CONCEPTS OF THE GERMAN RESEARCH GROUP SPAAZ (SIMULATION PROJECT GENERAL (Allgemeine) ATMOSPHERIC CIRCULATION (Zirkulation)) AND SOME SPECIAL RESULTS

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INTRODUCTION

During the fifties numerical weather prediction within the German Weather Service (Deutscher Wetterdienst) was developed quite successfully under the leadership of K. Hinkelmann. Shortly later, education in dynamic meteorology at German universities was intensified at various places, leading to a potential of young capable theoreticians. Since the IUGG - meeting in Berkeley (1963) and the following meeting in Boulder shortly after that, but especially during the IUGG - meeting in Lucerne (1967) plans developed to found an interuniversitary research group on long - term weather prediction and global circulation in close cooperation with the German Weather Service.

The establishment of such a group took place in Hamburg under the sponsorship of K. Brocks (December 1967). The first program discussion was arranged by the German Weather Service in Offenbach (January 1968). Here, the author of this report developed a program which was approved by the group, and he was elected to be the project leader. Funds for the SPAAZ - program were provided by the German Science Foundation (Deutsche Forschungsgemeinschaft) within a more comprehensive program "Energetics and Circulation of the Atmosphere". The whole program consisted of four main groups :

1. The SPAAZ - group was considered to be responsible for the development not only of a large - scale model, but also of a variety of subsynoptic - scale models.

2. The boundary layer - group was expected to provide the necessary empirical input for testing assumptions regarding the parametrization of the planetary boundary layer. In addition, it was expected to obtain information on parametrization of cumulus convection.

3. The research group on radiation was expected to review radiation theories in order to provide parametrized radiation input data for model calculations.

4. The group on data acquisition and analysis had to provide the necessary data for model verification in general.

ACTIVITIES OF THE SPAAZ - GROUP

During the time of developing this program the availability of large and very fast computers was very limited. Therefore, especially the research group of SPAAZ concentrated on model - orientated basic research for a large - scale model as well as for subsynoptic - scale models. It was agreed to start a training program during the first yearly summer schools. Subjects were: Parametrization of the planetary boundary layer (1968); Parametrization of thermal convection (1969); parametrization of topographic effects and physical properties of current models of global circulation (1970). Parallel to this training program research began in the field of simulation of the planetary boundary layer, boundary layer instability, and on non - stationary boundary layers. In the field of thermal convection the simulation of ensembles of convective elements (dry and moist convection) as well as successful simulation of deep moist convection was performed. In summer 1970 the global spectral model (F. Schmidt) was discussed, and also the program of dynamic stochastic forecasting and predictability. During the subsequent seminars a number of studies on the energetics of baroclinic forecasting models were performed.

Becoming more specific, the original philosophy developed during the first meeting by the author was the following: Firstly, making available the full theory of irreversible processes as a scientific basis for the group. This formed the basis for a comprehensive physically complete one-dimensional model which included not only boundary layer physics, but also micro-physics of clouds and the physics of radiation. Secondly, providing the most general budget equations for turbulent fields within the boundary layer in order to make clear what has to be parametrized. Thirdly, an attempt was presented to break up the spectrum of atmospheric motions into spectral bands, where each spectral band represents a certain class of subsynoptic-scale motions. The idea of successive averaging was proposed for the case of boundary-free averaging as well as for the case of averaging including vertical averages, and thus including the full set of boundary conditions at the lower and internal boundaries.

The scope of this presentation was to develop a general frame of research within the group. The research activities covered the following subjects:

1. Berlin (Freie Universität), represented by H. Fortak:

   Development of general concepts, simulation of the instationary boundary layer with a vertically integrated model, simulation of ensembles of moist convective elements with one-dimensional models, simulation of precipitation with a comprehensive micro-physical model of clouds, and, at the same time, with a parametrized model. Experimental investigation of thermal convection and vertical transports within the convective layer by means of a powered glider.

2. Darmstadt (Technische Hochschule), represented by F. Wippermann:

   Parametrization of the planetary boundary layer for steady state and horizontal homogeneous conditions, instability of the planetary boundary layer, influence of non-stationary conditions on the parametrization of the planetary boundary layer. Simulation of ensembles of dry convective elements.

3. Hamburg (Universität), represented by G. Fischer:

   Large-scale simulation of hemispheric flow, investigation of baroclinic influences, and especially of the energetics within the model. Testing of various assumptions for parametrization and sensitivity analyses with regard to various parameters proposed by the other groups.

4. Hannover (Technische Universität), represented by F. Schmidt:

   Development of a spectral GCM-model and investigation of effects of non-homogeneous resolution on the results.

5. Mainz (Universität), represented by K. Hinkelmann:

   Development of a theory of irreversible processes applicable to the atmosphere and, on the basis of this, development of a physically complete one-dimensional model of the atmosphere.

6. München (Universität), represented by G. Hollmann (†) and J. Egger:

   Incorporation of subsynoptic-scale mountainous regions into large-scale models, development of stochastic dynamic models for long-range forecasting.

7. Offenbach (Deutscher Wetterdienst), represented by H. Reiser:

   Simulation of deep moist convection and cloud dynamics, flow across mountains with incorporation of moisture transport and generation of rain, fundamental numerical studies with regard to the numerical formulation of models. Development of a simplified version of a one-dimensional model of the atmosphere.

Quite recently a global spectral model of the atmosphere derived from Alyea's model is available to the group and will be used as a platform for experiments with the various proposed techniques for parametrization of subsynoptic - scale models.

SOME SPECIAL RESULTS

1. Boundary layer research (F. Wippermann et al.)

The main goal of connecting the internal parameters u_*, ϑ_*, s_* with the external parameters of the circulation model could be solved in terms of the turbulent fluxes for momentum, sensible heat and water vapour at the earth's surface. In this case the well - known resistance law formulas were used, in which the functions M_m, M_h, M_s and N were calculated for a boundary layer model, because sufficient empirical information was not available. The boundary layer model used a new mixing length hypothesis and led by numerical integration to universal profiles of properties of the planetary boundary layer including the influence of baroclinicity. With regard to the resistance laws observations and model calculations led to representations of the universal functions even in the case of baroclinic boundary layers. An extension of this research to conditions over sea led to satisfying results. Since the resistance laws are valid only for stationary conditions, special investigations estimated the error by applying these laws to known stationary conditions.

Another group of papers treated the instability of atmospheric boundary layers in the meso - scale. Here, the vortexes with horizontal axis take over the vertical transports of momentum, heat and moisture, which cannot be achieved by micro - turbulence. This type of boundary layer instability was investigated in its dependence on the thermal stratification and on realistic profiles of wind vector and eddy diffusivities.

Another type of parametrization was proposed by the author, what was called "parametrization by subsynoptic-scale modeling". One example will describe what is meant by this: Averaging the planetary boundary layer vertically from the earth's surface to the top introduces the lower boundary conditions at the bottom, which should be parametrized as usual. In addition, correlation products of wind vector and other field variables are produced by vertical averaging, and also a term containing the divergence of the mean vertical wind vector appears in the resulting two-dimensional prognostic equation for this wind vector. Assuming time-dependent traveling wind fields (e.g. geostrophic ones) as steering fields for the planetary boundary layer, the time-dependent structure of vertical motion at the top of the boundary layer is simulated. It is characteristic that without interaction between both layers of the atmosphere the scale of the fields within the boundary layers becomes smaller with increasing prediction time and shows band structures which are related to the steering fields. Synoptic evidence of this behaviour could be found.

2. One-dimensional comprehensive models of the atmosphere.

Many results of boundary layer research, research in radiation transfer as well as cloud physics were incorporated in the two comprehensive one-dimensional models of the atmosphere (K. Hinkelmann et al., G. Czeplak). The Mainz-model incorporates the complete theory of parametrization of the planetary boundary layer, it contains an also fairly complete theory of radiation (variation of absorbing substances as water vapour, ozone, carbondioxide, the influence of cloudiness on radiation transfer, the influence of aerosols, and the influence of absorption under complicated conditions with regard to water vapour). Further, the description of the mechanism of convection was improved beyond the well-known convective adjustment. In addition, the cycle of precipitable water was incorporated in a much more improved manner.

This time-dependent model was integrated, and it was attempted to find means for further parametrizations and simplifications which do not change the results significantly, but reduce the computing time such that the theory could be incorporated into a global model.

In summary it can be said that this model predicts the vertical structure of the atmosphere very accurately and demonstrates that the incorporation of all relevant physical effects is urgently needed to get realistic results with regard to the radiation field, the formation of clouds, and the small-scale turbulent fluxes of momentum, heat and water vapour. Needless to say that even the conditions below the earth's surface are predicted successfully.

Similar results are obtained by the second one-dimensional model within the group (G. Czeplak, DWD Hamburg), which is used for predicting properties of the planetary boundary layer, and especially for prediction of fog and ground frost. Although many assumptions differ from the Mainz-model, the predictive power for the goals envisaged by that group is quite good and has been tested successfully.

3. Deep moist convection (E. Müller, DWD Offenbach).

With regard to this problem it is best to refer to a very comprehensive report (Berichte des Deutschen Wetterdienstes Nr. 133, Band 17, 1974), in which E. Müller describes his method of simulation of deep moist convection on the basis of the primitive equations. The SPAAZ-group considered this to be one of its very significant contributions to the whole program. The same holds for the papers of W. Edelmann, DWD Offenbach, who worked on parametrization of thermal convection utilizing a quasi-stationary one-dimensional cumulus model. With regard to the simulation of ensembles of cumulus cells, their interaction among each other, and the influence of meso-scale organization, a dissertation by I. Jacobsen, Berlin, should be mentioned, as well as a dissertation on the time-dependent structure of meteorological properties below a cloud basis with outfalling rain (J. Pankrath, Berlin).

4. Influences of sub-grid topographical structures

During recent years much attention was paid to the incorporation of mountain ridges, e.g. the Alps, into numerical models for large-scale flow. Here, two groups were successful. The Munich group (J. Egger) applied a barrier theory with great success and the results can already be found in the open literature. Direct approaches by W. Edelmann, DWD Offenbach, led to very interesting results, especially with regard to baroclinic forecasting. Edelmann also made much progress in the direction of forecasting of precipitation in large-scale models.

5. Numerical modeling

Numerical investigations with baroclinic models were so to say delegated to the Hamburg group, represented by G. Fischer. Results of this work have been presented during this seminar by himself.

Unfortunately, the global spectral model of F. Schmidt, Hannover, was not developed further, although it was completed many years ago. Instead, another spectral model was chosen in addition, which aims at long-term prediction on a global scale. One of the students of the author cooperated with Alyea (MIT), such that Alyea's model was extended for the whole globe and was improved in certain respects. It is planned to incorporate the parametrization experience of the SPAAZ-group into that model and to use it in addition for purposes of stochastic dynamic forecasting.

6. Stochastic dynamic models for steady-state atmospheric circulation systems (J. Egger et al.).

Quite recently Lorenz' model was used for this purpose. The system of equations for mean values and second moments are closed by parametrizing or neglecting third order moments. Depending on the prescribed radiation equilibrium temperature, properties of the general circulation, i.e. Hadley-circulation, Rossby-circulation, vacillation and irregular circulation caused by orography, are simulated. It is possible in that model to calculate changes of the circulation in a quasi-stationary manner if the external parameters are changed gradually. These investigations touch already problems connected with changes of climate.

7. Models using prognostic equations for higher order moments (H. Fortak, J. Egger).

A general framework of equations for second order moments of all interesting atmospheric properties including all possible types of averaging was developed. Since no approximations (e.g. Boussinesq-approximation) are used, the system of equations can also be applied for zonally averaged models of the atmosphere (Egger). Here, Mintz-Arakawa's model was used, and third moments were neglected. Considering steady-state conditions, sensitivity analyses with regard to the drag coefficient were performed and were used to compare the models of Smagorinsky and Kung, and of Mintz-Arakawa.

It is impossible to describe eight years of scientific work of an active group of young scientists in such a short version. For further information it therefore might be best to contact the group leaders of SPAAZ:

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