J1.18 ATMOSPHERE-OCEAN-ICE INTERACTION PROCESSES IN THE GULF OF ST. LAWRENCE : NUMERICAL STUDY WITH A COUPLED MODEL

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1. INTRODUCTION

The accurate representation of sea ice thickness distribution in numerical model is a critical challenge for global or regional climate simulations (e.g., Allison et al., 2000). In coastal regions of eastern Canada, the winter climate is strongly influenced by the energetic exchanges between the atmosphere and the oceanic surface according to the seasonal sea ice cover. The presence of ice modifies the air-sea exchanges of momentum, heat and mass relative to the open ocean, which in turn influence the regional atmospheric circulation, especially in the Labrador Sea-Hudson Bay sector (Serreze, 1995; Gachon et al., 2001), and also in the Gulf of St. Lawrence (GSL; Gachon and Saucier, 2001). This influence must be studied with particular interest, especially in wintertime, because the Baffin Bay-Labrador Sea-GSL region shows intense cyclonic activity (Serreze et al., 1993; Serreze, 1995) extending from the Labrador Sea/Davis Strait sector toward the Iceland and Norvegian seas.

Recent work of Parkinson et al. (1999) indicates that a major part of the Arctic and subarctic basins shows a large decrease (in annual mean) in the sea ice extent over the 1978-1996 period, except in the Baffin Bay-Labrador Sea, Bering Sea, and Gulf of St. Lawrence, where more severe conditions were observed. However, among these regions, only the GSL positive anomaly in sea ice extent is being statistically significant at the 99% level. Moreover, these authors have suggested that the wintertime changes in sea ice extent in the GSL and Labrador Sea do not reveal a close correspondence. In order to increase our knowledge about the natural climatic variability in the northwestern Atlantic sector, the study of the interactions between these two regions, both in the ocean and atmosphere, must be better documented.

The aim of this paper is to get a better understanding of the effect of interactive processes between the atmosphere-ocean-sea ice in the GSL on the regional atmospheric circulation, and to demonstrate the importance of the coupling between atmospheric and oceanic models in the GSL region. To realize this, we compare two simulations performed over a period of seven days (between 1st and 8th January 1990). Firstly, an off-line coupling (coupled run) every 24 hours has been realized between an atmospheric model (the Canadian Regional Climate Model, hereafter the CRCM) and the oceanic model of Saucier et al. (2001). Secondly, prescribed constant oceanic conditions in the GSL have been used for the whole run (fixed run). The coupling consists of alternative runs with the CRCM and GSL models, and exchanges of fields between these two models every day.

First, we describe briefly the experimental setup of the simulations using the coupled model. We present the results of the two simulations in terms of atmospheric fields' differences during the simulation. We focus on the differences in air-sea exchanges between individual realizations.

2. EXPERIMENTAL DESCRIPTION, MODEL SETUP

The two simulations with the CRCM (recently described in Caya and Laprise, 1999) have been realized with a multiple nesting procedure from 60, to 30 and then 15 km horizontal resolution grid. The NCEP (National Center for Environmental Prediction) analyzes have been interpolated to drive the lateral boundary conditions of the 60 km grid. This 60 km grid covers a 4800×4800 km domain centered over the GSL (48°N, 61°W). Outputs of this first simulation (archived every 3h) drive a new CRCM simulation at a higher resolution (30 km) on a smaller grid (3600×3600 km). The results of this second simulation (archived every 1h) drive a final CRCM simulation at an even higher resolution (15 km) on a smaller grid (2400×2400 km; Fig. 1). The choice of a horizontal resolution of 15 km has been motivated by the preliminary study of Roy et al. (1999) who show that the sea ice drift in the GSL is improved with an increased wind resolution of 35 to 10 km, allowing to resolve the effect of the topography near the GSL. In this finer mesh CRCM grid (Fig. 1), the model timestep is 5 min and includes 30 levels on the vertical (staggered Gal-Chen levels, e.g. terrain-following vertical coordinate, Caya and Laprise, 1999) between the surface and near 20 km high (with 15 levels from the surface up to 2500 m high). This version with the highest resolution is used to produce the results presented here.

The two simulations were produced for the same period during the first week of January 1990. The coupling consists of alternative runs with the CRCM and GSL models, with daily exchanges of boundary fields between these two models. First, the oceanic model is run for December and forced by atmospheric fields issued from CRCM outputs at 60 km. On January 1st, we used the surface temperature (sea surface temperature, and ice surface temperature), and sea ice concentration and thickness archived from this run, to

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force the oceanic conditions in the CRCM (15 km grid). These oceanic conditions are used for the fixed run over the week of simulation. We archived the atmospheric fields at the end of this atmospheric run to drive the oceanic model over the same day. The output of this oceanic run (surface temperature and sea ice) is used to initiate the oceanic conditions in the CRCM over the Gulf for the second day of January. This procedure is repeated over seven days until the January 8th.

For the two CRCM simulations, outside the GSL region, we have prescribed the oceanic conditions with the same monthly mean observed data (valid for January 1990) of NCEP/GISST2.2 (Reynolds et Smith, 1994; Parker et al., 1995) issued from AMIPII (Atmospheric Model Intercomparison Project phase II) dataset. Therefore, the differences in mesoscale atmospheric fields between the two CRCM runs will be exclusively due to the differences between the daily changes in the sea surface conditions over the GSL and the constant ones.

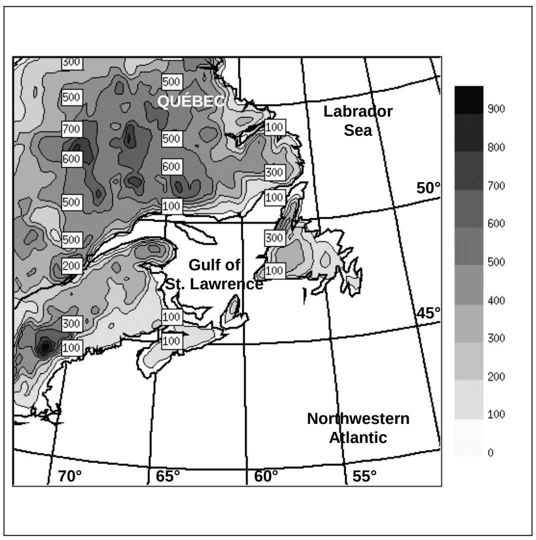

Fig. 1 Topography in m (in gray scale every 100 m) and geographic reference map on the 15 km CRCM grid.

During the simulation period, the atmospheric synoptic forcing over the domain corresponds to two major events of low pressure systems that have migrated from the Great Lakes area and Hudson Bay toward the Labrador Sea. In the wake of these low systems, cold and dry continental air was advected at low-level across the domain. It results in an intense surface diabatic flux over open water and thin sea ice favorable to the deepening of these synoptic cyclones (Mailhot et al., 1996; Gachon et al., 2001). This large scale atmospheric forcing is typical of winter time conditions over northeastern North America, and represents a favorable context to generate mesoscale atmospheric circulation sensitive to the sea ice conditions. During the first cyclone event, the deepening of the low issued from the Great Lakes was very rapid above the coastal regions of eastern Canada, resulting in high wind speeds, and an intense cold air advection in the low-level over the GSL. This system migrated toward the northeast and stalled over the Labrador Sea until January 4th. In the second case, the low pressure system was less deep and moved farther north from Hudson Bay toward the Labrador Sea. The low-level trough extended over the St. Lawrence valley and moved over the GSL. The track of this cyclone induced a wind direction favorable to the propagation of the atmospheric features developed over the GSL toward the northeast.

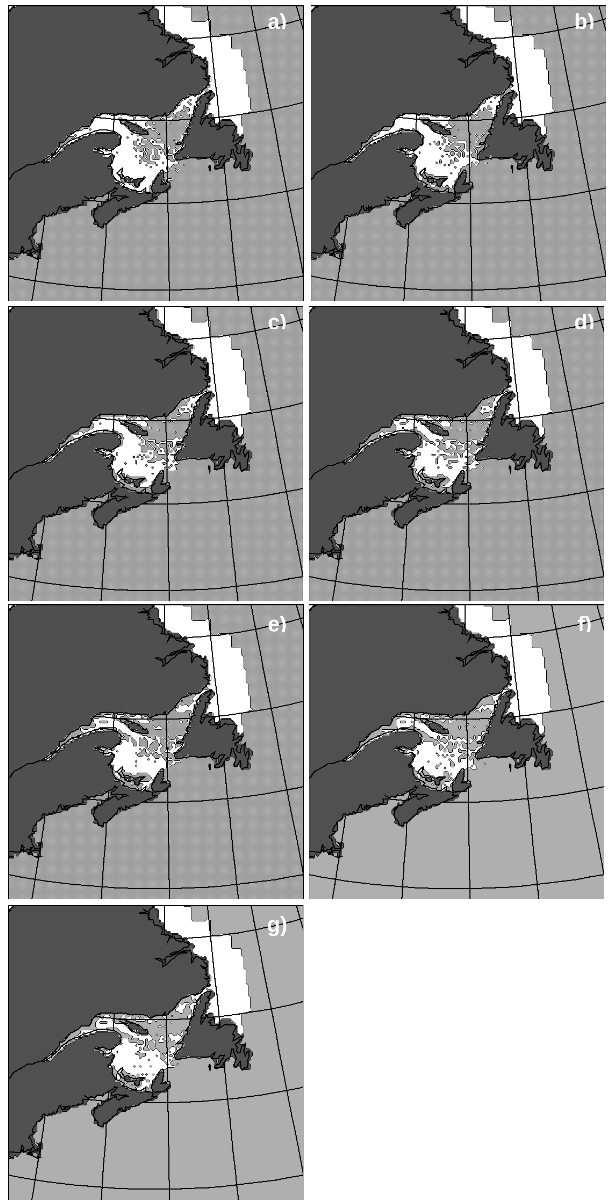

Fig. 2 Evolution of sea ice cover (in white) in the GSL every day, during the week (a to g correspond to 1st to 8th of January 1990, respectively).

3. RESULTS OF COMPARISONS BETWEEN TWO SIMULATIONS

As shown in Fig. 2, the sea ice cover in the GSL varies from one day to the next, with the formation of polynyas and leads along the north coast of the GSL. This modification in the distribution of sea ice is essentially the consequence of the passage of the two extratropical cyclones over the region with the predominant strong northwesterly winds in the cold sector of these lows which caused the ice displacement from the coast toward the southeast. This feature is also present near the Gaspesian Peninsula. Otherwise, a lead forms along the Gaspesian current in response to strong westerly winds near the surface.

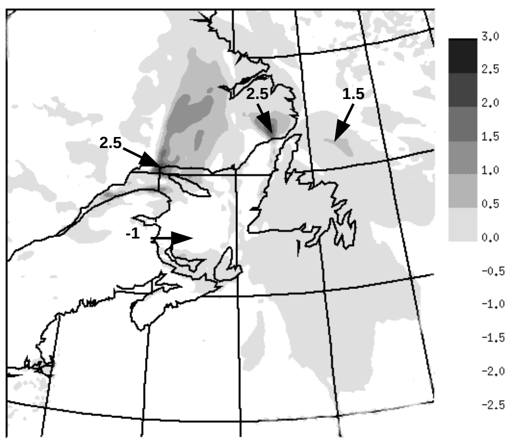

Fig. 3 Differences between coupled minus fixed runs on January 5th at 0300Z in temperature at 1000 hPa (in °C; positive values are in gray scale, i.e. $T_{\_coupled} > T_{\_fixed}$).

During the period of integration, the changes in sea ice cover generate a modification in surface heating over the Gulf which in turn modifies the low-level winds and temperature. With the migration of cyclone events, these anomalies in low-level atmospheric fields are progressively advected from the Gulf toward northern Québec (Fig. 3) and the Labrador Sea (Figs 4, 5, and 6). Hence, the cumulative effects of the daily spatial changes in surface oceanic conditions in the GSL affect in part the surface heat loss over the Labrador Sea, as indicated in Fig. 5 by the differences in surface sensible heat flux. These feedback mechanisms also depend on the oceanic conditions in the Labrador Sea, especially on the position of the sea ice margin which determines the distribution of air temperature gradients near the surface and in turn the distribution of surface heat loss both over the Labrador Sea and the GSL. In our case, these feedbacks in the Labrador Sea are not really taking in to account because the surface conditions are fixed during the simulation. However, the surface flux perturbations due to the GSL conditions can be isolated in prescribing the oceanic surface in the Labrador Sea and northwestern Atlantic.

Around the GSL, the temperature and the winds fields pattern is strongly influenced by the daily conditions in the GSL, especially along the land/ocean boundary where the low-level air temperature are most contrasted and land fast ice changes rapidly during the time. In this zone, the ice is strongly influenced by winds with the combined effect of the tide (a parameterization of the tidal effect is incorporated in the oceanic model; cf Saucier et al., 2001). Consequently, in these sectors, the daily changes in sea ice conditions in the coupled run induce a response in winds and temperature fields pattern in the model, compared to the fixed run where these effects are absent or fixed at spatial scale (see Fig. 6).

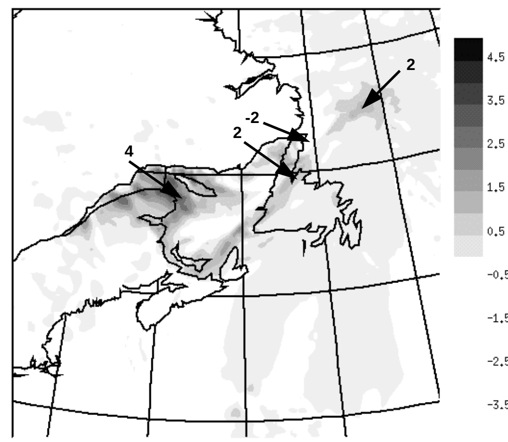

Fig. 4 Same as Fig. 3 but on January 7th at 0300Z.

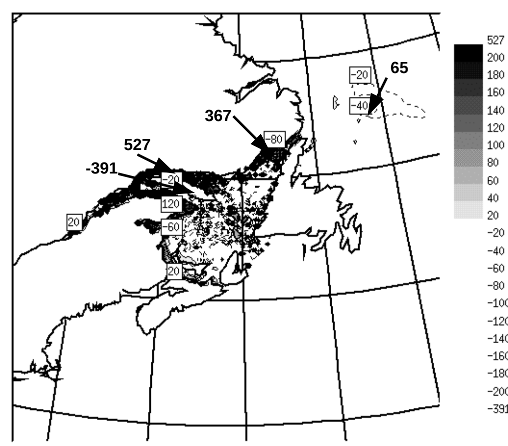

Fig. 5 Same as Fig. 4 but for the surface sensible heat flux in W m^{-2} (positive values are in gray scale).

Finally, during the week, the temperature anomaly at regional scale is affected locally, by the differences in surface heating over the GSL due to the changes in ice conditions between the two runs, and at regional scale, by the anomaly in the temperature advection at low-level during the migration of the cyclones. In that way, the connection between the GSL and the adjacent oceanic basins via the atmospheric response above the GSL can presumably influence the interactive processes between the atmosphere, ocean and sea ice in the northwestern Atlantic during all the winter season. This aspect must now be better documented at seasonal or interannual scale. This work is in part underway by Faucher et al. (this issue) for the winter season.

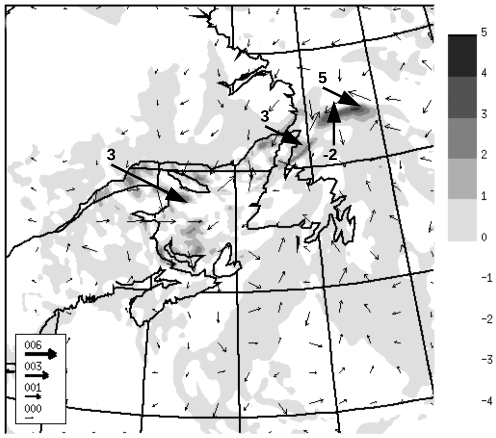

Fig. 6 Same as Fig. 4 but for the winds at 1000 hPa (direction and intensity in m s^{-1}; positive values are in gray scale).

4. CONCLUSIONS

As illustrated in this study, the atmosphere-ocean-sea ice interactions in the region of Labrador Sea-GSL-northwestern Atlantic depend on accurate representation of sea surface conditions in the model simulation. One of the main conclusion of our study is that the response of atmospheric circulation to surface oceanic conditions during cyclone events can not be well represented in the prescribed monthly/weekly mean oceanic data, used in climate/forecast model when the atmosphere is not coupled with the oceanic component. Presumably, the cumulative effects of the mesoscale pattern of atmospheric circulation due to the sea surface conditions in the GSL could modify the climate variability (or forecast meteorological system) in numerical simulation at regional scale, in the context of rapid and intense winter variation in sea ice cover, as it is regularly observed in the GSL. The regional atmospheric and oceanic changes induced by the GSL sea ice cover must be analyzed in detail in our future works, especially in order to understand how the response of atmosphere-ocean feedbacks evolve in time. This research is particularly important for winter conditions because the synoptic and mesoscale cyclones are very frequent and intense in this region (Serreze, 1995; Mailhot et al., 1996; Serreze et al., 1997), and the GSL-Labrador Sea sector offers a wide range of hydrodynamics conditions. Finally, this study confirms how regional sea ice extent is important directly and indirectly (via atmospheric response) for surface energetic budget over ocean which in turn controls the regional climate in winter. The next step toward an on-line coupling between the atmospheric and oceanic models is presently underway.

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