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Pollution, Greenhouse Gases and Climate Clash in South Asia, Scripps Study Shows
Pollution clouds in region appear to 'mask' aspects of
South Asian climate, leading to drought and other impacts

A new analysis by scientists at Scripps Institution of Oceanography at the University of California, San Diego, has produced surprising results showing how air pollution, global warming-producing greenhouse gases and natural fluctuations in the climate may have a range of significant consequences on the world's most populous region.

In a study published in the May 15 issue of the American Meteorological Society's *Journal of Climate*, Chul Eddy Chung and V. Ramanathan of Scripps Oceanography describe their analysis of sea-surface temperatures and a range of other data from the Indian Ocean region. In the analysis, they found that cooler-than-normal temperatures in the northern part of the ocean have weakened the natural climate circulation and monsoon conditions in the region, resulting in reduced rainfall over India and increased rainfall over the Sahel area south of the Sahara in Africa.

As the tropical Indian Ocean heats up due to greenhouse gases, the authors say, the northern Indian Ocean, which is adjacent to highly populated regions, is not warming as quickly as the rest of the ocean, resulting in increased drought conditions that could hold repercussions for more than 2 billion people in South Asia. These conditions impact a range of industries and resources, from agriculture to freshwater availability.

The culprit behind the changes, the authors argue, is an ongoing and intricate clash between air pollution, greenhouse gases and naturally produced climate changes.

"It appears that the whole tropical region in this area is being pulled in different directions," said Ramanathan, director of the Center for Clouds, Chemistry and Climate at Scripps. "The observed trend of reduced sunlight reaching the Earth's surface, with compensating solar heating aloft from the pollution, also called the 'brown haze,' appears to be masking the greenhouse warming in the northern Indian Ocean, while the greenhouse warming continues unabated in the southern Indian Ocean. We are starting to see that the air pollution affects sunlight and is potentially having a major disruption of the rain patterns, with some regions getting more and some less."

In a separate but related study published in 2005 in the *Proceedings of the National Academy of Sciences (PNAS)*, Ramanathan and Chung, along with their colleagues at the National Center for Atmospheric Research, the University of Washington, and in India and Switzerland, found through simulations that tiny particles of air pollution called aerosols are "masking" the warming effect from greenhouse gases.

"The greenhouse gases are pushing in one direction, warming the ocean and trying to make more rain, and the aerosols are pushing in another direction for cooler oceans and less rain. The net effect is to drive the monsoon rain system away from South Asia into the equatorial and southern oceans," said Ramanathan. "Some years the aerosols might win and in some years the greenhouse effect may win. So we are concerned that in coming decades the variability between the two will become large and it will be difficult to cope with rapid changes from year to year."

Both studies support the initiatives of Project Atmospheric Brown Clouds (ABC), a Scripps Oceanography-based international program, sponsored by the United Nations Environment Program (UNEP), investigating how dust and pollution particles are transported and their impacts on the environment, climate,

agricultural cycles and quality of life. Project ABC participants from China, India, Japan, Korea, Sweden, Thailand and the United States are setting up air pollution/climate observatories in the Indo-Asia-Pacific region in an aim to integrate science with impact assessments to provide scientific information to decision makers.

In addition to Asia, similar pollution clouds, or brown haze clouds, can be seen in various regions around the world, including over major urban locations such as Los Angeles and Denver in the United States.

"About five to 10 years ago we used to think about pollution as an urban problem," said Ramanathan. "Now we have discovered, with new observations including satellite data, that these pollution clouds travel quickly and can cover an entire ocean. Scientists have shown that in a matter of five days pollution traveled from China to the United States, and in a matter of three to four days it can travel from the U.S. to Europe."

The monsoonal rainfall over India has decreased by approximately five to eight percent since the 1950s, Chung and Ramanathan note in their *Journal of Climate* paper. Many of the field observations referenced in the study were made during the Indian Ocean Experiment (INDOEX), a \$25 million international campaign funded by the National Science Foundation, the U.S. Department of Energy and the National Oceanic and Atmospheric Administration (NOAA), and led by Scripps in the spring of 1999.

Observations from INDOEX and other necessarily time-limited field studies are taken only intermittently. Chung believes continuous, year-round aerosol observations are necessary to augment satellite data to further help researchers understand the highly variable seasonal and interannual nature of aerosol effects in Asia and elsewhere. Dust particles from Africa, which also play a significant but not fully understood role in climate systems, also require further investigation and analysis.

Results from the INDOEX campaign and follow-up studies by Ramanathan and his colleagues showed that human-produced aerosols over South Asia and the northern Indian Ocean decreased solar radiation reaching the planet's surface by as much as seven percent from 1930 to 2000. This is sometimes referred to as the dimming effect. In the *Journal of Climate* study, Chung and Ramanathan say the net effect from the sea-surface temperature changes and the haze particles is less rainfall over India and more over the Indian ocean and sub-Saharan Africa.

However, the scientists also warn of a reverse effect: "Greenhouse gases by themselves lead to large positive anomalies in the simulated Indian rainfall, which leads to the speculation that, when the South Asian aerosol pollution is cut down significantly, India may witness a large increase (10 to 20 percent) in monsoon rainfall, but be subject to a large surface warming due to the greenhouse gases. Given the importance of these findings, simulations by independent regional climate models, coupled with continuous routine observations from project ABC, are urgently needed to better understand the uncertainty and complexity of the monsoon response to air pollution."

In the PNAS study, the researchers conducted an ensemble of ocean-atmosphere simulations to help understand the role of atmospheric brown clouds, or ABCs. The simulations showed that aerosols within ABCs may have played a major role in regional climate and hydrological cycle changes. The simulations also raise the possibility that if current trends in emissions continue, the subcontinent may experience a doubling of drought frequency in the coming decades.

"The impact of the ABC on monsoon rainfall, in conjunction with the health impacts of air pollution, provides a strong rationale for reducing air pollution in the developing nations," the authors conclude in the PNAS study. "However, a sudden reduction in air pollution without a concomitant reduction in global greenhouse gases also can accelerate the warming in South Asia because,

according to the present simulations, ABCs have masked as much as 50 percent of the surface warming due to greenhouse gases."

The research in the Journal of Climate study was supported by NASA and NSF. In addition to Ramanathan and Chung, coauthors of the PNAS paper include D. Kim (Scripps Institution of Oceanography); T. Bettge, L. Buja, J. T. Kiehl and W. M. Washington (National Center for Atmospheric Research); Q. Fu (University of Washington); D. R. Sikka (emeritus director of the Indian Institute of Tropical Meteorology); and M. Wild (Swiss Federal Institute of Technology). The PNAS study was supported by NSF's Atmospheric Sciences Division and NOAA. The statements, findings, conclusions and recommendations in the papers cited above are those of the authors and do not necessarily reflect the views of the funding agencies or the UNEP-sponsored Project ABC.

NOTE: In April 2006, Ramanathan and his colleagues announced the successful technological demonstration of autonomous unmanned aerial vehicles to study pollution clouds. See http://scrippsnews.ucsd.edu/article_detail.cfm?article_num=724 for more information.

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