UQÀM
Université du Québec À Montréal

CENTRE **ESCER**
POUR L'ÉTUDE ET LA SIMULATION DU CLIMAT
À L'ÉCHELLE RÉGIONALE

Chaos in Regional Climate Model simulations: Budget diagnostics of internal variability

Développement économique, innovation et Exploitation
Québec

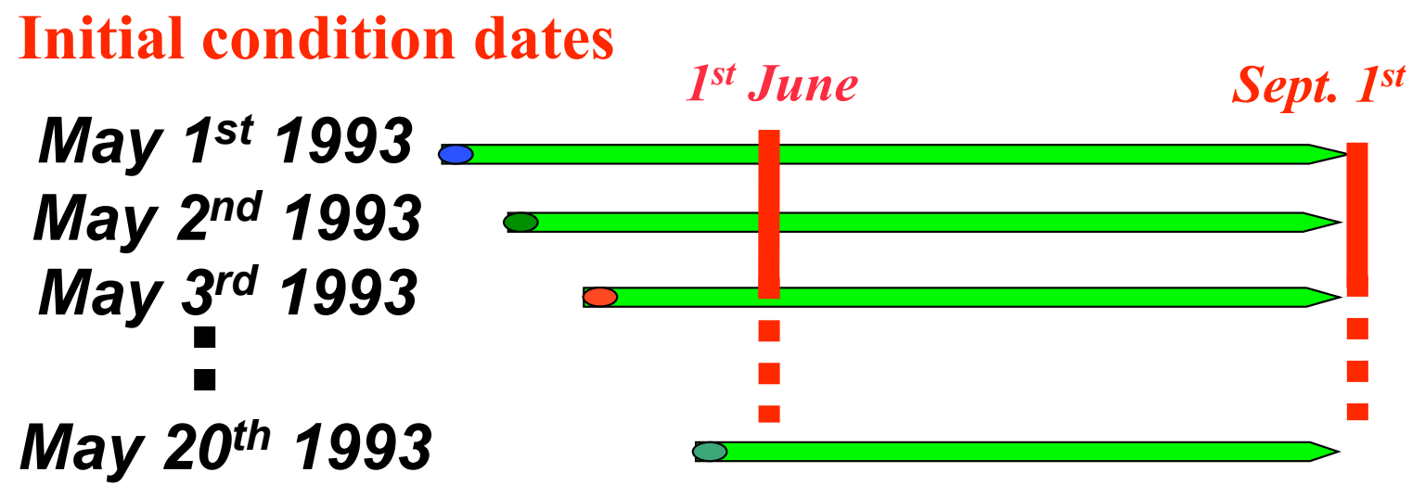
NIKIÉMA Oumarou and LAPRISE René, ESCER, Département des Sciences de la Terre et de l'Atmosphère,
UQAM, B.P. 8888, Stn Downtown, Montreal, QC, Canada H3C 3P8, E-mail : nikiema@sca.uqam.ca

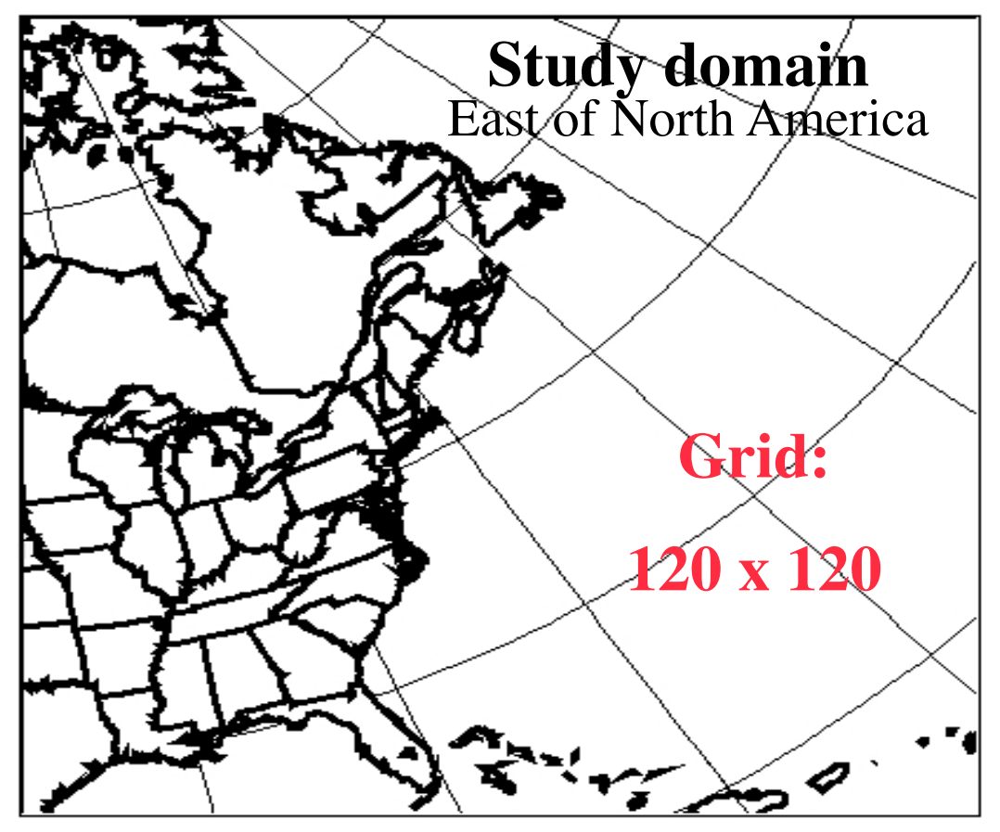
1- Introduction

In chaotic systems…

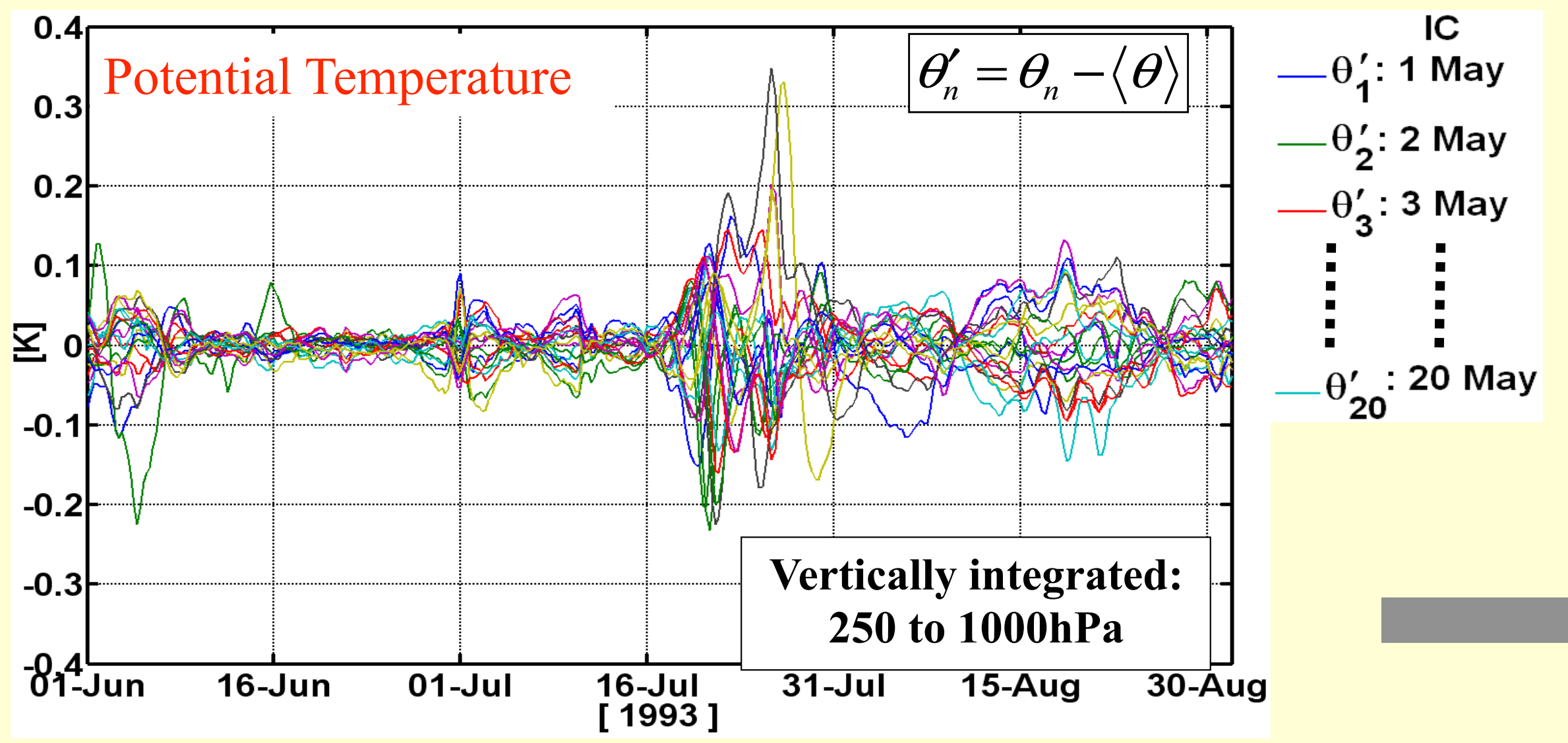
when an **ensemble of Regional Climate Model (RCM) simulations** is run with **different initial conditions** (IC$_s$), the differences between simulations fluctuate in time. In this study, we perform a quantitative diagnostic budget calculation of the various diabatic contributions to the time evolution and spatial distribution of **internal variability** (IV) in Canadian RCM simulations. The Potential Temperature **IV is computed as the inter-member spread in an ensemble** of 20 simulations that **differ only in their initiation time**. The decomposition of the various contributions to the IV tendency sheds light on the underlying physical mechanism to the development of IV in RCM simulations.

Ensemble: *20 simulations with different IC (delay of 24 hours at the beginning of each run)*





Time evolution of domain- and vertical-average potential temperature deviation for N = 20 simulations



How is Internal Variability calculated ?

Variance

$$\sigma_\theta^2 = \frac{1}{N-1}\sum_{n=1}^{N}\big(\underbrace{\theta_n - \langle\theta\rangle}_{\theta'_n}\big)^2$$

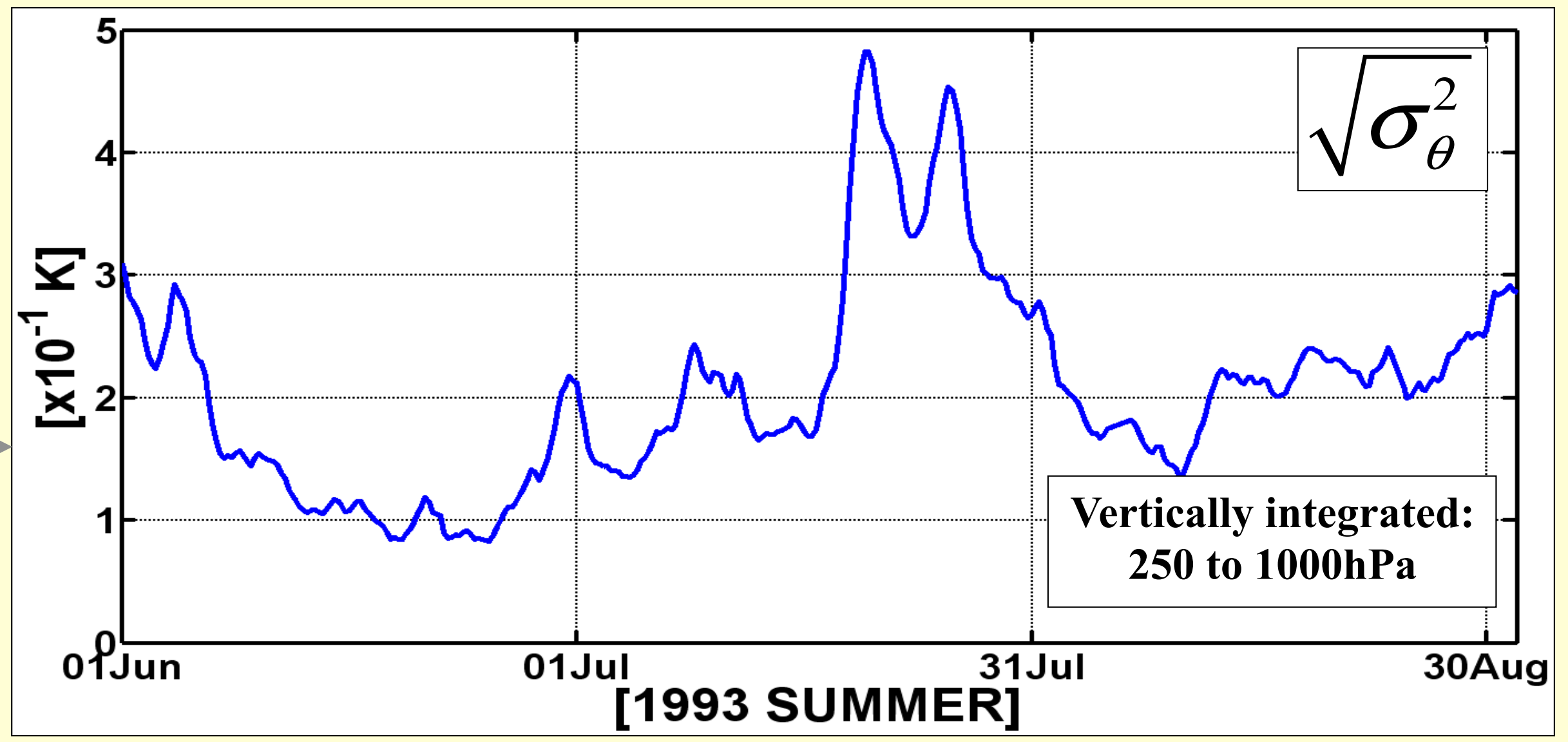
Potential temperature ($\theta = T\left(\frac{p_o}{p}\right)^{R/C_p}$) deviation from the ensemble-mean ($\langle\theta\rangle$) for the member *n*

Scientific motivations

Internal Variability greatly fluctuates in time!

What are the physical processes that contribute to maintain the IV in RCM simulations ?

Time evolution of the vertical- and domain-averaged of inter-member variance standard deviation in potential temperature field



2- Budget Equation for Internal Variability of Potential Temperature

$$\underbrace{\frac{\partial\sigma_\theta^2}{\partial t}}_{L_\theta} = \underbrace{-\vec{\nabla}\bullet\left(\langle\vec{V}\rangle\sigma_\theta^2\right)}_{A_h} \underbrace{-\frac{\partial\left(\langle\omega\rangle\sigma_\theta^2\right)}{\partial p}}_{A_v} \underbrace{-2\langle\theta'_n\vec{V}'_n\rangle\bullet\vec{\nabla}\langle\theta\rangle}_{B_h} \underbrace{-2\langle\theta'_n\omega'_n\rangle\frac{\partial\langle\theta\rangle}{\partial p}}_{B_v} \underbrace{+2\langle\theta'_n J'_n\rangle}_{C} \underbrace{-2\left\langle\theta'_n\vec{\nabla}\bullet\left(\theta'_n\vec{V}'_n\right)\right\rangle - 2\left\langle\theta'_n\frac{\partial\left(\theta'_n\omega'_n\right)}{\partial p}\right\rangle}_{E}$$

L_{θ}: Internal Variability Tendency

A: Transport of IV by ensemble-mean flow

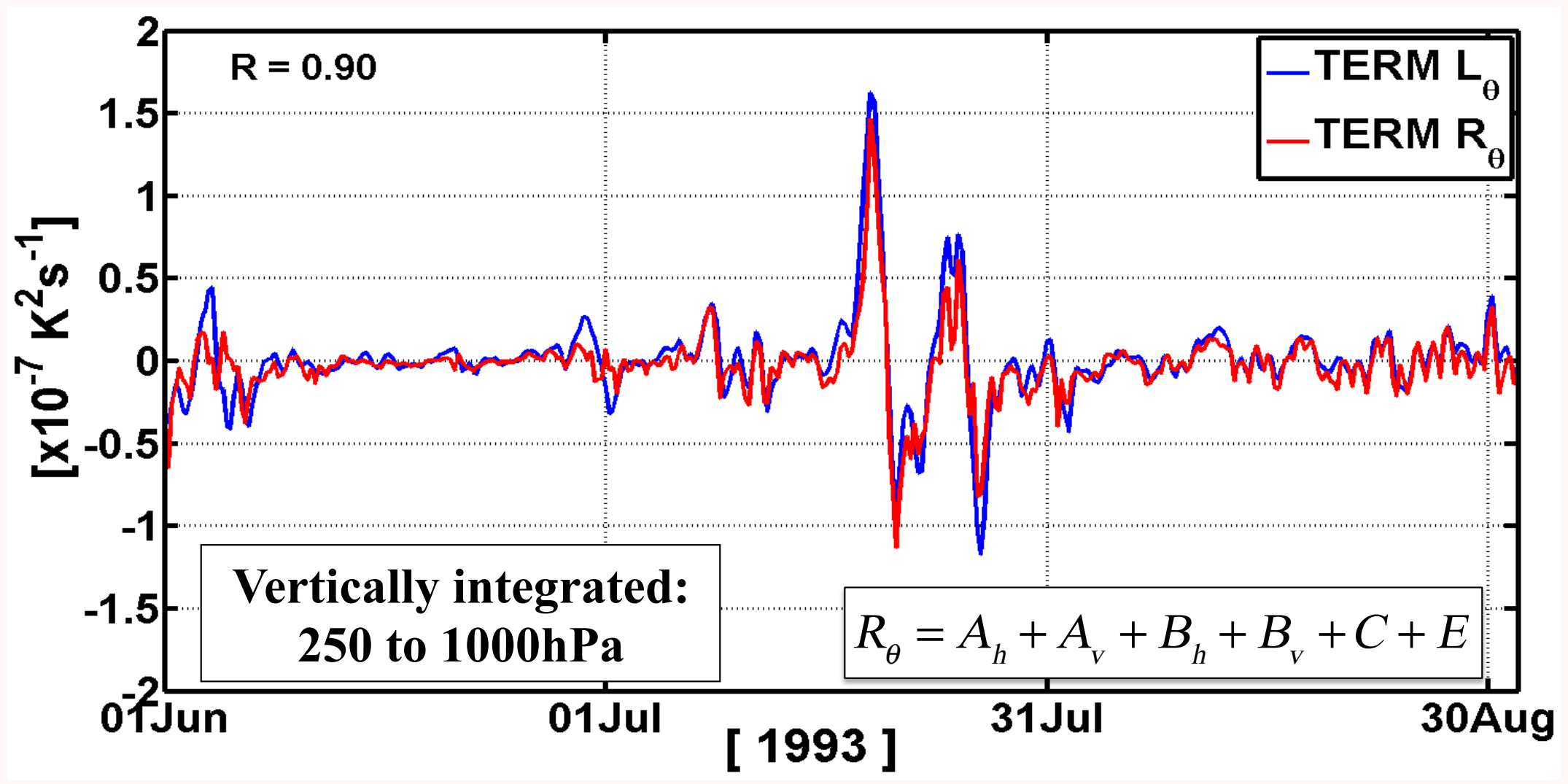
B: Covariance of fluctuations in the direction of ens.-mean Pot. Temp. gradient

C: Covariance of fluctuations of Pot. Temp. and total diabatic heating rate

E: Third order terms

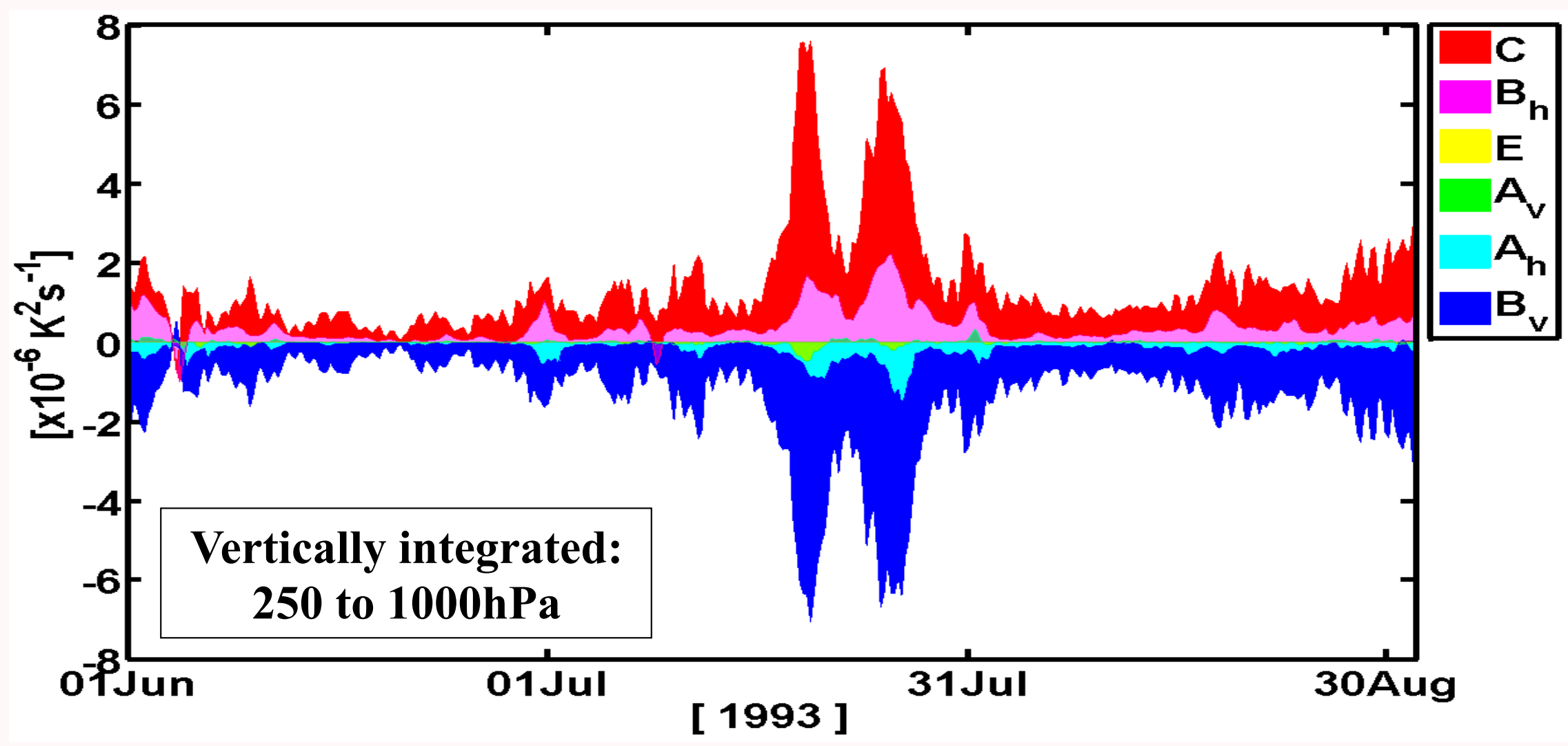
Validation

Time evolution of vertical- and domain-average of L_θ vs R_θ



IV tendency budget

Time evolution of different contributions to the IV tendency

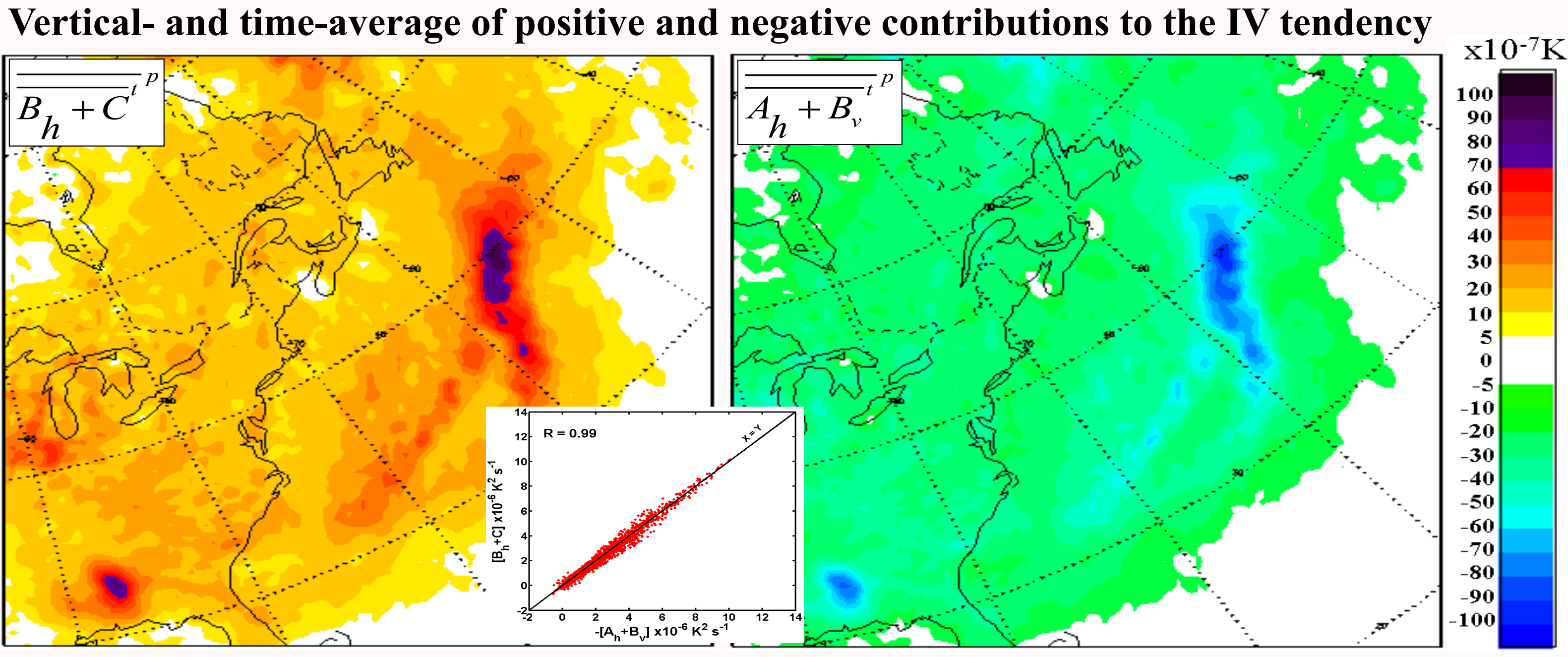


At the seasonal scale…

$$\frac{\partial\sigma_\theta^2}{\partial t} \approx 0$$

$$\underbrace{C + B_h}_{\text{Generation (+)}} + \underbrace{B_v + A_h}_{\text{Destruction (-)}} \approx 0$$

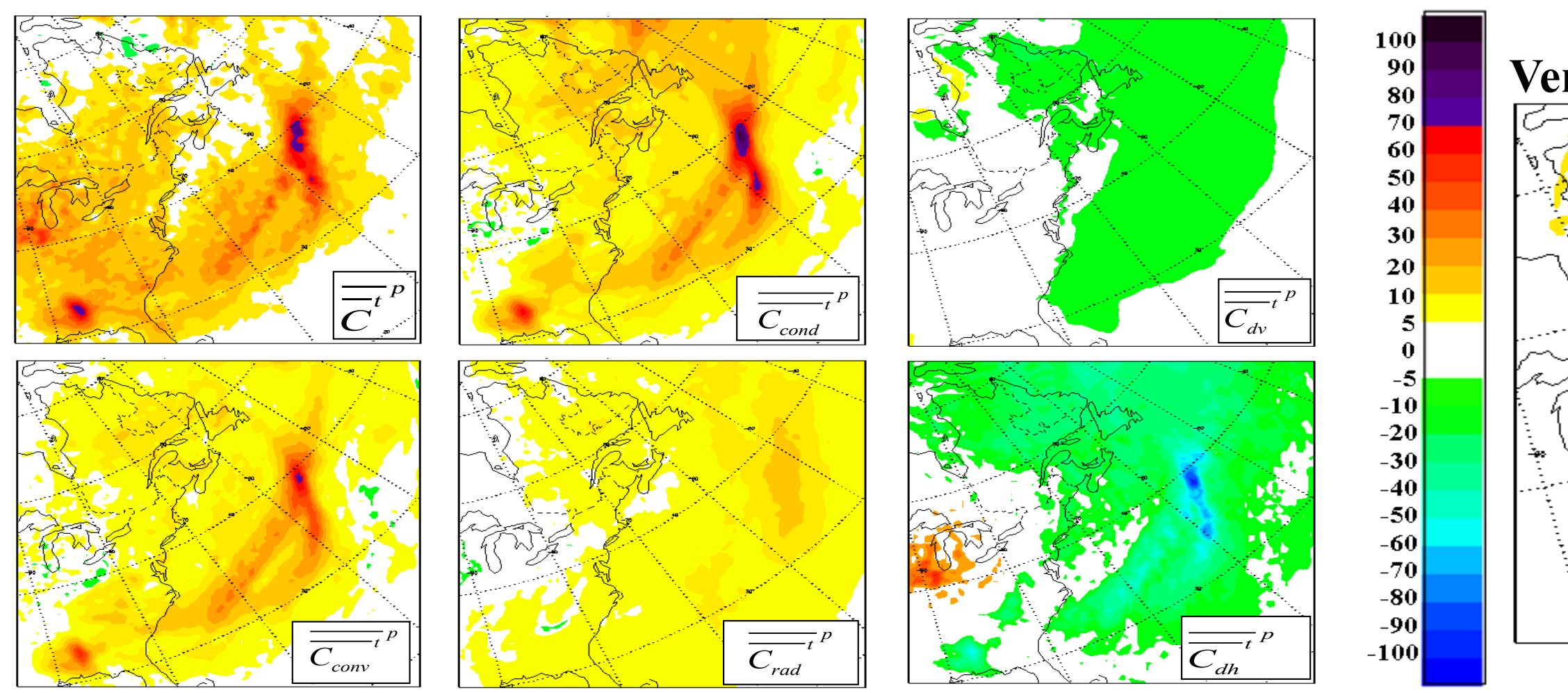
Vertical- and time-average of positive and negative contributions to the IV tendency



3- Physical interpretations: physical processes responsible of Internal Variability in RCM simulations

Why does C contribute to the IV growth?

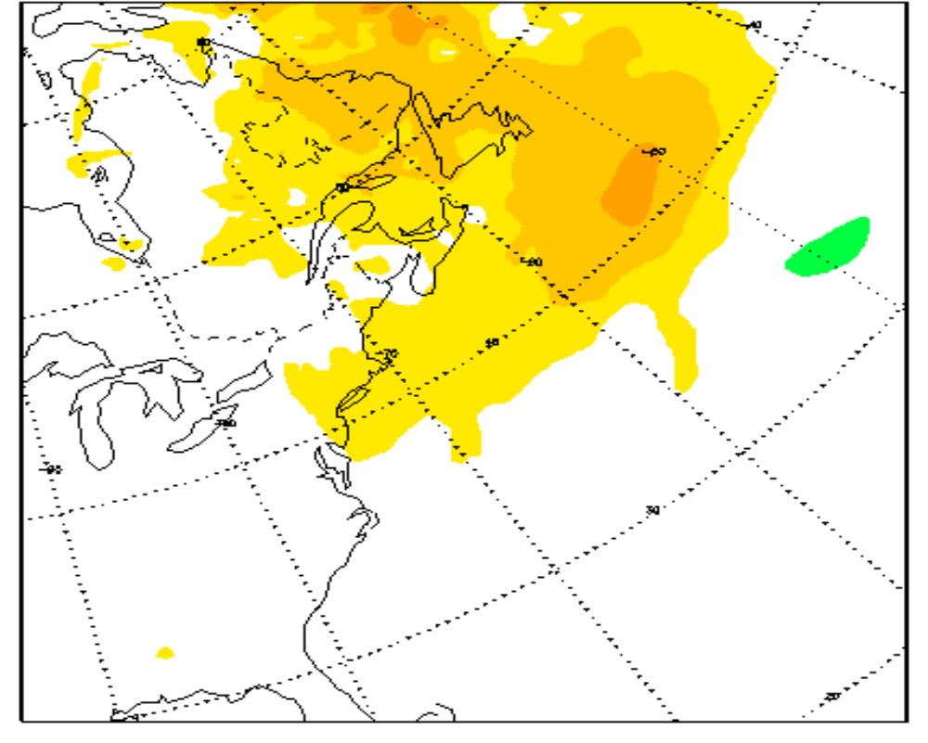
$$C = \underline{C_{cond} + C_{conv} + C_{rad}} + \underline{C_{dv} + C_{dh}}$$

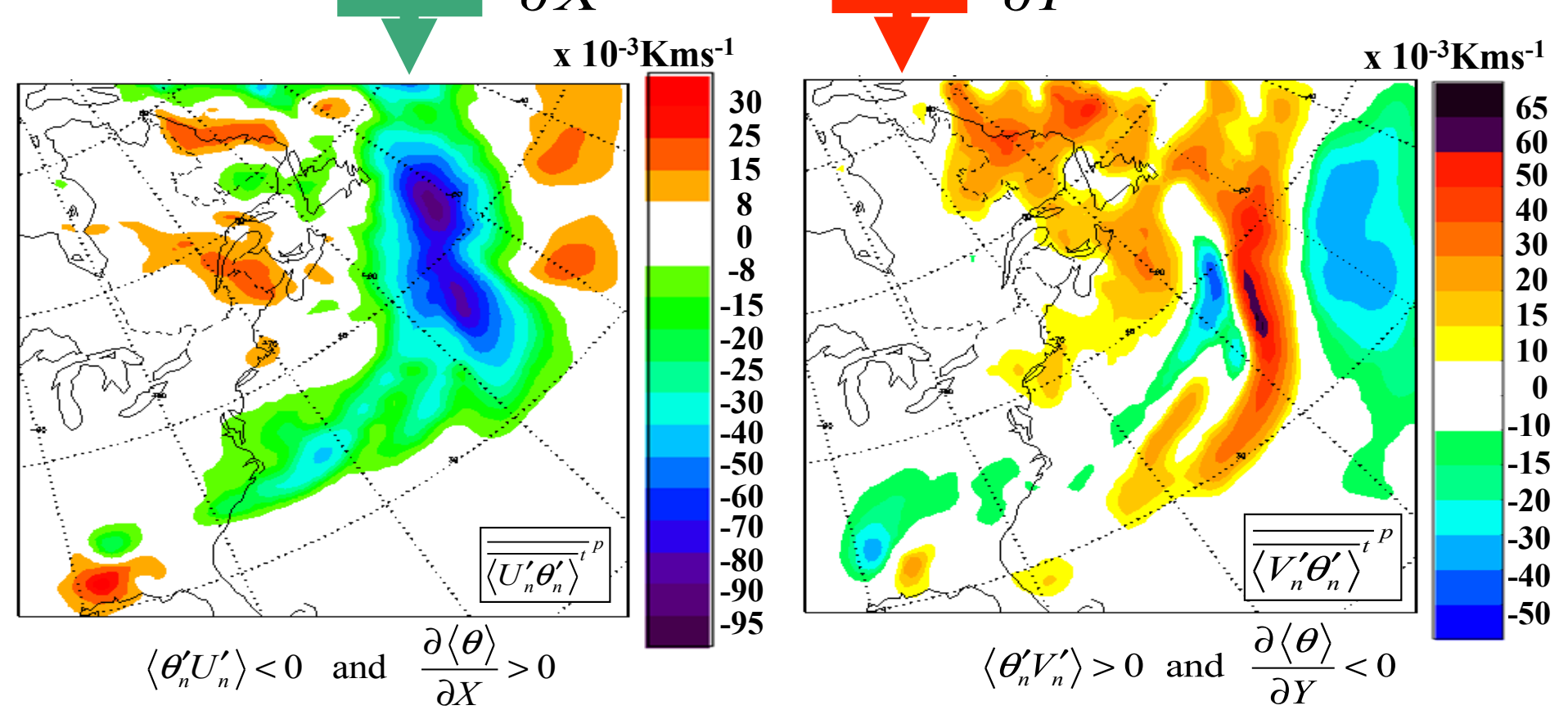


Why does B$_h$ contribute to the IV growth ?

$$B_h = -2\langle\theta'_n U'_n\rangle\frac{\partial\langle\theta\rangle}{\partial X} - 2\langle\theta'_n V'_n\rangle\frac{\partial\langle\theta\rangle}{\partial Y}$$

Vertical- and time-average of B_h





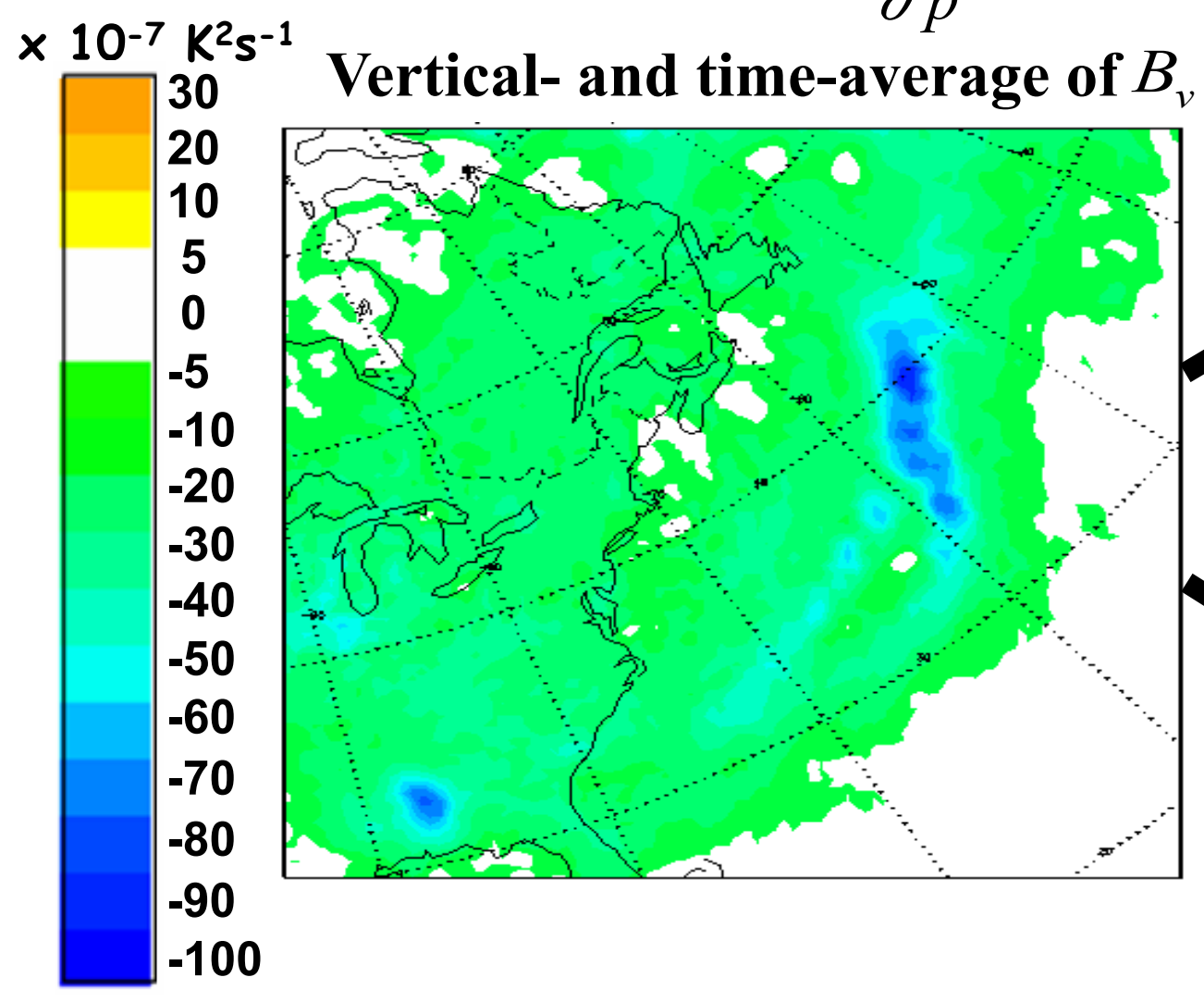
$\langle\theta'_n U'_n\rangle < 0$ and $\frac{\partial\langle\theta\rangle}{\partial X} > 0$ $\langle\theta'_n V'_n\rangle > 0$ and $\frac{\partial\langle\theta\rangle}{\partial Y} < 0$

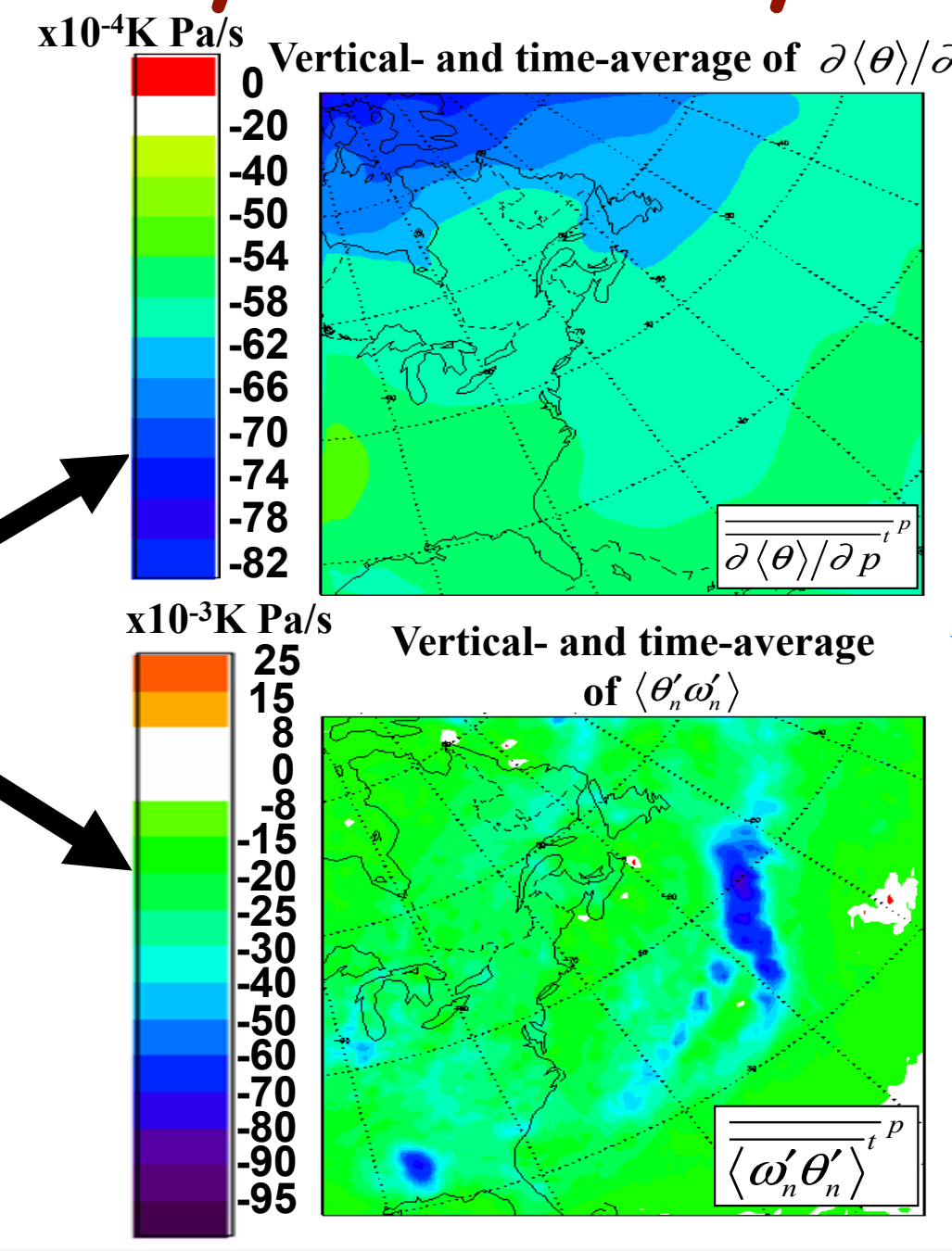
- **Ensemble-mean state: Temperature increase eastward and southward**
- **Transport of warm perturbations westward/northward contributes to increase the IV**

Why is IV growth greatly reduced by Bv?

$$B_v = -2\langle\theta'_n\omega'_n\rangle\frac{\partial\langle\theta\rangle}{\partial p}$$

Vertical- and time-average of B_v





$$\frac{\partial\langle\theta\rangle}{\partial p} < 0$$

Ensemble-mean state: statically stable

$$\langle\theta'_n\omega'_n\rangle < 0$$

Warm perturbations rise

$\theta'_n > 0$ & $\omega'_n < 0$

Cold perturbations sink

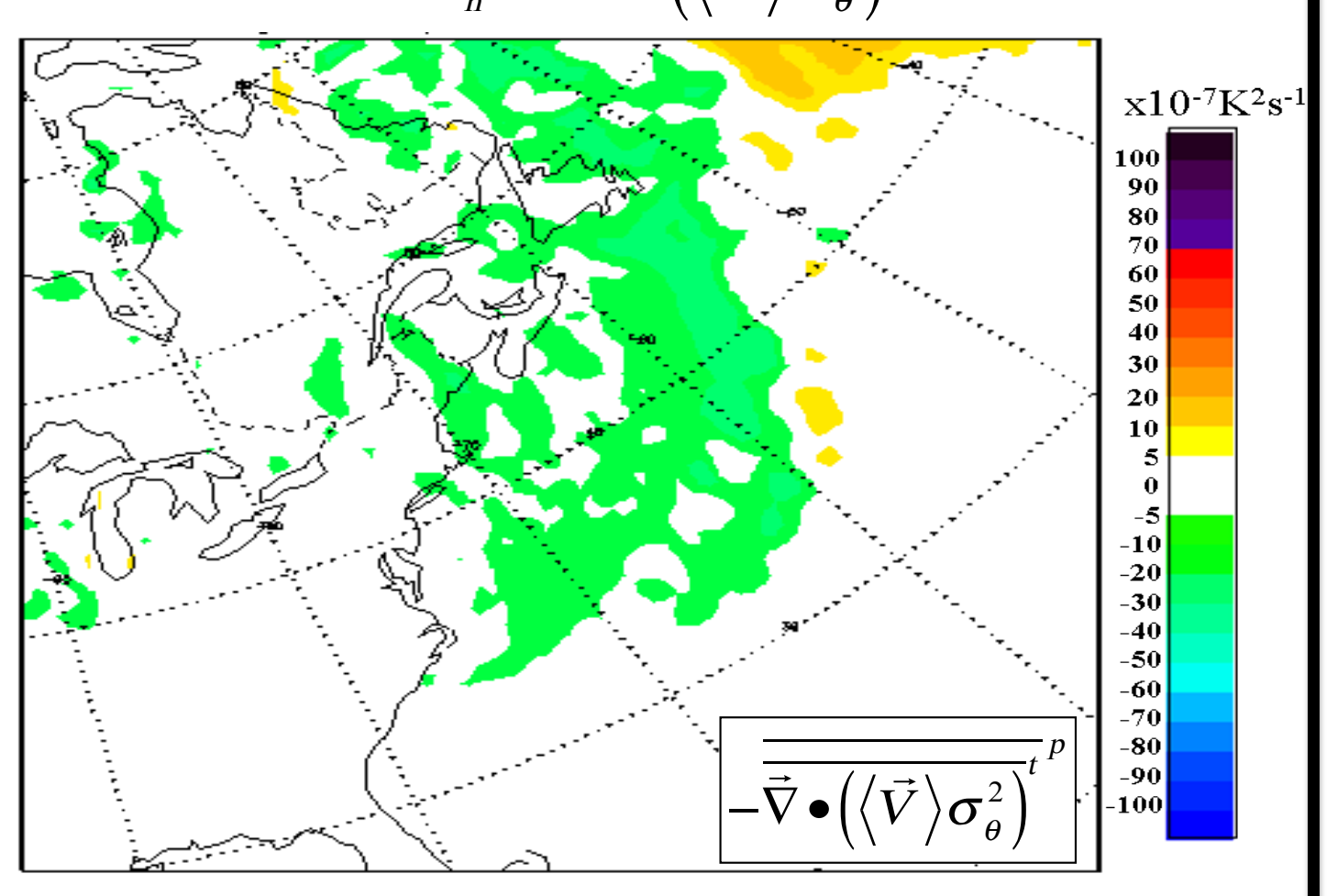
$\theta'_n < 0$ & $\omega'_n > 0$

in perturbation from the ensemble-mean conditions.

Static stability tends to consume the Temp. IV

Why is IV reduced by A$_h$?

$$A_h = -\vec{\nabla}\bullet\left(\langle\vec{V}\rangle\sigma_\theta^2\right)$$



$A_h < 0 \Rightarrow$ **Transport of IV out of the regional domain contributes to reduce IV**

4- Conclusion

We analysed the physical processes responsible for the maintenance and variations of internal variability (IV) in an **ensemble of twenty simulations** performed with the nested Canadian RCM (CRCM) for the summer 1993 season over northeastern North America. The **IV is computed as the inter-member spread in an ensemble** of simulations that **differ only in their initiation time**. At the seasonal time scale, results showed an **absence of IV trend due to an approximate balance between terms** on average in the troposphere. The time-mean IV budget can be expressed as the following approximate balance: $B_h + C \approx -(B_v + A_h)$

The **most positive contribution term is *C* due mostly to the condensation and convection contributions to *J'*** (diabatic heating rate). Radiation processes slightly contribute to increase IV in RCM simulations, whereas the vertical and horizontal diffusions act as destruction terms during the season. B_h also contributes to the growth because the transport of heat by covariance of fluctuations is down-the gradient in the ensemble-mean state.

The **most negative contribution to the IV tendency is B_v** because the time-average of the covariance of fluctuations ($\overline{\overline{\langle\theta'_n\omega'_n\rangle}^t}^p$) and the gradient of the ensemble-mean potential temperature ($\overline{\overline{\partial\langle\theta\rangle/\partial p}^t}^p$) are negative in the entire troposphere. These results reveal that **warm fluctuations rise and cold fluctuations sink in perturbations from the ensemble-mean state in order to consume IV**. Thus the energy conversions associated to IV perturbations appear to behave quite similarly to those in weather systems, with fluctuation available potential energy being generated by condensation and convection processes (term *C*), and this energy being converted back to fluctuation kinetic energy [e.g., *Lorenz,* 1955, 1967]. Physically, **Ah is a sink term because of its contribution to transport large IV value out of the regional domain** by the horizontal ensemble-mean flow.

Our results indicate that **RCM's internal variability is a natural phenomenon issued from the chaotic nature of the atmosphere.**

References:

Lorenz, E. N. (1967), The nature and theory of the general circulation of the atmosphere. World Meteorological Org. 218 TP 115 161 pp

Nikiéma, O., R. Laprise (2010), Diagnostic budget study of the internal variability in ensemble simulations of the Canadian RCM. Clim. Dyn. DOI: 10.1007/s00382-010-0834-y

Nikiéma, O., R. Laprise (2011), Budget study of the internal variability in ensemble simulations of the Canadian Regional Climate Model at the seasonal scale, Journal of Geophysical research, 116, D16112, doi: 10.1029/2011JD015841