

## ***Interactive comment on “Modelling the variability of the Antarctic Slope Current” by P. Mathiot et al.***

**P. Mathiot et al.**

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1 This paper considers issues of forcing and grid resolution for the proper simulation of the westward flowing Antarctic Slope Current (ASC) around most of Antarctica. The analysis uses a global model with 4 different grid spacing as well as a Southern Ocean model with different surface wind and surface temperature estimates. Since the focus of this study is on the seasonal variability of the Slope Current, I would recommend that "seasonal" be added to the title before "variability".

Mathiot et al.: We are agree. DONE

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2 The global models are run for the 10 year time period from 1990 to 2000. The regional

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model is run for the 10 year period 1980 to 1990. Why use different time periods for the two models?

Mathiot et al.: The global simulations were run over the last 50 years (1958-2004) within an European project which provided the needed computer resources. The regional configuration was run only during 10 years because computer resources dedicated to this study didn't permit longer simulations with the MAR forcing fields available. Further more, when the simulations were carried out, the MAR forcing fields were not available until year 2000. The results shown here with the regional model are presented over the period 1985-1989 in order to avoid the spin up period. To clarify the paper, the figures, showing results from the global configuration were redrawn for the period 1985-1989.

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3 All four of the global simulations have different results for the flow near the Antarctic coast (Figs 3, 4). The 2 degree and 1 degree global simulation are much too coarse to properly represent the Southern Ocean. Even the 0.25 degree model may be too coarse to represent ACC frontal jets which have widths of 50 km or so which is 2-3 grid points in the model with the finest resolution. The 0.5 and 0.25 degree global simulations have rather different results along the Indian Ocean sector (Fig 3). How well is the bathymetry of PET represented in these cases? Why are the results so different? Neither one is particularly realistic.

Mathiot et al.: We can see that even if the model can't simulate the strong ACC frontal jets, it can simulate a reasonable annual mean state and seasonal cycle of Southern Ocean. About the highest resolution run (ORCA025), the simulated ASC transport in the Australian Antarctic Basin is not very realistic (Figure 5b of the revised manuscript). Main recirculation of the Ross Gyre occurs in Balleny Island area, except 5 Sv, which recirculate near Adelie Land (140°E). Between 130°E and 100°E, a very small gyre is present (5 Sv) compared to the observations of Mc Cartney 2007 (35 Sv) or Bindoff et al. 2000 (~15 Sv) and 36 Sv in Park et al. 2009. The barotropic streamfunction of

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ORCA025 in Australian basin shows many unrealistic stationary eddies (up to 25 Sv close to the latitude  $60^{\circ}\text{S}$ ). Presence of these eddies likely inhibits the formation of a realistic gyre. The Weddell Gyre in ORCA025 is located between  $90^{\circ}\text{E}$  and  $40^{\circ}\text{W}$ . This large gyre is unrealistic, as observations don't show the Weddell Gyre crossing the PET. Park et al. (1994) find the Eastern boundary of the Weddell Gyre at  $53^{\circ}\text{S}$ , which is close to the ORCA05 one (Fig. 3). Sensitivity experiments of oceanic circulation in Australian Antarctic Gyre to bathymetry are performed by Roquet (2009) with a regional model centered on Kerguelen Plateau ( $20^{\circ}\text{E}$  to  $120^{\circ}\text{E}$ ) and based on ORCA025. These simulations show a strong sensitivity in this region to the smoothing of the bathymetry: Australian Gyre increases by 5 Sv, transport across Fawn Trough increases by 5 Sv and number and intensity of stationary eddies decrease. The bathymetry used in ORCA025 simulation is smoothed 2 times by a Shapiro filter (weight 0.6) as in Roquet et al. (2009). This may explain the problems in this configuration. ORCA05 bathymetry is not smoothed but the 1 grid point pools or rises are removed to avoid spurious circulations around them. Information has been added in the revised manuscript in section 3:

"... In ORCA025, the ASC has a different behavior than in the other simulations. The transport does not increase continuously between  $140^{\circ}\text{E}$  and  $90^{\circ}\text{E}$  as in ORCA2, ORCA1 or ORCA05. The mean transport in this area is also lower than in ORCA05. The wide gyre between  $135^{\circ}\text{E}$  and  $100^{\circ}\text{E}$  simulated in ORCA05 is smaller in ORCA025 (7 Sv). Furthermore, the ASC transport presents many large peaks due to stationary eddies in the Australian Antarctic Basin (Fig. 3). As far as the PET is concerned, there is no recirculation along the Kerguelen Plateau in ORCA025. All the flow crosses the PET. This feature is characteristic of one large gyre (Weddell Gyre merged with Australian Antarctic Gyre), while two are present in the observations (Roquet, 2009). In the Fawn Trough on the Kerguelen Plateau, ORCA05 is also better than ORCA025. A flow across this passage is observed at 43 Sv (Park et al., 2009). ORCA05 simulates a transport of 39 Sv. ORCA025 underestimates this transport (29 Sv) as shown in Table 2. Simulations carried out with a regional model based on ORCA025 in the Kerguelen Plateau area (Roquet, 2009) indicate that the representation of the details of

bathymetry, which are related to the resolution, has a large impact on the oceanic circulation simulated. The number and intensity of the spurious stationary eddies present in the Antarctic-Australian basin using in simulation using a raw bathymetry (instead of a smoothed bathymetry as in the present study; Fig. 3, 4 and 5b) are lower, with lower intensity. With such a raw bathymetry, the transport of the Antarctic Australian gyre and the transport across the Fawn Trough both increase by 5 Sv. Thus, it appears that a large part of the biases observed in ORCA025 are linked with the choice of the bathymetry. . . .”

4 Why choose 0.5 degree as the resolution for the Southern Ocean model? Is there any purpose in showing the global model results other than to justify the selection of grid spacing for the Southern Ocean model?

Mathiot et al.: Results shown in the first part of the paper demonstrate that the model at 2° and 1° resolutions is not able to simulate a realistic ASC. Furthermore, 1° and 2° resolutions are typical for IPCC models and it is important to assess their behaviour. The 0.5 ° resolution model shows realistic circulation patterns (Weddell Gyre, Pridz Bay Gyre, Australian Antarctic Gyre and Ross Gyre) with reasonable transport. The 0.25 ° resolution model exhibits a very spurious behavior in the area of the Kerguelen Plateau (very small Australian Antarctic Gyre, no recirculation along the Kerguelen Plateau, and a too large Weddell Gyre). However, circulations in Weddell Gyre and in Ross Gyre are similar to the ORCA05 ones. In order to limit the CPU cost and problems, the regional simulations are only conducted with the lowest resolution model that gives reasonable results (i.e. 0.5 ° resolution). This is now explained in the revised manuscript in section 3:

” ... Because of the good results and its affordable computational cost, the resolution of 0.5° is kept in the next section to study the impact of the atmospheric forcing on the ASC with a regional model. A circumpolar overview of the ASC is given for this reso-

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lution (Fig. 5a) for the best simulation ORCA05. The four main gyres seen in the observations (Gouretsky, 1999; McCartney and Donohue, 2007; Nunez Vaz and Lennon, 1996; Klatt et al., 2005) are well represented (the Ross Gyre at roughly 150°W, the Antarctic Australian Gyre at 90°E, the small Prydz Bay Gyre at 75°E and the Weddell Gyre at 0°E) and transports across typical sections and in gyres (0°E, Fawn Trough, Antarctic Australian gyre, Drake) presented in Table 2 are realistic. ...”

5 The focus of the analysis is on the transport of the westward flow near the coast and off the shelf break. This transport can develop alongshore changes (Fig 3) only by importing or exporting water from offshore. Basically, this involves the development of local (oceanic) gyres next to the continent. How well do the annual mean streamlines (Fig 5) match with annual average satellite altimetry or mean dynamic topography from climatological hydrographic reconstructions showing such gyres? Is there evidence for these gyres and their seasonal changes in strength?

Mathiot et al.: There are several gyres observed around Antarctica. In the Weddell Sea, the Weddell Gyre is observed (Klatt et al. 2005). In Prydz Bay, a small gyre (between section 8 and 9 in Fig. 8) has been observed (Nunez Vaz and Lennon, 1996). At the east of the Kerguelen Plateau, one finds the Australian Antarctic Gyre (Mc Cartney et al., 2007). And the last Gyre is the Ross Gyre observed by Gouretsky (1999). All these gyres are simulated by the model with 0.5 ° resolution (Fig. 5). Comparison of the southern part of those gyres with quantitative data around Antarctica is difficult because the satellite altimetry data (as Jason 1 and Jason 2) are not available below 66.6°S and below sea ice. The best estimate of the dynamic topography is the CMDT (Combined Mean Topography) ([http://www.aviso.oceanobs.com/no\\_cache/fr/donnees/produits/produits-auxiliaires/mdt/description/index.html?sword\\_list%5B0%5D=cmdt](http://www.aviso.oceanobs.com/no_cache/fr/donnees/produits/produits-auxiliaires/mdt/description/index.html?sword_list%5B0%5D=cmdt)) which combines all data source available. However, in the Southern Ocean, it is not very accurate (no Australian Antarctic Gyre and the ASC is not continuous along the East coast of Antarctica).

Nevertheless, we can compare our results with transport observed across specific sections and with the local reconstruction of oceanic circulation (based on section available in the area as done in McCartney and Donohue (2007)). In the new version of paper, in section 4, we insist on the comparison with observational data (current meters along the continental slope at 0°E named AWI 233 and 232) and some comparisons are added (like at Fawn Trough, across the Kerguelen Plateau and across the Greenwich Meridian). Diagnosing the seasonal cycle of such gyres needs many repeated sections in summer and in winter. Unfortunately, due to presence of sea ice and financial cost of such campaigns, the seasonality of southern branch of such gyres are almost unknown.

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The main result of the paper, based on the Southern Ocean model, is that stronger winds produce stronger transport near the continent and that colder temperatures produce more summer ice. Further, winds without a seasonal cycle do not produce seasonal changes in the ASC transport.

7 The second result from the paper is that there are different flow patterns with different model resolution. No surprise that 1 degree and coarser global models do poorly around the Antarctic continent (since much of the flow is bathymetrically controlled and there are small bathymetric features that are important, but not represented by the coarse models). Does the 0.5 degree Southern Ocean model have enough resolution to provide a realistic representation of critical bathymetry and produce a realistic circulation? The annual mean streamfunction (Fig 5) looks ok; do observations tell us what this annual mean pattern should look like?

Mathiot et al.: As said in Q5, the annual patterns of the stream function or of the SSH for all Southern Ocean cannot be obtained in area where sea ice is present. Comparison with local transports and local circulation schemes built from in situ campaigns is quite good for 0.5°. Transports across key passages are reasonable (Drake Passage,

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PET, Fawn Trough). The intensity of the Weddell Gyre is right. The Ross, Antarctic Australian, Prydz Bay and Weddell Gyres are present, and comparison with local study (especially in the Antarctic Australian basin) are quite good (Park et al., 2009; Mc Cartney 2007). Based on these comparisons, we can state that ORCA05 provides the best oceanic circulation in our study and that this circulation is realistic.

“... Because of the good results and its affordable computational cost, the resolution of  $0.5^\circ$  is kept in the next section to study the impact of the atmospheric forcing on the ASC with a regional model. A circumpolar overview of the ASC is given for this resolution (Fig. 5a) for the best simulation ORCA05. The four main gyres seen in the observations (Gouretsky, 1999; McCartney and Donohue, 2007; Nunez Vaz and Lennon, 1996; Klatt et al., 2005) are well represented (the Ross Gyre at roughly  $150^\circ\text{W}$ , the Antarctic Australian Gyre at  $90^\circ\text{E}$ , the small Prydz Bay Gyre at  $75^\circ\text{E}$  and the Weddell Gyre at  $0^\circ\text{E}$ ) and transports across typical sections and in gyres ( $0^\circ\text{E}$ , Fawn Trough, Antarctic Australian gyre, Drake) presented in Table 2 are realistic. ... ”

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8 Ultimately, I am not sure what is new in this paper. Most of the comparisons are between model simulations. It would be important to compare these results against observations as much as possible.

Mathiot et al.: We have added some comparisons such as the one at Fawn Trough and the comparison with current meter data at AWI 232 and 233 along the  $0^\circ\text{E}$  section. We also insist on the fact that the best simulation here is ORCA05 and that ORCA025 needs some bathymetry adjustment before to be used for sensitivity tests along the coast.

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9 As a further comment, the authors spend too much time describing figures that are included in the paper (for example, most of p. 14). It would be better to point out the

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important details of the figures and explain how these results illuminate processes in these coastal flows.

Mathiot et al.: We have followed this recommendation in the revised manuscript when possible.

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I recommend that the paper be returned to the authors for major revisions to focus on the important results that they have obtained by analyzing the simulation results.

Specific questions: p. 10, fig 3: Model simulations produce half (or less) of the observed ASC transport. Why does orca025 have an increase of transport to the west while the others do not? How well is the PET represented at these various model resolutions?

Mathiot et al.: The main differences in Figure 3 are due to the absence of Antarctic Australian Gyre and to the presence of stationary eddies. For more information, see Q3 in page 1.

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p. 11: The paper states that the westward flowing ASC is too wide by a factor of 2. Why? Is it just a matter of the wide grid spacing or is something else going on?

Mathiot et al.: We decided to redrawn this figure not with BROKE observations but with the more common data set of Orsi et al. (1995) about southern boundary of ACC. This boundary is defined here as the location where transition between westward and eastward flows occurs.

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p. 13: How can a model with a resolution of 0.5 degree represent a jet with a width of 0.2 degree? It can't. Of course, the jet will be too wide and too slow. Similar comments for current widths on p. 14.

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Mathiot et al.: Section at 60°E was replaced by section at 0°E as suggest by the other reviewer. This change allows comparing with mooring available on the continental slope. Comparison at 0°E shows large differences in terms of current width as mentioned in the revised text in section 4.1:

“... In all our simulations, the core of the simulated current is shifted (0.5° northwards) and the simulated northern boundary is shifted 1° northwards. Furthermore, the cyclonic circulation observed around Maud Rise is not strong enough in our simulations (compared to Klatt’s (2005) observations). ...”

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p. 14: Transport values are given in Fig 9 not Fig 8.

DONE

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p. 14: There is no observational evidence of westward flow (ASC) along the west side of the Antarctic Peninsula. There is some observed (estimated) westward flow at the coast which is driven either by buoyancy (ice melt) or local winds. Since the ACC is at the shelf break in this region and the winds are largely westerlies, I would not expect to see any westward flow (ASC) in this area. So, I don’t think this is a failure of the model but a representation of fact (?) that there is no ASC off the west side of the Antarctic Peninsula.

Mathiot et al.: The following text has been added in section 4.1:

“... Along the west side of the Antarctic Peninsula (section #1), the Antarctic Circumpolar Current reaches the shelf (presence of an eastward current in Fig. 5 and Fig. 11). Consequently, ASC is absent in all simulations carried out (at least on the annual average). This is also the case in other observations and modelling studies (Beardsley et al., 2004; Martison et al., 2008; Pinones et al., 2010) ...”

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Fig 10: This figure is very hard to understand, particularly the upper panel. With small figures it will be hard to differentiate circles and squares. A better presentation would be to remove the mean for each year and plot monthly variability as a line for each year. Then we can tell the magnitude and variation of these seasonal variations.

Mathiot et al.: DONE

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fig 11: It is very hard to differentiate the solid dots and the open squares in this figure. Present the results another way.

Mathiot et al.: The figure has been redrawn.

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figs 12, 13: I am not sure that the SSH figures add much to the discussion. Since the flow is geostrophic, these differences basically show the difference in transport.

Mathiot et al.: This part is to confirm that differences in transport are due to a direct effect of the change in sea surface height along the Antarctic coast via Ekman drift. We prefer to keep it in the new version.

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