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Editorial

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Chemistry's Contributions to Our Understanding of Atmospheric Science and Climate

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Supporting Information

ABSTRACT: Chemistry, a field focused on the molecular scale, provides important contributions in understanding global-scale phenomena, including climate and climate change. This editorial focuses on chemistry's contributions to our understanding of atmospheric science and climate from both research and chemical education perspectives.

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There is a great deal of chemistry occurring in Earth's atmosphere, from the well-known gas-phase OH-initiated radical chemistry in the troposphere to the unintended chemistry (and consequences) of industrial compounds that make their way into the atmosphere. For example, chlorofluorocarbons (CFCs) catalytically destroy ozone in the stratosphere, leading to the ozone hole. Mario J. Molina and F. Sherwood Rowland first discussed the basis of this chemistry in 1972.[1] In the case of CFCs, since their banning through the international treaty called the Montreal Protocol on Substances That Deplete the Ozone Layer in 1987,[2] the ozone hole is closing. Although this is a slow healing process because of the long lifetime of CFCs in the atmosphere, this is an example that provides some context of how human activities can negatively impact Earth's atmosphere, but upon understanding the details of the chemistry involved can provide a scientific basis for reversing course.

Understanding the detailed chemistry and molecular processes involved in climate can also be important for providing a scientific basis for making informed decisions and policies. According to the U.S. Environmental Protection Agency (EPA):[3]

> *Climate change refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer.*

While Earth's climate naturally changes over thousands of years, change today is accelerated by human activities. The future of humankind depends on our ability to mitigate and adapt to climate change. The field of chemistry deals with the world at the molecular level, which can provide a fundamental basis for understanding the phenomena that determine Earth's climate and how human activities are altering the atmosphere.

For example, although other gases and processes can play a role, it is well understood that the rise in greenhouse gases is mainly due to the combustion of fossil fuels. As any student in chemistry knows, when hydrocarbons are completely oxidized the products that result are carbon dioxide and water. From a thermodynamic perspective, this is a very favorable, energetically downhill process. Therefore, combustion chemistry can cause increases in CO_2 levels in the atmosphere. As a greenhouse gas, CO_2 traps infrared radiation in Earth's atmosphere. Higher CO_2 concentrations have contributed to higher ocean and air temperatures across the globe, leading to decreases in polar ice, increases in the strength of storms, and changes to hydrologic cycles.[4] This is why there is such great interest in decreasing carbon dioxide emissions and having an international treaty to regulate emissions of greenhouse gases.[5]

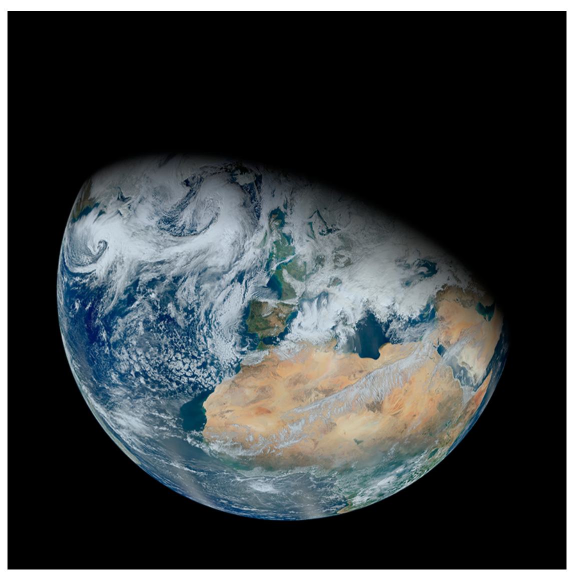

Figure 1. View of Earth from the Suomi NPP satellite (image by Norman Kuring, NASA) showing clouds that change the reflectivity of Earth and impact climate. Clouds are nucleated by atmospheric aerosol particles, which have a wide range of chemical composition and size. Chemists and other scientists at the Center for Aerosol Impacts on Climate and the Environment are working to better understand aerosol particles and their impact on climate from a fundamental chemistry perspective.

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Besides greenhouse gases, human activities have the potential to cause changes in Earth's reflectivity by impacting aerosols, which in turn affects clouds. Atmospheric aerosols are defined as solid or liquid particles suspended in air. These particles have both natural and anthropogenic sources spanning a wide range of chemical compositions that can include metals, salts, oxygenated organic compounds, and mixtures of these, and they can range in size from tens of nanometers to tens of micrometers. Atmospheric aerosols impact everything from human health and climate to concentrations of trace gases. In terms of their climate impacts, atmospheric aerosol particles play a role by scattering and absorbing solar radiation and by nucleating clouds (see Figure 1). However, quantifying these effects is difficult due to the large range of sizes and chemical compositions of these particles.

So how can increasing our knowledge of fundamental chemistry help understand climate and climate change? First, chemical processes make greenhouse gases, either ones that are well-known such as the formation of CO_2 due to combustion or ones that are less understood such as formation mechanisms for nitrous oxide, N_2O, another important greenhouse gas. Second, processes involved in the nucleation of particles from gas-phase precursors need to be better understood. Third, the role of particles in cloud formation is well-known, yet the details of the process and which particles are important remain to be determined. Fourth, the chemistry at the surface of particles can impact both the chemical balance of the atmosphere by providing active sites for reactions and the properties of the particle. Fifth, chemical properties of the particle surfaces will dictate how they interact with water vapor and cloud formation. These examples demonstrate how an increased understanding of these processes and feedbacks among them can provide the necessary scientific basis for understanding the factors that determine and are changing Earth's climate.

We can raise awareness of the important contributions that chemistry can play to better understanding Earth's atmosphere and climate to our students and communities by teaching the scientific principles of atmospheric science and climate change through chemistry.[6,7] Several interactive demonstrations that can be quite beneficial to learning about climate, as well as important chemical and physical concepts, include the following: albedo and surface reflectivity; light scattering by particles; cloud formation; greenhouse gases; the greenhouse effect; and ocean acidification. These topics are naturally linked to concepts commonly covered in college chemistry courses, including molecular structure, chemical and physical properties, light scattering, and infrared spectroscopy. Ocean acidification and acid rain are prime examples of complex equilibria that demonstrate interconnectedness of humans and Earth's atmosphere, oceans, and biosphere. Selected examples of learning materials on chemistry and climate change include the American Chemical Society Climate Science Toolkit;[8] the EPA's Student's Guide to Global Climate Change;[9] The King's Centre for Visualization in Science's module on Global Climate Change;[10] a laboratory experiment on global warming potential;[11] a demonstration of the greenhouse effect;[12] and other hands-on activities for at home, classrooms, and science fairs (see the Supporting Information). More information about all of this can be found at the website for the Center for Aerosol Impacts on Climate and the Environment (CAICE).[13]

Just as chemists can contribute to the benefit of society through drug development for better health, and development of new materials and energy sources with less environmental consequences, chemists can (and need to) play an important role in understanding the underlying chemical and molecular processes that can provide insights into poorly understood aspects of Earth's atmosphere and climate. Now more than ever, each one of us should find ways to make positive contributions that help society and humankind in our personal and professional lives.

■ ASSOCIATED CONTENT

Supporting Information

Learning materials to support informal education about chemistry and climate science (Chemistry and Climate Activity Kit), including the structure and properties of greenhouse gases, Earth's albedo, light scattering by particles, cloud formation, and ocean acidification. This material is available via the Internet at http://pubs.acs.org.

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Notes

Views expressed in this editorial are those of the author and not necessarily the views of the ACS.

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