P1.42

REPRESENTATION OF ANTARCTIC COASTAL POLYNYAS IN OCEAN CLIMATE MODELS: A JUSTIFICATION FOR ASSIMILATION OF SATELLITE-DERIVED ICE CONCENTRATION?

Achim Stössel$^{\star 1}$
Department of Oceanography
Texas A&M University, College Station

Thorsten Markus
NASA Goddard Space Flight Center
Greenbelt, Maryland

1 INTRODUCTION

The representation of high-latitude processes in global (ice-) ocean general circulation models (OGCMs) suffers from critical features such as leads and convective plumes not being resolved by the governing model physics. Furthermore, various nonlinear complications arise from sea-ice physics and atmosphere - ice - ocean coupling. Nevertheless, modern climate studies rely heavily on coupled atmosphere - ocean GCM results. It is thus important to estimate the impact of unresolved (subgrid-scale) high-latitude processes on global results.

In this paper, we focus on the impact of the representation of Antarctic coastal polynyas (AACPs) in global OGCMs. AACPs have a direct impact on the formation rate of Antarctic Bottom Water (AABW), mainly through vigorous new- ice formation and brine release occurring therein (e.g., Orsi *et al*, 2002). The formation rate of AABW appears to be directly correlated to the width of AACPs (e.g., Markus *et al.*, 1998; Timmermann *et al.*, 2002; Comiso and Gordon, 1998). The extent of AACPs, on the other hand, depends on various factors such as the strength of offshore, mostly katabatic winds (e.g., Gallee, 1997), interactive effects that modify the offshore winds in the presence of a coastal polynya (e.g., Parish and Bromwich, 1989; Goodrick *et al.*, 1998), the penetration of warm CDW onto the continental shelf (Fichefet and Goosse, 1999) and, in regions of multi-year ice in summer, the open-water albedo feedback (Hunke and Ackley, 2001).

Given the fact that detailed interactive subgrid-scale physics that determine the extent of AACPs will be hard to resolve in global climate models in the near future, we investigate in this study the potential usefulness and impact of assimilating AACPs in form of daily ice concentration derived from satellite passive microwave data.

2 THE MODEL

In order to investigate the actual model solution for the deep ocean, we can only afford a coarse-resolution OGCM which allows for a series of several- thousand year integrations. Here, we use a global coarse-resolution (3.5 deg x 3.5 deg x 11-layer) version of the Hamburg Ocean Primitive Equation (HOPE) model (e.g., Drijfhout *et al.*, 1996; Wolff *et al.*, 1997; Marsland *et al.*, 2003; Legutke and Maier-Reimer, 1999), which includes a comprehensive sea-ice model with ice dynamics based on Hibler (1979), and ice thermodynamics based on Owens and Lemke (1990).

The specific model configuration used in this study is that described in Stössel *et al.*(2002). It includes a global heat-balance calculation similar to Oberhuber (1993) and Large *et al.*(1997), and atmospheric synoptic scale wind forcing over Southern Ocean sea ice. Otherwise, the model is driven by climatological, monthly-mean winds, as well

---

[1] **Corresponding author address*: Achim Stössel, Texas A&M Univ., Dept. of Oceanography, College Station, TX 77840-3146; e-mail: astoessel@ocean.tamu.edu

as monthly-mean air temperature, and a salinity restoring. Where sea ice is present, such restoring is replaced by the actual fresh-water flux associated with freezing and melting. Results from two model versions will be shown that differ in the way convection is treated: in case PC, a subgrid-scale plume convection parameterization following Paluszkiewicz and Romea (1997) is employed, while in case CA convection in the Southern Ocean is parameterized by conventional grid-cell wide convective adjustment.

3 THE SEA-ICE DATA

For verification (section 4) and assimilation (section 5) we employ satellite passive microwave data, which have been converted to ice concentration using the "NASA Team 2" (in the following NT2) algorithm (Markus and Cavalieri, 2000). The NT2 algorithm utilizes daily brightness temperatures from the Special Sensor Microwave Imager (SSM/I). For the present purposes, full advantage is taken of the daily time resolution of the data, in particular in order to verify and assimilate leads and polynyas created by the atmospheric synoptic-scale variability.

4 SATELLITE-DERIVED VERSUS MODELLED POLYNYAS

Fig.1 illustrates April through September mean ice concentration within 5^0 latitude of Antarctic's coast line, the inverse of which we define as AACP. Besides NT2 data (thick solid line), Fig.1 includes the same product derived using the Bootstrap algorithm (Comiso, 1995; Comiso *et al.*, 1997), in the following abbreviated as BS. Both the NT2 and BS data reveal major areas of low ice concentration between 45^0 E and 60^0 E and between 90^0 E and 160^0 E. Both areas are known for their frequent polynyas (e.g., Comiso and Gordon, 1996; Cavalieri and Martin, 1985). Further east, ice concentration drops due to the Ross Sea polynya (at $\lambda = 180^0$). Another pronounced drop occurs west of about 100^0 W and naturally around the tip of the Antarctic Peninsula (60^0 W). In comparison to both satellite-derived products, both model simulations show substantial discrepancies. At first glance, there is no indication that one model version is systematically superior over the other. Overestimation of coastal ice concentration occurs all along East Antarctica, in particular between 100^0 E and 160^0 E, and major underestimation between 180 and the Antarctic Peninsula. The latter is more pronounced when verified against the NT2 data than when verified against the BS data. Some of this discrepancy may be explained by the fact that during winter, polynyas frequently refreeze within hours such that by the time the satellite monitors an area, a polynya may already be covered with thin ice, and therefore detected as ice in the NT2 algorithm. The BS algorithm, on the other hand, shows lower ice concentrations for thin (snow free) ice under cold conditions (Comiso *et al.*, 1997).

Therefore, large differences between the NT2 and BS ice concentrations are indicative of the presence of thin ice. While such differences are large in the Ross and Weddell Sea, there is no indication that any of the model results agree systematically better with either of the algorithms. Various discrepancies are also detected on local space and short temporal scales, and are predominantly related to the way convection is treated in the model. In Fig.2, ice concentration is plotted for a grid cell along East Antarctica. At this location (as at others around Antarctica), the amplitude of the high-frequency variability of CA is underestimated, while that of PC is overestimated, in particular during fall. Furthermore, the mean ice concentration in winter is overestimated in CA and underestimated in PC.

The reason for the larger amplitude and lower frequency variability occuring in PC relative to NT2 is seemingly the allowance of strong instabilities to build up (up to $0.1\ \mathrm{kg/m^3}$). Upon meeting such threshold, plume convection is initiated, occuring randomly in space and time, and lasting for a few days. The associated vigorous vertical exchange yields strong enough oceanic heat flux to locally and temporarily melt overlying sea ice. To our knowledge, such local and sporadic polynyas have not been observed, at least not on spatial scales as those of the current model's grid cells. While unrealistic on such scales, it is nevertheless conceivable that such features exist on horizontal scales of plumes (typically 500 - 1000m; e.g. Marshall and Schott, 1999).

5 ASSIMILATED POLYNYAS

Assimilation by imposing specified ice concentration in a sea-ice - ocean model where ice concentration is a prognostic variable requires that the overall sea-ice physics be not disturbed and that the integrated net freezing rate will remain zero. The aim is to improve the overall fresh-water flux along Antarctica in a global OGCM by assimilating observed AACPs. For these reasons, ice concentration is only assimilated where thermodynamics are separated subgrid-scale between warming, cooling, or new-ice growth in the open-water part of a model gridcell and ice growth or melt of existing ice in the ice-covered part. Thus, the role of the two subgrid-scale heat balances and the associated fresh-water fluxes are weighted according to what is observed, in this case NT2 ice concentration. This being the only modification guarantees that the net fresh-water flux for the ocean associated with freezing and melting is globally balanced. The assimilation is invoked every time step, thus resolving for the daily variability provided by the data (the model time step is 20 hours).

Upon assimilation in experiment CA, a striking enhancement of the net freezing rate emerges in the sector between 90^0 E and 150^0 E (Fig.3). This enhancement is clearly correlated with areas along the coast line where, on fall and winter average, CA overestimates ice concentration in comparison to the NT2 data (see Fig.1). Note that since this is the region where the observed winter ice extent is smallest (Gloersen et al., 1992), NT2 AACPs do not just represent actual coastal polynyas, but also open water that exists beyond the outer ice edge where this lies within 5^0 latitude from the coast line. The effect is thus more a reflection of the model ice edge extending farther offshore than observed. Another region of enhanced net freezing rate is between 20^0 W and 70^0 E. This is not correlated with overestimation of winter ice concentration, but rather with such in fall. Consistent with Fig.1, regions of underestimated model ice concentration (from 180^0 to 60^0 W and sites along the deep southern Weddell Sea embayment) are associated with reduced net freezing.

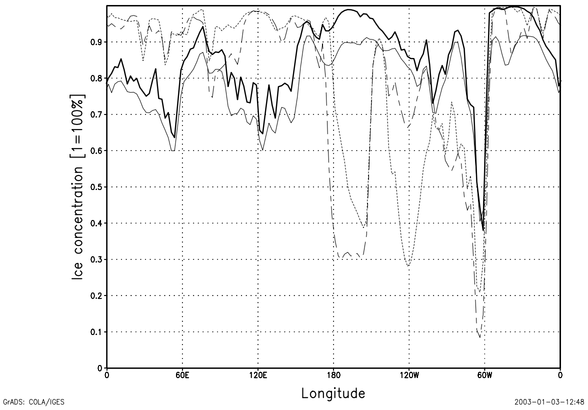

Figure 1: April through September mean ice concentration within 5^0 latitude off the coast of Antarctica. Thick solid line: year 1992 NT2 data; thin solid line: year 1992 BS data; short-dashed line: simulated with model version CA; long-dashed line: simulated with model version PC (see text).

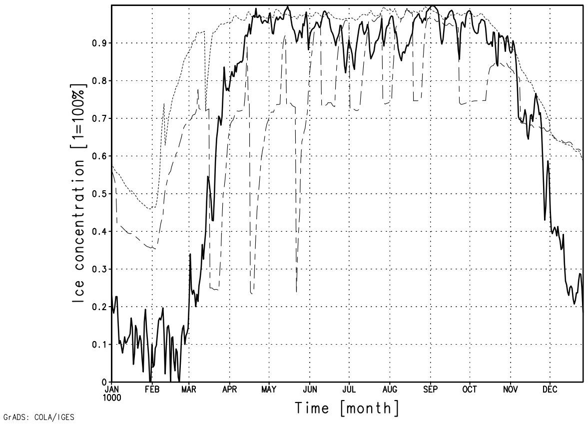

Figure 2: Seasonal cycle of ice concentration at $\varphi = 77^0 S$, $\lambda = 174^0 E$, representing an area of $\Delta\varphi \times \Delta\lambda = 5^0 \times 2.5^0$; otherwise as Fig.1.

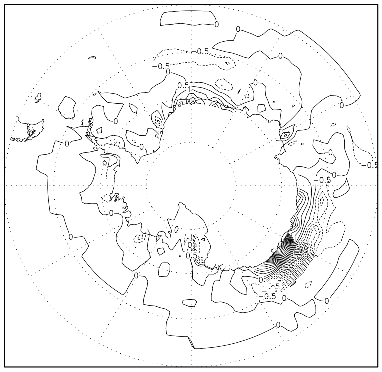

Figure 3: Net annual freezing rate difference of simulation where daily NT2 AACPs of the year 1992 are assimilated into model version CA minus corresponding simulation without assimilation.

6 CONCLUSIONS

The potential for improving the representation of AACPs in global ocean climate models, and thus their crucial effects on global deep-ocean properties and circulation has been investigated.

The validation of model AACP performance against NT2 data revealed significant regional, seasonal, and local, high-frequency discrepancies. Large differences occurred between two model versions that differed by the way convection has been parameterized, the latter constituting a major uncertainty in representing southern hemisphere high-latitude processes in global OGCMs (e.g., Sarmiento and Gruber, 2002). With respect to this validation, no particular model version appears superior over the other. Using a subgrid- scale plume convection parameterization leads to better agreement in various large-scale, long-term features, but reveals sporadic short-term events of vigorously enhanced convective potential energy release with corresponding impact on the ice pack.

Assimilation has been used here in a very general sense. The only effect of the assimilation is to determine the overall heat flux along Antarctica more realistically (and thus the fresh-water flux for the ocean associated with freezing and melting at one of the most crucial sites of source water formation for AABW) by making use of satellited-derived AACP widths. Indeed, this procedure revealed substantial impacts on long-term deep-ocean properties and circulation, as well as Southern Ocean sea-ice thickness and the strength of the ACC (not shown), most of which reflected improvements over the corresponding un-assimilated model version.

Acknowledgments

Thanks are due to Marion Stössel for processing the NT2 data to match the model configuration, and Seong-Joong Kim for valuable comments on an earlier draft of this paper. This proceedings abstract constitutes an outline of an unrevised manuscript that has recently been submitted to JGR-Oceans. This research was supported through NASA grant NAG5-10641.

References

Cavalieri, D. J. and Martin, S. 1985. A passive microwave study of polynyas along the Antarctic Wilkes Land coast. In: Oceanology of the Antarctic continental shelf, *AGU Ant. Res. Ser.* **43**, 227-252.

Comiso, J. C. 1995. SSM/I Sea Ice Concentrations Using the Bootstrap Algorithm, *NASA Reference Publication 1380.*

Comiso, J. C. and Gordon, A. L. 1996. Cosmonaut polynya in the Southern Ocean: structure and variability. *J. Geophys. Res.* **101**, 18,297 -18,313.

Comiso, J. C., Cavalieri, D. J., Parkinson, C. L., and Gloersen, P. 1997. Passive microwave algorithms for sea ice concentration - a comparison of two techniques. *Rem. Sens. Env.* **60**, 357-384.

Comiso, J. C., and Gordon, A. L. 1998. Interannual variability in summer sea ice minimum, coastal polynyas and bottom water formation in the Weddell Sea. In: Antarctic sea ice: physical processes, interactions and variability. AGU, *Antarctic Research Series*, **74**, 293-315.

Drijfhout, S. S., Heinze, C., Latif, M. and Maier-Reimer, E. 1996. Mean circulation and internal variability in an ocean primitive equation model. *J. Phys. Oceanogr.* **26**, 559-580.

Fichefet, T. and Goosse, H. 1999. A numerical investigation of the spring Ross Sea polynya. *Geophys. Res. Let.* **26**, 1015-1018.

Gallee, H. 1997. Air-sea interactions over Terra Nova Bay during winter: simulations with a coupled atmosphere-polynya model. *J. Geophys. Res.* **102**, 13835- 13849.

Gloersen, P., Campbell, W. J., Cavalieri, D. J., Comiso, J. C., Parkinson, C. L., and Zwally, H. J. 1992. Arctic and Antarctic sea ice, 1978-1987: Satellite passive microwave observations and analysis. Spec.Publ., NASA SP- 511, NASA, Washington, D.C.

Goodrick, S. L., McNider, R. T., and Schroeder, W. W. 1998. On the interaction of the katabaticland-sea wind system of Antarctica with the high latitude Southern Ocean. In: Ocean, Ice, and Atmosphere: Interactions at the Antarctic continental margin (eds. S. S. Jacobs and R. F. Weiss), *Antarctic Res. Ser* .75, 51-65.

Hibler, III, W. D. 1979. A dynamic thermodynamic sea ice model. J.Phys.Oceanogr. 9, 815-846.

Hunke, E.C. and Ackley, S.F. 2001. A numerical investigation of the 1997- 1998 Ronne polynya. J.Geophys.Res.106, 22,373-22,382.

Kim, S.-J. and Stössel, A. 2001. Impact of subgrid-scale convection on global thermohaline properties and circulation. J.Phys.Oceanogr.31, 656-674.

Large, W.G., Danabasoglu, G., Doney, S.C., and McWilliams, J.C. 1997. Sensitivity to surface forcing and boundary layer mixing in a global ocean model: annual-mean climatology. J.Phys.Oceanogr.27, 2418-2447.

Legutke, S. and Maier-Reimer, E. 1999. Climatology of the HOPE-G global ocean general circulation model. German Climate Computer Center, Techn.Rep.21, Hamburg, Germany.

Markus, T., Kottmeier, C., and Fahrbach, E. 1998. Ice formation in coastal polynyas in the Weddell Sea and their impact on oceanic salinity. In: Antarctic sea ice: physical processes, interactions and variability. AGU, Antarctic Research Series, 74, 273-292.

Markus, T. and Cavalieri, 2000. An enhancement of the NASA Team sea ice algorithm. IEEE Trans.Geosc.and Remote Sens. 38(3), 1387-1398.

Marshall, J. and Schott, F. 1999. Openocean convection: observations, theory,and models. Rew.Geophys.37, 1-64.

Marsland, S.J., Haak, H., Jungclaus, J.H., Latif, M., and Roeske, F. 2003. The Max-Planck-Institute global ocean / sea ice model with orthogonal curvilinear coordinates. Ocean Modelling 5(2), 91-194.

Oberhuber, J.M. 1993. Simulation of the Atlantic circulation with a coupled sea ice - mixed layer - isopycnal general circulation model. Part I: model description. J.Phys.Oceanogr.23(5), 808-829.

Orsi, A.H., Smethie Jr., W.M. and Bullister, J.L. 2002. On the total input of Antarctic waters to the deep ocean: a preliminary estimate from chlorofluorocarbon measurements. J.Geophys.Res.107, 10.1029/2001JC000976.

Owens, W. B. and Lemke, P. 1990. Sensitivity studies with a sea ice - mixed layer - pycnocline model in the Weddell Sea. J. geophys. Res. 95, 9527-9538.

Paluszkiewicz, T. and Romea, R.D. 1997. A one-dimensional plume model for the parameterisation of oceanic deep convection. Dyn.Ocean and Atmos.26(1), 95-130.

Parish, T.R. and Bromwich, D.H. 1989. Instrumented aircraft observations of the katabatic wind regime near Terra Nova Bay. Mon.Wea.Rev.117, 1570-1585.

Sarmiento, J.L. and Gruber, N. 2002. Sinks for anthropogenic carbon. Physics Today 55(8), 30-36.

Stössel, A., Yang, K., and Kim, S.-J. 2002. On the role of sea ice and convection in a global ocean model. J.Phys.Oceanogr.32, 1194-1208.

Timmermann, R., Hellmer, H.H., and Beckmann, A. 2002. Simulations of ice- ocean dynamics in the Weddell Sea 2. Interannual variability 1985-1993. J.Geophys.Res.107, 10.1029/2000JC000742.

Wolff, J.O., Maier-Reimer, E. and Legutke, S. 1997. The Hamburg Ocean Primitive Equation model HOPE. Technical Report No.13, Hamburg/Germany: Deutsches Klimarechenzentrum.