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Present and Future Developments in Numerical Weather Prediction

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Mr Gauntlett, acting Officer-in-Charge, Commonwealth Meteorology Research Centre*, commenced his talk with some general comments regarding the typical organisational structure of conventional numerical weather prediction (NWP) systems. Essentially, they consist of three subsystems operated sequentially and with virtually no feedback between each other or within themselves. In the observational subsystem, the necessary data (*ie*, temperature, reference pressure, wind velocity and moisture) are collected and processed for input to the next subsystem, the numerical stage, which produces the forecast to be used by the third subsystem, the applications stage. This final subsystem translates the NWP output into a form appropriate for operational use. In a chronological sense this organisation implies a cycle starting with a first guess analysis field provided by an earlier prognosis, the updating of the field with available data, and the computation of the next prognosis - the so called 'analysis-prognosis' cycle.

As an introduction to a discussion on the performance in Australia in the NWP area, Mr Gauntlett outlined the hierarchy of numerical models that have been used here. These are:

(i) the 'filtered' barotropic single level models - virtually vorticity advection algorithms;

(ii) the 'filtered' baroclinic multi-level models which allow both barotropic and baroclinic energy conversions;

(iii) the 'unfiltered' baroclinic primitive equations (PE) models which filter out sound waves but not gravity waves, have a small timestep, and facilitate the introduction of sub-grid scale processes; and

(iv) 'enhanced' PE models; *eg*, featuring semi-implicit time differencing techniques, or using spectral representations of atmospheric variance.

In Australia, real-time evaluations have been made of models from each generation. Mr Gauntlett showed the average monthly operational S1 skill score for the Australian region at the 300, 500 and 1000 mb levels against time for the period January 1970 to January 1972. (The S1 skill score gives a measure of the skill in predicting geopotential gradients.) At 500 mb, manual forecasts achieved a higher skill than 'persistence' forecasts but were less skilful than barotropic models; this led to

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the abandonment of manual forecasts at the 500 mb level. The next generation, the filtered baroclinic model, did not achieve an appreciably higher skill than the first generation. At the 300 mb level, the second generation models scored better than manual forecasts, but the serious shortages of accurate high level data still caused important deficiencies in the quality of the operational product. At 1000 mb, the difference in skill achieved by the various prognosis methods is negligible. Lack of extended operational statistics precluded a direct comparison between second and third generation models, but the indications are that the skill of the latter is slightly better.

Thus, we can achieve better prognoses of the large scale flow in the middle troposphere by numerical methods assisted by skilled manual intervention during the initial state specification than by exclusively manual methods. At other levels, the skill of the two methods is comparable but the machine has the advantage of consistency and efficiency. The machine has important secondary advantages in that models may be used to probe atmospheric physics, and also to maintain a data bank for research purposes. Notwithstanding this, the speaker suggested that there is no evidence that NWP has improved the skill and accuracy of the operational weather forecasts made in this country. In order to improve the effective use of NWP products there is a need for a national program to coordinate theoretical and applied research in the overall NWP problem in Australia.

Short term improvement can be made in all three areas of the NWP system. In the applications area, there is a need to provide better education in the use of the NWP model output, and to obtain feedback on the usefulness of the numerical product. There is also an important requirement for fundamental research to be conducted into the problem of how scale interactions occur to actually produce weather. As well, the importance of providing appropriate hardware to translate the NWP output into a form compatible with field requirements should not be overlooked.

In the numerical area, Mr Gauntlett displayed diagrams which demonstrated the inability of current models to maintain the amplitude of lower wave numbers. This was directly attributed to a lack of horizontal resolution. Cyclogenesis was also a problem area in current models in that, while the position of cyclones was predicted with some accuracy out to 48 hours, often the degree of development was not. The speaker suggested four main reasons for the deficiencies:

(i) Lack of accuracy in the initial data.

(ii) Lack of vertical resolution. The work of Hunt at CMRC has suggested that better vertical resolution in general circulation models improves the ratio of eddy to zonal kinetic energy.

(iii) Inappropriate or inaccurate numerical methods. As an example, the speaker showed a diagram giving some results of Orzag, in which a right circular cone was numerically advected around a horizontal plane using different methods to approximate a simple passive scalar advection equation. The obvious improvement in the maintenance of the cone as the numerical methods varied from second and fourth order Arakawa finite difference schemes to higher resolution grids and spectral methods points the way to more use of the last two methods, although the higher resolution method is limited by the increased computing requirements mentioned earlier. At present, Dr Bourke of CMRC is developing a real-time spectral model to test its advantages.

(iv) Incomplete representation of sub-grid scale processes, particularly convection. Mr Gauntlett compared some results achieved with CMRC's basic PE model to the results achieved by the same model incorporating a new convective scheme developed by Barker and Kininmonth at CMRC. The scheme is similar to that originally reported by Kuo in that air is assumed to rise moist adiabatically from the boundary layer and then mix with the large scale flow. However, major variations from the parameterisation are the explicit consideration of the effect of liquid hydrometeors and the strict maintenance of moisture and energy conservation. The results compared were four day forecasts of the mean sea level field by both the basic and the augmented models. The augmented model with the new convective scheme gave better movement and development of both anticyclones and troughs, and verified better with the observed field. This improved model is to be put through extensive real-time trials in the near future.

The well known inadequacies in the accuracy and resolution of conventional networks in the third area of the system - the observational subsystem - are just beginning to be overcome with the implementation of the newer satellite systems. However, their introduction poses new problems. As their data are continuous in time, how are they to be incorporated into the current NWP system based on observations made at fixed intervals? The solution requires a continuous assimilation model - effectively a prognosis model integrating continuously with special provisions to allow the insertion of data as they become available. At appropriate times, the model would move ahead of the atmosphere to produce operational forecasts. A second problem is that satellite deduced vertical profile data are strongly dependent on the first guess profile. This suggests that some form of feedback from the numerical to the observational subsystem is of critical importance. The difficulty here is that such a feedback is, of necessity, international and presents a considerable logistics and resources problem.

Another reason for a feedback loop is to facilitate interactions between the individual components of the observational subsystem itself. For example, experiments have shown that it is possible to sacrifice superfluous accuracy or data density in one part of the subsystem to achieve improvements in others. The impact of moisture on satellite temperature reductions is another example.

Based on his earlier remarks, Mr Gauntlett then presented his concepts of a fully interactive numerical forecast processing system to replace the conventional system that he had introduced at the beginning of the talk. In the new system, new forms of data are included in the observational subsystem with interactions occurring between the various parameters while the analysis/prognosis models of the old numerical subsystem are replaced by an assimilation model with feedback between it and the observational subsystem.

In closing his talk, Mr Gauntlett emphasised that, with the growing complexity and expense of modern numerical systems, no single Australian group can claim exclusive possession of all the expertise required to successfully create, improve, operate and maintain them - a high level of national coordination is required. He expressed reservations about the level of technical coordination currently being achieved, citing two examples:

(i) very little research work is being done here on the very important problem of translating the broadscale numerical products into a form suitable for field applications;

(ii) given the important role of the tropics in Australian weather, it seems incongruous that we have such a miserly involvement in physical and dynamical research projects pertaining to the low latitudes.

To remedy the situation, which is ultimately one of research priorities and resources allocation, he called for a clear definition of national objectives and priorities in meteorological research and proposed that, as far as NWP is concerned, such objectives should be pursued within the framework of a coordinated program involving both applied and fundamental research groups. He expressed confidence in the ability of the Australian scientific community to organise such a framework; if the GARP can achieve an international focus in NWP endeavours, surely we are capable of achieving a corresponding local focus.

Dr R. Smith asked how northern hemisphere forecasting skills compared to southern hemisphere skills, given the better data sources in the northern hemisphere, in particular at the lower levels. In reply, the speaker showed a diagram giving the average monthly S1 skill score for 36 hour forecasts made by the US National Meteorological Center in the period 1949 to 1972. This showed an increasing skill with the introduction of succeeding generations of models. Australian statistics show no comparable increase in skill, and the speaker gave the reasons for this as poorer data sources and the fact that Australia has tended to build on overseas experience. Mr H.R. Phillpot asked if a direct comparison was even possible between Australian and US statistics. Mr Gauntlett replied that a direct comparison of S1 skill scores is difficult since they measure the skill in predicting gradients and are therefore dependent on local synoptic climatology.

Dr G.B. Tucker asked if forecasters were as enthusiastic as the speaker about the relevance of machine prognoses, and what areas did the speaker see as the main ones to concentrate on in future. The first part of the question was answered by Mr J. Brown, who stated that the operational forecasters were enthusiastic up to the point that the machine prognoses freed the meteorologists to do more 'professional' work. In reply to the second part of the question, Mr Gauntlett suggested that more work should be done in the areas of tropical meteorology and in the optimal use of new data now becoming available. It was important to realise that the man and the machine should complement, and not compete with, each other. Mr M. Manton asked if the models have too much short-wave energy, to which the speaker replied that they did but that the new Barker-Kininmonth convective scheme had overcome this to some extent.

Mr H.R. Phillpot queried the need for the attention to detail at the tropopause level. Mr Gauntlett replied by saying that this was dictated by operational requirements, especially aviation. Dr P. Baines inquired about the resolution limit of current models; in particular, could they resolve fronts? The speaker cited some results of workers in the UK who seem to be making encouraging progress towards the description of smaller scale features with high resolution models. There is a minimum wavelength that can be resolved with a given grid length, but the lower limit of useful information lay above this wavelength.

Mr T.T. Gibson asked if it would be necessary eventually to use global numerical models since some studies have shown interhemispheric effects to be important; and would the weaknesses of the current numerical models be significant in this context? The speaker replied that this was a difficult question to answer; 'one off' experiments in this area had shown some effects across the equator for forecasts beyond several days.

Mr R.H. Clarke asked about the precipitation forecasting skill of current models (given that this is a good indicator of model skill) and the sort of results obtained by the speaker in this area. Mr Gauntlett said that, as current Australian operational models have no explicit precipitation mechanisms, there are no operational statistics available. However, the general consensus overseas seems to be that numerical precipitation forecasts have little practical value after about 36 hours. The UK high resolution model does give some detail in this area, but at present, we only have broad scale indications of precipitation.

J.L.G.