Supplementary Table 1.

Capabilities and limitations of IPCC-class climate models versus requirements of ecologists

This table summarises key questions that Southern Ocean ecologists involved in this study would like to address using climate models and presents them alongside current limitations of the models.

Ecologist's perspective – "what ecologists want to know"	**Climate scientist's perspective – limitations of IPCC-class climate models and observations**
Which models should ecologists use for Southern Ocean projections of change? i.e. which are the "best models"?	Analyses of multi-model ensembles included in the IPCC reports generally assume that all members of a given ensemble of climate models are equally valid. However, there are issues with using all models. Some of these are noted below: - Inter-model spread: climate models can differ in many ways including resolution, grid design, numerical solution techniques, and in sub-grid parameterisations (see below); - Models are often not independent of each another; - Each model has different strengths and weaknesses and some will reproduces aspects of the climate system better than others, e.g. one model may be very good at representing ocean mixed layer depth, while having a significant bias in location of sea ice. Other general issues include:

	- The large regional climate variability around Antarctica makes it difficult to assess the performance of climate models in simulating recent change; - Observational data against which models are assessed is often limited in both time and space, particularly for the marine environment; - As yet there is not a broad consensus across the climate science community as to how best to constrain climate model projections using observational data.
Temporal variation, including seasonality is important ecologically. How well do the models do throughout the year? E.g. for sea ice, timing is key for ecological processes (Table S3). Can changes on inter-annual to decadal time scales be predicted? Spatial variation is also important ecologically. How well do the models do regionally?	Model performance decreases at smaller spatial and temporal scales. E.g. on shorter (decadal or less) temporal scales sea ice variations will be dominated by internal variability of the climate system. Decadal prediction is difficult, but is starting to be explored. Even a ‘perfect’ model would in general exhibit differences from reality on decadal time scales. Seasonality hasn’t been a major focus of these models. Regional processes are not fully resolved by current models. Model projections around the continent are highly variable which brings difficulty at regional scales, but they can be done at a circumpolar scale which at least gives a sense of the errors and potential issues. Regional model bias is an issue. The regional scale models are not very representative, e.g. may have sea ice retreating at the wrong location. The models are run with spatial intervals of around 200km that allow for the required number of global scale simulations (the smaller the scale the more processing power is required).

The influence of natural variability: when are we going to reach the point where we see anthropogenic signals emerging from the noise?	This will vary depending on parameter. E.g. for sea ice we are not yet at the point where we can see the anthropogenic signals emerging from the natural variability.
Many ecological processes are influenced by physical features such as ocean eddies, sea ice thickness, one-year versus multi-year ice, the marginal ice zone, etc (Table S3). How well are these represented in models?	Such features are not captured by typical climate model resolutions and tend to be represented by relationships to properties that are resolved (sub-grid-scale-parameterizations). Note that variations in how sub-grid scale processes are parameterised is a source of model bias (see above). With regard to sea ice thickness and multi-year ice, these are not evaluated in current models largely because the observations are uncertain. Representing the marginal ice zone would be very difficult due to factors such as the large horizontal grid sizes and uncertainty over processes such as ocean-atmosphere heat fluxes in regions of partial ice cover.
It is often extreme events that give rise to shifts in an ecosystem. E.g. the collapse of an ice-shelf. What can the models tell us about the chances of extreme events?	Due to their broad scale global models struggle to capture the extreme events that have the largest impact on ecosystems (e.g. hurricanes, heatwaves, etc). In the Antarctic extreme events include marine heat waves leading to rapid loss of sea ice, intense storms destroying habitat or collapse of ice shelves. Downscaling is often required to estimate frequency of extreme events, however changes to indicators of extremes can give us some indication of likely changes to rare events.
Many ecological changes are due to complex climate process interactions. How well are these represented in the models? How do we account for interactions between multiple stressors?	Due to limits on computational resources it is generally not feasible for global climate models to capture the level of detail required to fully understand complex systems. See also the points above. Essentially a model that is best for one variable might not be the best one for another. - These issues are largely unexplored;

	- Little has been done even for strongly related variables (e.g. in the case of the Southern Ocean, sea ice and sea surface temperature).

Supplementary Table 1 Reference

Flato, G.J., Marotzke, B., Abiodun, P., Braconnot, S.C., Chou, W., Collins, P. et al. (2013). Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.