Helmholtz Climate Initiative

Regional Climate Change

Topic 1: Coupled modelling of regional Earth systems

Budget study of internal variability of ensemble simulations of HIRHAM5 for the Arctic

A. Sommerfeld (1), O. Nikiema (2), A. Rinke (1), K. Dethloff (1), R. Laprise (2)

(1)Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung in Potsdam

(2)Université du Québec à Montréal

Introduction

- chaotic and nonlinear nature of atmospheric dynamics [1]
  → changes in initial conditions (IC) of climate models influence the evolution of simulations
- ensemble of simulations with different IC result in internally generated variability (IV) [2 and references therein, 3] (Fig. 1, 2)
  → estimation of the diabatic and dynamical contribution to time evolution of IV to understand the physical processes leading to IV

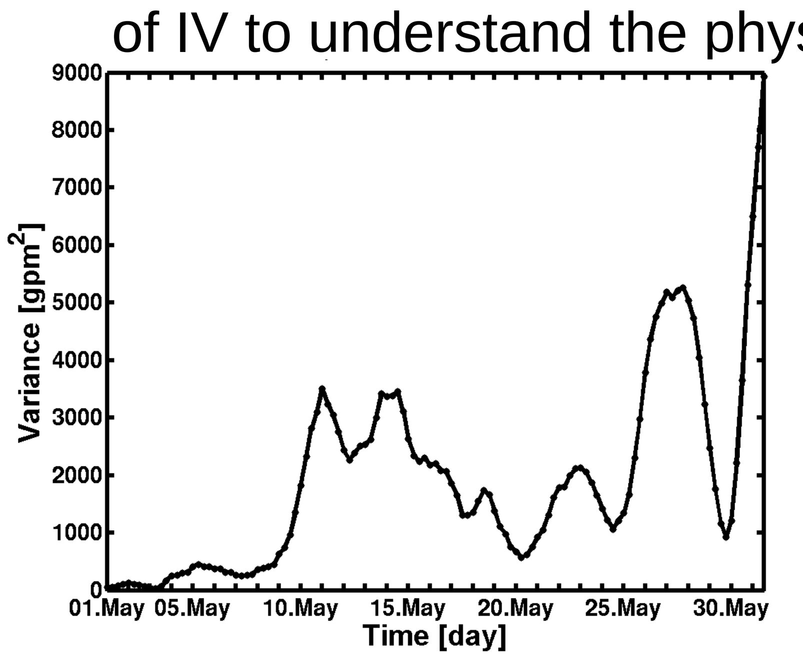

Fig. 1: Inter-member variance of domain-averaged geopotential in 500 hPa due to different IC for the Arctic

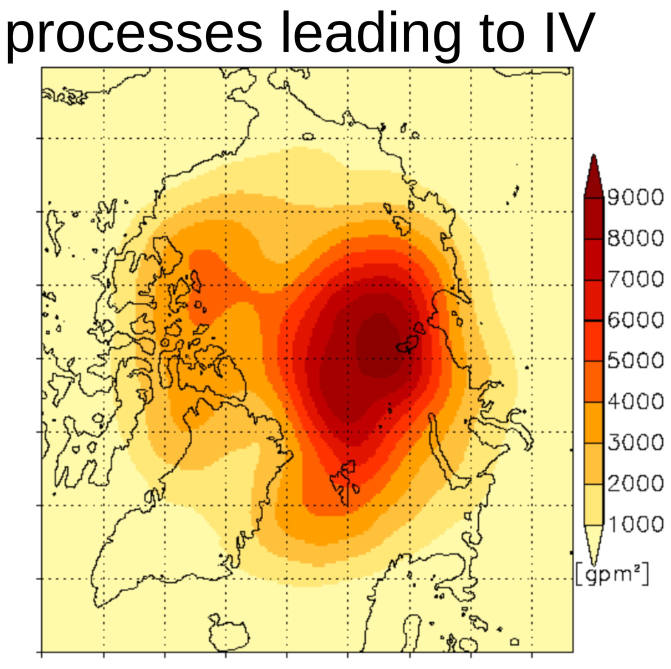

Fig. 2: Inter-member variance of time-averaged geopotential in 500 hPa due to different IC during May 2012 for the Arctic

Model Setup

- HIRHAM5 [4] is a hydrostatic regional climate model first applied on a circum-Arctic region by [5]
- combination of HIRLAM [6] (dynamics) and ECHAM5 [7] (physical parametrization)
- driven by ERA-Interim [8]

- runs with a spatial resolution of 25 km covering 218x200 grid cells and 40 vertical levels up to 10 hPa over the Arctic region (Fig. 3)

- runs without nudging
- 5 simulations covering May 2012 differ only in IC (starting times for each run shifts about 1 day)

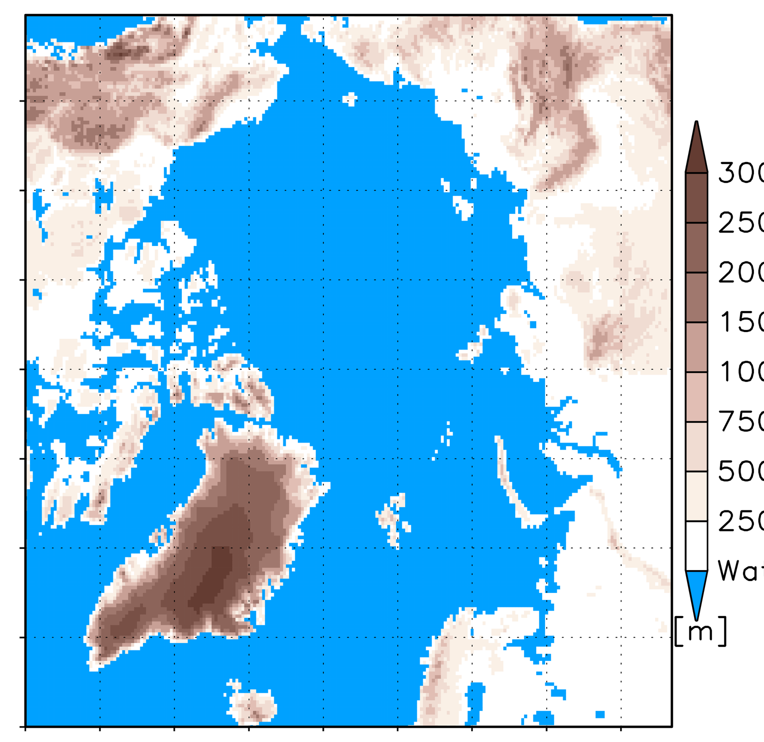

Fig. 3: Considered region and its orography simulated with HIRHAM5

Equations and Method

- IV is defined as the inter-member variance of each variable [2,3] $\sigma_\varphi^2 \approx \langle \varphi_n'^2 \rangle$ (Eq. 1)
- emanating from the first law of thermodynamics and the mass-continuity equation in vertical pressure coordinates for potential temperature using the Reynolds decomposition
  → splitting a variable in the ensemble mean $\langle \varphi_n \rangle$ and the deviation from ensemble mean φ_n' $\quad \varphi_n = \langle \varphi \rangle + \varphi_n'$ (Eq. 2)
- results in a IV budget equation (Eq. 3) developed by O. Nikiema [2,3]

$$\underbrace{\frac{\partial \sigma_\theta^2}{\partial t}}_{L_\theta} = \underbrace{-\vec{\nabla}\cdot\left(\langle\vec{V}\rangle\sigma_\theta^2\right)}_{A_h} \underbrace{-\frac{\partial\left(\langle\omega\rangle\sigma_\theta^2\right)}{\partial p}}_{A_v} \underbrace{-2\langle\theta'_n\vec{V'_n}\rangle\cdot\vec{\nabla}\langle\theta\rangle}_{B_h} \underbrace{-2\langle\theta'_n\omega'_n\rangle\frac{\partial\langle\theta\rangle}{\partial p}}_{B_v} \underbrace{+2\langle\theta'_n J'_n\rangle}_{C} \underbrace{-2\left\langle\theta'_n\vec{\nabla}\cdot\left(\theta'_n\vec{V'_n}\right)\right\rangle}_{E_h} \underbrace{-2\left\langle\theta'_n\frac{\partial}{\partial p}\left(\theta'_n\omega'_n\right)\right\rangle}_{E_v} \quad \text{(Eq. 3)}$$

L_θ: diagnostic potential temperature IV tendency

A_h, A_v: horizontal and vertical transport terms describing the convergence of IV by the ensemble-mean flow

B_h, B_v: horizontal and vertical conversion terms indicating the covariance of potential temperature and flow fluctuations in direction of the ensemble-mean flow potential temperature gradient

C: diabatic source and sink term resulting from the covariance of fluctuations of potential temperature and diabatic heating rate

E_h, E_v: horizontal and vertical covariance of potential temperature fluctuations and divergence of potential temperature flux due to fluctuations

Results

- IV of the vertical- and domain-averaged potential temperature is smallest at the bottom, at 400 hPa and at the model top at 10 hPa (Fig. 4)
- highest IV is simulated in the upper troposphere and smaller peak at the middle troposphere → probably due to meridional wind speed maxima

- largest contribution to growth of IV is provided by B_h (Fig. 5)
- B_v and E_h reduce the IV (Fig. 5)
- the terms A_h, A_v, E_v and C have only a small contribution (Fig. 5)
- stronger peaks during time evolution indicate synoptic events [2,3] (Fig. 5)

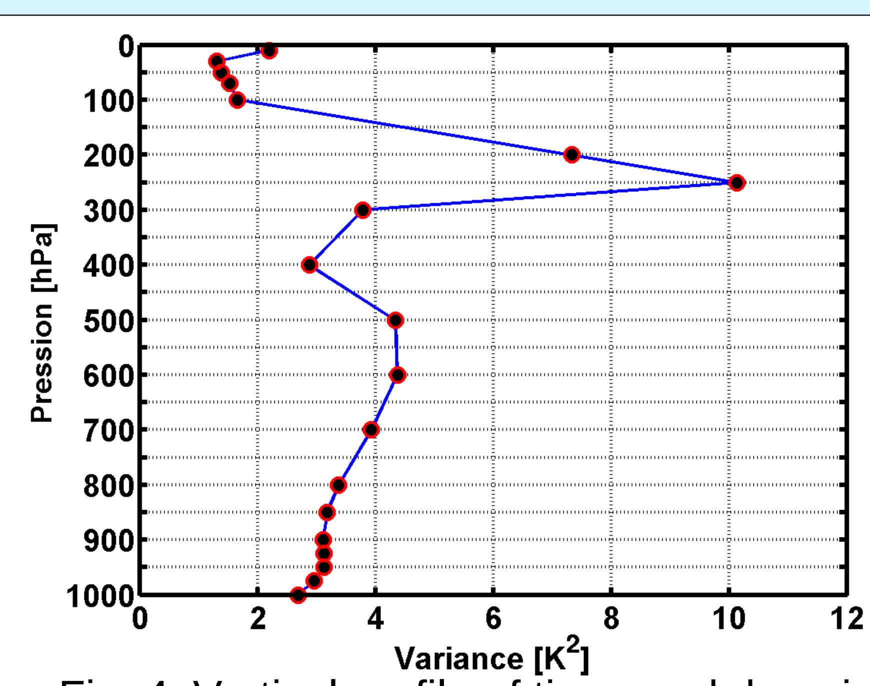

Fig. 4: Vertical profile of time- and domain-averaged IV for potential temperature during May 2012

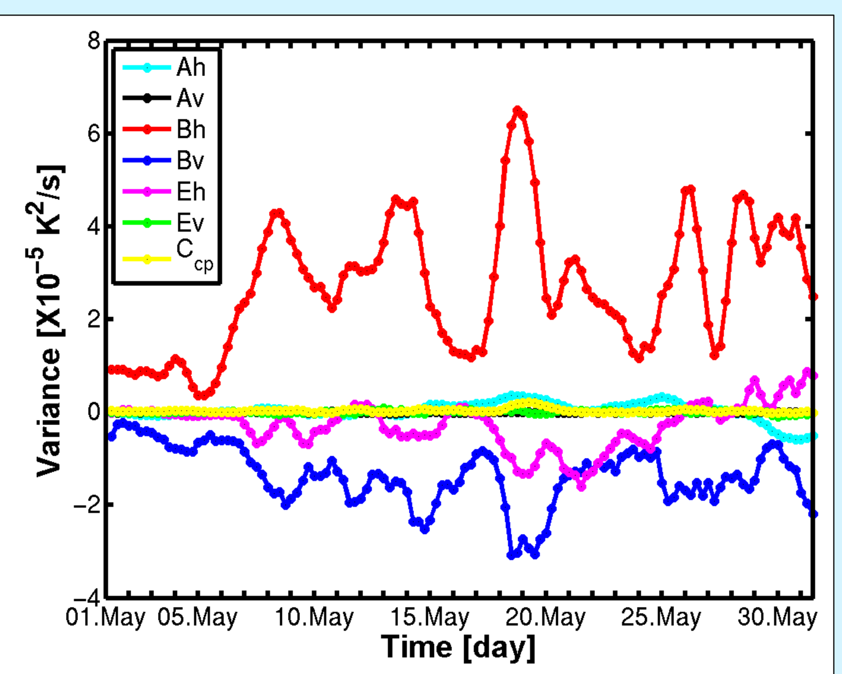

Fig. 5: Time evolution of the vertical- and domain-averaged contributions of IV

Outlook

- development of the ensemble of simulations
  - low ice years and high ice years
  - calculations for 3h-output
  - at least 20-member simulations changing only in IC
- detailed analysis of the time evolution, of vertical profiles including single levels and of the spatial distribution of the contributions to IV
- budget study for absolute and relative vorticity and kinetic energy

References

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