Soaring with the **Global Hawk**

Last year a new UK-made atmospheric science instrument flew for the first time on NASA's Global Hawk unmanned aircraft. Hartmut Bösch and Paul Palmer describe how it got there – and how it will help scientists understand the way greenhouse gases are transported around the world and where they are being emitted and absorbed.

It seems every year marks a new milestone in levels of atmospheric carbon dioxide (CO_2). Increasing emissions from the burning of fossil fuels and anomalous weather patterns associated with a strong El Niño has resulted in atmospheric CO_2 increasing by more than 3 parts per million (ppm) to 402ppm over the last year.

In an attempt to prevent a rise in surface temperature above 2°C associated with the increasing concentrations of greenhouse gases, leaders of 195 countries agreed at the 2015 Paris UN Climate Conference to limit their greenhouse gas emissions (predominately CO_2).

Dr Neil Humpage (University of Leicester) during the calibration of GHOST at UK ATC. UK ATC

Each year, the oceans and terrestrial vegetation typically absorb the equivalent of half the CO_2 released to the atmosphere by human activities such as burning fossil fuels. So we also have to keep a watchful eye on these so-called 'sinks' of atmospheric CO_2 because without them we would be in an even more dire environmental situation. Measurements of atmospheric CO_2 are a combination of these natural and anthropogenic emissions and uptake of CO_2, as well as the weather.

Sparse networks of ground-based measurements of CO_2 are the foundation of much of what we currently understand about atmospheric CO_2. Unfortunately, these networks are not dense enough, leaving substantial gaps in both space and time where we lack good data on CO_2 levels. New technologies and platforms (such as satellites) are beginning to fill in these gaps.

As part of a project funded by NERC and the Science and Technology Facilities Council (STFC), we designed and built a short-wave infrared (SWIR) spectrometer to observe minute changes in atmospheric CO_2. The instrument measures the whole atmosphere from top to bottom (the total column of the gas), rather than having to rely on samples taken at a particular point. The purpose of this instrument was to be deployed on the NASA Global Hawk unmanned aircraft, which can comfortably fly at 20km altitude for the best part of a day – the next best thing to a satellite. Over two years, the universities of Leicester and Edinburgh and the STFC Astronomy Technology Centre (UK ATC) in Edinburgh designed and built the GreenHouse gas Observations of the Stratosphere and Troposphere (GHOST) spectrometer.

A GHOST in the machine

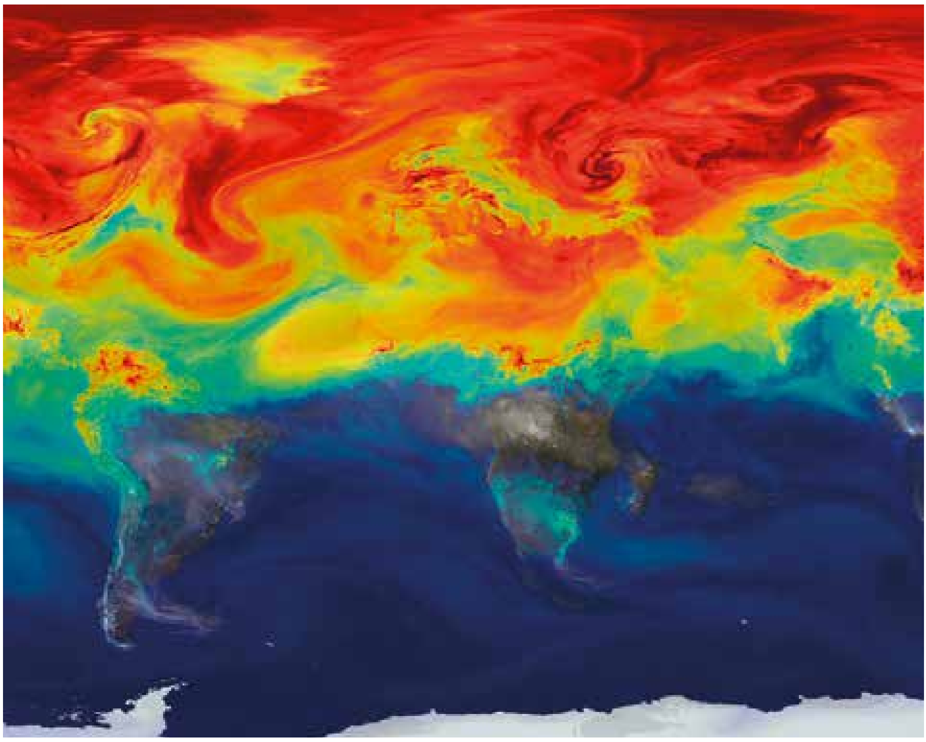
A Global Hawk flying in the stratosphere is a harsh environment for any instrument, with temperatures falling to -70°C and pressures less than a tenth of what we experience at ground level. As well as dealing with these conditions, GHOST also had to prove that it could reliably operate autonomously and could produce accurate and scientifically useful data. We met the environmental criteria by working closely with engineers at UK ATC, who contributed expertise that is more often used to build sensitive components for ground-based and space-borne telescopes focused on other parts of the solar system.

Using some ingenious solutions to make GHOST as small and light as possible, the UK ATC engineers developed an instrument that can measure levels of atmospheric CO_2, methane and carbon monoxide by detecting the way they absorb SWIR radiation. Since the Global Hawk can usually only fly over the ocean and since the amount of sunlight reflected from the water surface is very low, GHOST was designed to use a mirror-based tracking system to track reflection of sunlight over the ocean, ensuring a good signal level. GHOST provides new insight into how CO_2 is transported around the atmosphere; it will be invaluable in helping us understand where on Earth greenhouse gases are being emitted and absorbed.

After rigorous testing and calibration, we shipped GHOST to NASA's Armstrong Flight Research Centre in California in December 2014 to be integrated into the Global Hawk. Its maiden flight was on 26 February 2015 – part of the four-year collaboration between NERC's Co-ordinated Airborne Studies in the Tropics (CAST) project and NASA's Airborne Tropical Tropopause Experiment (ATTREX). This test range flight took us over the Mojave Desert, where a Beechcraft T-34 chase plane was able to take some amazing inflight photos. It also took us over a ground-based column CO_2 reference site, allowing us to check the measurements GHOST was producing.

Yet the following two flights over the western Pacific were the more scientifically valuable. A highlight of the campaign was a near-perfect under pass of the NASA Orbiting Carbon Observatory and the Japanese Greenhouse gases Observing Satellite (GOSAT), providing us with a unique opportunity to compare all three instruments. On the Global Hawk, GHOST gives us a vital link between the satellite observations and more conventional aircraft and ground-based observations.

Soon after GHOST returned to the UK we deployed it on the NERC Airborne Research and Survey Facility Dornier aircraft as a demonstrator for UK technology, funded by the Centre for Earth Observation Instrumentation. Unlike the Global Hawk, the Dornier aircraft can fly slow and low, letting it map the plume of emissions from a particular source in great detail. On these deployments our targets included the Ratcliffe-on-Soar power station, landfill sites near Bedford, Leicester city centre, and a heath fire in Northumberland that had been started deliberately by land managers. In this type of deployment, GHOST provides a unique perspective on regional emissions of greenhouse gases.



High-resolution model of atmospheric CO_2, showing high values in the northern hemisphere during winter. We can see also very large fluctuations in CO_2 associated with atmospheric transport due to weather patterns. NASA

GHOST's success is due to the close collaboration between all the UK and US scientists and engineers involved with designing, building and deploying it. The new instrument also demonstrates the value of merging the expertise of environmental physicists with that of another community – in this case, astronomers. GHOST represents a new and unique resource for the UK science community that can be adopted for many different platforms and science applications. Over the coming years it will be shedding new light on emissions and uptake of greenhouse gases all over the world, and so helping us get a better idea of how our climate is changing.

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