Joint IMD-WMO Group Fellowship Training

on

Numerical Weather Prediction

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Lecture Note

on

Definition of initialization, its importance and its different types, viz., Static, Dynamic, Normal mode, Dynamic normal mode & Physical, Nudging

by

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<u>Initialization in Numerical Weather Prediction</u>

1. Introduction:

The atmospheric motions are comprised of phenomena encompassing a vast spectrum of periods ranging from seconds to years. In the short to medium range, the atmospheric motions which are typical of interest to the forecasters have time scales of few hours to days. The weather models used for numerical weather prediction (NWP) describes a broader span of dynamical features than those which are of direct concern. These higher frequency components for many purposes are considered as noise, which contaminates the atmospheric motions of meteorological interest. These noises can be eliminated by adjusting the initial model fields. The process used to eliminate these noises and reduce the imbalance in the initial conditions is called ***<u>'Initialization'</u>***.

In the atmosphere, a very delicate balance exists between the pressure and wind fields which ensure that the fast travelling gravity waves have a much smaller amplitude compared to the slow rotational part of the flow. The balance maintained in the atmosphere is very subtle and is delicate such that even minor perturbations can disrupt the balance. For numerical weather prediction, the basic equations used are unable to maintain the balance between the mass and velocity fields in the analysis. This can generate anomalously large gravity-inertia waves and may induce spurious oscillations in the forecast fields, with high frequency and large amplitude. These spurious oscillations may persist for a long. It is required to incorporate in the forecast model some strong dissipative forces, which will restrict these spurious oscillations to persist for long.

The purpose of the Initialization procedure is to prepare grid point data with which the model can integrate forward in time with a minimum of noise and maximum accuracy of the forecasts of the meteorological scales that the model is designated to simulate. Thus the procedures for eliminating gravity waves and reducing the imbalance in the initial fields before integrating the mathematical equations in a numerical weather model are known as ***Initialization*** (Sen 2019).

The different types of Initialization procedures used in NWP can be classified as:

i. Static Initialization
ii. Dynamic Initialization
iii. Nudging
iv. Normal Mode Initialization
v. Dynamic Normal Mode Initialization
vi. Physical Initialization

2. *Static Initialization*

In 1950, Charney, Fjørtoft and Von Neumann used a set of quasi-geostrophic equations as a filtered system to modify the prediction equations. This resulted in poor forecasts as they involved approximations that are not always valid. A Non-linear Balance equation that more accurately filters the primitive equations is given by:

$$\nabla \cdot (f\nabla\Psi) + 2\left\{\frac{\partial^2\Psi}{\partial x^2}\frac{\partial^2\Psi}{\partial y^2} - \left(\frac{\partial^2\Psi}{\partial x\,\partial y}\right)^2\right\} = \nabla^2\varphi \tag{1}$$

In eq-1, 'Ψ' implies the Stream Function and 'φ' the Geo-potential. From analyzed geo-potential fields on the pressure surfaces, the geo-potential 'φ' is evaluated at each grid-point and eq-1 is solved as a boundary value problem for 'Ψ'.

A simplified version of eq-1 is used and can be represented as:

$$\nabla \cdot (f\nabla\Psi) = \nabla^2\varphi \tag{2}$$

Eq-2 has fewer complexes compared to eq-1 and can be used for initialization. Eq-2 is called Linear Balance Equation. When used for initialization, the process is termed ***Static Initialization***.

3. Dynamic Initialization

In numerical weather prediction (NWP), the primitive equation models have the mechanism for geostrophic adjustment. If these models are integrated forward and backwards about the initial time and are allowed to make adjustments before the starting of the forecast, they can themselves do the initialization job. The initialization process which involves the integration of the NWP models backwards and forward in time about the initial state is called the *Dynamic Initialization* (Sen 2019). For this process, the integration schemes used are desired to have selective damping characteristics, which will damp the high-frequency waves more efficiently than the low-frequency waves.

4. Nudging

Newtonian Relaxation or Nudging is one form of Dynamic Initialization. This involves performing an initialization integration during which the model variables are driven or nudged towards the observed values by using extra forcing terms in the prognostic equations. These extra forcing terms are called Nudging Coefficients. On reaching the initial time, the nudging coefficients are removed and the forecast continues without any forcing. The objective of this initialization is to bring the observed data and the model values in close harmony so that it provides a relatively noise-free start for the model to integrate. Nudging coefficients added to each prognostic equation can be assumed to be a function of observation accuracy, of the distance between an observation and the grid point, of the variable nudged, and of the typical magnitudes of the other terms in the prognostic equations (Pielke, Sr. 2002).

5. Normal Mode Initialization (NMI)

Normal Mode Initialization provides a useful and efficient alternative to dynamic initialization. This approach eliminates the integration period needed by the dynamic initialization method to remove inconsistencies in the input data. For an oscillating system, the Normal Mode is defined as a pattern of motion in which all parts of the system moves in sinusoidal with the same frequency. These fixed frequencies of the normal mode of an oscillating system are termed as Natural Frequencies or, referred to as Eigen Function. In the Normal Mode Initialization process, the high-frequency and low-frequency modes of the model are segregated using horizontal and vertical structure functions for the atmosphere at the initial time. The undesirable high-frequency modes considered as noise, having no metrological significance is eliminated. This initialization method proves effective with the availability of sufficient observations.

6. *Dynamic Normal Mode Initialization*

Dynamic Normal Mode Initialization (DNMI) is a simpler variation of Normal Mode Initialization where all physical processes used in the model were taken into account through the initialization but no problem of convergence was found (Satomura 1988). In this method, the NWP model equations are integrated forward and backwards about the initial time in cycles with a selective damping scheme. During the integration cycle, the non-linear terms are kept constant. After the completion of the integration cycles, the non-linear terms are updated. The integration cycle is repeated and the corresponding update of the non-linear terms. The older version of Dynamic Initialization though capable of eliminating high-frequency gravity waves from the initial fields required much more computational time compared to DNMI. This was because, unlike DNMI, it updated the non-linear terms at each forward and backward integration.

7. *Physical Initialization*

In the 4-dimensional assimilation techniques, the rotational part of the wind, the temperature and surface pressure fields can be represented reasonably contrary to the humidity variables, rainfall rates and the divergent winds (Krishnamurti 1991). The Physical Initialization involves the assimilation of precipitation or humidity fields using the Newtonian Relaxation technique, through which the temperature and moisture profiles are modified so that the model during the analysis cycle is forced to produce precipitation similar to the observed precipitation (Kalnay 2003). In general, the physical initialization method consists of two steps (Krishnamurti 1991).

In the first step diagnostics of surface fluxes, humidity analysis consistent with the surface fluxes and observed rainfall rates, humidity analysis consistent with the net outgoing longwave radiation, are computed. In the second step, the computed values from the first step are incorporated during the NWP model's pre-integration phase. Newtonian Relaxation or Nudging method is used, where an additional term is added to the model's dynamical and thermos-dynamical equations.

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