INTERNAL VARIABILITY OF THE CANADIAN REGIONAL CLIMATE MODEL AND SINGULAR VECTORS DECOMPOSITION

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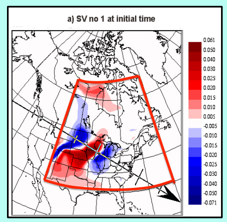
1. Introduction

The dispersion of model solutions caused by its sensitivity to small differences in the initial conditions defines the model internal variability (IV). Unlike GCM, the RCM solutions are also subject of model lateral boundaries constraints. As a consequence, the RCM IV varies in time presenting periods of growth and decay. This study analyses one episode of rapid RCM IV growth using the singular vector (SV) technique. SVs represent the dynamically most unstable perturbations and finite-time instabilities in the context of a linear model named the tangent linear model. We used the SV technique to find if the IV growth can be express in terms of rapidly growing perturbations. The main idea consists in expressing the model IV in terms of perturbations from a reference state and to project them onto a base of SVs computed using as initial conditions the RCM reference state.

2. CRCMv5 ensemble

21 simulations with CRCM5 v. 3.3.0 with different initial conditions: (October 23 to November 12, 1992) noted: NA23, … , NA01, … , NA12.

- ***Time step: 30 minutes***
- ***Horizontal resolution: 0.5°***
- ***Blending zone: 10 points***
- ***Analysis period: December 1992***
- ***Driver: ERA40 re-analyses***
- ***Same sea surface temperature***
- ***Over land the surface is fully interactive***



$$IV_X(t) = \iiint_{vol} \frac{1}{M-1}\sum_m X_m'^2(t)$$

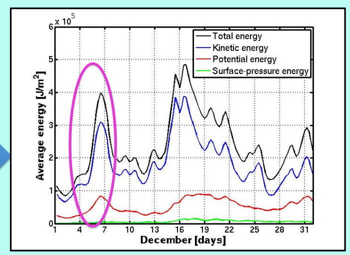
$$X_m(t) = X_{reference}(t) + X_m'(t)$$

$$X_m' = \{U_m', V_m', T_m', ps_m'\}$$

Simulation (NA23 to NA12) — CRCMv5 Perturbation

$m = \{NA23,\ldots,NA01,\ldots,NA10,NA12\}$ — Reference simulation (NA11)

$$Et = \frac{1}{M-1}\sum_m (Et_m) = \frac{1}{M-1}\sum_m\left[\iiint_{Vol}\rho(U_m'^2+V_m'^2)dV + \iiint_{Vol}\rho(\frac{c_p}{T_r}T_m'^2)dV + \iint_{surface}(\frac{RT_r}{p_r g}ps_m'^2)dA\right]$$

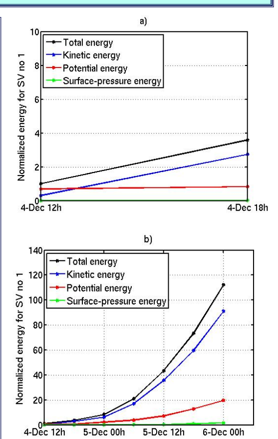


3. Set of Singular vectors

Singular vectors ***= orthogonal set of perturbations that, under dynamics linearized about a time-evolving trajectory, will grow fastest over a finite-time interval with respect to a specific metric.***

- ***Dry tangent linear and adjoint operators***
  GEM (400 x 200 uniform Gaussian grid and 28 eta levels)
- ***Initial conditions:*** ***CRCM5 reference simulation (04 December 12Z) combined with ERA40***
- ***Optimization time interval = 36 h***
- ***Initial and final time norm = dry total energy norm***
- ***Initial and final norm domains = sub-domain of CRCM***
- ***Dry total energy norm:***

$$\langle y_j, E_t y_j\rangle = \iiint_{Vol}\rho(u_{y_j}^2 + v_{y_j}^2)dV + \iiint_{Vol}\rho(\frac{c_p}{T_r}T_{y_j}^2)dV + \iint_{surface}(\frac{RT_r}{p_r g}ps_{y_j}^2)dA$$



4. Projection on SVs

Perturbation decomposition in terms of SVs:

$$x(t) = \sum_{j=1}^{N}\alpha_j \hat{y}_j(t) \qquad \alpha_j = \langle x(t), E_t \hat{y}_j(t)\rangle$$

projection coefficients

For a truncated base of "J" SVs:

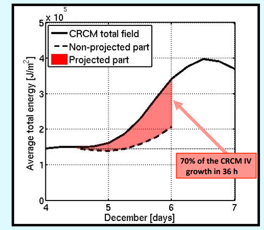
$$x(t) = \sum_{j=1}^{J}\alpha_j\hat{y}_j(t) + \sum_{l=J+1}^{N}\alpha_l\hat{y}_l(t) = \tilde{x}(t) + \Delta x(t)$$

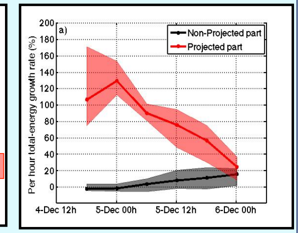
projected part — **non-projected part**

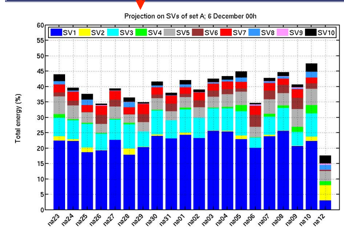
$$E(x_k) = E(\tilde{x}_k) + E(\Delta x_k)$$

$$\frac{1}{M-1}\sum_{k=1, k\neq NA11}^{M-1} E_k; E_k = \{E(x_k), E(\Delta x_k), E(\tilde{x}_k)\}$$

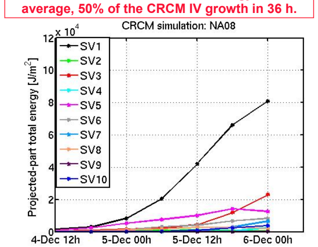
$$r(t) = \frac{1}{\Delta t}\frac{E_t - E_{t-\Delta t}}{E_{t-\Delta t}}; E = \{E(\tilde{x}_k), E(\Delta x_k)\}$$



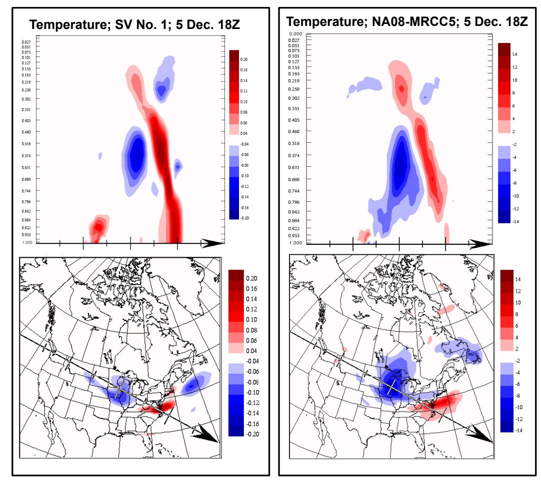




SV1: 18% to 26% of CRCM total energy, and, on average, 50% of the CRCM IV growth in 36 h.



5. CRCM perturbations versus SV no 1



6. Conclusion

The analyses of one episode of high growth in the CRCM IV showed that a significant fraction of the IV growth is due to small and rapidly growing perturbations represented by the first ten SVs. The leading singular vector explains an average 50% of the internal variability growth in 36 hours. The rest of growth results from perturbations with lower growth rate. For this case, we find a great similarity between the CRCM perturbations and the first singular vector at final time. The vertical westward tilt in the structure of CRCM perturbations suggests that the baroclinic instability is the dominant process in the growth of IV in this particular episode. Further information in the paper "Singular vector decomposition of the internal variability of the Canadian Regional Climate Model" accepted for publication in Climate Dynamics.

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