Predictability of Limited-Area Models: Twin and Big-Brother Experiments

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1. Introduction

The purpose of this work is to study the predictability of limited-area models (LAMs) in an idealized context, where verification data and model errors are not an issue. Normaly, this kind of study is carried out by means of a "Twin Experiment", which consists in comparing runs of a given model initialized with slightly different initial conditions over the same domain (Anthes et al. 1985). This approach, however, does not allow to investigate the effect of the one-way nesting procedure on the predictability. The "Big-Brother Experiment" (BBE) was developed in order to analyse the effect of one-way nesting on internal variability and predictability of LAMs in a perfect-model context. It consists of a high-resolution simulation in a large domain that is considered as a reference run, and compared to other runs performed with the same model but within a smaller domain and nested in the reference simulation. The BBE, unlike to the Twin Experiment, accounts for the effect of the one-way nesting on predictability.

2. Experimental framework

The Canadian Regional Climate Model (CRCM) described in Caya and Laprise (1999) is used for a series of simulations with 45-km horizontal grid spacing, 18 levels in the vertical, and a 3-h nesting frequency. A first integration is made for a month in a domain of 196x196 grid points in the horizontal (centered in New England), nested with NCEP analyses of February 1993. This high-resolution simulation reference run becomes the "truth" to which other runs will be compared. The output fields produced by this reference run are then used to drive simulations performed over a smaller domain (100x100 in the horizontal, keeping the vertical and horizontal resolution untouched) located in the centre of the larger domain. This setup permits the comparison of the output of both simulations in the same region and therefore assesses the ability of the one-way nesting to reproduce the results of the larger domain. Since both simulations use the same formulation (dynamics, physics, resolution, numerics, etc), differences in results can be attributed unambiguously to the nesting technique.

In order to make values statistically stable, results were obtained for 24 runs of the small-domain model integrated during 4 days, each one starting on successive days of February 1993. A more detailed description of this experiment can be found in de Elia et al. (2002).

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3. Differences between the Twin and the Big-Brother Experiments

a. The Twin Experiment

For the Twin Experiment the internal variability may be defined as the RMS difference between two runs started with "almost" identical initial conditions on the small domain, and it can be expressed as

$$Y_S = X_S + \epsilon_{int}, \tag{1}$$

where Y_S and X_S represent horizontal fields from two different runs of the small domain S that are function of time; X_S being considered as ground truth, and Y_S as the perturbed run. The term ϵ_{int}, the difference between these two fields, represents: $\epsilon_{int}(t=0)$ the difference in initial conditions, and $\epsilon_{int}(t>0)$ an estimation of the internal variability at subsequent times. The three terms in the expression are function of the integration time and are case dependent. The root-mean-square difference for this Twin Experiment can be expressed as

$$\mathrm{RMS}_\mathrm{T}^2 = \sum_D (Y_S - X_S)^2 = \sum_D \epsilon_{int}^2 = \sigma_{int}^2, \tag{2}$$

where the summation is performed over the domain D. When several cases C are available the ensemble average root-mean-square difference can be rewritten as

$$\overline{\mathrm{RMS}_\mathrm{T}^2} = \sum_C \sigma_{int}^2 = \overline{\sigma_{int}^2}. \tag{3}$$

The term on the right should be interpreted as the ensemble average of the spatial variance associated with the internal variability at a given integration time.

b. The Big-Brother Experiment

When the comparison of the small-domain run is carried out against the large-domain reference run, additional sources of error such us the nesting method, the nesting frequency, and the resolution in the boundary conditions should be considered. Since the internal variability cannot be separated from other sources of error, all of them are included in a single term. This can be expressed as

$$Y_S = X_L + \epsilon_W, \tag{4}$$

where the subscript S stands for small-domain run, L for large-domain reference run, and W for one-way

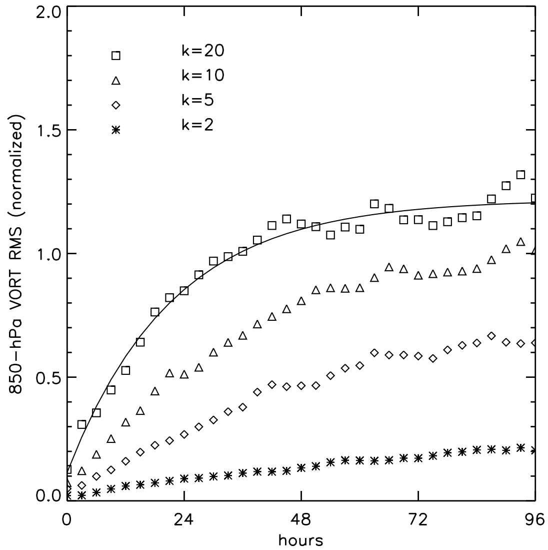

Figure 1: *Time evolution of selected wavenumbers for the normalized RMS difference for the 850-hPa vorticity fields in the BBE.*

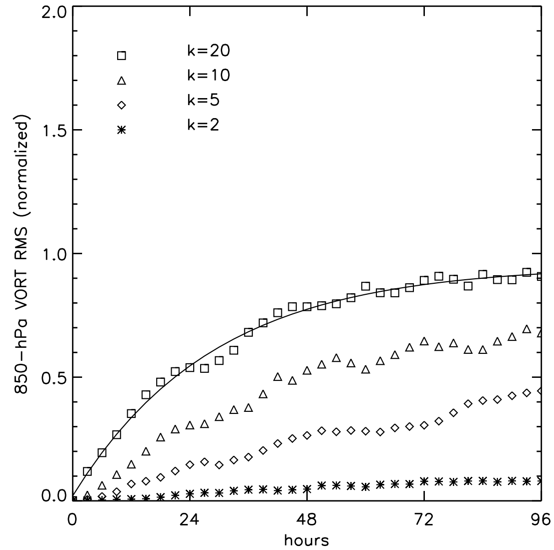

Figure 2: *Same as Fig. 1 but for the Twin Experiment.*

nesting. Following the same procedure as in the previous section the RMS of the Big-Brother Experiment can be written as

$$\overline{\mathrm{RMS}^2_{\mathrm{BB}}} = \overline{\sigma^2_W}, \qquad (5)$$

where the term on the right-hand side represents the spatial variance associated with internal variability and other sources of error. Since the Big-Brother Experiment accounts for more sources of error than the Twin Experiment, this inequality must hold

$$\overline{\mathrm{RMS}^2_{\mathrm{T}}} \leq \overline{\mathrm{RMS}^2_{\mathrm{BB}}}. \qquad (6)$$

In the following section, both RMS values will be estimated as a function of spatial scale with data from the simulations described in section 2.

4. Results

The difference between the 850-hPa vorticity fields of the reference run and the perturbed simulations has been decomposed spectrally, and then normalized by the average vorticity spectrum of the reference run. This normalized spectrum may be interpreted as the normalized root-mean square difference (RMS) between the fields as a function of wavenumber. Here the wavenumbers are nondimensionalised with respect to an 80-gridpoint wide domain used to do the Fourier Transform. Hence $k = 20$, for example, corresponds to a wavelength of 180 km.

The temporal evolution of selected wavenumbers is displayed in Fig. 1 for the Big-Brother Experiment. It can be seen that the error growth is highly dependent on wavenumber; being very limited for small wavenumbers and almost reaching the critical value associated with uncorrelated signals ($\sqrt{2}$) for large wavenumbers. This behavior, found in all variables studied, shows that one-way nesting mostly controls the error growth at large scales, despite the presence of all wavenumbers in the boundary conditions.

The temporal evolution of selected wavenumers for the Twin Experiment is displayed in Fig. 2. As in Fig. 1, it can be seen that growth is highly dependent on wavenumbers, being small for the large scales and large for the small scales. However, it can be seen that RMS values smaller than those of the Big-Brother Experiment are attained at all wavelengths, suggesting that the internal variability of the model does not account for the total variability observed in Fig. 1, as discussed in section 3.

5. Conclusions

Comparison of the RMS values obtained from the Big-Brother Experiment against those from the Twin Experiment indicates that the former accounts for a larger internal variability. This result suggests that measure of predictability obtained in a Twin-Experiment protocol could overerestimate its real value. For this reason, it may be convenient at the time of testing sensitivities to certain parameters in a regional model to evaluate whether a Twin or a Big-Brother Experiment are more appropriate for the interest of a particular research.

References:

Anthes et al., 1985; *Advances in Geophysics*, Vol. 28, 159-202.

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