OUTCOMES AND CONTEXT FOR FUTURE WORK FROM THE WORKSHOP ON ECOSYSTEM ESSENTIAL OCEAN VARIABLES (EEOVS) FOR THE SOUTHERN OCEAN

RUTGERS UNIVERSITY, NEW BRUNSWICK, USA

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by

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and the workshop participants (Attachment A)

Contents

BACKGROUND

B1. A workshop on *identifying ecosystem Essential Ocean Variables (eEOVs) and enhancing collaboration in ecosystem observing, with an emphasis on the Southern Ocean* was hosted by Oscar Schofield (Co-chair, Southern Ocean Observing System (SOOS)) at Rutgers University, New Brunswick, USA from Tuesday 18 March to Friday 21 March. This workshop was attended by 30 international experts (Attachment A) and undertook the work program outlined in Attachment B.

B2. The workshop was convened by Andrew Constable (AAD, ACE CRC), Dan Costa (UCSC), Oscar Schofield (Rutgers), Tosca Ballerini (APECS), Louise Newman (SOOS), and Ed Urban (SCOR).

B3. This workshop is part of the SOOS initiative '*Identifying Ecosystem Essential Ocean Variables for measuring changes in Southern Ocean ecosystems*' overseen by SCOR, SCAR, IMBER, and APECS, and sponsored by Rutgers University, ICSU, SCOR, SCAR, and CAML.

Summary Outcomes against Workshop Objectives

B4. Summary outcomes against each of the four workshop objectives from the proposal to ICSU are reported here. Note: the SOKI wiki mentioned below is a web-based tool for collaborating, collating, communicating and disseminating scientific materials on ecosystem research. Materials from the project can be reviewed at
http://www.soki.aq/display/Projectd/International+Project+on+Ecosystem+Essential+Ocean+Variables+in+the+Southern+Ocean

This page is password protected but access can be granted by notifying the SOKI Administrator. soki@aad.gov.au.

B5. Although the original agenda was designed to address these outcomes, most of the workshop time was spent discussing and clarifying the context and process for developing eEOVs. This discussion benefitted from the experience in the GOOS Biogeochemistry and Biology Panels; the approach in the Southern Ocean Observing System is intended to be harmonised with that in the GOOS. This workshop made significant progress in clarifying the context and procedures for Southern Ocean eEOVs.

1. Summarising current knowledge on biodiversity indicators and how they may inform the development of indicators of marine ecosystem structure, function, and dynamics.

B6. Summaries of indicators discussed in the literature were added to SOKI and considered in the development of the discussion paper circulated prior to the workshop. The discussion paper considered how indicators had been used to date and the context in which ecosystem indicators (and eEOVs) may be considered in the future. Discussion in the first half of the workshop focussed on the questions that eEOVs would address and the ecosystem properties important to be estimated in order to help address the questions. This discussion benefited from knowledge of the workshop participants on the capabilities available for field measurements and for using indicators of change.

2. Identifying indices that could be used to detect and track change in the structure, function, and dynamics of marine ecosystems.

B7. As indicated above, the workshop spent most time discussing and clarifying a process for identifying appropriate indicators for an observing system and the types of indicators (or derived products) that would be useful to answer policy-oriented questions. Several examples were considered in the workshop discussions. This discussion will be concluded in post-workshop tasks that aim to develop candidate eEOVs based on the outcomes of the workshop.

3. Determining the eEOVs that would need to be monitored on a sustained basis to produce the composite indices identified in the second objective.

B8. The workshop has initiated a process for determining eEOVs for the Southern Ocean that would need to be monitored on a sustained basis. While progress will be made after the workshop on considering the tools and procedures that will be used, this objective was not fully realised with a mature set of eEOVs in time for this report. Nevertheless, there was a genuine commitment of the workshop participants and the broader community to continue this work. A significant outcome of the workshop was a common understanding about the attributes and definition of an eEOV and how one would be used to support the questions being addressed by the observing system.

4. Providing expert advice to policymakers on the technical development and, where possible, requirements for measuring these eEOVs.

B9. Based on the Framework for Ocean Observing (FOO) and progress in the GOOS Biogeochemistry Panel, the workshop successfully specified a context and process in which eEOVs may be designed, selected and made ready for inclusion in the Southern Ocean Observing System. Several participants at this workshop also participated in a workshop convened by the GOOS Biology Panel in November 2014 in Townsville, Queensland, Australia. In addition, 59 individuals who could not attend the workshop are contributing to the work in SOKI. A number of tasks have been agreed by the workshop participants to complete after the workshop in order to be able to provide advice on the next steps for implementing eEOVs in the Southern Ocean Observing System. Overall, the workshop drew the conclusion that establishing a cost-effective set of eEOVs will take time to develop but that significant progress was made at the workshop to achieve this task.

Aim of this document

B10. This document provides outcomes of the workshop and the context for future work. It will form the basis for a paper from the workshop for *Marine Policy* and other materials to contribute to meeting the project objectives.

B11. This document draws on the discussions at the worskhop, as well as the reviews and materials developed in the online wiki (SOKI) used for pre-workshop reviews and workshop discussions. It does not provide specific views or presentations expressed during the meeting, nor does it report on the variety of ways that eEOVs may be considered. Instead, the document provides a consolidated, collective overview on the agreed way forward.

B12. This work aims to achieve consistency with the ongoing work in GOOS and, where appropriate, other observing systems.

B13. The layout of this document follows the sequence of discussions (Attachment B):

1. Context for ecosystem Essential Ocean Variables (eEOVs)
    - 1.1 Framework for Ocean Observing
    - 1.2 SOOS
    - 1.3 An ongoing process
2. Ecosystem questions to be addressed by an observing system
3. Using eEOVs to help address the questions
4. Candidate eEOVs
5. Evaluating eEOVs for inclusion in the observing system
    - 5.1 Criteria
    - 5.2 Process to assess priorities for development
    - 5.3 Platforms and measurements
    - 5.4 Existing capability and a gap analysis
    - 5.5 Evaluating readiness of eEOVs
6. Next steps
    - 6.1 Proposal to SCOR for a Working Group on eEOVs for the Southern Ocean

B14. Note that some of the figures and elements of this report were developed after the workshop in order to conceptualise the discussions at the workshop. Some figures have also been developed to help resolve issues raised at the workshop.

1. CONTEXT FOR *ECOSYSTEM ESSENTIAL OCEAN VARIABLES* (EEOVS)

1.1 Framework for Ocean Observing

1.1.1 The development of eEOVs for SOOS aims to be consistent with the Framework for Ocean Observing (FOO; Lindstrom *et al*. 2012) and the development of eEOVs in the Global Ocean Observing System (GOOS) and other observing systems. The FOO aims to achieve time-series of observations (essential variables) that will be used to develop outputs to address the questions identified as the input requirements of the system (Figure 1). Essential variables are being developed for physical and chemical attributes of ecosystems as *Essential Ocean Variables* (EOVs) or *Essential Climate Variables* (ECVs) and as *ecosystem Essential Ocean Variables* (eEOVs) for the biological attributes.

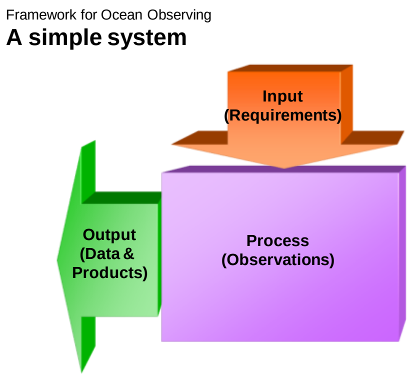

Figure 1 **The Framework for Ocean Observing** (FOO): The framework aims to achieve time-series of observations (essential variables) that will be used to develop outputs to address the questions identified as the input requirements of the system (from Lindstrom *et al*. 2012)

1.1.2 Francisco Chavez (who provided a presentation but was unable to attend the workshop), Tim Moltmann, Dan Costa and Katja Fennel provided useful background on progress in the GOOS panels of Biogeochemistry and Biology. The draft report and draft EOVs for Biogeochemistry were available to the workshop for consideration (http://www.ioccp.org/foo). Reference was made to the discussions of the Biology Panel and this report extends those discussions further, particularly in relation to the Southern Ocean.

1.2 SOOS

1.2.1 The Southern Ocean Observing System has been established to develop long-term observations to address 6 themes (Rintoul *et al*. 2011, Meredith *et al*. 2013; http://www.soos.aq/index.php/science/themes):

Theme 1: The role of the Southern Ocean in the planet's heat and freshwater balance

Theme 2: The stability of the Southern Ocean overturning circulation

Theme 3: The role of the ocean in the stability of the Antarctic Ice Sheet and its future contribution to sea-level rise

Theme 4: The future and consequences of Southern Ocean carbon uptake

Theme 5: The future of Antarctic sea ice

Theme 6: Impacts of global change on Southern Ocean ecosystems

1.2.2 Theme 6 on ecosystems is the least developed of the themes in SOOS. This workshop aims to progress consideration of eEOVs that will then be evaluated using Southern Ocean case studies and simulations.

1.3 Process for developing eEOVs

1.3.1 Identifying, developing and communicating eEOVs for the Southern Ocean will be a continual process; it was not intended that all eEOVs would be resolved from this initial workshop. Further, any biological observing plan developed around the identified eEOVs should be flexible, and able to respond to new knowledge and requirements. The aim was, therefore, to develop a process that would enable inclusion of new eEOVs when their need has been identified. Some candidate eEOVs may not be able to be implemented immediately, but their feasibility may improve with technological innovation that allows less expense instruments and deployments. Some eEOVs may become superfluous over time and cease to be used. The criteria used to identify eEOVs are not intended to exclude options for the future, but should enable development of a plan to implement the eEOVs that are mature (as identified through the FOO "stages of readiness", see below) and to identify prospective eEOVs that require development.

1.3.2 The FOO provides guidance on how to set priorities for eEOVs. Figure 2 shows the schema for assessing which eEOVs may be targetted first, based on feasibility for implementation and impact on the questions being asked:

- eEOVs that may have a high impact, but low feasibility, could be developed further (through better technologies or design) in order to make them a priority for inclusion in the observing system.
- eEOVs that would only have a low impact would not be adopted in their current form because their relative importance (to the questions being addressed by the observing system) remains to be demonstrated.
- eEOVs that have a high feasibility and would provide a high impact would be targeted for investment.

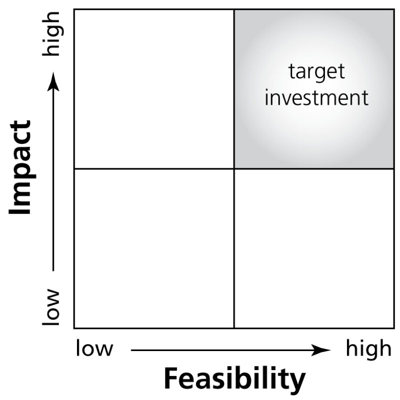

Figure 2 **Feasibility-Impact Schema**: A schema for assessing which eEOVs may be targetted first based on feasibility for implementation and impact on the questions being asked. (from Lindstrom *et al.* 2012)

1.3.3 eEOVs will emerge naturally using the FOO stages of "readiness" (Figure 3). Those eEOVs that have been demonstrated to be highly feasible and have a high impact on answering the questions will be regarded as mature. Alternatively, eEOVs that require further development before adoption would be regarded as conceptual or pilot eEOVs. The FOO provides guidance on how to evaluate readiness, as shown in Figure 4.

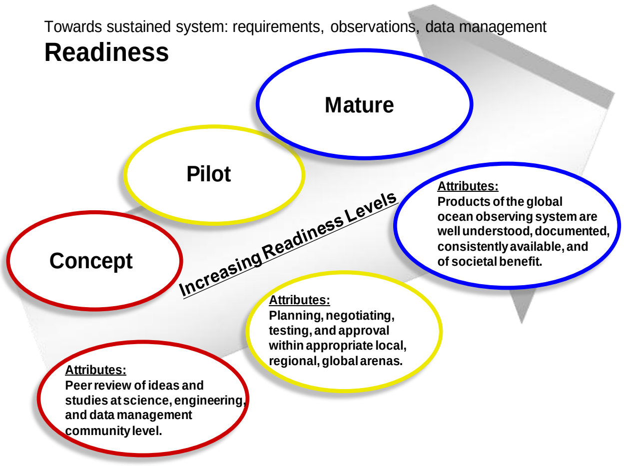

Figure 3 **Stages of readiness**: the stages of readiness for essential variables as developed in the Framework on Ocean Observing. (from Lindstrom *et al*. 2012)

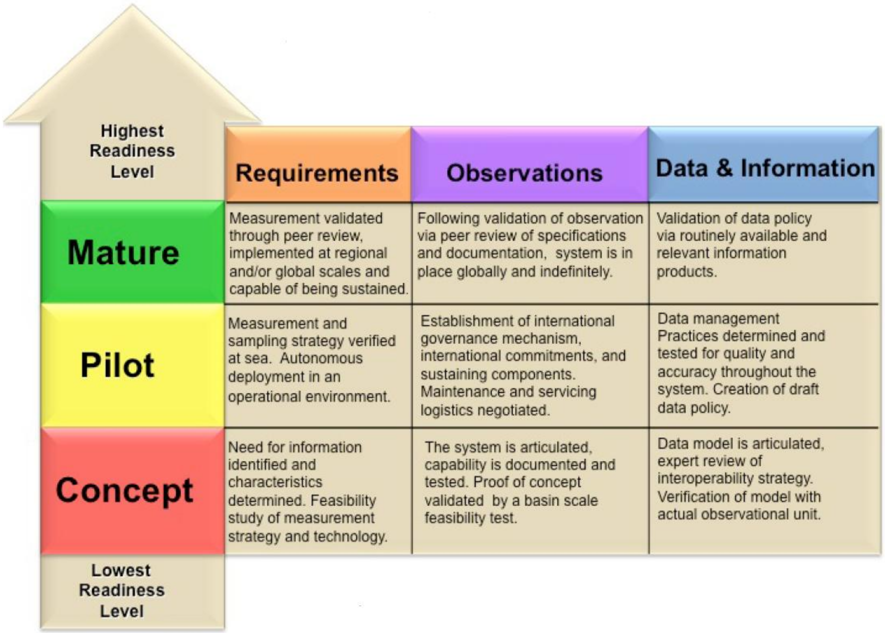

Figure 4 Readiness of an eEOV will require an assessment of whether the requirements for the eEOV to support the questions have been established, the field measurements have been standardised and adopted and the data and information management has been established. (from Lindstrom *et al*. 2012)

2. ECOSYSTEM QUESTIONS TO BE ADDRESSED BY A SOUTHERN OCEAN OBSERVING SYSTEM

2.1 Several questions that can be addressed by an observing system in the Southern Ocean have particular relevance to society. The **overarching question** that encompasses these questions, embraces a variety of needs and will be used to guide the development of the observing system is:

> ***Is the ecology of the Southern Ocean changing as a result of regional (e.g., fishing, pollution, tourism) and/or global (e.g., climate change) pressures?***

2.2 Thus, the design of the observing system needs to facilitate our ability to estimate change and assess the impacts of human pressures (e.g., enable attribution of the causes of any observed changes).

2.3 Workshop participants agreed that **four specific questions** capture the main societal concerns in the overarching question:

1. ***Are food webs changing?***
2. ***Are habitats changing?***
3. ***Is species diversity changing?***
4. ***Are regional human pressures changing?***

2.4 Each question has a specific focus – **foodwebs, habitats, diversity, regional human pressures**. Each of these questions relates to the overarching question in asking the following kinds of questions: Is there a change in that area of focus, what are the consequences of that change, and can we attribute that change to one or more causes? Global human pressures that produce changes in physical and chemical forcings in the Southern Ocean are not included here because they are being considered by other groups of experts. EOVs related to global human pressures and the physical and chemical forcings are naturally connected to the above four questions as identified in Figure 5, but do not require direct attention in the design of the biological observing system for the Southern Ocean.

2.5 The four foci have a natural sequence of connections (Figure 5). For example, changes in habitats result primarily from physical and chemical forcings. Diversity in an area is determined by the ranges of suitable habitats in which species can reside, along with the availability of species (species pool) to disperse into the suitable habitat. The species pool for an area combined with habitat then determines the food web and the relative importance of species in each functional component. Feedbacks can arise between these foci. For example, events in the food web can lead to changes in relative abundance of species in the species pool and may change the long-term viability of some species in the region. Similarly, bioengineers (e.g., habitat-forming corals and bioturbators) may give rise to changes in habitats if they become dominant. Species may also have important feedbacks on physical systems as well, such as the role of phytoplankton in the carbon cycle and cloud formation, among others.

2.6 Regional human pressures can impact on (i) habitats through disturbance, (ii) diversity through the introduction of alien species or through extinction (regional or global) of species, and (iii) foodwebs through mortality (e.g., removals or incidental mortality) or sublethal effects (e.g., disturbance of aggregations). All these impacts can have additional effects within and between the foci. For example, habitat disturbance may affect species diversity at some location in the food web, which may then have top-down or bottom-up consequences in the food web.

2.7 Global human pressures are recognised to impact on physical and chemical forcings, which will then have concomitant effects on habitats, diversity and food webs. Changes in these forcings do not necessarily need to result in only bottom-up effects in food webs through primary production and the microbial loop. It may be that habitats of higher trophic level species are affected, which then result in both top-down and bottom-up incidental effects in the food web.

2.8 Essential Ocean Variables (EOVs) for the physical and chemical forcings and the effects of global human pressures on these are being developed by the physical and biogeochemical themes in SOOS and the respective panels in GOOS. Figure 5 illustrates how these may be directly linked, primarily through habitats, into the consideration of eEOVs.

2.9 Each focus has its own natural variability that will need to be accounted for in the development of eEOVs. For example, habitats will naturally vary with the variability in physical and chemical forcings (seasonal variability, ocean variability over years, disturbance by iceberg scour), as well as any variability in bioengineers, for example, succession and the development of biological habitats. Diversity in any particular area will be influenced by habitats and food webs, giving rise to variation in the relative importance of different species in the species pool, such as might occur in successional processes or seasonally for microbial systems. Foodwebs naturally vary over time, through variability in habitats and the physiology, life history and behaviours of organisms. Regional pressures will vary as a result of varability in economics, government priorities and regulations.

2.10 Long-term change (trends) in each focus may be through a trend in the mean or a change in the variability, such as the frequency of extreme events. Once again, trends in habitats may be a result of long-term trends in ocean, ice and benthic environments, or in the frequency of extreme disturbance events in those habitats. For diversity, some species may adapt, new species may evolve and some species may naturally go extinct, without any change in habitat or food webs. Of course, range extensions may change diversity in a given area through long-term trends in the physical and chemical conditions of an area. For food webs, their dynamics are such that hysteresis may be inherent in the foodweb properties, so that even if conditions return to earlier states, food webs do not. Change in habitats and diversity may increase or decrease the likelihood for alternative stable states. Change in regional pressures may arise from long-term change in the economics, governments or governance arrangements. Also, long-term change may arise through advances in technology and/or capability for human activities in a region.

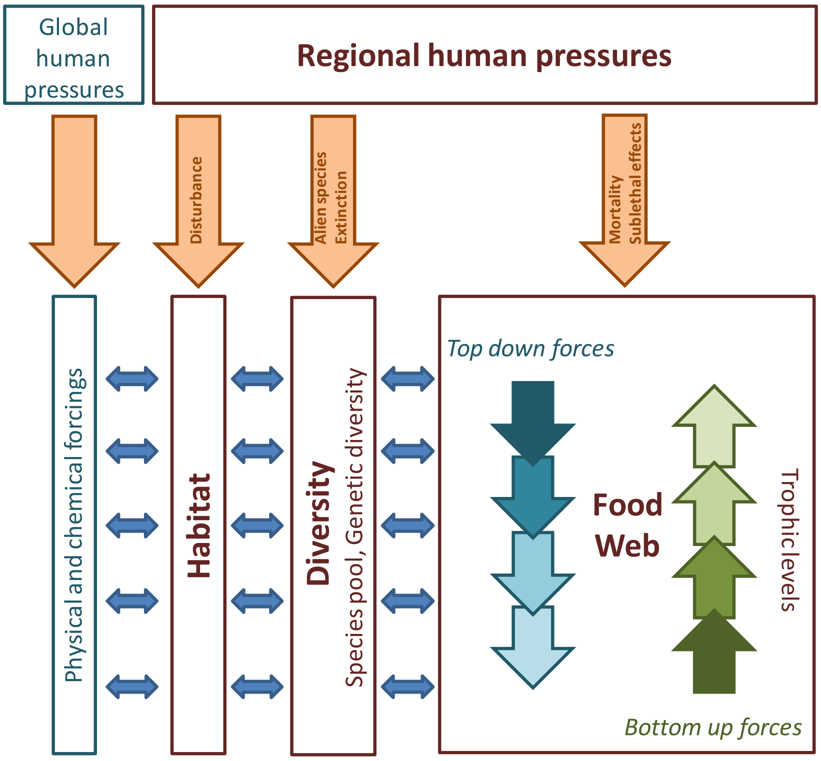

Figure 5 **Foci for ecosystem Essential Ocean Variables** (eEOVs): eEOVs will be developed in four naturally connected ecosystem foci – Habitat, Diversity, Food Web and Regional Human Pressures. *Essential Ocean Variables* (EOVs) are being developed for physical and chemical forcings and the *global* human pressures by physical and biogeochemical experts. Horizontal blue arrows indicate the connections, including feedbacks, between the foci. Downward orange arrows show the effects of global and regional human pressures in the system. The foodweb can be considered as a number of trophic levels, each of which will be impacted by both bottom-up and top-down forces in the food web. The number of blue arrows indicate that changes in habitats, diversity and foodwebs may occur at any trophic level, potentially giving rise to both bottom-up and top-down affects in the foodwebs. Examples for interpreting the figure are given in the text (Section 2). (modified from Constable *et al*. 2014)

Post-workshop Task 1:	Provide summaries of the scientific justification (motivation) and emphasis of each specific question that requires sustained observations
Post-workshop Task 2:	For each specific question, provide example statements that use ecosystem properties to answer the questions and further illustrate the linkages between questions

3. USING EEOVS TO HELP ADDRESS THE QUESTIONS

3.1 The observing system will be designed to provide the information (data) required to address the scientific questions defined above and then contribute to meeting societal questions such as

- from the SOOS *Initial Science and Implementation Strategy* (Rintoul *et al*., 2011, www.soos.aq)

  "A better understanding of the impact of global change on Southern Ocean ecosystems is essential to guide conservation and marine resource management decisions (Clarke et al.*, 2007; Barnes & Peck, 2008) […including an…] ability to predict changes in marine resources and biodiversity, to assess ecosystem resilience, and determine feedbacks between food webs and biogeochemical cycling.."*

- Is the health/stability of Antarctic ecosystems deteriorating? If yes, where? At what rate?
- Are fish stocks (and other economically important living resources) declining? If yes, how fast?
- Is the capacity of the Southern Ocean to take up CO_2 released by human activities decreasing? If yes, at what rate? What are the implications for global climate?

3.2 Adopted eEOVs must, therefore, be able to provide the required data, across the spatial and temporal scales necessary, as part of a long-term (i.e., sustainable) observing system. eEOVs may contribute to two roles of the observing system, which are to provide time series of data that will enable:

i) direct estimates of ecosystem change, and

ii) the development of ecological models that

   a. are realistic;

   b. can help with investigating impacts of change on the ecosystem, particularly for parts of the ecosystem that are unable to be observed; and

   c. if possible, can assist with attributing change to one or more causes.

3.3 Workshop participants recognised that there is an essential interplay between the collection of field data and modelling (qualitative models, simple algorithms, empirical/statistical models, and dynamic models). Thus, as identified by the GOOS Biogeochemical Panel, there is a natural hierarchy between field measurements (called subvariables and supporting variables by that panel), the algorithms that might be used to deliver quantities useful to ecologists (e.g., Chl *a* from ocean colour, abundance from acoustic measurements, etc.) and the derivation of products (derived products) that would be used to answer the questions (e.g., change in diet from a change in stable isotopes). This hierarchy was adopted by the workshop, noting that biology adds a layer of complexity that should be reflected in the heirarchy.

3.4 In order to account for the added complexity of ecosystems within the hierarchy, Workshop participants agreed that each question would be addressed by knowledge of one or more (but often all) Ecosystem Properties (EP):

EP1 Primary production

EP2 Production

EP3 Abundance

EP4 Energy Transfer

EP5 Habitat Characteristics

EP6 Spatial Distribution of Organisms

EP7 Diversity

EP8 Regional human pressures

3.5 These properties take account of how state quantities as well as processes may change, along with change in the species pool and in the regional human pressures. The hierarchy for ecosystems would include these Ecosystem Properties above the level of derived products (see Figure 6).

3.6 Workshop participants wrestled with how an eEOV might be defined, and where it would sit within this hierarchy, noting that the experience from other groups would suggest that an EOV could be anything from a direct field measurement to an ecosystem property (and therefore sit at various levels within the hierarchy). Instead, Workshop participants agreed that the system would be most easily understood if an eEOV would be at one recognised level in this hierarchy. They therefore defined an eEOV as:

> ***an ecosystem Essential Ocean Variable (eEOV) is an agreed unit of biological or ecological measurement***

where a biological/ecological unit is one that is difficult to define on the basis of natural principles, as it is in physics, but would be identified by agreement of the community.

3.7 Some example eEOVs are:

i) Density of Chlorophyll *a* - a quantity with which everyone is familiar.

ii) Diet – a quantity where the unit of measurement is the diet of one animal.

iii) Foraging Range – a quantity where the unit of measurement is the foraging trip of one animal.

Rate processes can also be included, such as annual reproductive success.

3.8 In this context, an eEOV would sit above the level of Measurement, but below Derived Products. For example, ocean colour would be the Measurement and would be converted into an eEOV "Chlorophyll *a*" using an algorithm. Chl *a* would then be used with other eEOVs to provide a Derived Product on primary production and abundance. In this case, the derived product of primary production would also be an ecosystem property.

3.9 This eEOV-to-Question hierarchy and the interplay with models is illustrated in Figure 6, along with an example. Workshop participants agreed that the observing system would focus on elaborating and implementing eEOVs that would significantly contribute to the two tasks of the observing system indicated above. Scientific and technological creativity would lead to standard methods to acquire field measurements, but these methods may change over time through improved design of sampling or through technological innovation.

3.10 Workshop participants noted that the observing system will also need to be supported by the development of libraries of information, such as genetic reference collections, as well as standard methods for acquiring, storing and managing the data collected by the system. These need to be considered as part of the design of each eEOV.

3.11 Workshop participants also noted that only some processes will be important to include in an observing system in order to detect ecosystem change. Models may benefit from studies of other processes, but these would be identified as gaps to be addressed elsewhere by the scientific community, rather than included as part of the observing system directly.

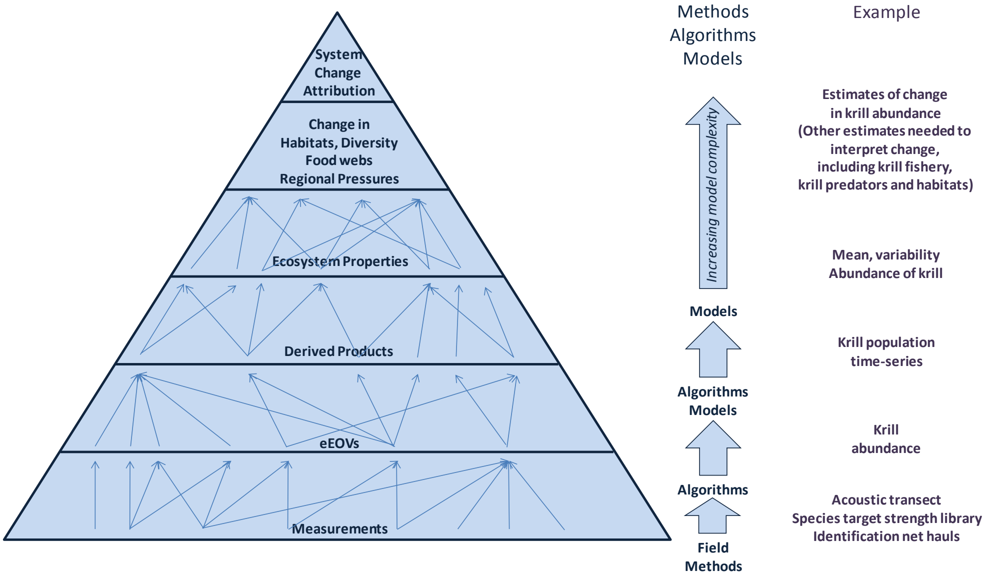

Figure 6 **eEOV-to-Question Hierarchy**: The hierarchy of the process required to move from discrete field measurements to data and products that address the overarching question of ecosystem change and its attribution. The interplay between data collection and different types of models is shown to the right. The triangle illustrates that the process may have 1-to-1 relationships between each level but, more likely, will have many elements from a lower level contributing to fewer synthetic elements at the next level, and that, on the whole, there is a general reduction in the number of elements from one level to the next. The observing system would have standard methods to collect measurements used in the eEOVs. The example illustrates how measurments of the acoustic backscatter can deliver estimates of abundance (eEOV) that help assess change in this ecosystem property.

Post-workshop Task 3:	Develop suitable descriptions of ecosystem properties and the types of long-term observations of those properties that would help address the questions. Consideration can be given to differences between pelagic and benthic environments.

4. CANDIDATE EEOVS

4.1 eEOVs may be developed for the two roles identified above: (i) direct estimation of change and/or (ii) inclusion of time series of eEOVs in ecological models.

4.2 A good example of a possible set of eEOVs for estimating change is the CCAMLR Ecosystem Monitoring Program (CEMP; Agnew 1997, http://www.ccamlr.org/en/science/ccamlr-ecosystem-monitoring-program-cemp) and its standard methods, part of which are illustrated in Figure 7. The expectation is that these eEOVs would form the foundation of statistical models for detecting changes in krill, penguins and the fishery.

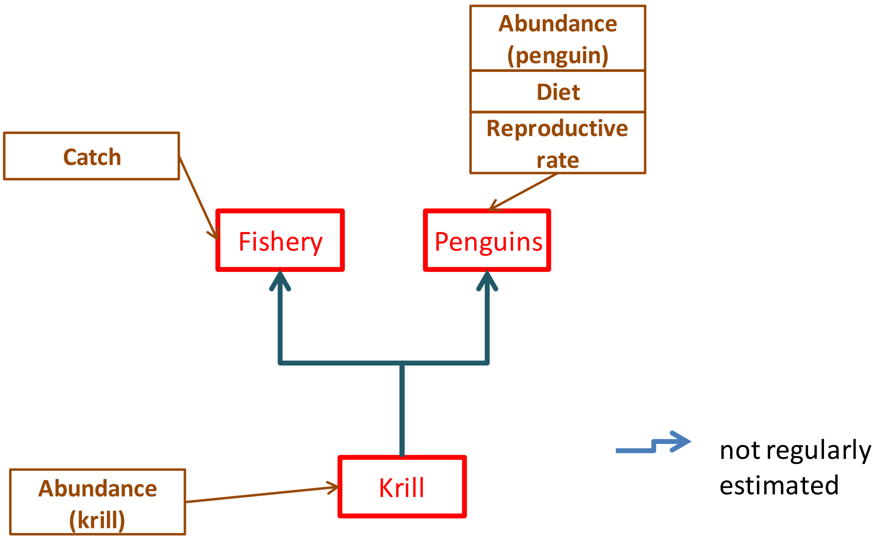

Figure 7 **Using eEOVs for estimating change**: Schematic diagram showing the main elements being observed in the CCAMLR Ecosystem Monitoring Program (CEMP) – Krill, Penguins, Fishery (red boxes). The blue arrows indicate linkages that are not regularly estimated. The brown boxes indicate CEMP parameters that could be defined as eEOVs according to the definition in this report.

4.3 An observing system cannot measure and monitor everything—it must be selective to be economically sustainable and logistically feasible. The observing system seeks to have sufficient eEOVs to make the models realistic or to enable estimates of change, without too much redundancy. Efficiencies may be gained by using indicator species or measurements, reference locations, or relative measures (compared with absolute measures) that provide the robust measurements required.

4.4 The key question then becomes "what is the most efficient way of estimating the required eEOV quantity (e.g., quantified sampling targets) that is robust through time (see criteria)?" eEOVs will vary in their spatial and temporal sampling requirements. Also, some eEOVs may have field sampling requirements that are at longer temporal scales and/or broader spatial scales, but which will require finer resolution temporally/spatially once a signal has been observed that indicates the need for measurements at finer resolution. The sampling may then return to the coarser resolution after a specified period or a counter-signal has been observed.

Post-workshop Task 4:	With assistance from the external community, develop conceptual diagrams similar to those in Figure 7 and Figure 8, which help identify candidate eEOVs that could be used to address the specific questions.

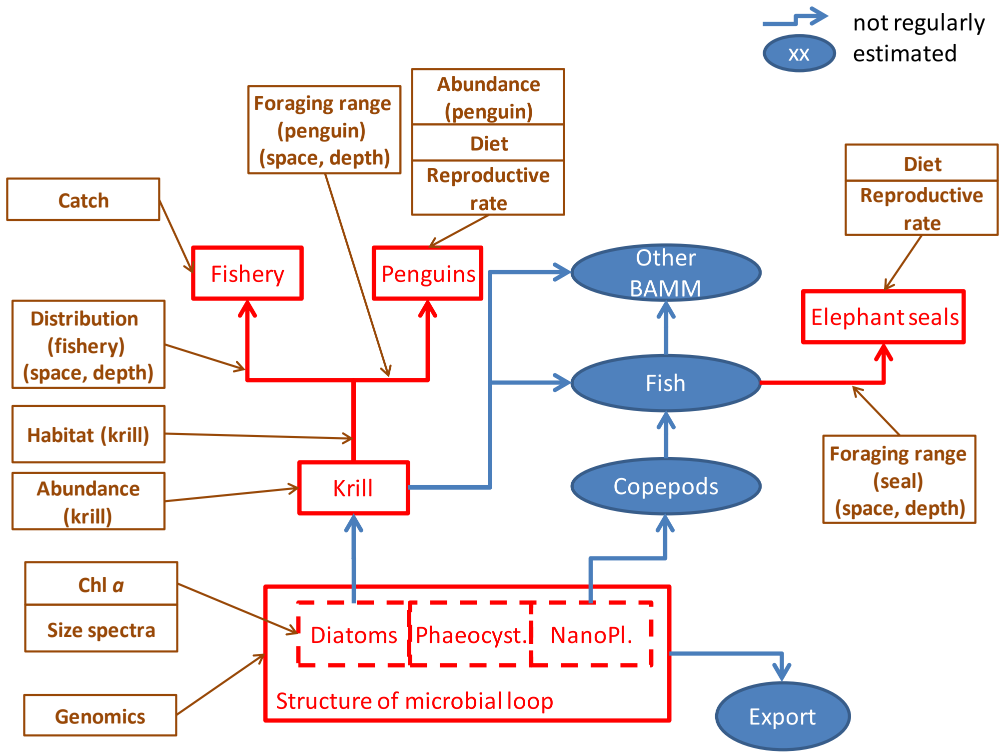

Figure 8 **Using eEOVs in ecological models:** Schematic showing the main elements of a food web model that might use time-series of eEOVs to make the model realistic, either through validation procedures, model fitting or data assimilation. Red boxes and arrows indicate components of the food web for which products may be derived from the eEOVs or for which the eEOVs may be used directly in the models. Blue arrows indicate linkages that are not regularly observed. The brown boxes indicate potential eEOVs according to the definition in this report. CEMP parameters in Figure 7 are included in this diagram in the set of boxes for krill, fishery and penguins, illustrating how eEOVs can support a number of questions and approaches and use observations already being collected.

4.5 The workshop considered the GOOS Biogeochemistry EOV Template and modified some sections to take account of the requirements of eEOVs for biological measurements (Attachment C). As an important step following the workshop, the first and second tables in the template need to be developed for candidate eEOVs to facilitate an initial examination of feasibility and impact. The remainder of the template will then be completed for the identified priority eEOVs, to determine whether they can progress to mature eEOVs.

Post-workshop Task 5:	With assistance from the external community, develop candidate eEOVs using the template in Attachment C, based on the requirements for questions but condensing similar eEOVs within respective ecosystem properties.

5. EVALUATING EEOVS FOR INCLUSION IN THE OBSERVING SYSTEM

5.1 The process of the GOOS Biogeochemistry Panel was to prepare high-level descriptions of candidate EOVs in the template in Attachment C and then to consider these against criteria that would assist in evaluating feasibility, impact and readiness as in Figure 2 and Figure 4. Evaluation of readiness of Southern Ocean eEOVs will need to consider what platforms, sensors and sampling equipment are available or are in development. Assessments of feasibility will necessarily be associated with the cost of operating the different platforms and the ability to develop a network of activities across existing national operations. The impact of each eEOV will be assessed in terms of its importance in addressing the specific questions, as well as how many of the questions it is used to answer.

5.2 Figure 9 indicates the flow in the development of the readiness of eEOVs according to the detail in Figure 4. It also summarises the eEOV-Question Hierarchy from Figure 6 to illustrate how the need for eEOVs might be identified, either through the development of the observing system or because of a key gap in addressing policy-oriented questions. This process overall indicates that the assessment of impact will initally comprise a theoretical judgement of how eEOVs relate to the questions. Subsequent to this, the evaluation of impact will benefit from using case studies (pilot field studies) to examine the process in practice for delivering derived products and assessments. This will help to realistically assess whether the eEOV will have an impact on answering the question. Further, simulations can be used to determine the degree to which that impact will be sustained in the long term. Thus, the impact of an eEOV will need to be evaluated in three steps, which correspond to the 3 stages of readiness for an eEOV:

i) theoretical impact, in advance of case studies

ii) case studies to realistically assess the properties of the data and whether the eEOV will be able to contribute to answering the questions, and

iii) simulation and/or other evaluation of the likely long-term impact of an eEOV on addressing the questions.

5.3 This section outlines progress made towards defining criteria for assessing feasibility and impact of a candidate eEOV, the process to assess priorities for developing eEOVs, and the current and future capability and platforms for field measurements to be made.

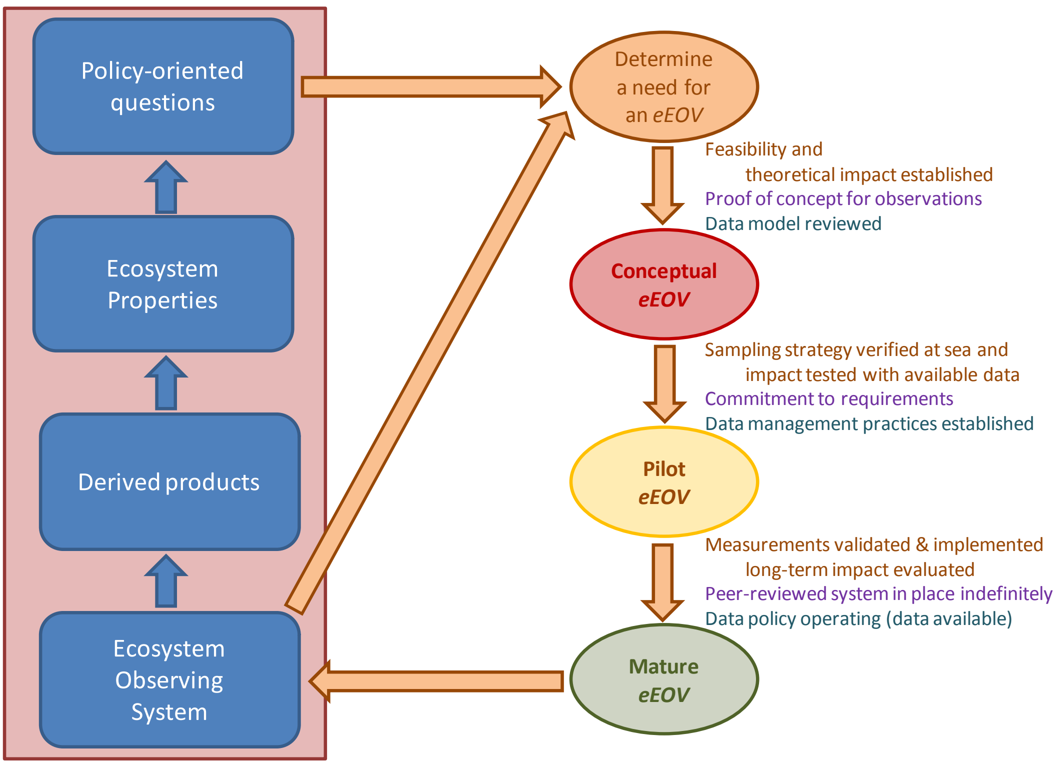

Figure 9 **Development and implementation of eEOVs**: Flow chart showing the development of eEOVs (ovals) through the different stages of readiness (oval colours) identified in Figure 4. Text adjacent to arrows are coloured according to the columns in the table of Figure 4. The methods for assessing impact capture the discussion of the workshop providing additional detail to the FOO stages of readiness. The eEOV-to-Question hierarchy is shown within the red box on the left with the need for an eEOV being identified by either the observing system itself or by a gap in addressing the policy-oriented (specific) questions.

5.1 Criteria

5.1.1 The workshop considered several draft criteria relating to feasibility and impact. Initial Workshop participants agreed that an eEOV should be assessed against a range of criteria, which initially could include:

- The degree to which it contributes to signalling change in the ecosystem.
- The degree to which it contributes to the development and/or application of models investigating change and attribution.
- Whether it provides the basis for a model to realistically represent the system (at various scales).
- Whether it is understandable to policy-makers and the public.
- Whether its implementation will be satisfactory to correctly attribute differences to changes over time, i.e., the differences are not because of differences in space where one place was sampled at one time and a different place was sampled at a later time.
- The degree of alignment with other eEOVs
- Have a sufficiently high signal-to-noise ratio, i.e., have low sampling error, adequately captures the variability of the eEOV, and that a signal (trend) can be detected in the time-scale required.
- Have the ability to be connected to historical (legacy) datasets to extend the time series into the past
- Have the potential to evolve through time with improved knowledge and greater capacity for measurements; the signal derived from the eEOV is robust to changes in the methods or design of data collection or, at least, can be standardised such that this robustness is achieved
- Potential for adaptive response, e.g., coarse-grain sampling until a signal is observed to institute fine-grain sampling and then later revert to coarse-grain sampling when a counter-signal is observed.

5.1.2 Workshop participants noted that some criteria relate to impact and others relate to feasibility. They also noted that eEOVs do not necessarily need to be rated highly on all criteria to be given a high priority, but that such criteria can be used to help determine the priorities in the combined assessment of impact and feasibility.

5.1.3 The adoption of an eEOV in the observing system will also need to consider

a. utility to scientists and policy makers
b. readiness - feasibility, maturity and sustainability, and
c. costs, noting that, in the case of a pilot eEOV, the cost may be a low risk with a potential value for impact.

Post-workshop Task 6:	With assistance from the external community, consolidate the criteria for prioritising candidate eEOVs for further development, including explanations on what the criteria mean.

5.2 Initial assessment of readiness of eEOVs

5.2.1 Workshop participants agreed that, following the initial development of candidate eEOVs and the criteria, a process for evaluating feasibility and impact of those candidate eEOVs will be initiated. This process will be similar to the one developed by the GOOS Biogeochemical Panel where eEOVs will be ranked in feasibility and impact (including their accumulated importance across the specific questions). These results will be represented as in Figure 2. eEOVs regarded as highly feasible and high impact will be further developed in the template in Attachment C. Case studies and assessments of their long-term impact will begin in 2014, as discussed in this document.

Post-workshop Task 7:	With assistance from the external community, begin assessing the readiness of eEOVs, based on feasibility and impact, and their priority for further development, after the ICSU report has been submitted.

5.3 Platforms and measurements

5.3.1 Workshop participants noted that many eEOVs would rely on the same platforms and sampling methods (e.g., sensors). Therefore, a common description of these sampling capabilities is needed. The descriptions of platforms and sampling methods would need to include the spatial and temporal resolution of sampling in addition to the type of data that sampling would produce, such as:

- spatial point data (e.g., trawl)
- spatial line transect data (e.g., AUV, acoustics, CPR, animal track, benthic video)
- spatial synoptic data (e.g., satellite)
- spatial depth profile data (e.g., ship CTD, mooring vertical profile), and
- organismal data (e.g., diet, molecular signatures).

5.3.2 Existing platforms and measurements will be useful to catalogue, along with any opportunities that may be on the horizon. These can then be used to help develop spatial and temporal sampling designs for implementing eEOVs and to identify priorities for developing future capabilities to implement eEOVs in the observing system (i.e., improve their feasibility).

Post-workshop Task 8:	Compile existing platforms and measurements in SOKI, including sensors, with appropriate links to full descriptions on web sites or PDFs.

5.4 Existing capabilities and a gap analysis

5.4.1 Workshop participants agreed that a compilation of existing capabilities and activities would help identify key gaps in the capability of the observing system. The following compilations of capability are being undertaken:

i) existing field programs and measurements, and

ii) availability of different platforms and sensors.

5.4.2 This compilation can then be used to help determine which eEOVs are viable for implementation immediately. The compilation will also help identify how the existing resources might be coordinated to develop a network of observing to support regional assessments.

Post-workshop Task 9:	Compile existing programs, platforms and measurements in SOKI.

5.5 Evaluating readiness of eEOVs for inclusion in SOOS

5.5.1 Workshop participants noted that the readiness of candidate eEOVs for use in the SOOS will be assessed through case studies (based on existing data), pilot work to further assess them, and the use of simulation models to evaluate the degree to which an eEOV and its field implementation will contribute to answering the specific questions in the long term. The compilation of existing activities, as outlined above, will assist in identifying datasets that could be used initially to assess impact of candidate eEOVs based on existing data (e.g., CEMP data) according to the process in Figure 9. The procedures for undertaking simulation evaluation of observing systems are well described in the oceanographic literature. It was noted that existing modelling activities are likely to be able to contribute to these evaluations and that the oceanographic modelling literature can provide guidance on what can be achieved.

Post-workshop Task 10:	Compile information on existing modelling efforts that can be used to simulate and evaluate observing systems and candidate eEOVs.

6. NEXT STEPS

6.1 Looking ahead, the next step is to use the groundwork agreed at the workshop to undertake the 10 post-workshop tasks along with those listed in this section (summarised in Attachment D).

6.2 Beyond these tasks, there is a significant amount of work required to statistically evaluate the candidate eEOVs and design the observing system. Towards this end, Workshop participants agreed to submit a proposal for a SCOR Working Group on Southern Ocean eEOVs.

6.3 Workshop participants noted the need to continue to align efforts in developing eEOVs across SOOS, GOOS and other national and international programs. They agreed that a summary document from this report would be useful to convey to these programs and researchers generally the outcomes of this workshop and the project to date.

6.4 They also agreed that two products of this work should be one science and one marine policy publication, which will be developed soon after the workshop.

6.5 Workshop participants were encouraged to work with national and international programs to facilitate external contributions to the development of eEOVs. They noted that the development of descriptions of standard methods and approaches in SOKI will facilitate the development of activities, including regional networks of coordinated activities.

Post-workshop Task 11:	Prepare a summary document and presentation of workshop outcomes for sharing with researchers, national programs and international programs.

Post-workshop Task 12:	Write manuscripts on the outcomes of this project for the science and marine policy literature.

Post-workshop Task 13:	Compile and review standard methods of field measurements in SOKI.

6.1 Proposal to SCOR for a Working Group on eEOVs for the Southern Ocean

6.1.1 Workshop participants agreed to submit a proposal to SCOR for a Working Group on eEOVs, with an emphasis on the Southern Ocean Observing System. The proposed work will need to be described in the context of related ongoing activities of other groups: GEOBON Marine Working Group and IUCN Red Listing of Ecosystems, and articulate how it will interact with GOOS, DOOS, IMBER, OBIS, ICES, PICES, and the Future of Ocean Observations.

6.1.2 Workshop participants noted that the deadline for proposals to SCOR is 15 April and that the proposal's Terms of Reference should be very specific in relation to activities and products, particularly around the further development and evaluation of eEOVs to address the specific questions on change, including:

1. evaluate eEOVs with case studies and simulations, involving statisticians and modellers,
2. develop simulation modelling capability to assist in designing ecosystem observing systems, and
3. undertake a gap analysis of eEOVs (which other ones might be needed in addition to what is already being done) to facilitate the two roles of observing systems: (i) direct estimation of change and/or (ii) inclusion of time-series of eEOVs in ecological models.

Post-workshop Task 14: Develop and submit a proposal for a SCOR Working Group on ecosystem Essential Ocean Variables in the Southern Ocean.

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ATTACHMENT A: WORKSHOP PARTICIPANTS

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ATTACHMENT B: WORK PROGRAM (AGENDA)

Agenda and presentations can be downloaded from SOKI (http://www.soki.aq/display/Projectd/07+Agenda+and+Workshop+Information).

The table below is a summary of the work undertaken.

Time	Topic	Convenor
Tuesday, 18 March		
9:00 - 9:15	Welcome and Introductions Road to the workshop presented by Ed Urban	Ed Urban
9:15 - 9:30	The Southern Ocean Observing System: Objectives and proposed Workplan as a basis for the eEOV initiative Presentation by Louise Newman	
10:00 - 10:15	Framework for Ocean Observing as a basis for eEOV discussions Introduction by Francisco Chavez / Oscar Schofield	
10:15 - 10:30	eEOVs and the workshop: Discussion paper presented by Andrew Constable (available as a recorded presentation)	
10:45 - 12:45	Group discussion on the discussion paper - framework, eEOVs, criteria	Andrew Constable
14:00 - 15:30	Further group discussion on the discussion paper - framework, eEOVs	
16:00 - 17:30	Breakout discussions & Group discussions on questions being addressed by eEOVs	
Wednesday, 19 March		
9:00 - 10:30	Group discussion on questions being addressed by eEOVs and candidate eEOVs as ecosystem properties.	
11:00 - 12:45	Further group discussions and breakout groups	
14:00 - 15:30	Breakout groups on eEOVs relevant to the four specific questions	
16:00 - 17:00	Breakout groups on eEOVs relevant to the four specific questions	

Time	Topic	Convenor
17:00 - 17:30	Presentations: Greg Mitchell: Scoping for Interdisciplinary Coordinated Experiment of the Southern Ocean Carbon Cycle (ICESOCC) Funded by NASA 2014-2015. Workshop at Scripps Institution week of 22 September 2014. Sophie Fielding: Southern Ocean Network of Acoustics (SONA)	
Thursday, 20 March		
9:00 - 10:30	Platforms, sensors and current field capability to support eEOVs - group discussion	Oscar Schofield
11:00 - 12:45	Group discussion – report back from breakout groups on eEOVs	
14:00 - 15:30	Group discussion -	Andrew Constable
16:00 - 17:30	Breakout groups Group discussion on process for using eEOVs to deliver answers to questions	
Friday, 21 March		
9:00 - 9:30	Presentations and discussion on existing activities: Hyoung Sul La : Ecosystem observations in the Amundsen Sea Tosca Ballerini : expert survey of current activities and priorities for the future	Tosca Ballerini, Dan Costa
9:30 – 10:30	Discussion of the hierarchy from field measurements to the questions and the place of eEOVs in the hierarchy and definition of eEOVs, including purpose and examples of eEOVs	Andrew Constable
11:00 – 12:00	Criteria for evaluating eEOVs	
12:00 - 12:20	Where to from here - identify individuals and groups to complete the post-workshop tasks aimed at populating the report to ICSU (Attachment E) and to continue this work.	Andrew Constable, Oscar Schofield, Dan Costa, Louise Newman, Tosca Ballerini
12:25 - 12:30	Close of workshop	Andrew Constable, Oscar Schofield, Dan Costa, Louise Newman, Tosca Ballerini

ATTACHMENT C: DRAFT EEOV TEMPLATE DERIVED FROM GOOS BGC PANEL TEMPLATE

Draft Template for nominating/evaluating ecosystem Essential Ocean Variables (eEOV). Black text is from the BGC template. Red text is the proposed text to replace the black text in the first two tables and Figure 1. The remainder of the figures and tables are proposed to remain the same, although it is suggested to delete the stages of readiness figure.

EOV Information eEOV Information	
Name of EOV **Name of eEOV**	e.g. SST Definition: a unit of biological/ecological measurement. e.g. Abundance (krill)
Sub-Variables **Sub-Variables**	e.g. Skin/Bulk SST Measurements needed to estimate the eEOV. e.g. Acoustics, target strength library, target net hauls for species identification.
Derived Products **Derived Products**	e.g. Heat flux Ecosystem properties that this eEOV may support e.g. krill population time series
Supporting variables **Supporting variables**	Definition: Covariates or other measurements that may be useful for understanding change of eEOV, including other EOVs or eEOVs e.g. Habitat
Contact/Lead Expert(s) **Contact/Lead Expert(s)**	e.g. Group for High Resolution Sea Surface Temperature (GHRSST) Project. e.g. CCAMLR ad hoc WG ASAM

Requirements Settings					
Readiness Level **Readiness Level**					
Societal Benefit Area(s) **Societal drivers** **Societal Benefit Area(s)** **Societal drivers**					
Scientific Application(s) **Scientific Application(s)**	which specific questions of the observing system does this eEOV relate to				
Phenomena to capture. **Phenomena to capture**	e.g. Diurnal Cycle e.g. Diurnal Cycle	e.g. Seasonal Cycle e.g. Seasonal Cycle			
Temporal Scales of the phenomena **Temporal resolution of sampling**					
Spatial scales of phenomena **Spatial resolution of sampling**					
Magnitudes/range of the signal, thresholds to capture **Magnitudes/range of the signal, thresholds to capture**			.		

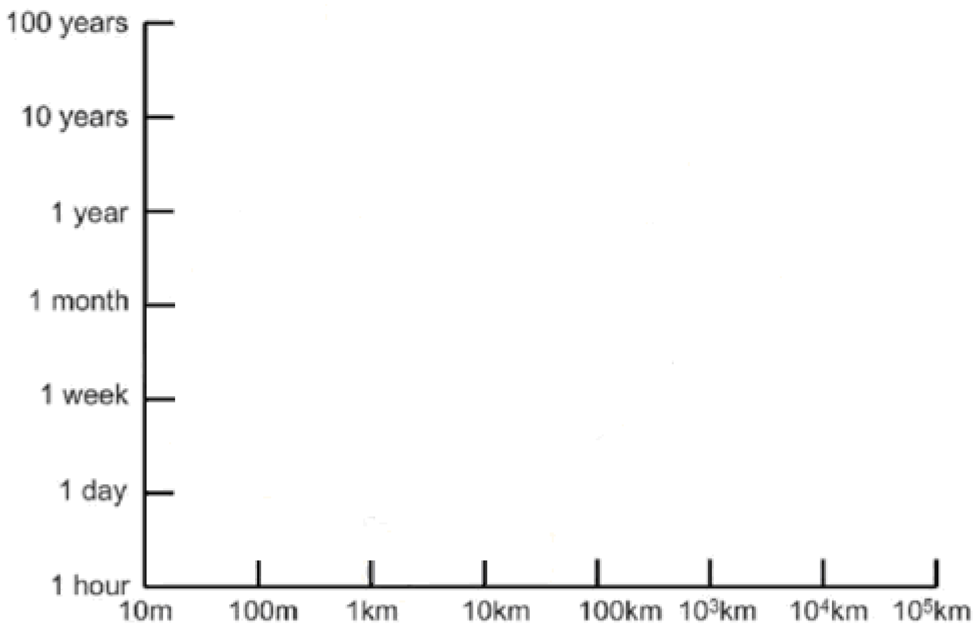

Figure 1: Draw Scales of phenomena to be addressed, and fill in the magnitude of the signal to capture.

Figure 1: Draw resolution of phenomena to be sampled, and fill in the magnitude of the signal to capture.

Observation Deployment & Maintenance					
Observing Elements	e.g. Satellites	e.g. Moorings	e.g. Drifters		
Phenomena addressed					
Readiness Level [1]					
Spatial scales					
Temporal scale					
Relevant measured variables					
Sensor(s)/Technique					
Accuracy/Uncertainty estimate (units).					

Future observing Elements					
Observing Elements					
Readiness Level [1]					
Spatial scales					
Temporal scale					
Time-scale until part of observing system					
Relevant measured parameter(s)					
Sensor(s)/Technique					
Accuracy/Uncertainty estimate (units).					

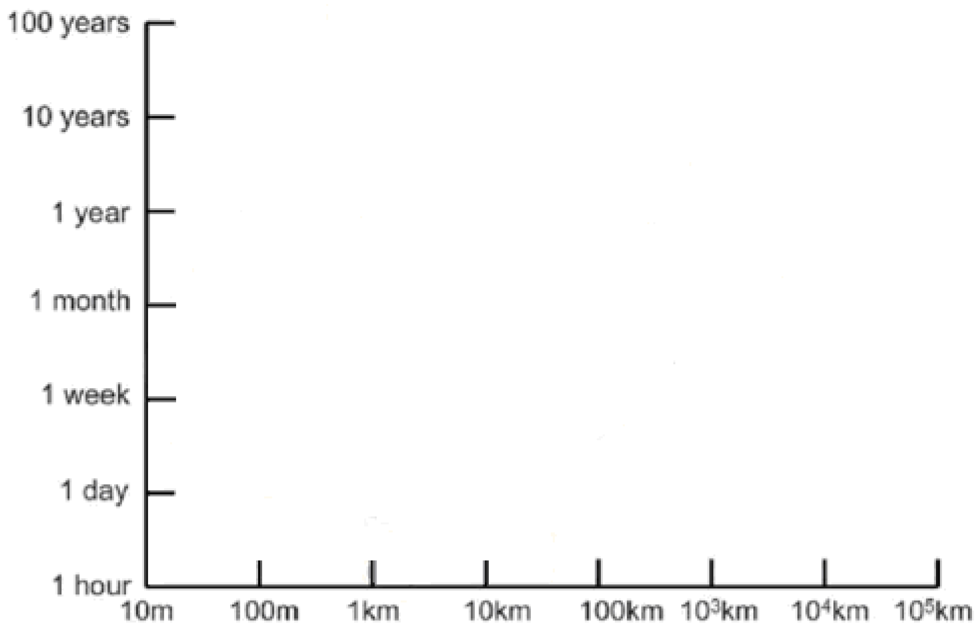

Figure 2. Draw in the well-resolved observation scales of the component networks . If these scales are highly dependent on location or time, separate ovals could be drawn to capture this variability (e.g., one for the West Antarctic Peninsula, and another for the Indian Sector of the Southern Ocean). If the capability has changed or will change in the near future (i.e., within five years), provide examples from two times.

Data & Information Creation			
	e.g. Merged Satellite/In Situ SST	e.g. Gridded in situ SST Product	Gridded in situ SST climatology
Readiness Level $_1$			
Oversight & Coordination	e.g. GHRSST	e.g. HADSST	
Data Centre/repository			
Data Stream delivery and QC…			
Derived Products			

Links & References	
Links* (especially regarding Background & Justification)	
Links for Contributing Networks	
Data References	

ATTACHMENT D: FUTURE WORK PLAN

Task Number	Task	Lead
1.	Provide summaries of the scientific justification (motivation) and emphasis of each specific question that requires sustained observations	Leads on specific questions[1]
2.	For each specific question, provide example statements that use ecosystem properties to anwer the questions and further illustrate the linkages between questions	Leads on specific questions[1]
3.	Develop suitable descriptions of ecosystem properties and the types of long-term observations of those properties that would help address the questions. Consideration can be given to differences between pelagic and benthic environments	Leads on ecosystem properties[2]
4.	With assistance from the wider scientific community, develop conceptual diagrams similar to those in Figure 7 and Figure 8, which help identify candidate eEOVs that could be used to address the specific questions.	Leads on specific questions[1]
5.	With assistance from the wider scientific community, develop candidate eEOVs using the template in Attachment C, based on the requirements for questions but condensing similar eEOVs within respective ecosystem properties.	Leads on specific questions[1]
6.	With assistance from the wider scientific community, consolidate the criteria for prioritising candidate eEOVs for further development, including explanations on what the criteria mean.	Andrew Constable
7.	With assistance from the wider scientific community, begin assessing the readiness of eEOVs, based on feasibility and impact, and their priority for further development.	Project Committee
8.	Compile existing platforms and measurements in SOKI, including sensors, with appropriate links to full descriptions on web sites or PDFs	Oscar Schofield
9.	Compile existing programs, platforms and measurements in SOKI	Tosca Ballerini, Monica Muelbert
10.	Compile information on existing modelling efforts that can be used to simulate and evaluate observing systems and candidate eEOVs	Andrew Constable, Eileen Hofmann
11.	Prepare a summary document and presentation of workshop outcomes for sharing with researchers, national programs and international programs	Andrew Constable, Louise Newman
12.	Write manuscripts on the outcomes of this project for the science and marine policy literature	Project Committee[3]
13.	Compile and review standard methods of field measurements in SOKI	All
14.	Develop and submit a proposal for a SCOR Working Group on ecosystem Essential Ocean Variables in the Southern Ocean	Project Committee[3]

[1] Lead experts on specific questions:

1. Changing foodwebs – Oscar Schofield
2. Changing habitats – Mark Hindell, Monica Muelbert
3. Changing diversity – Huw Griffiths, Anton Van de Putte, Marc Eleaume, Angelika Brandt
4. Changing Regional Human Pressures - Jess Melbourne-Thomas

[2] Lead experts on ecosystem properties:

1. Primary Production – Oscar Schofield, Greg Mitchell, Ian Salter
2. Production – Andrew Constable, Dan Costa
3. Abundance – Sophie Fielding, Christian Reiss
4. Energy Transfer – Kerry Swadling
5. Habitat Characteristics – Mark Hindell, Monica Muelbert
6. Distribution of Organisms - Anton Van de Putte
7. Diversity - Huw Griffiths, Anton Van de Putte, Marc Eleaume, Angelika Brandt
8. Regional Human Pressures – Jess Melbourne-Thomas, Keith Reid, Louise Newman

[3]Project Committee

1. Andrew Constable
2. Dan Costa
3. Oscar Schofield
4. Louise Newman
5. Tosca Ballerini
6. Ed Urban
7. Mike Sparrow
8. Eileen Hofmann
9. Gerlis Fugmann

ACRONYMS

AAD	Australian Antarctic Division
ACE CRC	Antarctic Climate and Ecosystems Cooperative Research Centre
APECS	Association of Polar Early Career Scientists
AUV	Autonomous Underwater Vehicle
AWI	Alfred Wegner Institute
BAS	British Antarctic Survey
CAML	Census of Antarctic Marine Life
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CEMP	CCAMLR Ecosystem Monitoring Program
CPR	Continuous Plankton Recorder
CTD	Instrument to measure Conductivity (salinity), Temperature, Depth
DOOS	Deep Ocean Observing System (GOOS)
ICED	Integrated Climate and Ecosystem Dynamics of the Southern Ocean (IMBER program)
ICSU	International Council for Science
IMAS	Institute of Marine and Antarctic Studies
IMBER	International Marine Biogeochemistry and Ecosystem Research
IMOS	Integrated Marine Observing System (Australia)
KOPRI	Korea Polar Research Institute
MNHN	Muséum national d'histoire naturelle, Paris
SAHFOS	Sir Alister Hardy Foundation for Ocean Science
SCAR	Scientific Committee on Antarctic Research
SCOR	Scientific Committee on Oceanic Research
SOOS	Southern Ocean Observing System
UCSC	University of California, Santa Cruz
UCSD	University of California, San Diego
USA-AMLR	USA Antarctic Marine Living Resources Program