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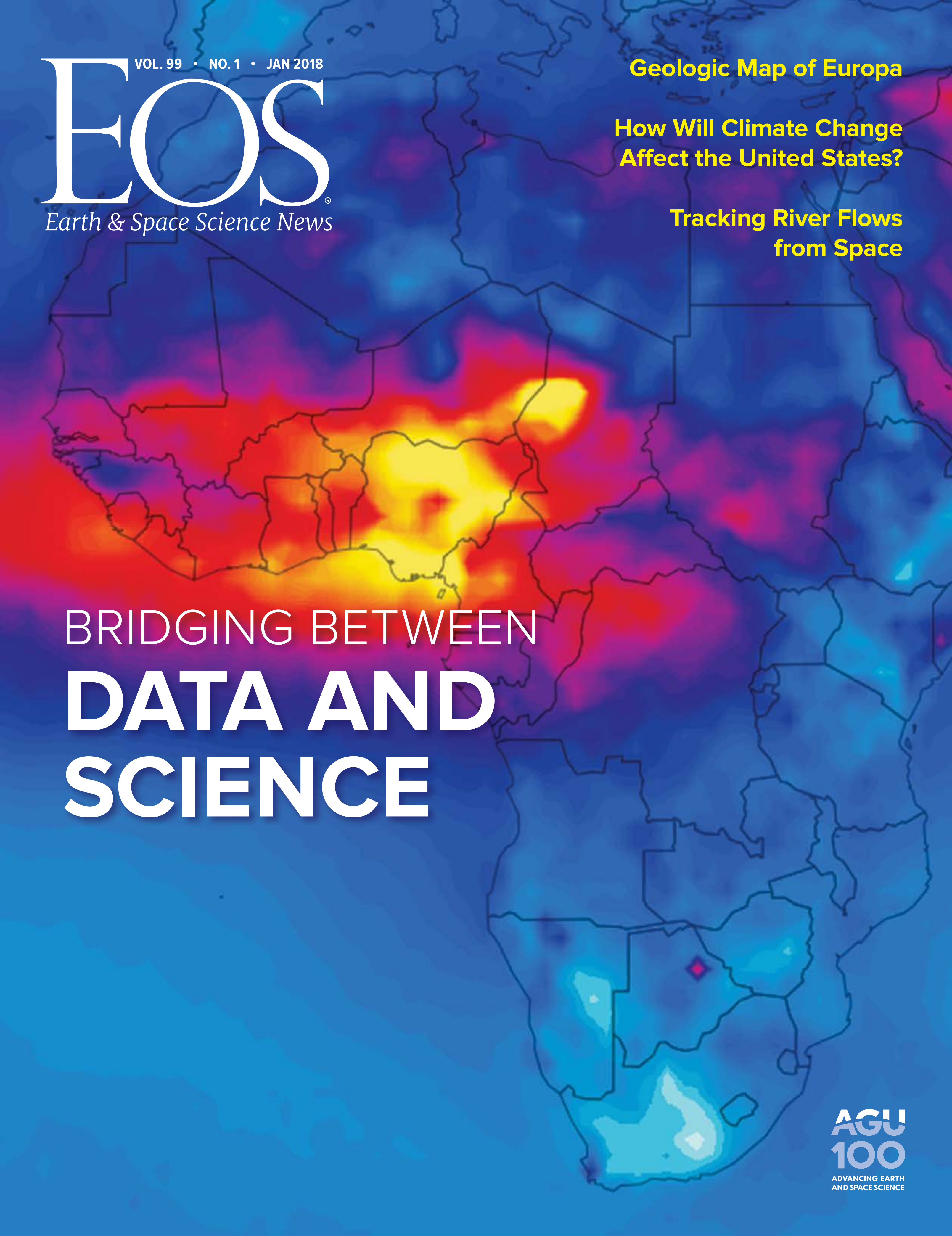


BRIDGING BETWEEN DATA AND SCIENCE

AGU 100 ADVANCING EARTH AND SPACE SCIENCE

To Understand Future Solar Activity, One Has to Know the Past

Staff Sgt. Erin O'Connell, a solar analyst with the U.S. Air Force 2nd Weather Squadron, creates a sunspot drawing from a projected image of the Sun at the Holloman Solar Observatory in New Mexico on 24 September 2015. Credit: Senior Airman Aaron Montoya, U.S. Air Force

Solar activity waxes and wanes in 10- to 11-year cycles; this is now general public knowledge. However, we know this only because of existing long-term records. Thanks to these histories, we also know that properties of solar cycles vary on timescales of 100 years and even longer. Thus, some of the most important processes on the Sun may take decades if not centuries to reveal themselves [*Owens*, 2013].

This long timescale means that some issues are not resolved, or even identified, at the time when data are acquired. Synoptic observations of solar activity, programs that span many years, feed future research to solve these issues.

However, present-day research funding schemes tend to focus on providing effective funding for rapidly changing research goals. Funding agencies and the U.S. National Academies emphasize short grants, lasting 3–5 years, as the prime vehicle for funding scientific research, a duration too short to ensure the survival of synoptic programs.

> Unfortunately, we are witnessing an alarming decline in funding, and even cancellation, of long-term programs.

How do we change this focus so that the synoptic studies so critical to our understanding get sustainable funding?

Insights Gained from Taking the Long View

Historical data show the presence of grand minima and grand maxima, when the Sun was either inactive or extremely active for an extended period. Those major changes in solar activity seem to have created significant changes in the past Earth climate, making long-term records essential to solving critical issues of the 21st century.

Even records of past solar activity that come from isotopic sources such as ice cores and tree rings rely on establishing a relationship between radiocarbon measurements and direct observations of solar activity. Because the natural circulation of carbon in Earth's atmosphere was affected by the explosive increase in the use of fossil fuels at the beginning of the Industrial Revolution, only historical observations of solar activity can be used for calibrating radiocarbon data. The absolute radiocarbon standard is based on wood from the year 1890.

Sometimes, historical records of direct observations of solar activity themselves may require critical analysis. Recently recalibrated records of sunspot numbers [*Clette et al.*, 2016] indicate, for instance, that solar cycle amplitudes may have been more uniform in the past 3 centuries than assumed until recently. If this result can be fully confirmed, it weakens the evidence for a solar cause of global warming.

We also have historical time series of direct measurements of sunspot magnetic field strengths and ultraviolet observations of the Sun going back more than a century. In combination with modern dynamo models, these historical data allow us to explore the possible changes in properties of solar plasma in the convection zone, where these magnetic fields are generated, and form a better understanding of future cycles. Paraphrasing Carl Sagan, "You have to know the past to understand the future."

Shortsighted Funding Strategies

Unfortunately, despite the importance of long-term time series, we are witnessing an alarming decline in funding, and even cancellation, of long-term programs. For example, 2016 brought us the disbanding of a solar group at Debrecen Heliophysical Observatory in Hungary, thus interrupting the recording of a historical time series of sunspot group areas that spans more than a century. (However, see the comment at http://bit.ly/Debrecen-update for an update; the core scientific staff has continued its work.) This project had started at Greenwich Royal Observatory in May 1874 and was transferred to Debrecen at the end of 1978.

At Mount Wilson Observatory in California, scientists continue direct measurements of sunspot field strength that began in 1917. Funding for this project has been discontinued, but the effort lives on because of heroic efforts of remaining observing personnel. Similar cuts to sunspot measuring programs threaten research around the world.

Orchestrating Change

The success of long-term synoptic observations requires long-term sustainable funding. The short-duration project funding schemes that have prevailed in recent years are unsuitable for long-term data collection and continuous monitoring. Indeed, long-term continuity is a key requirement for producing meaningful and usable data sets.

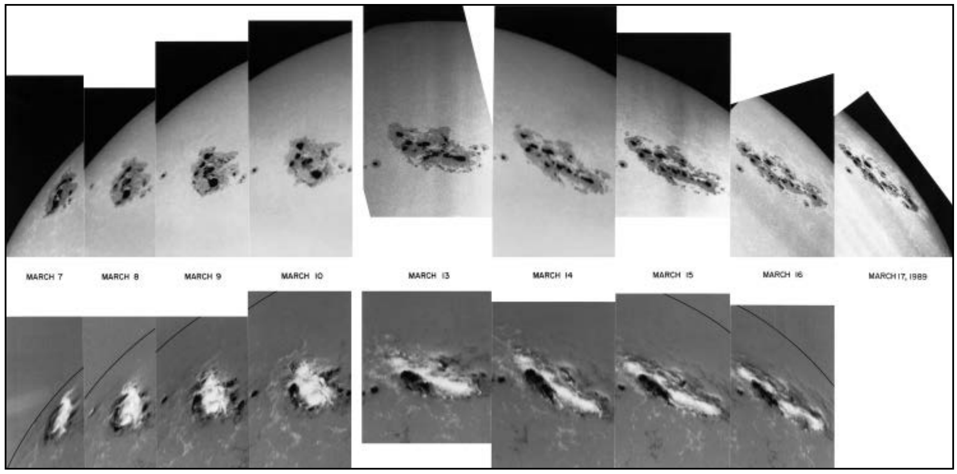
This does not mean that nothing changes over the term of a time series. Not all historical time series need to be continued, and instruments inevitably change over the lifetimes of long-term time series. However, change must be carefully planned and orchestrated to maintain the uniformity of a time series, including cross calibration of new and old instruments.

Although some efforts are being made to develop replacements for aging synoptic facilities, there is an overall lack of long-term planning for such programs. This lack of planning may lead to the creation of ad hoc "networks" of nonuniform instrumentation and unnecessary duplication.

This area of research also benefits from close international collaboration. One strategy for using funding efficiently would be to establish a list of observables that the international community considers worthy of continuing for an extended period of time. Then the funding agencies and the U.S. National Academies could be approached to establish a mechanism for shared funding for such time series. In this funding model, even countries with limited research capabilities may contribute to the overall success. To ensure the survival of historical time series, this work needs to be done *now*.

Our Obligation to Future Scientists

To some, conducting synoptic solar observations today may not seem as attractive as running space-based telescopes or the newest experimental instruments on the ground. Actually, our epoch proved highly efficient at exploiting past scientific records, thanks to



A series of images of the Sun taken 7–17 March 1989 shows the evolution of a large sunspot group (NOAA 5395) as it moves around the Sun. The top sequence, taken in white light, shows the sunspot as it appears in the photosphere (solar visible surface). The bottom images are magnetograms of the same sunspot region, showing variations in magnetic polarity. During its disk passage, this active region produced more than 100 X-ray flares, including 11 flares in the most powerful X class. This eruptive activity was the cause of the "great geomagnetic storm" of 13–14 March, which affected radio communications and satellite operations and caused the famous Quebec blackout on 13 March 1989. See Allen et al. *[1989] for a detailed description of solar and geomagnetic activity associated with this active region. Credit: NOAO/AURA/NSF*

modern computing and "big data" technologies, which often led to scientific breakthroughs.

For example, one recent study [*Svalgaard*, 2016] used 46 million hourly measurements of the geomagnetic field to reconstruct the solar extreme ultraviolet flux from 1740 to 2015. If we neglect to continue these long-term data collection activities, we will prevent future generations of researchers from solving critical scientific issues that we can hardly foresee today.

Remember, the impacts of solar magnetic activity on our current technologies or global climate warming issues were completely unknown when Galileo, Schwabe, and Wolf began patiently recording dark sunspots centuries ago, but their efforts were vital to our current understanding of this impact. Scientists 15–20 years from now will perhaps wonder with disapproval why we did not continue the long-term record of observations.

Several recent meetings indicate a recognition of a growing demand in the solar physics community for sustainable and coordinated efforts in respect to long-term synoptic programs. One such meeting was the Splinter Meeting on Coordination of Synoptic Observations, held 16 October 2017 at the Max Planck Institute for Solar System Research in Göttingen, Germany (see http://bit.ly/SMCSO-2017). The U.S. National Academy of Sciences' Committee on Solar and Space Physics discussed long-term synoptic programs and data preservation at its 24–25 October 2017 meeting in Irvine, California (see http://bit.ly/CSSP-2017).

We live next to a variable star, and the only way to learn about its long-term behavior and, ultimately, to be able to predict it, is to guarantee the survival and continuity of long-term synoptic observations.

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