ATS/CIRA Colloquium

Professor Scott Denning

The Curious Case of Carbon: from Cosmos to Carbonate

3 p.m. Thursday, Sept. 17
Microsoft Teams meeting link

Carbon and oxygen are made in dying stars, and are the most abundant elements in the universe after hydrogen and helium. The plane of our galaxy is thick with carbonaceous particles which we call "dust" but which are really more like a mixture of smoke and grease. Thousands of organic compounds including all the amino acids that form the basis of biochemistry are found in cosmic dust. Thermal distillation in the early solar system depleted the inner solar system of volatiles, but carbon, nitrogen, and oxygen derived from cosmic dust have played critical roles in the evolution our living planet and its climate anyway. Carbon in Earth's early atmosphere was abundant as both oxidized CO_2 and reduced CH_4, but the introduction of free oxygen around 2.5 billion years ago eliminated almost all the methane and led to a series of iceball episodes, the latest around 700 million years ago. Aqueous carbonate equilibria in seawater determine the partition of labile carbon between the oceans and atmosphere. Over hundreds of millions of years, atmospheric CO_2 and climate are modulated via plate tectonics through the balance between volcanic outgassing and chemical weathering of fresh igneous rocks. The tectonic collision of India with Asia around 50 million years ago exposed enormous amounts of rock in the Himalayas and Tibetan Plateau, whose weathering subsequently drew CO_2 levels down far enough to produce a series of dozens of planet-wide ice ages over the last few million years. Subtle, gravitationally-driven changes in Earth's orbit have since interacted to produce a roughly 100,000-year cycle of climate and CO_2 by modulating summer sunshine at 60 N latitude.

Global photosynthesis converts about 1/7 of atmospheric CO_2 into plants each year, and has been in nearly perfect balance over geologic time with death and decomposition by oxygen-breathing microbes which produces 1/7 of all CO_2 annually. A minuscule imbalance of growth over decay has very gradually led to enormous reservoirs of fossil carbon that have been mined since the industrial revolution, producing a 45% increase in atmospheric CO_2 in just the past 200 years. We estimate recoverable fossil organic carbon at about 10 times the total amount burned to date. The increase in CO_2 due to fossil fuel combustion is substantially mitigated by the physics and chemistry of seawater and by subtle changes in terrestrial biology. Remarkably, only half the CO_2 from fossil fuels remains in the atmosphere, with the remainder sequestered in the oceans and on land. Land uptake its limited by biological productivity but ocean uptake will continue for many millennia until the deep oceans and atmosphere reach equilibrium. The transfer of a large fraction of the fossil carbon to air and water is expected to produce profound changes to both physical climate and the chemistry and biology of the oceans. Depending on the eventual size of the industrial pulse, between 10% and 40% of the CO_2 from fossil fuels will remain in the atmosphere for thousands of centuries until it is converted to carbonate rocks.