7.4 SEA ICE IMPACTS ON GFS FORECASTS AT HIGH LATITUDES

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1. INTRODUCTION

Sea ice is an integral component of the global climate and weather system. The extent of sea ice is mainly influenced by, and has a significant effect on, the surface energy budget and ocean-atmosphere energy exchange. Regional and global changes in sea ice fraction and extent influence oceanic and atmospheric conditions, which in turn influence the evolution of sea ice itself. A sea ice cover significantly reduces the amount of solar radiation absorbed at the earth's surface in summer due to marked changes in the surface albedo. The presence of extensive areas of sea-ice suppresses heat loss by the ocean in winter and impacts the turbulent heat exchange between ocean and atmosphere. The presence of leads and polynyas in the ice is also significant to the energy budget of the ice-covered ocean. The impact of sea ice on climate and climatic change has been extensively investigated using global climate models. However, much less work has been done on the effect of sea ice on numerical weather prediction. In this work, a thermodynamic sea ice model is coupled to the NCEP Global Forecast System (GFS) atmospheric model to investigate sea ice impact on GFS predictions for both the winter and summer seasons.

2. SEA ICE MODEL

The sea ice model used here is based on Winton's (2000) three-layer (two equally thick sea ice layers and one snow layer) thermodynamic process. It predicts sea-ice/snow thickness, the surface temperature and ice temperature structure. In each model grid box, the heat and moisture fluxes and albedo are treated separately for ice and open water (Wu et al. 1997).

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3. EXPERIMENTS

Two case studies were chosen for this work, one for January (Northern Hemisphere winter) 2004 and the other for July (Northern Hemisphere summer) 2004. Three cycled data assimilation and forecast experiments were conducted for each case (Table 1). The first experiment is the control ("EXPC") test, or standard GFS forecast. A resolution of T62L64 is used here. The second experiment ("EXPI") is GFS plus interactive sea ice. The third experiment ("EXPJ") is the same as the second experiment, but using a new analysis scheme with an improved snow/ice microwave emissivity model used for satellite-observed radiance assimilation. With the new analysis scheme more radiance data (from the Advanced Microwave Sounding Units - A and - B) are used at high latitudes (Okamoto et al. 2004). For the January case the experiment started on December 15, 2003, for the July case it started on May 15, 2004. For the "EXPI" and "EXPJ" experiments, sea ice fraction is initialized using satellite observations and kept fixed during the 5-day prediction.

Table 1. Experiments for cycled data assimilation and forecast for January and July 2004.

Exp	Description
EXPC	Control or Standard GFS
EXPI	"EXPC" plus a thermodynamics sea-ice model
EXPJ	"EXPI" plus a new analysis scheme

4. FORECAST IMPACTS

The impacts of sea ice (and new analysis) on GFS prediction are mainly over the lower troposphere in the high latitudes, with the largest effect occurring near the surface during winter. Figure 1 shows the temperature bias verified against its own analysis for January 2004 over 60°N-90°N at 1000 hPa and 850 hPa. It can be seen that the cold bias has been greatly reduced, from more than –1.1 K in "EXPC" to less than –0.6 K in "EXPI" at 850 hPa on day 5. The reduction was even greater at 1000 hPa, from more than –1.4 K in "EXPC" to less than –0.5 K in "EXPI" on day 5. The reduction was not apparently as great in "EXPJ" as in "EXPI", which was due to the fact that there was also a cold bias in the present analysis, but the analysis was improved with the new scheme (Okamoto et al. 2004). This can be seen in Fig. 2. The analyzed temperature was warmer, using a new improved emissivity model for snow/ice. When the forecast of "EXPJ" is compared with a warm analysis, the reduction for the cold bias is thus less. In fact, the predicted temperature in "EXPJ" has the lowest bias in the lower troposphere of the three experiments (verified against the same analysis). This can also be seen in the comparison between the forecasts of GFS and European Centre for Medium-range Weather Forecasts (ECMWF) in Fig. 3.

The temperature bias for Southern Hemisphere winter (July) is shown in Fig. 4. The improvement in predicted temperature is greater than in Northern Hemisphere winter (January). The difference between "EXPI" and "EXPJ" is much smaller than that in the Northern Hemisphere because of the smaller impacts of the new analysis scheme in the Southern Hemisphere (not

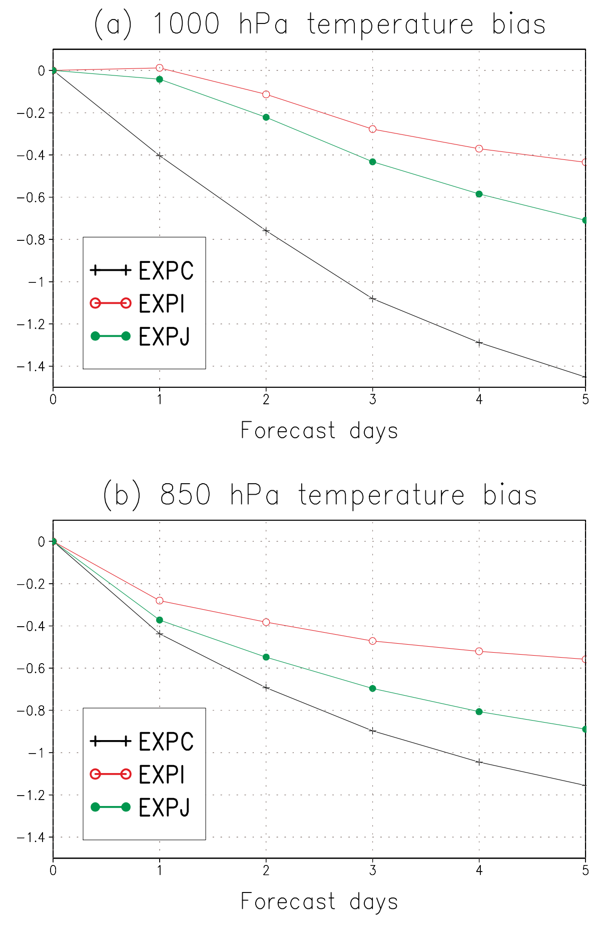

Fig. 1. The temperature bias calculated over 90°N-60°N for January 2004 for "EXPC" (black line), "EXPI" (red line) and "EXPJ" (green line) at (a) 1000 hPa and (b) 850 hPa.

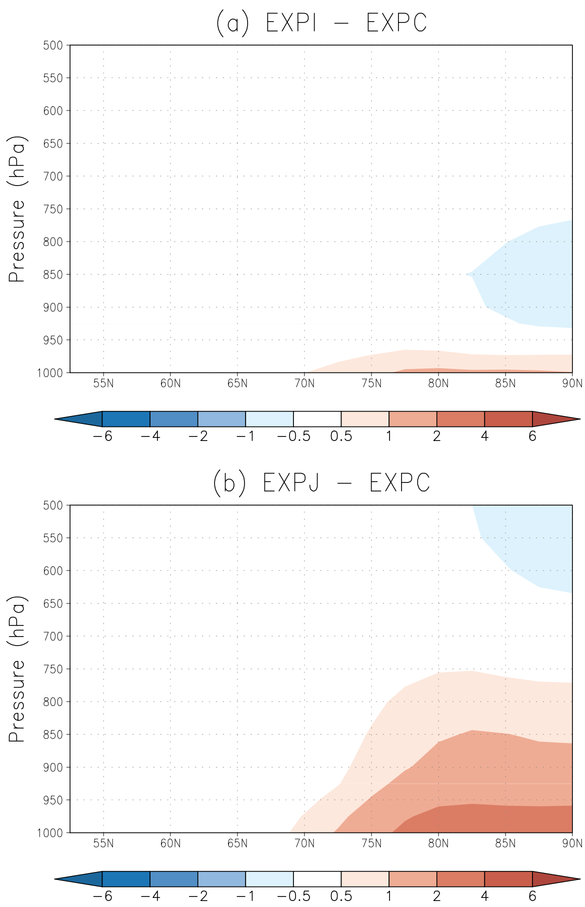

Fig. 2. The zonal mean of the analyzed temperature difference between (a) "EXPI" and "EXPC" and (b) "EXPJ" and "EXPC" for January 2004.

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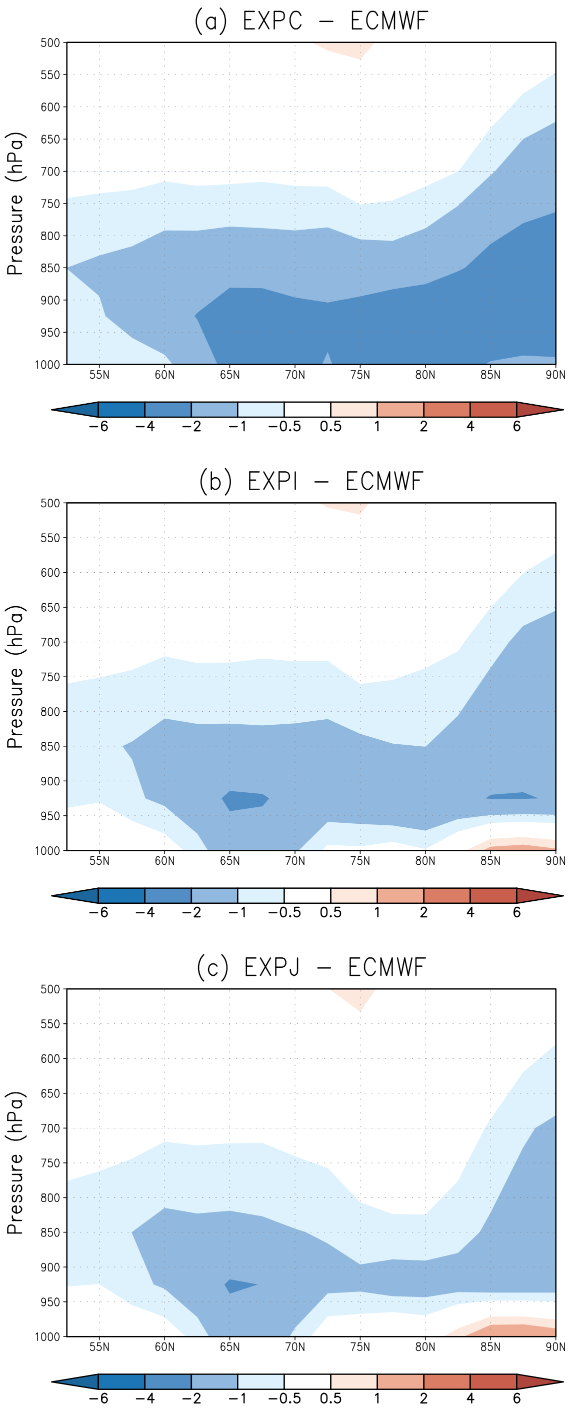

Fig. 3. The zonal mean of the forecasted temperature difference between (a) "EXPC" and "ECMWF", (b) "EXPI" and "ECMWF", and (c) "EXPJ" and "ECMWF" at day 5 (or 120 hours) for January 2004. "ECMWF" is for ECMWF prediction.

The forecasted temperature has also been improved for the summer season. However, because the bias is small in GFS the reduction in the cold bias is much less than that of the winter season. Figure 5 shows the Northern Hemisphere July case at 850 hPa over 60^{o}N-90^{o}N. It can be seen that the bias was reduced from –0.75 K in "EXPC" to about –0.50 K in "EXPI" and –0.56 K in "EXPJ" on day 5.

The sea ice model with the new analysis scheme has a small but positive effect on the prediction skill as shown in Figs. 6 and 7 for the 500 hPa anomaly correlation for 60^{o}N-90^{o}N for January and July. For the Southern Hemisphere the prediction skill was improved for the lower troposphere (Fig. 8) but this does not transfer to the high levels at 500 hPa (not shown).

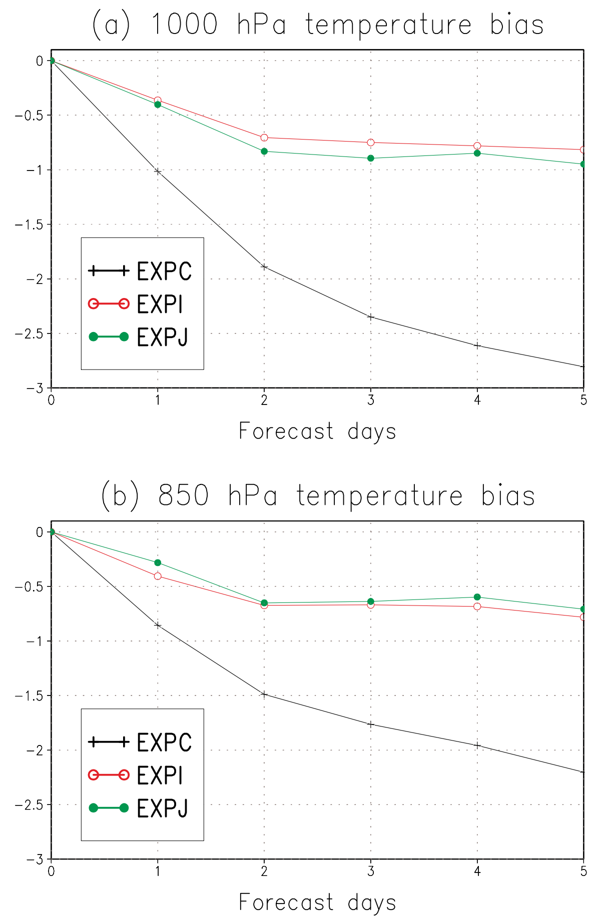

Fig. 4. The temperature bias calculated over 60^{o}S-75^{o}S for July 2004 for "EXPC" (black line), "EXPI" (red line) and "EXPJ" (green line) at (a) 1000 hPa and (b) 850 hPa.

5. CONCLUSION

A three-layer thermodynamic sea-ice model, including leads, is coupled to the NCEP Global Forecast System atmospheric model. Two case studies from cycled data assimilation/forecast experiments for January and July 2004 show satisfactory performance of the new forecast model. While good agreement in the anomaly correlation between the new and old models is observed, the low-temperature bias in the lower troposphere in the high latitudes during winter has been greatly reduced in the new model, especially when a new data assimilation scheme is used (Okamoto et al. 2004). For the summer season the cold bias is much smaller in the standard forecast and the reduction of the cold bias is thus less with an interactive sea ice model.

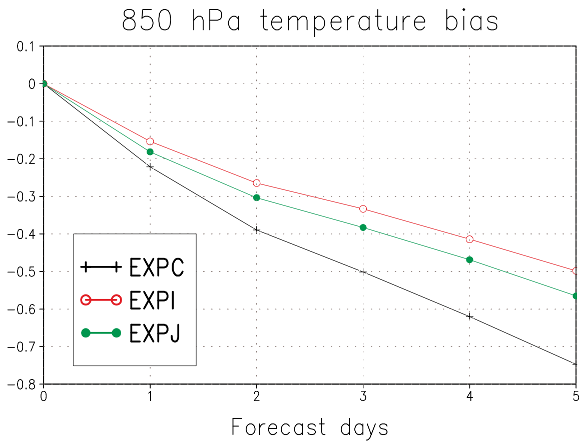

Fig. 5. The temperature bias calculated over 60^{o}N-90^{o}N for July 2004 for "EXPC" (black line), "EXPI" (red line) and "EXPJ" (green line) at 850 hPa.

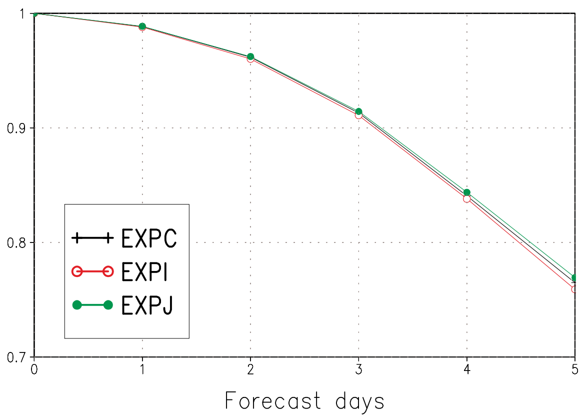

Fig. 6. 500 hPa anomaly correlation for 60^{o}N-90^{o}N for January 2004.

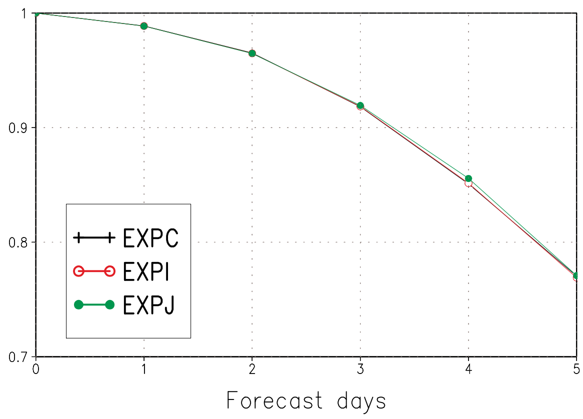

Fig. 7. As in Fig. 6 but for July 2004.

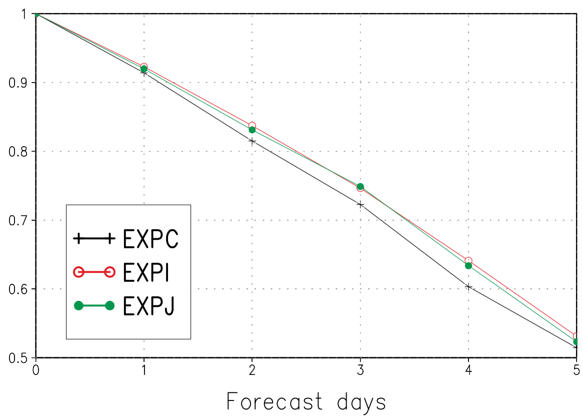

Fig. 8. 1000 hPa anomaly correlation for 60^{o}S-75^{o}S for July 2004.

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