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On dynamic initialization experiment in Indian region*

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सार – भारतीय क्षेत्र में पूर्वंग समीकरण दाबघनत्वी प्रतिदर्श के लिये प्रारम्भिक पवन एवं दाब क्षेत्रों के संतुलन के लिये गतिक प्रारम्भीकरण (ग० प्रा०) और स्थिति प्रारम्भीकरण (स्थि० प्रा०) के तुलनात्मक कौशल की खोज की गई है। गतिक प्रारम्भीकरण प्रयोग के उद्देश्य के लिये प्रतिदर्श समीकरणों के समुच्चय को किसी चर के बिना पुन: स्थापन किये आयलरपश्चगामी समयान्तर अधियोजना का पालन करते हुए प्रारंभिक समय के अग्र और पश्चगामी पर समाकलित किया गया है। स्थित प्रारम्भिकरण के लिये अरैखिक संतुलन समीकरण को अनपसारी पवन से संतुलन ऊंचाई क्षेत्र को ज्ञात करने के लिये हल किया गया है।

दोनों अधियोजनाओं से प्रारम्भीकरण प्रयोगों के परिणामों की तुलना की गई और चर्चा की गई। गतिज प्रारम्भीकरण अधियोजनाओं के प्रारम्भिक क्षेत्रस्थित प्रारम्भीकरण अधियोजना पर आधारित प्रारम्भिक क्षेत्रों से ज्यादा अच्छे पाए गए हैं।

ABSTRACT. A comparative performance of dynamic initialization (DI) and static initialization (SI) schemes for balancing initial wind and pressure fields for primitive equation barotropic model in Indian region has been investigated. For the purpose of dynamic initialization experiment the set of model equations are integrated forward and backward around the initial time following Euler backward time difference scheme without restoration of any variable. For static initialization the nonlinear balance equation is solved to obtain the balance height field from non-divergent wind.

The results of initialization experiments from both the schemes are compared and discussed. The initial fields from DI scheme are found to be superior than those based on SI scheme.

1. Introduction

The large-scale atmospheric motions are normally in quasi-nondivergent hydrostatic balance and small scale fluctuations are rapidly restored towards a balanced state through the adjustment processes and by dissipative forces. However, the observed mass and motion fields show large imbalances due to inaccurate observations and analyses. Thus, state of quasi-nondivergent hydrostatic balance in the initial field known as initialization is the basic prerequisite of initial data for successful integration of numerical models.

Basically, there are two approaches, *viz.*, static initialization and dynamic initialization. The examples of static initialization are:

(a) The solution of balance equation and omega equation and

(b) the normal mode initialization.

Normal mode initialization is based on the idea of expanding initial data into normal modes or free oscillations of linear or nonlinear versions of the model. The model amplitude thought to be unrealistically large can be set to zero or considerably reduced. Recently a number of

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studies have been reported to balance initial mass and motion fields by normal mode initialization (Williamson and Dickinson 1976, Machenhauer 1977, Baer 1977, Baer and Tribbia 1977).

The dynamic initialization scheme which uses primitive equations directly has been developed by Miyakoda and Moyer (1968) and Nitta and Hovermale (1969). In this approach the data of dominant variable are inserted into the prognostic equations and the balance is achieved by integrating the system of equations back and forth by using numerical analogue which tend to suppress the gravity waves but do not affect the meteorological component significantly.

The object of the present study is to discuss the applicability of dynamic initializaton scheme and assess whether it is superior than the conventional balance scheme for the synoptic scale disturbances in the summer monsoonal flow. For this purpose we propose to use primitive equations relevant to the divergent barotropic model for dynamic initialization following Winninghoff (1973), Kanamitsu (1975) and Kiangi (1977). The initial balance data has also been constructed using nonlinear balance equation. The salient features and differences among the two sets of initialized fields are discussed.

2. Methods of computation

2.1. *Model equations*

In the case of a divergent barotropic model the prediction equations (shallow water equations) for the three unknown u, v and h in cartesian coordinate system on Mercator projection are:

$$\frac{\partial u}{\partial t} + m\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial h}{\partial x}\right) - fv = 0 \quad (1)$$

$$\frac{\partial v}{\partial t} + m\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial h}{\partial y}\right) + + fu = 0 \quad (2)$$

$$\frac{\partial h}{\partial t} + m\left[u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} + + h\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)\right] - vh\frac{\partial m}{\partial y} = 0 \quad (3)$$

where u, v, are the components of the horizontal velocity vector (u-along the x-coordinate pointing eastward and v-along the y-coordinate pointing northward), h the height of a free surface ($h = 0$ is the mean sea level), t time, g acceleration due to gravity, m the map factor (secant of latitude) and f the coriolis parameter.

2.2. *Static initialization scheme*

The mass and motion fields are balanced through the solution of non-linear balance equation. Details of the scheme are given in Singh and Saha (1976) and Singh (1978).

2.3. *Dynamic initialization scheme*

For achieving mutual adjustment between motion and mass fields the set of Eqns. (1) through (3) are simultaneously integrated 10 time steps forward and backward (one iteration) using Euler backward time difference scheme with one predictor and one corrector. The scheme is carried out using the initial observed wind (u, v) and height (h) derived from the solution of nonlinear balance equation. The above operation is repeated nine times equivalent to 180 time steps of integration. All the variables are allowed to freely adjust and no variable is restored. The root mean square difference of two successive iteration for u, v and h fields is used as criteria for convergence of the scheme. The parcel invariant quantities for the closed system of Eqns. (1) through (3) are the following:

Potential vorticity $[(\zeta+f)/h]$ and all powers of it;

and the total energy $[(h/2)(u^2+v^2+gh)]$

where ζ is the relative vorticity. Therefore, it is necessary that the application of this model should ensure near invariance of these quantities. In addition, the mean absolute value of velocity divergence have also been constructed for the whole domain and for the area covered by the synoptic scale cyclonic circulation under consideration within the domain to check the quality of initialization.

2.4. *Finite difference scheme and boundary condition*

In numerical solution of Eqns. (1) through (3) the finite difference scheme suggested by Shuman (1962) has been used throughout. For the purpose of boundary condition, no flow is permitted across north-south boundaries and cyclic continuity in east-west direction removes the requirement of boundary specification.

3. Data

For the present study, two typical synoptic situations dominated by a monsoon depression, *i.e.*, on 4 and 5 August 1968, have been chosen. Since input to the model is wind the manual analysis of streamlines — isotachs are done for 0000 GMT at 700 mb in both cases. Singh and Saha (1976) have given the justification for selecting 700 mb level for the summer monsoon flow forecast. Fig. 1 presents the wind vector

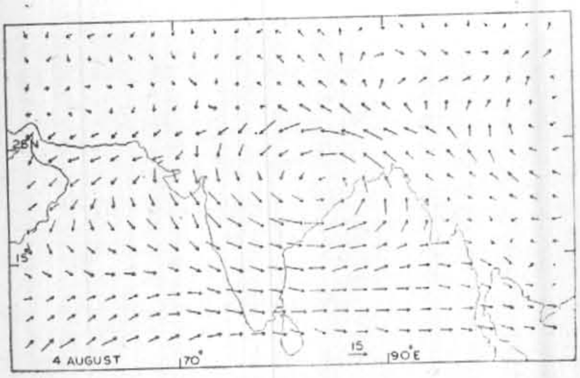

Fig. 1. Observed wind vector (ms^{-1}) at 0000 GMT, 700 mb 4 August 1968

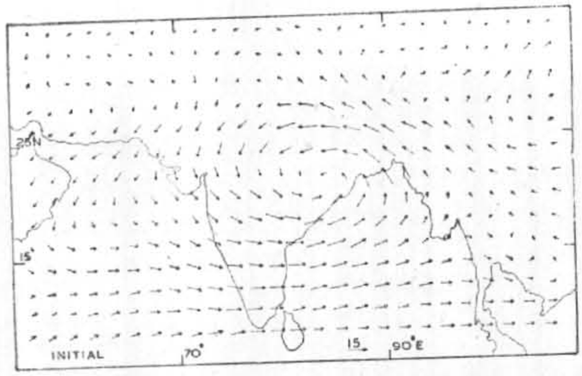

Fig. 2. Initial wind vector field (ms^{-1}) 0000 GMT, 700 mb 4 August 1968 (dynamic initialization scheme)

TABLE 1

Variations of mean potential vorticity, mean square potential vorticity, mean total energy, mean absolute divergence for the whole domain and mean absolute divergence for the cyclonic domain (from latitude 16-28° N and longitude 74°-94° E) during dynamic initialization experiments

Iteration No.	Time step	Mean potential vorticity (10^{-8} m^{-1} s^{-1})		Mean square potential vorticity (10^{-16} m^{-2} s^{-2})		Mean total energy 10^{-7} m^3 s^{-2}		Mean total divergence 10^{-6} s^{-1} Whole domain		Mean total divergence 10^{-6} s^{-1} Cyclonic domain	
		4 Aug	5 Aug	4 Aug	5 Aug	4 Aug	5 Aug	4 Aug	5 Aug	4 Aug	5 Aug
1	20	2.675	2.693	8.471	8.456	1.945	1.956	5.479	5.506	3.274	6.091
2	40	2.675	2.693	8.470	8.455	1.945	1.956	4.478	4.577	2.468	5.028
3	60	2.675	2.693	8.469	8.454	1.945	1.956	3.800	3.922	1.946	4.316
4	80	2.675	2.692	8.469	8.453	1.945	1.956	3.316	3.449	1.597	3.842
5	100	2.675	2.692	8.468	8.452	1.945	1.956	2.959	3.106	1.402	3.486
6	120	2.675	2.692	8.467	8.451	1.945	1.956	2.687	2.851	1.271	3.220
7	140	2.675	2.692	8.467	8.451	1.945	1.956	2.471	2.657	1.174	3.009
8	160	2.675	2.692	8.466	8.450	1.945	1.956	2.300	2.501	1.114	2.828
9	180	2.675	2.692	8.466	8.449	1.945	1.956	2.161	2.371	1.084	2.676

field at 0000 GMT, 700 mb 4 August 1968. The domain of integration extends from 6 deg. N to 36 deg. N and 56 deg. E to 106 deg. E. A two-degree latitude-longitude grid is used in both the cases. A time step of 5 minutes is found suitable for this purpose for the choice of grid distance. The mean height of the free surface is taken as 2000 gpm corresponding to 700 mb. This value is little higher than the one used by Singh and Saha (1976). However, 2000 gpm was found to be more suitable in the present experiments. Krishnamurti *et al.* (1978) have also suggested the same value for the GATE area.

4. Results of experiments in dynamic initialization

Since the results of the initialization experiments are similar for both synoptic situations, figures in respect of 4 August 1968 will be presented only in the paper, and wherever necessary the results of 5 August 1968 will be discussed.

Fig. 2 presents the dynamically initialized wind fields at 0000 GMT, 700 mb for 4 August 1968. The figure reveals that all map features of the observed wind are retained in the dynamically initialized wind with more or less same intensity. Thus, the basic desirability of any initialization scheme that the difference between balanced and unadjusted input parameter (wind in this case) should be small is satisfied. Fig. 3 presents the rms difference of two successive iterations in respect of u, v and h fields for various iterations. The rms difference for all fields rapidly decreases for first few iterations and then decreases rather slowly. Towards the end, the percentage decrease is nearly 10 per cent which suggest the achievement of convergence of the

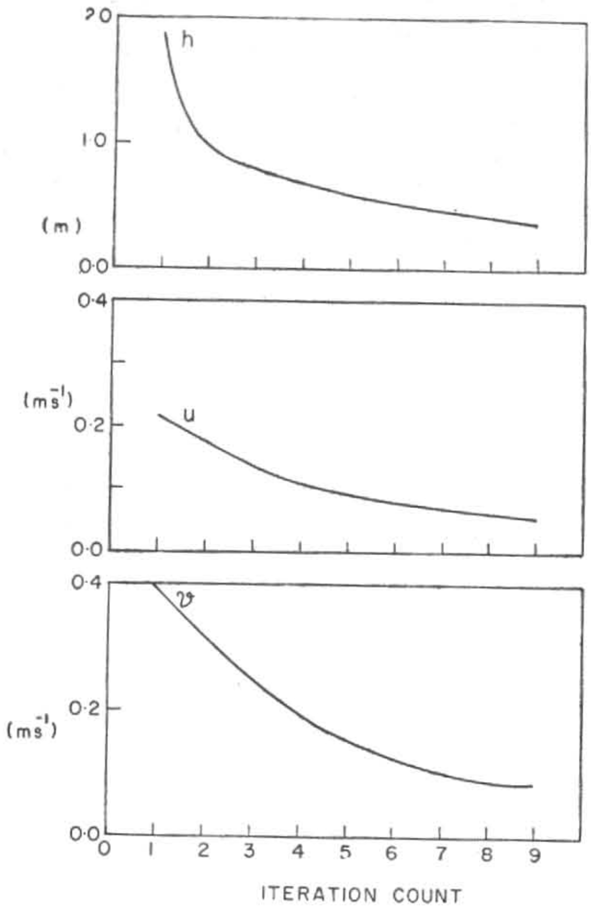

Fig. 3. Root mean square difference between two successive iterations (input-4 August 1968)

TABLE 2

Geopotential height at the centre of depression, location and height gradient ($\partial h/\partial x$, $\partial h/\partial y$) obtained in various schemes of initialization

Scheme	I	II	III	IV	V
	Input — 0000 GMT, 700 mb 4 August 1968				
Height values at the centre (gpm)	1902	1926	1923	1906	1909
Location of the centre	22°N, 83°E	22°N, 83°E	22°N, 83°E	22°N, 83°E	22°N, 83.5°E
Height gradient (10^{-5})	7.9 (N-S) 5.2 (E-W)	5.7 (N-S) 3.5 (E-W)	5.8 (N-S) 3.3 (E-W)	7.5 (N-S) 5.1 (E-W)	7.6 (N-S) 5.2 (E-W)
	Input — 0000 GMT, 700 mb 5 August 1968				
Height values at the centre (gpm)	1905	1927	1923	1910	1914
Location of the centre 23°N	23°N, 79°E	23°N, 79°E	23°N, 79°E	23°N, 79°E	23°N, 79°E
Height gradient (10^{-5})	6.4 (N-S) 4.2 (E-W)	5.0 (N-S) 3.2 (E-W)	5.5 (N-S) 3.3 (E-W)	7.4 (N-S) 4.8 (E-W)	6.9 (N-S) 4.7 (E-W)

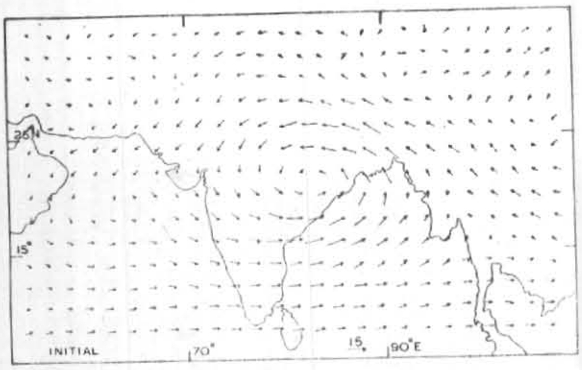

Fig. 4. Initial wind vector field (m s^{-1}) 0000 GMT, 700 mb 4 August 1968 (non-divergent wind)

scheme. Similar criteria were utilised by Kanamitsu (1975) and Carr (1977) in their tropical prediction models.

Table 1 gives the numerical value of the conservative quantities of the model, *viz.*, the mean potential vorticity, mean square potential vorticity and mean total energy at various stages of the dynamic initialization. In addition, the mean absolute value of divergence for the whole domain and for the region covered by cyclonic flow have also been presented in the table. Small fluctuations in the conservative quantities suggest that the numerical model experiment satisfactorily preserves these domain averaged quantities.

Mean divergence decreases continuously throughout the experiment which is due to geostrophic adjustment between mass and motion fields. While comparing the observed wind field with the finally adjusted wind field after the dynamical initialization, it is found that the total wind field did not show much change. It is also observed that the rate of decrease of mean divergence over the entire domain during the initialization was comparable with that over the cyclonic domain. Besides, at the end of the experiment weak divergence (Table 1) is retained over the region.

5. Comparison of initialization schemes

Geopotential height fields (not presented) derived from SI scheme and DI scheme show that the flow patterns remain similar in both the schemes although individual values and the horizontal gradients are slightly different from each other. As far as wind is concerned there is remarkable difference in the intensity of the wind from static (Fig. 4) to dynamic initialization experiments. The latter schemes yields stronger wind field than the former which is understandable since the SI scheme retains nondivergent part of wind only where as the DI scheme incorporates the total wind.

In order to examine the height fields more critically, the height gradient around the depression is computed for both the schemes and presented in Table 2. The location and the absolute value of the free surface height at the centre of monsoon depression have also been presented in Table 2. The minor difference between the two schemes as seen from Table 2, appears to suggest that for a barotropic model the balance equation initialization is quite effective and dynamic initialization brings out very little improvement in the initial height field. However, in the present experiment our chief synoptic feature lies sufficiently away from the equator. Therefore, to test the validity of the SI *vis-a-vis* DI, a case study of equatorial latitude weather system would be desirable.

6. Concluding remarks

Although our earlier studies (Singh and Saha 1976 and Singh 1978) and the present experiment suggest that the nonlinear balance equation solution is quite adequate to bring out balance between mass and motion fields for one level primitive equation model; the better geometry of weather system and restoration of nearly the observed intensity of wind field obtained in dynamically initialized fields might improve the useful range of forecast.

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