Climate change affecting Earth's outermost atmosphere

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Carbon dioxide emissions from the burning of fossil fuels will produce a 3 percent reduction in the density of Earth's outermost atmosphere by 2017, according to a team of scientists from the National Center for Atmospheric Research (NCAR) and The Pennsylvania State University (PSU). The research, which appears in the latest issue of *Geophysical Research Letters*, will be presented today at the annual meeting of the American Geophysical Union.

"We're seeing climate change manifest itself in the upper as well as lower atmosphere," says NCAR scientist Stan Solomon, a co-author of the study. "This shows the far-ranging impacts of greenhouse gas emissions."

The research team includes Solomon, Liying Qian, and Ray Roble of NCAR's High Altitude Observatory; and Tim Kane of PSU. The study was supported by NASA's Living With a Star program and by the National Science Foundation, NCAR's primary sponsor.

Lower density in the thermosphere, which is the highest layer of the atmosphere, reduces the drag on satellites in low Earth orbit, allowing them to stay airborne longer. Forecasts of upper-level air density could help NASA and other agencies plan the fuel needs and timing of satellite launches more precisely, potentially saving millions of dollars.

Confirming and extending a prediction

Recent observations by scientists tracking satellite orbits have shown that the thermosphere, which begins about 60 miles above Earth and extends up to 400 miles, is beginning to become less dense. This confirms a prediction made at NCAR in 1989 by Roble and Robert Dickinson (now at the Georgia Institute of Technology) that the thermosphere will cool and contract because of increasing carbon dioxide levels. The new study is the first to analyze whether the observed change will become more pronounced over the next decade.

Why the cooling is a sign of global warming

Carbon dioxide cools the thermosphere, even though it acts to warm the atmosphere near the Earth's surface (the troposphere). This paradox occurs because the atmosphere thins with height. Near the Earth's surface, carbon dioxide absorbs radiation escaping Earth, but before the gas molecules can radiate the energy to space, frequent collisions with other molecules in the dense lower atmosphere force the carbon dioxide to release energy as heat, thus warming the air. In the much thinner thermosphere, a carbon dioxide molecule absorbs energy when it collides with an oxygen molecule, but there is ample time for it to radiate energy to space before another collision occurs. The result is a cooling effect. As it cools, the thermosphere settles, so that the density at a given height is reduced.

The role of the solar cycle

Also affecting the thermosphere is the 11-year cycle of solar activity. During the active phase of the cycle, ultraviolet light and energetic particles from the Sun increase, producing a warming and expansion of the upper atmosphere. When solar activity wanes, the thermosphere settles and cools.

In order to analyze recent solar cycles and peer into the future, the NCAR-PSU team used a computer model of the upper atmosphere that incorporates the solar cycle as well as the gradual increase of carbon dioxide due to human activities. The team also used a prediction for the next solar cycle, issued by NCAR scientist Mausumi Dikpati and colleagues, that calls for a stronger-than-usual solar cycle over the next decade. The model showed a decrease in thermospheric density from 1970 to 2000 of 1.7 percent per decade, or about 5 percent overall, which agrees with observations. The team found that the decrease was about three to four times more rapid during solar minimum than solar maximum.

Impacts on satellites

Many satellites, including the International Space Station and the Hubble Space Telescope, follow a low Earth orbit at altitudes close to 300 miles. Over time, the upper atmosphere drags the satellites closer to Earth. The amount of drag depends on the density of the thermosphere, which is why satellite planners need better predictions of how the thermosphere changes.

"Satellite operators noticed the solar cycle changes in density at the very beginning of the space age," says Solomon. "We are now able to reproduce the changes using the NCAR models and extend them into the next solar cycle."

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