The 7th US Climate Modeling Summit Report

21 August 2021

Summary

The 7th US Climate Modeling Summit (USCMS) was held virtually due to COVID-19-related restrictions. The Summit consisted of a three-day Workshop during 28-30 June 2021 and a one-day Summit Meeting on 01 July 2021. The Workshop engaged scientists, primarily from the modeling centers, working on Earth system predictability and prediction. The USCMS, involving core members (see Appendix C) and the US Global Change Research Program's (USGCRP) Interagency Group on Integrative Modeling (IGIM) managers, continued to be an opportunity for high level modeling discussions to enhance coordination and collaborations across the centers. The Summit Meeting was dedicated to the progress made at centers and other recent updates as well as discussions on coordination to tackle relevant issues. The meeting concluded with planning coordinated activities for the upcoming year, including the 8th USCMS.

Background on USCMS and Workshop

To improve the coordination and communication of national climate modeling goals and objectives, the USGCRP's IGIM has been convening an annual USCMS since 2015. The Summit brings together representatives from the US climate model development centers and from operational climate and weather prediction programs. Specifically, two representatives – one lead and one additional delegate – from each of the following groups are invited to participate in the Summit: Geophysical Fluid Dynamics Laboratory (GFDL CM/ESM); Goddard Institute for Space Studies (GISS ModelE); Global Modeling and Assimilation Office (GMAO GEOS); NCAR Community Earth System Model (CESM); NWS/NCEP (GFS); and DOE Energy Exascale Earth System Model (E3SM) (Appendix C).

As envisioned by the IGIM, the high-level USCMS objectives include:

1. Developing a shared understanding of modeling groups' directions and implementation strategies;
2. Identifying opportunities for enhanced coordination and synergy among modeling groups; and
3. Identifying outreach opportunities to user communities.

Starting in 2017, a topical workshop has also been organized under the auspices of the USCMS and in conjunction with the annual meeting. These workshops serve as a venue to have focused technical communications on a high-priority modeling-related topic identified by the modeling centers together with the IGIM, and they may include invitees from the broader community.

Summary of Activities Since the Previous USCMS

Progress was reported from two projects that were initiated at previous USCMS meetings.

The "world-avoided" mini Model Intercomparison Project (mini-MIP) aims to look at the impacts that the Clean Air Acts have had on air quality and climate. This project, led by Jean-François Lamarque (NCAR), has developed appropriate emission scenarios. An initial set of simulations have been performed by CESM2 (WACCM), DOE (E3SM), NASA GISS (modelE), and NOAA GFDL (ESM4). The results show significant impacts of US emission trajectories on global surface ozone concentrations and particulate pollutions (Fig. 1). Next steps will involve more analysis of the simulations focusing on impacts on climate, air pollution, and health by the modeling centers and collaborators from the Columbia University. The project is expected to be completed within the next year.

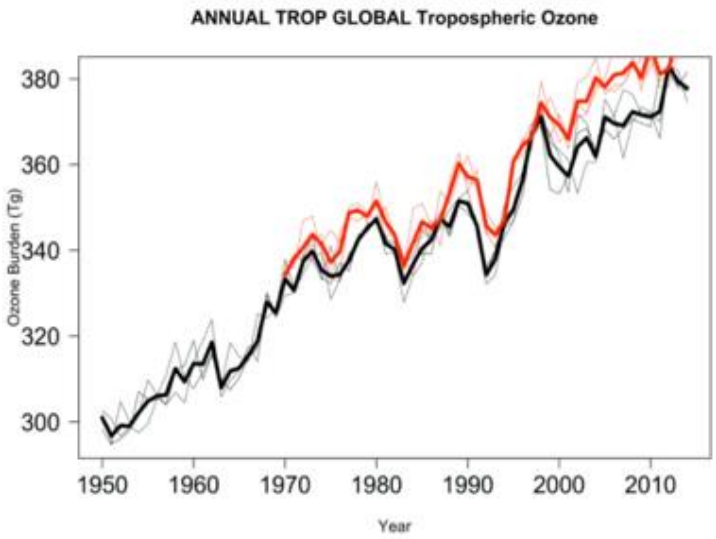

Figure 1. Global mean surface ozone concentrations in the control run (black) and the run with frozen US emissions (red). Figure by A. Fiore and S. Hancook, from the Columbia University.

Following last year's USCMS Workshop on Aerosol – Cloud Interactions, Johannes Mülmenstädt (PNNL) initiated a collaborative proposal which has been just funded by the agencies. The ideas and plans for the proposal were presented at the Summit. All six modeling centers are participating in this project that combines observational data with model results and theoretical studies to better understand the physical realism of aerosol-induced cloud drying across models. The research plan includes the following steps: 1) Evaluation of the relationships between cloud droplet number concentrations and liquid water path; 2) investigation of physical realism of the entrainment fluxes in models; 3) testing process interpretation of satellite correlations; and 4) linking entrainment mediated aerosol – cloud interactions with cloud feedbacks. The project is anticipated to be completed within a one-year time frame.

Topical Workshop

The USCMS Topical Workshop on Predictability Limits Arising from Model and Prediction System Challenges was held virtually during 28-30 June 2021 just before the Summit Meeting. The general topic of *predictability* was decided on during the previous year's Summit. It is aligned with a report by the Fast Track Action Committee (FTAC) on Earth System Predictability Research and Development of the National Science and Technology Council entitled "Earth System Predictability Research and Development Strategic Framework and Roadmap". This Report identifies several goals and our Workshop was particularly aligned with their third goal which calls for accelerated exploration and effective use of inherent Earth system predictability through advanced modeling. Among the areas of opportunities articulated in the

Report, the Workshop was closely related to the fifth objective that advocates advanced modeling and technology, and enhanced collaborations.

While predictability as a topic is too broad to completely cover and discuss within a limited workshop, with input from the modeling centers concerning their interest areas, the scope of the Workshop was narrowed down to two specific topics that are naturally inter-related:

- Impacts of model errors (biases) and resolution on predictability, including air-sea and aerosol-cloud interactions that can limit predictability; and
- Signal-to-noise ratio paradox, and role of large ensembles.

Again, reflecting centers' interests, specific emphasis areas included: impacts of these issues and challenges on predictability of extreme events such as heat waves, precipitation, droughts, hurricanes, and atmospheric rivers. The time scales of interest were left unspecified prior to the Workshop not to limit discussions a priori, extending from weather and subseasonal to decadal and longer time scales.

The Workshop had about 85 registered participants with attendance ranging from 40 to 70 across sessions. The agenda is provided in Appendix A. All the recordings and presentations for each day are available for the Workshop participants from the Workshop website at https://www.cesm.ucar.edu/events/2021/uscms/ and https://www.cesm.ucar.edu/events/2021/uscms/presentations, respectively. A username and password are required to access the presentations.

Some background information for the Workshop was provided during the opening session. This included a summary from the National Academies of Sciences, Engineering, and Medicine Workshop on Earth System Predictability that was held in June 2020 whose outcomes were included in the FTAC Report mentioned above. This report was also introduced and discussed in this session. The second session had a series of presentations from the modeling centers related to their Earth system prediction and predictability activities, highlighting their capabilities and some results. The presentations also included discussions on impacts of model biases on prediction skill; role of data assimilation to reduce model biases; drift correction methods; issues with signal-to-noise paradox; need for large ensembles; and use of analogs for seasonal prediction.

The next session included three invited presentations. Chris Roberts from the ECMWF discussed the impacts of horizontal resolution and sea surface temperature (SST) biases in their forecasting system. They found that increasing ocean resolution has a larger impact on the coupled climate system than increasing atmospheric resolution. Further, artificially correcting the SST bias associated with the incorrect separation of the Gulf Stream and the subsequent path of the North Atlantic Current improved the state of the North Atlantic leading to significant impacts on remote atmospheric circulations. Based on these results, better representation of the North Atlantic SSTs is expected to lead to improvement in skill in subseasonal-to-seasonal predictions. Along similar lines, Ben Kirtman from the University of Miami stressed that high resolution can indeed help with bias reduction, but it does not solve all the bias issues. He also discussed the importance of ocean mesoscale eddies on regional climate.

Doug Smith from the UK Hadley Center discussed the signal-to-noise paradox in detail. Essentially, the paradox states that for some phenomena models predict the real world better than

predicting themselves despite perfectly representing themselves (Fig. 2). Figure 3 shows the North Atlantic Oscillation (NAO) forecast for lead years 2-9. Although the simulated ensemble mean is highly correlated with the observations, the simulated variability is much too small (left panel). Adjusting the model variance to match that of the observations indeed shows much better agreement with the observations (right panel). Some recent studies indicated that climate models usually have the right amount of total variability, but the portion of variability that is predictable seems just too small. The paradox impacts the interpretation of perfect model-based predictability limits – that is, such a limit might in some cases represent an underestimate of the predictability with respect to the real world, and resolving this paradox could increase prediction skill while reducing needed ensemble sizes.

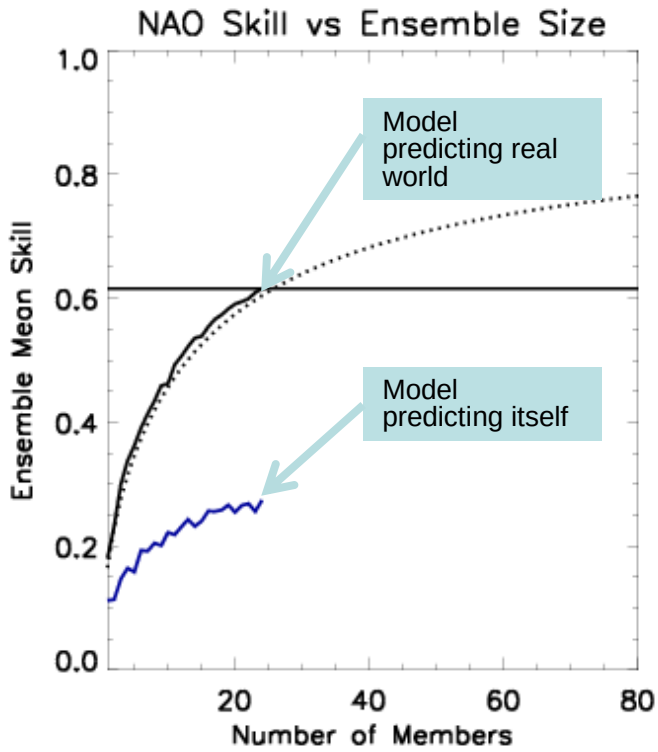

Figure 2. Ensemble mean skill in predicting NAO as a function of ensemble size, showing that a model can predict the real world with higher skill than predicting itself. (Doug Smith).

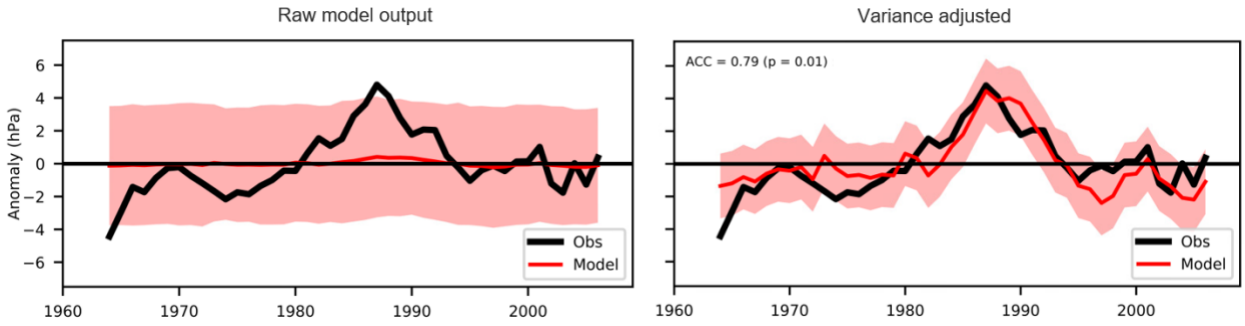

Figure 3. Model representation of NAO variability: (left) raw annual data and (right) model variance adjusted to match that of observations. (Doug Smith).

The last presentation session covered several, perhaps more specific topics that included impacts of model deficiencies on representation of low frequency variability; predictability limits due to aerosol – Earth system interactions; application of machine learning for detecting model predictability limits; future changes in atmospheric rivers and monsoons; and understanding the causes of the 1990s shift in the Northern Hemisphere mid-latitude temperatures and using it as a testbed for our prediction systems, including the prediction of the most recent heat wave in the Northwest US.

A goal of the Workshop was to serve as a venue for exchange of information and ideas which, we believe, was accomplished. Another goal was to identify one or two studies that can be undertaken by the modeling centers collaboratively – consistent with the USCMS' primary aim of enhancing coordination and collaborations among the centers. For this purpose, the Workshop included a breakout session with five separate Breakout Groups. To facilitate discussions, the groups were provided with the following guiding questions:

- How can we demonstrate aspects of the impacts of model biases and resolution on limiting predictability?
- Relatedly, what are the limits on predictability of, say, extreme events that arise from model fidelity issues?
- How can we make meaningful contributions to furthering our understanding of the signal-to-noise ratio (paradox)?
- What is the role of initialized and uninitialized large ensembles in these efforts?

The summaries of the Breakout Group discussions were presented and further discussed by the broader group in a plenary session at the end of the Workshop. Many good suggestions and possible topics for joint studies were received. As the time frame for such a study is envisioned to be about 1 year, it will behoove us to use existing simulations at our disposal. These would include various Coupled Model Intercomparison Project phase 5 and 6 (CMIP5/6) simulations, large ensembles, and predictions. Consensus view was to focus on particular set of events or modes to keep the effort relatively focused. A specific idea is how a limited set of modes of variability with impacts on predictability and prediction skill (e.g., NAO, Madden-Julian Oscillation) or an event (e.g., current heat wave in the Northwest US) is represented in the models and how their representation depends on model biases, resolution, etc. This would also include investigating if there is a clear evidence for reduced bias leading to better predictability and prediction skill in some select fields. As a next step for a joint USCMS activity, we will soon propose a project on this topic to the program managers that can be completed in about a year.

Longer term efforts were also suggested, involving, e.g., running bias-corrected sensitivity simulations and subsequent prediction simulations, to evaluate impacts of model biases on predictability and prediction skill. These would need more resources and a higher level of commitment from the modeling centers.

Center Updates and Discussions at the 7th USCMS

The 7th USCMS agenda and the link to presentations are given below in Appendix B. The agenda consisted of three segments. The first segment was devoted to a summary of the Workshop and updates from activities that started at previous USCMS meetings (all summarized above). In the

second segment, the centers provided updates on their science, priorities, challenges, and plans relevant to the IGIM efforts. These presentations generally covered the centers' new model configurations, developments, frameworks, initiatives, and some results of interest, including those from CMIP6 simulations. Because the updates are too detailed to be summarized in this report, the reader is referred to the presentations available via the link provided in Appendix B.

The last segment of the Summit was primarily dedicated to two discussion topics. The first concerned the impact of the new administrations focus on climate science for the direction of research undertaken by the modeling centers. It was noted that the current administration is very supportive of climate research and applications, which is expected to translate into new opportunities for the centers. Climate-related research by itself will be of importance, with renewed focus on topics such as basic (fundamental) research, modeling, projections, and Earth system predictions. However, more emphasis should be put on specific areas of climate actions and solutions, adaptations, preparedness for extreme events, to name a few, noting that climate solutions include growing interest areas of clean energy, climate policy, cost of carbon, financial and human risks. Also, there was a strong agreement that more interdisciplinary research must be enabled. One new emerging opportunity concerns the topic of environmental justice. Related research would tackle, among others, what relevant and actionable information models can provide for use, e.g., in densely populated areas, or in areas where we expect the largest climate extremes, such as coastal areas, or in areas where disadvantaged communities reside. Furthermore, it was discussed that climate data have to be more easily accessible, and mapped for a wider array of applications, e.g., accessible to Federal Emergency Management Agency and similar steak holders and climate services. Essentially, climate research must be translated into more innovative solutions, integrating climate science with information needed by stakeholders.

A question was posed regarding what USCMS can deliver as a modeling community towards addressing these new questions and challenges. It was agreed upon to focus work on environmental justice. Next steps would be to agree on action items to start and expand this discussion. There was the idea to have an additional meeting within this group to discuss or to have it as part of the IGIM meeting agenda, including invited talks about environmental justice.

The second discussion topic covered the future of the CMIP and the centers' participation in related activities. CMIP6, with its many MIPs, was an enormous undertaking, generating 9 PB of data globally and significantly straining US modeling centers' human and computational resources. Despite its challenges, CMIP6 enabled meaningful collaborations globally between modeling centers and many research institutions that usually led analysis. CMIP6 certainly resulted in new science and findings, particularly via its MIPs. Relatedly, the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report was published in August 2021. Four US modeling centers participated heavily in CMIP, i.e., DOE/E3SM, NASA/GISS, NOAA/GFDL, and NSF/CESM, and feature strongly in the overall report. While plans for the future of CMIP are still under discussion, the US modeling centers strongly favor a more continuous approach where model simulations can be contributed to repositories as they become available on the centers' own development and science timelines. It was also acknowledged that such a continuous approach was also the intention in CMIP6.

Plans for the 8th USCMS

For the 2022 meeting (the 8th USCMS), the group agreed that Gokhan Danabasoglu (NCAR) and Ruby Leung (PNNL) would co-chair the meeting. The meeting location (virtual and / or in-person) and schedule are TBD, but should be scheduled around the April – July 2022 timeframe. The topic of next years workshop will be *Water in the Climate System*, possibly focusing on extreme events and maybe also considering the connection to environmental justice. More detailed ideas will be discussed among the chairs and will be coordinated with the IGIM over the next year.

Summary

In summary, the Summit and the Workshop provided a unique opportunity to enhance our collective understanding of changes in the emergent properties of the models, share plans and challenges among the groups, and collectively (and productively) work on common projects of interest.

Susanne Bauer (NASA GISS, 7th USCMS Chair)
Gokhan Danabasoglu (NCAR, 7th USCMS co-Chair)

Appendix A: Agenda for the Workshop

USCMS Topical (virtual) Workshop on
Predictability Limits Arising from Model and Prediction System Challenges

28-30 June 2021
(All times are EDT)

28 June 2021 (Monday)

11:00 Gary Geernaert: Welcome and Background

11:10 Gokhan Danabasoglu: Workshop objectives and outcomes

11:20 Annarita Mariotti: Earth system predictability R&D interagency strategy and roadmap

11:45 Jim Hurrell: Summary and outcomes of the NAS meeting on predictability

Modeling Center Efforts

12:10 Baoqiang Xiang: "Seamless system for Prediction and EArth system Research" (SPEAR) S2S prediction system and its prediction of different types of MJO

12:35 Feiyu Lu: Relating predictability, predictions, and model bias for seasonal predictions with GFDL's "Seamless system for Prediction and EArth system Research" (SPEAR)

13:00 *Break*

13:25 Yaga Richter: Subseasonal prediction research framework with CESM2 and examples of its use for understanding sources of predictability

13:50 Steve Yeager: The benefits of large ensembles in CESM multiyear to decadal predictions

14:15 Ruby Leung: Overview of DOE activities

14:40 Jerry Meehl: Initialization method and model bias, drift, trends, and skill of seasonal-to-decadal initialized climate predictions in CESM and E3SM

15:05 Gokhan Danabasoglu: Charge for breakout groups and anticipated outcomes

15:30 *Adjourn for the day*

29 June 2021 (Tuesday)

Modeling Center Efforts (continued)

11:00 Vijay Tallapragada: Development of coupled UFS for medium range and S2S predictions: A collaborative effort supported by the UFS-R2O project

11:25 Avichal Mehra: Development of GEFS/SFS models

11:50 Clara Orbe and Ron Miller: Overview of predictability using the GISS model

Air-Sea Interactions; Signal-to-Noise Paradox; Model Deficiencies

12:15 Doug Smith: A signal-to-noise paradox in climate science

12:40 Chris Roberts: Role of resolution and SST biases in predictability in the ECMWF model

13:05 *Break*

13:30 Ben Kirtman: Sub-seasonal to decadal predictability and prediction with ocean eddy resolving models

13:55 Isla Simpson: Model deficiencies in the representation of low frequency variability and/or forced trends

14:20 Breakout Groups (5-10 groups)

15:30 *Adjourn for the day*

30 June 2021 (Wednesday)

Focus Areas

11:00 Susannah Burrows: Predictability limits due to aerosol – Earth system interactions

11:25 Maria Molina: Overcoming and detecting model predictability limits using machine learning

11:50 Yuejian Zhu: Stochastic forcing, ensemble development, and reanalysis and reforecast

12:15 Ming Zhao: Simulations of atmospheric rivers, their variability, and response to global warming using GFDL's new high-resolution general circulation model

12:40 Wenhao Dong: Projected changes in monsoon low pressure/depression systems and precipitation patterns

13:05 *Break*

13:30 Celine Bonfils: Disentangling the role of aerosols and greenhouse gases in the recent decadal changes in hydroclimate

13:55 Haiyan Teng: Heat waves and the 1990s shift

14:20 Summaries from Breakout Groups

14:45 Discussion

15:30 *End of the Workshop*

Appendix B: The 7th USCMS Agenda

Date and Time: 11 am – 4:30 pm EST July 1st 2021
Location: Virtual

11:00 Introductions (Susanne Bauer and Gary Geernaert)

11:10 Summary of the Predictability Workshop and next steps (Gokhan Danabasoglu)

11:30 Status of the Climate Sensitivity project resulting from USCMS 2020 (Johannes Mülmenstädt)

11:45 Status of the 'World Avoided experiment' resulting from USCMS 2019 (Jean-François Lamarque)

Model group updates (20 minutes per center)

- What is new since last year in science, priorities, challenges
- Highlights of USGCRP priority-relevant current activities

12:00 E3SM (Ruby Leung)

12:20 GFDL (V. Ramaswamy)

12:40 GISS (Gavin Schmidt)

Break 1pm – 1:30pm

13:30 GMAO (Steve Pawson / Bill Putman)

13:50 NCAR (Gokhan Danabasoglu)

14:10 NCEP (Vijay Tallapragarda)

General Discussion Topics

14:30 Climate focus of the new administration (impact on USCM) (Gary Geernaert; Annarita Mariotti; Anjuli Bamzai; Gavin Schmidt, Jin Huang)

15:10 Value and urgency of CMIP participation (Jean-François Lamarque)

15:50 Discussion/Action items for coming year….. Chair: Gokhan Danabasoglu; Co-chair: TBD

Next Year's Workshop: Theme and co-chairs (Ruby Leung? and Dave Bader?)

16:30 Adjourn

Presentations for the summit can be found at:
https://www.dropbox.com/sh/85xg0rihpydw5me/AAAJ9_L1kYQdyruzO56wiY-Ma?dl=0

Appendix C: Modeling Center Representatives

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