On the Influence of the Technique of Nonlinear Normal Mode Initialization on the Nonconvective Precipitation Rate

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ABSTRACT

A primitive equation grid-point model is used as a tool to study the impact of nonlinear normal mode initialization on the nonconvective precipitation rate in the model. It is found that the precipitation rate is affected if a simplified precipitation model is used, but no influence is found when a more sophisticated model is used.

1. Introduction

In a recently published paper (Lejenä, 1979) the formulation of nonconvective condensation and subsequent precipitation in primitive equation models for synoptic-scale motion were discussed, and it was shown that under unfavorable conditions it may take up to 15 h until the hemispheric precipitation rate, starting from an initially low value, reaches a constant level. The reasons for this were found to be the initial moisture fields, and the lack of initial vertical velocities. Operational analysis of moisture data normally yields moisture fields which are too smooth. It was shown that, provided the model in some way has created appropriate vertical velocities, it will take about 6 h to reach a constant hemispheric precipitation rate, starting the forecast with operationally analyzed moisture data. Equally important is lack of initial vertical velocities, which is the case if mass and wind data are adjusted to each other by solving the balance equation. It was also demonstrated that including vertical velocities into the initial state, calculated according to quasi-geostrophic theory, does not influence the hemispheric precipitation rate significantly.

A matter not discussed in Lejenä (1979) is the possible influence of the normal-mode initialization technique on the precipitation rate. An improvement, compared to the precipitation rate in models using other initializations techniques, might be expected, as the normal mode technique yields initial vertical velocities. Another point of interest not discussed in that paper is the effect of utilizing a more sophisticated model for release of precipitation.

The purpose of the present note is to present results throwing some light on these two questions.

A series of forecasts have been made with the ECMWF (European Centre for Medium Range Weather Forecasts) grid-point model. The main features of this model is that it has an enstrophy-conserving finite-difference scheme and a semi-implicit time-stepping scheme. The time step in the present experiments was 15 min. The horizontal grid was a latitude/longitude system with grid lengths $\Delta \lambda = \Delta \phi = 1.875^\circ$ (N48), and the vertical resolution was 15 vertical levels, unequally spaced so as to give sufficient resolution in the troposphere near the lower boundary and near the tropopause1 (for further details see Burridge and Haseler, 1977).

Data from 0000 GMT 16 January 1979 were used, and mass and wind fields were adjusted using the technique of nonlinear normal mode initialization (Temperton and Williamson, 1979). The moisture fields were obtained from the ECMWF routine analysis, that is, by analyzing precipitable water at standard pressure levels followed by a vertical interpolation utilizing spline functions. This analysis procedure appears to give results comparable to others, i.e., the moisture fields are too smooth.

2. Simplified large-scale condensation

The first experiments were devoted to studying the possible impact of the technique of nonlinear normal mode initialization on the large-scale precipitation. The condensation model in these experiments was the simplest possible; condensation was assumed to occur if

$$q \geq q_{\text{max}},$$

1 The vertical coordinate was $\sigma = \rho/\rho_v$. 
where \( q \) is the specific humidity, \( q_{\text{max}} \) the saturation specific humidity and \( \alpha \) a constant (\( \ll 1 \)) used for tuning purposes. The condensed water was assumed to fall out immediately at the surface, except the part that was assumed to evaporate in dry layers of the air. Evaporation was treated as suggested by Kessler (1969).

Three experiments were done, by varying \( \alpha \) as follows:

(i) \( \alpha = 1 \),
(ii) \( \alpha = 0.90 + 0.10 \exp[-7(1 - \sigma)] \),
(iii) \( \alpha = 0.80 + 0.20 \exp[-7(1 - \sigma)] \).

In experiments (ii) and (iii) \( \alpha \) was given an exponential decrease with height, following the suggestion by Hollingsworth et al. (1979). It means that \( \alpha \approx 0.9 \) above \( \sigma = 0.7 \) for experiment (ii) and \( \alpha \approx 0.8 \) above \( \sigma = 0.7 \) for experiment (iii). The global average of the precipitation rate during the experiments was evaluated as released latent heat per square meter, that is, the gain of energy per unit time by the atmosphere due to condensation. The results from these three experiments are shown in Fig. 1. The full line is from experiment (i), the dashed line from experiment (ii) and the dash-dotted line from experiment (iii). As expected, experiment (iii) gives more precipitation than experiment (ii), which in turn gives more than experiment (i). The most striking features are that a considerable amount of precipitation falls from the beginning, and that it takes \(~6 \text{ h}\) until the precipitation rate has reached a level at which it becomes constant. In Lejenäs (1979) it was shown that too a smooth moisture field and lack of initial vertical velocities caused a delay of up to 15 h before the precipitation rate became constant. It was also demonstrated that vertical velocities deduced from quasi-geostrophic theory had no impact on the precipitation rate. Thus, we have just seen the pronounced impact of the normal mode technique on the precipitation rate. The presence of initial vertical velocities supplied by this method leads to a considerable improvement of the precipitation rate from the beginning of the forecast. These findings are in accordance with those of Daley (1979). He showed that the precipitation at a specific point increased during the first few hours of the forecast if the normal mode technique was applied to initial data. The problem with the quasi-geostrophic vertical motions is probably not that they are inaccurate, but rather that they oscillate rapidly in time because the model is not properly balanced by the quasi-geostrophic method. It requires the steady non-oscillating vertical motion given by the normal mode method to achieve a constant precipitation rate rapidly. Although the results presented here (Fig. 1) show considerable improvement over those in Lejenäs (1979), they are not completely satisfactory. Thus, for instance, the equilibrium precipitation rate, reached after 6 h, is \(~50\%\) higher than the initial rate. Obviously more work has to be done on moisture analysis and initialization.

The dotted line in Fig. 1 shows the energy input per time unit into the atmosphere caused by convective precipitation parameterized following the suggestion by Kuo (1974). We notice the same behavior of the global convective precipitation rate as for the global nonconvective precipitation rate, \textit{viz.}, it takes some time, in this case \(~10 \text{ h}\), before the convection is entirely developed.

According to Sellers (1965) the climatological global mean value of the precipitation is 1000 mm year\(^{-1}\), and we thus should have an energy input into the model atmosphere of the order 80 W m\(^{-2}\) due to condensation (in our case immediately released as precipitation), if the model correctly
reproduces the precipitation in the atmosphere. In view of the fact that most of the convective precipitation falls in tropical regions, the latitudinal distribution of precipitation as given by Sellers (1965) indicates that the amount of released latent heat per unit area due to convective and nonconvective precipitation should be about the same. Thus, according to Fig. 1 the second experiment, when \( \alpha = 0.90 + 0.10 \exp[-7(1 - \sigma)] \), should be the best parameterization of the nonconvective precipitation (the amount of convective precipitation was about the same in all experiments), although it seems as this model, compared to reality, underpredicts the precipitation, also after 6 h.

It seems that the vertical velocities resulting from the normal mode technique partly solve the problem of too little precipitation during the first hours of a prognosis, when a simplified condensation model is used. Such an improvement is important, if not necessary, in connection with short range forecasts and especially for limited area forecasts. One should, however, remember that for limited area forecasts, this approach of adjusting mass and wind fields to each other has not yet been solved.

3. A condensation model allowing the existence of cloud water

The condensation products in the atmosphere do not fall out immediately as precipitation. A simple model, taking this into account, was used in another three experiments to study the behavior of the precipitation rate when a somewhat more sophisticated (compared to that one in Section 2) condensation model is used. In this model vertical redistribution of condensed water is allowed, and conditions for release of precipitation may be put forward. It is thus possible to account for the fact that precipitation from freezing clouds will not start until the temperature of the cloud top reaches a certain value. For non-freezing clouds, observations indicate that precipitation will not fall from cloud layers having a depth \( \leq 1 \) km. We also know that the coalescence increases as the number of droplets per unit volume increases, and that a thick cloud layer is more effective in forming raindrops than a shallow one.

Assuming that the condensation products are water droplets, a parameter \( q_{ew} \), which may be interpreted as cloud water mixing ratio, was introduced, and \( q_{ew} \) was defined as:

\[
q_{ew} = \begin{cases} 
0, & q \leq \beta q_s(T), \\
q - \beta q_s(T), & q > \beta q_s(T),
\end{cases}
\]

where \( \beta \) is a constant (\( \leq 1 \)) used for tuning purposes. The two mechanisms for release of precipitation were parameterized as follows:

1) FREEZING CLOUDS: Precipitation was assumed to start as soon as the cloud top temperature was equal to or below \(-12^\circ\)C.

2) NON-FREEZING CLOUDS: The precipitable cloud water defined as

\[
P_{ew} = g^{-1} \int_{P_t}^{P_b} q_{ew} dp
\]

was evaluated and rain was assumed to start as soon as the precipitable cloud water exceeded 2 mm (2 kg m\(^{-2}\)). This threshold value was chosen to account for the observed facts discussed above.

The results from two of these experiments are
shown in Fig. 2. In this figure we have plotted that part of the released latent heat that corresponds to released precipitation. The full line is from an experiment in which $\beta = 1$, and the dotted line from another one in which $\beta = 0.9$. The most outstanding feature in these experiments is that the precipitation rates are considerably smaller than those obtained with the model in Section 2. We also notice that during the first 15–20 h most of the condensed water vapor is used to produce clouds. This is also seen in Fig. 3 which shows the percent of the condensed water that falls out as precipitation (the full line is obtained when $\beta = 1$, and the dotted line when $\beta = 0.9$). The curves were obtained by evaluating the ratio between that part of the released latent heat that corresponds to precipitation, and the total amount of released latent heat. It should be stressed that intensities were used, that is, the values in Fig. 2 and corresponding values for the total amount of released latent heat. Fig. 3 shows that this model needs at least 18 h to build up the nonconvective clouds. Figs. 2 and 3 suggest that the full and the dotted lines in Fig. 3 will reach the same level as corresponding lines in Fig. 1, and we thus conclude that a good treatment of the condensation and precipitation processes will not be the case until after a forecast length of 18–20 h. Finally, it should be mentioned that the very last experiment, when $\beta = 0.8$, showed the same behavior of the precipitation rate as corresponding curves in Fig. 2. The precipitation amounts were, however, unrealistically high, and it is believed that $\beta = 0.8$ is not a realistic value to use in this cloud model.

The vertical velocities resulting from the normal mode initialization technique seem to have little impact on the global precipitation rate in a more sophisticated cloud model. Presumably the positive impact of the initial vertical velocities was lost because of the long spin-up period required by the model to fill the cloud-water reservoir which was virtually empty initially. The normal mode initialization, when used with a cloud initialization, would probably improve the initial precipitation rates to the extent that they were improved for the simple cloud model (Fig. 1).

REFERENCES


