Report of the Section on *Climate Change Effects on Marine Ecosystems*

The Section on *Climate Change Effects on Marine Ecosystems* (S-CCME) held a meeting immediately following its workshop (W4) on "*Synthesizing projected climate change impacts in the North Pacific*", on October 28, 2018, in Yokohama, Japan. Fourteen members and observers from five countries attended (***S-CCME Endnote 1***). Drs. Jacquelynne (Jackie) King and Shin-ichi Ito chaired the meeting. The meeting agenda is detailed in ***S-CCME Endnote 2***.

AGENDA ITEM 1
Introductions and new members

Prof. Chung Il Lee is a new member of S-CCME, replacing Prof. Suam Kim and representing Korea. Dr. Shin-ichi Ito was scheduled to step down from S-CCME leadership at the conclusion of PICES-2018; unfortunately, an election of a replacement was not done at the annual meeting, and therefore, Dr. Ito will serve as Asian Co-Chair through the completion of PICES-2019 in Victoria. An election of a new Asian Co-Chair will be held at PICES-2019.

This year there was no Russian participation at the S-CCME meeting. S-CCME would like to request additional Russian members be appointed from BIO and/or FIS to complement membership from POC and to hopefully increase the availability of members to attend meetings

AGENDA ITEM 2
2018 activities and accomplishments

a. IPCC WG II – Author meetings

S-CCME experts have contributed to several assessments of the Intergovernmental Panel on Climate Change (IPCC), including the forthcoming report on the "*Ocean and Cryosphere in a Changing Climate*". This activity will continue in 2019 and is due to be published by the IPCC in next summer. Anne Hollowed (PICES S-CCME, USA) is a Lead Author of Chapter 3. William Cheung (ICES S-CCME, Canada) is the Coordinating Lead Author of Chapter 4. These two authors participated in lead author meetings in Quito, Ecuador in February and Lanzhou, China in July.

b. CERES Annual Meeting

ICES SICCME members met at the CERES Annual Meeting (March 12–16, 2018, Olhão, Portugal) to review progress on future scenarios for EU fisheries as well as vulnerability assessments. CERES (Climate Change and European Aquatic Resources) is coordinated by Myron Peck (ICES SICCME, Germany) with many ICES SICCME participants (including John Pinnegar (UK); Mark Payne, (Denmark). PICES S-CCME member Anne Hollowed, (USA) attended as a member of the Research Advisory Board.

c. Fourth International Symposium on "*The effects of climate change on the world's oceans*"

This symposium (June 4–8, 2018, Washington D.C., USA) was co-sponsored by PICES, ICES, IOC, and FAO. Jason Link (ICES SICCME, USA), Shin-Ichi Ito (PICES S-CCME, Japan), Manuel Barange (ICES SICCME, Italy/FAO), and Veronique Garçon (CNRS) were the lead conveners. S-CCME was represented on the Scientific Steering Committee including Anne Hollowed (PICES S-CCME, USA), Myron Peck (ICES SICCME, Germany), John Pinnegar (ICES SICCME, UK), Angelica Peña (PICES S-CCME, Canada), Kirstin Holsman (PICES S-CCME, USA), and Motomitsu Takahashi (PICES S-CCME, Japan). Details regarding the outcomes of this symposium can be found in ***S-CCME Endnote 3***.

Cisco Werner (PICES S-CCME, USA) and Manuel Barange (ICES S-CCME, Italy/FAO) participated in a Science Panel during the Opening Plenary Session. The focus of the Science Panel was "Tell me more: What people really want to know about oceans in a changing climate". This panel of distinguished scientists and journalists helped to kick off the symposium with a fast-paced discussion of key conference topics in the form of a mock press conference. In brief introductory remarks, a panel of experts highlighted critical dimensions and intersections on the effects of climate change on our present and future oceans. Then, journalists from the *New York Times*, National Public Radio, *Science*, *The Guardian* and the news website *Oceans Deeply* quizzed the panelists to elicit what their audiences would want to know.

The following are sessions and workshops that were co-convened by S-CCME members:

- Mark Payne (ICES SICCME, Denmark), Session S2: *From prediction to projection: the role of seasonal to decadal forecasts in a changing climate*;
- Vince Saba (ICES SICCME, USA), Session S5: *Climate change impacts on high latitude systems on multiple scales in space and time*;
- Angelica Peña (PICES S-CCME, Canada), Session S9: *Drifting into the Anthropocene: How will pelagic marine ecosystems be affected and what are the biogeochemical and lower trophic consequences*;
- Shin-ichi Ito (PICES S-CCME, Japan), Session S10: *Management and conservation of species on the move*;
- William Cheung (ICES SICCME, Canada), Session S12: *Scenarios and models to explore the future of marine coupled human-natural systems under climate change*. Kirstin Holsman (PICES S-CCME, USA) was the invited speaker for this session;
- John Pinnegar (ICES SICCME, United Kingdom), Workshop W1: *Communicating and responding to climate change*;
- William Cheung (ICES SICCME, Canada), Workshop W3: *Exploring potential ocean-based solutions to climate change impacts on marine biodiversity and ecosystem services*;
- Myron Peck (ICES SICCME, Germany) and Kirstin Holsman (PICES S-CCME, USA), Workshop W6: *Utilizing bioenergetics measurements and modeling to evaluate climate change effects on marine species and ecosystems*;
- Xiujaun Shan (PICES S-CCME, China), Workshop W11: *Quantifying thresholds in driver-response relationships to identify reference points* (PICES Working Group 36 (CERP) workshop).

d. ICES-PICES Workshop on "*Political, economic, social, technological, legal and environmental scenarios used in climate projection modelling*" (WKPESTL)

This workshop was chaired by John Pinnegar (ICES SICCME, UK), Jörn Schmidt (Germany), Alan Haynie (PICES S-CCME, USA), and Tyler Eddy (USA), convened in Washington D.C., USA (immediately after the 4th International Symposium on "*The effects of climate change on the world's oceans*"). Prior to and during this workshop, invited participants:

- Compiled and compared future scenarios currently used by different research groups projecting the socio-ecological consequences of climate change on fisheries and aquaculture;
- Discussed the rationale and data sources employed to establish elements of "PESTLE" scenarios for socio-economic projections;
- Debated the virtues of having a common set of scenarios and outputs to facilitate region-region and region-global comparison of social-ecological impacts of climate change on fisheries and/or aquaculture;

The Conveners submitted a theme session proposal on "Scenarios for the Future Ocean" to the Scenarios Forum 2019 (March 11–13, 2019, Denver, Colorado, USA; https://www.scenariosforum2019.com/; see ***S-CCME Endnote 4***.

A synthesis paper based on the 20 projects and their scenario approaches has been initiated, and will be submitted in 2019 to a peer-reviewed journal.

e. FAO Fisheries and Aquaculture Technical Paper 627 chapters

Manuel Barange (FAO, ICES S-CCME) led an FAO publication titled: Fisheries and Aquaculture Technical Paper 627: Climate change implications for fisheries and aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options. This 628-page book was published in July 2018. Myron Peck (ICES SICCME, Germany) and John Pinnegar (ICES SICCME, UK) contributed Chapter 5 on "North Atlantic and Atlantic-Arctic Marine Fisheries" (pp. 87–111) and Kirstin Holsman (PICES S-CCME, USA), Anne Hollowed (PICES S-CCME, USA), Jackie King (PICES S-CCME, Canada) and Shin-ichi Ito (S-CCME, Japan) contributed Chapter 6 on "North Pacific and Pacific-Arctic Marine Fisheries" (pages 112– 138).

Citation: Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.) 2018. Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options. FAO Fisheries Technical Paper 627 (2018). http://www.fao.org/3/I9705EN/i9705en.pdf.

f. ICES Annual Science Conference 2018

The ASC 2018 Opening Session on "Do you know more about marine climate change issues than the wider European populace?" was held September 25, 2018, in Hamburg, Germany, and was chaired by John Pinnegar (ICES SICCME, UK) and Myron Peck (ICES SICCME, Germany). This session explored whether ICES scientists express higher levels of awareness and concern than the general public. What elements of marine climate change do participants feel are most important to include in the forthcoming ICES Strategic Plan? What research topics should be prioritized in future collaborative bids or PICES–ICES S-CCME workshops?

The session began with a fully interactive, mini-polling exercise using a freely available smart-phone survey tool. Participants were requested to log-on and answer background questions (nationality, expertise, *etc*.) in plenary, before proceeding to a series of questions that echo those included in a poll of European citizens. Aggregate responses were displayed in 'real time' and compared with those from the European poll. A number of novel questions were added, focusing on research priorities (for ICES and PICES), climate impacts on fisheries and aquaculture as well as a discussion about where S-CCME should focus effort in the next 5 years.

g. 2018 ESSAS Annual Science Meeting

Ken Drinkwater (ICES SICCME, Norway) and Franz Mueter (PICES S-CCME, USA) co-convened the ESSAS Annual Science Meeting that was held at Fairbanks, Alaska, USA, from June 11–15, 2018. During the meeting Ken Drinkwater and Franz Mueter convened a workshop titled: "*On the use of satellite oceanography to explore ecosystem dynamics in Subarctic and Arctic regions*".

h. PICES-2018

At PICES-2018 (October 25–November 4, 2018, Yokohama, Japan), a S-CCME workshop (W4) on "Synthesizing projected climate change impacts in the North Pacific" was convened by Anne Hollowed (PICES S-CCME, USA), Shin-ichi Ito (PICES S-CCME, Japan), Jackie King (PICES S-CCME, Canada) and Myron Peck (ICES SICCME, Germany). The workshop was held just prior to S-CCME's meeting and provided a forum for discussions of:

- Projection outcomes under different modeling approaches;
- Opportunities for comparative studies looking at projected impacts on selected species or fisheries in different LMEs;
- How modeling teams addressed the uncertainty landscape including issues of scenario, parameter and model uncertainty; and
- The range of potential harvest strategies selected and their performance.

See the W4 summary in Session and Workshop Summaries at PICES-2018.

AGENDA ITEM 3

Activities in 2019

a. IPCC WG II – Author Meetings

S-CCME experts have contributed to several assessments of the Intergovernmental Panel on Climate Change (IPCC), including the forthcoming report on the "Ocean and Cryosphere in a Changing Climate". This activity will continue in 2019–2020 in preparation for the 6th Assessment Report (AR6) due to be published by the IPCC in 2021.

- IPCC WG II - AR6 First Lead Author Meeting: January 21–25, 2019, Durban, South Africa,
- IPCC WG II - AR6 Second Lead Author Meeting: July 14–19, 2019, Kathmandu, Nepal.

Both meetings will be attended by John Pinnegar (ICES SICCME, UK; lead author – Small Islands chapter), Kirstin Holsman (PICES S-CCME, USA; lead author – North America chapter), and Shin-ichi Ito (PICES S-CCME, Japan; lead author - Ocean and coastal ecosystems and their services chapter).

Relevant deadlines for S-CCME activities and members in publishing results to be available for AR6 are: papers submitted by July 1, 2020; papers accepted by May 1, 2021. It is important for S-CCME member publications to be ready and available for reference in AR6, and a collective S-CCME publication list will help. The S-CCME Co-Chairs will work with the PICES Secretariat to improve the S-CCME webpage, with inclusion of a publications page that can be updated with relevant publications by members.

b. CERES Annual Meeting

The next CERES meeting (March 11–15, 2019, Bordum, Turkey) will focus on bio-economic projections of climate impacts on European marine fisheries. Anne Hollowed, (PICES S-CCME, USA) and William Cheung (ICES SICCME, Canada) are members of the Research Advisory Board.

c. ICES ASC 2019

Proposals for SICCME-sponsored theme sessions at ICES ASC (September 9–12, 2019, Gothenburg, Sweden):

- Friedland, Smoliński and Frelat: *Advances in habitat models to inform ecosystem-based management: From theory to practice*;
- Elliott, Dankel *et al*.: *Stakeholder involvement and social aspects of climate change adaptation in fisheries and aquaculture*;
- Kerr, Tommasi, Howell: *Management strategies for fisheries in a changing ocean*.

d. PICES-2019

For PICES-2019, October 16–27, 2019, Victoria, Canada, S-CCME supports the following topic sessions which support Phase 3 key activities:

- *Trends in ocean and coastal ecosystems and their services and its future*,
- *Creating more effective Integrated Ecosystem Assessments (IEAs) in PICES countries*.

e. Scenarios Forum 2019

The Scenarios Forum is open to the diverse set of communities using and developing scenarios to carry out research and policy analysis related to climate change and sustainability. See Agenda Item 2d and ***S-CCME Endnote 4***.

f. ICES-PICES inter-sessional Workshop on "*Physical and biogeochemical projections for regional seas*"

See ***S-CCME Endnote 5***.

AGENDA ITEM 4

Progress and planning for S-CCME Phase 3 key activities

A 3-year (Phase 3, 2018–2020) plan was submitted to PICES and ICES for approval at the end of March 2018. The plan includes slight modifications and additions to the S-CCME mission and activities in light of the success of Phase 2 (2015–2017), including identifying and aligning climate change research activities in regional nodes across the northern hemisphere and elsewhere. A number of planned 2019 activities and opportunities align to fulfilling Phase 3 key activities, namely:

a. S-CCME will continue to provide forums for communication and coordination between national climate impact modeling teams. Support for this activity will come from the accepted session on "*Scenarios for the Future Ocean*" at the Scenarios Forum 2019 (March 11–13, 2019, Denver Colorado, USA) and the proposed ICES-PICES inter-sessional Workshop on "*Physical and biogeochemical projections for regional seas*" (see Agenda Item 3f).

   Michael Jacox provided an overview of a NOAA climate impact modeling project Future Climate Change in the California Current (FUTURE SEAS; 2017–2020). The project will project climate change impacts on three major California Current fisheries: drift gillnet fishery (swordfish), albacore and sardine. The approach is end-to-end modelling, from GCM to ROMS-NPZ to an ensemble of ecosystem models, and finally to management strategy evaluation (MSE).

   An opportunity to communicate results of national climate impact modeling and to expand the FAO Chapter 6 information would be to offer S-CCME participation in NPESR. This may be relatively straightforward if there is a Climate Impacts section. The Co-Chairs will investigate this opportunity in 2019.

b. S-CCME will expand its focus to include an effort to compare and contrast results from climate vulnerability assessments with regional coupled socio-ecological projection models. Support for this key activity will come from a proposed PICES-2019 Topic Session on "*Creating more effective Integrated Ecosystem Assessments (IEAs) in PICES countries*". The Topic Session will consider vulnerability assessments, since those analyses represent tools of IEA.

c. S-CCME will consult with the Human Dimensions Committee to develop social science and economic metrics. Support for this key activity will come from the proposed PICES-2019 Topic session on "*Creating More effective Integrated Ecosystem Assessments (IEAs) in PICES countries*". Additionally, there are plans to participate in MSEAS 2020.

d. A proposed new activity identified in Phase 3 is to communicate and integrate climate science through international symposia and training. ICES SICCME will investigate opportunities to provide training on Ecopath with Ecosim through the ICES Training Courses.

e. The Belmont Forum has announced a new funding opportunity for ocean sustainability research (www.belmonforum.org/news) with a focus on:
   Topic 1 – Pathways toward a sustainable and equitable use of oceans,
   Topic 2 – Accounting for and minimizing impacts of global change.

   S-CCME members will submit a proposal in support of S-CCME related activities. Shin-ichi Ito (PICES S-CCME; Japan), Nancy Shackell (ICES SICCME; Canada), Myron Peck (ICES SICCME; Germany), Elliot Hazen (USA) are preparing a proposal on Climate Vulnerability Assessments, which supports a key activity of S-CCME Phase 3.

S-CCME Endnote 1

S-CCME participation list

Members

Alan Haynie (USA)
Kirstin Holsman (USA)
Anne B. Hollowed (USA)
Shin-ichi Ito (Japan, PICES Co-Chair/PICES)
Sukgeun Jung (Korea)
Jacquelynne (Jackie) King (Canada, Co-Chair/PICES)
Hiroshi Kuroda (Japan)
Guimei Liu (China)
Myron Peck (Germany, Co-Chair/ICES)
Angelica Peña (Canada)
Xiujuan Shan (China)
Jinhui Wang (China)

PICES members unable to attend

China: Chuanxin Qin
Japan: Motomitsu Takahashi
Korea: Sukyung Kang, Chung Il Lee
Russia: Yury I. Zuenko
USA: Franz Mueter, Cisco Werner, Phoebe Woodworth-Jefcoats

Observers

Albert Hermann (USA)
Michael Jacox (USA, Co-Chair WG 40)

S-CCME Endnote 2

S-CCME meeting agenda

1. Introductions and welcome to new members
2. Review on 2018 activities and accomplishments
   a. IPCC WG II – Author meetings
   b. CERES Annual Meeting (March 12–16 , 2018: Olhão, Portugal) (Peck)
   c. Fourth International Symposium on the Effects of Climate Change on the World's Oceans (4-8 June 2018, Washington D.C., USA) (Hollowed)
   d. ICES-PICES Workshop on Political, Economic, Social, Technological, Legal and Environmental scenarios used in climate projection modelling (WKPESTL) (June 9, 2018, Washington D.C., USA) (Haynie)
   e. FAO Fisheries and Aquaculture Technical Paper 627: "Climate change implications for fisheries and aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options" (Holsman)
   f. ICES Annual Science Conference (ASC) 2018 - Open session (Sept 25, 2018, Hamburg, Germany): "Do participants at the ICES ASC know more about marine climate change issues compared with the wider European populace?" (Peck)
   g. 2018 ESSAS Annual Science Meeting
   h. PICES-2018: Workshop 4 - Synthesizing projected climate change impacts in the north Pacific (October 28, 2018: Yokohama, Japan)
3. Activities in 2019
   a. IPCC WG II – Author Meetings (Holsman/Ito)
   b. CERES Annual Meeting (March 11–15, 2019, Bordum, Turkey)
   c. 2019 ICES Annual Science Conference theme sessions: (Peck)
      - Advances in habitat models to inform ecosystem-based management: From theory to practice
      - Stakeholder involvement and social aspects of climate change adaptation in fisheries and aquaculture
      - Management strategies for fisheries in a changing ocean
   d. 2019 PICES Annual Meeting (All)
      - POC/BIO/FIS/FUTURE Topic Session: *Trends in ocean and coastal ecosystems and their services and its future*
      - HD/FIS Topic Session: *Creating more effective Integrated Ecosystem Assessments (IEAs) in PICES countries*

e. Scenarios Forum 2019 (March 11-13, 2019)
f. ICES-PICES Inter-sessional Workshop on "*Physical and biogeochemical projections for regional seas*" (Peck)

4. Progress and planning for S-CCME Phase 3 key activities

End of meeting

S-CCME Endnote 3

The Fourth International Symposium on
"*The effects of climate change on the world's oceans*"

The "Fourth International Symposium on "*The effects of climate change on the world's oceans*", co-sponsored by PICES, ICES, IOC and FAO, was held June 4–8, 2018 in Washington D.C. (USA). In total, 95 separate submissions were received for theme sessions and an additional 20 suggestions were received for associated workshops. Of these, 18 were selected as theme sessions and 11 were selected as workshops. This was an extremely successful event. There were 669 registrations from 51 countries. The symposium had 14 plenary speakers representing 12 nations, 350 oral presentations and 158 poster presentations. This included 102 presentations by early career researchers. There were also 4 Town Halls and 3 Receptions.

Key take-home messages from the symposium included:

- The oceans and the social-ecological systems that depend on them are changing and our understanding of social-ecological systems has improved, allowing us to contrast the ecological and human impacts of different future scenarios;
- Tactical and strategic opportunities for adaptation to climate change have been revealed through engagement with human communities. Opportunities for adaptation are more limited if society remains on a high emission scenario;
- Extreme events provide an opportunity to assess human and ecological responses to climate change (*i.e.*, stress test). Our ability to predict anomalous ocean conditions on seasonal to decadal time scales is also improving;
- Research continues to reveal complex energetic and physiological trade-offs associated with the adaptation of organisms to changing environmental conditions. There are energetic and physiological costs;
- Coastal communities are turning to aquaculture, marine ranching and fish attraction technologies to fill critical needs for food security. Research is needed to identify appropriate adaptation actions and good governance through stakeholder engagement and representation;
- More targeted measurements are necessary to better understand the oceanic carbon cycle and minimize uncertainties for both short-term prediction and long-term projection of carbon uptake, ocean acidification, and deoxygenation. Global observation networks with technological advancements for data collection will improve our understanding of key processes;
- Blue carbon solutions are emerging;
- International planning and assessment activities have and continue to play a key role in guiding and informing marine climate research;
- One challenge of the symposium, also experienced with the previous one in 2015 (Santos, Brazil), is the low number of papers submitted for the special issue of the *ICES Journal of Marine Science*. This may reflect the relative high number of presentations that are based on published results, and in the preference of physical oceanographers to publish in physical oceanography journals. Future organizers should consider arranging a special publication in an additional journal of interest to physical oceanographers.

S-CCME Endnote 4

Proposal for a Theme Session on "*Scenarios for the Future Ocean*"
Scenarios Forum 2019
Denver, Colorado, USA

Organizers: Tyler Eddy (University of South Carolina), Jörn Schmidt (University of Kiel), Alan Haynie (NOAA), John Pinnegar (CEFAS)

See: https://www.scenariosforum2019.com/session-13

Call for abstracts submission deadline: September 28, 2018.

Formal methods and tools for scenario analysis are used in support of ecosystem-based management of natural resources, including marine fisheries. In addition, there is a growing requirement for these methods and tools to enable the evaluation of alternative decision rules that fully encompass (i) the dynamics of marine social-ecological systems and transition phases associated with management implementation, and (ii) multiple political, economic, social, technological, legal, and environmental objectives of management. To date, most socio-economic scenarios have been developed in the context of the IPCC and are focused on land-based activities. However, coupling ocean and coastal systems is attracting growing attention and debate, demonstrating that this is an important research area. While many studies focus on the exploration of possible futures, there is also a need to develop normative scenarios, which consider objectives for the management of ocean uses, and possible pathways for these objectives to be met in the future. This session will focus on the presentation and discussion of recent advances and key challenges in scenario development for ocean and coastal systems.

We invite papers describing approaches to develop future trajectories of change in some or all of the elements of the "PESTLE" approach (Political, Economic, Social, Technological, Legal, and Environmental) needed to project bioeconomic consequences of climate change on fisheries and aquaculture. Scenario approaches can be at local, regional, and global scales and of varying time horizons. They can include ecosystem-based management and fisheries strategies, integrated ecosystem assessments or biodiversity scenarios, such as those being developed for the Intergovernmental Panel on Biodiversity and Ecosystems Services (IPBES). We also encourage approaches that connect land and sea as well as approaches that would be relevant to model intercomparison projects (MIPs), such as CMIP, ISIMIP, and Fish-MIP.

S-CCME Endnote 5

Proposal for an inter-sessional workshop on
"*Physical and biogeochemical projections for regional seas*"

Convenors: Myron Peck (corresponding, Myron.peck@uni-hamburg.de), Enrique N. Curchitser (USA), Youyu Lu (Canada), Momme Butenschön (Italy)

Duration: 3 days

Invited speakers: Charlie Stock (USA), TBD (Asia)

Advancing in the spatial resolution and in the depiction of physical and biogeochemical processes in Global Climate Models (GCMs) and Earth System Models (ESMs) are ongoing. Regional downscaling, either dynamic or statistical, has often been employed to capture features and processes in regional seas (and finer spatial scales) relevant to projecting climate impacts on populations of living marine resources. With the latest developments in ESMs, trade-off may exist between higher resolution and biogeochemical model complexity. GCMS and ESMs are heading towards 0.1 degree resolution but they may not have the vertical resolution needed to model shelf breaks and shelf seas. Moreover, the potential exists for these global models to provide seasonal biogeochemical forecasts.

This workshop provides a forum to discuss the next generation of products stemming IPCC projections available from GCMs and ESMs contributing to CMIP6 and to review how CMIP5 products have been utilized to project changes in the future distribution and productivity of lower and upper trophic levels within regional seas.

Some (draft) topics of discussion include:

a. Resolution of mesoscale hydrographic structures
b. Depiction of seasonal dynamics of lower trophic levels (Net PP, secondary production)
c. Capturing uncertainty in projections
d. Utilizing model outputs to inform projections of change in upper trophic levels

Some specific questions that could be addressed (from Susan Kay, PML):

a. What are the trade-offs between higher resolution and having an ensemble of runs? How do we make the best choice for a given application?
b. How do we best make use of GCMs and ESMs in regional work?
c. The biogeochemical models used in the global ESMs have been developed for modelling long-term carbon cycle. Are they also useful to address shorter time scales and to examine nutrients and productivity, or are tailored models necessary?
d. Operational seasonal forecasts are currently made in areas such as the Barents Sea and SE Australia (*e.g.*, using global ensembles + regional downscaling). What is the best way forward?
e. Do GCMs / ESMs have the vertical resolution needed to capture the dynamics of shelf and shallower-water systems (*e.g.*, the use of z-levels rather than sigma coordinates).
f. Can we build on the developments in global modelling to approach the 1 km scale needed for aquaculture applications? Are unstructured grids the best way forward?