CLOUD PARAMETERIZATION FOR MEDIUM RANGE FORECASTING MODELS

Garth W. Paltridge
CSIRO, Mordialloc, Victoria, Australia

1. INTRODUCTION

This talk is divided into three very unequal parts. The first concerns the basic question as to whether clouds are necessary in the sort of medium-range forecasting models you people play with, and how one might go about answering that question. The second concerns the radiative calculations themselves once your models have generated their cloud. The third makes a couple of suggestions for new ways of "parameterizing the generation" of planetary-boundary-layer and of cirrus-cloud ways which get away from this strange business of switching cloud on and off depending on nothing other than relative humidity.

2. ARE CLOUDS NECESSARY?

The first point to make is that in climate models certainly, and I suspect in your models as well, it is not known whether clouds are necessary to get the "right" answer. Furthermore, things are moving so fast in the numerical modelling world that it is likely we never will know if clouds are important, unless very shortly someone calls a halt and says "stop - let us go back a bit and do the thing properly".

One aspect of the problem is as follows: Imagine (see Fig. 1) a model simulating some real path of the system from A to B over a time period (bearing in mind the present company) of about a week. If the model is actually full of propagating errors, it will perhaps go from A to C where C is some situation bearing no relation whatsoever to that of B. The model is therefore wrong. It is not "half-right", "in reasonable agreement" or "not bad considering". Its macroscopic response is wrong. Thus if one now modifies the model by adding another process such as cloud generation which makes the model finish up at C' instead of C, the apparent improvement is no proof that clouds are important in the real system or in the simulation process of an otherwise good model. All it says is that clouds are important to a model which is wrong.

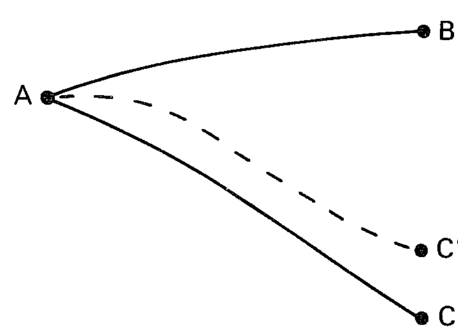

Fig. 1

It is possible that, if one follows the course indicated by macroscopic improvement in a model which is wrong, one can set a field back by decades.

Note that at this stage the concern has not been with the merits of one particular cloud parameterization over another, but simply whether clouds are necessary at all. In any event, the obvious question is whether, given the tool of a lousy model full of propagating errors, one can ever prove anything about the significance of clouds. I suspect the answer is no if one insists on absolute proof, but presumably a somewhat better job can be done by forcing the model to be correct at every time step in all aspects other than clouds. That is, force the model by reference to observation back to the line AB at each time step, and at each time step try the model with and without clouds.

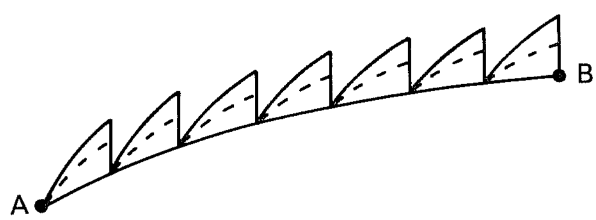

Fig. 2

There is probably a more elegant way of looking at this, but intuitively it seems that the differential response when the model is close to where it should be will be a better measure than the macroscopic response when the model is not even vaguely a good simulation of the actual situation.

(Incidentally, I realise the practical difficulties of this "differential" method - difficulties of data assimilation, etc. Fortunately that is not my problem.)

3. TO WHAT DEGREE ARE CLOUDS NECESSARY

It seems to me that these days people are so proud of having models which generate their own cloud that they (the people) are not overly concerned as to whether the generation process is realistic or not. To be fair, there is not much information around to check the clouds that the models produce, and so the only verification that is done is a sort of qualitative assessment as to whether the long-term average global distribution of total cloud amount "looks" right. As it happens, and saying nothing about all the other significant characteristics of clouds such as their optical thickness, height and etc., even the long-term average cloud amounts generated by GCM's do not look very "right" to me.

Thus we come to basic question number 2: How can it be established how good a cloud parameterization has to be before it is better than none at all. It is certainly not likely to be the case that the accuracy requirement will be the same for all clouds - it will presumably depend (for instance) on where the clouds are relative to particular synoptic systems.

I am not sure how this question will be answered, but I can say how it will not be answered - namely by putting a complete cloud generation scheme in a global model and seeing the overall effect. This would be equivalent to a sensitive experiment in which a large number of knobs (as opposed to a single knob) are twiddled at once.

The start to answering the question is obvious enough - it will require two basic steps.

1) Development of (calculation of ?) a table of the sensitivity of the atmospheric columnar heating or cooling to all changes of cloud character - that is, to cloud amount, cloud height, cloud albedo, cloud emissivity, cloud layer overlap etc., etc. Note that for the ECMWF concern (i.e. for forecast time scales of a week or two) it seems to me that the actual columnar heating will be more important than the total planetary heating. Apart from other considerations, the SST (sea surface temperatures) of ECMWF models is fixed, so the variability of radiative heating in the atmosphere (as opposed to the ground) will be the most important factor.

2) Having established the likely heatings and coolings due to cloud, one must then look at the effect on the model of such heatings or coolings when they are inserted one at a time in specific positions relative to particular synoptic situations. Again I am glad that the practical method of doing this process is not my concern.

While on this general subject, there are various figures floating around which give the accuracy requirements of (say) predicted cloud height in climate models. The figures are generally arrived at by "back of the envelope" calculations on the basis of steady-state energy balance models, and the implication is that instantaneous values of cloud height or whatever at a particular grid point need not be very accurate at all. This concept could be (repeat could be) nonsense.

Certain synoptic systems may be extremely sensitive to heatings and coolings at certain points, and for such situations one might need high accuracy even in the short term.

Finally in this section, this point about getting the correct geographic relation between cloud and system may be particularly relevant to the initial question as to whether clouds are important at all. Further, it may be even more relevant in the case of the ECMWF models since they already have an "artificial" constraint (i.e. observed SST) which may be out of kilter with the model atmosphere.

4. RADIATION PARAMETERIZATION WHEN GIVEN CLOUD

In this section I wish to make only a couple of fairly obvious points.

(1) Given a big enough computer, the actual calculation of radiation fields is simple enough in principle and is not really a fundamental problem. This problem is the accurate specification of cloud character on which to perform the radiative calculations.

(2) Since cloud has a dominant control on radiative heating and cooling of the atmosphere, my guess is that the limit on the accuracy of radiative calculations will always be set by the accuracy of the model cloud generation scheme. Therefore (and particularly for ECMWF purposes where the concern is not with long-term trends) I would also guess that any great detail of clear-sky calculations will be a waste of time.

5. TWO CLOUD GENERATING SCHEMES

The physics of how planetary-boundary-layer cloud is formed and maintained is known quite well in a qualitative sense - certainly it is known well enough not to have to rely on a "relative humidity switch" which does not (as is now well established) give even a reasonable simulation of such cloud in GCM climate models.

In brief, the physics is as follows: The PBL cloud is created by the evaporative flux E from the surface feeding or creating a layer of liquid water (i.e. the cloud) beneath the boundary layer inversion. Radiative cooling at the top of the cloud increases the inversion strength, but more importantly destabilizes the cloud layer. The turbulence so created tends to "erode" the inversion and to bring down drier air from above the inversion into the cloud layer. This dry air forms a sink for the water vapour flux E, so that in <u>steady-state</u>

(and a stable steady state can exist) the thickness (and amount?) of the cloud is governed by the radiative cooling at the cloud top, by the relative dryness of the air above the inversion, and by E.

It should be very easy to "dream up" a parameterization of PBL cloud in these terms which is far more realistic than the present scheme. I understand the NCAR people are using such a parameterization.

Cirrus cloud is a major problem not only for the real situation but also in the model simply because the model layer thickness at cirrus altitudes is very great. Nevertheless it should be possible, even with our scant present knowledge of the physics of cirrus formation, to do much better than rely on the "relative-humidity-switch" technique. A general picture may be as follows (and this is based on many lidar studies of cirrus cloud).

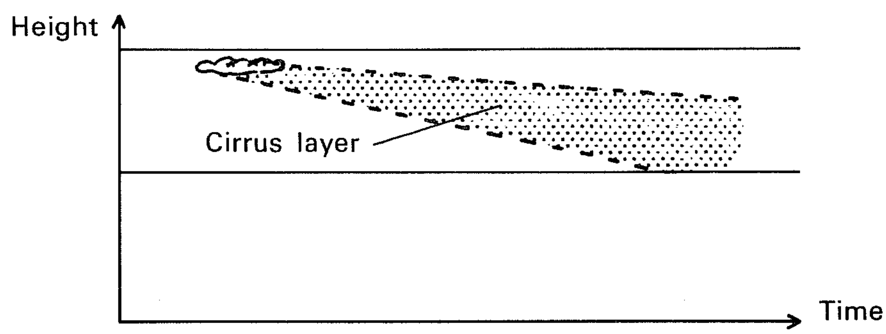

Fig. 3

Referring to Fig. 3, one can picture the establishment of a thick layer of high humidity. Initial cirrus formation is likely to occur somewhere close to the top of the layer. The cirrus particles typically have fall velocities from 0.1 to 0.5 m/sec, and as they fall they will nucleate more particles - so that as time goes on the cirrus layer thickens. The base extends with the particle fall velocity, the top comes down at a much slower rate as the falling particles deplete the water vapour in the upper levels. As the particles fall out of the bottom of the layer they evaporate.

On this picture must be superimposed any large-scale vertical advection of humidity, as well as the effect of any convection induced by radiative heating of the cloud layer.

All of which is both qualitative and complex. However, it should not be too hard to evolve a mathematically simple scheme to simulate the overall process, and furthermore to extend the scheme to give a realistic picture of the time variations of cirrus albedo α and emissivity ε (this last via observed relations (Stephens 1980) between vertical ice path and α and ε).

Reference

Stephens, G.L. 1980 Radiative properties of cirrus clouds in the infrared region. J.Atmos.Sci., 37, 435-446