ATMOSPHERIC SCIENCE

Severe weather in a warming climate

During the past few decades, the Sahara Desert has become even hotter. Satellite observations suggest that this warming has led to a rise in the frequency of extreme storms in the Sahel region of West Africa. SEE LETTER P.475

CHUNTAO LIU

One of the most frequently asked questions regarding climate change is how a warming climate will affect weather in the future. Many disastrous weather events in the past few decades, including Hurricane Katrina (2005) and Hurricane Sandy (2012), have driven scientists to seek a better understanding of the occurrence, frequency and intensity of such events. For example, there has been debate over whether warming will lead to an increase in the number of intense tropical cyclones[1,2]. A major obstacle in reaching a conclusion from these discussions is that extremely destructive weather events are rare, making it difficult to obtain robust statistics. On page 475, Taylor *et al.*[3] make progress in this direction. They use 35 years of satellite observations to show that there has been a persistent increase in the frequency of extreme storms called mesoscale convective systems in the Sahel — the semi-arid region to the south of the Sahara Desert (Fig. 1).

It is always tricky to identify a long-term trend from satellite observations, because of complications associated with calibration. In particular, the instrumental sensitivity of a satellite can vary if its sensor wears out or if its orbit drifts. When multiple satellites are involved, the concern is with the compatibility of calibrations between sensors that have different resolutions, geometries and sensitivities: newer satellites usually have higher resolution and sensitivity than older ones.

Taylor and colleagues analysed satellite images of the Sahel produced by thermal infrared sensors on board the Meteosat geostationary satellites over 35 years (1982–2016). The authors address the calibration issues by downgrading all the satellite images to a coarser resolution. They then focus on populations of clouds that are large (with areas exceeding 25,000 square kilometres) and cold (with temperatures below –40 °C), because these are typical features of mesoscale convective systems[4]. This approach removes, to a reasonable extent, the possible biases caused by different sensors, making the statistical analysis more convincing.

LUIS DAFOS/GETTY

Figure 1 | Gathering storm clouds in Timbuktu, Mali. Taylor *et al.*[3] have used long-term satellite observations to show that, since 1982, there has been a persistent rise in the frequency of extreme storms in the Sahel region of West Africa, south of the Sahara Desert. The authors suggest that this is caused by an increase in the temperature gradient across the region, which is driven by a warming Sahara.

The authors found a three- to fourfold increase in the number of intense mesoscale convective systems in the Sahel in recent years, compared with 1982. If this trend continues, it will have implications for both agriculture and infrastructure in the region, because these storms are responsible for about 90% of the Sahel's rainfall[5].

Over the past two decades, the effect of a warming climate on the organization of convection has been a topic of debate[6,7]. In particular, it has been speculated that convection will become more organized in the future — under the assumption that a warmer climate would give rise to an environment that supports less entrainment (mixing of dry environmental air into clouds), a stronger updraft (small-scale currents of rising air) and more-intense convection. If true, this could lead to an increase in the frequency of extreme weather events, because these are often tied to large, intense convective systems. To go beyond speculation, however, it will be necessary to understand the distribution and characteristics of extreme precipitation events across many different regions. This is because there will be substantial regional variations in how the atmosphere responds to the changing climate[7].

Taylor and colleagues show that the number of intense mesoscale convective systems in the Sahel is highly correlated with global land temperatures. Because Sahelian temperatures have not risen during the past few decades, the authors propose that their results are instead caused by an increase in the temperature gradient across the region, which is driven by a warmer Sahara. They argue that this warming has led to increased convection through enhanced wind shear (the difference in wind speed over a relatively short distance, either vertically or horizontally, in the atmosphere) and changes to the Saharan air layer. These are reasonable speculations that could probably be validated using simulations of the regional climate. The authors' conclusions confirm the complicated nature of how regional weather patterns respond to climate change.

There are two key messages from Taylor and colleagues' work. First, the authors have demonstrated that severe weather events have substantially increased in certain regions over the past few decades. This observation is clear evidence of a variation in weather patterns, and is likely to be related to climate change. Second, the authors have shown that, with a careful analysis, satellite observations can be used to monitor such long-term variations.

In addition to the infrared images used by Taylor *et al.*, observations of microwave radiation[8], dating back to the mid-1980s, can reveal details about the distribution of precipitation on Earth's surface. Furthermore, space-borne radar[9,10] has been in orbit since the late 1990s. Observations from these satellites contain a great amount of information about the process of precipitation and the structure of

precipitation systems. It is therefore anticipated that more evidence of variations in weather patterns in different regions will be revealed by these valuable observations. ■

Chuntao Liu *is in the Department of Physical and Environmental Sciences, Texas A&M University at Corpus Christi, Corpus Christi, Texas 78412, USA.*
e-mail: chuntao.liu@tamucc.edu

1. Emanuel, K. *J. Climate* **20,** 5497–5509 (2007).
2. Landsea, C. W., Vecchi, G. A., Bengtsson, L. & Knutson, T. R. *J. Climate* **23,** 2508–2519 (2010).
3. Taylor, C. M. *et al. Nature* **544,** 475–478 (2017).
4. Houze, R. A. Jr *Rev. Geophys.* **42,** RG4003 (2004).
5. Mathon, V., Laurent, H. & Lebel, T. *J. Appl. Meteorol.* **41,** 1081–1092 (2002).
6. Bretherton, C. S., Blossey, P. N. & Khairoutdinov, M. *J. Atmos. Sci.* **62,** 4273–4295 (2005).
7. Muller, C. J. & Held, I. M. *J. Atmos. Sci.* **69,** 2551–2565 (2012).
8. Sapiano, M. R. P., Berg, W. K., McKague, D. S. & Kummerow, C. D. *IEEE Trans. Geosci. Remote Sens.* **51,** 1492–1503 (2013).
9. Kummerow, C., Barnes, W., Kozu, T., Shiue, J. & Simpson, J. *J. Atmos. Oceanic Tech.* **15,** 809–817 (1998).
10. Hou, A. Y. *et al. Bull. Am. Meteorol. Soc.* **95,** 701–722 (2014).

MICROSCOPY

A larger palette for biological imaging

Biological molecules are often imaged by attaching fluorescent labels — but only a few label types can be used at a time. A method that could smash the record for the number of labels that can be used together is now reported. See LETTER P.465

CHARLES H. CAMP JR & MARCUS T. CICERONE

If we could walk around a cell system, observing protein synthesis, witnessing the dynamic choreography of regulation processes and identifying the plethora of transported molecules, then our understanding of cell biology would expand explosively. Instead, we must settle for experiments in which just a few biological molecules of interest (biomarkers) can be labelled and imaged at once. But on page 465, Wei *et al.*[1] report a method that dramatically enhances our ability to distinguish between labels, thus increasing the number of labels that can be used together — ironically, by adapting a microscopy technique that was originally developed as a label-free imaging method.

Biological samples can be readily prepared with multiple labels, but imaging one label among many is challenging. Fluorescent labels known as fluorophores (Fig. 1a) each emit a broad range of colours, and these ranges often overlap — which makes it difficult to discriminate between more than four or five labels. Furthermore, multiple lasers (sequentially applied) might be necessary to excite each fluorophore at its characteristic absorption wavelength to induce fluorescence. Labels known as quantum dots were developed to resolve these issues (and others)[2] by having broader absorption and narrower emission profiles than fluorophores, but so far their simultaneous usage has been limited to eight colours[3].

An alternative approach for bioimaging does not use labelling, but instead detects the vibrational signatures of molecules. These signatures are composed of one or more vibrational resonances, with each resonant frequency determined by the number and type of atom involved, and by the vibrational mode (such as stretching or twisting). The signatures can be obtained from a molecule's infrared absorption spectrum, or from its Raman spectrum — which is generated through 'inelastic' scattering of incident light, and forms the basis of an imaging technique called Raman microscopy.

Raman microscopy provides spatial resolution akin to current fluorescence microscopy techniques, but the signals produced are extremely weak[4] (typically requiring tens of milliseconds to seconds per spectrum to acquire sufficiently strong signals for detection in biological specimens). A variant of the technique called coherent Raman imaging (CRI)[5,6] uses pulsed laser sources to actively drive molecular vibrations. This substantially enhances signal intensities, enabling video-rate imaging for concentrated biomolecules. In general, however, techniques based on Raman scattering (coherent or not) require[6] high molecular concentrations of about 10 millimoles per litre (approximately 6 million target molecules per femtolitre; 1 fl is 10^{-15} litres). It has therefore not been possible to use these techniques to map molecules that occur at low concentrations, such as those found on cell surfaces.

Wei and colleagues attack the detection-limit problem for Raman imaging in an unexpected manner: by using fluorescent labels. Their approach uses stimulated Raman scattering[5,6] (SRS; a CRI method that involves two laser sources, Fig. 1b) to detect the enhanced vibrational signatures of labels that have been

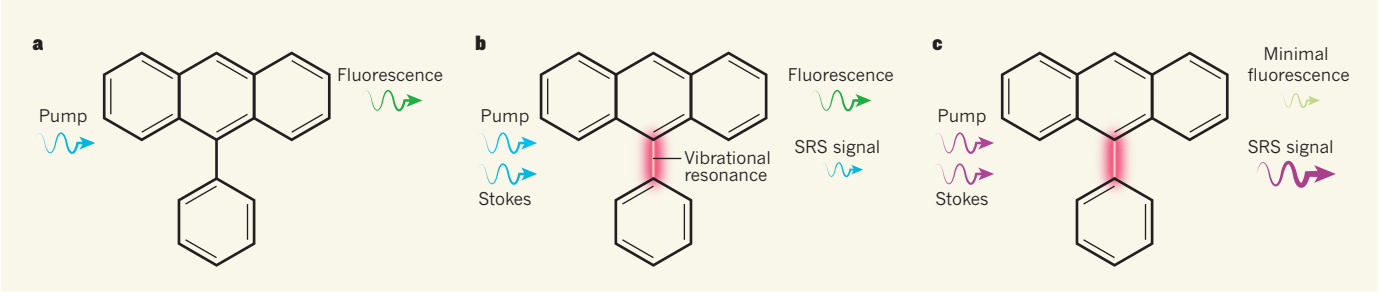

Figure 1 | Modes of light emission from fluorescent molecules. **a**, When fluorescent molecules are irradiated with 'pump' laser light at the molecules' electronic resonance wavelength, an electronic excitation occurs that generates fluorescence. **b**, If the same molecules are irradiated with pump and 'Stokes' laser sources at different frequencies, certain frequency combinations cause the molecules to vibrate at a resonance frequency. This causes a process called stimulated Raman scattering (SRS) to generate more light at the Stokes wavelength, which can be obscured by fluorescence. **c**, Wei *et al.*[1] pumped fluorescent molecules with laser light at pre-resonance wavelengths (which are close to the electronic resonance wavelength) and with a Stokes laser so as to stimulate vibrational resonance. This generated a much larger SRS signal than in **b**, with minimal fluorescence. The authors demonstrate that, for each molecule, only a narrow range of input light frequencies induces a signal — which allows many different types of molecule to be used simultaneously as labels for biological molecules in imaging experiments.