CLIMATE CHANGE

Shifts in season

David J. Thomson

It's cold in winter and hot in summer. But the latest analysis illustrates the need to put observational data at the forefront of attempts to achieve a more detailed understanding of the annual temperature cycle.

It has been known for more than a century[1] that increasing the concentration of carbon dioxide in the atmosphere results in an increase in Earth's surface temperature. By contrast, it is only just over a decade since the discovery that CO_2 levels also affect the timing of the annual temperature cycle[2,3], although the details remain enigmatic.

On page 435 of this issue, Stine and colleagues[4] describe how they have updated and extended earlier studies of the annual cycle[5,6], using better spatial coverage and more recent data. They have concentrated on the temperate zones because of the dominant annual temperature cycle and, at least in the Northern Hemisphere, the reasonable spatial data coverage in those zones. As well as incorporating some technical improvements, the authors analysed the annual temperature cycle over the oceans.

The annual cycle has two distinct components, amplitude and phase. Stine and colleagues conclude that the amplitude — loosely, half the difference between summer and winter temperatures — has been decreasing over most continental areas and increasing over the oceans. The phase describes the relative timing of the periodic (seasonal) component of temperature. For the most part, the seasons occur earlier over land and later over the oceans, and Stine *et al.* estimate the terrestrial phase shift to have been 1.7 days between 1954 and 2007. This shift, and the changes in amplitude, are highly anomalous when compared with the data from between 1900 and 1953, implicating human agency as the cause.

The common perception of the timing of the seasons is more complicated because it involves both changes in the annual cycle, discussed here, and the increase in average temperature. (See Figure 1 of the Supplementary Information[4] for a graphic description of the different effects.) For example, taking the date from which the temperature usually stays above freezing as marking the start of spring, the increase in average temperature, the smaller seasonal amplitude (which implies warmer winters) and the change in phase all work in the same direction, so the observed effect is large. This is well documented in studies of bird migrations and similar phenomena[7,8], where one finds many examples of seasonal patterns shifting to an earlier date by more than a month (Fig. 1). Phase changes have also been invoked to help explain problems ranging from the theory of palaeoclimates[9] to changes in sea level[10] and even in human mortality[11].

Stine *et al.*[4] also compare their observations with the results of a suite of two dozen climate models used by the Intergovernmental Panel on Climate Change (IPCC), and the results are dismaying. Some of these models reproduce the decrease in amplitude, first shown in 1980 (ref. 12), but none predicts, or even reproduces, the change in phase. I have no personal experience with these models, so beyond a general scepticism about complicated models (perhaps best expressed by George Box's dictum, "All models are wrong but some are useful"), I cannot say why they fail. We must remember, however, that although climate models incorporate an amazing variety of effects and get many things right, they are almost certainly missing many more.

As an example, in the mid-1990s I was discussing the phase problem with members of a modelling group and learned that their model had Earth in a circular orbit with no precession. This was astonishing. First, we are trying to measure the effects of CO_2 to high accuracy — say 0.01 °C, in a system in which annual temperature extremes routinely exceed ± 50 °C. Second, on an ice-age timescale, the effects of precession are immense, strong enough to be used as a clock. Third, we have known that the orbit is elliptical since Johannes Kepler in the seventeenth century, and about precession since Hipparchus (around 150 BC). The duration of the instrumental temperature record is now 1% or 2% of the 26,000-year precession cycle: when trying to measure small effects it is unwise to ignore large ones.

One should also note the contrast between the enormous computational resources used by the models and the relatively meagre effort required to analyse real data. Thus, work of the type done by Stine *et al.* is to be applauded. Ignoring the time required to assemble the data and write the programs, it probably took no more than a few seconds of computer time to show effects that were not predicted by any of the models. As Richard Feynman commented, "It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong."

S. PANTHAKY/AFP/GETTY IMAGES

Figure 1 | Migrating greylag geese. Spring, and associated phenomena such as bird migrations, now occur earlier than at the start of the twentieth century. Stine and colleagues' data[4] quantify the seasonal shift.

Where do we go from here? One of many perplexing problems is the year-to-year variations in phase and amplitude in temperature data. These variations are obvious in all of the long-term temperature records and are reasonably consistent with variations in the Sun's magnetic field. We do not understand the subtle influences on climate exercised by solar effects such as the solar wind, the charged particles that flow out from the Sun. Observational evidence for such a coupling has been accumulating for decades, through both palaeoclimate data[13] and studies of the upper atmosphere[14]. However, when one has observed the Sun's acoustic oscillations in barometric pressure[15], it is possibly time to pay attention to solar observations.

The solar wind carries much more energy than is available from Edward Lorenz's butterflies, often used to 'explain' purported chaotic behaviour in climate. This raises a philosophical question, as to whether the fascination with 'chaoplexology' in climate research has resulted in a failure to take observations and statistics seriously enough. Climate may be formally chaotic, but so is Earth's orbit[16] and this has not prevented people from analysing it in exquisite detail. In my opinion, chaos, fractals, long-memory processes and their ilk should be invoked only when all of the various climate forcings have been carefully studied and all simpler explanations eliminated. We are not even close to meeting that goal.

Finally, independent of any shortcomings in the models, we must remember that the observational evidence for human influence on the climate system is overwhelming. Stine and colleagues' paper[4] adds to that evidence. If we do not stop polluting Earth's atmosphere, we may not have enough time left to develop models sophisticated enough to show what is obvious in the data now. ■

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MOLECULAR BIOLOGY

Concealed enzyme coordination

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Coordination between subunits is crucial for the proper functioning of multi-component molecular machines. A single-molecule study now allows glimpses into the mechanism used by subunits of one such machine.

Even 2,000 years ago, Aristotle had noted that the whole is more than the sum of its parts. This maxim also holds true in the cell, where enzymatic proteins frequently combine to form multimeric complexes that allow individual subunits to coordinate their activities and so perform more difficult tasks than they could alone. A prominent example of such a complex is the ring ATPases[1], in which — as their name implies — several subunits form circular complexes consisting of identical (homomeric) or non-identical (heteromeric) subunits. These enzyme complexes use energy released from the hydrolysis of ATP molecules to perform diverse cellular functions, such as DNA translocation, protein degradation and ion transport. On page 446 of this issue, Moffitt and co-workers[2] provide the first direct measurement of a single enzymatic cycle by a homomeric ring ATPase, revealing an unexpected form of coordination between the subunits.

Subunits of the various ring ATPases can coordinate their activities in different ways. For instance, the three heterodimers of the F1-ATPase act sequentially, each binding an ATP molecule and hydrolysing it in order[3] (Fig. 1a). By contrast, subunits of the L Tag helicase of simian virus 40 seem to act in concert, all six of them simultaneously binding then hydrolysing ATP molecules[4] (Fig. 1b). Subunits of the unfoldase enzyme ClpX, however, are thought to act randomly, each one hydrolysing ATP independently, with their activities probably being coordinated by the geometry of the complex[5] (Fig. 1c).

To investigate the coordination mechanism of a homomeric ring ATPase in detail, Moffitt

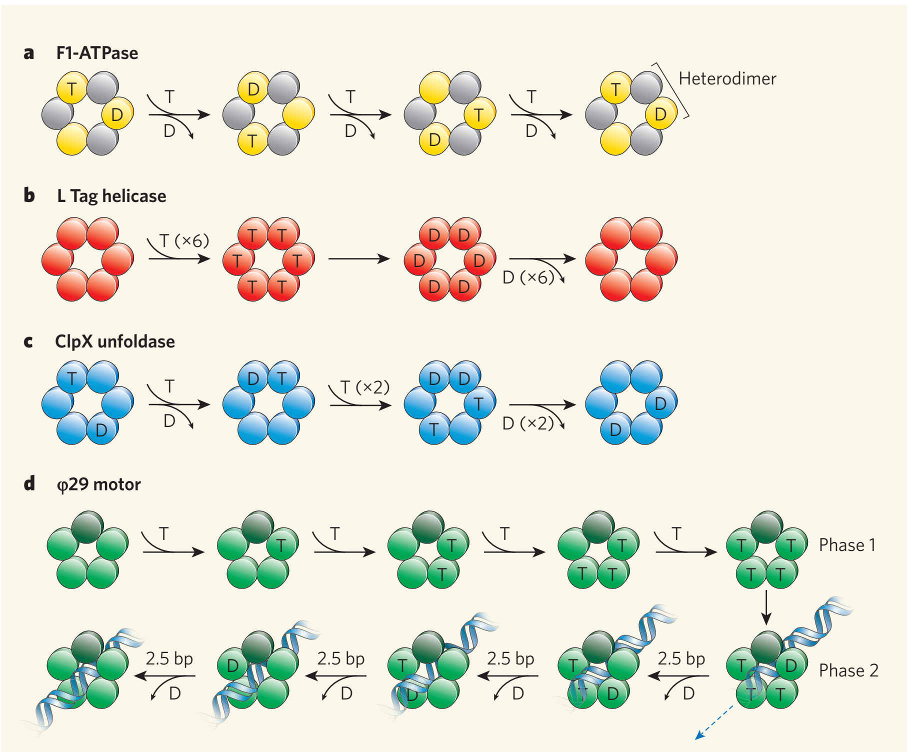

Figure 1 | Proposed coordination mechanisms of ring ATPases. a, The subunits of F1-ATPase, which exist as three heterodimers, bind to and hydrolyse ATP molecules sequentially. **b,** Subunits of the L Tag helicase, by contrast, function in concert, all simultaneously binding to ATP molecules before hydrolysing them. **c,** Subunits of the ClpX unfoldase seem to function semi-independently in a random order. **d,** Moffitt *et al.*[2] describe a newly discovered two-phase coordination mechanism for the homomeric ring ATPase of the bacteriophage φ29. Here, the subunits sequentially bind ATP molecules during the loading phase, and then, in a separate phase, sequentially hydrolyse ATP to translocate the DNA substrate. The exact timing of ATP hydrolysis is not known, and might not occur in conjunction with the steps. Circles indicate enzyme subunits, T denotes ATP, and D refers to its hydrolysis products.