Global dimming

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Global dimming is the gradual reduction in the amount of global direct irradiance at the Earth's surface that was observed for several decades after the start of systematic measurements in 1950s. It is thought to have been caused by an increase in particulates such as sulfur aerosols in the atmosphere due to human action. The effect varied by location, but worldwide it was of the order of a 4% reduction over the three decades from 1960–1990. The trend reversed during the past decade. Global dimming has interfered with the hydrological cycle by reducing evaporation and may have caused droughts in some areas. Global dimming also creates a cooling effect that may have partially masked the effect of greenhouse gases on global warming.

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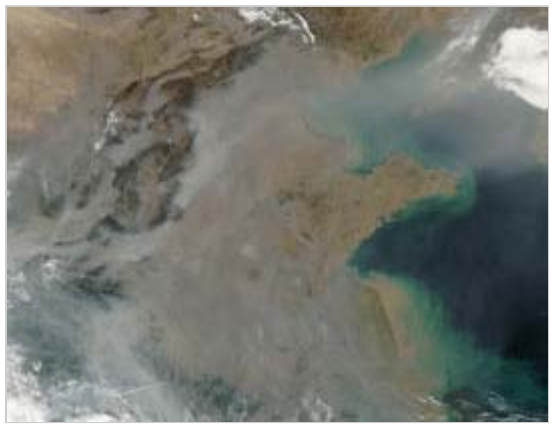
It is thought that global dimming was probably due to the increased presence of aerosol particles in the atmosphere caused by human action. Aerosols and other particulates absorb solar energy and reflect sunlight back into space. The pollutants can also become nuclei for cloud droplets. It is also thought that the water droplets in clouds coalesce around the particles. Increased pollution causes more particulates and thereby creates clouds consisting of a greater number of smaller droplets (that is, the same amount of water is spread over more droplets). The smaller droplets make clouds more reflective, so that more incoming sunlight is reflected back into space and less reaches the earth's surface.

Clouds intercept both heat from the sun and heat radiated from the Earth. Their effects are complex and vary in time, location and altitude. Usually during the daytime the interception of sunlight predominates, giving a cooling effect; however, at night the re-radiation of heat to the Earth slows the Earth's heat loss. Also it has been thought that humans help produce the particles in the earth's atmosphere, resulting in global dimming.

Research

Further information: Climate model and pyranometer



Eastern China. Dozens of fires burning on the surface (red dots) and a thick pall of smoke and haze (greyish pixels) filling the skies overhead. Photo taken by MODIS aboard NASA's Aqua satellite

In the late-1960s, Mikhail Ivanovich Budyko worked with simple two-dimensional energy-balance climate models to investigate the reflectivity of ice.[1] He found that the ice-albedo feedback created a positive feedback loop in the Earth's climate system. The more snow and ice, the more solar radiation is reflected back into space and hence the colder Earth grows and the more it snows. Other studies found that pollution or a volcano eruption could snap us into an ice age.[2][3]

In the mid-1980s, Atsumu Ohmura, a geography researcher at the Swiss Federal Institute of Technology, found that solar radiation striking the Earth's surface had declined by more than 10% over the three previous decades. His findings are in apparent contradiction to global warming—the global temperature has steadily been going up. Less light reaching the earth would mean that it would have to cool. Ohmura published his findings "Secular variation of global radiation in Europe" in 1989.[4] This was soon followed by others. Viivi Russak in 1990 "Trends of solar radiation, cloudiness and atmospheric transparency during recent decades in Estonia",[5] and Beate Liepert in 1994 "Solar radiation in Germany - Observed trends and an assessment of their causes".[6] Dimming has also been observed in sites all over the Former Soviet Union.[7] Gerry Stanhill who studied these declines worldwide in many papers (see references) coined the term "Global dimming".[8]

Independent research in Israel and the Netherlands in the late

1980s showed an apparent reduction in the amount of sunlight,[9] despite widespread evidence that the climate was actually becoming hotter. The rate of dimming varies around the world but is on average estimated at around 2–3% per decade, with the possibility that the trend reversed in the early 1990s. It is difficult to make a precise measurement, due to the difficulty in accurately calibrating the instruments used, and the problem of spatial coverage. Nonetheless, the effect is almost certainly present.

Golden Gate Bridge with California's characteristic brown cloud in the background — a likely contributor to global dimming. Photo CC 2004 by Aaron Logan

The effect (2–3%, as above) is due to changes within the Earth's atmosphere; the value of the solar radiation at the top of the atmosphere has not changed by more than a fraction of this amount.[10]

The effect varies greatly over the planet, but estimates of the terrestrial surface average value are:

- 5.3% (9 W/m²); over 1958–85 (Stanhill and Moreshet, 1992)[8]
- 2%/decade over 1964–93 (Gilgen *et al*, 1998)[11]
- 2.7%/decade (total 20 W/m²); up to 2000 (Stanhill and Cohen, 2001)[12]
- 4% over 1961–90 (Liepert 2002)[13][14]

Note that these numbers are for the terrestrial surface and not really a global average. Whether dimming (or brightening) occurred over the ocean has been a bit of an unknown though a specific measurement (see below, Causes) measured effects some 400 miles (643.7 km) from India over the Indian Ocean towards the Maldives Islands. Regional effects probably dominate but are not strictly confined to the land area, and the effects will be driven by regional air circulation.

The largest reductions are found in the Northern Hemisphere mid-latitudes.[15] The region of the spectrum

of light radiation most affected seems to be the visible and infrared rather than the ultraviolet part of the spectrum.[16]

Pan evaporation data

Further information: Pan evaporation

Over the last 50 or so years, pan evaporation has been carefully monitored. For decades, nobody took much notice of the pan evaporation measurements. But in the 1990s scientists spotted something that at the time was considered very strange, the rate of evaporation was falling although they had expected it to increase due to global warming.*.[17] The same trend has been observed in China over a similar period. A decrease in solar irradiance is cited to be the driving force. However, unlike in other areas of the world, in China the decrease in solar irradiance was not always accompanied by an increase in cloud cover and precipitation. It is believed that aerosols may play a critical role in the decrease of solar irradiance in China.[18]

BBC Horizon producer David Sington believes that many climate scientists regard the pan-evaporation data as the most convincing evidence of solar dimming.[19] Pan evaporation experiments are easy to reproduce with low-cost equipment, there are many pans used for agriculture all over the world and in many instances, and the data has been collected for nearly a half century. However, pan evaporation depends on some additional factors besides net radiation from the sun. The other two major factors are vapor pressure deficit and wind speed. The ambient temperature turns out to be a negligible factor. The pan evaporation data corroborates the data gathered by radiometer[12][17] and fills in the gaps in the data obtained using pyranometers. With adjustments to these factors, pan evaporation data has been compared to results of climate simulations.[20]

Probable causes

Further information: Particulate, Black carbon, Contrail, and Volcanic ash

The incomplete combustion of fossil fuels (such as diesel) and wood releases black carbon into the air. Though black carbon, most of which is soot, is an extremely small component of air pollution at land surface levels, the phenomenon has a significant heating effect on the atmosphere at altitudes above two kilometers (6,562 feet). Also, it dims the surface of the ocean by absorbing solar radiation.[22]

NASA photograph showing aircraft contrails and natural clouds. The temporary disappearance of contrails over North America due to plane groundings after the September 11, 2001 attacks, and the resulting increase in diurnal temperature range gave empirical evidence of the effect of thin ice clouds at the Earth's surface.[21]

Experiments in the Maldives (comparing the atmosphere over the northern and southern islands) in the 1990s showed that the effect of macroscopic pollutants in the atmosphere at that time (blown south from India) caused about a 10% reduction in sunlight reaching the surface in the area under the pollution cloud - a much greater reduction than expected from the presence of the particles themselves[23] Prior to the research being undertaken, predictions were of a 0.5–1% effect from particulate matter; the variation from prediction may be explained by cloud formation with the particles acting as the focus for droplet creation. Clouds are very effective at reflecting light back out into space.

The phenomenon underlying global dimming may also have regional effects. While most of the earth has warmed, the regions that are downwind from major sources of air pollution (specifically sulfur dioxide emissions) have generally cooled. This may explain the cooling of the eastern United States relative to the warming western part.[24]

Some climate scientists have theorized that aircraft contrails (also called *vapor trails*) are implicated in

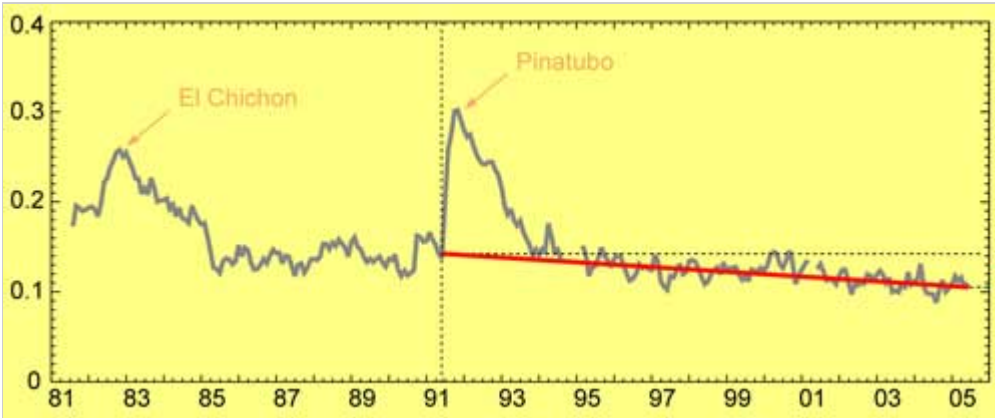
global dimming, but the constant flow of air traffic previously meant that this could not be tested. The near-total shutdown of civil air traffic during the three days following the September 11, 2001 attacks afforded a rare opportunity in which to observe the climate of the United States absent from the effect of contrails. During this period, an increase in diurnal temperature variation of over 1 °C was observed in some parts of the U.S., i.e. aircraft contrails may have been raising nighttime temperatures and/or lowering daytime temperatures by much more than previously thought.[21]

Airborne volcanic ash can reflect the Sun's rays back out into space and cool the planet. Dips in earth temperatures have been observed from large volcano eruptions such as Mount Agung in Bali that erupted in 1963, El Chichon (Mexico) 1983, Ruiz (Colombia) 1985, and Pinatubo (Philippines) 1991. But even for major eruptions, the ash clouds remain only for relatively short periods.[25]

Recent reversal of the trend

Further information: Clean Air Act

Wild et al. using measurements over land report brightening since 1990.[26][9][27] and Pinker et al.[28] found that slight dimming continued over land while brightening occurred over the ocean.[29] Hence, over the land surface, Wild et al and Pinker et al disagree. A 2007 NASA sponsored satellite-based study sheds light on the puzzling observations by other scientists that the amount of sunlight reaching Earth's surface. The sunlight reaching the earth had been steadily



Sun-blocking aerosols around the world steadily declined (red line) since the 1991 eruption of Mount Pinatubo, according to satellite estimates. Credit: Michael Mishchenko, NASA

declining in recent decades, suddenly
started to rebound around 1990. This switch from a "global dimming" trend to a "brightening" trend happened just as global aerosol levels started to decline.[30][25]

It is likely that at least some of this change, particularly over Europe, is due to decreases in pollution. Most governments of developed nations have done more to reduce aerosols released into the atmosphere, which helps reduce global dimming, than to reduce CO_2 emissions.

Sulfate aerosols have declined significantly since 1970 with the Clean Air Act in the United States and similar policies in Europe. The Clean Air Act was strengthened in 1977 and 1990. According to the EPA, from 1970 to 2005, total emissions of the six principal air pollutants, including PM's, dropped by 53 percent in the US. In 1975, the masked effects of trapped greenhouse gases finally started to emerge and have dominated ever since.[31]

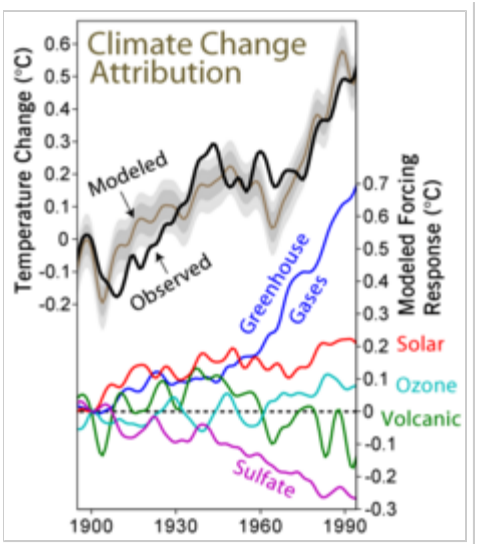
The Baseline Surface Radiation Network (BSRN) has been collecting surface measurements. BSRN was started in the early 1990s and updated the archives in this time. Analysis of recent data reveals that the surface of the planet has brightened by about 4% in the past decade. The brightening trend is corroborated by other data, including satellite analyses.

Relationship to hydrological cycle

Further information: Hydrological cycle

Pollution produced by humans may be seriously weakening the Earth's water cycle - reducing rainfall and threatening fresh water supplies. A 2001 study by researchers at the Scripps Institution of Oceanography suggests that tiny particles of soot and other pollutants have a significant effect on the hydrological cycle. "The energy for the hydrological cycle comes from sunlight. As sunlight heats the ocean, water escapes into the atmosphere and falls out as rain. So as aerosols cut down sunlight by large amounts, they may be spinning down the hydrological cycle of the planet," according to prof. V. Ramanathan.[32]

Large scale changes in weather patterns may also have been caused by global dimming. Climate models speculatively suggest that this reduction in sunshine at the surface may have led to the failure of the monsoon in sub-Saharan Africa during the 1970s and 1980s, together with the associated famines such as the Sahel drought, caused by Northern hemisphere pollution cooling the Atlantic.[33] Because of this, the Tropical rain belt may not have risen to its northern latitudes, thus causing an absence of seasonal rains. This claim is not universally accepted and is very difficult to test.



This figure shows the level of agreement between a climate model driven by five factors and the historical temperature record. The negative component identified as "sulfate" is associated with the aerosol emissions blamed for global dimming.

It is also concluded that the imbalance between global dimming and global warming at the surface leads to weaker turbulent heat fluxes to the atmosphere. This means globally reduced evaporation and hence precipitation occur in a dimmer and warmer world, which could ultimately lead to a more humid atmosphere in which it rains less.[34]

A natural form of large scale environmental shading/dimming has been identified that affected the 2006 northern hemisphere hurricane season. The NASA study found that several major dust storms in June and July in the Sahara desert sent dust drifting over the Atlantic Ocean and through several effects caused cooling of the waters - and thus deadening the development of hurricanes.[35][36]

Relationship to global warming

Further information: Global warming

Some scientists now consider that the effects of global dimming have masked the effect of global warming to some extent and that resolving global dimming may therefore lead to increases in predictions of future

temperature rise.[14] According to Beate Liepert, "We lived in a global warming plus a global dimming world and now we are taking out global dimming. So we end up with the global warming world, which will be much worse than we thought it will be, much hotter."[37] The magnitude of this masking effect is one of the central problems in climate change with significant implications for future climate changes and policy responses to global warming.[38]

But it's much more complicated than an either warming or dimming issue. Global warming and global dimming are not mutually exclusive or contradictory. In a paper published March 8 in the American Geophysical Union's Geophysical Research Letters, a research team led by Anastasia Romanou of Columbia University's Department of Applied Physics and Mathematics, New York, also showed that the apparently opposing forces of global warming and global dimming can occur at the same time.[39] Global dimming interacts with global warming by blocking sunlight that would otherwise cause evaporation and the particulates bind to water droplets. Water vapor is one of the greenhouse gases. On the other hand, global dimming is affected by evaporation and rain. Rain has the effect of clearing out polluted skies.

Climatologists are stressing that the roots of both global dimming-causing pollutants and global warming-causing greenhouse gases have to be dealt with together and soon.[40]

Possible use to mitigate global warming

Further information: Mitigation of global warming and Albedo

Some scientists have suggested using aerosols to stave off the effects of global warming as an emergency measure. Russian expert Mikhail Budyko understood this relationship very early on. In 1974, he suggested that if global warming became a problem, we could cool down the planet by burning sulfur in the stratosphere, which would create a haze.[41][42][43] According to Ramanathan (1988), an increase in planetary albedo of just 0.5 percent is sufficient to halve the effect of a CO2 doubling.[44]

However, we would still face many problems, such as:

- Using sulfates causes environmental problems such as acid rain[45]
- Using carbon black causes human health problems[45]
- Dimming causes ecological problems such as changes in evaporation and rainfall patterns[45]
- Droughts and/or increased rainfall cause problems for agriculture[45]
- Aerosol has a relatively short lifetime

"Ideas that we should increase aerosol emissions to counteract global warming have been described as a 'Faustian bargain' because that would imply an ever increasing amount of emissions in order to match the accumulated greenhouse gas in the atmosphere, with ever increasing monetary and health costs."[46] In essence, the sources of both greenhouse gases and air particulates must be addressed.

See also

- Climate change
- Insolation
- Iris hypothesis
- Snowball Earth
- Solar variation

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