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Assessment of radiation forcing data sets for large-scale sea ice models in the Southern Ocean

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ABSTRACT

Little is known about errors in the atmospheric forcings of large-scale sea ice-ocean models around Antarctica. These forcings involve atmospheric reanalyses, typically those from the National Center for Environmental Prediction and National Center from Atmospheric Research (NCEP-NCAR), climatologies, and empirical parameterizations of atmosphere-ice heat and radiation fluxes.

In the present paper, we evaluate the atmospheric forcing fields of sea ice models in the Southern Ocean using meteorological and radiation observations from two drifting station experiments over Antarctic sea ice. These are Sea Ice Mass Balance in the Antarctic (SIMBA, Bellingshausen Sea, October 2007) and ISPOL (Ice Station POLarstern, Weddell Sea, December 2004). For the comparison, it is assumed that those point measurements are representative of the whole model grid cell they were collected in.

Analysis suggests that the NCEP-NCAR reanalyses have relatively low biases for variables that are assimilated by the system (temperature, winds and humidity) and are less accurate for those which are not (cloud fraction and radiation fluxes). The main deficiencies are significant day-to-day errors in air temperature (root-mean-square error 1.4–3.8 °C) and a 0.2–0.6 g/kg mean overestimation in NCEP-NCAR specific humidity. In addition, associated with an underestimation of cloud fraction, NCEP-NCAR shortwave radiation features a large positive bias (43–109 W/m^2), partly compensated by a 20–45 W/m^2 negative bias in longwave radiation. Those biases can be drastically reduced by using empirical formulae of radiation fluxes and climatologies of relative humidity and cloud cover. However, this procedure leads to a loss of day-to-day and interannual variability in the radiation fields. We provide technical recommendations on how the radiation forcing should be handled to reduce sea ice model forcing errors. The various errors in forcing fields found here should not hide the great value of atmospheric reanalyses for the simulation of the ice-ocean system.

1. Introduction

The Southern Ocean is a key component of the climate system. The large uptake of heat and CO_2 in the Southern Ocean significantly moderates global warming in future climate projections (e.g., Stouffer et al., 2006; Bitz et al., 2006; LeQuéré et al., 2007). An important agent in the Southern Ocean is its sea ice cover (Goosse and Fichefet, 1999; Worby et al., 2008; Cavalieri and Parkinson, 2008).

Simulating the large-scale evolution of Antarctic sea ice has proved more difficult than for the Arctic. Hindcast simulations of the Antarctic sea ice pack forced by atmospheric and radiation data forcing (hereafter 'hindcasts') show reasonable agreement with observations in terms of large-scale distribution of ice thickness and concentration, but are not as accurate as those made for the Arctic (see, e.g., Vancoppenolle et al., 2009). This is illustrated by the statistics of a global sea ice 1979–2006 reconstruction

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Table 1
Model-data comparison statistics for the model NEMO-LIM3 (Vancoppenolle et al., 2009) for a global sea ice hindcast over 1979-2006 forced by a combination of NCEP atmospheric reanalyses (Kalnay et al., 1996) and climatologies at 2° resolution. Bias is defined as the average model-observation difference. Observed ice area is taken from passive microwave data (Comiso et al., 2008). Arctic ice thickness estimates come from submarine ice draft data set (Rothrock et al., 2008). Antarctic ice thickness data come from the ASPeCt data set (Worby et al., 2008). For more details on procedures, see Vancoppenolle et al. (2009).

Diagnostic	Arctic	Antarctic
Model—obs. relative bias on summer ice area (%)	−21	−71
Model—obs. relative bias on winter ice area (%)	−0.9	14
Model—obs. relative bias on ice thickness (%)	−17	−44
Correlation between model and obs. ice area variability	0.74	0.65

performed using their state-of-the-art global ice-ocean model (Table 1), which shows the following deficiencies. The main sea ice model errors in the Southern Ocean include an overestimation (underestimation) of winter (summer) sea ice extent, as well as an underestimation of mean ice thickness. This in turn deteriorates the simulated interannual variations. Some of these features were found in other Antarctic sea ice simulations (Fichefet et al., 2003; Timmermann et al., 2005; Stössel et al., 2007; Zhang, 2007; Mathiot, 2009; Timmermann et al., 2009). Another dilemma is that sea ice simulations performed with coupled climate models used in the last IPCC climate assessment show the same tendency of lower performance for the Antarctic than for the Arctic (Arzel et al., 2006). Averaged over all IPCC model simulations, the current sea ice is reasonably well reproduced. However, this averaging procedure hides large errors from individual models (Holland and Raphael, 2006; Lefebvre and Goosse, 2008).

Errors in Antarctic sea ice hindcasts have been attributed to grid resolution, missing physical processes in the models, and quality of available forcing data (see, e.g., Fichefet et al., 2003; Timmermann et al., 2005, 2009; Vancoppenolle et al., 2009). First, increasing horizontal model resolution improves simulation of the ice edge on some locations, but does not explain all simulation errors (Mathiot, 2009). Second, the effects of velocity divergence, formation of frazil/pancake ice and of snow cover (flooding, superimposed and snow ice formation) are more prevalent in the Antarctic than in the Arctic (e.g., Heil and Allison, 1999; Nicolaus et al., 2006; Heil et al., 2008; Lewis et al., 2011), and because these processes are not completely understood, they may not be adequately represented in current models. Finally, there are uncertainties associated with the forcing that are an important issue: at this stage, they complicate model physics improvements. As the Southern Ocean is poorly data-covered, the atmospheric reanalyses climatologies may carry significant errors (e.g., Bromwich and Fogt, 2004). However, over Antarctic sea ice, little is known on the skill of reanalysis products.

The NCEP-NCAR (Kalnay et al., 1996; Kistler et al., 2001) reanalyzed data of the atmospheric state over the last 50 years everywhere on Earth on a daily basis. Those extremely valuable data combine information from both weather prediction models and observations and are available on $\sim 2^\circ$ grids. Reanalyzed near-surface temperature and pressure fields have been evaluated at high Southern latitudes using weather station data by Bromwich and Fogt (2004) and Bromwich et al. (2007). They mention poorer behavior in the Antarctic compared to the Arctic due to large data gaps, especially before 1978. Reasonable skill was found after that year because of the introduction of satellite data in the system. In addition, a strong coastal cold bias, from 0 to $-15\,^\circ$C, was found around Antarctica. However, Bromwich and Fogt (2004) mention that the latter is not extremely robust and rather indicates that the sharp change in altitude is not resolved by reanalysis systems. To our knowledge, the unique study evaluating reanalysis over Antarctic sea ice is the one by Vihma et al. (2002). Using temperature and wind data from floating buoys over a year in 1996, they found a cold bias of $-3.2\,^\circ$C in NCEP and a warm bias of $3.5\,^\circ$C in ECMWF reanalyses, inducing significant differences in turbulent fluxes of sensible and latent heat. Radiation fields in reanalysis systems were not assessed in that study. In the Arctic, a recent study by Walsh et al. (2009) suggests that reanalysis system contain large biases because of their inaccurate representation of clouds.

Errors in atmospheric reanalyses impact sea ice models through computation of the surface energy budget. Some information on observations of the latter over Antarctic sea ice can be found in Vihma et al. (2002, 2009) and Andreas et al. (2004). They indicate that the annual surface energy budget is dominated by the net longwave radiative loss, which is compensated about equally by incoming shortwave radiation and sensible heat. In summer, significant differences were found, in particular, an upwards sensible heat flux (Vihma et al., 2009). Over Antarctic sea ice long time series of meteorological products do not exist, so little is known about the skill of reanalysis products.

In this paper, we use field data from two Antarctic sea ice drifting stations, Sea Ice Mass Balance in the Antarctic [SIMBA], (Lewis et al., 2011) and Ice Station POLarstern [ISPOL] (Hellmer et al., 2008), to characterize the surface radiation budget over Antarctic sea ice in spring and early summer. In addition, we evaluate the errors in radiation fluxes in reanalyses and in the forcing formulations used in large-scale hindcast sea ice simulations. We assume that point measurements are representative of the whole model grid cell. This is likely a reasonable approximation for daily averages of most variables. However, the presence of polynyas or the proximity of the ice edge could influence the comparison.

2. Material and methods

2.1. Drifting stations

Two sets of *in situ* meteorological and radiation data from two sea ice drifting stations have been used here: SIMBA and ISPOL (see Fig. 1). Prior to analysis, the data discussed here were quality controlled and averaged on common hourly and daily bases.

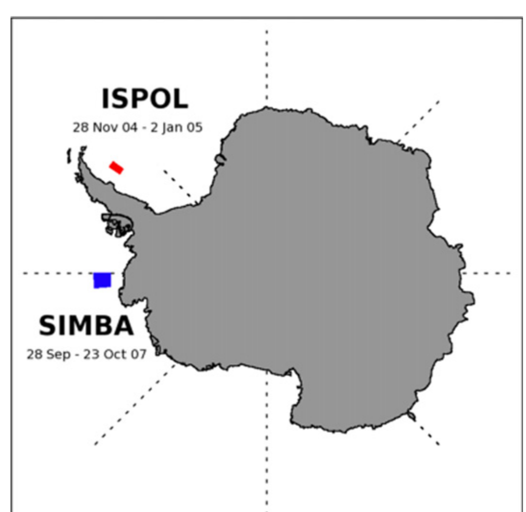

Fig. 1. Map of Antarctica with locations of SIMBA and ISPOL drifting stations.