CLIMATE SCIENCE FORUM

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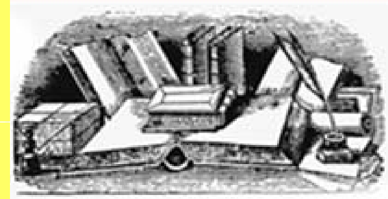
Airborne Particles & Climate



Do *Smoke & Smog* still offset CO_2 greenhouse effect ?

"Dust Bowl" storm gallops through Stafford, Texas in the 1930s. CREDIT: NOAA Photo Library

Climate News: *this Issue*

CLIMATE SCIENCE FORUM

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A fresh breeze of new research in 2009 has swept away the murky uncertainty about how airborne particles affect global climate.

It's agreed that particles generally cool the land and climate, and offset much of the heating caused by greenhouse gases like carbon dioxide (CO_2). But sooty, dark particles heat the atmosphere, and this so-called "black carbon" portion is becoming larger. The hundred-year "grace period" when airborne particles have counteracted up to one-half of global warming appears to be nearing an end. This is one more reason why the trend of rising global temperatures is expected to accelerate.

Phenomena from smoke, haze, and smog to the "brown clouds" of pollution that plague many cities and continents are made up of tiny solid particles that remain airborne for days or a week or so. Two different types of particles have distinct effects on sunlight shining through murky air. Lighter, reflective particles (lighter in color, not in weight) cool the planet by scattering sunlight back to space. It is well known that volcanoes can cool the entire Earth for one to two years after a large eruption. The cataclysm expels an enormous cloud of ash and sulfate particles high into the stratosphere, where particles remain for months, scattering some light back to space – light that normally illuminates and heats up the land.

Most pollution particles likewise scatter light, except that polluted air is washed out by rainfall within a few days. Yet so much pollution is emitted that it has kept the climate cooler than expected over the last hundred years. Many scientists maintain that "scattering" particles were largely responsible for the cooling that the Northern Hemisphere experienced from 1940 to 1975, even when greenhouse gases were increasing. The amount by which they offset the greenhouse effect has been highly uncertain.

Light-colored particles not only scatter light di-

(Continued on page 2, Col. 1)

(Smoke, Haze, & Smog — Continued from page 1)

rectly, some also aid the formation of clouds, which indirectly affects climate. These particles attract water vapor that condenses on them so that tiny droplets of water form—so-called "cloud droplets." Once formed, a cloud can reflect most of the sunlight that strikes it. Clouds are much brighter and more reflective than either smoke, haze, or the underlying land. Unfortunately, it is quite uncertain how important this indirect effect of particles may be for climate cooling.

Dark smoke and soot particles from incomplete burning have the opposite effect. Collectively called "black carbon," darker particles absorb sunlight and heat up the atmospheric layer where they are found. When black carbon falls on snow, it darkens snow and makes it melt faster. These sooty particles originate mainly in fires: forest fires, fires set to burn agricultural waste and debris after land is cleared, coal or wood incompletely burned, and cook stoves widely used in Asia, tropical Africa and the Americas. Black carbon contributes to the greenhouse warming effect, unlike scattering particles in pollution, haze and dust.

In the end does the mix of pollution particles cool or warm the planet? Scientists now are putting forth evidence that black carbon is gaining ground over the scattering particles and is increasing twice as rapidly. The concentration of reflective, scattering particles has declined in developed countries where air pollution campaigns were successful – in most of Europe and North America. And new research (reported in the Climate Briefs) has reduced the uncertain climatic impact of all particles.

Clean air campaigns in Europe and North America have resulted in a cleaner atmosphere which is speeding the pace of global warming. Scattering particles are less abundant now than from 1900 to 1970 and no longer offset as much warming from greenhouse gases. Worse, brown clouds containing black carbon are becoming pervasive. As a result the Polar and middle-latitudes of the Northern Hemisphere are warming faster than the rest of the Earth, and faster than they did before.

Read about research news on airborne particles and climate in the "**Climate News Briefs**."

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Black Carbon or Soot:
Second most important agent of climate warming

The insidious role of "*black carbon*" (here termed *soot* or soot particles) has been debated since at least 2000. In an excellent update[1] of the climatic effects of black carbon, Ramanathan and Carmichael write that the warming effects are more powerful than had been thought.

Unlike all other airborne particles, soot particles absorb solar energy and heat the air where they are found. In clean air that sunlight would warm the surface of the Earth; but in dirty air the surface cools while the atmosphere is warmed.

Soot causes considerable warming of the planet: Carmichael and Ramanathan say its warming is at least half as large as that due to carbon dioxide alone, and more than any of the other greenhouse gases. They estimate its warming effect is more than twice as much as what the Intergovernmental Panel on Climate Change (IPCC) estimated in 2007. This warming is heavily concentrated in China, equatorial Africa, and other nations in the tropical belt where people burn traditional biofuels for cooking or burn agricultural wastes and forests to clear the land.

Sooty particles and scattering particles have opposite effects on global climate change: these authors calculate that black carbon adds energy at the rate of +0.9 Watts per square meter into the climate system, while all other particles remove energy at minus 2.3 Watts per square meter. The net effect of all airborne particles is an overall cooling, but less and less cooling as the proportion of black carbon increases.

Since soot particles heat the air but cool the surface, they *stabilize* air layers and make it less likely that the atmosphere will mix. That hurts the dispersal of smog, haze, or pollution. And there's more: less water evaporates from the cooler land or ocean surface. When the two effects are combined, the conditions necessary for clouds to form and rain to fall occur less often. Then pollution is less likely to be washed out of the air.

These are some of the reasons that the brown cloud over Asia and the Indian Ocean is believed to be weakening the Asian monsoon, diminishing the life-giving rainfall that sustains one billion people in the region.

CITATION:

1. V. Ramanathan and G. Carmichael (2008): "Global and regional climate changes due to black carbon": *Nature Geoscience*, v. 1, 221-227, April, 2008.

More Climate News - next 3 pages

Airborne Particles Magnify Climatic Impact of Greenhouse Gases

(Nov. 23) Certain common gases interact with particles in the air to cause more warming or more cooling of the Earth than the gases or particles alone would cause, say Drew Shindell and five colleagues at NASA's Goddard Institute for Space Studies. In a new published report[1], they write that airborne particles chemically interact with methane, ozone, and carbon monoxide in ways that magnify the warming that these gases cause. Similarly, nitrogen oxides are known to cool the earth, but when sulfur-containing particles are also present, the cooling is *from two to five times* greater than this gas alone can cause. Sulfur and sulfate particles cool the climate without the help of any gas (*story on page one*), but the effects of particles and gases are not simply adding up, but multiplying due to chemical reactions that generate new particles.

The climatic impact of a gas is often measured by its "*Global Warming Potential*" (GWP), a measure that compares the ability of any gas to warm the atmosphere with the ability of one kilogram (1 kg) of carbon dioxide to warm the air. The GWP came to be used for the Kyoto treaty agreements and in carbon trading markets. It is common to measure the global warming potential of a gas over a 100 year period. Obviously this underestimates the impact of transient gases and of all particles (which float in the air for mere days or weeks). Nevertheless, Shindell reported the 100-year GWP for the three gases in keeping with standard practice.

Among greenhouse gases, methane is the #2 contributor to warming (after CO_2 which is #1). Interactions with airborne particles magnify this warming by 10% to 15% when only the direct effect of particles on solar and thermal radiation is considered. As discussed on page 1 (bottom), particles can indirectly affect global temperature by aiding the formation of clouds. When this indirect effect is considered, the warming is magnified 20% to 40% above the pure greenhouse warming of methane alone. That is greater than the calculation of the Intergovernmental Panel on Climate Change (IPCC), now used as a baseline for economic planning, carbon trading, and climate projections into the future.

Other gases such as carbon monoxide also interact with particles and ozone so that their warming is magnified. On the other hand, nitrogen oxides "cause substantial cooling on all time scales," Shindell writes, a cooling greatly magnified by airborne particles. The global warming potential of methane is about as great as, but in the opposite direction from, the "global cooling potential" of nitrogen oxides. The direct effect of particles magnifies the cooling due to nitrogen oxides *by two to five times*, and the indirect (cloud) effects plus the direct effects magnify it by 10 times or more.

It should be mentioned that the chemistry of nitrogen oxides in the air was so complex, and the effects so uncertain, that the IPCC did not estimate their global warming or cooling potential in 2007.

Though the authors do not mention this, greenhouse "cooling" by nitrogen oxides has not made the news largely because the gas is much less abundant than the better-known CO_2 and methane. Nitrogen oxides, like ozone, carbon monoxide, and particles in the air, are local pollutants that trouble cities and regions with smog, smoke, and poor air quality. Shindell asserts that their global impacts are minor compared to their major local impacts on health, mortality, visibility, and quality of life. Local pollutants will be regulated more effectively by policies targeting air pollution, rather than efforts to stabilize climate, he adds. But their global impacts have been underrated because each gas or pollutant is considered in isolation.

CITATION

1. "Improved attribution of climate forcing to emissions" by Drew Shindell and five other authors at NASA Goddard Institute for Space Studies, *Science*, vol. **326**, 716-718, 30 Oct. 2009, doi:10.1126/science.1174760.

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CLIMATE NEWS in BRIEF

Arctic climate very sensitive to effect of particles in air

In a paper[2] in *Nature Geoscience* early in 2009, Shindell and Faluvegi found out that particles in the atmosphere had a large role in the climate changes of the 20th century, a larger role than the IPCC was ready to admit in 2007. The authors also determined that the Arctic is especially sensitive to airborne particles and ozone pollution from the Northern Hemisphere. Over the last 30 years, when the Arctic warmed by 1.5°C, trends in airborne particle concentrations were probably responsible for *two-thirds* of the warming in the Arctic region. (Both the light-colored scattering particles and dark-colored sooty particles were responsible.) Decreasing numbers of light-colored particles has had a similar effect as an increasing presence of dark particles: both trends caused a warming atmosphere.

Clean-air campaigns in the most developed nations combined with continuing emissions of black carbon particles from Asia have caused a rapid and large warming in the polar North.

Predictions of climate changes must take into account where airborne particles and ozone pollutants are emitted, or else the predictions will likely be in error for polar and temperate zone climates.

CITATION:

2. D. Shindell and G. Faluvegi, "Climate response to regional radiative forcing during the 20th Century", *Nature Geoscience,* v. 2, 294-300, March 22, 2009.

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Warming by black carbon is accelerating

Observations now reconciled with models

The climatic consequences of polluting the air by releasing particles are clouded by disagreements between observations and models. Observations suggested more cooling from pollution than the aerosol models predicted. Norwegian **Gunnar Myhre** claims to have reconciled the observational and the modeling work in a study in July of this year[3]. He corrected some faulty assumptions in the observational studies, and noted that optical properties of aerosol particles have been changing over the last several decades, which had not been considered in the models.

Black carbon particles increased *six-fold* from early industrial times to today; while scattering particles increased *only* three-fold, Myrhe calculated. Warming by black carbon and sooty aerosols is becoming more important while cooling by the scattering aerosols is becoming less important. Thus warming from black carbon is canceling ever more of the cooling from all other aerosols (the indirect effect of particles on clouds was not considered—see paragraph 5 of the lead story for information on the indirect effect, which is larger than the direct effect). He concludes that particles now cool the global climate at a rate of minus 0.3 Watts per square meter, which is less cooling than the best estimate of the 2007 Intergovernmental Panel on Climate Change (IPCC).

CITATION

3. G. Myhre (2009), "Consistency between Satellite Derived and Modeled Estimates of the Direct Aerosol Effect" – *Science,* v. 325, 187-190, July 10, 2009.

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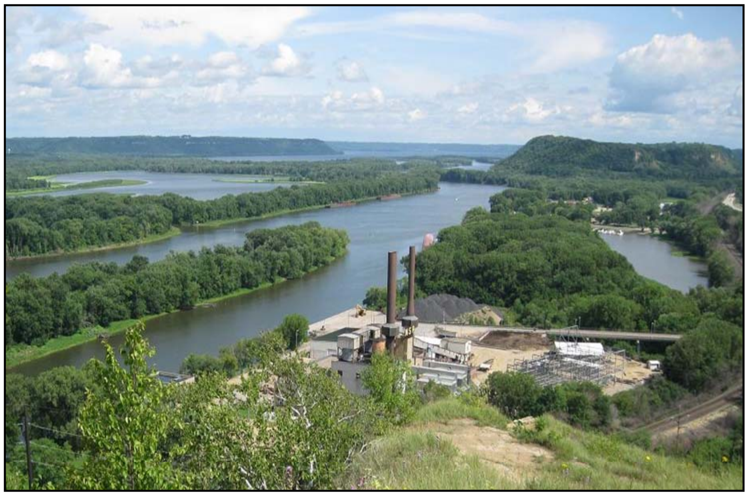
MORE CLIMATE NEWS IN BRIEF



Record High & Low Daily Temperatures further Evidence of Current Warming

(Nov. 17) For a few decades weather stations have been reporting more record-setting daily high temperatures than daily low temperatures in the United States. A new study [1] by Meehl (of the National Center for Atmospheric Research) and four other authors (from the Weather Channel, Climate Central, and the National Climatic Data Center) reveals that in ten years ending this Fall, twice as many record high temperatures as record low temperatures have been reported. This is fairly strong evidence that the annual average temperature from 2000 to now has jumped above the averages of the 20th century, for most locations in the US, and above the 30-year averages that make up the climate "normals" used to describe the climate of a particular location. (Climate normals now are based on averaged observations from 1971 to 2000.)

The authors looked into whether any logical or physical reason could explain this surprising ratio of 2 to 1. They found that this ration is temporary and coincidental. It has been increasing for some time, and may attain 20:1 by the year 2050 and 50:1 by the end of this century, if temperature projections of the Intergovernmental Panel on Climate Change (IPCC) come to pass. This result, that record-breaking high temperatures become more frequent as record-breaking low temperatures become less frequent, is statistically expected when the observed average temperature increases as time goes on.

The ratio in the western United States is now about 3:1. This agrees with the observation that climate has warmed more rapidly in the western than the eastern US.

The ratio of high-to-low record temperatures has also increased in climate model simulations of US climate, but the ratio in the models (now 4:1) is already higher than in the observations, and is increasing faster. Since the models have been overestimating the rate of climate warming in recent years, these higher ratios are not surprising.

CITATION

1. "The relative increase of record high maximum temperatures compared to record low minimum temperatures in the U.S." by G.A. Meehl, C. Tebaldi, G. Walton, D. Easterling, L. McDaniel (2009): *Geophysical Research Letters*, **36**, L*23701*, (1 December 2009), doi:10.1029/2009GL040736.

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