Integrated Cumulus Ensemble and Turbulence (ICET): An Integrated Parameterization System for General Circulation Models (GCMs)

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Project Statement

Successful simulations of the global circulation and climate require accurate representation of the properties of shallow and deep convective clouds, stable-layer clouds, and the interactions between various cloud types, the boundary layer, and the radiative fluxes. Each of these phenomena plays an important role in the global energy balance, and each must be parameterized in a global climate model. These processes are highly interactive.

One major problem limiting the accuracy of parameterizations of clouds and other processes in general circulation models (GCMs) is that most of the parameterization packages are not linked with a common physical basis. Further, these schemes have not, in general, been rigorously verified against observations adequate to the task of resolving subgrid-scale effects.

To address these problems, we are designing a new Integrated Cumulus Ensemble and Turbulence (ICET) parameterization scheme, installing it in a climate model (CCM2), and evaluating the performance of the new scheme using data from the Atmospheric Radiation Measurement (ARM) Program Cloud and Radiation Testbed (CART) sites.

Objectives

1. Development of an Integrated Cumulus Ensemble and Turbulence model for global models: ICET

2. Analysis of data from the ARM Southern Great Plains (SGP) site to provide driving terms and validation for the ICET scheme.

3. Concomitant analysis of data from the Tropical Western Pacific (TWP) site to provide driving terms and validation in a tropical regime.

ICET Design

Overview

The cumulus parameterization consists of a cloud ensemble model that represents the lifecycles of cumulus clouds, coupled to a level 2.5 turbulence scheme. The cumulus cloud ensemble model is initialized with information from the turbulence scheme when conditions at any vertical level are sufficiently unstable to produce buoyant, saturated vertical drafts. These cumulus ensembles simulate flues of quantities resulting from eddies that penetrate vertical distances greater than one model level.

In ICET, the closure is specified in terms of the cloud ensemble mass flux at cloud base. The assumption here is that the cloud ensemble will maintain an equilibrium of the stability of the layers immediately above cloud base. Increasing the cloud base mass flux warms and stabilizes this air, inhibiting further convection, while grid-scale uplift, radiative cooling, and other large-scale processes tend to cool and destabilize air in this layer. Coupling the cumulus parameterization directly to the turbulence scheme provides a mechanism for linking the host climate model's boundary layer parameterization, shallow and deep convection, and diffusion into a single, physically consistent package. Finally, the ICET package is fully interactive with the stable cloud parameterization and provides important information to the radiative transfer parameterization. A schematic of ICET is shown in Figure 1. CCM2 is available in single column or fully three-dimensional time dependent forms. Implementation and testing of the new ICET parameterization package in both configurations of CCM2 is one goal of the work here. The Pennsylvania State University Department of

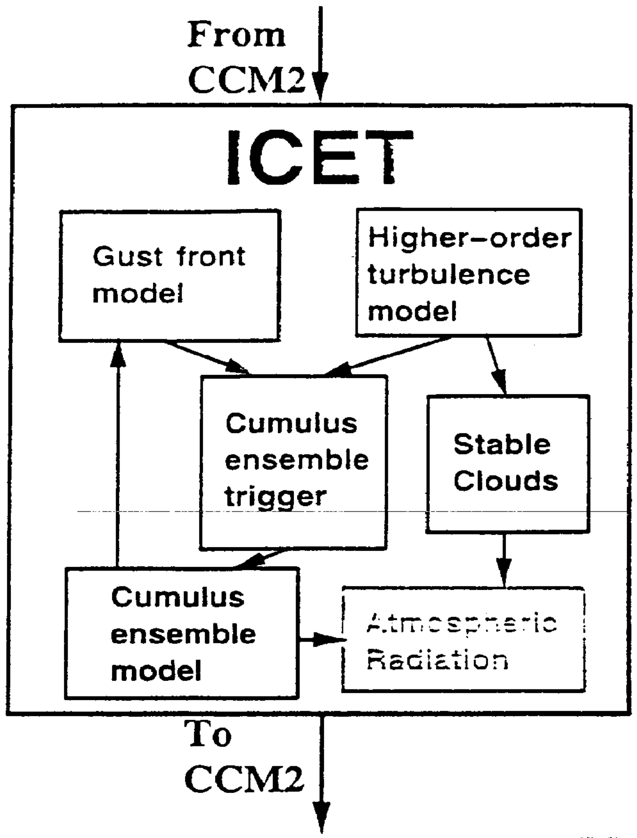

Figure 1. Schematic of the interactions of the ICET parameterization package. Gridscale variables (such as winds, temperature, moisture and surface fluxes) are fed in from the host model (CCM2). Arrows within the ICET box indicate forcings and feedback relationships contained within ICET. The resultant gridscale forcing effects due to subgrid-scale processes are fed back from ICET to CCM2.

Meteorology has been chosen as a β-test site for the CCM2 single column model. To this end, CCM2 is currently installed on the Department's Sun workstation network.

Gust Front Model

Convection is extremely sensitive to variations in boundary layer structure on scales smaller than those resolved by GCMs. From a cumulus parameterization standpoint, the two most important resolution problems are

1. Convection is typically fed by the undisturbed, unstable air that exists outside the disturbed (cooled by downdrafts) regions of the boundary layer. The GCM cannot resolve the disturbed and undisturbed regions and so it mixes them to single values of temperature and moisture in the grid column and, hence, tends to stabilize convectively active regions prematurely.
2. Once deep convection becomes organized, it provides forced uplift of unstable air to depths determined in large part by the depth of the downdraft gust fronts. This has a major effect on the parameterization trigger functions.

To address these two problems, we have designed an embedded gust front model that partitions the GCM boundary layer into disturbed and undisturbed regions. The spreading of cold downdraft air and wake recovery due to enhanced surface flues are accounted for in this simple model. This model also provides estimates (distance and vertical velocity) of the lifting of boundary layer air by the moving gust fronts. A schematic of the gust front model is shown in Figure 2.

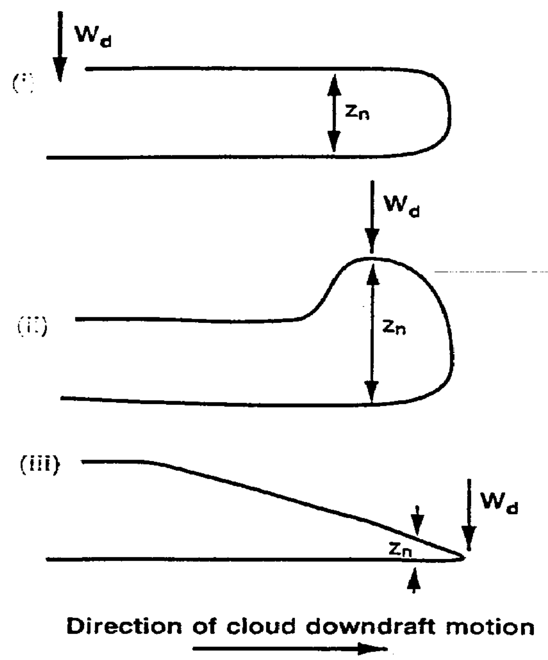

Figure 2. Schematic of gust front structure dependence on storm (downdraft) speed: (i) gust front speed (i.e., the density current) > twice the storm speed; (ii) gust front speed = twice storm speed; (iii) gust front speed < twice storm speed.

ICET Model Testing

Since the ICET parameterization is to be used in a global model, it must be validated over a variety of atmospheric regimes. The ARM testbed sites are ideal sources of data for this validation process. Currently, data from the ARM SGP site are being analysed to provide forcing and validation fields for the ICET modeling system (see the companion poster of Flatley and Mace).

Immediately after the data become available, similar analyses are planned on the data from the ARM TWP site. The inclusion of an extra tropical site in a regime with less frequent deep convective activity would provide an additional very useful control for validation of the cumulus ensemble in the tropics. Data from these two ARM sites are being (or will be) used to run the ICETsystem within the single column version of CCM2 and, later, within the three-dimensional CCM2 global model.

Future Work

Testing of the parameterized gust front is almost completed. The next phase of this research is to couple this gust front model to the ensemble cloud model. Once we are satisfied that this gust front model provides a sensible forcing for the ensemble cloud model, the full system will be assembled by coupling to the higher order turbulence scheme and feeding the relevant inputs to both the stable cloud and atmospheric radiation schemes.