Commentary

Communicating climate complexity

From a climate perspective, we live in difficult times. Last year several high-temperature records were broken in Europe, a spectacular heat wave struck Australia, and the American Midwest experienced bitter-cold temperatures. This year California entered a fourth year of exceptional drought, another heat wave invaded western Europe with temperatures of more than 40 °C (104 °F) in some regions of Germany, and Montreal experienced one of its coldest winters on record. Such extremes have devastating consequences on societies and infrastructures. Predicting the moods of our climate a few seasons in advance has become a distinct field of research.

Scientists agree that rapid climate changes in polar regions must be considered in order to improve predictions. Even so, several obstacles still hinder society's practical use of climate predictions. A major three-day international workshop[1] held in December 2014 in Barcelona, Spain, brought attendees together to review those obstacles and discuss solutions. One success of the workshop lay in its unique structure: keynote presentations followed by "challenger" talks to provide participants with complete overviews on controversial topics, and large windows for breakout groups to discuss ways forward.

Polar regions have experienced rapid changes in response to anthropogenic influences. What effects those changes have had on the climate at lower latitudes or will have in the near future is an important question. The Barcelona workshop, convened by the Polar Prediction Project (PPP), which was established by the World Weather Research Programme, brought together about 80 leading scientists and researchers from 20 countries. Bearing the title "International Workshop on Polar–Lower Latitude Linkages and Their Role in Weather and Climate Prediction," the meeting had three objectives: Update the scientific community with the latest understanding of how polar climate affects lower latitudes and vice versa, identify what those links could mean for improving our climate prediction systems, and formulate guidelines for future research activities.

For a young scientist like me, such international meetings often seem both prestigious and impenetrable. This time, though, I was involved closely in developing, organizing, and participating in the workshop. I decided I should share its conclusions and my personal impressions with a larger audience.

The path between the scientist's understanding of the fundamental physical laws that govern the evolution of our climate and the delivery of tailored services to end users is anything but a straight line. In Barcelona, at least four obstacles were identified to explain why that is so. The workshop was focused on linkages between polar and lower-latitude phenomena, but the problems discussed below and ways forward that emerged from the conference are common throughout the climate community.

No climate laboratories

Most natural scientists spend a good part of their time in laboratories where they can design, test, and repeat experiments under control. Climate scientists are not so fortunate. They have access to only one unique "experiment"—our climate, observed as it is and has been changing. The lack of a "climate laboratory" can hamper the establishment of causal links. For certain cases, such as the relationship between carbon dioxide concentration and the rise in global temperatures, solid physical understanding is sufficient to give scientists a high confidence in the claimed link. For others, like the pole- to mid-latitude connections, the impossibility of conducting a controlled real-time experiment is a much wider concern.

To overcome the impossibility of manipulating the climate themselves, scientists have for decades developed numerical models. The models aren't perfect substitutes for reality. But they simulate our climate accurately enough to allow us to understand past changes and predict future ones and attribute observed extremes to certain factors. In Barcelona, participants recognized that central role of models and agreed that improving the way key processes are represented in them should be a priority to improve understanding of polar and lower-latitude linkages.

Complex, dynamical system

Imagine a set of three springs hung vertically end to end. An external influence—your hand moving the bottom spring up and down, for instance—will force the system to move. If you release the bottom spring, each one in the set will keep oscillating in a complicated way.

The components of our climate system exhibit variations that follow the same principles. In "forced variability," they respond to external influences, such as changes in greenhouse gas concentration. But they also exhibit "internal variability," in which variations are due to their own dynamics and interactions with other components. Interpreting climate time series and, by extension, possible linkages within the system is often difficult because forced and internal changes are superimposed on each other.

Here again, climate models can help. By running the same model many times under nearly identical conditions, researchers can partially filter out internally generated climate variability. However, to obtain meaningful statistics, the size of the ensembles of simulations should be large, typically more than 30, which poses several computational challenges. Coordinated model experiments are needed, as was emphasized in Barcelona, to avoid the possibility that scientific results would be model dependent. In all cases, studying groups of climate models is a necessary condition for robustly demonstrating possible links between polar and lower-latitude events.

Sparse observational record

The continuous monitoring of our climate rests on relatively recent technologies and devices. Reliable data extending further back in time would increase our understanding of climate variability and linkages, but they will obviously never be available. The observational record is also patchy: As you are reading these lines, thousands of instruments—rain gauges, radiosondes, buoys, floats, satellite-borne sensors—are deployed across the planet, but they only cover a tiny fraction of Earth's atmosphere, land, cryosphere, and oceans.

Our climate will never be monitored in a comprehensive way and in real time; the system is just too big. That said, it is certainly possible to optimize the current observational network by spotting key locations, periods, and variables to measure. One emblematic example is the upcoming Year Of Polar Prediction (YOPP, http://www.polarprediction.net/yopp), sponsored by the PPP. For a full year, intensive campaigns will be conducted at our two poles to enhance our understanding of polar processes and their role in connections with lower latitudes. One complementary way we could fill the sparse observational network is by using climate models and available observations to update model data. That field of research, known as data assimilation, bears particular promise and was often mentioned during the workshop.

Language barrier

A climate service, according to the World Meteorological Organization, is the "dissemination of climate information to the public or a specific user." So far, information has not flowed smoothly from scientists to service users for at least two reasons. First, climate scientists think probabilistically while most users think deterministically. Predicting the atmosphere's exact evolution beyond a few days is impossible because irreducible errors are present. Therefore, the best that scientists can do is to formulate probabilities about whether or not an event will occur. Unfortunately, users want deterministic, yes-or-no answers. Second, the time and distance scales of variables in climate models often do not match users' expectations or needs. Nowadays, most climate models output temperature, precipitation, and other physical variables that are averaged monthly over coarse (approximately 70-km) grids. Generally, users need much more specific information at much finer scale and higher frequency.

As was often said during the workshop, scientists should never second-guess user needs. Participants recognized that for climate research to be useful to the general public, it should start with no preconceptions about the nature of the problems. The best way to improve communication between climate scientists and service users is to get them to work together in the field. Several ongoing European projects like SPECS, which aims to improve climate forecast systems, or EUPORIAS, which is developing prototypes to maximize societal benefit of these improved forecast systems, represent significant breakthroughs in that respect.

Making progress

Providing society with tailored climate information at strategic time scales is a commendable objective. The Barcelona participants helped elucidate why providing that information is so challenging: The mathematical and physical problems of seasonal to interannual climate prediction are inherently difficult, our observational networks are limited in space and time, and suboptimal communication between very different communities can be a waste of everyone's energy and time.

The Barcelona workshop, crystallized around the question of linkages between polar and lower-latitude climate phenomena, addressed all those questions and represented, in that regard, a major milestone for the community. It was also an opportunity for me to realize that scientists spend a good share of their time disagreeing with each other, particularly about topics for which new theories are needed. I understood that science is not about simply crafting theories—any theory is necessarily incomplete—but about crafting theories that cannot be disproved. To date, no one has proposed a robust and simple theory that can explain how our poles affect our climate, but we now agree on the ways to make progress with the research. That agreement is perhaps what keeps our scientific community moving forward.

Reference

1. For the official Barcelona workshop report, see T. Jung et al., *Bull. Am. Meteorol. Soc.* (in press), doi:10.1175/BAMS-D-15-00121.1.

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Letters

The future of ITER

Fusion has long been an interest of mine, and I have followed closely the progress of ITER, the international prototype fusion reactor project. I found David Kramer's story (PHYSICS TODAY, May 2015, page 21) particularly revealing.

I began my career as a program manager and had the good fortune to serve under a group of managers who worked together on the Apollo program, where many of the tools for program management were developed. Coincidentally, the programs I took part in were primarily fusion related, including the Large Coil Project intended to develop prototype toroidal field coils for tokamaks.

The current state of ITER is easy to understand. None of the basic tenets of program management—well-defined specifications and budgets, effective change control, clear lines of authority, and a manager with the ability to promptly make key decisions—have been applied to it. The optimism apparently associated with the recent appointment of Bernard Bigot as director general is laughable. Until the participants are committed to converting ITER from a technopolitical hodgepodge into a real project, the US is completely justified in its skepticism. ITER has no chance of success under the current conditions.

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A data archive for storing precision measurements

Precision measurements are essential to our understanding of the fundamental laws and symmetries of nature.

Traditionally, fundamental symmetry tests focused on effects that are either time independent or subject to periodic modulation due to Earth's rotation about its axis or its revolution around the Sun. In recent years, however, attention has been drawn to time-varying effects, starting with the searches for a possible temporal variation of fundamental "constants." Even more recently, researchers are looking for transient effects[1] and oscillating effects[2] due to ultralight bosonic particles that could be components of dark matter or dark energy.

To search for nonuniform dark energy or dark matter, researchers have proposed networks of atomic magnetometers and clocks.[1] The readings of remotely located network sensors are synchronized—for example, using the timing provided by GPS—and analyzed for specific transient features. Also being discussed are hybrid networks consisting of different types of sensors that would be sensitive to different possible interactions with the dark sector (see http://www.nature.com/nphys/journal/v10/n12/extref/nphys3137-s1.pdf).

A compelling example of time-stamped and stored datasets is the orbit and clock estimates of the Global Navigation Satellite Systems (GNSS) available through the International GNSS Service (http://igscb.jpl.nasa.gov). This service is the backbone of modern precision geodesy. The available multiyear archival data can be used to search for transient variations of fundamental constants associated with the galactic motion through the dark-matter halo (see http://www.dereviankogroup.com/gps-dm/).

The field of precision measurement appears to be undergoing a paradigm shift, with new theoretical and experimental ideas sprouting almost daily. For instance, reanalysis of data from using atomic dysprosium to look for the variation of the fine-structure constant and to test Lorentz invariance has set new limits on the scalar dark matter.[3,4] That has been made possible by the existence of well-documented, accessible data sets stored electronically.

An example of a new experimental idea is using precise beam-position monitors in particle accelerators to test for specific types of Lorentz-invariance violations.[5]

Inspired by all those exciting developments, we propose that data streams from any ongoing precision measurements be time-stamped and stored for possible future analysis. We are convinced that the cost of data storage and GPS timing is relatively small and that the data storage will be straightforward to implement technically, though, of course, the price and complexity crucially depend on the precision of the time stamp and the data rate. Conversely, failing to time-stamp and store the data is likely to be an enormous waste. The search for transient effects of the dark sector is already a good motivation to create a data archive, and additional ideas of how to use such data are likely to emerge in the future.

What information should be time-stamped and recorded as a raw data stream? Data from optical and matter interferometers, experiments measuring parity violation and looking for permanent electric dipole moments, precision-measurement ion traps, all precision experiments with antimatter, and, by default, anything measured precisely.

We live in the age of Google and GPS; our thinking about experimental data should be keeping up with the times!

References

1. S. Pustelny et al., *Ann. Phys.* **525**, 659 (2013); A. Derevianko, M. Pospelov, *Nat. Phys.* **10**, 933 (2014).
2. P. W. Graham, S. Rajendran, *Phys. Rev. D* **88**, 035023 (2013); B. M. Roberts et al., *Phys. Rev. D* **90**, 096005 (2014).
3. K. V. Tilburg et al., *Phys. Rev. Lett.* **115**, 011802 (2015).
4. Y. V. Stadnik, V. V. Flambaum, http://arxiv.org/abs/1504.01798.