DIMMING THE SUN

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NARRATOR: He warned us, more than 25 years ago, that human activity was changing the Earth'sclimate. Since then, the world has gotten hotter, and NASA scientist James Hansen's warning has been echoed by the vast majority of climate scientists everywhere.

JAMES HANSEN (NASA Goddard Institute for Space Studies)**:** Global warming in the past century is about eight-tenths of a degree Celsius, with most of it occurring in the last 30 years.

NARRATOR: And now the warnings have become more urgent.

JAMES HANSEN: I don't agree that we've passed the point where there's no hope, but, but, on the other hand, we're darned close.

NARRATOR: Close, because scientists have uncovered a new factor that may be masking the full impact of global warming. Called global dimming, it's powerful enough to alter temperatures in a matter of days. It may have contributed to the world's deadliest drought, and it could mean that the Earth's climate is about to start heating up as fast as the most dire predictions.

JAMES HANSEN: I think we have less than a decade to avoid passing what I call "point of no return."

NARRATOR: What will the future of our planet be, now that we're *Dimming the Sun*? Right now on NOVA.

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What would you ask an oil company? What is being done to make us less reliant on oil? That's a question. If we're going to keep our dependency on oil, primarily, for the coming years, the initial future years, where's it coming from?

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NARRATOR: September 12th, 2001, the aftermath of tragedy: ironically, as America mourned, the weather all over the country was unusually clear and sunny. Eight hundred miles west of New York, in Madison, Wisconsin, climate scientist David Travis was on his way to work.

DOCTOR DAVID TRAVIS (University of Wisconsin-Whitewater)**:** Around the 12th, later on in the day, when I was driving to work, and I noticed how bright blue and clear the sky was, and...at first I didn't think about it, then I realized the sky was unusually clear.

NARRATOR: For 15 years, Travis had been researching a relatively obscure topic: whether the vapor trails left by aircraft were having a significant effect

Dimming the Sun


The Contrail Effect
Are vapor trails from aircraft influencing the climate?


The Producer's Story
A filmmaker's take on why many people remain skeptical about global warming


Discoveries in Global Dimming
See what paved the way to our understanding of this phenomenon.


Clean Air Technologies
Explore a handful of creative solutions to help reduce pollution.

on the weather. In the aftermath of 9/11, the entire U.S. fleet was grounded, and Travis finally had a chance to find out.

DAVID TRAVIS: It was certainly, you know, one of the tiny positives that may have come out of this—an opportunity to do research—that hopefully will never happen again.

NARRATOR: Travis suspected the grounding might make a small, but detectable, change to the weather, but what he observed was both immediate and dramatic.

DAVID TRAVIS: We found that the change in temperature range during those three days was just over one degree centigrade. And you have to realize that from a layman's perspective that doesn't sound like much, but from a climate perspective that is huge.

NARRATOR: The temperature range is the difference between the highest and the lowest temperatures in a 24-hour period. Usually, it stays much the same from day to day, even if the weather changes, but not this time. Travis had come across a new and powerful phenomenon, one which would call into question all our predictions about the future of our planet.

The trail that would lead to this extraordinary discovery of global dimming began 40 years ago, in Israel, with the work of Gerry Stanhill, a young English immigrant. Trained as a biologist, Gerry got a job helping to design irrigation systems. His task was to measure how strongly the sun shone over Israel.

DOCTOR GERALD STANHILL (Israel Ministry of Agriculture)**:** It was important, for this work, to measure solar radiation, because that is the factor that basically determines how much water crops require.

NARRATOR: For a year, Gerry collected data from a network of light meters. The results were much as expected and were used to help design the national irrigation system. But, 20 years later, in the 1980s, Gerry decided to update his measurements. What he found stunned him.

GERALD STANHILL: Well, I was amazed to find that there was a very serious reduction in sunlight, the amount of sunlight in Israel. In fact, if we compare those very early measurements, in the 1950s, with the current measurements, there was a staggering 22 percent drop in the sunlight, and that really amazed me.

NARRATOR: A 22 percent drop in solar energy was simply massive. If it were true, surely the effects would be obvious to every Israeli. The figures were hard for other scientists to take seriously, so when Gerry published, his results were ignored.

GERALD STANHILL: I must say that the publications had almost no effect whatsoever on the scientific community.

NARRATOR: But Gerry was not the only scientist who had noticed a decline in sunlight. In Germany, a young graduate student, Beate Liepert found that the same thing seemed to be happening over the Bavarian Alps, as well.

DOCTOR BEATE LIEPERT (Lamont-Doherty Earth Observatory)**:** I was the same; I was as skeptical as any other climatologist. But then I, I saw the same results in Germany, so I believed him.

NARRATOR: Germany, Israel, what about the rest of the world? Working independently of each other, Liepert and Stanhill began searching through journals and meteorological records from around the world. And everywhere they looked, they found the same story.

Between the 1950s and the early 1990s, the level of solar energy reaching the Earth's surface had dropped: nine percent in Antarctica, 10 percent in areas of the U.S.A., by almost 30 percent in one region of Russia, and by 16 percent in parts of the British Isles. This seemed to be a global phenomenon, so Gerry gave it a suitable name: "global dimming."

But again, the response from other scientists was one of disbelief.

GERALD STANHILL: The scientific community was obviously not ready to

deal with the fact that there was a global dimming phenomenon.

NARRATOR: Gerry claimed that, on average, the solar energy reaching Earth had fallen by two percent to four percent. That should be making the world significantly cooler, yet scientists knew the Earth was getting hotter.

As we burn coal, oil and gas, we increase the concentration of carbon dioxide and other greenhouse gases in the atmosphere. Like a thermal blanket, they prevent the Sun's heat from radiating back into space, causing global warming.

BEATE LIEPERT: My friends' reaction, actually, to Gerry's and to my work—at the same time, too—was, "Oh my god, this is really extreme. You are contradicting global warming. Do you know how many billions of dollars was spent on global warming research? And you and this old guy are contradicting us?"

NARRATOR: So Liepert and Stanhill's work was widely dismissed. But global dimming was not the only phenomenon that didn't seem to fit with global warming. In Australia, two other biologists, Michael Roderick and Graham Farquhar, were intrigued by another paradoxical result, the worldwide decline in something called the "pan evaporation rate."

PROFESSOR GRAHAM FARQUHAR (Australian National University)**:** It's called pan evaporation rate because it's evaporation rate from a pan. Every day, all over the world, people come out in the morning and see how much water they've got to add to a pan to bring it back to the level it was the same time the morning before. It's that simple.

NARRATOR: In some places, agricultural scientists have been performing this routine daily task for more than a hundred years.

GRAHAM FARQUHAR: The long-term measurements of pan evaporation are what gives it its real value.

DOCTOR MICHAEL RODERICK (Australian National University)**:** And the fact that they're doing the same thing, day in, day out, with the same instrument.

GRAHAM FARQUHAR: Yeah, they deserve a medal, each of them.

MICHAEL RODERICK: Yeah.

NARRATOR: Nobody outside of agriculture took much notice of the pan evaporation measurements, but, in the 1990s, scientists spotted something very strange, the rate of evaporation was falling.

GRAHAM FARQUHAR: There is a paradox here about the fact that the pan evaporation rate's going down, an apparent paradox, but the global temperature's going up.

NARRATOR: This was a puzzle. Most scientists reasoned that like a pan on the stove, turning up the global temperature should increase the rate at which water evaporated. But Roderick and Farquhar did some calculations and worked out that temperature was not the most important factor in pan evaporation.

MICHAEL RODERICK: Well, it turns out, in fact, that the key things for pan evaporation are the sunlight, the humidity and the wind. But really, the sunlight is a really dominant term there.

NARRATOR: They found that it was the energy of the photons hitting the surface—the actual sunlight—that kicks the water molecules out of the pan and into the atmosphere. And so they, too, reached an extraordinary conclusion.

MICHAEL RODERICK: You know, if the pan is going down, then maybe that's the sunlight going down.

NARRATOR: Was the falling pan evaporation, in fact, evidence of global dimming? Somewhere in the journals, they felt, must be the hard numbers that could tie the two things together.

MICHAEL RODERICK: And then one day, just by accident, I had to go to the library to get an article out of *Nature*. And, as you do, I couldn't find it, and I just glanced at a...through the thing, and there was an article called "Evaporation Losing Its Strength," which reported a decline in pan evaporation over Russia, the United States and Eastern Europe.

And there, in the measurements, they said that the pans had, on average, evaporated about a hundred millimeters less of water in the last 30 years.

NARRATOR: Mike knew how much sunlight was needed to evaporate a millimeter of water, so he put the two sets of figures together, the drop in evaporation with the drop in sunlight.

MICHAEL RODERICK: So you just do the sum in your head: a hundred millimeters of water, less a pan evaporation, two and a half mega joules, so two and a half times a hundred is two hundred and fifty mega joules. And that was, in fact, what the Russians had measured with the decline in sunlight in the last 30 years. It was quite amazing.

NARRATOR: It was the same in Europe and the U.S.A. The drop in evaporation rate matched the decline in sunlight reported by Beate Liepert and Gerry Stanhill. Two independent sets of observations led to the same conclusion. Here, at last, was compelling evidence that global dimming was real.

BEATE LIEPERT: All of a sudden you see, "Oh my god, the world is dimming." And then you, all of a sudden, you see, "Oh my god, this really has an im..., tremendous impact.

GRAHAM FARQUHAR: And it had to be dimming in Europe and in America and in Russia. This is on a global scale. And we thought, "This is really important," because the amount of dimming was enormous. So this is big on a, on a global scale.

NARRATOR: But what was causing it? Scientists knew there was nothing wrong with the sun itself. The culprit had to be somewhere here on Earth.

The Maldives, a nation of a thousand tiny islands in the middle of the Indian Ocean: it was here that Veerabhadran Ramanathan, one of the world's leading climate scientists, began to unravel the mystery of what's causing global dimming. He had first noticed declining sunlight over large areas of the Pacific Ocean in the mid-1990s.

PROFESSOR VEERABHADRAN RAMANATHAN (University of California, San Diego)**:** But we didn't know, at that time, it was part of a much larger global picture, but I knew we had to find out what was causing that.

NARRATOR: Ramanathan was certain of one thing, the big drop in sunlight reaching the ground had to be something to do with changes in the Earth's atmosphere. There was one obvious suspect.

VEERABHADRAN RAMANATHAN: Almost anything we do to create energy causes pollution.

NARRATOR: Burning fuel doesn't just result in the invisible greenhouse gases which cause global warming; it also produces visible pollution, tiny airborne particles of soot and other pollutants. These create the haze that shrouds many of our cities. So Ramanathan wondered, "Could this pollution be behind global dimming?" The Maldives were the perfect place to find out.

The Maldives seem unpolluted, but in fact the northern islands sit in a stream of dirty air descending from India. Only the southern tip of the long island chain enjoys clean air, coming all the way from Antarctica.

So, by comparing the northern islands with the southern ones, Ramanathan and his colleagues would be able to see exactly what difference the pollution made to the atmosphere and the sunlight.

Project INDOEX, as it was called, was a huge multinational effort. For four years, every possible technique was used to sample and monitor the atmosphere over the Maldives. INDOEX cost $25,000,000, but it produced results; and they surprised everyone.

VEERABHADRAN RAMANATHAN: The stunning part of the experiment was this pollutant layer, which was three kilometers thick, cut down the sunlight reaching the ocean by more than 10 percent.

NARRATOR: A 10-percent fall in sunlight meant that particle pollution was having a far bigger effect than anyone had thought possible.

VEERABHADRAN RAMANATHAN: Our models led us to believe the human impact on the dimming was close to half to one percent, so what we discovered was 10-fold.

NARRATOR: INDOEX showed that the particles of pollution were blocking some sunlight themselves. Even more significant was what they were doing to the clouds. They were turning them into giant mirrors.

Clouds are made of droplets of water. These form when water vapor in the atmosphere starts to condense on the surface of naturally occurring airborne particles, typically pollen or sea salt. As they grow, the water droplets eventually become so heavy they fall as rain.

But Ramanathan found that polluted air contained far more particles than the unpolluted air, particles of ash, soot and sulfur.

VEERABHADRAN RAMANATHAN: We saw 10 times more particles in the polluted air mass north of the Maldives compared with what we saw south of the Maldives, which was a pristine air mass.

NARRATOR: In the polluted air, billions of manmade particles provided 10 times as many sites around which water droplets could form. So, polluted clouds contained many more water droplets, each one far smaller than it would be naturally. Many small droplets reflect more light than fewer big ones, so the polluted clouds were reflecting more light back into space, preventing the heat of the sun from getting through. This was the main cause of global dimming over the Indian Ocean.

VEERABHADRAN RAMANATHAN: Basically, the global dimming we saw in the north Indian Ocean was contributed, on the one hand, by the particles themselves shielding the ocean from the sunlight, on the other hand, making the clouds brighter. So this insidious soup, consisting of soot, sulfates, nitrates, ash and what have you, was having a double whammy on the global dimming.

NARRATOR: And when he looked at satellite images, Ramanathan found the same thing was happening all over the world: over India; over China, and extending into the Pacific; over Western Europe extending into Africa; over the British Isles. But it was when scientists started to investigate the effects of global dimming that they made the most disturbing discovery of all. Those more reflective clouds could alter the pattern of the world's rainfall, with tragic consequences.

MICHAEL BUERK, Newscaster: Dawn, and as the sun breaks through the piercing chill of night, on the plain outside Korum, it lights up a biblical famine, now, in the 20th Century. This place, say workers here, is the closest thing to Hell, on Earth.

NARRATOR: The 1984 Ethiopian famine shocked the world. It was partly caused by a decades-long drought right across sub-Saharan Africa, a region known as the Sahel. For year after year, the summer rains failed. There were many factors at work, but now there's evidence that among them was global dimming. The Sahel's lifeblood has always been a seasonal monsoon. For most of the year it is completely dry, but every summer, the heat of the sun warms the oceans north of the Equator. This draws the rain belt that forms over the Equator northward, bringing rain to the Sahel.

But for 20 years, in the 1970s and 80s, the tropical rain belt consistently failed to shift northward, and the African monsoon failed. For climate scientists like Leon Rotstayn, the disappearance of the rains had long been a puzzle. He could see that pollution from Europe and North America blew right across the Atlantic, but all the climate models suggested it should have little effect on the monsoon.

But then Rotstayn decided to take the Maldive findings about the impact of pollution on clouds into account.

DOCTOR LEON ROTSTAYN (Commonwealth Scientific and Industrial Research Organisation, Atmospheric Research)**:** What we found, in our model, was that when we allowed the pollution from Europe and North America to affect the properties of the clouds in the northern hemisphere, the clouds reflected more sunlight back to space, and this cooled the oceans of the northern hemisphere. And to our surprise, the result of this was that the tropical rain bands moved southward, tracking away from the more polluted northern hemisphere towards the southern hemisphere.

NARRATOR: In Rotstayn's model, polluted clouds kept the heat of the Sun from getting through, the heat that was needed to draw the tropical rains northward. So the life-giving rain belt never made it to the Sahel.

LEON ROTSTAYN: So, what our model is suggesting is that these droughts in the Sahel, in the 1970s and the 1980s, may have been caused by pollution from Europe and North America affecting the properties of the clouds and cooling the oceans of the northern hemisphere.

NARRATOR: Other models suggest that global warming was also a factor in the Sahel disaster. But Rotstayn's work shows the potential for air pollution to have far reaching effects on rainfall, perhaps even contributing to a terrible drought that blighted the lives of over 50,000,000 people. And this could be just of taste of what global dimming has in store.

VEERABHADRAN RAMANATHAN: The Sahel is just one example of the monsoon system. Let me take you to anther part of the world, Asia, where the same monsoon brings rainfall to 3.6 billion people, roughly half the world's population. My main concern is this air pollution and the global dimming will also have a detrimental impact on this Asian monsoon. We are not talking about few millions of people, we are talking about few billions of people.

NARRATOR: For Ramanathan the implications are clear.

VEERABHADRAN RAMANATHAN: There is no choice here; we have to cut down air pollution, if not eliminate it altogether.

NARRATOR: In Europe and North America, air pollution is already in decline. Scrubbers in power stations, catalytic converters in cars, and low sulfur fuels, though they do nothing to reduce greenhouse gases, have already led to a marked reduction in visible air pollution.

Coincidence or not, this should be good news for the Sahel, and in recent years the droughts have not been nearly so bad. But in developing countries, like China and India, air quality has been getting worse. The health effects are terrible. It's estimated that respiratory diseases kill a million Indians each year.

As a result, it's likely that India and China will follow the same path as the developed world and strive to bring air pollution under control. But there's a terrible catch. While global dimming is a major threat, it now appears it has been protecting us from an even greater threat: accelerated global warming.

It was David Travis who first caught a glimpse of what the world could be like without global dimming. It happened in those chaotic days following the tragedy of 9/11. For 15 years, Travis had been studying the vapor trails, or contrails, left behind by high-flying aircraft. As a jet passes through the air, the pollution particles it emits can trigger the condensation of water droplets. These manmade clouds seem small, but when they all spread out, they can blanket the sky.

DAVID TRAVIS: Here are some examples of what we call "outbreaks" of contrails. These are large clusters of contrails. And here's a particularly good one from Southern California. Here's the west coast of the United States. And you can see, here, this lacing network of contrails, covering at least 50 percent, if not 75 percent or more of the sky in that area. It doesn't take an expert to realize that if, if you look at the satellite picture and see this kind of contrail coverage that they've got to be having an effect on temperature at the surface.

NARRATOR: But the problem Travis faced was to establish exactly how big an effect the contrails were actually having. The only way to do that was to find a period of time when conditions were right for contrails to form, but there were no flights. And, of course, that never happened—until September, 2001. Then, for three days after the 11th, virtually all commercial aircraft were grounded, so Travis set about gathering temperatures from all over the U.S.A., and comparing them to records from the last 30 years.

DAVID TRAVIS: ...initially, data from over 5,000 weather stations across the 48 United States, the area that was most dominantly affected by the grounding.

NARRATOR: Travis was not looking just at temperature, which varies a lot from day to day. Instead he focused on something that normally changes quite slowly: the temperature range, the difference between the highest temperature during the day and the lowest at night. Had this changed at all during the three days of the grounding?

DAVID TRAVIS: As we began to look at the climate data and the evidence began to grow, I got more and more excited. The actual results were much larger than I expected.

So here we see, for the three-day period preceding September 11th, a slightly negative value of temperature range with lots of contrails, as normal. Then we have this sudden spike right here of the three-day period. This reflects lack of clouds, lack of contrails, warmer days cooler nights, exactly what we expected, but even larger than we expected.

NARRATOR: During the three-day grounding, the nights had gotten colder and the days, warmer. Averaged over the whole continental U.S., the temperature difference between day and night had suddenly increased by over a degree Celsius or two degrees Fahrenheit. Travis had never seen anything like it before.

DAVID TRAVIS: This was the largest temperature swing of this magnitude in the last 30 years.

NARRATOR: Manmade clouds from aircraft are a minor contributor to global dimming. If removing them had such a dramatic effect, what would happen if air pollution were to be reduced all over the world?

DAVID TRAVIS: The 9/11 study showed that if you remove a contributor to global dimming, jet contrails, just for a three-day period, we see an immediate response of the surface temperature. Do the same thing globally, we might see a large-scale increase in global warming.

NARRATOR: This is the crux of the problem. While the greenhouse effect has been warming the planet, it now seems global dimming has been cooling it down.

This new understanding is something that climate modelers like Peter Cox have to contend with.

DOCTOR PETER COX (University of Exeter)**:** Climate change, to the current date, appears to have been a tug of war, really, between two manmade pollutants. On the one side, we've got greenhouse gases that are pulling the system towards a warmer state, on the other hand, we've got particles from pollution that are cooling it down. And there's a kind of tug of war going on between the two, in which the middle of the rope, if you like, determines where the climate system is going in terms of warming or cooling.

NARRATOR: So which is stronger in the tug of war? Something powerful enough to push and pull on the global temperature has what scientists call a "climate forcing" effect.

PETER COX: Since we're pumping up greenhouse gases, we actually provide what's called a forcing on the climate system, a warming effect, which you can measure in terms of watts-per-meter-squared, much like you could measure watts from a light bulb. And that forces the climate to a warmer state.

NARRATOR: Because greenhouse gases trap heat, when we add to them we

increase the heat energy trapped in the atmosphere. Today, the extra energy trapped by manmade greenhouse gases would be enough to run a 100-watt light bulb, placed every six meters over the entire surface of the globe, an extra 2.6 to three watts of energy for every square meter. It's this extra energy that's driving global temperatures ever higher.

But it's now clear to the world's climate scientists that this greenhouse warming is not the only factor at play. There's also the cooling from global dimming. The question is, "How big an effect is it having?"

In 2002, NASA launched the Aqua satellite. Onboard was a suite of instruments designed to measure the effect of dimming pollutants on the energy budget of the Earth. The observations from Aqua have enabled climate scientists to make a rough estimate of global dimming's total cooling effect on our planet.

JAMES HANSEN: Our estimate for the particle forcing is minus-one-and-a-half-watts- per-meter-squared. So that would imply a cooling of more than one degree Celsius.

NARRATOR: In other words, while the human greenhouse effect has produced 2.6 to three watts of extra energy for every square meter of the Earth, global dimming has subtracted about 1.5 watts, so, more than half the warming effect of our greenhouse emissions has been masked by the cooling effect of particle pollution.

Perhaps this is why, despite a large rise in the concentration of greenhouse gases, until recently, the temperature rise has been hard for most of us to notice.

JAMES HANSEN: In a way, it is unfortunate that the small particles were in the atmosphere because we would have realized much earlier that the...how strong the greenhouse effect is, and would have had more time to make the adjustments that are going to be necessary to slow down and eventually stop the growth of greenhouse gases.

NARRATOR: Despite the cooling from global dimming, scientists agree that over the past century or so, average temperatures have risen between .6 and .8 degrees Celsius, about one to one and a half degrees Fahrenheit.

The increase, small as it may seem, is very fast by the standards of Earth history, but now we face something much faster. Ironically, if we keep bringing particle pollutants down—with great benefits to health—but continue pumping greenhouse gases into the atmosphere, Peter Cox believes we could be creating the worst possible combination for global temperatures.

PETER COX: We're going to be in a situation, unless we act, where the cooling pollutant is dropping off while the warming pollutant is going up. CO_2 will be going up and particles will be dropping off, and that means that we'll get an accelerated warming. We'll get a double whammy. We'll get reducing cooling and increased heating at the same time, and that's, that's a problem for us.

JAMES HANSEN: If the particle forcing is what we estimate, about minus-1.5 watts, that would imply that removing that forcing would cause a global warming of more than one degree Celsius. That's more than the warming that we've seen already, so this is a huge factor.

NARRATOR: If we continue as we are, combining reduced air pollution with an increase in greenhouse gases, temperatures could rise by a further two or even three degrees Celsius. That's as much as five degrees Fahrenheit by mid-century, much sooner than current models predict.

JAMES HANSEN: But, in my opinion, three degrees Celsius is not the level of dangerous interference; that's the level which guarantees disaster.

NARRATOR: James Hansen is particularly worried about what this rise in temperature would do to the Greenland ice sheet. Even at today's temperature, there are signs that substantial melting is already underway.

JAMES HANSEN: It has been overlooked how sensitive ice sheets are to

global temperature. We can see that in the last year, the mass of Greenland decreased by 200 cubic kilometers of ice. That's a lot of ice.

I cannot imagine that the ice sheets could survive more than a few centuries with a three-degree Celsius warming. So that would mean a sea level rise of several meters per century, and it would just continue. And once that starts, it's out of our control.

NARRATOR: The last time the Earth was three degrees warmer was 3,000,000 years ago, when there was a natural increase in the level of greenhouse gases in the atmosphere. The geological evidence indicates that melting ice raised sea levels 25 meters higher than today.

JAMES HANSEN: In the United States, New York City...with a 25-meter sea level rise, most of the city would be under water; Washington, D.C....much of it would be under, but there are other regions that would be...suffer much more; Florida...almost the entire state would be under water; and, likewise, Louisiana. So we really can't afford to go down that path.

NARRATOR: And it would not just be coastlines that would be transformed if the Earth warms by three degrees. Climate models suggest the Amazon basin would become much drier and vulnerable to fire. What's left of the world's greatest tropical rainforest could simply burn away, and, in the process, release still more carbon dioxide, further accelerating global warming.

Most models do not yet take full account of the impact of global dimming and predict warming between two and five degrees Celsius, by the end of the century. But just as global dimming may have lulled the public and politicians into a false sense of security about climate change, has it misled climate scientists about the real power of the greenhouse effect to change global temperatures?

Peter Cox, a leading climate modeler, has come up with a controversial new analysis based on the observed warming of the last century. If scientists have underestimated the cooling effects of global dimming in the past, he believes, they may also be underestimating the heating effects of global warming in the future.

PETER COX: We've got two competing effects, really, that...we've got the greenhouse effect, which has tended to warm up the climate, but then we've got this other effect, that's much stronger than we thought, which is a cooling effect that comes from particles in the atmosphere. And they're competing with one another.

And we know the climate's moved to a warmer state by about six-tenths of a degree over the last hundred years. So the whole thing's moved this way. If it turns out that the cooling is stronger than we thought, then the warming, also, is a lot stronger than we thought. And that means the climate's more sensitive to carbon dioxide than we originally thought, and it means our models may be under-sensitive to carbon dioxide.

NARRATOR: While today's models foresee a maximum warming of five degrees Celsius by the end of the century, Cox thinks that it is not beyond the realms of possibility that by 2100, temperatures could rise by as much as 10 degrees Celsius, 18 degrees Fahrenheit.

Many plant species could not survive such rapid climate change. In his scenario, trees would die all over the planet; the world's best agricultural land would be struck by drought and soil erosion; famine would not be far behind. And in the far north, there would be a risk of releasing a vast natural store of greenhouse gas bigger than all the oil and coal reserves of the planet.

PETER COX: We will be in danger of destabilizing these things called "methane hydrates," which store a lot of methane at the bottom of the ocean, in a kind of frozen form—ten thousand billion tons of this stuff—and they're known to be destabilized by warming.

NARRATOR: If this were to happen, some or all of the ten thousand billion tons of methane, a greenhouse gas eight times stronger than carbon dioxide, would be released into the atmosphere. When this last happened 50,000,000 years ago, when the Earth was already warmer than it is today, the average

temperature rocketed by 13 degrees Fahrenheit, making the Earth 25 degrees hotter than today, and life struggled to survive.

Some scientists consider this model extreme, but all climate models contain important unknowns and ranges of possibility. Our new understanding of global dimming has complicated the task of forecasting the future but has also brought the probability of dangerous climate change much closer.

Today, there's a strong scientific consensus that without urgent action to reduce our burning of coal, oil and gas, we risk creating a world very different from the one which has been so hospitable to humanity.

JAMES HANSEN: I think we have less than a decade to avoid passing what I call "point of no return." I think we have to keep global warming less than one degree Celsius, or we're going to get very bad effects. And the problem is that to achieve...to keep the warming less than one degree Celsius, we have to level off the emissions and get them to decline before the middle of the century, substantially.

Right now, the course that we're on—plus 2 percent per year in greenhouse gas emissions—well, if you continue that, even for 15 years, it's a 35 percent increase. And then there's no way that you could possibly meet this alternative scenario with warming less than one degree Celsius.

PETER COX: One of the real driving forces is that you leave an environment that is comfortable for your children. And if we carry on going the way we're going, we're not going to do that. We're going to leave an environment that's much worse than the environment we lived in, and it will be down to what we did when we were using that environment, and that would be, tragic, really, if that happened.

What clean technologies are on the horizon or already in use to reduce our impact on the world's climate? Learn more on NOVA's *Dimming the Sun* Web site. Find it on PBS.org.

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