SIMULATION OF ARCTIC STORMS

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1. Introduction

On the average, there were about 14 storms per storm season (June-November inclusive) in southern Beaufort Sea. October has the highest storm frequency, whereas July has the lowest. Overall, 58% of the storms originate in the Arctic, and 27% in the Pacific (Hudak and Young, 2002). In addition, studies suggest that there is a strong connection between storm intensity and coastal erosion rates (Solomon et al., 1993). Therefore, better understanding of severe arctic storms is of great interest to coastal communities along Beaufort Sea coastal areas.

In this study, a coupled regional climate model is implemented in the Canadian Arctic region. Two Arctic storms are simulated with this coupled regional climate model. The first one originated in the Pacific in September 20, 1993 and moved northeastward into the Beaufort Sea. Its lowest central pressure was reached when the storm passed over Tuktoyaktuk, with high winds developing rapidly and veering from the southeast to the west. Winds over 70km/h continued for 11 hours and peaked at 96km/h. The second storm originated in the Chukchi Sea during August 9-11, 2000. Its low pressure system reached a minimum central pressure of 994hPa as it moved rapidly into Beaufort Sea.

2. Model description and experiment design

The coupled regional climate model system consists of three components: an atmospheric model CRCM (Canadian Regional Climate Model, version 3.4), ocean model POM (Princeton Ocean Model, 1998 version) and Hibler ice model.

2.1 Model description

CRCM is based on the dynamical formulation of the Canadian Mesoscale Compressible Community (MC2) model, and solves the fully elastic nonhydrostatic Euler equations using a semi-implicit semi-Lagrangian numerical scheme. The physical parameterisation package of the second-generation Canadian Global Climate Model (CGCM2), following McFarlane et al. (1992), is implemented to solve the subgrid-scale processes. The Kain-Fritsch scheme was chosen for deep convection while large-scale condensation is simulated using the CGCM2 physics formulation (Kain and Fritsch 1990; Paquin and Caya 2000). In this study, the CRCM simulations were performed at a horizontal resolution of 25 km. In the vertical direction, there are 29 levels. A 15-min time step is employed. Initial and boundary conditions are specified by CMC analyses data. A detailed description of CRCM is given by Caya and Laprise (1999), Laprise et al. (2003) and Caya and Biner (2004).

POM is a three-dimensional, primitive equation model with complete thermohaline dynamics, using a sigma (σ) vertical coordinate and a free surface. A second-order turbulence closure scheme (Mellor and Yamada, 1982) is used to represent the mixed layer dynamics. The bathymetry is ETOP2. The Polar Science Center Hydrographic Climatology (PHC; http://psc.apl.washington.edu/pscweb2002/data/datasets.html) provides initial and boundary conditions for POM. It has 23 vertical levels. The horizontal resolution is $0.29^{o}\times0.25^{o}$. Time step is 30 minutes.

The sea ice component of the coupled model was developed at Bedford Institute of Oceanography (Yao et al., 2000), using a thermodynamic model based on a multi-category ice thickness distribution function (Throndike et al 1975; Hibler 1980), and a viscous-pastic sea ice dynamics model (Hibler 1979). Heat and salt fluxes at the ice-ocean interface are governed by boundary processes as discussed by Mellor and Kantha (1989). The time step is 30 minutes.

2.2 Experiment design

The coupled ice-ocean model is integrated from 1988, forced with daily NCEP reanalysis, in order to provide initial conditions for ice and ocean components of the coupled regional climate model. The integration lasts 4 days from September 20 to 23 for the 1993 storm and from August 10 to August 13 for the 2000 storm. In the coupled atmosphere-ice-ocean system, CRCM provides the ice-ocean model with surface air temperature, precipitation rate, surface wind, sea level pressure, surface specific humidity and total cloud, and the ice-ocean model provides CRCM with surface temperature and ice cover. CRCM and the ice-ocean model exchange variables every 30 minutes.

3. Results

3.1 Storm simulations

Sea level pressure simulated by the coupled regional climate model is compared with CMC analysis in Fig. 1. At 00 UTC on September 20, 1993, a low pressure system in the Gulf of Alaska is evident, which slowly moves northeastward. Meanwhile, there are two low pressure systems in Chukchi Sea and Beaufort Sea. At 00 UTC on September 21, it makes landfall at Alaska, merges with the low in the Chukchi Sea and intensifies. It then weakens as it moves over land. At 18 UTC on September 21, the storm reaches the northern coast of Alaska and re-intensifies. Comparisons in Fig. 1 suggest the coupled model reproduces the storm track and intensity well, relative to CMC. However, the coupled model slightly overestimates the storm's intensity as it moves along the Beaufort Sea coastline. Meanwhile, a strong trough is located over the Beaufort and Chukchi Seas at 261hPa. This high-level low may be responsible for strengthening the 1993 storm.

However, compared to the 1993 storm, the storm in 2000 is a typical polar low, with a very small spatial scale (Fig.3). In CMC analysis, there is a low pressure system in Chukchi Sea at 0:00 UTC on August 10, 2000. It moves along the coast of the Beaufort Sea and intensifies. The storm begins weakening at 18:00 UTC August 10, 2000. Although CRCM reproduces the storm track well, it fails to simulate the intensification. Moreover, in the 2000 storm, no deep trough can be seen over the Beaufort Sea (Fig.4).

3.2 Surface currents

Fig. 5 shows the storm-induced ocean surface currents. For the two Arctic storms, the dominant surface current is westward, and it is relatively weak near the storm centers. For the 1993 storm, the surface current along the Beaufort coastline is westward everywhere. However, for the 2000 storm, it is westward in front of the storm and eastward behind the storm. Moreover, the westward current is obviously stronger than the current behind the storm.

3. Conclusions

In this study, a coupled regional climate model is implemented in the Arctic Ocean to simulate Arctic storms over the Beaufort Sea. Two Arctic storms are simulated with this coupled system. One originated in the Pacific and the other near the Siberian coast.

Although the storm tracks of the two storms are simulated well by this coupled system, its ability to simulate the storm intensities of these two Arctic storms is very different. The 1993 storm is a large-scale system, related to a deep trough in the upper atmosphere. The coupled regional climate model is able to capture the deepening and weakening processes well. However, the 2000 storm has a very small spatial scale and is a typical polar low, and the coupled model significantly underestimates its intensity. This further suggests that some physical processes related to the polar low are not well represented in the coupled model system.
This study also suggests that, during the two Arctic storms, the dominant surface current along the coast of Beaufort Sea is westward. However, surface currents are relatively weak near the storm centers.

Acknowledgements

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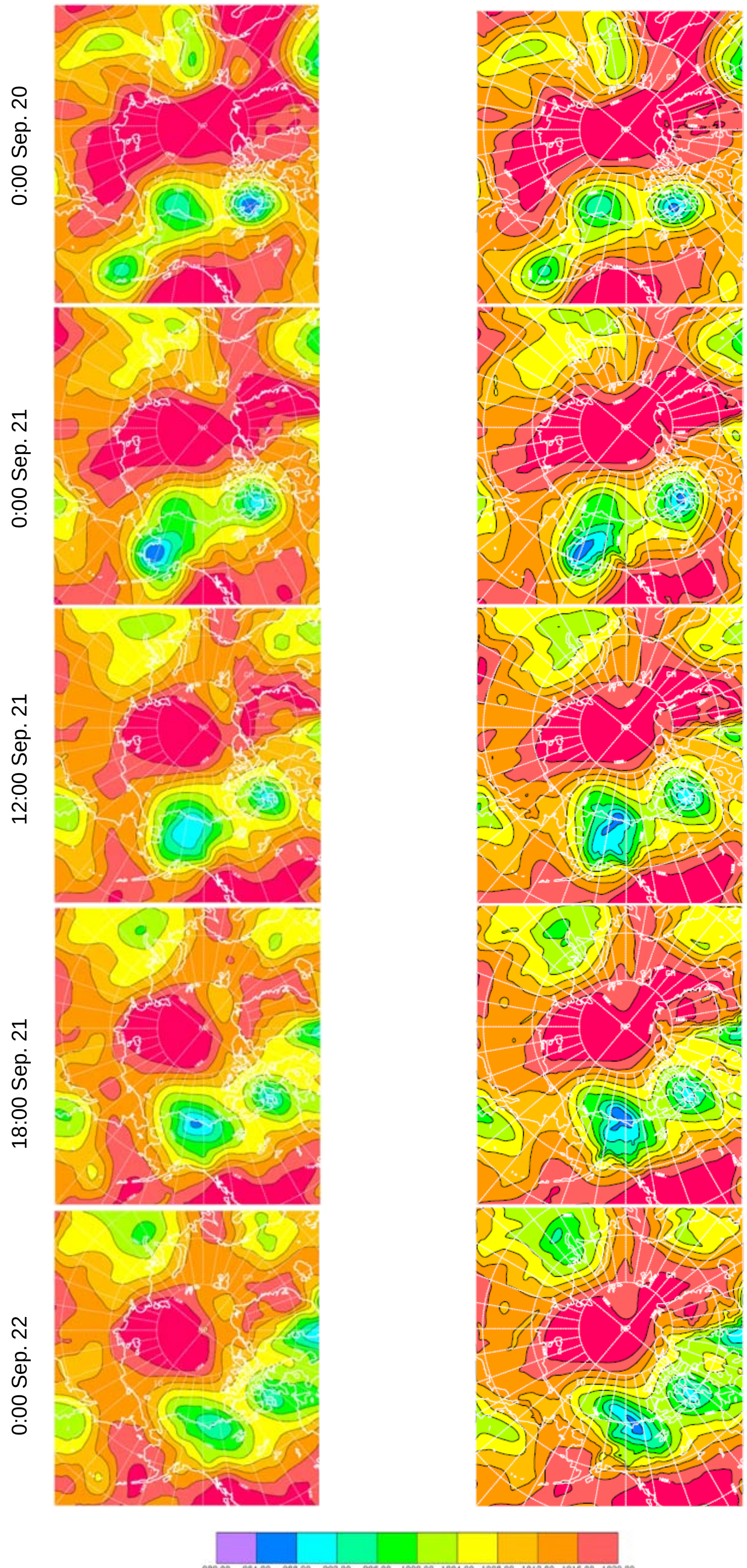


Fig. 1 Sea level pressure from CMC analyses (left panel) and from the coupled model simulation (right panel).

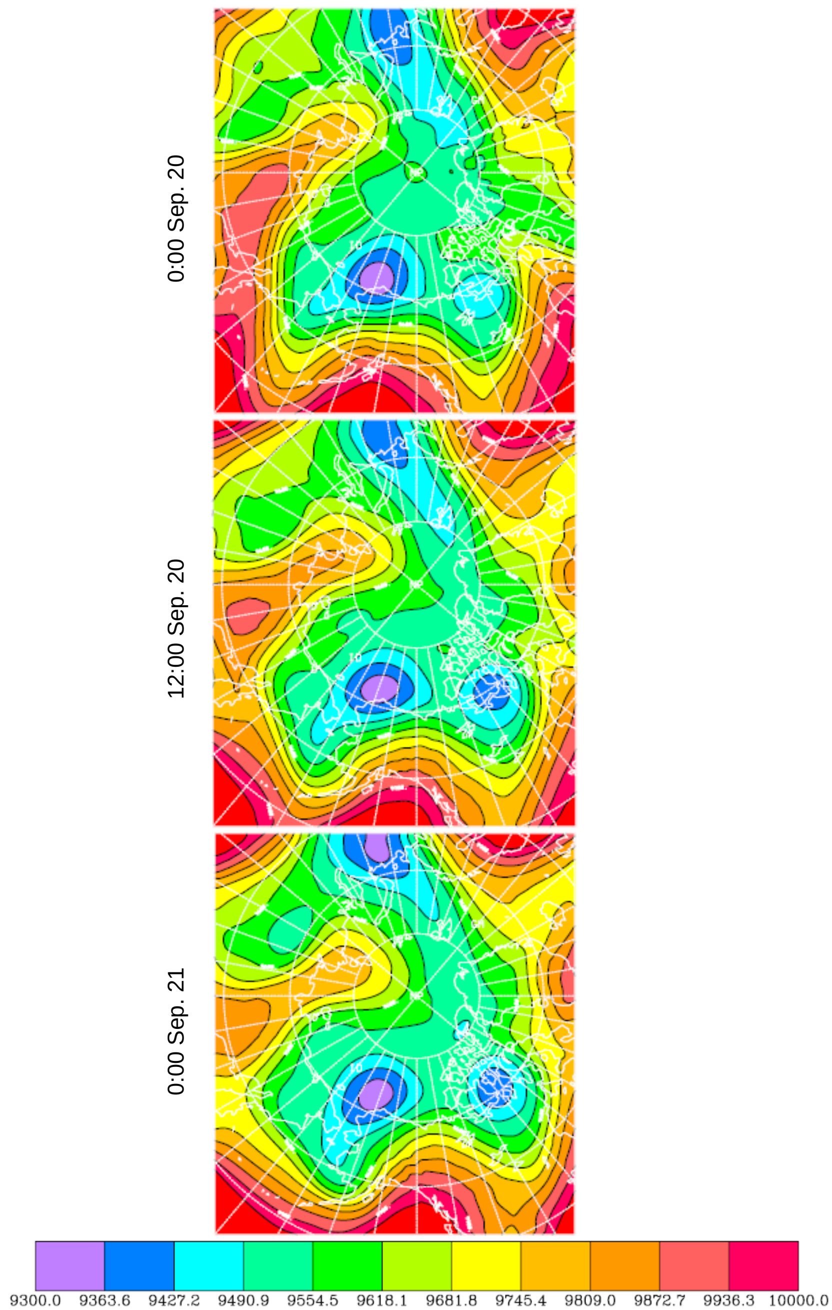


Fig.2 Geopotential height at 261hPa simulated by CRCM

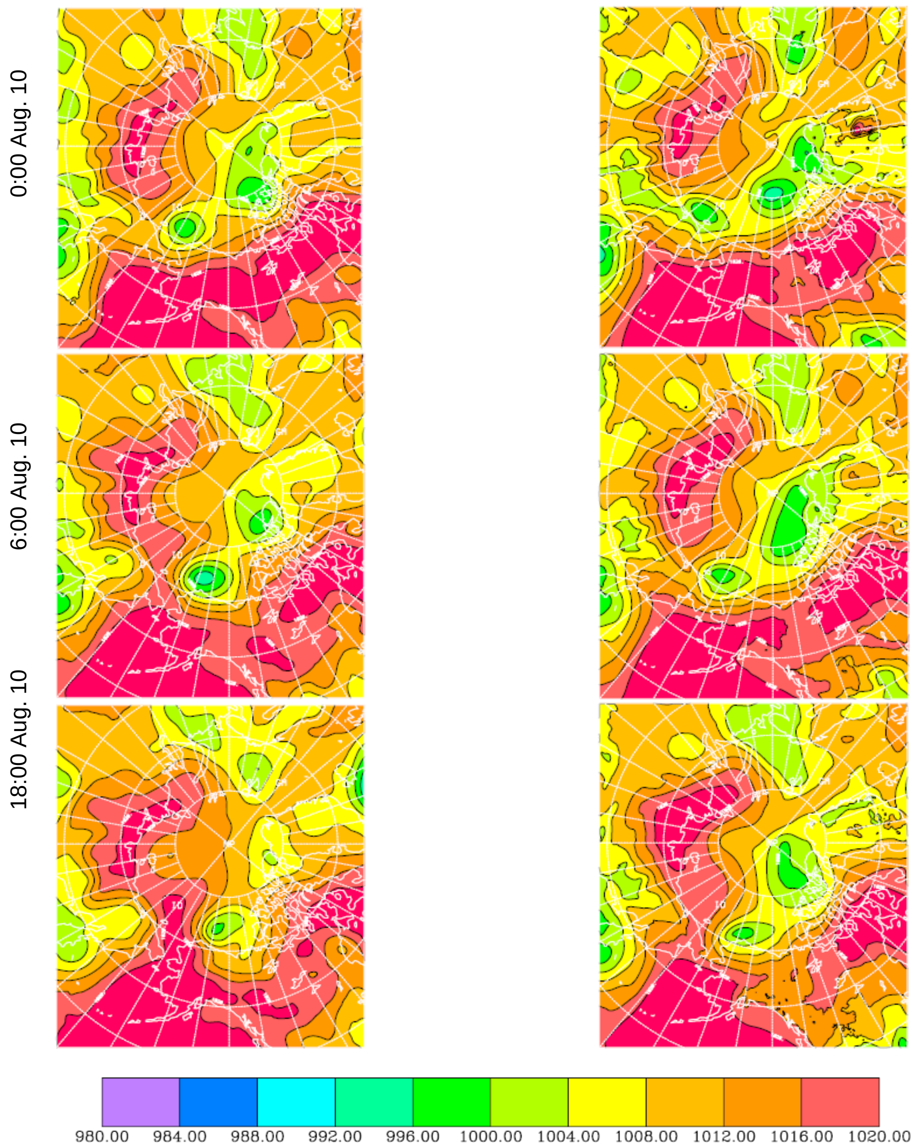


Fig.3 As Fig.1, but for 2000 storm.

0:00 Aug. 10

12:00 Aug. 10

0:00 Aug. 11

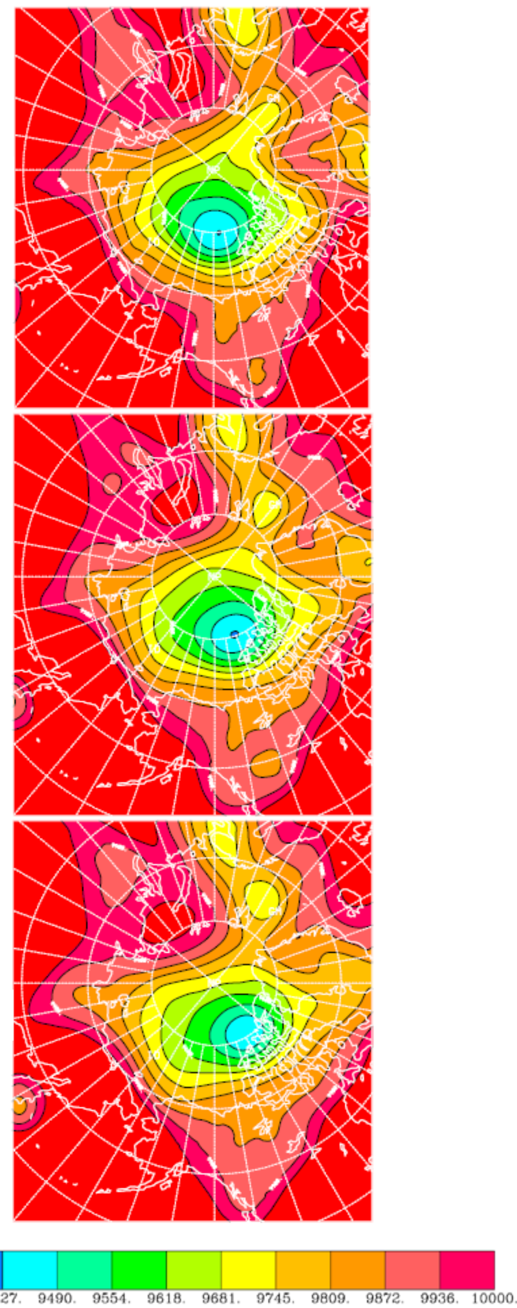
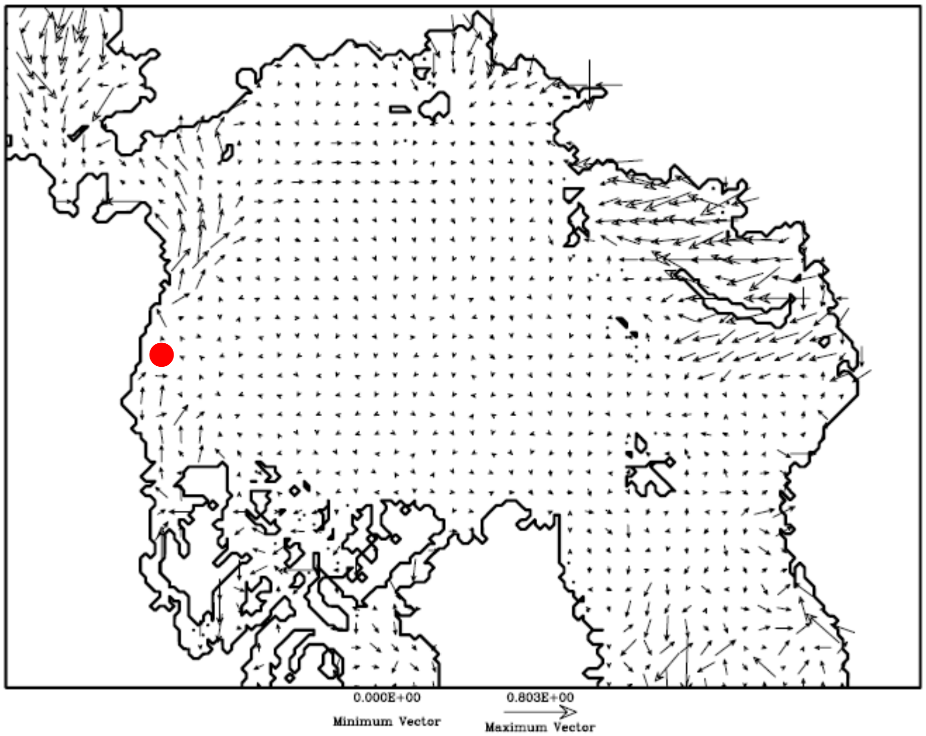
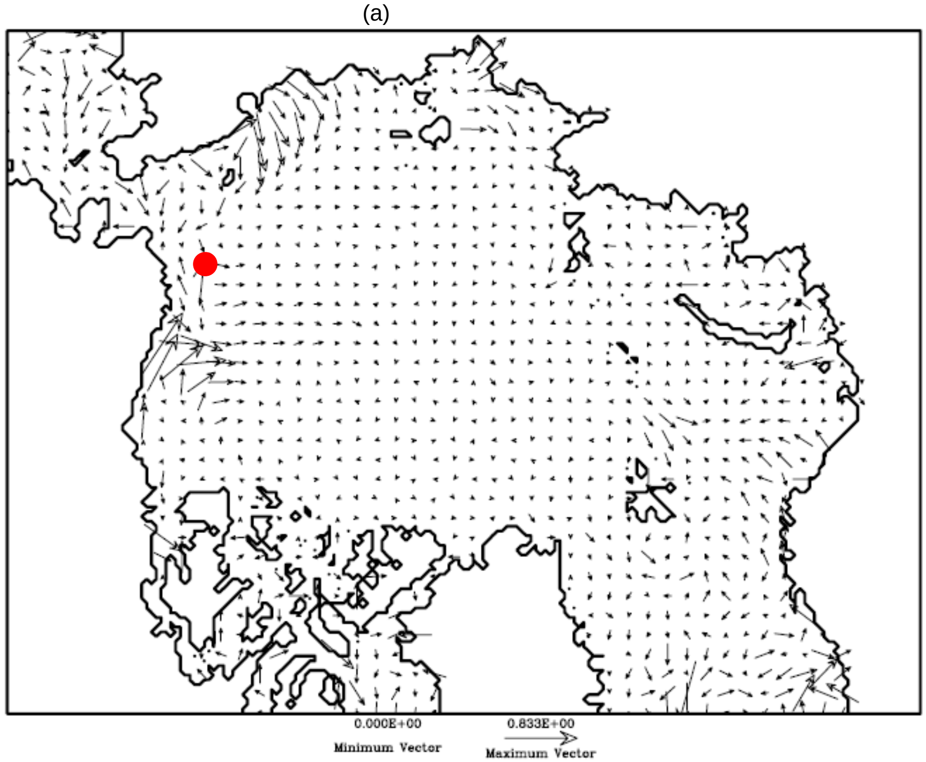


Fig.4 As Fig.2, but for the 2000 storm.



(a)



(b)

Fig.5 Surface currents: (a) 12:00 Sep. 21, 1993, and (b) 06:00 Aug. 11.