THE ECMWF PROGNOSTIC CLOUD SCHEME

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As the material presented at the workshop is discussed in previous papers (*Tiedtke*, 1993 and *Tiedtke et al*, 1993) only a summary is given here.

The problem of representing cloud fields in large-scale models was addressed and a new parametrization based on prognostic equations for cloud water content and cloud area was presented.

Most of the difficulties in representing clouds are of a fundamental nature while some are more specific such as the specification of cloud optical properties, which are still rather uncertain. The most obvious inadequacy is the inconsistent and incomplete treatment of cloud processes which is most evident in the decoupling of the radiation cloud scheme from the rest of the model's physics. There have been various attempts in recent years to develop unified cloud schemes for large scale models (e.g. *Sundqvist*, 1978; *Smith*, 1990) but these schemes are still rather incomplete and inconsistent in various aspects (e.g. the treatment of convective clouds) and contain undesirable diagnostic features (e.g. for specifying cloud cover and cloud water content). The prognostic cloud scheme developed recently at ECMWF overcomes some of these shortcomings by adopting a model approach where all cloud related processes are treated in a fully consistent way.

DESIGN OF ECMWF PROGNOSTIC CLOUD SCHEME

The new scheme considers explicitly the sources and sinks of cloud water and cloud air. Clouds form as a result of moist adiabatic lifting in large scale ascent, in cumulus updraughts, in convective updraughts in well-mixed boundary layers and diabatic cooling by radiation etc. Clouds dissipate through: evaporation in moist adiabatic descent (i.e. large scale, cumulus induced subsidence), diabatic heating, turbulent mixing with unsaturated environmental air and precipitation processes:

Cloud formation:

1) Formation of stratiform clouds by large scale ascent and/or diabatic cooling
2) Formation of convective clouds by detrainment of cloud air from convective updraughts
3) Formation of boundary layer at top of convective boundary layer

Cloud dissipation:

1) Evaporation by moist adiabatic descent (large scale and/or cumulus induced subsidence and diabatic heating)
2) Turbulent mixing of clouds with unsaturated environmental air
3) Entrainment processes at top of boundary layer clouds
4) Precipitation processes

It should be noted that the scheme has two prognostic equations and, in contrast to other prognostic schemes, predicts cloud water content (CLW) as well as cloud cover. The equation for fractional cloud cover is derived from the large-scale budget equation for cloud air and contains source and sink terms due to cloud formation and cloud dissipation.

Consistency: The new cloud scheme provides a large step towards a consistent treatment of cloud processes in large scale models, as cloud formation and dissipation are linked directly to model processes. The physical basis is that formation and evaporation of cloud water is determined by the time change of the saturation water vapour content. This physical concept is applied equally to stratiform and convective clouds. With regard to cumulus convection we note that part of the cloud water condensed in updraughts immediately falls out as rain while the remainder is transported upwards and detrained into the environmental air, thereby contributing to cloud formation.

Completeness: Although the original motivation for developing the new cloud scheme has been to obtain a model-consistent treatment of cloud processes, the more apparent benefit is that of a more complete representation of cloud processes than with the ECMWF operational cloud scheme. The increased complexity is most evident in the model's hydrological cycle, e.g. formation and storage of cloud liquid water with the possibility of re-evaporation, introduction of partial cloudiness, formation of anvil and cirrus clouds by convection and the representation of boundary layer clouds. The coupling of cloud formation to the model's cumulus convection scheme represents an important extension of the present cumulus parametrization with benefits not only for the simulation of anvil and cirrus clouds due to cumulus convection but also for the overall hydrological cycle.

Accuracy: Accuracy of the prognostic scheme depends on the representation of the processes for formation and dissipation of clouds. Formation of clouds is determined by model processes such as large-scale ascent, cumulus convection, radiative cooling and boundary layer turbulence. Therefore, errors in simulated cloudiness may first of all indicate errors and deficiencies in those processes. Additional errors originate from the uncertainty of the tunable parameters for the precipitation processes, the turbulent diffusion coefficient for mixing of cloud air and unsaturated environmental air and the assumption for the critical humidity above which stratiform clouds are assumed to form, which at present is between 80% and 100% depending on height above ground.

VALIDATION OF THE NEW CLOUD SCHEME

Initially we have verified cloudiness in extended integrations by comparing time averaged model-produced cloud cover against satellite observations from ISCCP and climate data from surface observations. Recently, we have also started to evaluate cloudiness synoptically in short range forecasts at resolution T213. Results show that:

1) Total cloud cover appears realistic as the major cloud fields are reproduced: i.e. along the ITCZ, extratropical stormtracks and over the cold water off the subtropical west coasts of the continents.

2) High level clouds appear excessive in comparison to ISCCP, but model clouds are optically thin to a large extent as indicated by values of effective cloudiness. Recent satellite observations employing multispectral techniques indicate widespread occurrence of thin cirrus which support the model's large cloud cover. The excess in high level cloudiness in tropical regions is smaller with the new scheme than the operational scheme.

3) In order to represent boundary layer clouds we have extended the model's boundary layer scheme by including the formation of clouds at the top of convective boundary layers. The scheme is successful in reproducing maritime stratocumulus fields to the west of the continents. Also, the transition to the cumulus regime downstream of the stratocumulus clouds is captured realistically by the model.

RECENT REFINEMENTS OF THE PROGNOSTIC SCHEME

The original scheme has been refined recently in two aspects:

1) Validation of simulated OLR against Satellite measurements show that OLR values produced by the new scheme are systematically too large indicating that simulated clouds are either optically too thin or cloud tops are not high enough. Therefore we have reconsidered the precipitation of ice which plays a dominant role for the maintenance of ice content and have replaced the original parametrization by a more realistic scheme based on observational evidence. Following *Heymsfield and Donner* (1990) the fallout of cloud ice is represented in terms of sedimentation using average values for the fall speed of ice crystals.

2) Validation of the scheme over Europe and the Atlantic has shown that the new scheme fails to dissipate low level clouds fast enough and may produce spurious rain from low level clouds over the sea. Boundary layer clouds may dissipate due to various processes such as adiabatic and diabatic heating and by entrainment of dry environmental air at cloud tops. The effect of top entrainment is considered in the scheme but only as a result of buoyancy production by turbulent processes. The effect of longwave radiative cooling has not been included in the original version because little is known about its effect and therefore parametrization is uncertain. However, in order to reduce the bias towards excessive boundary layer cloudiness we have extended the parametrization of top entrainment by including long wave radiative cooling as proposed by *Stull* (1988, p 576).

Further extensions presently in progress are a) the advection of cloud variables using a shape preserving scheme and b) the incorporation of the scheme into the data assimilation system so that cloud variables can be carried forward in time for the purpose of initializing cloud water content and cloud cover.

REFERENCES

Heymsfield, A J and L J Donner, 1990: A scheme for parametrizing ice-cloud water content in general circulation models. J Atmos Sci, 47, 1865-1877.

Smith, R N B, 1990: A scheme for predicting layer clouds and their water content in a general circulation model. Quart J Roy Meteor Soc, 116, 435-460.

Sundqvist, H, 1978: A parametrization scheme for non-convective condensation including prediction of cloud water content. Quart J Roy Meteor Soc, 104, 677-690.

Stull, R S, 1988: An introduction to boundary layer meteorology. Kluwer Academic Publishers, Dordrecht, Netherlands, 666pp.

Tiedtke, M, 1993: Representation of clouds in large-scale models. Mon Wea Rev, 121, 3040-3061.

Tiedtke, M, J-J Morcrette and N Kvamsto, 1993: Cloud and radiation modelling. Technical Report No. , ECMWF, Reading, UK.