



## NERC Peer Reviewer Comments - assessment of the ORCHESTRA project:

**1. Please comment on the strengths and weaknesses of the proposed research (i.e. Excellence of the Science), the risks associated with the research, the resources requested and the value added by any project partners. Before completing their reviews, reviewers should refer to the reviewer guidance.**

### Reviewer 1:

“The ORCHESTRA project is a large-scale ambitious project that aims to apply an integrated approach of modelling and observations to elucidate the key mechanisms governing the exchange rate of heat and carbon from the atmosphere into the surface ocean and consequently into the ocean interior over decadal to centennial time scale. The focus domain of the study is the Southern Ocean, a region of importance for climate change. Thus the project would advance fundamental understanding of the climate system and potentially improve predictive skills of future climate models. Given the limitation of our understanding of the Southern Ocean, due to the limited long-term high quality observations and representative model system, the scientific objective is timely and considered relevant for the society in the next few decades.

The project gathers interdisciplinary climate scientists among key NERC institutes and international partners to address scientifically challenging questions that are also relevant for the broader community. The project tasks and outcomes for each WP are generally sufficiently defined. If successful, the team will be one of the core groups in the world with advance knowledge in heat and carbon dynamics in the Southern Ocean through wealth experience in complex modelling and state-of-the-art observational data collections. The new knowledge from the project will provide a substantial advance in Earth system modelling and climate system understanding. The work will also foster further national and international collaborations.

#### Foreseen risks:

- The strong dependency on continuous/future observing campaigns e.g., surface pCO<sub>2</sub> and GO-SHIP which depends on other sources of future funding
- The availability of reliable autonomous carbon sensors to be integrated to the gliders during the project lifetime (T3)

#### Strength:

- Interactions between major environmental research institutes in the UK
- Strong international supports and partnerships
- Novel targeted and processes-oriented data collections
- The applications of state-of-the-art UK Earth System Model and the plan to analyse the emerging

CMIP6 models

#### Weakness:

- Lack of full biogeochemical understanding (the used of statistical instead of process-based ocean carbon cycle models) may hinder the overall carbon dynamics
- Although the management and leaderships of the centre are very competence and well-recognized in their fields, some key collaboration/partners in ocean carbon cycle and sea-ice could further strengthen the team.”



## Reviewer 2:

“This proposal seeks to address a significant weakness in our understanding of the climate system and a major source of uncertainty in projections of future climate: the uptake and storage of heat and carbon by the Southern Ocean (specifically the Atlantic sector). The proposal is ambitious in its aims, and in the use of some emerging technologies, notably a number of autonomous measurement platforms.

The scientific aims of the proposal are robust, and the approaches to tackling them are generally well thought through.

The project is timely, having explicit links to a number of related studies through project partners or other projects on which members of the project team are working. There are also potential links to a number of proposed studies both in the UK and overseas with different, but complementary, science objectives (e.g. US proposed SOCRATES project, and NERC large grant proposal for SEASCAPE project – both addressing issues related to the energy budget of the Southern Ocean and biases in models, but with a focus on the atmospheric controls on it rather than the oceanographic processes).

The anticipated outcomes are clear, and research priorities well justified. In particular, the prioritisation of where cuts would be made if funded at 20% below the proposed funding are clear, the rationale well justified, and the impact on the science explicitly stated. I would emphasise here that while the project would clearly achieve its primary objectives should such a cut be made, a great deal of the most exciting (and world-leading) science (notably the direct measurements from autonomous platforms during the winter season) and capitalisation on the results for improving models (development of new high resolution ocean model) would be lost.

The science team is extensive, covering the wide range of expertise in both observations and modelling need to undertake this study. All the key personnel and work-package leads have excellent experience and track records. I don't think there are any missing links in the experience necessary to complete the project. The project is also truly multi- and inter-disciplinary, and could not be undertaken by any one centre alone. The scale of the project is such that it would not be viable as a NERC Large Grant proposal, requiring multiple cruises and aircraft campaigns, deployment of novel cutting-edge technologies in autonomous measurement platforms, and very extensive modelling work – including new development; it is thus inherently a project that is only viable as multi-centre long term science programme. The collaborating facilities are well placed to deliver the proposed science, having world leading expertise in many of the areas required, and world-class competence in all of them.

### Weaknesses:

I don't think there are any major weaknesses in the proposal; however, there are a few points that raised questions in my mind:

-One of the tasks proposed is the development of an autonomous system for making eddy covariance measurements of air - side turbulent fluxes from the research ship – in particular of heat and CO<sub>2</sub>. This task is listed as part of the work to be undertaken by PML. This seems curious since there is already a well-established system developed at NOC by one the Cols (Yelland) – Autoflux. This system is well tested, and readily expanded to handle any additional data streams from new gas sensors. It is anticipated that the JCR will be the vessel used for most if not all of the cruises; Autoflux has been operated on JCR for several years in the past, and it would make sense to use it rather than spend time and effort on developing a new equivalent system.

-The aim to test existing parameterizations for the turbulent exchange over the Southern Ocean – where high winds and wave states will at times likely be outside the range of conditions from which existing parameterizations were developed – is eminently viable with the proposed measurements. Developing new parameterizations, while doable, is a more challenging task because of the large volume of data required to reduce the uncertainty to acceptable levels – this is particularly challenging for the gas fluxes at high wind



conditions where (a) the duration of the extreme conditions is short, and (b) the ship would usually try to avoid the most extreme conditions. Of particular note is the need for measurements during the winter period when the air-sea exchange is likely to be most extreme. These measurements rely entirely on the deployment of (and perhaps some development work on) an effective autonomous surface platform. The text in section T4 regarding this platform states only that it will measure ‘flux-related parameters’. It is not clear if that means direct eddy covariance measurements or just mean quantities relevant to the parameterization of fluxes. While I think a surface platform could effectively measure fluxes at moderate wind/wave states, I’m not convinced at high wave states. Once the wave height is greater than the measurement height, the measurements are effectively within the wave -influenced layer of atmospheric flow – suffering sheltering, potentially recirculating flow in the lee of waves, and a large variation in effective measurement height with the mean surface level, as the platform rides over waves. In such conditions interpreting the measurements will be a significant challenge. I would not say this is not worth doing, but it will be a challenge to deliver meaningful surface flux products.

The project is planned over 5 years, with measurements in all 5 years. It can take significant effort to work up some data products, undertake quality control, etc.; it thus seems questionable to what extent the measurements scheduled in the final 6 months of the project can really be used within the analysis. While I’m sure analysis and modelling activity will carry on well beyond the formal lifetime of the project (I don’t think I’ve ever been involved in a project where this wasn’t the case), if the LTS-M programme allows, I would really like to see time dedicated purely to analysis/modelling after the end of measurements – a further 2 years would be appropriate.”

### Reviewer 3:

“The proposal is addressing one of the most important questions in the climate system: how is heat and carbon sequestered in the Southern Ocean? The proposal aims to address this problem via a series of substantive challenges, each of scientific merit: addressing the transfer of heat and carbon across the air-sea interface; heat and carbon exchange between the winter mixed layer and the ocean interior; estimating the heat and carbon budgets in the Atlantic sector of the Southern Ocean; assessing the effect of eddy circulations via high-resolution circulation models; and linking to climate model representations of the Southern Ocean.

The proposal is compelling, important and highly ambitious. The science case is robust and comprehensive. There is a strong team of researchers from the Institutes, which offer the prospect of delivering high-quality work by collectively focussing on the Southern Ocean. The vision in the proposal makes one optimistic that significant progress can be made by this co-ordinated focus. Previously the work on the Southern Ocean has been rather fractured in the UK, separate activities led by BAS generally close to the ice and open ocean circulation studies led by NOC. In fact one probably has to go back to 1980s when the Fine Resolution Antarctic Model was used to consolidate the University ocean modelling community or in the 1990s via the UK WOCE initiative to pull the national oceanographic community together. Thus, this initiative on a compelling problem has the prospect of providing added value by bringing together the different expertise sitting within National Capability.

The only reservation I have about the bid is that the scientific challenge of understanding heat and carbon sequestration is much larger than can be solved by the requested £8.4M to support the National Capability. Thus, while I fully support ORCHESTRA, there is simply not enough resource to fully answer the question of how heat and carbon are sequestered in the Southern Ocean. For example, air-sea heat and carbon fluxes vary strongly seasonally and spatially over the domain and, even though this proposal promises a significant step forward, the central questions posed will not be completely answered by this proposal alone.

The proposers have partly mitigated against this constraint by developing excellent international partnerships: of particular note is the six year NSF funded SOCCOM project led by Professor Jorge Sarmiento to deploy 200 autonomous biogeochemical profiling floats, which offers a new way of examining



the data-sparse Southern ocean; the US GO-SHIP programme led by Professor Lynne Talley; and the Southern Ocean Observing System Scientific Steering Committee. There is also a strong partnership with the UK Met Office via the Hadley Centre.”

In summary, this proposal and the involvement of the Centres are well placed to deliver a substantial improvement in our understanding of how heat and carbon are cycled in the Southern Ocean. The proposal is exciting, timely and important, and should be supported.”

**2. Fit to Scheme – Scientific Objectives. Please provide comments on the fit of the proposed research to the scientific objectives and requirements (i.e. Strategic Context in the attached instructions) of the Research Programme as outlined in the guidance:**

**Reviewer 1:**

“Based on my limited knowledge, I feel that the proposal is well within the NERC strategic priorities. If the activities within the project are successfully carried out, it will have prolonged impacts and contributed to future climate initiatives. The new knowledge produced by the project will also benefit the broader international scientific communities.

If model improvements is realized as a results of better process understanding attributed to the new data collections, we can expect other modelling communities to follow the same model development approach. International funding agencies will be more incline to develop more research programmes focusing on the Southern Ocean. This is critical as the ORCHESTRA mainly focused on the Atlantic sector of the Southern Ocean, and only full international joint effort can unlock the full understanding of the sophisticated Southern Ocean system.”

**Reviewer 2:**

“The proposal seems a good fit to NERC objectives, capitalising on existing expertise and previous work at the collaborating centres. It is also timely – the energy balance of the Southern Ocean is a topic addressed by a number of proposed studies in both the UK and overseas. The bias in modelled Southern Ocean sea surface temperature is a problem for all the CMIP5 model. There are likely contributions to the bias from both atmospheric (primarily modelled cloud biases) and oceanographic process representation. Addressing these problems are essential to provide reliable assessment of future climate. I am aware of several proposed studies of related issues from the atmospheric perspective which would link well with the science proposed in ORCHESTRA. I am not aware of any other projects proposing to address the oceanographic issues; ORCHESTRA thus seems well placed to take the leading role in addressing this topic. I would expect many opportunities for beneficial collaboration with atmosphere-focused studies of the Southern Ocean energy balance – particularly in relation to air-sea exchange – and opportunities for piggy-backing other studies on the cruises proposed here.

Success on the part of ORCHESTRA would lead to significant improvements in modelling of future climate – existing model biases in this region lead to likely unrealistic climate feedback processes and erroneous assessment of future climate. Correcting this problem – even in part – should enable much improved assessment of the impacts of future climate change. The links to policy bodies in the UK – primarily DECC – are well established within the proposal.”



### Reviewer 3:

“There is an outstanding fit to scheme by the ORCHESTRA proposal.

The proposal is addressing a central NERC strategic goal of understanding how the climate system is operating in a data sparse region, the Southern Ocean. Climate models suggest that the Southern Ocean dominates the drawdown of anthropogenic heat and carbon (Froelicher, Sarmiento et al., 2015, Dominance of the Southern Ocean in Anthropogenic Carbon and Heat Uptake in CMIP5 Models, *Journal of Climate*, 28, 862). This dominance is due to the combined effects of upwelling of deep waters and subduction of mode waters uniquely occurring together in the Southern Ocean (Morrison, Froelicher and Sarmiento, 2015, Upwelling in the Southern Ocean, *Physics Today*, January, 27).

ORCHESTRA draws upon prior support for a combined NERC and NSF supported programme, The Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES).

Supporting ORCHESTRA will provide a substantive programme of work in the Southern Ocean, which should preferably align with other strategic support over the wider UK community. In particular, the wider UK community is strong on the theory for how the Southern Ocean circulation is controlled and on how transient tracers may be utilised to infer changes in ocean ventilation. Neither of these two aspects are fully exploited in the ORCHESTRA proposal. Without this alignment, the full benefit of the NERC investment will not be met. This criticism is not one of the ORCHESTRA proposal, but is an inevitable outcome of how national capability and strategic research support for the wider UK research community have become fractured and artificially separated.

The international context of the work has been fully taken into account. The ORCHESTRA bid draws upon a long engagement with the international partners over the last 5 years or so, which has been instigated by the US-led SOCOOM float program. The international partners then could not be stronger or more fully aligned.

If this work is supported, then a substantial fraction of the National Capability community would be aligned together and working on a substantive and important problem. Almost certainly this support will then make a major difference to how the UK scientific community contributes internationally to this problem.

Turning the question around, if the programme is not supported, then the UK community will become relative bystanders in Southern Ocean research, probably limited to monitoring Drake Passage and changes close to the Antarctic shelf. The UK research community would be avoiding major questions of how the Southern ocean operates as a whole, ignoring one of the most important ocean responses to climate change, and avoiding a limitation of present-day climate models.”

**3. Resources. Please comment on the resources requested (i.e. Finances and Management in the attached instructions). Are all the costs requested required for the research proposed, and sufficiently justified?**

### Reviewer 1:

“The requested resource is reasonable. The plan for project implementation and resources are well documented. Partnerships and task of other institutions without funding dependencies are clearly defined.

The applicants are well-known scientists with proven track records on the proposed topic. The project coordinator has demonstrated experience in large-scale research team management with strong international networks. The project PIs have the competence and resources needed to ensure the success of the project.



Comments on the project scalability (section 8): instead of T8, it seems more sensible to cut activity in T9. Though not optimal, sensitivity studies can still be performed within T7 without using the labour intensive adjoint model in T9. On the contrary, an ultra-high resolution modelling in T8 is critical to advance our understanding on the role of eddies in the air-sea fluxes and interior transport of heat and carbon.”

**Reviewer 2:**

“The resources requested are appropriate and reasonable. As noted above, I think a longer period for analysis and modelling after the last field measurements would be beneficial, although this may not be viable within the funding framework for the programme.”

**Reviewer 3:**

“The resources appear plausible and reasonable. The caveat remains that this programme and level of support by itself will not answer all the challenges identified in the proposal.”