BAMS
Essay

The Weather–Climate Schism

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ABSTRACT: The atmospheric science community includes both weather and climate scientists. These two groups interact much less than they should, particularly in the United States. The schism is widespread and has persisted for 50 years or more. It is found in academic departments, laboratories, professional societies, and even funding agencies. Mending the schism would promote better, faster science. We sketch the history of the schism and suggest ways to make our community whole.

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The atmospheric science community includes both weather and climate scientists. Weather research focuses in part on understanding and forecasting weather on time scales up to about 10 days. Climate research deals with understanding the statistics of weather and how they change due to internal variability and external forcing.

Here we state directly what is widely perceived but rarely openly acknowledged: particularly in the United States, some climate scientists view weather research, with its focus on relatively small space and time scales, as narrow in scope and detached from the grand issues of past and future climate change. On the other side, some weather scientists believe that climate scientists are ignorant of weather and that climate science is excessively focused on scenario-based "projections" of future climate change that cannot be evaluated using present-day observations. These unfortunate stereotypes are especially prevalent in the United States. They are slowing the progress of Earth system science in this country.

The schism is not new; it has been with us for 50 years or more. It is found in academic departments, laboratories, professional societies, and even funding agencies. Here are some examples:

- While many academic departments include research and teaching of both weather and climate, the two streams are often quite separate, with weather students learning little about climate and climate students emerging with little understanding of weather systems.
- NOAA's primary climate research laboratory (the Geophysical Fluid Dynamics Laboratory, GFDL) and operational numerical weather prediction center (the National Centers for Environmental Prediction, NCEP) have, until quite recently, used completely different models, and are located in different states. While Europeans have migrated toward unified modeling, in which the same model is used for both operational weather forecasting and research on weather and climate, the operational and research enterprises remain largely separate in the United States. This, and the relative lack of interaction between academic researchers and those involved in operational weather prediction, can partially explain why the United States trails Europe in the quality of its numerical weather forecasts.
- In 1979, the Atmospheric Analysis and Prediction Division (AAP) of the National Center for Atmospheric Research (NCAR) was split into the climate-oriented Climate and Global Dynamics Laboratory (CGD) and the weather-oriented Mesoscale and Microscale Meteorology Laboratory (MMM). Today, CGD and MMM are housed in different buildings on opposite sides of Boulder. In our opinion, splitting AAP into CGD and MMM and segregating them geographically were tragic mistakes. The problem is exacerbated today by the work-from-home culture that emerged from the pandemic.
- The American Geophysical Union (AGU) leans toward climate, while the American Meteorological Society (AMS) is more focused on weather.

- The Atmospheric Sciences Section of the Division of Atmospheric and Geospace Sciences (AGS, within the Geosciences Directorate) includes a climate-oriented program called "Climate and Large-Scale Dynamics" and a separate weather-oriented program called "Physical and Dynamic Meteorology."

How did we get here?

We doubt that there is a single cause for the schism, but we believe that it is traceable to the early development and organization of numerical weather prediction (NWP) in the United States. Although the conceptual groundwork for NWP was laid in Europe (e.g., Bjerknes 1904; Richardson 1922), the first numerical weather forecast was performed in the United States by a team at the Institute for Advanced Study in Princeton (Benjamin et al. 2019). The team was led by Jule Charney, a mathematician and atmospheric theoretician. The decidedly academic origin of American NWP set it apart from the operational forecasting community of the time. Perhaps the schism started there. A further important U.S. advance was the two-layer hemispheric model of Norman Phillips (Phillips 1956), which he used in an attempt to simulate the general circulation of the atmosphere. His model was a key precursor of today's NWP and climate models. The first *global* operational NWP was carried out by the United States during the 1970s (Stackpole 1978). The first four global atmospheric circulation models used for climate research were all developed in the United States, at GFDL; the University of California, Los Angeles; NCAR; and the Lawrence Radiation Laboratory (see the review by Randall et al. 2019). In addition, the first global ocean model was developed at GFDL in the late 1960s (Bryan and Cox 1967). At the end of the 1970s, the United States was firmly at the forefront of global modeling. Within the United States, climate modeling had been established as a curiosity-driven, academic enterprise, while NWP was a more utilitarian, operational activity.

The creation of the European Centre for Medium-Range Weather Forecasts (ECMWF) in 1979 (Woods 2005) heralded a European renaissance in weather and climate modeling, which continues to this day. ECMWF's universally recognized scientific excellence, strong academic connections, and robust funding model produced the world's most skillful global weather forecasts and also exerted, through collaborations and publications, a major influence on all of the world's climate models. Today, ECMWF is directly involved in climate science through the EC-Earth project (Hazeleger et al. 2010), the Copernicus Climate Change Service (Thépaut et al. 2018), and the Destination Earth initiative (Wedi et al. 2022).

In 1990, the United Kingdom Meteorological Office created the "Unified Model," which is now used for both weather forecasting and climate studies (Cullen 1993; Brown et al. 2012). About 10 years later, the Max Planck Institute for Meteorology (in Hamburg) and the German Weather Service undertook a joint project to use a single model, now called ICON (Icosahedral Nonhydrostatic Weather and Climate Model), for both weather forecasting and climate research (Majewski et al. 2002; Giorgetta et al. 2018). Today, the use of the same model for both weather and climate prediction is often called "seamless prediction" and has been widely advocated in Europe (e.g., Vitart et al. 2008; Palmer et al. 2008; Hoskins 2013). The Unified Model, ICON, and ECMWF's Integrated Forecasting System are among the most advanced global models in the world today. In retrospect, Europe took the lead in global atmospheric modeling decades ago, due in part to their visionary unification of weather and climate modeling. In 2012, the National Academy of Sciences recommended that the United States should also pursue a unified approach to weather and climate modeling (Bretherton et al. 2012), but this has been slow to develop. The United States has fallen behind.

Unified modeling

We believe that the increasing power of computers is making it possible to bring American weather and climate research closer together by adopting the same high-resolution global models for both weather and climate research, as recommended by the Bretherton et al. (2012) report. There are many opportunities here. Some of the most important parameterized processes in climate models fall under the heading of "weather." An example is deep convection, which gives rise to thunderstorms and strong precipitation that are universally perceived as dramatic weather events. As a model's grid is refined, more and more of this weather is explicitly simulated. Some of the changes are *qualitative*, not just quantitative. For example, with 100-km or even 50-km grid spacing, deep convection must be fully parameterized and mesoscale organization is not simulated, but with a grid spacing of 10 km or finer mesoscale convective systems appear in the right places and propagate realistically. These very-high-resolution global models are sometimes called global storm-resolving models (GSRMs) because they can simulate the mesoscales but their grids are not fine enough to realistically simulate individual thunderstorms. Today, some climate research is being conducted using GSRMs (e.g., Hohenegger et al. 2020; Judt 2020: Caldwell et al. 2021). Mesoscale modelers (weather people!) have decades of experience with regional storm-resolving models and the weather phenomena that they can fully or partly resolve. Some of these same mesoscale modelers are now working in the global domain (e.g., Skamarock et al. 2012). Global mesoscale modeling would profit from more input from mesoscale meteorologists, and they in turn can benefit from this important new capability.

It has been known for decades that, for a given model, many of the systematic errors in short-range deterministic forecasts resemble the model's climate biases. It is therefore possible to use an ensemble of deterministic forecasts to efficiently diagnose the model deficiencies that cause those biases. ECMWF pioneered work of this type (Arpe and Klinker 1986), and it continues today (Mayer et al. 2022; Frassoni et al. 2023). Seasonal simulations of the statistics of weather systems (e.g., mesoscale convective systems) are of climatological interest in themselves and can reveal problems with the models (e.g., Feng et al. 2023; Beverley et al. 2023). Such seasonal simulations are very feasible with GSRMs running on today's supercomputers (e.g., Wedi et al. 2020; Judt 2020; Shevchenko et al. 2023) and can be used to investigate such things as how severe weather will change in a future, warmer climate.

The same model can be configured as a GSRM for high-resolution applications, and as a lower-resolution model for long, CMIP-style simulations. A current scientific challenge is to formulate "scale-aware" parameterizations that work well for a wide range of grid spacings. Steps have been taken toward this important goal (e.g., Arakawa and Wu 2013), but much more work is needed, and input from weather scientists will be crucial.

Mending the schism

U.S. science will benefit enormously if we can mend the weather–climate schism. Climate research stands to benefit from increased interactions with the weather research community, while long-range weather forecasting would profit from what has been learned about bias trends in climate models. Here are some suggestions for how to move forward:

- Graduate students training to do climate research should be required to take courses in atmospheric dynamics and synoptic and/or mesoscale meteorology. Graduate students specializing in meteorology should at least take a good introductory course on climate dynamics. University departments should foster weather–climate balance in their curricula and encourage research and/or teaching collaborations between weather- and climate-oriented faculty members.

- Moving CGD and MMM into the same building and merging the two laboratories into one would enable and encourage greater collaboration. This would benefit not only NCAR itself, but also the university community that relies on NCAR to support community models. We note with approval that NCAR is heading in the direction of a unified modeling framework.
- NSF, NASA, and NOAA should each move to a single, unified global model for weather and climate studies, i.e., one model per agency. This would improve the science and simultaneously increase organizational efficiency. Each model should be tested in part by performing a large number of medium-range weather forecasts that are initialized with observations. Similar recommendations were made in the Bretherton et al. (2012) report, more than 10 years ago.
- NOAA's operational weather prediction models should be developed and tested in full collaboration with the academic community. This is the case in Europe, where it is also the norm in climate model development. We recognize that GFDL and NCEP are now using the same global atmospheric dynamical core, perhaps because of the recommendations in the Bretherton et al. (2012) report. The Earth Prediction Innovation Center (EPIC) led by NOAA and Raytheon may lead to additional progress. A further useful step would be to merge weather and climate model development into a unified framework that can be configured as a GSRM.
- The ongoing rapid introduction of machine-learning techniques into quantitative weather prediction offers a new opportunity for strong collaboration between research, operational, and private sector communities and makes mending the schism between weather and climate science even more urgent.
- The AMS and AGU should strive for better balance of weather and climate and for more society-based interactions between the weather and climate contingents of their member communities. We note that the theme of the 2024 AMS Annual Meeting, headed by a private-sector weather scientist, is "Living in a Changing Environment." Progress!
- NSF should support both weather and climate research through a unified program office. NSF's recent creation of the Division of Research, Innovation, Synergies, and Education (RISE) may prove to be a partial step in this direction. We also suggest that NSF issue a call for proposals for university-based participation in the development and testing of a GSRM based on the Community Earth System Model.

We have written this essay to provoke a national discussion that can lead to mending the schism. The process will be challenging, but the eventual payoff will be huge.

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