Impact of enhanced greenhouse gases on Northern Hemisphere extra-tropical cyclone activity in 2041-2070 as simulated by the CGCM3

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General circulation model (GCM) projections indicate that enhanced greenhouse gases (GHG) will result in a warming of the lower troposphere particularly, in the polar regions, in winter, over the continents. The reduction of the pole to equator low-level temperature gradient is expected to influence the distribution of extra-tropical cyclones. The goal of this study is to investigate the possible effect of increasing GHG on the climatology of NH extra-tropical migratory cyclones using the simulations of the third-generation Canadian Coupled (atmosphere-ocean) General Circulation Model (CGCM3).

An analysis approach is used here to identify and track extra-tropical cyclones, and then to compare their seasonal statistics over a 30-year model simulation. The cyclone climatology is based on the automated objective synoptic systems identification and tracking algorithm, developed by Sinclair (1997). Cyclones are here identified as local maxima of gradient-wind vorticity (ζ_{gr}) computed as the Laplacian of the gridded 1000-hPa geopotential (for more details, see the companion contribution on the CGCM3 validation in this book).

The atmospheric component of CGCM3 is a spectral model with triangular truncation at wave number 47, and with 32 levels in the vertical on hybrid coordinates. The model projection under investigation corresponds to the period 2040 to 2070, with the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (IPCC SRES) A2 scenario forcing. The control simulation covers the period 1960 to 1990.

In order to eliminate weak perturbations and quasi-stationary centres from the cyclone statistics, we imposed following conditions: 1) threshold of ζ_{gr} is $2.5 \cdot 10^{-5}$ s^{-1}, 2) minimum track lifetime is one day, 3) total track length is at least of 1200 km, and 4) minimal distance between final and initial track positions is at least of 600 km. The cyclone centre density is defined as the number of discrete cyclone centres passing within 333 km of any grid point. Because of the overlapping area(s) between neighbouring search circles, one cyclone centre may be taken into account at several grid points at the same time. A cyclone is considered as intense if its central ζ_{gr} is at least $6 \cdot 10^{-5}$ s^{-1}. The location of cyclone genesis and lysis corresponds to the initial and final track positions, respectively.

According to the results shown in the Table 1, the total number of both, cyclone occurrences and cyclone tracks, over the 2040-70 period, is slightly reduced, by about 2%, compared to the control run. Thus, it seems that the enhanced-CO_2 climate is less favourable for the extra-tropical cyclones formation.

Since the geographical distribution of the frequency of cyclone genesis density remains mainly unchanged under the warmer climate, only the results from the control run and the differences are presented (Fig. 1). In winter (DJF), genesis maxima are located along southern part of the North Pacific, east of the Rocky Mountains, the North American East Coast and the Tyrrhenian Sea (Fig. 1a). During the summer (JJA), the genesis maxima are shifted north-eastward (Fig. 1c). In the warmer climate, the cyclone density becomes less frequent everywhere on the NH, in the winter (Fig. 1b) as in the summer (Fig. 1d).

The NH winter frequency of cyclone density in the enhanced-CO_2 climate (Fig. 2a.1), is shifted northward in the north-eastern Canada (the Nunavut Territory) and in the Mediterranean Sea, and is reduced in the Gulf of Genoa, compared to the control climate (Fig. 2b.1). The greatest winter frequency of density of intense cyclones, extending from the Japan to the Gulf of Alaska, shows a minor eastward shift (Fig. 2d.1) in comparison with the control climate (Fig. 2e.1). During the NH summer, there is no change in the cyclone density as in the density of intense cyclones (Fig. 2d.2 and Fig. 2e.2). There are no significant changes in the other averaged cyclone characteristics such as lifetime, speed, central ζ_{gr}, cyclone circulation and precipitable water vapour.

In the enhanced-CO_2 climate, generally, the activity of the NH extra-tropical mobile cyclones slightly decreases in the mid-latitudes, while it increase in the high latitudes near the continents (Fig. 2c.1, 2f.1, 2c.2 and 2f.2). The results here confirm overall those of Lambert and Fyfe (2006).

Reference

Sinclair, R. M., **1997**: Objective Identification of Cyclones and Their Circulation Intensity, and Climatology. Weather and Forecasting, 12, 595 – 612

Lambert, S.J., and J.C. **Fyfe**, **2006**: Changes in Winter Cyclone Frequencies and Strengths Simulated in Enhanced Greenhouse Warming Experiments: Results from the Models Participating in the IPCC Diagnostic Exercise. Climate Dynamic (in press).

(www.cccma.bc.ec.gc.ca/models/cgcgm3.html)

(www.cccma.bc.ec.gc.ca/data/cgcm/cgcm_forcing.shtml)

	Control run: 1960 - 1990	Enhanced-CO_2 run: 2040 - 2070
Winter (December-February)	146 672 (**11 919**)	143 932 (**11 627**)
Summer (June-August)	137 982 (**12 418**)	134 282 (**12 184**)

Table 1. Total number of NH extra-tropical cyclone occurrences (**tracks**), poleward of 20°N, over the 30 winters and summers.

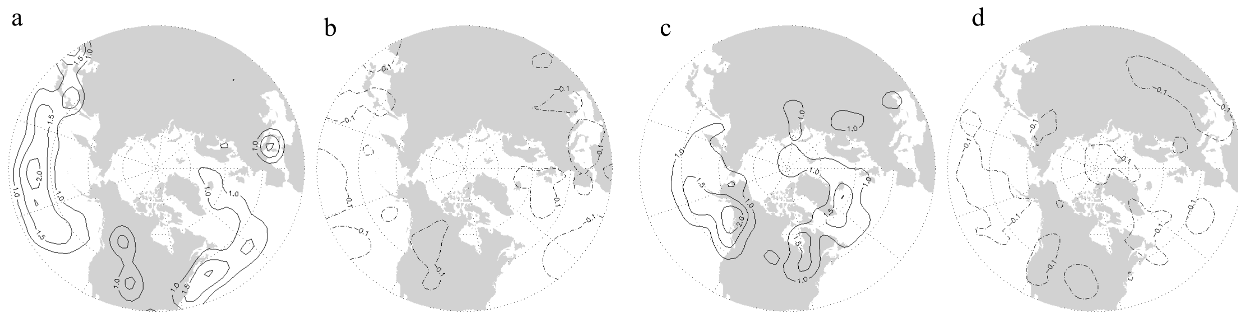

Fig. 1. Mean of extended NH winter (DJF) cyclogenesis density for (a) control, (b) enhanced-CO_2 minus control; (c)-(d) as for (a) and (b) except for the summer (JJA). Contour interval every 0.5 centre per 333 km circle per season for (a)-(d). Solid lines for positive differences and dashed lines for negative differences.

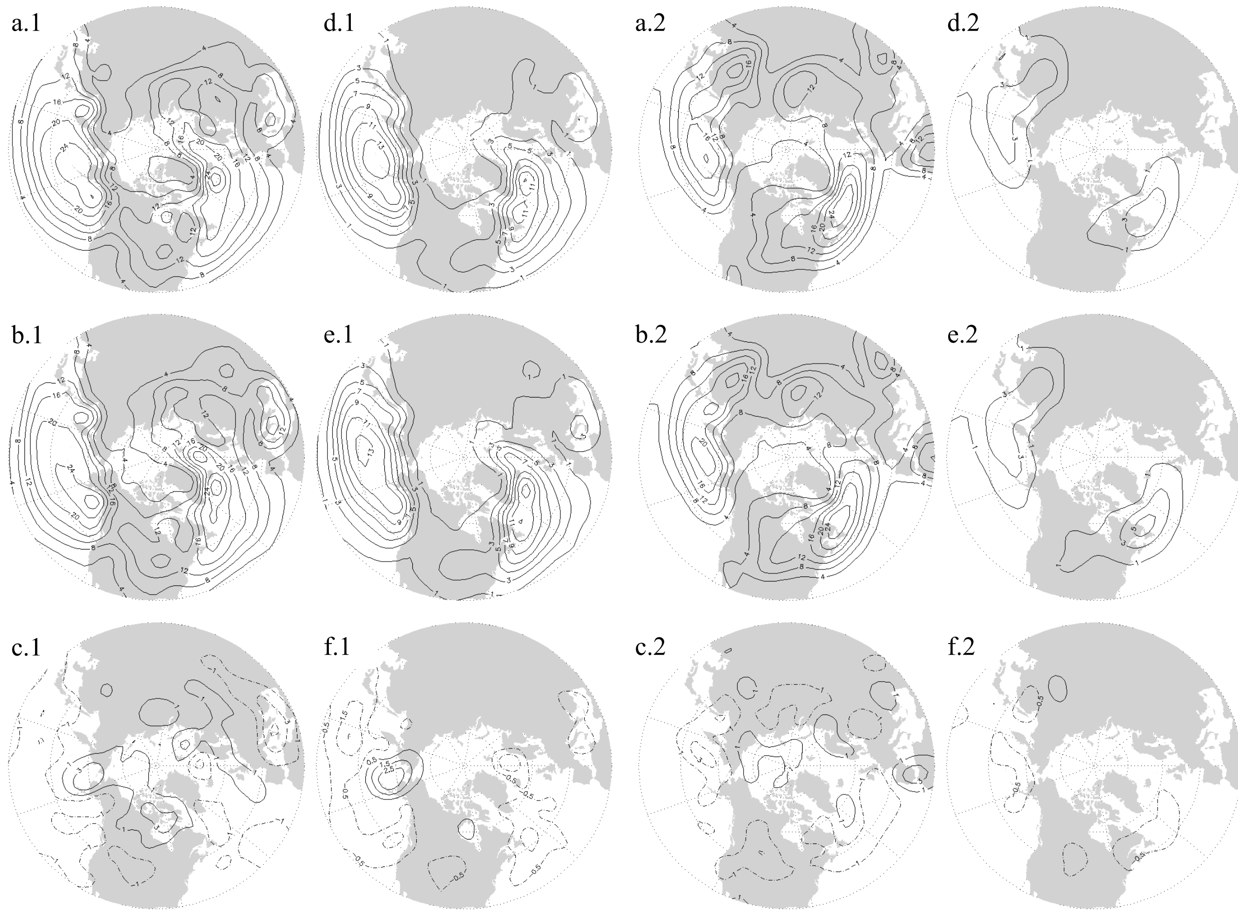

Fig. 2. Mean of NH winter (DJF) cyclone density for (a.1) enhanced-CO_2, (b.1) control and (c.1) enhanced-CO_2 minus control, respectively; (a.2)-(c.2) as for (a.1)-(c.1) except for summer (JJA). (d.1)-(f.1) as for (a.1)-(c.1) except for the intense cyclones; (d.2)-(f.2) as for (d.1)-(f.1) except for the summer (JJA). Contour interval every 4 centres for (a.1), (b.1), (a.2) and (b.2), every 2 centres for (c.1), (c.2), (d.1), (e.1), (d.2) and (e.2), and every 1 centre for (f.1) and (f.2), per 333 km circle per season. Solid lines for positive differences and dashed lines for negative differences.