DIONYSOS, a Fully Balanced Diagnostic Tool for Studying Weather Systems, and its Potential Role in THORPEX

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Abstract: DIONYSOS is a diagnostic package specifically adapted to standard output from numerical weather prediction models that allows for the diagnosis of significant parameters related to weather systems evolution and structure such as development (vorticity, geostrophic vorticity and height tendencies), temperature tendencies, vertical motion and divergence. The most recent version is based on a complete omega equation, the full vorticity equation, the thermodynamic equation and a nonlinear balance equation. The only assumptions used are that the atmosphere is in hydrostatic and nonlinear balance. We present a web based interactive interface that allow the user to explore the diagnostics results on a daily basis and plans to further enhance the online and interactive diagnostics interface to allow THORPEX scientists to diagnose any weather system from any available numerical model.

1. Introduction

DIONYSOS is a diagnostic software specifically developed to be applicable to standard output of numerical weather prediction (NWP) models. This diagnostic package allow for the interpretation, intercomparison and verification of model forecast from synoptic to dynamic perspectives on a real-time and retrospective basis. DIONYSOS have the uniqueness that in can be run using only standard output from most of NWP model ensuring its applicability to a variety of modeling system. This was made possible by developing parameterizations of the forcings that would have required special model output. The newest version of DIONYSOS adopts Räisänen (1997) diagnostic approach, based on only a few approximations to the primitive equations and similar to Krishnamurti (1968), to partition vertical motion, vorticity tendency and height tendency into several forcing contributions, including diabatic heating and friction. Complementary equations were added to compute individual forcing contributions to temperature and geostrophic vorticity tendencies, and to divergence. Currently, DIONYSOS is running operationally at the Canadian Meteorological Center (CMC) in Montreal. It is also running daily at the Université du Québec à Montréal on three different models (GEM, GFS and NAM) from two different countries, over three different domains: North America, Western Europe and New Zealand and the results are available online trough an interactive web-based interface.

The present paper present a brief description and validation of this diagnostic package as well as an overlook of the current and plan capabilities of the interactive web-based interface. For complete details on DIONYSOS interested readers are referred to Caron *et. al.* (2003).

2. Input data and forcings

To be executed DIONYSOS needs three-dimensional gridded model data (u, v, T, ϕ and ω) on isobaric surfaces between 1000 hPa and 100 hPa. Surface field of pressure, accumulated precipitation and sensible heat flux are also needed. From these data six forcings are computed: the Laplacian of temperature advection (*LTA*), the Laplacian of diabatic heating (which is, in DIONYSOS, divided into only a Laplacian of sensible heat flux (*LSH*) and a Laplacian of latent heat release (*LLH*)), vorticity advection (*VA*), friction (*FR*) and orography (*OR*). *VA* and *LTA* are computed directly from the model wind and temperature data while *LSH*, *LLH*, *FR* and *OR* are derived from the model data using in-house parameterization.

3. Diagnostic equations

DIONYSOS is based on a complete ensemble of hydrostatic diagnostic equations that are solved using the assumption that the atmosphere is in a nonlinear balanced state *a) Omega equation – Vertical motion*

To partition the vertical motion into forcing contribution, the complete hydrostatic omega equation in pressure coordinate from Räisänen (1995) is used:

$$\eta(\omega_F) = F + f\frac{\partial}{\partial p}\left(\frac{\partial \zeta_{AG}}{\partial t}\right)_F$$

where F represent the individual forcings and η is a three-dimensional operator linear with respect to ω and function of the static stability, the coriolis parameter, the relative vorticity and the vertical shear. The ageostophic vorticity tendency term (*AG*) on the right hand side of the equation is, in DIONYSOS, divided into forcing contribution. The AG term is neglected the first time that the equation is solved and only included in the end of the diagnostic procedure as explain later on. Given homogenous conditions (ω=0) on all (lateral, upper and lower) boundaries, a contribution to vertical motion for each forcing is obtained by using three-dimensional sequential over-relaxation.

b) Continuity equation - Divergence

The forcing contributions to divergence can be obtained directly by using the continuity equation and the diagnosed vertical motion for each forcing:

$$(\nabla \cdot \mathbf{V})_F = -\frac{\partial \omega_F}{\partial p}$$

c) Vorticity equation – Vorticity tendency

Following Räisänen (1997), using the diagnosed vertical motion for each forcing and the complete vorticity equation, contributions to vorticity tendency for the six forcing can be obtained separately:

$$\left(\frac{\partial \zeta}{\partial t}\right)_X = X + (f+\zeta)\frac{\partial \omega_X}{\partial p} - \omega_X \frac{\partial \zeta}{\partial p} - \left(\frac{\partial \omega_X}{\partial x}\frac{\partial v}{\partial p} - \frac{\partial \omega_X}{\partial y}\frac{\partial u}{\partial p}\right), \quad X = VA, FR$$

$$\left(\frac{\partial \zeta}{\partial t}\right)_Y = (f+\zeta)\frac{\partial \omega_Y}{\partial p} - \omega_Y \frac{\partial \zeta}{\partial p} - \left(\frac{\partial \omega_Y}{\partial x}\frac{\partial v}{\partial p} - \frac{\partial \omega_Y}{\partial y}\frac{\partial u}{\partial p}\right), \quad Y = \text{LTA, LLH, LSH, OR}$$

d) Thermodynamic equation –Temperature tendency

Using the diagnosed vertical motion for each forcing and the thermodynamic equation, contributions to the temperature tendency for the six forcings can be obtained separately:

$$\left(\frac{\partial T}{\partial t}\right)_W = S\omega_W + W \qquad , W = LTA, LLH, LSH$$

$$\left(\frac{\partial T}{\partial t}\right)_Z = S\omega_Z \qquad , Z = VA, FR, OR$$

e) Nonlinear balance equation - Height Tendency

As in Räisänen (1997), a partition of the height tendencies is perform by converting each diagnosed vorticity tendencies in term of streamfunction tendencies and inverting the left hand side Laplacian operator of the temporal differentiation of the nonlinear balance equation (e.g. Charney 1955):

$$\nabla^2\left(\frac{\partial \phi}{\partial t}\right)_F = f\nabla^2\left(\frac{\partial \psi}{\partial t}\right)_F + 2\left[\frac{\partial^2}{\partial x^2}\left(\frac{\partial \psi}{\partial t}\right)_F \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial x^2}\frac{\partial^2}{\partial y^2}\left(\frac{\partial \psi}{\partial t}\right)_F - 2\frac{\partial^2}{\partial x \partial y}\left(\frac{\partial \psi}{\partial t}\right)_F \frac{\partial^2 \psi}{\partial x \partial y}\right] + \frac{df}{dy}\frac{\partial}{\partial y}\left(\frac{\partial \psi}{\partial t}\right)_F$$

f) Geostrophic Vorticity Tendency

Using the complete geostrophic definition and the diagnosed height tendencies a forcing contribution to geostrophic vorticity tendencies is obtained for each of the six forcing:

$$\left(\frac{\partial \zeta_g}{\partial t}\right)_F = \frac{1}{f}\nabla^2\left(\frac{\partial \phi}{\partial t}\right)_F - \frac{1}{f^2}\frac{df}{dy}\frac{\partial}{\partial y}\left(\frac{\partial \phi}{\partial t}\right)_F$$

g) Ageostrophic vorticity tendency (AG) term

Traditionally the AG term in the omega is either neglected (e.g. Gachon *et al.*, 2003) or considered as an independent forcing term (i.e. compute from model data as for example in Räisänen 1995 and 1997). Here an alternative approach is adopted, that consist to consider the AG term as a dependent term of each forcing (i.e. that the AG term can be divided into forcing components). After computing the various diagnostics without the AG term in the omega equation, an ageostrophic vorticity tendency is computed for each forcing by substracting the diagnose geostrophic vorticity tendency from the diagnose vorticity tendency for each individual forcing. The omega equation is then solved again for each forcing but this time with the respective forcing contribution to the AG term added on the right hand side of the omega equation. Finally, the subsequent diagnostics are computed again to obtained 'new diagnostics' that contains the influence of the AG term for each of the forcing.

The different steps and equations presented in this section and used in DIONYSOS are summarized in Figure 1.

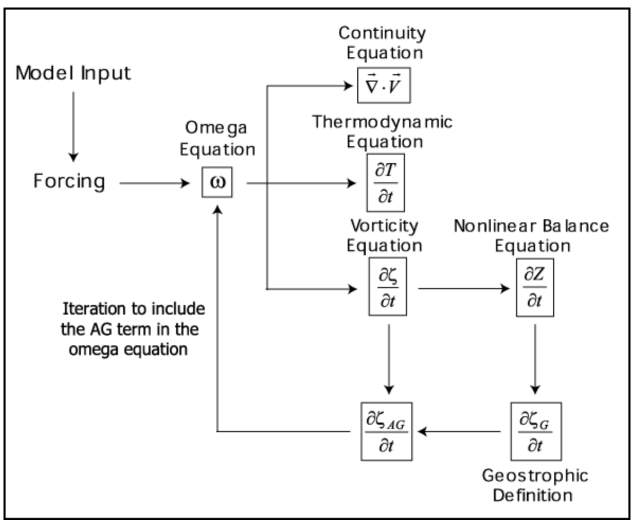

Figure 1. DIONYSOS diagnostics equations and procedure for each individual forcing considered: the Laplacian of temperature advection (*LTA*), the Laplacian of sensible heat flux (*LSH*), the Laplacian of latent heat release (*LLH*), vorticity advection (*VA*), friction (*FR*) and orography (*OR*).

4. Diagnostic Validation

The only possible way to validate the forcing partitioning and the accuracy of the diagnostics equation used here is to compare to sum of the forcing contribution for a given variable to model values of that variable. In general the correlation coefficients between model and diagnosed values for vertical motion, vorticity tendency, temperature tendency, height tendency and geostrophic vorticity tendency are between 0.85 to 0.95 in the vertical domain. The root mean square ratio between model and diagnose values are for their part between 0.9 and 0.95. These statistics measure are excellent and reveal that the diagnostics fields reproduce very well the original model fields. The reader can see direct comparisons for one specific case for vertical motion at 700 hPa and geostrophic vorticity tendency at 950 hPa in Figures 2 and 3 respectively.

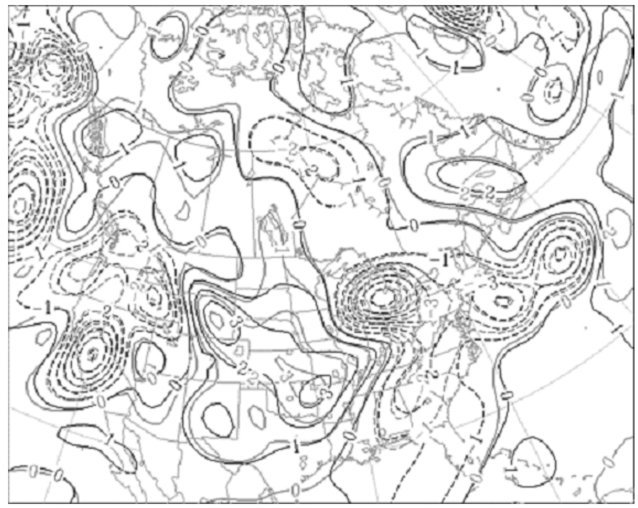

Figure 2. Comparison at 700 hPa between the model vertical motion (black lines, 10^{-1} Pa s^{-1}) and the diagnose vertical motion produce by the all the forcings from DIONYSOS (gray lines, 10^{-1} Pa s^{-1}) valid at 1630 UTC 7 December 2004 from the Canadian GEM model forecast initialized at 00 UTC 7 December 2004.

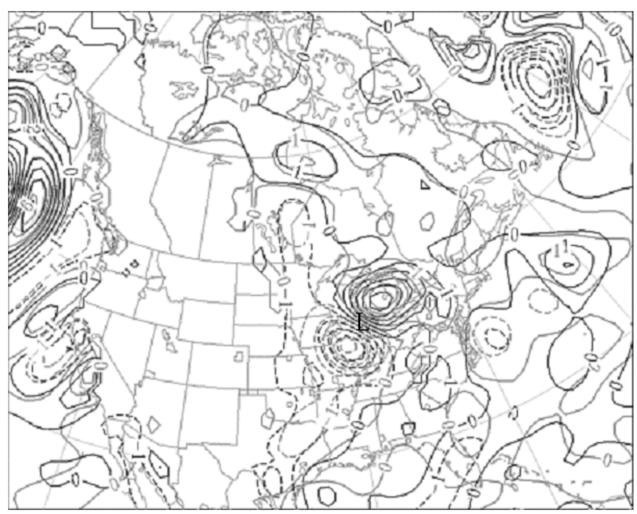

Figure 3. Comparison at 950 hPa between the model geostrohic vorticity tendency (black lines, 10^{-9} s^{-2}) and the diagnose geostrophic vorticity tendency produce by the all the forcings from DIONYSOS (gray lines, 10^{-9} s^{-2}) valid at 1630 UTC 7 December 2004 from the Canadian GEM model forecast initialized at 00 UTC 7 December 2004.

5. Online and interactive diagnostics

a) Currently available

For more than 7 years now, DIONYSOS is run on a daily basis at the Université du Québec à Montréal from 00 UTC model forecast for a 24 hours period starting at 09 UTC for three different operational NWP models:

- GEM-Global (CMC): North America, Western Europe and New Zealand
- NAM (NCEP): North America
- GFS (NCEP): North America and Western Europe

The diagnostic results are available to scientists and educators world-wide. trough an interactive web based interface at www.dionysos.uqam.ca. After a free registration procedure users can generate unlimited forcing contribution profile for vertical motion, vorticity tendency, geostrophic vorticity tendency and temperature tendency as well as to explore the forcings distribution (both horizontal and vertical) and visualize standard maps.

b) Enhancement for THORPEX

Some enhancement to the online version of DIONYSOS are currently planned for THORPEX.:

- Increase the number of forecast model available and cover the entire domain for each model.
- Add interactive cross-section capability
- Add interactive nonlinear balance PV inversion
- Allow for user to diagnose archived cases

6. Summary

DIONYSOS is a diagnostic package specifically adapted for the identification of the physical processes responsible for the formation of precipitation and the evolution of weather systems in NWP models.

The current web based interface allow scientific and educator world-wide to access DIONYSOS diagnostics on a daily basis to explore and intercompare forecast weather systems from various operational NWP models. The currently plan enhancement to the online version of DIONYSOS will provided a more complete online tool to the users as well as the opportunity to performed case study on a retrospective basis.

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