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THE WEATHER FORECASTING PROBLEM – IS IT SOLVED IN PRINCIPLE?

By R.H. Clarke

Mr. R.H. Clarke, of the C.S.I.R.O. Division of Meteorological Physics, outlined the general circulation experiments performed by Dr. J. Smagorinsky and collaborators of the Geophysical and Fluid Dynamics Laboratory (G.F.D.L.), Washington, U.S.A.

The primitive equations, consisting of the equations of horizontal motion, continuity, state, and the thermodynamic and hydrological equations formed the basis of all models used. Constraints were kept to a minimum. No attempt was made to remove gravity waves.

The equations of motion take account of horizontal and vertical mixing. The thermodynamic equation includes non-adiabatic heating terms and later models have incorporated a full hydrological cycle. Radiative computations assumed a climatological pattern of cloud cover. Orography was incorporated by using as the independent variable in the vertical, $Q = p/p^*$, where p is the atmospheric pressure and p^* the pressure at the earth's surface. In some models, a "moist convection" process allowing convective precipitation was incorporated.

The equations were integrated on a polar stereographic grid of the northern hemisphere. The highest resolution grid used had 40 grid points from pole to equator, corresponding to grid lengths varying from 160 to 320 km. Nine atmospheric levels, corresponding to pressures of 991, 926, 811, 664, 500, 336, 189, 74 and 9 mb were considered, whilst vertical gradients of the dependent variables were determined at levels midway between these.

Finite difference formulations in the earlier models were of the centred-difference type, but later models used the energy and momentum conserving schemes of Arakawa. Time steps ranged from five to ten minutes. "Smoothing" was performed every 53rd time step, by averaging all dependent variables over three time steps.

For experiments using real data input, initial wind conditions were in some cases supplied by solutions of the "balance" and "ω" equations, whilst in others non-divergent initial conditions were assumed and the former equation only was used. Arbitrary assumptions on the initial distribution of water vapour were also made over no-data and "dry" regions.

The effects on predictions of varying certain parametric controls were as follows. Little difference was observed up to 3 days ahead, between predictions resulting from the energy and momentum-conserving finite difference scheme, and the conventional centred difference scheme. Inclusion of orography produced improved precipitation forecasts in the vicinity of mountain ranges and an overall improvement in forecasts of geopotential, although there was a slight deterioration in the latter east of mountain ranges. The assumption of initial non-divergence had little effect on predictions more than 6 hours ahead. Inclusion of the moist convection process produced predictions, consistent with latitude, of larger precipitation amounts. Doubling the grid resolution produced a dramatic five-fold increase in predicted precipitation, and also produced better prediction of the speed of movement of synoptic features. In general, however, both speeds of movement and intensity of developments of systems were under-predicted.

The best primitive equation model produced an R.M.S. error in a 24-hour prediction of M.S.L. pressure of 4 mb, compared with 5 mb for the best available subjective forecast, where the R.M.S. interdiurnal change was 9 mb. A similar improvement occurred, for 500 mb geopotential forecasts up to 3 days ahead, over the operational Cressman 3 level model used at National Meteorological Centre, Washington (N.M.C). Precipitation forecasts over the U.S. area, both on quantitative and on a 'rain/no rain' basis were significantly better than current subjective forecasts. Forecasts up to 4 days ahead on a 'rain/no rain' basis were 70% successful. Overall, Mr. Clarke considered that if 24 hours forecasts were in question, the answer to the title of the colloquium was "yes".

Future developments likely in general circulation models included extension of experiments to a global scale and an increase in grid resolution as the density of the observational network increased. Also, an advance in the physical understanding of processes such as convection and turbulence might enable the elimination of more constraints.

In conclusion, Mr. Clarke strongly advocated that, in view of the success achieved at G.F.D.L., Australian meteorologists should consider the applicability of primitive equation models to current forecast problems.

In the following discussion, Dr. C.H.B. Priestley said that, when comparing predictions using the primitive equation model and the Cressman 3 level model used at N.M.C., it should be remembered that the latter was specifically designed for real-time operation, whilst the G.F.D.L. model was operating in non-real time.

In reply to questions from Mr. K.T. Morley, Mr. Clarke said that with real data input the models took some hours to reach equilibrium, and that for periods up to 24 hours the mixing terms could possibly be neglected.

Mr. C.E. Wallington said there was a danger that assumptions concerning, for instance, frictional terms and boundary conditions might generate disturbances which appeared realistic but were, in fact, spurious. He emphasised the importance, therefore, of isolating the effects of individual constraints.

Two papers in Monthly Weather Review, December 1965, contain a general account of the models used in G.F.D.L. up to that time.

R.S.S.

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