Cloud tracking in cloud-resolving models

Article

Accepted Version

Cloud Tracking in Cloud-Resolving Models

R. S. Plant[1]
[1]*Department of Meteorology, University of Reading, Earley Gate, Reading, RG6 6BB, United Kingdom. r.s.plant@reading.ac.uk*
(Dated: May 2, 2007)

I. INTRODUCTION

In recent years Cloud Resolving Models (CRMs) have become an increasingly important tool for the study of convective phenomena. CRMs should not be regarded as simply providing surrogates for observations; rather, they allow idealized but realistic simulations to be produced which provide a laboratory for the careful diagnostic analysis of generic convective systems. Such analysis is a distinctive methodology that is necessary to improve our understanding of the basic phenomena and to develop improved parameterization methods for the larger-scale models.

We will describe a novel analysis technique for CRM data, which allows one to investigate statistical properties of the lifecycles of the "clouds" produced during CRM simulations.

II. MOTIVATION

Many of the existing analyses of CRM data have focussed on determining and understanding spatial and temporal average properties of the full ensemble of convective clouds that are generated in response to some specified forcing. Rather less attention has been devoted to the lifecycle behaviour of individual clouds. One exception is Zhao and Austin (2005). That study looked at six clouds. Thus, there are practical constraints on the number of individual clouds that can be investigated in detail, and this hampers our ability to understand the role of the individual clouds within the full convective ensemble.

The philosophy here is to collect statistical information about the lifecycle behaviour of individual clouds. Such information could allow simple, straightforward improvements to be made to existing convective parameterizations. As an example, first note that from the pioneering work of Arakawa and Schubert (1974), parameterizations have been developed which consider a spectrum of convective clouds. Indeed the author has recently developed a scheme (Plant and Craig, 2007) of this general type. Second, note that most parameterizations suffer from the defect that there is little or no concept of the cloud lifecycle. Convective clouds are usually assumed to persist for precisely one timestep of the large-scale model. An important feature of the popular Kain and Fritsch scheme (2004) is that a rudimentary lifecycle is obtained by giving the clouds a lifetime which extends over multiple timesteps. However, the Kain Fritsch scheme only admits a single cloud type. An improved parameterization could be constructed by simply combining these two features: multiple cloud types and a simple cloud lifecycle. However, no such schemes are available, essentially because there is no information currently available on how the cloud lifecycle varies with cloud type (and forcing regime).

Such information can be obtained by constructing automated procedures to first identify and then also to track the development of individual clouds. By isolating many distinct lifecycles, statistically-significant information can be gathered to build up a picture of cloud evolution and decay across the spectrum of convective clouds.

III. METHODOLOGY

Code which identifies and tracks individual clouds has been implemented within the Met. Office LEM. This has three main aspects:

1. identify clouds from CRM results at a given timestep

2. identify the relationships between clouds present at the current timestep and those present at the previous ones (i.e., establish the continuations, the births, the deaths, the splits and the mergers)

3. store data about each cloud as a time history that is output on the death of the cloud.

The code tracks the complete time evolution of the clouds. A variety of identification criteria have been proposed in the literature and are straightforwardly implemented. These are based on connected sets of gridpoints satisfying some criteria (e.g., $w > 1\mathrm{ms}^{-1}$). Thus, the focus could be on all cloudy air, or just on the up- or down-draughts.

The tracking methodology was developed and extensively tested and validated independently of the CRM in a purely artificial system (using a modified game-of-life algorithm). Clouds are tracked on a timestep-by-timestep basis, allowing a simple but robust methodology to be applied for step 2. Since the model timestep satisfies the CFL condition, it follows that a cloud at one timestep must be in the same location, or at an adjacent point, at the next timestep. The number of links between clouds at one timestep and the next then reveals the evolution of each cloud, whether that be a birth or death (0 links), a direct continuation (1 link, and by far the most

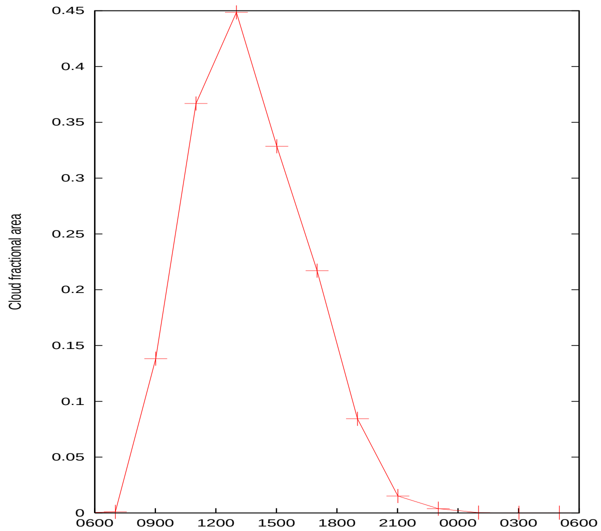

FIG. 1: Fraction of the CRM domain covered by cloud, as a function of the time of day. The points represent time-means over 2h centered around the time marked.

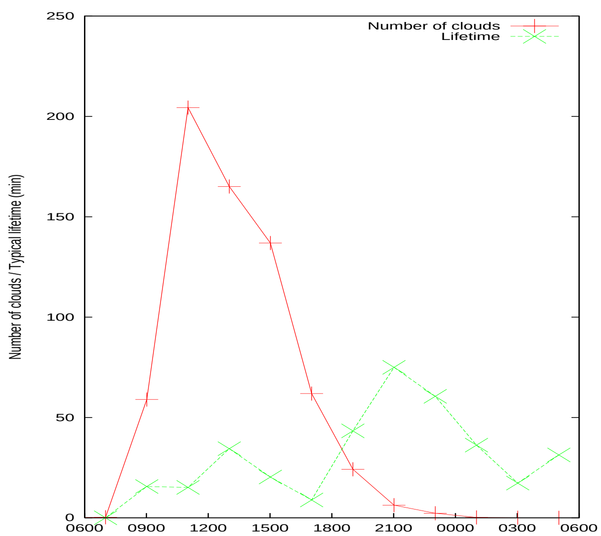

FIG. 2: Number of clouds (red) in the CRM domain and average lifetime of those clouds (green), as a function of the time of day. The points represent time-means over 2h centered around the time marked.

common possibility) or a split or merger (>1 link). Different options have been implemented and investigated for assigning lifecycle properties (e.g., lifetimes) to clouds that have undergone splits and mergers.

IV. PRELIMINARY RESULTS

Results will be presented at the conference. In Figs. 1 and 2 we show some preliminary results in order to illustrate some of the information that is produced.

These example results are from a high-resolution (250m) 2D simulation of the idealized diurnal cycle over land. 2048 horizontal grid points were used. For the purpose of these plots, "cloudy" points were defined as the significant updraughts: specifically, points with $w > 1\mathrm{ms}^{-1}$. Fig. 1 is the fractional area of the domain covered by cloud, which is strongly peaked around the early afternoon. Fig. 2 shows the number of clouds in the domain and their average lifetimes. During the morning, the average updraught size is around 4 gridpoints and the average lifetime 10 or 15 minutes. Updraughts become larger during the afternoon, occupying 5 or 6 gridpoints on the average, while the lifetime peaks at around 30 minutes in the early afternoon. During the early evening and at night there are just a few small updraughts, but those which do occur appear to be rather persistent.

The progression from small, short-lived to larger, longer-lived updraughts as convection develops over the day is hardly a surprise, and similar conclusions could no doubt be drawn from careful visual inspections of the raw CRM data. However, one of the uses of this cloud-tracking methodology is that it allows such statements to be made quantitative.

V. REFERENCES

Arakawa, A., Schubert, W. H., 1974: Interaction of a Cumulus Cloud Ensemble with the Large-Scale Environment. Part I. *J. Atmos. Sci.*, 31, 674-701.

Kain, J. S., 2004: The Kain–Fritsch Convective Parameterization: An Update. *J. Appl. Meteorol.*, 43, 170-181.

Plant, R. S., Craig, G. C., 2007: A Stochastic Parameterization for Deep Convection Based on Equilibrium Statistics. Submitted to: *J. Atmos. Sci.*

Zhao M., Austin P. H., 2005: Life Cycle of Numerically Simulated Shallow Cumulus Clouds. Part I: Transport. *J. Atmos. Sci.*, 62, 1269-1290.