How the Earth's atmosphere shows its face

Atmosphere of the Earth

Looking from outer space, the Earth's atmosphere appears as an encapsulating fluid that flows in patterns caused by the rotation of the planet and the heating from the Sun. Up close, however, the atmosphere shows its face in much more detail, helping researchers understand the complex interactions in the Earth system.

Temperature of the atmosphere

The temperature of the Earth is much like the temperature of a person: it is a symptom of everything else that is going on in that person's body. It may seem like a basic property of the atmosphere, but it is a product of many other aspects of the Earth system, including land and oceans.

Recently, there has been much discussion of the so-called 'temperature hiatus', the weakening of the trend in global mean surface air temperature since the late 1990s. Observations, such as those from the HadCRUT4 dataset, appear to show temperatures in the past decade rising more slowly than in the preceding two decades (see figure below).

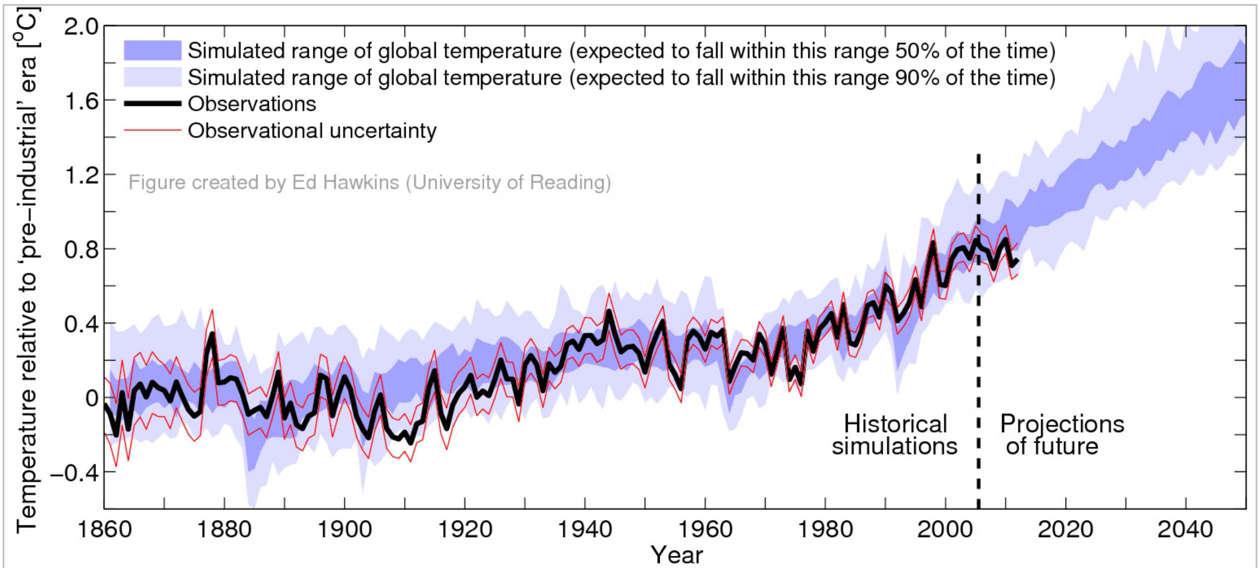
The HadCRUT4 dataset is a combination of ground-station and sea surface temperature measurements, which represent about 85% of Earth's surface. Recent analysis by Cowtan and Way has tested whether this data contains a bias due to incomplete coverage of the globe, and they conclude that it has led to an underestimate of recent global warming. The authors point out that satellite data, models and isolated weather station data show that regions not covered by the dataset, especially the Arctic, have warmed faster than other parts of the world. Accounting for this gives a trend two and a half times greater than that from HadCRUT4, for temperature since 1997.

So even establishing the magnitude of the temperature hiatus is an ongoing area of research. The range of different studies investigating the causes of it is indicative of just how many different factors affect the air temperature.

Work by Estrada, Perron and Martínez-López explores global temperature data sets and radiative forcing variables (greenhouse gases in the atmosphere, natural changes in composition and land use, and solar irradiance) using statistical techniques. Their method interrogates the data without the use of models, and the authors conclude that the temperature record and the radiative forcing (which describes whether the Earth system has a net warming or cooling) can be described by linear trends punctuated by breaks. In this picture, the hiatus is simply a period with a different trend following a break. But what caused this break to occur?

The results suggest that the predominant cause was an unintended consequence of the 1987 Montreal Protocol, the international treaty to stop the destruction of stratospheric ozone by chlorofluorocarbons (CFCs). CFCs are also greenhouse gases, so reducing them to protect the ozone layer also led to a relative cooling of the atmosphere. Pretis and Allen tested this finding in an energy balance model and found that global mean temperatures are 0.1°C cooler because of the Montreal Protocol.

Estrada and colleagues also attributed a cooling from the reduction in the methane growth rate in recent years. Methane is a potent but short-lived (about a decade) greenhouse gas, with major natural and anthropogenic sources. The amount of methane in the atmosphere had been growing in the latter half of the 20th century, until it levelled off in the period around 2000 to 2006. The cause of this stagnation is in itself an active research area, with changes



This graph of average global temperatures is generated using 42 different climate simulators, assuming 'medium' (Representative Concentration Pathway: RCP4.5) future emissions of greenhouse gases, and compares their projections to observations from the HadCRUT4 dataset. A common reference period of 1961–1990 is used, but the temperatures are presented relative to the 'pre-industrial' era. (Image and caption: Ed Hawkins, Climate Lab Book)

The dome of the Jungfraujoch atmospheric observatory in Switzerland is seen in the distance in this photo. (Credit: Michelle Cain)

to agricultural practices, variability of wetlands, and changing fossil fuel emissions being likely factors.

Others have looked to the oceans to find a cause for the temperature hiatus. Modelling work by Kosaka and Xie shows that it can also be explained by recent La Niña events. La Niña events are characterised by cooler tropical Pacific sea surface temperatures and cooler surface air temperatures. By putting observed tropical Pacific sea surface temperatures in to an atmospheric model (which also contained the observed greenhouse gas concentrations), the authors were able to reproduce the hiatus.

This is not necessarily in contradiction to the Estrada study, as Kosaka and Xie do not specify what is causing the sea surface temperatures to be La Niña-like – the cause could be linked to greenhouse gas warming. A trend towards more La Niña-like conditions since 1950, coinciding with increases in global mean surface temperature, has been identified by L'Heureux et al..

These studies illustrate some of the complex interactions between atmospheric temperature, composition and climate. If temperature is the symptom, then we have seen that the make-up of the atmosphere is one of the many causes. To complicate things further, the symptom can also feed back into the cause. For example, wetland emissions of methane depend on temperature, so a warming Arctic may cause increased methane emissions and therefore even more warming.

Composition of the atmosphere

We are finding ever more sophisticated ways of measuring the atmosphere's composition: continuous ground-station measurements, sensors attached to weather balloons, aircraft- and ship-based instruments, drones, and satellites are all used to analyse the components of the atmosphere. This array of measurements at different scales is used in combination with models to paint the clearest picture of the atmosphere possible, within current understanding.

The MACC (Monitoring Atmospheric Composition and Climate) project has done just this, by assimilating satellite data into a global model of the atmosphere to produce an 8-year data set of atmospheric composition. The data for carbon monoxide, ozone, nitrogen dioxide and formaldehyde are evaluated against independent satellite, weather balloon, ground station and aircraft observations in Inness et al., which goes on to highlight where the discrepancies lie and also indicates the direction for future work. With so much varied data to consider, this kind of large modelling study is a good way of bringing together the current knowledge of atmospheric composition.

These are just a few facets of the atmosphere, with weather patterns, climate modes, aerosol, boundary layer flows, and interactions with the surface being some of the other parts of the atmospheric system that we take interest in studying in just as much depth. It is thanks to the multitude of ways of observing and describing this encapsulating fluid we have today, that we get the atmosphere to show its face.

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