Global Shading

Reducing Global Warming Using Arrays of High-Altitude Balloons

Providing a small degree of shade to the earth can reverse global warming in the near term. This will not happen with our current approaches.

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It's going to get hotter for the rest of your life. A lot hotter. This will happen irrespective of how many electric vehicles we buy or how many wind farms we install. The warming will likely be accompanied by increased rainfall, flooding, and violent storms. Figure 1 shows the projected warming using the MIT En-ROADS model based on current assumptions. En-ROADS is a comprehensive climate model with an interactive interface that allows a user to explore the effects of most of the variables that are thought to affect climate.

The vertical dashed red line shows where we are now, in 2024, at almost 1.5 degrees C above temperatures in pre-industrial times -- that is, before about 1900, when the world started to experience the emission of significant amounts of carbon dioxide. It projects that if current trends continue, total temperature rise by the end of this century will more than double, to 3.3 degrees Centigrade (C) above pre-industrial times.

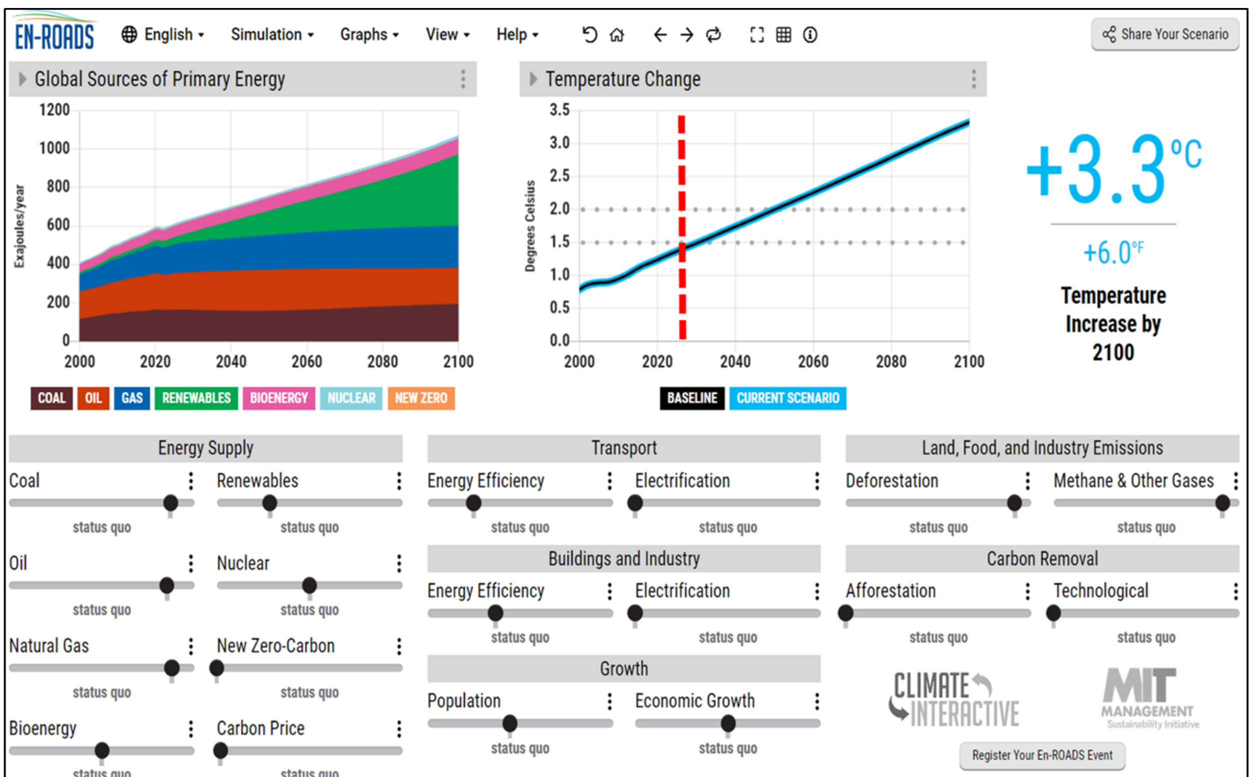

Figure 1. Projected global warming relative to pre-industrial times through the end of the century
https://en-roads.climateinteractive.org/scenario.html?v=23.9.0

Figure 2 shows the projected temperature rise if we set the model to show *maximal global* incentivization of vehicle electrification and renewable energy installation *worldwide* (shown in the red ovals).

Figure 2. Projected global warming if maximum global transformation to renewable energy and electric vehicles occurs https://en-roads.climateinteractive.org/scenario.html?v=23.9.0

Thus, even under these unlikely, aspirational conditions, the temperature rise between now and the end of this century will still be 3.0 degrees C above pre-industrial times, twice today's increase. If you think things are bad now, imagine what it will be like 75 years from now.

Why is this? Let us start with some basic science. Carbon dioxide is a greenhouse gas, and it persists in the atmosphere for a very long time. It is like adding blankets to your bed. As long as more carbon dioxide gets added to the atmosphere than is removed, global temperatures will continue to rise. About 40 billion tons of carbon dioxide are emitted each year worldwide; U.S. passenger cars emit about 1 billion tons, or less than 3 percent. Thus, although switching to electric vehicles and using renewable energy would slightly reduce *the rate of the addition of carbon dioxide*, it would not nearly offset the huge amounts of greenhouse gases emitted by the coal plants in China and India and other fossil fuel use around the world, and the planet will grow inexorably warmer.

In the best case, it will take about 50 years for the world to achieve net zero carbon dioxide emissions. If we stay on the current path, the net result will be that the countries of the world will spend hundreds of trillions of dollars and yet we will continue to get warmer for the rest of our lifetimes. This is money that could have been spent on reducing global poverty or preparing for the next pandemic.

Is there an effective alternative?

The answer is yes. Blocking a few tenths of a percent of sunlight from reaching the earth would reduce global temperatures immediately. This has been demonstrated by the effect of past major volcanic eruptions. Large volcano eruptions such as Mount Pinatubo in 1991 and Mount Tambora in 1815 discharged large amounts of sulfur dioxide and particles into the upper atmosphere. This achieved a small amount of blockage of sunlight which resulted in markedly lower temperatures for the next year or so; in fact, in 1816 it snowed in Virginia on the 4th of July. Figure 3 shows the global temperature effects of the eruptions of Mount Saint Helens, El Chichon, and Mount Pinatubo.

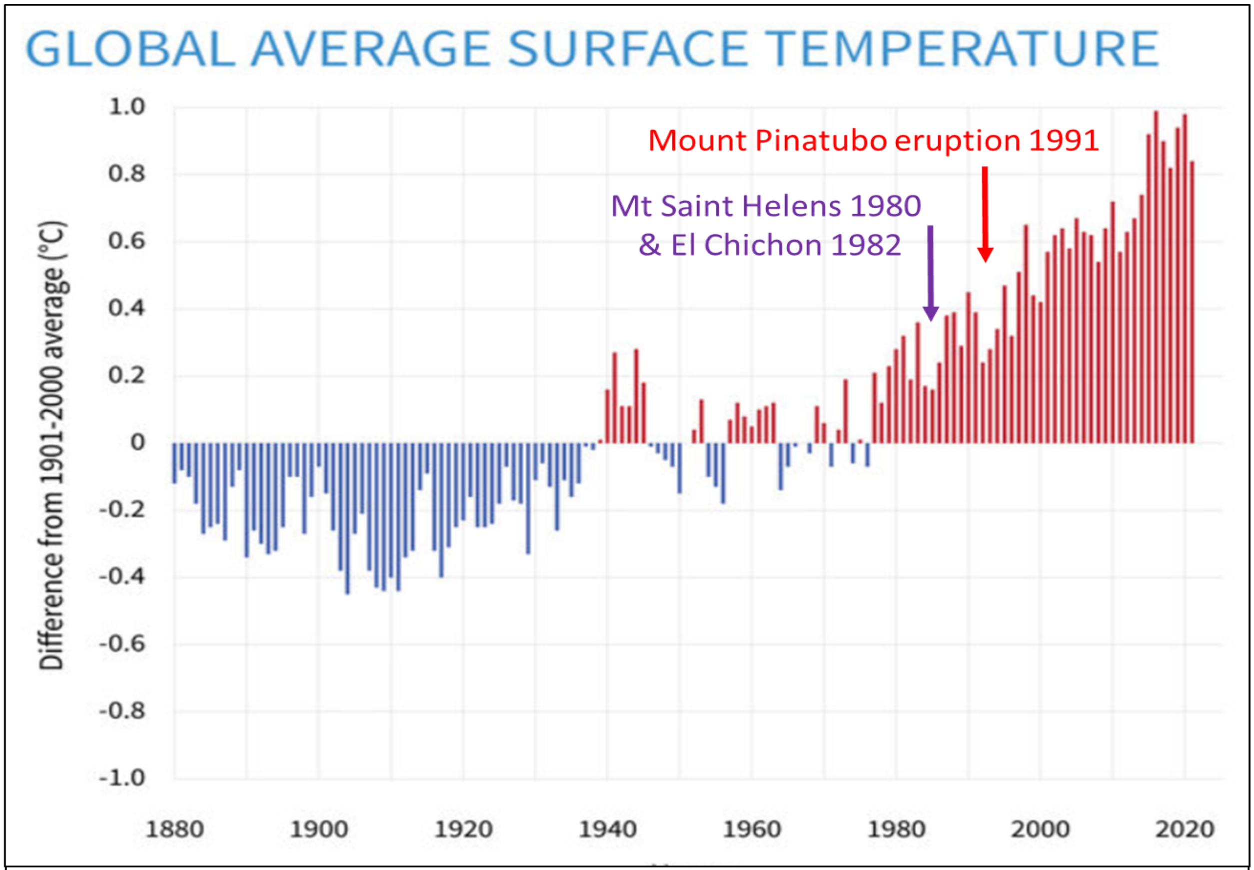

Figure 3. The effects of sunlight blockage from volcanic ash on global temperature
https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

There has been some study of doing this artificially by injecting large quantities of sulfur dioxide into the stratosphere, but the challenges are enormous, the effect would be limited to a year or two, and there are adverse health and environmental effects. In addition, the politics are fraught, so that in reality this will never be done.

There is, however, an alternative that is environmentally benign: global shading. A recent article in the New York Times discusses a concept for doing this that would involve a very large solar shield located deep in space. The science behind this is sound. Shading the earth would, indeed, reduce global temperature. But beyond the tremendous cost and engineering challenges there are other practical problems that will prevent a deep space shield from ever being deployed, some of which are discussed below.

Fortunately, there is another way to achieve similar results that is much simpler: an array of large high-altitude balloons. Here is how that would work.

Recall the high-altitude Chinese spy balloon that flew across the U.S. in early 2023. It was big -- about 150 feet across -- so, like a giant umbrella, it shaded the area underneath it. The shading was not noticeable on the ground because the balloon appeared much smaller than the sun, so it did not produce a distinct shadow. Nevertheless, it did provide a slight, nearly imperceptible decrease in solar heating in the shaded area.

This effect can be extended to produce a significant reduction in global warming. For example, suppose we manufactured a large number of balloons 300 feet in diameter, about the size of the large tarps that cover football fields, but far smaller than the 800-foot-long Hindenburg zeppelin that was produced nearly 100 years ago.

A 300-foot diameter balloon will shade an area equal to its cross section, which is a bit over 70,000 square feet. A square mile is almost 28 million square feet, so, as an example, if you put such a balloon up over every square mile of the earth you would shade about a quarter of a percent (70,000 / 28,000,000 = 0.0025) of the sun's light from reaching the ground.

This may not sound like a lot but it would have a significant effect on global temperature. How much? Enough to set the "climate clock" back by decades and buy time for other measures to take effect. We will quantify this temperature reduction below, using two different methods.

First, consider that the average temperature of the earth is about 59 degrees Fahrenheit, which is 288 degrees Kelvin (relative to absolute zero). Since essentially all the earth's heat comes from the sun, blocking one quarter of 1% would result in cooling of one quarter of 1% of 288, which comes to a little over -0.7 degrees Kelvin, which is the same as -0.7 degrees Centigrade.

As a check on this, consider an alternative method. Rind et al examined the expected effect of differing measurements of total sunlight energy reaching the top of the atmosphere. In section 1 of that article, they compare the effect of 1361.3 W/m^2 (watts per square meter) versus an older and commonly used value of 1367 W/m^2. This is a reduction of about four tenths of 1%. Using a value for climate sensitivity forcing of 0.7 deg C /W/ m^2, they estimate a global average temperature reduction of -0.43 deg C.

More recently, Hansen et al assert that the correct value for climate sensitivity forcing is 1.2 deg C / W /m^2 Substituting this value and computing for one quarter of 1%, the effect of the shading due to the balloons would be -0.46 degrees C for global average temperature reduction. Thus, the cooling effect for this example would likely be somewhere in the range between -0.46 degrees C and -0.7 degrees C. For simplicity, let’s call it about -0.5 degrees C.

But we can do better. The -0.5 degree C case would pertain if the balloons were distributed evenly around the entire globe. But this is inefficient. A better solution would be to cluster them in a belt around the solar equator where the sun’s energy is greatest. The Solar Energy Guide provides a value of 163 W/m^2as a worldwide day/night average for solar energy received. Multiplying this by 24 hours per day results in results in an average of 3.9 kilowatt-hours per day over the entire earth, which is represented by the yellow areas on the map in Figure 4 below. However, the area in the shaded box has an average irradiance of 6 kW-hrs / day. Concentrating the balloons over this area would increase the effect of the balloons to -0.5 x 6 / 3.9 = -0.77 deg C.

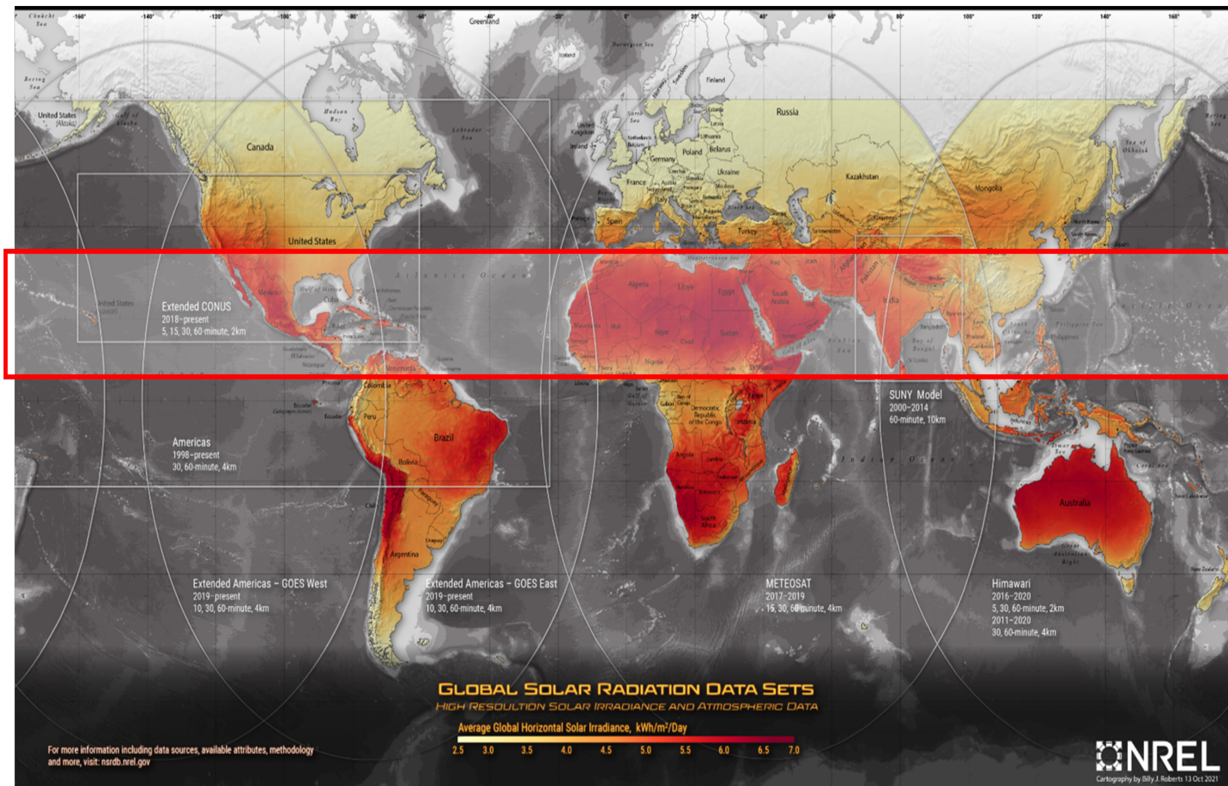

Figure 4. Map of global solar radiation showing improved locations for shading balloons in the white band
Underlying map courtesy of NREL https://nsrdb.nrel.gov/assets/NSRDB%20Graphic%20Update%202021%2009%2022.6d4966d2.jpg

This has enormous promise as a technical solution that would set the "climate clock" back by more than 40 years, as shown in figure 5.

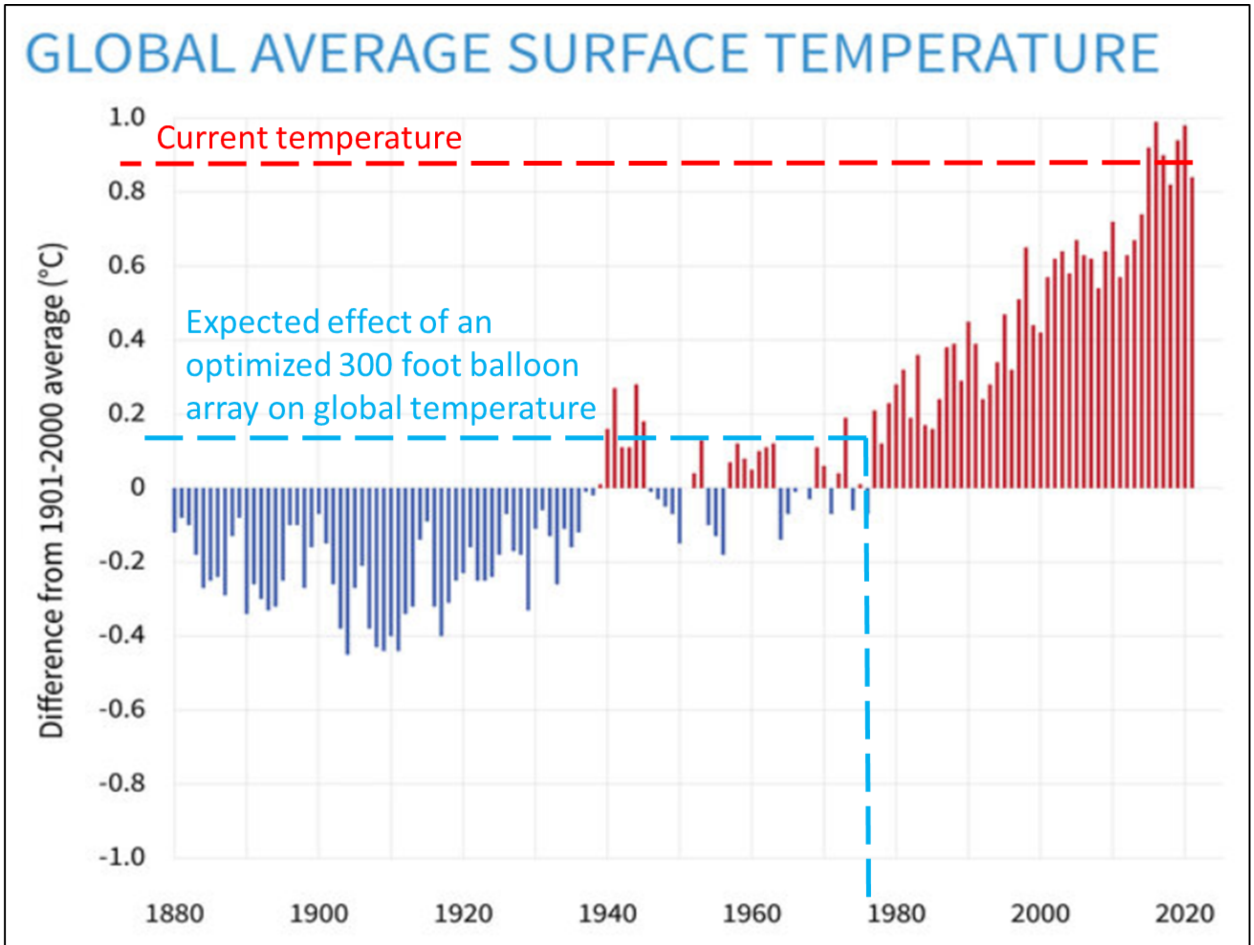

Figure 5. Potential effects of balloon shading on global temperatures
https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Unfortunately, like all other global climate-oriented solutions such as the space shield, this would require international consent by every nation on earth. Given current politics, this seems unlikely, so this solution appears to be a non-starter, at least for now.

However, there is a meaningful approach that could be implemented by the U.S. alone. If we confined the balloons to U.S. airspace, it would require no international consent. We would again concentrate them over the hottest areas. This is depicted in Figure 6. The indicated area is about 700,000 square miles. If we put 3 balloons per square mile it would come to about 2 million balloons. That's a lot, but we produce about 9 million automobiles in the US *each year* and they are far more complicated than balloons. And each year we already make millions of hot air and weather balloons, and launch over half a million weather balloons worldwide. These are smaller in size, but the point is that this industry already exists. And if the balloons cost the same as the world average price of a car, which is under $30,000, the total price would be around $60 billion – a small fraction of the green energy portion of the $891 billion Inflation Reduction Act of 2022.

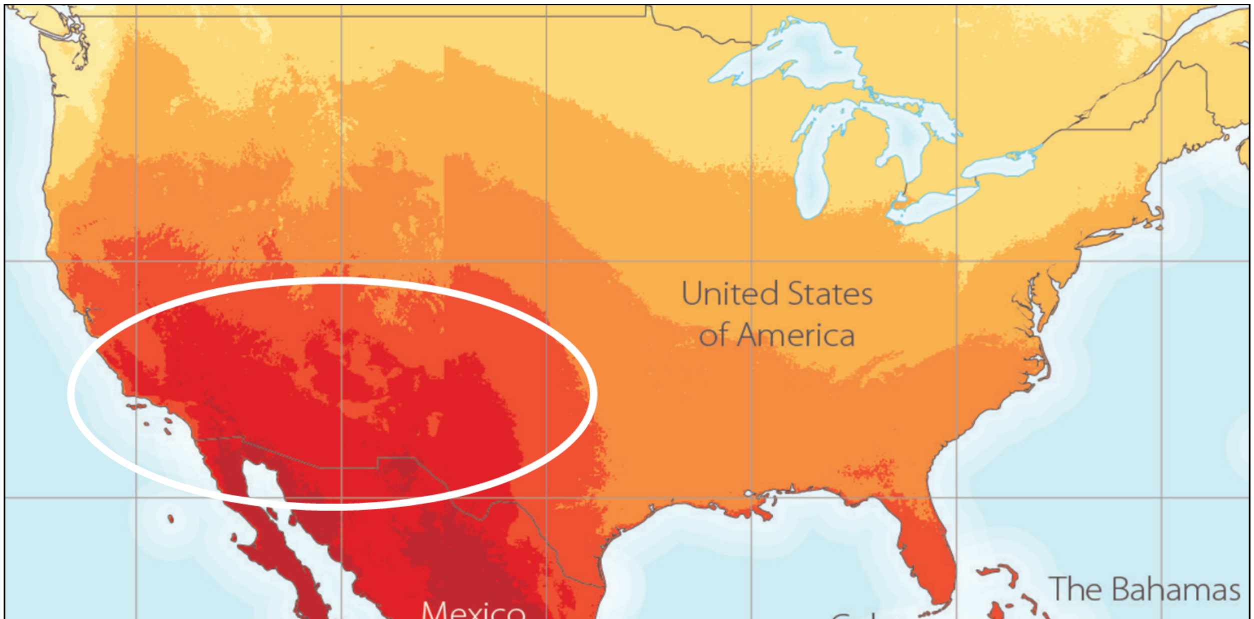

Figure 6. Map of solar radiation in the United States showing optimal balloon locations within the white circle
Underlying map courtesy of NREL https://nsrdb.nrel.gov/assets/NSRDB%20Graphic%20Update%202021%2009%2022.6d4966d2.jpg

Hovering 3 balloons per square mile over the U.S. Southwest would have a clear and immediate impact on the temperatures there. Ground temperatures in this area would be reduced by 1.5 to 2 degrees C. And because weather systems generally travel west to east in the United States, this would provide some relief to other portions of the U.S. as the cooler air flowed into those areas. This would allow U.S. taxpayers to get a direct benefit from their investment and, if successful, might induce other countries to follow suit until a global result ensued.

What would these balloon systems be like? They could be quite simple. They would be made much like the spy balloon but without the spy equipment. They would have a tracking device and some minimal propulsion and navigation capabilities in order to aid in effective spacing and recovery. They would fly at around 80,000 feet, well above aviation altitudes. It would probably be most economical to fill them with hydrogen, as with most weather balloons, and of which we have an unlimited supply. They would have the ability to descend upon command. And they would not result in actual shadows on the ground because their apparent size is smaller than the sun, so there would just be a slightly darker area, less noticeable than a cloud passing overhead, and far fewer than the hundreds of jet aircraft flying over each day.

Another important characteristic is the ability of the balloons to maneuver to a desired location and hover there. This was achieved in Project Loon by the Google X company. Because winds in the stratosphere vary in direction with altitude, they were able to use an ingenious algorithm that predicted winds aloft to navigate balloons to a desired location and hover by changing altitude dynamically.

In addition, there are likely secondary uses for a constellation of balloons, such as communications and sensing, that could defray their cost. This might be used, for example, to bring 5G internet to hard-to-reach locations such as mountain valleys and Indian Reservations.

There are many advantages of this approach. First, it is environmentally benign -- no sulfur dioxide or other lung-irritating particles in the air, and no large-scale cobalt mining required.

Second, it is scalable – you can put up as many balloons as you need, or increase their size. The NASA ASTHROS balloons are almost 500 feet in diameter and the Hindenburg airship was over 800 feet long, so making and deploying large balloons is clearly achievable.

Third, it will exert its effects in the near term -- it starts working immediately, not decades later.

Fourth, it is far less expensive -- tens of billions versus trillions of dollars, avoiding the negative impacts of depriving taxpayers of vast amounts of wealth.

Fifth, it is reversible -- you can bring the balloons down at any time, for any reason.

Sixth, because it is entirely within U.S. airspace, no international agreements are needed, and U.S. investment will directly benefit U.S. citizens. And it will not interfere with aircraft because the balloons are at a much higher altitude.

This is not to say that we should not be reducing our carbon dioxide output -- we should. That will benefit the inhabitants of the 22^{nd} century. But our balloon concept will buy time for those solutions to have an effect.

We could call this Project Parasol. We recommend that it begin with several teams of independent climate scientists examining the expected temperature reductions and also several engineering teams investigating balloon construction and management. Then, if prospects are favorable, select a team to begin building a prototype system. This would start small – we could put up a number of “trial balloons” and take measurements of critical variables. With a limited deployment we could ascertain what the expected cost and life of each balloon would be and how hard it is to keep a constellation of balloons in geostatic locations.

Thereafter, we would make improvements and add more balloons if it is working. And if this works in the U.S., other countries might adopt it. This kind of research has been recommended by the U.S. National Academies of Sciences, Engineering, and Medicine and the White House Office of Science and Technology Policy. Note that *the targetability of a specific region such as the U.S. is unique to this concept*.

Using current approaches, the world will continue to warm for a very long time. We are not aware of any other realistic method that could reduce temperature and the consequences of warming in the U.S. in the near term.

Getting started is cheap and simple. Wouldn't this be worth a try?

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