GENERAL INTRODUCTION

This is a time of considerable activity in the study of clouds, radiation and the hydrological cycle. New results and new datasets are becoming available from a number of major observational projects. These datasets provide extensive new possibilities to validate the parametrization schemes in existing Numerical Weather Prediction (NWP) and General Circulation Models (GCM's). They also provide a basis for the development of more accurate parametrizations. These developments are of interest to both the weather prediction and to the climate modelling communities. It is therefore appropriate that the workshop was supported by both ECMWF and by WMO's World Climate Research Programme.

The aim of the workshop was to bring together i) those involved in producing the datasets, ii) those concerned with the problems of using the datasets for model validation, and iii) those engaged in the development of new parametrization schemes, in order to discuss current scientific problems and future lines of research and development. Experience shows that the results of workshops such as this have been of great value to developments at ECMWF and elsewhere. We thank the participants most sincerely for their considerable formal and informal contributions to the workshop.

The main body of the report contains the papers presented at the meeting. In addition, in the next three sections of this introduction, we summarize the discussions and recommendations of the working groups. The suggestions for future work are of interest to both the observational and modelling communities.

The discussions of the Workshop were organized in three working groups. We begin with a discussion of the datasets themselves. This is followed by a discussion of the problems of using the data for model validation. Finally, there is a discussion of new developments in parametrization stemming from the theoretical and observational studies.

1. WORKING GROUP 1: DATA SETS CONCERNING CLOUDS, RADIATION AND HYDROLOGY

1.1 INTRODUCTION

Current availability of data sets for radiation, clouds, water vapour, precipitation and other parameters is reviewed. On-going and planned projects likely to provide data in these areas are also discussed. Finally, some specific recommendations are made in relation to obtaining datasets. In reviewing the various datasets it should be emphasized that information on variability (including diurnal) as well as on mean values is needed. This requirement is met to an extent by some datasets, but not at all by others.

1.2 CURRENT STATUS OF DATA SETS

1.2.1 Radiation

Planetary radiation

Two long-term and global datasets are now available from fixed wide-angle detectors on the NIMBUS-7 ERB and ERBE instruments. These datasets provide regional, monthly mean measurements of the upward solar and thermal fluxes at the top of the atmosphere (TOA) covering a period from 1979 through about 1988. Long-term global datasets are also available from the narrow-band AVHRR scanners (1979 - present), which are expected to continue through the 1990's. The ERBE dataset subdivides the fluxes into total and clear-sky, which provides an index of cloud effects on the planetary radiation, and provides information about mean diurnal variations. These data are well documented (Hwang et al., 1988; Jacobowitz et al., 1984 a, b; Smith and Smith, 1987; Barkstrom and Smith, 1986; Barkstrom et al., 1989) and available from the NASA Space Science Data Center in Greenbelt, Maryland, USA. Accuracies of these data exceed current GCM capabilities.

Surface radiation

A re-processing of the Leningrad collection of surface measurements of radiation fluxes is nearing completion at ETH in Zurich (Ohmura et al., 1989). No other general collection of such data is readily available.

Atmospheric profiles

No comprehensive dataset of atmospheric profiles of radiative fluxes is available.

1.2.2 Clouds

Cloud amount

Three global climatologies are available that describe cloud amount: ISCCP from 1983 onwards

(Schiffer and Rossow, 1983, 1985; Rossow and Schiffer, 1991), Surface Observations (Warren et al., 1986, 1988) for 1952-1981 over ocean and 1971-1989 over land (but this will be extended), and NIMBUS-7 for 1979-1985 (Stowe et al., 1988, 1989). The first two datasets agree to within about 10%, except in polar regions, while the NIMBUS-7 dataset underestimates low level cloudiness over oceans by about 10-15%. All datasets provide some statistics on cloud type, with the first two being more detailed. Information of diurnal variation of clouds is available in the latter two datasets. These data are well documented and are available from NOAA/NESDIS, NCAR and NSSDC, respectively. Accuracies exceed current GCM capabilities.

Cloud vertical distribution

The Surface Observations provide classification information about low, middle and high cloud types, as well as estimates of cloud base height for low clouds. ISCCP and NIMBUS-7 both provide estimates of cloud top location. Uncertainties in these cloud top heights are associated primarily with problems in the treatment of optically thin clouds. Different information on cloud top location is contained in SAGE observations from 1979-1990, which are documented (Woodbury and McCormick, 1986) and available from NSSDC. More work is needed to refine this information into explicit vertical distributions of condensed water; however, the distribution statistics already available should provide useful constraints on GCMs.

Cloud optical thickness

Only ISCCP provides information on cloud optical thickness, measured at visible wavelengths. Preliminary studies of cloud effects on planetary and surface radiative fluxes suggest that it is of useful quality.

Cloud water content

Although cloud water content may be inferred from optical thickness, it depends on cloud particle size, number density and vertical extent which are not well known. Total column water content, estimated by microwave measurements, may be combined with cloud top location and optical thickness data to retrieve cloud water contents. (cf. Curry et al., 1990). Processing of SSM/I data (available from 1987 onwards) is not yet routine; older SMMR results are available from NSSDC. Although final accuracy is not yet determined, it appears high enough from GCM improvement, e.g. to determine location and frequency of occurrence of dense clouds.

Cloud particle size and phase

It may be possible to survey cloud particle sizes over the globe from current satellite data (Arking and Childs, 1985), but this has not been done. Currently, the large collection of aircraft field data forms the best set of data, but these have not been systematically collected and analyzed.

Clouds in polar regions

The amounts and properties of these clouds are more poorly determined in current datasets, which exhibit large disagreements (see forthcoming WMO/WCRP workshop report). Although some studies are underway to try to improve these results, current data should be used with some caution. The ISCCP results appear to be a reliable lower limit on polar cloud amounts.

1.2.3 Water vapour profile

Two sources of water vapour are available. The first, from operational retrievals of satellite infrared radiances, is documented by NOAA/NESDIS (Smith et al., 1979). The second consists of experimental analyses of satellite microwave radiances (total water only, SSMR 1979-1987, SSM/I 1987 onwards). More study of these data, together with available surface observations, is required. A re-analysis effort to produce the precipitable water from SMMR data is underway to make them consistent with SSMI data. The microwave sensors provide only precipitable water over the ocean. Similar efforts on TOVS data will provide additional cover over land. The results will be more than a decade of continuous and consistent time series of global precipitable water starting 1979. This set of data products will be available from the NASA Ocean Data System at JPL.

A significant exception to the above is upper tropospheric water vapour. Little credible information has been available except from a few special radiosonde stations, so the quality of GCM simulations at pressure levels higher than about 400 hPa is unknown. A new seasonal climatology of upper tropospheric water vapour has now become available from an analysis of SAGE data for 1985 - 1988 (Rind et al., 1991). These data are well documented, have good accuracy, and are available from NSSDC.

The classical data source is from radiosondes. Long series of monthly means as well as twice daily data are available at NOAA/NCDC and NCAR. Problems result from representativeness and from uncertainty in the upper troposphere and stratosphere.

1.2.4 Precipitation

Exchange of precipitation data over the GTS, other than regionally, is currently only done on a voluntary basis. Global dissemination should be encouraged.

Land

Available data are from weather station reports, in particular frequency of occurrence information, and from satellite IR indices in the tropics (Arkin and Ardonuy, 1989). Station reports suffer from sparse sampling, but frequency of occurrence information and geographical location should be useful for GCM studies. Satellite indices are not well calibrated, but distribution and variability information may provide a useful dataset of GCMs.

Ocean

Data are available from IR indices in the tropics and from experimental microwave retrievals (Arkin and Ardenuy, 1989); however, evaluation of the analysis methods is still underway, so that these data should be treated with some caution. The information of the geographical distribution contained in these data should be useful for GCM experiments. Rainfall frequency can be determined from ship observations.

Precipitation in the form of snow

The measurement of snow is generally less accurate than that of rain, in particular at low temperatures and in windy conditions. Weather station reports are not routinely transmitted or collected.

1.2.5 Other parameters

Atmospheric temperature profiles

Atmospheric temperature profiles are well determined by radiosondes where available. The capabilities of the operational satellite retrievals are inferior to current assimilation capabilities, but refinements of the satellite retrievals are possible with more sophisticated methods.

Oceanic surface fluxes

The COADS dataset has been extensively used to estimate mean winds and variability. F. Wentz (Remote Sensing Systems, Santa Rosa, CA) is producing surface wind speed and atmospheric precipitable from SSMI data starting July 1987. He is also conducting reanalysis of SMMR data using an algorithm consistent with SSMI. T. Liu (Jet Propulsion Laboratory, Pasadena, CA) have produced several years of latent heat flux in the tropical oceans using SMMR data (Liu, 1988) and the effort is being continued with SSMI and AVHRR data.

Surface skin temperature and albedo

These two parameters can be retrieved from available satellite radiances. However, a global analysis covering many years has not been carried out. Some research efforts are underway to produce surface albedo datasets from AVHRR. ISCCP routinely retrieves surface skin brightness temperatures (emissivities are assumed to be unity), but these have not been evaluated for land areas as yet. Accuracies of ocean skin temperatures from ISCCP appear to be about 2K for monthly means. For bulk SST measurements, Reynolds (1988) estimates an uncertainty of up to 1K on a 2 degree grid (but less than 0.5K in the West Pacific).

Soil evapotranspiration and runoff

There are no new comprehensive datasets for these parameters.

Surface fluxes over land

The new compilation of surface measurements of energy fluxes at ETH (Zürich) includes some information about surface latent and sensible fluxes, but no global datasets exist.

1.3 ON-GOING AND PLANNED PROJECTS

1.3.1 Radiation

Planned new satellite missions to measure planetary radiative fluxes are the French-Soviet SCARAB, which will begin flights in 1991, and the EOS CERES experiment. CERES may fly on the TRMM mission in 1996 before the launch of EOS platforms. A Surface Radiation Budget project has been established under the WCRP, beginning in 1989. Plans call for some preliminary datasets to be released within one to two years.

1.3.2 Clouds

Both ISCCP and the analysis of surface observations are on-going. An ECLIPS effort to collect systematic observations of cloud base height from surface lidar measurements was started in 1988, with a pilot phase completed in 1989. Experimental production of cloud data from operational satellites has begun in NOAA/NESDIS. It is expected to become operational in phases over the next five years. The first phase, to be implemented in 1991, will include total cloud amount from AVHRR and cloud-top pressure and effective cloud amount from TOVS.

1.3.3 Water vapour

The sounder dataset (HIRS/MSU) may be reanalysed with an improved method as part of an EOS program to develop the EOS Data and Information System with "Pathfinder" datasets. A climatological Aerological Reference Data Sets (CARDS), consisting of quality controlled rawindsonde observations is also being prepared. Research is currently underway on retrievals of upper tropospheric water vapour from the water vapour channels on METEOSAT and GOES satellites.

1.3.4 Precipitation and surface run-off

Under WCRP there is a GPCP that began in 1986 to prepare a global precipitation climatology by combining surface and satellite measurements. Especially valuable parts of this project are intercomparison of satellite microwave analysis methods over several validation areas and intercomparison o conventional and satellite datasets. A NASA-sponsored project, called WETNET, is working on the SSM/I data to infer total water vapour amounts, cloud water amounts and precipitation. TRMM is a joint Japan-USA satellite mission to fly a rain radar along with passive microwave and imaging instruments to improve measurements of tropical precipitation. Launch is planned from 1996. Frequency of occurrence of precipitation will be made available from surface weather reports. The GRDP under WCRP is to collect hydrological observations of land water runoff.

1.3.5 Field experiments

Two other key projects of note are TOGA-COARE, a field campaign to the western Pacific to measure clouds, radiation, precipitation and ocean variations. A second FIRE cirrus experiment is planned for November 1991. ASTEX is a marine stratus cloud and ocean mixed layer experiment, which is planned for summer of 1992.

1.3.6 GEWEX

A major effort to diagnose the global water and energy cycles is in the planning stages. Called GEWEX, this project is expected to combine the several independent projects discussed above into a comprehensive analysis system, beginning by mid-decade. Planning is also underway for a continental-scale intensive field experiment early in GEWEX to take place in the eastern USA.

1.3.7 Snow cover and depth

An analysed product is available from NESDIS. The SSM/I can sense snow but results are not available. Exchange of telegrams between WMO regions, over the GTS, should be encouraged.

1.4 RECOMMENDATIONS

- More work is possible and needed concerning observations that contain relevant information about water vapour and precipitation. The efforts of the GPCP to intercompare the several precipitation datasets that are available should be strongly supported. A reanalysis of available water vapour measurements must also be supported. More effort should be directed to collection of surface reports of snow amounts.

- Comparisons of atmospheric models with the newer datasets should now begin to emphasize regional variability, rather than average quantities, in order to diagnose energy and water exchange processes.
- Notable datasets that are now available for study are:
  - a) for planetary radiation fluxes - NIMBUS-7 and ERBE,
  - b) for surface radiation and energy fluxes - a new analysis of station measurements by ETH,
  - c) for clouds - ISCCP, Surface Observations (Warren, Hahn, London), and NIMBUS-7,
  - d) for upper tropospheric clouds and water vapour - SAGE,
  - e) for total water vapour, cloud water path and precipitation - SSM/I.
- We would welcome the formal archiving of the data from field experiments such as, for example, FIRE, ICE, WENPEX, MIZEX. The archived data should include both the field data and the data from AVHRR, VAS, GOES, METEOSAT.

2. WORKING GROUP 2: VALIDATION OF MODELS

2.1 INTRODUCTION

Validation of GCMs using satellite data has made significant progress since the last workshop on clouds held at ECMWF in 1984. A variety of data (e.g. ERBE, NIMBUS-7, ISCCP) have become available and model earth radiation budget diagnostics are now routinely verified against satellite products.

A striking result of the current workshop is the variety of ways in which the satellite products are now being used to validate not only the time mean Earth Radiation Budget diagnostics, but also the spatial and temporal variability of the cloud and radiation fields. Attempts to make the model diagnostics more compatible with the satellite measurements are also a notable feature of this workshop.

A concern of the group was the increasing development of prognostic cloud schemes and the need to address the role of cloud optical property feedback in climate change. This has introduced a new realm of validation requirements with their accompanying uncertainties. It is this area that required the most attention. The development of these schemes has far outstripped the availability and accuracy of the validation data as well as our knowledge of the processes involved.

2.2 MODEL PARAMETERS TO BE VALIDATED

2.2.1 Monthly mean TOA radiation budget

Net radiation fluxes at the top of the atmosphere measured from satellites are widely used to verify operational forecasts and climate simulations. They provide an invaluable first guess of the quality of the hydrological cycle in numerical models. At the present time large differences between model fluxes and radiation budget observations suggest that model errors are still larger than interannual variations. The improved cloud and radiation schemes will soon require a simultaneous comparison between observation and mode simulation. With the current time lag in processing ERBE data a validation of the model fluxes can only be done by performing forecast or data assimilation experiments for past events. For the validation of climate experiments some estimates of interannual variability are necessary.

2.2.2 Monthly mean clear sky fluxes and cloud forcing

The availability of clear sky radiative fluxes from ERBE is considered a valuable tool to validate the radiation models employed in the GCMs; the fluxes are also relevant to the verification of the thermal and moisture structure of the model atmosphere, as well as the surface albedo data and the parametrization of the land and ocean surface temperature.

However, at present, the uncertainties in the observed clear sky fluxes have not been well documented. We recommend that the ERBE community provide better estimates of the regional uncertainties ion these data. Knowledge of the frequency of occurrence of clear sky regions from the monthly mean data would assist the modellers in their attempts to compare model and observation data. It also would be useful if the ERBE team could supply a limited number of clear sky fluxes for regions, and times, where clear sky data have been validated by surface observations. Modellers could then employ temperature and moisture sounding data from nearest location to further verify their radiation algorithms.

In a recent study by Cess et al., (1990) of the response of 19 atmospheric GCMs to an imposed change in sea surface temperature (used as a surrogate climate change), an almost 3-fold variation in the cloud feedback from weakly negative to strongly positive was obtained. Whilst this variation in feedback can be attributed to the difference in the treatment of clouds between the various models, a contributory factor may also be the definition and method of computation of the cloud forcing itself. The paper by Potter et al. in these proceedings advocates Method II of Cess and Potter (1987): (where the clear-sky radiation fields are computed by the model radiation scheme at every grid point) as the only unambiguous way to produce consistent radiative diagnostics for intercomparing model results.

2.2.3 Total precipitable water content

Atmospheric water vapour is undersampled by the present global observing system; indeed, even gross statistics such as the global amount of precipitable water content and its seasonal and interannual variations are not well known. Satellite data can provide much needed information on global moisture distribution; although the present sampling, only allows for monthly mean values.

2.2.4 Cloud and cloud water

Many groups now use cloud parametrizations based on a prognostic cloud variable. However, no climatologies of cloud water are available. Validation is limited, therefore, to data from isolated fields experiments or to estimates derived from satellite measurements (SMMR, SSM/I). Currently available estimates from satellite data show substantial differences, and are based on a variety of algorithms. However, all models must also predict the effects of these clouds on TOA and surface radiation, so that the inferred cloud optical parameters can be compared to those deduced from satellite and surface radiation measurements such as from ISCCP.

The morphology of cloud (the distribution of cloud water with a grid box) is also important. Thus total cloud cover, despite the difficulties in defining thresholds of cloudiness, is still a useful validation parameter. The vertical distribution of cloud cover is important. However, objective classification of cloud heights based on satellite data can be misleading, (for example, cold cloud under a low level inversion can be mistakenly identified as medium level cloud). Hence, surface observations of cloud height and low cloud amount are still useful for model validation.

2.2.5 Cloud microphysics

It is evident from a number of the workshop papers that prognostic schemes are highly sensitive to the cloud microphysics in both ice and water domains. An increased understanding of these processes and at least some estimates of the various parameters from field experiments are urgently required. The group proposes that, perhaps under the auspices of the WCRP, an exhaustive study of the literature and contacts with groups involved in field studies should be made in order to collect as much cloud microphysical data as possible. A collation could then be made of the typical range of values of (a tentative list at this stage):-

- Liquid water and ice content, cloud vertical extent
- Cloud particle number density and size distribution
- Transition temperatures for water to ice clouds
- Sedimentation rates for ice crystals
- Crystal structure/size

The data should be stratified by height and geographical locations/synoptic situations(e.g. latitude, land vs. ocean, frontal clouds etc). This document would be invaluable in providing reasonable limits within which prognostic cloud schemes should operate.

2.2.6 Precipitation from cloud top temperatures

The relationship between cloud top temperatures and precipitation proposed by Arkin could be investigated by using the model generated cloud top statistics. The inferred precipitation from the algorithm could then be compared with the actual model precipitation. The relationship should be explored for various regions and synoptic situations. The method should, in particular, be applied to the GATE region.

2.2.7 Spatial and temporal variability

Recent results obtained with the NCAR Community Climate Model (CCM1) have shown that the representation of the physical processes strongly depends on the horizontal resolution of the model. On the other hand, simulations with meso-scale models of the FRONTS 87 situations show that, at horizontal resolutions close to those planned for future versions of the ECMWF model, the balance between precipitation produced by implicit and explicit parametrizations of the convective processes becomes a more and more delicate issue. This is likely to affect the 3-D distribution of cloudiness and resulting radiation fields. Verification of the behaviour of the different physical parametrizations when the model horizontal resolution is increased is timely. It can benefit from simulations on a regional basis with the limited area model.

Direct comparisons with ISCCP-B3 radiances (or a more statistical basis with ISCCP-C1 products) can provide a validation of the model cloud and radiation fields and an indirect evaluation of the moist convective parametrizations.

The study of short time scale fluctuations (diurnal to a few days) of radiation fields is important to test the response of the cloudiness and convection to different radiative and dynamical forcings. Furthermore, study of space-time variability of radiation fields is relevant to understanding variations in model moisture structure and surface hydrology processes.

An important radiative forcing is obviously the diurnal cycle which appears to have a strong influence on tropical cloudiness (and the surface temperature). The diurnal cycle may be tested by using the ISCCP B3 and C1 data sets which are global in coverage (since July 1983) and which should exist until 1995. Several methods already exist to compare the diurnal cycle of a model to that of observations.

For inter-diurnal variations, the time scale of the fluctuations may be tested by computing the time spectral variance of the radiation fields as a percentage of the total inter-diurnal (> 1 day) variance. This method makes it possible to compare model to observation which avoids calibration problems, since it does not depend on the absolute value being known or modelled accurately. Climate runs of the model or an ensemble of 12 hour (to a few days) forecasts with at least 3 hour time sampling could be used for this validation. Note that the ensemble "forecast" time series will serve as a validation of the response of the cloud parametrization to realistic dynamical and thermodynamical fields, while the "climate" time series will serve as validation of the self generated model variability.

The spatial and temporal response of the cloudiness to different perturbations should also be tested. These include, for example, equatorial easterly waves (3-5 days), mid-latitude synoptic scale disturbances, Madden-Julian waves (30-50 days) or other local, well established periodic features such as the Central African standing oscillation, or the Indian Monsoon breaks.

It should be noted that validation of the absolute day to day (interdiurnal) variability will require a good estimation of the daily averaged radiative components, which in turn would need good intra-diurnal sampling (at least 3 hourly) to account for the diurnal variation of radiative fluxes. These variations are linked, first, to the natural astronomical variability, and, second, to the real meteorological fluctuations (advected or generated cloudiness). At this time, the filling techniques used in the daily averaging procedures for both the polar orbiter satellite data and for model calculations does not take into account for this second cause of diurnal variability and may yield biases in the estimation of daily mean fluxes. The ERBE dataset, whilst having global and broad band fluxes, should be used with care, since the day-to-day variability has yet to be tested. However, inferences of radiative fluxes from ISCCP data, which is 3 hr time resolution, could be used to study this problem.

2.2.8 Surface Radiation Budget

The first release of SRB (Surface Radiation Budget) data is due in the near future. Preliminary results indicate some differences between the estimates of the participating groups. it seems, however, that large errors in the ECMWF model's surface solar radiation budget can be related to gross errors in cloudiness which have been inferred from the TOA radiation budget comparisons.

2.2.9 Surface latent heat flux

Data to validate the surface latent heat fluxes is still very limited. Climatological data for oceans is based on ship observations and on bulk parametrizations. Direct observations from platforms are a valuable validation set for the surface flux parametrizations and TOGA should provide good estimates for the tropical oceans. A further estimate of evaporation and precipitation can be derived from operational analyses by calculating the diabatic forcing to balance the humidity budget. This is of course not a completely independent estimate since errors in the humidity analysis and in the model used for the assimilation will affect these estimates.

2.3 RECOMMENDATIONS

- A systematic collation of cloud microphysical data from field studies should be instigated to provide a basis for prognostic cloud schemes.

to the satellite community

- The current satellite estimates of total precipitable water content should be validated and every effort should be made to obtain at least monthly mean climatologies to be used for model verification.
- Uncertainties in current estimates of cloud water from satellites should be documented.
- Models should continue to be used to investigate the biases in clear sky fluxes that arise from various clear sky identification methods.
- The ERBE community should provide better estimates of the regional uncertainties in the clear-sky flux data (e.g. frequency of occurrence of clear sky, diurnal bias).

- The day-to-day variability of the ERBE data should be examined before using it to validate broad band flux model variability.
- The ISCCP B3 and C1 data sets should be used to verify the diurnal and inter diurnal variability of cloudiness and radiation in both the solar and thermal parts of the spectrum.

to the modelling (ECMWF) community

- ECMWF model clear-sky fluxes should be operationally archived.
- Three-dimensional distributions of ECMWF model cloud cover and liquid water content should be routinely archived.
- The ECMWF model should be used to investigate the relation between cloud top temperatures and precipitation.
- The dependence on model horizontal resolution of the outputs of the ECMWF physical parametrizations should be studied, in particular using the ECMWF limited area model.
- The response of the model cloudiness and radiation to quasi-periodic tropical synoptic scale perturbations should be studies.
- Further effort should be made to evaluate the surface energy budget and to perform a comparison between estimates from different NWP centres. Over land the close balance between the net radiation at the top of the atmosphere and the total diabatic forcing suggests the use of ERBE data for a validation.

3. WORKING GROUP 3: PARAMETRIZATION OF CLOUDS IN LARGE SCALE MODELS

3.1 INTRODUCTION

Accurate representation of clouds in numerical models of the atmosphere is important for both numerical weather prediction and climate simulation. In NWP models, improved cloud parametrization will act to reduce model systematic errors (e.g. regional temperature biases), to produce more accurate predictions of surface weather, and to assist the maintenance of baroclinic-wave energy. In the forecast/analysis cycles of these models, it may also prevent unrealistic analysis-drift in no-data regions. For monthly and longer-range prediction, accurate cloud parametrization will act to produce more realistic surface radiative fluxes for coupled ocean-atmosphere integrations, and will assist in maintaining a proper heat budget simulation.

Two types of cloud parametrizations are being used. Diagnostic schemes use model variables to infer cloudiness and have been successful in simulating gross features of the observed clouds. More physically-based prognostic schemes use new model variables (e.g. cloud water) to explicitly describe many aspects of clouds.

3.2 DIAGNOSTIC SCHEMES

Diagnostic schemes derive cloud cover and occasionally cloud water content from other model variables such as relative humidity, vertical velocity, atmospheric stability, cumulus mass flux etc. Present schemes are successful in reproducing the gross features of global cloudiness. The main advantages are the simple treatment and the low computational requirements. However, they lack a sound physical basis and, in particular, are not capable of dealing with the interaction between cloud optical properties and the hydrological cycle of the numerical model.

3.3 PROGNOSTIC SCHEMES

In prognostic cloud schemes the cloud evolution is linked, interactively, to the rest of the model physics (dynamics, radiative transfer, hydrology, convection, turbulence). The development of such a scheme requires the consideration of the following problem areas, namely, advective transport of cloud variables, sub-grid scale transport, cloud microphysics, cloud optical properties.

3.3.1 Advective transport of cloud variables

Characteristic mean values of water vapour content change by orders of magnitude between pole and equator and between near-surface and stratosphere. Water vapour is also characterized by variations on very small temporal and spatial scales (for example, in the vicinity of fronts and at land sea interfaces). The distribution of cloud water has even stronger discontinuities and smaller scales.

These characteristics pose severe problems for numerical methods traditionally used for advection in global atmospheric GCMs, which generate over and undershooting of these fields, and consequently supersaturation, and negative mixing ratios respectively. At very low resolutions, particularly for warm clouds, it may be justifiable to neglect the advection processes. The neglect of the advective process is less justifiable as the resolution (both horizontal and vertical) of global models increase, and efforts to model cold clouds intensify. It is thus time to revisit this issue. Recently, numerical methods have been developed which can handle the above mentioned problems. One class of these "non-oscillatory" methods have been tested in cloud models. Tests of another class of non-oscillatory methods have been made for water vapour transport in global models.

3.3.2 Sub-grid scale processes

Physical cloud schemes require an adequate description of sub-grid scale processes. This depends on the cloud type:

- the convective transport of mass is described in the mass flux schemes and these sub-grid scale motions can be used to relate cloud fraction to cloud liquid water evolution,
- the physical basis for stratiform cloud treatment is less established, although various approaches are used presently with some success (either statistical, or more fully prognostic),
- the ability of prognostic models to simulate boundary layer clouds through a careful treatment of the cloud/turbulence interaction still needs to be clarified.

3.3.3 Cloud microphysics

Condensation and cloud formation in current GCMs is assumed to start if a specified relative humidity threshold is exceeded. Precipitation formation is treated differently for warm clouds (autoconversion, cloud collection) and for cold clouds (sedimentation of ice crystals). Evaporation of cloud droplets and precipitation is proportional to the respective saturation deficit.

The formulation has to be simplified due to the coarse space and time resolution of current models. The results (e.g. the cloud lifetime and the cloud optical properties) depend crucially on the specification of microphysical parameters which are somewhat uncertain. A tuning strategy has to be developed.

3.3.4 Cloud optical properties and cloud geometry

Cloud optical properties are currently parametrized in terms of liquid water path on the basis of the radiative transfer theory for spherical cloud droplets. The optical properties of ice clouds depend on shape, size and orientation of the ice crystals. These parameters cannot presently be provided by numerical models.

In areas where different cloud types (convective and stratiform) occur simultaneously, the use of only two parameters (cloud cover and grid-mean cloud water path) may not be sufficient for an accurate calculation of the grid-mean radiance.

The total cloud cover and the radiances also depend on assumptions of cloud overlap (maximum, random).

3.3.5 Advantages

a) Physical basis

b) Consistency with the rest of the model

c) Potential for further improvement with progress in research (field experiments, mesoscale models)

d) Less sensitivity to parameter changes and model resolution

3.3.6 Disadvantages

a) More storage and computation time

b) More programming effort

3.4 RECOMMENDATIONS

General

- There was no consensus among members of the working group that one type of cloud parametrization scheme has more value than another. We strongly recommend, however, that the ECMWF should increase its efforts to evaluate prognostic schemes.
- The development of prognostic a scheme for the ECMWF model should be based on theory, results from a hierarchy of finer resolution models, and data from cloud field-experiments (e.g. FIRE, ICE, WENPEX, EUCREX).

Short term

- The treatment of cloud liquid water and ice in the present diagnostic cloud scheme should be carefully re-examined and re-formulated.
- Effort should be made to include cloud types that are absent, misrepresented or under-represented in the present diagnostic cloud scheme.

Longer term

- Since clouds are simulated by separate schemes (stratiform and convective), particular care needs to be taken to assure compatibility between them.

- Attention should be paid to different cloud types and their associated microphysics and related optical properties.
- Attention should also be paid to the role of turbulence in the formation of clouds.
- Refined numerical techniques should be used for re-examining the role of advection in prognostic cloud parametrization.
- More effort is needed in the specification of initial values of cloud variables.

References

Arkin, P. A., and P. E. Ardenuy, 1989: Estimating climatic-scale precipitation from space: A review. J. Climate, 2, 1229-1238.

Arking, A., and J. D. Childs, 1985: Retrieval of cloud cover parameters from multi-spectral satellite measurements. J. Climate Appl. Meteor., 24, 322-333.

Barkstrom, B., E. Harrison, G. Smith, R. Green, J. Kibler, R. Cess and the ERBE Science Team, 1989: Earth Radiation Budget Experiment (ERBE) archival and April results. Bull. Americ. Meteor. Soc., 70, 1254-1262.

Barkstrom, B. R., and G. L. Smith, 1986: The Earth Radiation Budget Experiment: Science and implementation. Rev. Geophys., 24, 379-390.

Cess, R. D., et al., 1990: Intercomparison and interpretation of climate feedback processes in 19 atmospheric general circulation modes. J. Geophys. Res., 95D, 16,601-16,615.

Cess, R. D., and G. L. Potter, 1987: Exploratory studies of cloud radiative forcing with a general circulation model. Tellus, 39A, 46-473.

Curry, J. A., C. D. Ardell and L. Tiau, 1990: Liquid water content and precipitation characteristics of stratiform clouds as inferred from satellite microwave measurements. J. Geophys. Res., (in press).

Hwang, P. H., L. L. Stowe, H. Y. M. Yeh, H. L. Kyle and the NIMBUS_7 Cloud Data Processing Team, 1988: The NIMBUS-7 global cloud climatology. Bull. Americ. Meteor. Soc., 69, 743-752.

Jacobowitz, H., R. J. Tighe and the NIMBUS-7 ERB Experiment Team, 1984: The earth radiation budget derived from the NIMBUS-7 ERB Experiment. J. Geophys. Res., 89, 4997-5010.

Jacobowitz, H., H. V. Soule, H. L. Kyle, F. B. House and the NIMBUS-7 ERB Experiment Team, 1984: The Earth Radiation Budget (ERB) experiment: an overview. J. Geophys. Res., 89, D4, pp. 5021-5038.

Liu, W. T., 1988: Moisture and latent heat flux variabilities in the tropical Pacific derived from satellite data. J. Geophys. Res., 93, 6748-6760.

Ohmura, A., H. Gilgen, and M. Wild, 1989: Global Energy Balance Archive GEBA, World Climate Program Water Project A7, Report I: Introduction. Eidgenössische Technische Hochschule (ETH), Zurich, 62 pp.

Reynolds, R. W., 1988: A real-time global sea surface temperature analysis. J. Climate, 1, 75-86.

Rind, D., E. W. Chiou, W. Chan, J. Larsen, S. Ottmans, J. Lerner, M. P. McCormick and L.

McMaster, 1991: Satellite validation of water vapour feedback in GCM climate change experiments. Nature, (in press).

Rossow, W. B., and R. A. Schiffer, 1991: ISCCP cloud data products. Bull. Amer. Meteor. Soc., 72, (in press).

Schiffer, R. A., and W. B. Rossow, 1983: The International Satellite Cloud Climatology Project (ISCLP): The first project of the World Climate Research Program. Bull. Amer. Meteor. Soc., 64, 779-784.

Schiffer, R. A., and W. B. Rossow, 1985: ISCCP global radiance dataset: A new resource for climate research. Bull. Amer. Meteor. Soc., 66, 1498-1505.

Smith, E. A., and M. R. Smith, 1987: Atlas of earth Radiation Budget Measurements from NIMBUS-7 ERB, 1979-1983. Florida State University, 254 pp.

Smith, W. L., H. M. Woolf, C. M. Hayden, D. Q. Wark and L. M. McMillin, 1979: The TIROS-N Operational Vertical Sounder. Bull. Amer. Meteor. Soc., 60, 117-118.

Stowe, L. L., C. G. Wellemeyer, T. F. Eck, H. Y. M. Yeh and the NIMBUS-7 Cloud Data Processing Team, 1988: NIMBUS-7 global cloud climatology. Part I: Algorithm and validation. J. Climate, 1, 445-470.

Stowe, L. L., H. Y. M. Yeh, T. F. Eck, G. G. Wellemeyer, H. L. Kyle and the NIMBUS-7 Cloud Data Processing Team, 1989: NIMBUS-7 global cloud climatology. Part II: First year results. J. Climate, 2, 671-709.

Warren, S. G., C. J. Hahn, J. London, R. M. Chervin and R. L. Jenne, 1986: Cloud Distribution of Total Cloud Cover and Cloud Type Amounts Over Land. NCAR Tech. Note NCAR/TN-273 + STR.

__________, 1988: Global Distribution of Total Cloud Cover and Cloud Type Amounts Over Ocean. NCAR Tech. Note NCAR/TN-317 + STR.

Woodbury, G. E., and M. P. McCormick, 1986: Zonal and geographic distributions of cirrus clouds determined for SAGE data. J. Geophys. Res., 91, 2775-2785.