Physical Parameterization Development and Evaluation: Some Thoughts for RIME

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1. Introduction

Accurate numerical simulations of the atmospheric state, for both short-term weather forecasting or longer term climate studies, requires an accurate representation of all relevant physical processes occurring in the real atmosphere. These include processes that are either too complex or too small in scale to represent explicitly in numerical models, and thus need to be represented by physical parameterizations.

The physical parameterizations in use in the current generation of atmospheric models represent:

- Turbulence
- Cloud and precipitation microphysics
- Radiative transfer
- Moist convection
- Gravity wave drag (for lower resolution models).

A key question that needs to be answered with data from RIME is whether or not this list of parameterizations represents all of the important physical processes acting in the atmosphere. The current state of knowledge regarding atmospheric behavior leads us to believe that this list is complete, at least in terms of major physical processes, but that key elements of these processes are likely being neglected.

Some examples of processes that are being neglected in the current generation of atmospheric physical parameterizations, but that may be important include:

- heterogeneity on sub-grid scales
- role of small scale gravity waves on fluxes in the boundary layer and free atmosphere
- stable boundary layer processes such as intermittent turbulence

A combination of parameterization evaluation, using detailed observations, and analysis of process oriented observations will allow us to determine what processes are being neglected in the current generation of parameterizations.

Based on this analysis the existing parameterizations can be modified or new parameterizations can be developed that more accurately represent the key physical processes acting in the Antarctic atmosphere. These improvements will then allow for more accurate numerical simulations of the Antarctic atmospheric state for both short term weather forecasting and longer term climate simulations.

2. Parameterization Evaluation

In order to evaluate parameterizations, it is necessary to address the following questions:

- Do the observations match our understanding of the key processes acting in the atmosphere?
- Does the current generation of atmospheric physical parameterizations accurately reproduce the observed atmospheric state?
- Do the parameterizations accurately reproduce the observed atmospheric processes and feedbacks leading to the observed state?
- If not, are there important physical processes that are not included in the parameterizations?

Any evaluation of model parameterizations requires measurements from a carefully constructed observational program. The physical parameterizations used in numerical weather prediction models can be evaluated, given appropriate observations, using a combination of the following tests:

- Off-line parameterization tests
- Single column model tests
- Full (3d) model tests.

Each of these tests will be described in more detail below.

a. Off-line parameterization tests

In off-line parameterization tests a given parameterization is evaluated in a stand alone mode. The parameterization is forced with observed quantities, rather than model data as would be the case for online testing, and the output from the parameterization is then compared...
to observations of the variable(s) being diagnosed by the parameterization. As an example, off-line testing of a surface layer parameterization would require the parameterization to be forced with observations of the wind, temperature, humidity, and surface characteristics. With this forcing the parameterization will provide diagnosed surface fluxes of heat, momentum, etc. These parameterized fluxes can then be compared to directly observed fluxes, and any errors in the parameterization can be identified.

The primary advantage of off-line testing is the uncomplicated nature of the evaluation. Given adequate input data for the parameterization, any errors that are identified in an off-line test are caused by the parameterization being evaluated. Careful analysis of the errors can serve to highlight processes that are being neglected by the parameterization. The primary disadvantage of this type of evaluation is that it neglects feedback processes between the parameterization and the other model components. Also, this type of analysis cannot identify errors in the parameterized quantities caused by biases in other model components, and is difficult to apply to parameterizations that represent quantities that evolve in time (such as boundary layer depth or cloud properties).

Some off-line parameterization tests have already been conducted using data from the polar regions. Cassano et al. (2001) used surface layer measurements from Halley, Antarctica to evaluate a number of surface layer parameterizations from mesoscale and global numerical models. The results of this evaluation indicated that under statically stable conditions all of the parameterizations that were evaluated underestimated the magnitude of the turbulent fluxes. The source of this bias was thought to be due to the effects of gravity waves acting in the stable boundary layer, but the available observations were not sufficient to identify the source of the bias.

Another off-line surface layer parameterization test [the Surface Layer Model Intercomparison Project (SLMIP)] is being conducted under the auspices of the Arctic Regional Climate Model Intercomparison Project using surface layer measurements from SHEBA. A website with information regarding this project can be found at http://cires.colorado.edu/arc sym/slimip.html.

A radiation model intercomparison project is also being conducted using observations from SHEBA. Information regarding this project is available on the internet at http://paos.colorado.edu/~curryja/wg5/pintodata/rad_intcmp/. Some preliminary results from this intercomparison indicate the important role that atmospheric aerosols play in determining the surface radiation budget, and the need to account for this in radiation parameterizations.

b. Single column model tests

Single column model (SCM) tests use a single, vertical, column from an atmospheric model. The model physical parameterizations are allowed to act in this column, but all dynamical terms are specified (as advective tendencies on the lateral boundaries and by the vertical velocity). This type of test allows for all of the model physical parameterizations to act as a coupled system, and thus avoids the problem of neglecting feedback processes between different model parameterizations as occurs in off-line parameterization tests. A second advantage of the SCM test is the ability to evaluate parameterizations which are time dependent (i.e. parameterizations that have a memory of the previously predicted atmospheric state).

The primary disadvantage of this type of test is the difficulty of providing high quality forcing data in the form of advective tendencies and vertical velocity. If SCM tests are to be conducted using data from RIME careful attention needs to be given to providing observations of a sufficient quality to force the SCM. Another disadvantage of this type of test is the increased difficulty of identifying the source of any errors since all of the model physical parameterizations act in a coupled manner.

c. Full (3d) model tests

In full model tests, the entire atmospheric model is run (rather than using either single parameterizations or only considering a single column from the model). This type of test is the end goal of any parameterization evaluation, since it allows for an evaluation of all parameterizations and their interaction with other model components. The primary problem with this type of evaluation is the difficulty of identifying the source of any errors, since any of the model components may be the source of the error. This problem can be minimized with the combined use of off-line and SCM tests. In addition simulations using various degrees of constraint (such as specified surface state) can help narrow the search for the source of a given error.

One particularly useful method for conducting full model tests is to compare a number of models in a model intercomparison project. By comparing a number of different models it is possible to
identify errors and biases that are present in all (or a subset of) the models. Errors that occur in only some of the models can be traced to differences in the model formulation of the physics and dynamics.

3. Observational Strategy

When designing an observational campaign that will be used to evaluate model parameterizations, a number of items should be considered. Some of these include:

- Spatial and temporal consistency between the observations and the parameterizations
- Insuring that the observations measure the same feature the parameterization is modeling
- Are the observational errors as large as the uncertainty in the parameterizations?
- Collection of a sufficiently large data set for a statistically significant evaluation of the parameterizations
- Insure that all of the forcing data required to drive the various parameterization tests are collected.

Of these items, the last is particularly important for SCM tests. Also, observations of quantities that are not often measured may be necessary, such as detailed aerosol observations to force radiation parameterizations.

Some of the variables that may need to be measured as a part of RIME (for parameterization evaluations) include:

- Turbulent fluxes
- Boundary layer depth
- Boundary layer mean profiles
- Turbulence kinetic energy
- Radiative fluxes
- Radiative heating rates
- Liquid and ice water content in clouds
- Cloud particle mixing ratio
- Cloud particle size distribution
- Cloud cover
- Aerosol characteristics
- Precipitation amount.

4. Conclusions

From a scientific perspective, parameterization evaluation allows us to determine if our understanding of atmospheric processes, as represented by the physical parameterizations, is complete. By carefully reviewing the results of detailed parameterization evaluation studies and analyzing the available observations, new parameterizations that better represent our understanding can be developed.

The key processes which should be addressed by the RIME project, as indicated by the poor evaluations of current parameterizations are the linked phenomena of clouds, boundary layer development, and surface state. The specific parameterized processes that should be evaluated during RIME are:

- Radiative properties and impacts of clouds
- Surface processes affecting the surface energy budget
- Turbulent and wave processes that link the atmosphere to the underlying surface
- Boundary layer development under statically stable conditions.

References