric models, attempts have been made to find alternatives that are more complicated than the hydrostatic version (such that vertical acceleration is allowed - the vertical component of the momentum equation is prognostic instead of diagnostic) but still exclude sound waves. One of such systems is the *anelastic* equation set (Ogura and Phillips 1962). Your task in this assignment is to survey and explore the properties of this class of equations.

Main tasks

Read the original and review papers listed below on the anelastic and related approximations and perform a literature survey to find more articles on the subject. Read them, too. From the literature survey, answer the following questions:

(1) Describe the structure of the anelastic and related systems and discuss how they differ from the hydrostatic and fully non-hydrostatic systems. (Describe how the momentum, thermodynamic, and continuity equations in different systems differ from each other.)

(2) On what spatial and temporal scales is the anelastic approximation valid? What phenomena may be ideal to simulate using the anelastic equation set?

(3) In the derivation of the anelastic and related systems, what approximation(s) were made to filter out sound waves? Note that the generation of sound waves is related to the compressibility of the air, quantified by the change in perturbation density in response to the change in perturbation pressure, ($\partial\rho/\partial p$).

(4) Survey the literature to find examples (if any) of published results of numerical simulations that used the anelastic equation set. Why is the anelastic system not widely used in practice (compared to the hydrostaic and fully non-hydrostatic systems) for weather and climate simulations? For instance, is there any inherent difficulty for one to numerically implement the anelastic system for practical applications?

References

Do not restrict yourself to these 3 papers. They are merely the starting points of your literature survey.

Ogura, Y., and N. A. Phillips, 1962: Scale analysis of deep and shallow convection in the atmosphere, *J. Atmos. Sci*., **19**, 173-179

Lilly, D. K., 1996: A comparison of incompressible, anelastic, and Boussinesq dynamics, *Atmos. Res*., **40**, 143-151

Durran, D. R., and A. Arakawa, 2007: Generalizing the Boussinesq approximation to stratified compressible flow, *C. R. Mecanique*, **335**, 655-664