# Request to US CLIVAR for Workshop Sponsorship

**1. Requesting Panel, Working Group, or person/s:**
PSMI (Antonietta Capotondi, Sophie Clayton, Victoria Coles) and POS Panels (Michelle Gierach, Cécile Rousseaux)

**2. Title of workshop or meeting:**
Daily to Decadal Ecological Forecasting along North American Coastlines

**3. Venue:**
Woods Hole Oceanographic Institution, Woods Hole, MA (Week of June 21, 2021). Having the workshop in conjunction with the OCB meeting would be ideal. However, the OCB meeting ends on a Thursday, so we would need to decide whether to hold the workshop over the following weekend, or starting on the following Monday. The latter option would require some OCB participants to stay over the weekend and add additional cost.

**4. Dates:**
Pandemic situation permitting, we would prefer the workshop to be in-person. A key outcome of this effort will be the building of collaborations and research networks for which an in-person meeting is preferred. We suggest multiple options that will be considered serially as travel restrictions evolve. The first option is in June 2021, in conjunction with the summer annual OCB workshop. Secondly, we will consider Fall 2021. If the pandemic persists, our third choice would be to hold the meeting in spring 2022 perhaps in conjunction with the annual summer OCB workshop. Should the latest date be impossible, we will consider moving the program to a virtual session in order to move forward.

**5. Scientific Organizing Committee (include affiliations):**
Note that the organizing committee is not presently very diverse. However, this stems largely from the volunteer participation of the US CLIVAR panels. We plan to be highly intentional in our efforts to ensure diverse participants and speakers.

| **Name** | **Affiliation** | **Research** | **Diversity Measures** |
|---|---|---|---|
| Antonietta Capotondi (co-chair), Hers | U. Colorado & NOAA PSL, CO | Physical oceanography, climate modes of variability, climate model analysis | PSMIP, Gov't/University |
| Victoria Coles (co-chair), Hers | U. of MD Center for Environmental Science, MD | Physical oceanography and coupled ecological modeling | PSMIP/OCB, Hers, University |
| Sophie Clayton, Hers | Old Dominion University, VA | Coupled biophysical measurements and modeling. | PSMIP, Hers, Early Career, University |
| Marjorie Friedrichs, Hers | Virginia Inst. Of Marine Science, VA | Modeling climate change and human impacts on coastal & estuarine systems | OCB, Hers, University |

| | | | |
|---|---|---|---|
| Michelle Gierach, Hers | Cal Tech & NASA JPL, CA | Remote sensing, biophysical interactions, coastal water quality, and carbon fluxes | POS, Hers, Gov't/University |
| Andrew Pershing (to be confirmed), His | Gulf of Maine Research Inst., ME | North-east US climate variability and change, ensemble modeling methods, zooplankton to whales. | NGO |
| Cécile Rousseau, Hers | USRA & NASA GSFC, MD | Remote sensing, phytoplankton modeling and dynamics and climate variability | POS, Gov't/University |
| Charles Stock, His | NOAA/GFDL, NJ | Modeling marine ecosystem dynamics and impact of climate on marine ecosystems. | OCB, Gov't |

**6. Proposed attendees, include estimate number (indicate if open or by invitation):**
We envision 80-100 attendees in person, with the potential for additional remote participants. Attendance will be open, but subject to an application process to ensure a diverse group with balance across:

- climate scientists, biogeochemists, and global and regional modelers;
- expertise in observations, process understanding, modeling and prediction, and data science;
- career stage, with early career researchers strongly encouraged;
- measures of diversity in life experiences and perspective; and
- place-based focus (e.g., Gulf of Mexico, US East Coast, Arctic).

Attendees will include invited speakers, contributed presentations, and lightning talks (perhaps in more targeted sessions) available to each participant to ensure that all attendees have an opportunity to contribute. Following previous OCB/CLIVAR efforts, we will ask proposed attendees to list measures reflecting a diversity of prior experiences in order to bring broad perspectives to bear on this critical topic.

**7. Aims and objectives:**
Coastal areas at the interface between terrestrial and aquatic habitats share unique intersections of large-scale climate variability and local hydrology, wetland, benthic and pelagic ecosystems, and anthropogenic pressures. Coastal regions represent only 10% of the US area, yet are home to 40% of the population[1]. Coastlines often host rich and productive marine ecosystems that support industries and services of great economic value, including fisheries, aquaculture, tourism, recreation and shipping, each of which has different forecasting needs. The functioning of coastal marine ecosystems across a broad range of trophic levels is tightly connected with climate variability, which

[1] NOAA National Ocean Service, 2013: National Coastal Population Report: Population Trends from 1970 to 2020. *NOAA's State of the Coasts*, 19pp., https://aamboceanservice.blob.core.windows.net/oceanservice-prod/facts/coastal-population-report.pdf

influences both physical and biogeochemical coastal environmental conditions such as sea level, temperature, salinity, dissolved oxygen and pH.

Climate change and anthropogenic activities also affect coastal resilience through long-term trends, which are expected to exacerbate extreme conditions, creating serious threats to marine life. Therefore, the ability to predict harmful environmental conditions for planning, adaptation and mitigation purposes is urgently needed. The connection of coastal processes with the large-scale climate variability provides an important source of predictability for physical and biogeochemical ecosystem drivers. However, the impacts of climate variability (e.g., large-scale climate indices) and trends on coastal regions are mediated by the complexity of local processes specific to each region, involving interactions between land, ocean, hydrology, biogeochemistry and atmosphere. Some of these processes occur at spatial scales that are not resolved by climate models.

Modeling and prediction of ecosystem processes to date have relied substantively on empirical statistical methods for boundary and initial conditions, and for ecosystem forecasting itself. Where these methods are underpinned by mechanistic understanding, empirical methods – especially those informed by novel machine learning techniques – may be computationally efficient and have high skill. However, as coastal conditions increasingly deviate from climatological norms, these methods may become inadequate for capturing new baselines and response to extreme conditions. These concerns highlight the importance of developing mechanistic understanding to underpin the observed statistical relationships.

Recent syntheses[2], have highlighted many sources of predictability for ecological forecasting at seasonal to interannual scales relevant to specific applications (e.g., fisheries), but they have also revealed a disconnect between open ocean, coastal and estuarine forecasting communities, particularly in regions with broad shelves. At the estuarine scale, processes like tidal amplitude and mixing, riverine discharge, and nutrient loading are central to successful forecasts. Their impacts can be modulated by larger-scale processes, and, conversely, they can influence the broader coastal environment through changes in physical and biogeochemical quantities (e.g., salinity, dissolved oxygen).

The ability to properly understand these processes and their interaction is often limited by data availability at the proper spatial and temporal resolutions[3], and of sufficient duration to allow robust inferences. Due to the large spatial heterogeneity of the coastal environment, their characterization requires data at high spatial and temporal resolutions, thus posing significant challenges to ecological forecasting. While global databases such as the World Ocean Atlas or the Argo Float program exist with common formatting and

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[2] Jacox, M. G. et al. (2020), Seasonal-to-interannual prediction of North American coastal marine ecosystems: Forecast methods, mechanisms of predictability, and priority developments, *Progress in Oceanography*, doi:10.1016/j.pocean.2020.102307.

[3] Capotondi et al. (2019), Observational needs supporting marine ecosystems modeling and forecasting: From the global ocean to regional and coastal systems. *Frontiers in Marine Science,* https://doi.org/10.3389/fmars.2019.00623

straightforward interfaces, the coastal regions of the United States have a hodgepodge of data distributions, including various Integrated Ocean Observing System programs[4], individual state data repositories such as Maryland's Eyes on the Bay website[5], timeseries collected by individual research institutions[6], etc. Many data sets are archived by mission rather than measurement type, hindering their application to ecological forecasting, or indeed to model validation or data assimilation in general.

These challenges – heterogeneous and highly local topographic complexity, the difficulty of identifying underlying mechanisms driving potential predictability for complex ecosystem dynamics, gaps between processes resolved in climate vs coastal models, and the difficulty in synthesizing long records of physical and biogeochemical data sets in coastal regions – all delay progress in ecological forecasting at relevant coastal scales.

One example of how these challenges can be overcome is the California Current system. The narrow shelf and strong projection of climate modes, and the deep historical physical, biogeochemical, and fisheries data records as part of the CalCOFI program have enabled a diverse array of west coast ecosystem forecasting efforts not duplicated in most other US coastal regions. For this reason, and to support the US CLIVAR "Climate on the Coast" initiative, the workshop will primarily focus on other US coastal systems, however we will leverage the expertise of the groups working in the US west coast, as well as potentially include forecasting efforts from other countries and regions as examples of successful collaborations.

A further key challenge identified in the prior US West coast workshop and the US CLIVAR 2019 Summit meeting is bringing managers together with scientists very early in the design of a forecasting effort to ensure that products relevant to application are developed. End users must understand the predictability and uncertainty in the forecasts and forecasting efforts must be used in an ethical and sustainable manner to support long term healthy ecosystems[7]. These challenges are key to the development of individual forecasting efforts. However, our focus here is on the more technical challenges confronting prediction, the degree of predictability across regions, and the data gaps that limit prediction efforts. Thus, we are not planning to include practitioners and end user in this workshop, but will devote an opening plenary talk to a general overview of applications of ecological forecasting, as a motivating theme for the workshop. As collaborations start to form as an outcome of the workshop, key stakeholders will be identified and invited to provide input. In preparation for the workshop, we will work with our invited speakers (some of which have had long-term interactions with stakeholders) and other participants to identify key variables and timescales of interest needed by various stakeholders. This information will be used in the design of the

[4] https://ioos.noaa.gov/
[5] http://eyesonthebay.dnr.maryland.gov/
[6] https://web.uri.edu/gso/research/plankton/
[7] Hobday, A.J. Hartog, J.R., Manderson, J.P., Mills, K.E., Oliver, M.J., Pershing, A.J., Siedlecki, S. (2019), Ethical Considerations and unanticipated consequences associate with ecological forecasting for marine resources. *ICES J. of Mar. Sci*, 76(5), 1244-1256. doi:10.1093/icesjms/fsy210

breakout sessions and discussion questions. The pre-workshop activities will also include the creation of a blog to collect contributions by perspective participants on their specific research activities, results and challenges. The blog will initiate interactions among participants and contribute to the definition of the major challenges. The blog can also be maintained past the workshop to promote continuing interactions and collaborations.

The goal of this workshop is to bring together climate scientists, biogeochemists, and global and regional modelers to:

1. Examine the connections between large-scale physical and biogeochemical processes with coastal processes, and identify sources of predictability at daily to decadal timescales that are specific to regions along US coastlines.
2. Assess the suitability and needs for observations that robustly characterize the key physical and biogeochemical ecosystem drivers, their interactions across scales, and their vulnerability to climate change and regional anthropogenic changes in different coastal regions.
3. Assess the major gaps in both understanding and modeling/observing capabilities that limit our ability to produce reliable ecological forecasts at the scales needed for application and management along US coastlines, and identify potential avenues for accelerating progress.

Given the inherent interdisciplinary nature of ecological forecasting, this workshop is envisioned as a joint effort between US CLIVAR and the Ocean Carbon and Biogeochemistry (OCB) programs, and will be co-organized by members and experts of both communities. Recent joint efforts between US CLIVAR and OCB such as the Forecasting ENSO Impacts on Marine Ecosystems of the US West Coast workshop have demonstrated the value of bringing together communities that may otherwise not collaborate closely. Key priorities for the OCB community (e.g., Estuarine and coastal carbon fluxes, Changing Marine Ecosystems, Changing Ocean Chemistry, etc.) are strongly dependent on climate information and mechanistic understanding of observed correlations. In turn, variability and predictability of biogeochemical quantities can potentially deepen the understanding and characterization of climate variability and change.

The goals of the workshop closely align with NOAA's strategic priority on the Blue Economy, and the U.S. Integrated Ocean Observing System, NSF's emphasis in understanding the impacts of coastal variability on populated coastal regions (CoPe effort), NASA's Ecological Forecasting Program area, and DOE's Focus area on "Reducing Uncertainty in Biogeochemical Interactions through Synthesis and Computation (RUBISCO)". Finally, the aims and objectives of the workshop strongly project on the key foci of some FY2020 funding competitions, including the DOE-RGMA call on "Biogeochemical processes, feedbacks and interactions within the Earth System", the NOAA MAPP/CVC/COCA competitions focused on improving understanding, modeling and predictions of living marine resources and their physical drivers, NSF CoPe, and NASA's relevant Missions and Programs. The workshop will

assemble some of the scientists supported through these programs, enabling a dialogue among them, and creating the conditions for possible collaborations.

Because of the variability in regional dynamics, forcing factors, and the differences in potential predictability, the workshop will be characterized by a place-based focus. Plenary speakers will focus on regional differences in climate projections, hydrological forcing, and sensitivity to climate extremes in U.S. West coast, U.S. East coast, Gulf of Mexico, and Arctic/subarctic regions. Participants will then break into focus groups aligned along place-based themes to address specific questions, and follow-up reporting will identify common themes and disparate issues that can align future discussion.

**8. Relevance and/or benefits to US CLIVAR:**

The topic and objectives of the workshop and its interdisciplinary character strongly support the US CLIVAR research challenge themes (Decadal variability and predictability, Climate and extreme events, Polar climate, Climate and ocean carbon/biogeochemistry), as well as the new Research Challenge "Climate at the Coast".

In many ways, this is due to the uniquely place-based focus of coastal ecological prediction and to the intersection of each of these topics as they influence coastal dynamics. The degree of cross-disciplinary focus required to respond to the ecological forecasting challenge requires the leadership of the US CLIVAR panels to bring communities together in pursuit of common goals. This workshop builds on previous US CLIVAR-sponsored activities that focused on the US West Coast, and aims at extending that approach to the rest of the US coastlines.

Specifically, the workshop will address and advance the goals of the program by:

- Enhancing understanding of the processes that contribute to climate variability and change in coastal regions
- Better quantifying uncertainty in the observations, simulations, predictions, and projections of climate variability and change in coastal regions
- Improving the development and evaluation of climate simulations and predictions relevant to coasts and estuaries
- Collaborating with research and operational communities that develop and use climate information.

**9. Format of the meeting:**

The workshop will take place over two and a half days. It will include invited/keynote presentations that bring a large-scale climate perspective to each of the target regions. Contributed presentations will be split between plenary topics of interest to the whole community, and more regional topics presented in breakout sessions. Since a main objective of the workshop is to establish a dialogue among researchers of differing expertise, breakout groups will be organized to promote interactions, exchange of ideas and perspectives, and a vision for moving forward. Breakout groups will be created by the organizing committee to diversify research interests, career stages and expertise. Breakout groups will be tasked with addressing specific questions, which will be

prepared by the organizing committee and distributed to the participants in advance of the workshop.

While the meeting format will surely evolve, one goal of the workshop is to allow for a diverse array of opportunities for individuals to participate, whether orally to the whole group, in smaller groups, and through written named or anonymous venues such as Slack channels. These different avenues for participation may spark further discussion. As pre-work, volunteer facilitators for the small group sessions will be trained in techniques designed to elicit responses from all participants and not solely those dominating discussion. These facilitators will be assigned across group sessions.

While evening sessions are typical for US CLIVAR workshops, our hope here is to promote evening activities and discussion that is informal and encourages the development of new research teams that perhaps differ from prior funded groups. To that end, we will plan for the meeting to remain together in the evening. We will consider how to facilitate this informal discussion through designating tables and spaces for a mixture of fun and more informal discussion topics ranging from how to communicate forecast uncertainty visually or creatively to the public, to train graduate students in ecological forecasting, to brainstorming ecological forecasting applications for sports and or businesses.

**Day 1:**

AM 1: Meeting welcome and synthesis of pre-work activity.
AM 2: Management and Climate applied to the coast plenaries.
PM 1: Place-based breakout groups with lightning talks.
PM 2: Identification of common themes vs uniquely place-based themes. Reporting back to plenary.
Evening: SSC planning.

**Day 2:**

AM 1: Plenaries focusing on gaps and challenges identified by researchers currently working in ecological forecasting.
AM 2: Breakout groups that mix place-based researchers focused on common themes from Day 2. Future steps.
PM 1: Place-based breakout groups focusing on critical gaps identified in AM 1 and by the groups from AM 2.
PM 2: Future steps in place-based breakouts. Reporting back to plenary.

**Day 3:**

AM 1: Discussion of commonalities in future steps that need broader community support as opposed to more locally focused efforts.
AM 2: Breakout group discussion of future steps and planning of report writing.

**10. Tentative list of participants:**

- Samantha Siedlecki (Oxygen dynamics East and West Coast, U. Conn)
- Parker MacCready (Coastal physical oceanography, Univ. of Washington)

- Desiree Tommasi (Fisheries, UC Santa Cruz)
- Colleen Petrik (Zooplankton, fish, Texas A&M)
- Michael Jacox, (Physical Biological interactions, NOAA Southwest Fisheries Science Center)
- Michael Alexander, (Climate, NOAA PSL)
- Ruoying He, (Physics and biogeochemistry, Gulf of Mexico, North Carolina State University)
- Wei Chen, Ivonne Ortiz or Nick Bond (Bering Sea) NOAA PMEL
- Meng Xia or Maggie Sexton (Physics and Biogeochemistry in coastal lagoons, UMES HBCU)
- Cisco Werner (NOAA Fisheries and management)
- Lonnie Gonsalves or Laura Newcomb (NOAA NOS)
- Christopher Hintz or Dionne Hoskins-Brown (Carbon chemistry and trophic ecology in fisheries, SSU HBCU)
- Members of the ICES and PICES working groups on seasonal to decadal prediction of marine ecosystems and climate and ecosystem productivity.

**11. Deliverables:**

This workshop builds on a previous joint CLIVAR/OCB workshop on "Forecasting ENSO Impacts on Marine Ecosystems of the US West Coast[10], which was held in La Jolla, CA in Summer 2016. That workshop was very successful in bringing together scientists with different expertise and from different communities, and a key recommendation that emerged from that workshop included the development of a coordinated research network to leverage the individual efforts already underway. The US West Coast is an optimal incubator region for ecological forecasting as it is strongly influenced by ENSO variability in the tropical Pacific, which provides a critical source of predictability, and a long history of physical and biogeochemical observations.

The goal of this proposed workshop is to broaden the scope of the 2016 workshop to all the US coastlines, whose sources of predictability are much less understood and likely more tenuous, and whose observing capabilities and data availability are not as developed as along the US West Coast. This workshop will allow us to identify the sources of predictability and observational needs unique to each region, while identifying methodological approaches and data requirements that are common among different regions, an outcome that can be translated in recommendations and planning.

Expected deliverables are:

- We will prepare a workshop report that summarizes key outcomes of the workshop including: assessment of current efforts, identification of gaps in understanding and observation/model capabilities, roadmap for cross-disciplinary research agenda to develop prediction capability to meet the needs of coastal marine resource management. This report will be submitted to *BAMS* or *EOS*, to share the results of the workshop with the broader scientific community.

- Special attention will be placed to observational needs, which are a key limiting factor in the development of ecological forecasting systems, and may be common across regions. We plan to prepare a white paper that highlights key data limitations and outlines possible avenues to overcome this problem. In particular, this white paper is intended to foster the development of integrated observational archives, for example by combining data collected within regional Integrated Ocean Observing Systems (IOOS) or by individual institutions, following the example of the Surface Ocean $CO_2$ Atlas (SOCAT[8]). This white paper can also motivate the extension of ecosystems observations from space, for example those by the Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR) to a broader range of coastal regions.
- Finally, the workshop will initiate/facilitate collaborations between OCB and USCLIVAR investigators based on the interactions and discussions through the prework of the blog and during the workshop.

**12. Budget request from US CLIVAR:**

This effort will require support for meeting logistics and travel support for the seven meeting organizers (who are not federal employees), 5 invited speakers, and 20 scientists who are early career or from historically underserved institutions for which the development of collaborations with research oriented institutions may be transformative in broadening perspectives and developing of novel ecological forecasting targets.

| | |
|---|---|
| Supplies and Processing Fees | $2,550 |
| Catering for 100 | $19,100 |
| Buses | $8,448 |
| Webcasting Services | $1,992 |
| Travel of 32 | $49,324 |
| Overhead | $872 |
| Subtotal | $82,286 |
| Less Registration Revenue | -$14,500 |
| Total Request | $67,786 |
| | |
| US CLIVAR Request: | $33,893 |
| OCB Request: | $33,893 |

**13. Other sources of funding:**

A similar proposal will be submitted to OCB. If funded, we anticipate an even cost share between OCB and US CLIVAR to reflect an even distribution of participants. Further funds may be sought to bring in international collaboration from groups such as ICES/PISCES.

[8] https://www.socat.info/

We would also like to survey participants about whether child or eldercare needs influence their ability to participate, for which we might try to fundraise from societies such as AGU, or from foundations.

Registration revenue of $14,500 is projected based on $200 fee for regular registration and 50% discount for early career and underserved institution participants.

# Request to US CLIVAR for Workshop Sponsorship

## 1. Requesting Panel, Working Group, or person/s

Maria Rugenstein (Colorado State University)
Cristian Proistosescu (University of Illinois Urbana-Champaign)

## 2. Title of workshop or meeting

The Pattern Effect: Coupling of SST patterns, radiative feedbacks, and climate sensitivity

## 3. Venue

UCAR Center Green

## 4. Dates

3.5 days in Feb-April 2022, depending on UCAR room availability;
Avoiding AMS (Jan 23th-27th), Ocean Science (Feb 27th - Mar 4th), EGU (Apr 3rd-8th).

## 5. Scientific Organizing Committee (include affiliations)

*Confirmed*
Kyle Armour (University of Washington)
Natalie Burls (George Mason University)
Piers Forster (University of Leeds, UK)
Jonathan Gregory (University of Reading and Met Office, UK)
Sarah Kang (Ulsan National Institute, South Korea)
Norman Loeb (NASA Langley Research Center)
Bjorn Stevens (Max Planck Institute for Meteorology, Germany)
Laure Zanna (New York University)

## 6. Proposed attendees, include estimate number (indicate if open or by invitation)

We expect 80-120 scientists to participate in person, with a strong online component (see format).

The workshop will be **open** and will bring together scientists from a number of communities that have interests and insights into sea surface temperature patterns and radiative feedback "pattern effect." Participants would include those already working on the feedback pattern effect, which has traditionally been a subset of the Climate Sensitivity and Cloud Feedback community (i.e., typical attendees of the Cloud Feedback Model Intercomparison Project - CFMIP meeting) together with scientists from the oceanography, remote-sensing, climate modeling, paleoclimate, decadal prediction, and climate impacts communities. The make-up of the steering committee is intended to reflect and access that broad audience. A list of potential invitees can be found under item **10.**

Given the prominent role of coupled equatorial ocean-atmosphere dynamics, model-data discrepancy, and climate change projections, the proposed workshop will be of interest to several existing CLIVAR groups: the Process Study and Model Improvement Panel (PSMIP) and the Predictability, Predictions, and Applications Interface Panel (PPAI) of US CLIVAR, and the Pacific Regional Panel and the Tropical Basin Interaction focus group of International CLIVAR. We have already had conversations with the co-chairs of PSMIP (Charlotte de Motte & Patrick Taylor) and PPAI (Haiyan Teng & John Nielsen-Gaimon) and a member of the Tropical basin interaction focus group (Malte Stuecker) to confirm interest amongst them.

## 7. Aims and objectives

An emergent subject in climate dynamics, the "pattern effect" describes the impact of time-evolving sea surface temperature (SST) patterns on radiative feedbacks and climate sensitivity. Two primary regions appear to be involved. The first is the tropical Pacific, where changes in SST gradients associated with ENSO, Pacific Decadal Variability and the response to anthropogenic forcing interact with the tropical atmospheric circulation to actuate strong lapse rate, water vapor, and cloud feedbacks. The second is the Southern Ocean, where delayed warming can actuate strong cloud and sea-ice feedbacks.

The pattern effect is very pronounced in General Circulation Models (GCMs), where estimates of Equilibrium Climate Sensitivity (ECS) drawn from simulations forced with observed SST patterns are biased low by about a factor of two from the ECS of simulations of long-term warming. The magnitude of the pattern effect however, has not yet been constrained from observations, and GCMs show a large spread. This uncertainty in the magnitude of the pattern effect is so substantial that a recent comprehensive assessment concluded that the observational record of Earth's energy budget is unable to constrain the upper bound on ECS. Thus, uncertainty in the pattern effect presents one of the largest roadblocks to improved projections of future warming.

The mechanisms through which SST patterns impact radiation in model simulations is still uncertain, and an overarching theory is still missing. Over half a dozen different frameworks and conceptual models have been proposed, but the relationship between these models has not been worked out. Additionally, frameworks that have been put forth for CMIP5 models are not able to explain the pattern effect in the new CMIP6 models.

Furthermore, while coupled GCM simulations suggest radiative feedbacks should be getting more positive with time for both historical and future warming, atmosphere-only simulations forced with observed changes in SST patterns robustly show feedbacks getting more negative over recent decades. This discrepancy in the sign of the pattern effect can likely be attributed to the inability of coupled models to reproduce the observed evolution of SST patterns.

A disparate literature across different communities links model-observation discrepancies in recent SST trends to a range of possible deficiencies in our ability to model a range of atmospheric or ocean processes. However, no consensus currently exists on the underlying source of model deficiencies, or even if the recent trends reflect the forced response or unforced internal variability.
The problem of model bias and uncertainty in GCM simulations is compounded by the lack of observational constraints. However, two recent studies have demonstrated the existence of a pattern effect in the satellite record of atmospheric radiation. Additionally, advances in paleoclimate data assimilation now provide accurate reconstructions of changing SST patterns on time scales longer than the observational record. These advances raise the hopes that judicious use of the satellite record and paleoclimate information could produce empirical constraints.

The pattern effect touches several communities. Through its impact on radiative feedback and earth's energy budget, the pattern effect is important for climate change and prediction; understanding the impact of SSTs on radiation will require better understanding of radiation, cloud physics, and atmospheric dynamics; understanding the coupled ocean-atmosphere dynamics that determine SST patterns will benefit from the interaction of the atmospheric dynamics, ocean dynamics, and radiative feedbacks, oceanography, communities; the ability - or lack thereof - of coupled GCMs to represent recent SST patterns should be of interest to the climate modeling community; observationally constraining the impact of changing SST patterns on radiation will require close collaboration with the remote sensing community, while empirical constraints on the evolution of SST patterns on time scales longer than the observational record will ultimately require using the palaeoclimate record.

The pattern effect has been a dominant topic in the Climate Sensitivity session at the AGU fall meeting for several years. It has also received its own session at the annual Cloud Feedback Model Intercomparison Project (CFMIP) meeting over the last three years.

**The overarching goal of the workshop is to advance our understanding of the coupling between surface temperatures and radiative feedbacks and the origin and timescales of surface temperature pattern evolution. To that end, we aim to 1) synthesize the different strands of the discussion laid out above; 2) bring together different communities with interest and insight into the pattern effect; and 3) map out the most significant outstanding issues and propose novel ways to move forward.**

The format of the workshop will allow plentiful time for targeted discussions in breakout rooms. The goal of these discussions will be to map out the most significant outstanding issues and recommend pathways to advance the topic. These outstanding issues and recommendations will be summarized in a project report and a community piece to be submitted to EOS. Recommendations will consist of (a) the most promising mechanisms and theories to pursue in future research (b) ways in which existing or future observations and

paleoclimate proxies can be used to constrain the pattern effect (c) potential modeling frameworks for further examining the pattern effect in models, such as Green's Function experiments for atmospheric models or flux-adjusted coupled models. In particular, an effort to run a Green's Function Model Intercomparisson Project (GF-MIP), has already been initiated by the organizers (Maria Rugenstein and Cristian Proistosescu), with four modeling centers having tentatively signed on (MPI, GFDL, UK Met Office, CCCma). One session in the workshop will be dedicated to advancing this project, and we hope to expand the project to 6-10 participating centers.

## 8. Relevance and/or benefits to US CLIVAR

Incomplete understanding of the pattern effect is a primary source of uncertainty in quantitative estimates of Earth's Climate Sensitivity (see, for example, the recent WCRP assessment of Climate Sensitivity by Sherwood et al. 2020). Improved understanding of the pattern effect would help to *better quantify uncertainty in the observations, simulations, predictions, and projections of climate variability and change.*

The pattern effect is, next to ocean heat uptake, one of the primary mechanisms by which the ocean influences Earth's climate response to external forcing. Thus, progress on the topic of the pattern effect advances *understanding the role of the oceans in observed climate variability on different timescales*, one of CLIVAR's main scientific goals.

A primary question related to the pattern effect is why recently observed SST patterns that are not well simulated by models, and whether this model deficiency is due to the model error in simulating internal variability or forced response. This question makes the project relevant CLIVAR's goal of *understanding processes that contribute to climate variability and change in the past, present, and future.*

## 9. Format of meeting

The format will be focused on discussions, not on conference-style talks. The workshop will consist of four components

- A small number of synthesis talks on overarching themes followed by plenary discussion (see tentative schedule).
- Poster sessions for attendees to present and discuss ongoing research. All posters will be on display throughout the entire conference to maximize informal discussions.
- Breakout group discussions
    - Format of breakout rooms will be designed to increase engagement. Moderators and rapporteurs will be assigned for each breakout room.
    - Questions and "homeworks" (i.e. finding possible answers) will be sent to participants ahead of the workshop. Breakout rooms will be tasked with specific deliverables, such as identifying gaps, recommending ways forward, etc.

- Strong online component (which will be finalized in fall 2021 when the travel situation is clearer than now), including potentially:
    - Live streaming + a small number of remote speaker
    - Hybrid poster session: all posters submitted virtually in addition to the printouts
    - Virtual participants can submit questions using (e.g  using slide-o)
    - Breakout rooms for online participants

## Tentative Schedule

In the following we sketch out the content to be discussed. We did not finalize which parts will be covered in breakout group versus panel discussions. Each half day will be introduced with an introduction talk pinpointing the open questions and starting to discuss possible answers.

**1st day - morning: perspective, getting everybody on the same page**

- Intro talk on history of the pattern effect literature, introducing ties to ocean/palaeo/predictability/remote sensing
- AMIP: What do we know robustly across several models and from limited observations?
    - Which feedbacks matter? E.g., ScCu low clouds, mixed-phase clouds
    - Which regions and which processes?
        - Tropical circulation, linking to the Indo-Pacific Warm Pool
        - East Pacific - both equatorial and subtropical.
        - Southern Ocean
- Updates from GFMIP (Greens Function Model Intercomparison Project)

**1st day - afternoon: coupled perspective**

- SST patterns: where do they come from, where do they go? What controls the SST patterns in relevant regions on both historical and long time scales?
    - West Pacific
    - East Pacific & Subtropics
    - Southern Ocean
- For each region: What are the relevant mechanisms? How well do models simulate SST patterns and feedbacks?  What are the relevant observations (or lack thereof)?
- 1st poster session including 2 min introduction talks for each poster at the beginning (potentially showing pre-recorded videos which could be also shared online)
- Reception

**2nd day - morning: historical patterns**

- What has caused the anomalous recent SST patterns that models fail to capture (e.g., cooling in East Pacific and Southern Ocean)?
    - Aerosols

    - Volcanic forcing
    - Internal variability - ENSO & IPO & AMV
    - Southern Ocean wind stress and freshwater forcing
    - AMOC change
    - Response to greenhouse gases
- How limited or informative is the observational record?
    - Uncertainty and noise in SST observations
    - Length of CERES, possibility to use ERBE and earlier records

**2nd day - afternoon: long-term patterns**

- What mechanisms mediate changing SST patterns in response to forcing on decadal to centennial time scales?
    - Ocean heat uptake
    - Equatorial feedback
    - Role for land warming?

- What information can be drawn from the palaeo climate record?
    - What is the magnitude of Inter-decadal variability? (Holocene)
    - What are the long term (Equilibrium) SST patterns (LGM & Pliocene)
    - Given proxy uncertainty, how do models compare to proxies in terms of low-frequency variability?
- 2nd poster session including 2 min introduction talks for each poster at the beginning
- Meeting steering group to prep/improve breakout groups

**3rd day - morning: frameworks**

- How do the different (energy balance) frameworks fit together? Can the frameworks be physically and mathematically related? Do they explain the observations, CMIP5 and CMIP6 models, and large initial condition ensembles?
    - Ocean heat uptake efficacy
    - Estimated inversion strength
    - SST number
    - Precip-weighted SST
    - Warm pool/global temperature and E-W Passific gradient
    - Green's Functions

**3rd day - afternoon: implications**

- Decadal to centennial predictability of Pacific patterns, the pace of Southern Ocean and North Atlantic heat uptake and SST variations
- Implications for the transient and equilibrium climate sensitivities
- Links to other communities for which SST patterns might be more relevant than thought of until now, such as regional predictions, droughts, hurricanes, or marine heat waves

**4th day - morning, plenary: ways forward**

- Summary of discussions of day 1-3
- What observations could constrain pattern effect?
- How do we improve the model representation of historical patterns?
- How do we determine whether to trust the projected pattern evolutions from the models?
- How do we refine our analysis methods?
- Which information have to be more constrained to increase understanding (for paleo, observations, GCM analysis)?

**4th day - afternoon: Scientific organizing committee meeting**

## 10. Tentative list of participants

**Early Career Scientists (# of female: 10, # of male: 9)**
Radiative feedbacks: Yue Dong (U Washington); Paulo Ceppi (Imperial College); Jonah Bloch-Johnson (U of Reading)
Clouds: Anna Lea Albright (IPSL); Steve Po-Chedley (LLNL); Nick Lutsko (UCSD); Daniel McCoy (U of Wyoming); Ivy Tan (McGill); Raphaela Vogel (IPSL); Jessica Vial (IPSL)
Ocean: Yemi Garuba (PNNL), Fukai Liu (PNNL), Dave Bonan (Caltech); Emily Newsom (Caltech) ; Ulla Heede (Yale); Vivian Chao (Texas A&M); Giorgio Graffino (U Reading) Henri Drake (GFDL)
Paleoclimate: Sylvia Dee (Rice U)

**Mid-career to Senior Scientists (likely to attend)**
Tim Andrews (UK Met Office); Sandrine Bony (CNRS/IPSL); Sloan Coats (U Hawaii); Jason Cole (ECC-Canada); Gokhan Danabasoglu (NCAR); Andrew Dessler (Texas A&M); Thomas Frölicher (U Bern); Stephan Fueglistaler (Princeton U); Andrew Gettelman (NCAR); Kris Karnauskas (CU Boulder); Steven Klein (LLNL); Jian Lu (PNNL); Kate Marvel (NASA GISS); Thorsten Mauritsen (U Stokholm); Yi Ming (NOAA GFDL); David Paynter (NOAA GFDL); Brian Rose (SUNY Albany); Brian Soden (U Miami); Malte Stuecker (U Hawaii); Jess Tierney (U Arizona); Masahiro Watanabe (U Tokyo); Mark Webb (UK Met Office); Mike Winton (NOAA GFDL); Shang Ping Xie (UCSD); Mark Zelinka (LLNL); Ming Zhao (NOAA GFDL); Chen Zhou (Nanjing University)

***Others potentially interested:***
*Not yet involved in pattern effect research, but working on very relevant topics*

- Pattern of aerosol forcing - Frida Bender (MISU); Nicolas Bellouin (Reading); Andrea Dittus (Reading); Lei Duan (Carnegie Institute, Stanford); Geeta Persad (UT Austin); Chris Smith (Leeds); Philip Stier (Oxford)
- Oceanography - Amy Clement (U Miami); Alexey Fedorov (Yale); Jake Gebbie (WHOI); John Marshall (MIT)

- Atmospheric variability - Joe Barsugli (NOAA CIRES); Lawrence Jackson (Leeds); Dave Thompson (CSU)
- Tropical-Extra Tropical Interactions - Yen-Ting Hwang (National Taiwan U); Trude Storelvmo (University of Oslo); Sally Zhang (NCAR)
- Coupled Climate variability (ENSO, MJO, PDO) and its change - Charlotte DeMotte (CSU), Clara Desser (NCAR); John Fassulo (NCAR) Eric Maloney (CSU); Robb Wills (UW)
- Paleoclimate - Kim Cobb (Georgia Tech); Kevin Anchukaitis (U Arizona); Dan Amrhein (NCAR); Tom Laepple (AWI Bremen); Sara Sanchez (CU Boulder)
- Polar Oceanography - Edward Blanchard-Wrigglesworth III (UW); Alexandra Janh (CU Boulder)
- Cloud feedback and Climate Sensitivity - Jean-Louis Dufresne (IPSL); Jen Kay (CU Boulder); Reto Knutti (ETH Zurich); Steve Sherwood (UNSW); Diego Jimenez-de-la-Cuesta (MPI) Nadir Jeevanjee (NOAA GFDL); Brian Medeiros (NCAR); Gabe Vecchi (Princeton U); Hui Su (NASA JPL); Masakazu Yoshimori (U Tokyo)
- Decadal Prediction - Steve Yeager (NCAR); Geradl Meehl (NCAR); Elizabeth Maroon (UW-Madison)

## 11. Deliverables

- Workshop Report that summarizes the state of the knowledge and gaps in understanding, and puts forward recommendations for future modeling activities, necessary observations, theoretical frameworks, and other ways forward
- Community information piece to be submitted to EOS or BAMS
- Initiate a review and synthesis paper
- Finalize Green's Function - Model Intercomparison Project (GF-MIP protocol to be submitted as a paper to GMD)

## 12. Budget request from US CLIVAR

We request support for meeting logistics and travel support for 8 organizers, 7 invited speakers, and 20 early career scientists.

| | |
|---|---|
| Travel for 35 | $54,655 |
| Catering for 100 | 17,200 |
| Supplies & Service Fee | 300 |
| Overhead | 5,985 |
| Event Cost Subtotal | 78,140 |
| Less Registration Revenue | -21,300 |
| Total Request | $56,840 |

## 13. Other sources of funding

Seeking possible funding from the European Research Council project COUPLET, led by Jonathan Gregory, for travel of European participants.