Single-Column Models as a Bridge Between Observations and Climate Models

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How Do We Test Parameterizations for GCMs?

Parameterizations for general circulation models (GCMs) can be tested through several methods. These methods and their major advantages and disadvantages are as follows:

- Climate simulation - compare the simulation with observations. Advantage: Tests the parameterization as it is intended to be used. Problems: Expensive. Results are big and complicated and depend on all aspects of the model.
- Weather prediction - compare the forecast with observations. Advantage: Allows detailed comparison with data. Problems: Expensive. Results are big and complicated and depend on all aspects of the model. Need elaborate data-ingest system.
- Semi-prognostic tests - force the parameterization with observations, outside the GCM, and compare the results with data. Advantages: Average tendencies can be crazy (or not). Results independent of the rest of the GCM. Problems: No feedbacks whatsoever. Challenging data requirements.
- Single-column models - force the parameterization with observations, outside the GCM, and compare the results with data. Advantages: Very inexpensive. Results independent of the rest of the GCM. Parameterization immediately transferable to full GCM. Problems: Limited feedbacks. Average tendencies have to be about right. Challenging data requirements.

Single-Column Model

A single-column model (SCM) is essentially a single-grid column of a GCM. A GCM can be considered to be a collection of many single-column models, arranged to cover the entire earth, and interacting with each other through a set of rules known as “large-scale dynamics.” When we run a single-column model, we have to tell the grid column what the other grid columns would be doing to it, if they were there. We use observations to specify what the other grid columns would be doing. Alternatively, we could force the SCM with suitable model output, or with idealized forcing designed to mimic a situation of interest, or we could just run it in “radiative-convective equilibrium mode.”

SCMs are very inexpensive and can run on a powerful PC or an ordinary workstation. They go like the wind on a Cray.

When an SCM is forced with observations, errors cannot be attributed to problems with the GCM that have nothing to do with the column physics being tested. Errors must be due to the column physics being tested, or to problems with the observations that are used as input.

Once a parameterization has passed its SCM tests, it can immediately be used in a true GCM; there is no need to “transfer” it.

SCM tests cannot detect problems with parameterizations that arise through feedbacks with the large-scale circulation.

A cloud ensemble model (CEM) is a model with sufficient resolution to resolve the structures of individual clouds (e.g., cumulus clouds), run over a spatial domain large enough to contain many clouds and for a time long enough to include many cloud life cycles. Most CEMs today are two-dimensional, but this will change soon. The domain of a CEM can be considered to represent a single-grid column of a GCM; in this way, a CEM is analogous to an SCM, but a CEM computes clouds and convection explicitly, whereas an SCM must parameterize them. A CEM computes some things that are very hard to observe, such as the three-dimensional distribution of liquid water and ice. It is important to remember that CEMs do contain parameterizations, notably microphysics parameterizations, which introduce major uncertainties. CEM results are not reality.

SCM and CEM Applications

Common applications of SCMs and CEMs are to

- Debug new parameterizations.
- Develop new parameterizations (Xu and Randall 1994).
- Test new parameterizations in a physical sense by forcing them with data (e.g., Fowler et al., accepted).
- Study radiative-convective equilibrium and similar idealized problems (e.g., Randall et al. 1994).
- Study particular physical processes in isolation, e.g., diurnal cycle of precipitation over the oceans (Randall et al. 1991).

Data Requirements

The data requirements for an SCM and a CEM are essentially the same. The data are listed below, by type.

Initial Conditions

- Surface pressure
- Temperature profile
- Water vapor mixing ratio profile
- Vertical distributions of cloud water and cloud ice
- Horizontal wind components (vertical profile needed, but especially PBL values)
- PBL depth (pressure units) and turbulence kinetic energy (not critical, but useful)
- Ground temperature and wetness
- Mass of snow and/or liquid (e.g., dew or rain) stored on vegetation or ground surface.

Boundary Conditions

- Solar constant
- Latitude, longitude, Julian day and GMT
- Surface characteristics (elevation, albedo, roughness, vegetation type, etc.)
- Large-scale divergence as a function of height
- Tendencies of temperature and moisture due to horizontal advection as a function of height
- Pressure gradient force (if winds are predicted) as a function of height.

Data for Model Evaluation

- All variables for which initial conditions are needed
- Cloud amount as a function of height
- Precipitation rate
- Surface fluxes of sensible heat, moisture, and momentum
- The same turbulent fluxes as functions of height
- Solar and infrared (broadband) radiation fluxes as functions of height, from the surface to the top of the atmosphere.

"Derived fields" such as large-scale vertical motion and advective tendencies are particularly difficult to determine because they involve horizontal derivatives of the main flow. Important sources of error include instrumental error, inadequate spatial coverage, and inadequate temporal coverage. Aliasing can result from inadequate coverage in either space or time.

What Do We Use Until Suitable ARM Data Become Available?

Lacking ARM data that are suitable for driving SCMs and CEMs, various investigators have been "practicing" with GATE data, forecast model products (ECMWF, NMC, FSL), and ASTEX data and the associated special ECMWF products. The various model products are not real data and are not fully satisfactory substitutes for real data, although they can be of some use.

Conclusions

Among the several approaches to testing GCM parameterizations by comparison with observations, single-column models have some unique advantages. Cloud ensemble models are a useful supplement to SCMs. They can be used in much the same way and have essentially the same data requirements.

The data required to drive the SCMs and CEMs, and to evaluate their performance, are not easy to obtain. ARM, and especially the ARM SGP site, and especially the ARM SGP site during IOPs, has the potential to provide uniquely valuable data for SCM-based parameterization testing. Use of ARM data in SCMs and CEMs will be particularly valuable for testing cloud amount parameterizations.

References

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