INTRODUCTION

Since the start of operational forecasts at ECMWF we have made a few changes to the boundary layer parameterization scheme. These changes were relatively minor and could be considered as tuning of the scheme.

The performance of the present boundary layer scheme has been fairly satisfactory. However, some of the systematic errors of the forecasts may be related to wrong exchanges between the atmosphere and the earth's surface, which are partly determined by the distribution of variables within the planetary boundary layer (PBL). In addition, the present formulation has a number of inconsistencies between the various parts of the parameterization scheme.

Since we are now beginning to design our next generation model, it is a good time to start investigating other PBL parameterization schemes which are now becoming available, or have been used in other general circulation models.

This workshop on PBL problems was organized at ECMWF on 25-27 November 1981 to examine the performance of the current models and to help us in our design of a future scheme.

Discussions were held in three sub-groups on the following topics:

- Assessment of PBL models

    (Augstein, Fiedler, Geleyn, Tibaldi, Van Maanen, Weill)

- The physics of the PBL

    (Tennekes, Bolin, Bougeault, Cats, Du Vachat, Louis, Randall)

- Models of the PBL

    (Kraus, André, Carson, Dümenil, Müller, Tiedtke)

The following sections summarize the discussions and recommendations of these three groups. The remainder of these proceedings contain the text of the seminars presented at the workshop.

GROUP 1: ASSESSMENT OF PBL MODELS

DISCUSSION

Assessment of the performances of a given parameterization of the planetary boundary layer ideally requires experimental data which are free from any bias towards the parameterization itself. It seems to be dificult since the direct acquisition of data on the time and space scales of the ECMWF-type models is technically impossible; therefore, the link from observational data obtained in restricted areas under special conditions to data for the relevant model scales must be established by modelization (e.g. meso-scale models). The following approaches might be useful in order to overcome this difficulty:

1. Comprehensive assessment should encompass (a) verification on the basis of locally representative data sets, (b) extensive comparisons with larger scale field measurements and (c) long time period control of the ECMWF scheme with routine measurements.

2. For aspects (a) and (b) this requires a close co-operation between the ECMWF modellers and the experimentalists in order to ensure that the observational products best fit the demands of model verification.

3. For aspect (c) a suitable selection of area representative stations could be a first step; a second step should be to standardise information about the PBL structure (either exchange through GTS or otherwise diagnosed at ECMWF).

4. Meso-scale numerical experiments could provide answers to the question:
   To which extent does computation of PBL quantities based on a single grid point structure represent the space average of the detailed results?

Subsequently, some detailed problems about data will be addressed.

Land properties

An atlas of soil thermal inertia, soil water capacity, soil thermal conductivity and soil water conductivity is needed for the proper treatment of the lower boundary conditions (soil must be understood here as including vegetation if necessary). Although this is an enormous task it should be given high priority in the near future. The use of this atlas would be more effective if routine measurements of soil moisture and snow cover would be transmitted on the GTS. Finally, the determination of the representative aerodynamic roughness over complex terrain urgently needs further studies. Experiments like ALPEX should help to improve the present situation.

Surface fluxes

The first crucial step of an actual simulation of the PBL in a medium range forecast model is an accurate determination of surface fluxes; therefore, global scale data must be derived in order to control the model's output. To this aim one can make the following suggestions:

(a) Over the oceans utilization of satellite measurements for indirect determination of surface fluxes on a global scale must be encouraged.

(b) The time and space averaging problem must be considered in collaboration between modellers and experimentalists, especially for rapidly changing conditions of the synoptic scale (passage of fronts, for example). This means that experimentalists should investigate non-homogeneous and non-stationary situations for a better assessment of the non-linear aspects of PBL parameterization.

(c) Modelization of the upper ocean layer would increase the validity of model computed fluxes and should therefore be included in future model developments.

(d) On land, an accurate estimate of surface budget and fluxes is dependent on radiation surface flux measurements, which at present have a too coarse and irregular network. An improvement of this situation is highly desirable.

(e) Some uncertainties still exist for the determination of fluxes under extreme wind conditions, which are very important for medium range forecasting because of the effect of oceanic evaporation on the hydrological cycle and because of the adjustment between drag and wind speed over land. The acquisition of data under these difficult conditions should be considered in future PBL experimentation.

(f) The present analysis of standard levels does not satisfactorily cover the PBL regimes. Dissemination of more PBL data should enable an operational analysis on supplementary low level pressure surfaces (say, 800, 900 and 950 mb). Additionally, an objective definition of a small number of PBL characteristics (e.g. mixed layer height, cloud base level...) should be put forward and the routine dissemination of these products organized.

PBL vertical structure

Two kinds of data are available: (a) single location observations under conditions of homogeneity and stationarity that can be used for one column assessments of the parameterization schemes (Wangara, O'Neill, Voves ...), (b) results of three-dimensional field experiments (KONTUR, PUKK, ALPEX, JASIN, MESOKLIP, NEPHOS, COPT, GATE). If the experiments are post December 1978 analysis of model reruns at ECMWF can be carried out for verification of

PBL results in the model framework. In return, these model calculations could be used by the experimentalists for cross-referencing their data processing. For present and future experiments a close coordination between ECMWF and experimentalists would be advantageous.

Relations between PBL and cloud convection

Presently available cumulus convection parameterizations are still too coarse in their treatment of the interaction between PBL processes and cloud activity in order to allow for a clear strategy of experimental testing. In order to assess bulk effects resolved by large scale modelization, the already existing data of the previously quoted experiments provide sufficient information. Future development will depend on improvement of the convective schemes in the parameterization field.

RECOMMENDATIONS

i) ECMWF and other interested organizations should endeavour to obtain GTS exchange of standardized PBL information.

ii) ECMWF should implement a selection of area representative stations in order to facilitate direct verification of PBL parameterization products, both in operational and research modes.

iii) The use of land surface properties' climatologies and the operational acquisition of surface state properties should be part of future system developments at ECMWF.

iv) Experimental investigations under high winds and rapidly changing conditions, both over ocean and continental areas, should receive high priority in forthcoming PBL observational programmes.

Relevant data sets

KONTUR (H.Hinzpeter, University of Hamburg). Observation of organized convection, German bight, Aug-Sep 81.

PUKK (H.Kraus, University of Bonn).Similar to KONTUR in coastal area.

ALPEX (J.Keuttner, WMO) Flow over the Alps. March-April 82.

JASIN (H.Charnock, University of Southampton). Air-sea interaction in the Atlantic. August-Sept 78.

MESOKLIP (F.Fiedler, Univ.of Karlsruhe). Orographic effect in the Rheim Valley. Sept.79.

NEPHOS (Y.Fouquart, Univ. of Lilles) Comparison of satellite pictures of clouds with ECMWF analyses. 1982.

VOVES (A.Weill, CNET, Paris). Turbulence measurement at one point. June-July 1977.

COPT (G.Sommeria, CNRS, Paris): Convection in Ivory Coast. May-June 1981.

MONEX: Monsoon experiment 1979.

ATEX: Atlantic trade winds experiment 1979.

GROUP 2: THE PHYSICS OF THE PBL

DISCUSSION

The discussion ranged over a wide variety of issues. It began with a suggestion that among the physical processes to be simulated with a PBL parameterization are: The diurnal cycle (in particular that of the mixing height), frictional convergence, boundary layer cloudiness, all aspects of the moisture budget and, of course, the surface fluxes. The current model attempts to deal with these processes by predicting only the surface fluxes and the vertical profiles of the fluxes.

It was agreed that it is necessary to forecast PBL cloudiness because cloudiness is one of the most important elements of a forecast, and also because the clouds can influence the PBL turbulence and radiation, and thereby the synoptic motions. PBL stratus cloudiness is an important field which can be observed globally.

Several points were made concerning the interaction of the PBL with cumulus clouds. The cumuli tend to reduce the PBL depth, while a deep PBL is favourable for cumulus convection. This feedback loop should be simulated. In principle the second moment equations can apply to the cumulus layer, but no one knows how to do this.

It was agreed that shallow PBL cumuli are radiatively important, and should be parameterized if possible.

In order to model more realistically the relation between soil moisture and evaporation, it is worthwhile to include a simple parameterization of the effects of vegetation in the immediate future, because of the influence of vegetation on evaporation. It should be noted that subgrid scale lakes might significantly influence the concept of soil moisture.

The potential for testing PBL parameterization by experimental forecasting was discussed. For example, this method may help to assess the impact of PBL cloudiness on synoptic developments, or the importance of a detailed surface roughness specification. The value of composite studies was recognized. However, it was pointed out that parameterizations must also be tested outside of the forecast model (e.g., in one-dimensional models), since it is not always easy to determine why a forecast is good or bad.

Several members of the group agreed that, in the present state of the art it is better to parameterize boundary layer clouds with bulk models of the PBL which do not require extremely high vertical resolution. It was pointed out that Ekman layer similarity theories can give some information on the profiles of the mean fields in the PBL, and that this may make possible rather simple schemes capable of resolving two or more levels within the PBL.

RECOMMENDATIONS

(i) Emphasis should be placed on the interaction of the PBL parameterization with the other components of the model (such as cloudiness and large-scale dynamics), rather than on the internal details of the PBL's turbulence.

(ii) Particular attention should be paid to the interaction of the PBL with cumulus clouds.

(iii) It is important to predict PBL stratus clouds, and an effort should be made to develop a simple parameterization of shallow PBL cumuli.

(iv) Attention should be paid to mesoscale structures in the PBL, including those associated with the organizations of cumulus convection, orographic and coastal circulations.

(v) Some PBL validations should be in the form of composite synoptic studies, e.g., of extratropical cyclones and easterly waves.

(vi) The specification of surface properties such as roughness and vegetation should be tested, at least in part, through forecast experiments.

(vii) As boundary-layer models improve, more attention ought to be paid to the analysis of observed boundary-layer parameters, such as mixing height, cloudiness, surface temperature and moisture.

(viii) Higher-order closure methods with high vertical resolution can be used to test simple parameterizations now. Simpler versions of these models should be viewed as possible parameterization schemes for several years in the future, after their reliability has improved and the power of computers so permits.

GROUP 3: MODELS OF THE PBL

INTRODUCTION

The aim of the working group was to examine the various parameterizations currently available for representing boundary-layer properties and processes within the ECMWF model.

The features of the PBL that need to be simulated were identified. These include, for example,

Surface variables:	T_s, T_2, U_{10}, humidity, snow cover, soil water, fog.
Structure of the PBL:	Depth of boundary layer, stability, clouds.
Processes:	Turbulent mixing, convective mixing, effects of the large-scale flow, radiation, phase changes, precipitation.

The spatial and temporal scales of the processes to be parameterized were assumed to be 100 km, and 10 min, respectively.

Review of Methods

(a) Sub-surface and Surface Processes

The importance of these aspects for a complete parameterization of boundary-layer processes was acknowledged. They deserve a special separate study and were considered to be beyond the scope of this working group.

(b) Surface Fluxes

There are several viable methods for estimating the surface fluxes. Two in common usage are based on similarity theories; the Monin-Obukhov similarity theory applicable within the surface layer and the asymptotic similarity theory applicable to the boundary-layer as a whole. For good simulations of the surface fluxes and near-surface variables it would seem necessary to represent the surface layer (probably with a model level within the first few tens of metres above the surface), and consequently the Monin-Obukhov approach, in spite of its recognised deficiencies, appears to be the best currently available.

(c) Parameterization of turbulent exchanges within the boundary layer

(1) Eddy-diffusivity approach

This is defined to be any approach of the form

$$F_x = \overline{w'x'} = - K_x \frac{\partial \bar{x}}{\partial z} = - \ell_x^2 \left|\frac{\partial \bar{\mathbf{v}}}{\partial z}\right| \frac{\partial \bar{x}}{\partial z}$$

where either K_x (for heat, moisture and momentum transfer), or alternatively ℓ_x (a mixing length), has to be prescribed.

This approach has two serious shortcomings.

(i) There is no sound physical basis for postulating a "flux-gradient" relationship for all conditions of turbulent transfer within the atmospheric boundary layer.

(ii) Specification of the dependancy of K, or ℓ, on the large-scale variables lacks sufficient physical basis and adequate empirical verification.

In spite of these obvious objections the 'K' - approach remains an attractive and widely used method for determining the turbulent transfer throughout the boundary layer. There exists in the literature a large number of prescriptions of K which could, in principle, be tried in numerical models.

(2) Higher-order closure schemes

(i) In principle, higher-order closure methods avoid explicit specification of the stability dependence of the eddy fluxes.

(ii) In principle, such schemes provide a general framework for including better descriptions of the turbulent intensity and for adding representations of other physical and dynamical processes, e.g. convective mixing and partial cloudiness.

(iii) Reservations at present include, for example,

(a) Such methods have not been tried adequately in models with horizontal grid lengths of several hundred kilometres.

(b) It is not known if such methods will perform satisfactorily with the coarse vertical resolution typical of global numerical models.

(c) There remains the problem of specifying the coefficients required in higher-order schemes. The sensitivity of such schemes to the choice of coefficients may need to be determined more thoroughly.

(d) Bulk-layer models

A viable alternative approach to modelling the boundary-layer structure and processes is what we have loosely identified as the "bulk-layer" approach. We include in this category the formulation due to Randall which has already been incorporated and partially tested in the UCLA 9-level model. One can criticize this method because the assumptions made in such an approach relating to the character of the boundary-layer below a well defined top are not always appropriate for the observed boundary layer. This method also appears, a priori, to be less amenable to general application and further development than either the fairly common K-approach or the untried higher-order closure scheme. On the other hand, it is economical, and allows the treatment of boundary layer clouds in a relatively straightforward manner.

(e) Clouds and the boundary layer

Cumulus parameterization should be incorporated in the "boundary-layer scheme". There was no definite proposal as to how this could be done.

This problem was addressed recently by the WMO CAS Working Group on Atmospheric Boundary-Layer Problems.

RECOMMENDATIONS

i) We recommend that large scale models have a separate surface layer representation. This surface layer should be used in conjunction with Monin-Obukhov similarity theory to retrieve the surface fluxes. Asymptotic similarity schemes should be, in this context, disregarded for having too many restrictions to be useful.

ii) In the short term ECMWF should continue to use K-type approaches and try to improve the specifications of the functional relationship between K and the large scale flow characteristics.

iii) We strongly recommend that ECMWF examines the feasibility of using higher order closure schemes to parameterize vertical fluxes. A suggested problem area to be investigated is their applicability to lower vertical and/or horizontal resolution.

iv) Mixed-layer-type models should be monitored where already implemented in GCMs (e.g. UCLA, UKMO), but their experimental implementation at ECMWF is, for the moment, thought to be of lower priority.