Prospectus for US CLIVAR Working Group on Large "Initial-Condition" Earth System Model Ensembles

1. Motivation

Identifying anthropogenic influences on weather and climate amidst the "noise" of internal variability is a grand challenge for all areas of climate science and one that spans all components of the Earth system. This challenge is particularly acute for high impact events to which societies are especially vulnerable, for example extreme precipitation, storm surges, floods, heat waves, and droughts. The climate research community has dealt inadequately with this challenge due to a lack of coordinated effort and leadership. The proposed working group (WG) will fill this need by spearheading a dedicated effort across the national and international climate communities to advance progress on this central issue, and to ensure effective communication of results across disciplines and to stakeholder groups. The importance, timeliness and cross-cutting nature of the problem, together with promising new observational and modeling approaches, merit a CLIVAR WG. Indeed, such a WG has an unprecedented opportunity to make substantive progress on this tractable issue within a 3-year time frame, and to influence the future direction of national and international modeling efforts. Through coordination of key players, and fostering exchange of information and ideas across sub-disciplines of the climate sciences, the WG will achieve important milestones and leave a lasting legacy.

2. Background

Internally-generated climate variability occurs over a wide range of time and space scales as a result of processes intrinsic to the atmosphere, the ocean, and their coupled interactions. For example, the atmospheric circulation varies on a continuum of time scales, often with preferred large-scale spatial patterns that are anchored by features of the climatological flow such as stormtracks, baroclinicity, and stationary waves. Much of this variability is caused by chaotic atmospheric dynamics, and occurs in the absence of changes in surface boundary conditions, for example sea surface temperature (SST) anomalies. The ocean also exhibits intrinsic variability, for example high-frequency mesoscale eddies mostly located along fronts and strong currents, as well as interannual-to-centennial variability of the wind-driven gyres and global thermohaline circulation that is largely excited by stochastic atmospheric buoyancy and momentum fluxes. Finally, coupled ocean-atmosphere processes give rise to ENSO and related interannual phenomena, as well as the "Pacific Decadal Oscillation" (aka the "Interdecadal Pacific Oscillation") and "Atlantic Multi-decadal Oscillation".

Such internally generated climate fluctuations pose significant challenges for the identification of externally forced climate signals such as those driven by anthropogenic changes in greenhouse gas (GHG) concentrations, aerosol emissions, and stratospheric ozone depletion, as well as natural radiative changes associated with volcanic eruptions and solar variability. This challenge is exacerbated for regional climate responses evaluated from short (< 50 years) data records (i.e., Hawkins and Sutton, 2009; Deser et al., 2012a; Xie et al., 2015; Lovenduski et al., 2016). For example, it is often naively assumed that local and regional trends evident in observations over the satellite era (3-4 decades) are due entirely to human influences. However, it is clear from the growing literature on this topic that both internal and human factors contribute to trends of this length, often in equal parts. For example, the melting of Arctic sea ice in recent decades, communicated to the public as the "poster child" of global warming, is now understood to be caused by a roughly equal split between human and internal drivers (i.e., Swart et al., 2015), as is the accelerated pace of wintertime warming over Canada and Alaska during the past 50 years (Deser et al., 2016).

Climate projections contained in the CMIP3 and CMIP5 archives form much of the scientific basis of anticipated changes in weather and climate in the coming decades.

However, such multi-model archives confound structural uncertainty (i.e., differences in model formulation including physics, parameterizations, resolution, etc.) with internal variability for a given forcing scenario. This distinction is important, as the former is potentially reducible as models improve, while the latter is an intrinsic property of each model and is largely irreducible after the memory of initial conditions is lost. This key distinction is often not widely appreciated and communicated (see Deser et al., 2012b). Indeed, Deser et al. (2012a) estimate that internal variability accounts for at least half of the CMIP3 inter-model spread in air temperature and precipitation trends projected for the next 50 years.

Large "initial condition" Ensembles (LEs for short) of climate projections with a given model allow for easy separation of the forced response (estimated by the ensemble-mean) and internal variability (estimated by the residual from the ensemble-mean). In such ensembles, each member is subject to a common forcing scenario, but begins from slightly different initial conditions. With enough ensemble members, where "enough" is a function of the quantity of interest, location, spatial scale, temporal scale, etc. (see Deser et al., 2012b), this separation can be made with good precision. However, to date, only a handful of CMIP-class models have such LEs, and most are very recent (within the last year or so) and have not been widely disseminated to the climate research community for analysis. Further, there is no common protocol for these LEs. For example, they cover different time periods, use different forcing (i.e., GHG and aerosol emissions) scenarios and initialization procedures, and contain a variable number of ensemble members. We emphasize that without LEs from a diverse set of climate models and subject to a common protocol, the research community will be unable to separate uncertainty due to structural differences among models from that due to internal variability in archives such as the widely-used CMIP3/5 and associated Assessment Reports (AR), not to mention future CMIP/AR endeavors. The importance of this separation cannot be overestimated, with implications for our ability to narrow uncertainty in climate projections. Furthermore, this is a completely tractable problem, and one that the climate community is poised to solve now.

A final motivation for the proposed WG is the unprecedented success of the CESM1-LE (Kay et al., 2015) as demonstrated by the wide usage it has received and reflected in the high number of peer-reviewed publications (285) to date since the data were made publicly available in 2015. Indeed, the CESM1-LE reference paper was named a "New Hot Paper for Geosciences" in *Essential Science Indicators* (ESI) six months after its publication. It is fair to say that the massive impact that the CESM1-LE has had on the climate research community indicates that the "era of LEs" has come, and that the climate community would be remiss in not fostering leadership of a coordinated multi-model suite of LEs. This effort could be expanded beyond the set of "full forcings" for the historical period and 21st century to encompass a set of "single-forcing" simulations to isolate individual contributions from various external factors. Such LEs can also be used as boundary conditions for regional dynamical downscaling. And finally, the effort can be broadened to the last millennium, for which paleo-climate proxy records exist and for which there are more samples of natural (i.e., volcanic and solar) radiative forcing changes to draw on. In this regard, we note that the CESM1-LE inspired the CESM1 "Last Millennium" LE covering the period 850-2006 (Otto-Bliesner et al., 2016).

3. Utility of Large "Initial Condition" Ensembles (LEs)

The following is an incomplete list of the cross-cutting applications of LEs and insights gained to date. Additional examples are evident from the breadth of citations to the CESM1-LE reference publication

1) Separation of forced and internal components of simulated climate variability and change, and determination of the minimum number of ensemble members needed depending on the particular focus.

2) Test bed for statistical methodologies aimed at separating forced and internal components of climate variability and change, including modes such as the AMO, PDO and ENSO, in observations for which only one realization is possible.
3) Test bed for robustness of "emergent constraints" across the Earth system by reducing noise from internal variability.
4) Test bed for new approaches to "detection and attribution".
5) Robust determination of "time-of-emergence" of anthropogenic signals across the Earth system by reducing the noise of internal variability.
6) Robust statistics on extreme events and their changes due to the rarity of samples in any single model simulation, by definition.
7) Design of observing systems, sampling requirements, and optimal time of deployment across the Earth system ("biogeochemical-Argo" as an example).
8) Robust evaluation of internal variability in earth system models using the same period of record as available from observations to avoid comparison to pre-industrial control runs.
9) Enable robust comparisons of internal variability and forced responses across LEs with different models, including how internal variability may be affected by climate change. This will be done within the context of broader community efforts focused on the dynamics and physics of climate variability.
10) Advance the science of interpreting the observational record across the Earth system. Nature only gives us one "realization", but it is clear from existing LEs that there are many trajectories that might have taken place, and that might take place in the future, depending upon the particular (and unpredictable) sequence of internal variability that happens to unfold.
11) Robust determination of other types of "forced" climate responses such as those due to ENSO.
12) Evaluation of relative contributions of structural uncertainty and internal variability to ensemble spread across a multi-model LE.

4. Proposed tasks

1) Hold regular teleconferences at intervals of 1-3 months to foster exchange of information, results and brainstorming on uses of LEs (including all of those listed above); in-person meetings in years 1 and 3 at "meetings-of-opportunity" (e.g., AGU); and an open science workshop in summer 2019. Additional participants at teleconferences and meetings by invitation.
2) Communicate WG activities and results with the broader community via the US CLIVAR website, newsletter, and reports.
3) Convene sessions at Fall AGU 2018 and 2019.
4) Facilitate exchange of model output from existing LEs to the broad climate research community (patterned after CMIP5 or CESM1-LE)
5) Design a protocol for an LE-MIP that covers a common time period, forcing scenario, initialization procedure, and number of ensemble members.
6) Design an observationally-based LE. This can be done by taking the forced (ensemble-mean) trend from existing LEs or from the CMIP5 archive, as done for temperature in McKinnon et al. (2017). Such an "Observational-LE" is arguably the best approach for risk assessment of anthropogenic climate change. Building one is non-trivial, and will need to draw on many types of expertise including mathematicians, statisticians, and climate scientists.

5. Outcomes, Deliverables and Timeline

1) Foster exchange of ideas relevant to LEs across disciplines (i.e., atmosphere, ocean, land, biogeochemistry, …). (All Qs)

2) Peer-reviewed Perspective in Nature Geoscience or comparable journal containing a statement of the problem and its importance, first results from a comparison of existing LEs from 5 different models, proposed design of an LE-MIP, and opportunities for further progress. (Q2, year 2)
3) Lead the LE-MIP and dissemination of model output. (year 2 and beyond)
4) Design the "Observational-LE". (year 2 and beyond)

6. Benefits to US CLIVAR

LEs, while relatively rare, have already generated an enormous amount of new knowledge and promise to provide even more insight into climate variability and change as additional analyses are undertaken. With CMIP6 and the AR6 looming, now is the time to advocate for and help coordinate a new wave of LEs. These activities are actionable, measurable and cross-cutting, and merit a dedicated CLIVAR WG at this time. The topic of the proposed WG is relevant to fundamental science questions 3.3 and 3.4 and goals 4.3, 4.4 and 4.5 of the US CLIVAR Science Plan, and connects directly to the "Phenomena, Observations, and Synthesis" CLIVAR Panel (Di Lorenzo, Chair). It is also pertinent to the WCRP Grand Challenges on "Carbon Feedbacks in the Climate System", "Weather and Climate Extremes", and "Near-term Climate Prediction". It also links to the International CLIVAR "Climate Dynamics Panel" (M. Collins and S. Minobe, co-chairs).

7. Leadership and Suggested Membership

The WG will be chaired by Clara Deser (NCAR) and Keith Rodgers (Princeton U.).

Proposed US core members and their areas of expertise:

Toby Ault (Cornell U.) – Regional climate and emergent constraints
Tom Delworth (NOAA GFDL) – Ocean dynamics and modeling, GFDL model
Pedro DiNezio (U Texas-Austin) – Air-sea interaction including ENSO
Arlene Fiore (Columbia U.) - Atmospheric chemistry and air quality
Dan Horton (Northwestern U.) – Extreme events, climate impacts, atmospheric dynamics
Jennifer Kay (U. Colorado) - Polar processes, LE expertise
Nikki Lovenduski (U. Colorado) - ocean biogeochemistry
Jim Randerson (U. California-Irvine) – Terrestrial processes
Isla Simpson (NCAR) – Stratosphere-troposphere coupling
Mingfang Ting (Columbia U.) – Detection and attribution, atmospheric dynamics

Proposed international contributing members and their areas of expertise:

Claude Frankignoul (Université Pierre et Marie Curie) – air/sea interaction, IPSL model
John Fyfe (Canadian Centre for Climate Modelling and Analysis) – climate change, CanESM model
Jochem Marotzke (MPI) – ocean dynamics and modeling, MPI model
James Screen (U. Exeter) – Arctic sea ice, UK-ESM model
Reto Knutti (ETH) – climate sensitivity, CMIP6
Shohiro Minobe (Hokkaido University) – air/sea interaction, MIROC model

The proposed membership represents expertise across a range of disciplines, knowledge of LEs and connections to key modeling groups, and diversity of career stage and gender.

8. Resource Requirements

Resources are sought for WG meetings, quarterly teleconferences, a WG-drafted journal article, and a modest-sized open science workshop.

9. References

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