Engineers Combine Modeling and Satellites to Track Greenhouse Gases

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When NASA's Orbiting Carbon Observatory, or OCO-2, launches in 2013, there will be plenty of eyes anxiously watching it from Boulder. Among its array of followers is Daven Henze, an assistant professor of mechanical engineering in the department's air quality group.

Henze, who joined the CU faculty two years ago, uses scientific data from orbiting satellites to maintain and improve an "adjoint" model of the Earth's atmosphere. An adjoint model is one that traces atmospheric chemicals, like ozone and other greenhouse gases, backward to their source.

OCO-2 is one more Earth science satellite that Henze hopes to use in his research. A large portion of his research has followed the launches of other satellites in the NASA constellation, such as Aura and Aqua. He and his students integrate observational data from instruments aboard satellites with various atmospheric models to closely examine the role that greenhouse gases and particulate matter, known as aerosols, play in air quality and climate change. Using numerical models and inverse modeling techniques, they try to estimate the sources and the fates of various chemical species.

OCO-2 will be NASA's second attempt to launch a satellite specifically for the purpose of monitoring carbon dioxide, or CO_2. The first attempted OCO launch tragically failed to reach orbit in 2009. More recently, a satellite built to measure aerosol properties suffered a similar fate. Thus, the importance of maximizing data from existing climate-related satellites has become a pressing need, and the inherent risk in this field of research an increasing reality.

Henze's current studies of CO_2 have used data from a recently launched Japanese satellite called GOSAT. Henze is interested in data from GOSAT and OCO-2 to help improve our knowledge of sources and sinks of CO_2. It is hoped that the global coverage provided by these orbiting instruments will help scientists map the man-made and natural processes that govern carbon cycling, leading to better estimates of how future climate may respond to changes in emissions and our environment.

While CO_2 is a widely recognized driver of climate change, other more fleeting species, such as tropospheric ozone and aerosols, can also play important roles. Aerosols are solid particles in the atmosphere typically ranging in size from 1 to 10 microns that stay aloft for a period of several days. Although temporary in nature, some aerosols can create a cooling effect, which means they have to be considered in any strategy aimed at addressing climate change, Henze says.

Recently, Henze was awarded a NASA New Investigator grant to improve our understanding of the link between radiative forcing of aerosols and tropospheric ozone, and precursor emissions. Radiative forcing is the alteration of the energy balance that leads to global climate change.

The launch of several new Earth science satellites in the last decade has revolutionized our approach to atmospheric chemistry, Henze says: "They are giving us an unprecedented amount of data, and we now have much greater coverage of the planet."

For example, satellite data is showing that formation of ozone, amassing some five to seven kilometers above the Earth, far exceeds estimates from current models—a situation that can only be explained by unaccounted-for generation of nitrogen oxides from lightning, according to Henze.

Ammonia, another gas that is critical to constrain for understanding air quality and climate, also shows up in satellite data. A space-based spectrometer picked up its presence because it was interfering with the infrared-light energy (radiance) coming from the Earth, Henze says. Ammonia is emitted largely from agricultural feedlots and farming operations.

By incorporating these and other new data, researchers are able to improve on earlier atmospheric models, some of which were found to be off-kilter in certain parts of the world where observational data was not previously available.

Models are continuously being improved with the launch of additional instruments and integration of new data, but the question of where pollutants come from is still a challenging one requiring complex mathematical formulas and knowledge of the ways that chemicals change form.

The research being conducted by Henze's group is based on techniques borrowed from control and optimization theory, in which the sensitivity of a model's response is calculated with respect to numerous parameters.

Henze, who completed a postdoctoral fellowship at Columbia University's Earth Institute before coming to CU-Boulder, uses a high-performance computing system called Prospero to crunch the numbers and help answer the question of where pollutants originate. The system consists of a bank of 32 computers with 384 core processors, and calculations can sometimes take as much as a day or more.

Besides satellite data and a large amount of processing power for calculations, the models also require information taken on the Earth's surface.

"A lot of times, we don't even know what we are emitting," says Henze. There are only a few dozen sensors that regularly monitor ammonia concentrations in the entire country, for example.

Henze participated in a study with the U.S. Environmental Protection Agency in North Carolina in which researchers correlated satellite data on ammonia in the atmosphere with in-situ or surface measurements to show that the algorithm they wrote to retrieve satellite data is accurate.

"We hope to come up with a strategy for managing aerosols and greenhouse gases that takes more of these factors into account—and has a positive impact on human health, ecosystems, and climate."