I've looked at Clouds from Both Sides Now!

These two cloud types are more different than you probably know, when it comes to Global Warming. Here's <u>ONE</u> difference of several:

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Approximate "Cheat Sheet":

1 meter → 3 feet **1 degree Celsius (^{0}C)** → 2 degree Fahrenheit (^{0}F)
ppm = parts per million **CO_2** = Carbon Dioxide
1 tonne = 1000 kilograms = 2205 pounds **1 gigatonne (1 Gt)** = 1 billion tonnes
1 trillion tonnes (1Tt) = 1000 gigatons

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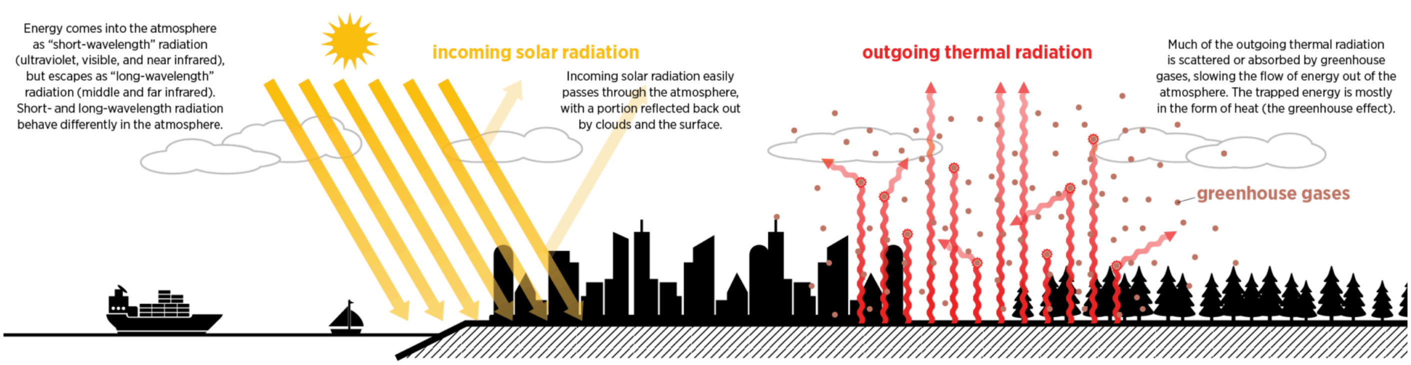
Here's what we'll look at today to sort this out:

1. Remember that incoming sunlight and outgoing heat from the earth's surface are very different.
2. How do clouds react with incoming (shortwave - mostly visible) light from the sun and with outgoing (longwave - infrared) heat coming up from the earth?
3. How do clouds get rid of heat, once they have absorbed it?
4. Given that background, how do the very high, wispy clouds affect warming/cooling?
5. How do the lower, thick clouds affect warming/cooling?
6. **Finally: How does this help inform our understanding of human effects: jet plane <u>contrails</u>; <u>ship exhaust plumes</u>; and postulated geoengineering concepts of <u>aerosols</u> in the Stratosphere and throwing <u>salt water</u> up into the Troposphere.**

So, here we go!

1. ***Remember that incoming sunlight and outgoing heat from the earth's surface are very different.*** *Generally, the incoming light is very energetic and can come right through the atmosphere to heat the surface. The outgoing heat (now converted to longwave infrared) loves to react with water vapor, carbon dioxide, methane, etc (i.e., greenhouse gases) in the air. (<u>Note that clouds seem to have a lot of that water vapor!</u>)*



Incoming solar radiation mostly passes through the atmosphere, but outgoing thermal radiation is scattered and absorbed/reemitted, leading to a slow diffusion of the energy back out of the atmosphere: the trapped energy keeps the atmosphere warm (the greenhouse effect). https://lmnarchitects.com/lmn-research/04-the-science-of-global-warming

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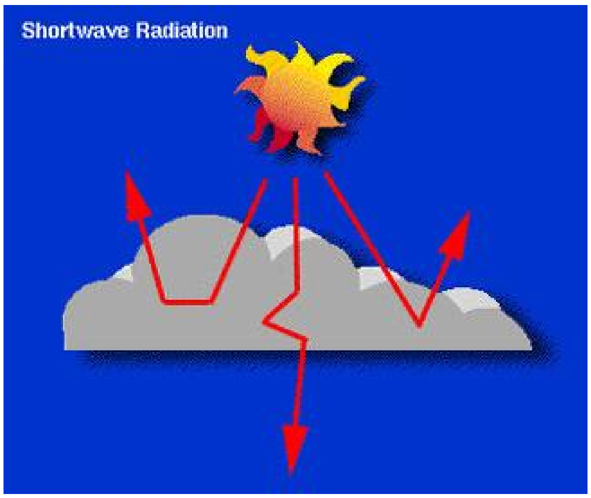
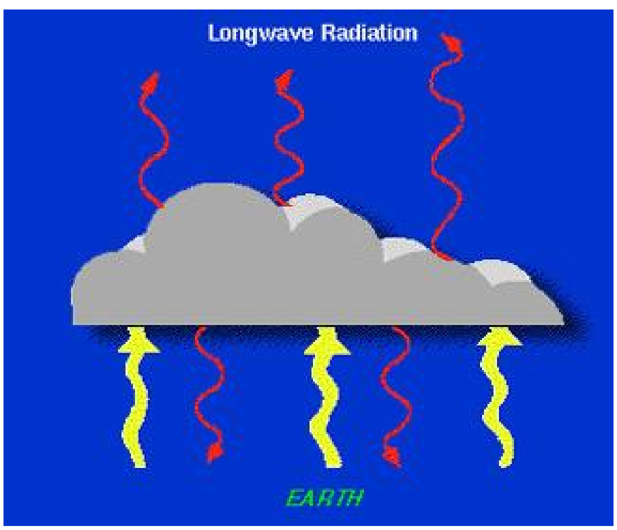
2. How do clouds in general react with incoming (shortwave - mostly visible) light from the sun and with outgoing (longwave - infrared) heat coming up from the earth?



FROM THE SUN: The shortwave rays from the Sun are scattered in a cloud. Many of the rays return to space. The resulting "cloud albedo forcing," taken by itself, tends to cause a cooling of the Earth.



FROM THE EARTH: Longwave rays emitted by the Earth are absorbed and reemitted by a cloud, with some rays going back to the surface. Thicker arrows indicate more energy. The resulting "cloud greenhouse forcing," taken by itself, tends to cause a warming of the Earth, because some of the upcoming heat is sent back down.

https://earthobservatory.nasa.gov/features/Clouds/clouds2.php

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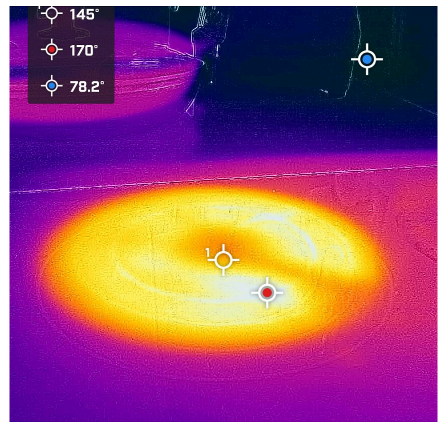
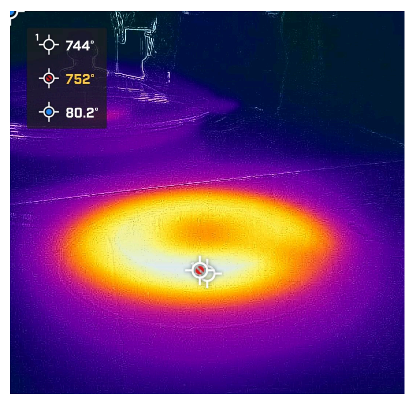
3. How do clouds get rid of heat, once they have absorbed it?

Now this is something you may not have thought about with respect to clouds: HOTTER THINGS GET RID OF HEAT MUCH BETTER THAN COOLER THINGS.

Think of your electric stove - you can keep your hand near the burner at low temperatures; you have to back off when it is hotter. **Hotter things give off more heat than cooler things**.





This means **cooler clouds** (because they're up high) can't give off as much heat to space as **warmer clouds** at lower altitudes can. **This means the earth will have to keep more heat under a layer of high altitude clouds, than below lower clouds!**

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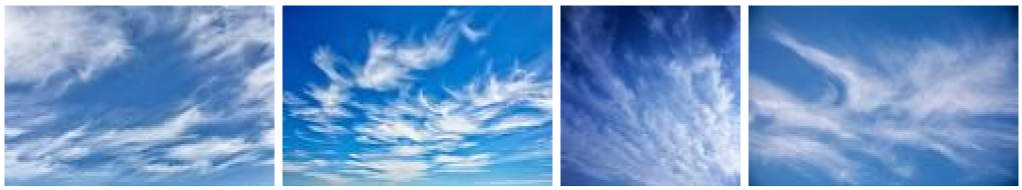
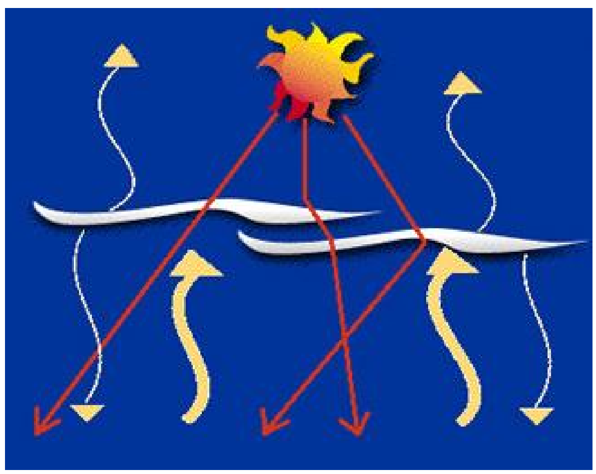
4. Given that background, how do the very high, wispy clouds affect warming/cooling?

Cirrus (def: a curl): a cloud forming wispy filamentous tufted streaks ("mare's tails") at high altitude, usually 16,500–45,000 feet (5–13 km). "long strands of high cirrus stretched across the eastern sky"





The high, thin cirrus clouds in the Earth's atmosphere act in a way similar to clear air because they are highly transparent to shortwave radiation, **but they readily absorb the upcoming longwave radiation, because the cloud moisture is a greenhouse gas**!

Because cirrus clouds are high, and therefore cold, the energy radiated to outer space is lower than it would be without the cloud. The portion of the radiation thus trapped and sent back to the Earth's surface adds to the shortwave energy from the sun and the longwave energy from the other greenhouse gasses in the air already reaching the surface.

The additional energy causes a warming of the surface and atmosphere. **The overall effect of the high thin cirrus clouds then is to enhance atmospheric greenhouse warming.**

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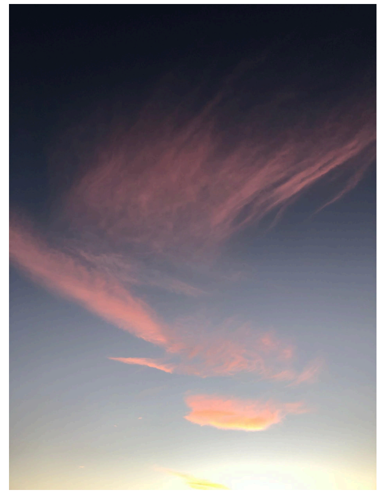

5. ***How do the <u>lower, thick clouds</u> affect warming/cooling?***

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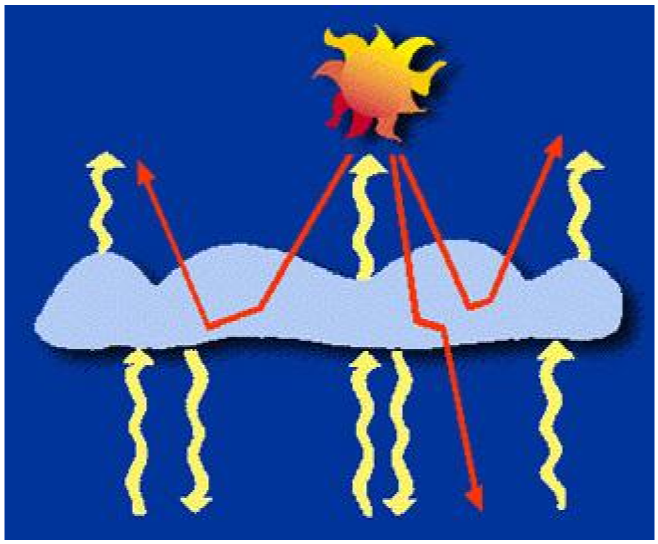

In contrast to the warming effect of the higher clouds, **low strato** (=layer) **cumulus** (=heap) **clouds act to cool the Earth system**. Because lower clouds are much thicker than high cirrus clouds, they are not as transparent: they do not let as much solar energy reach the Earth's surface, and the moisture doesn't readily absorb the short wavelength sunlight.

Instead, they reflect much of the solar energy back to space. The cloud shields the surface from enough solar radiation that the **net effect of these clouds is to cool the surface**.

Although these clouds are warmer than the high cirrus clouds, and so give off more energy to space, they are so close to the surface that they are actually a similar temperature as the surface and give off a similar amount to space. **So, the reflection of the sunlight is a bigger factor and these clouds tend to cool the planet as a result.**

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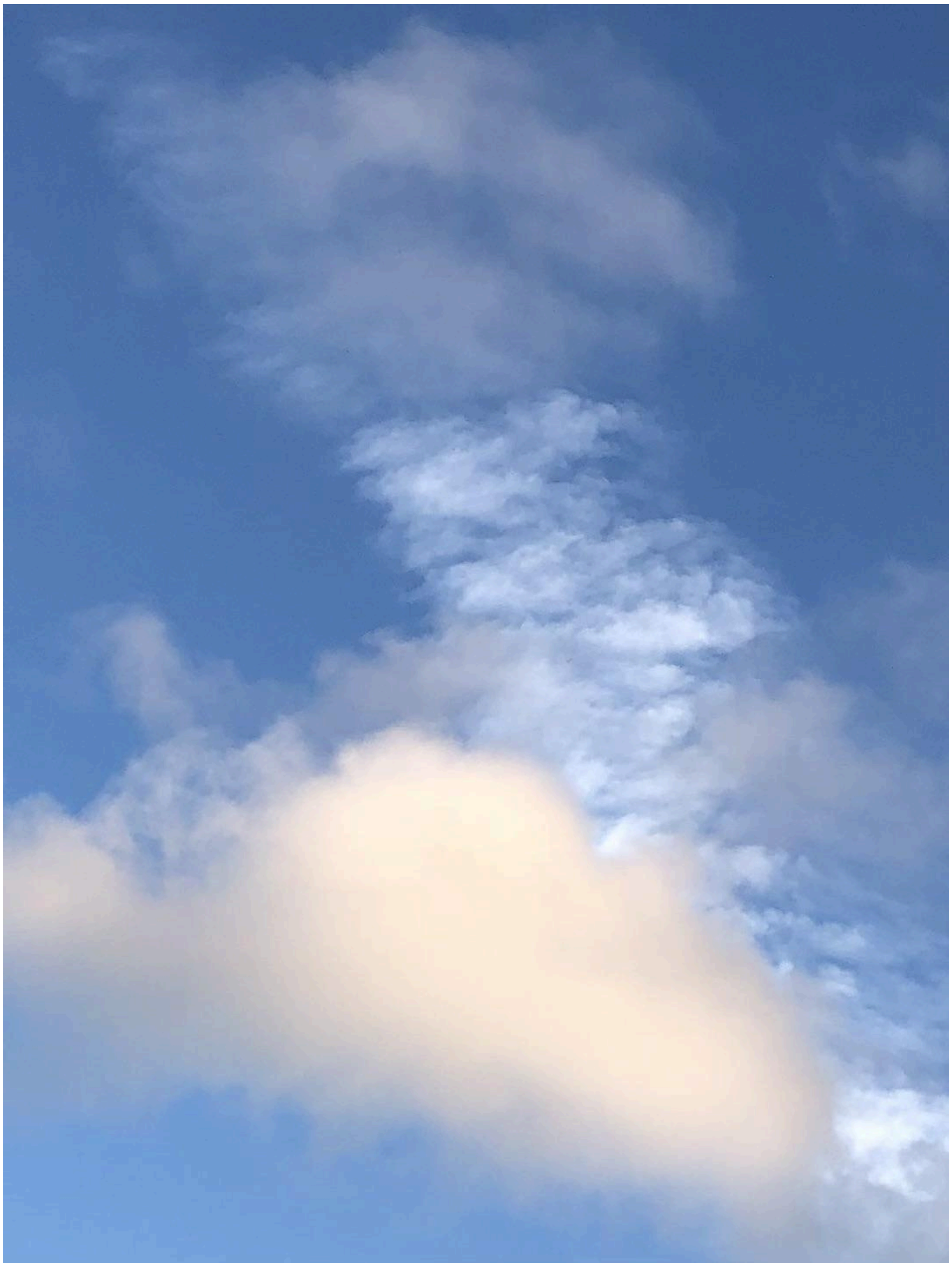
Let's check this out! Here is a recent cloud above WPB:



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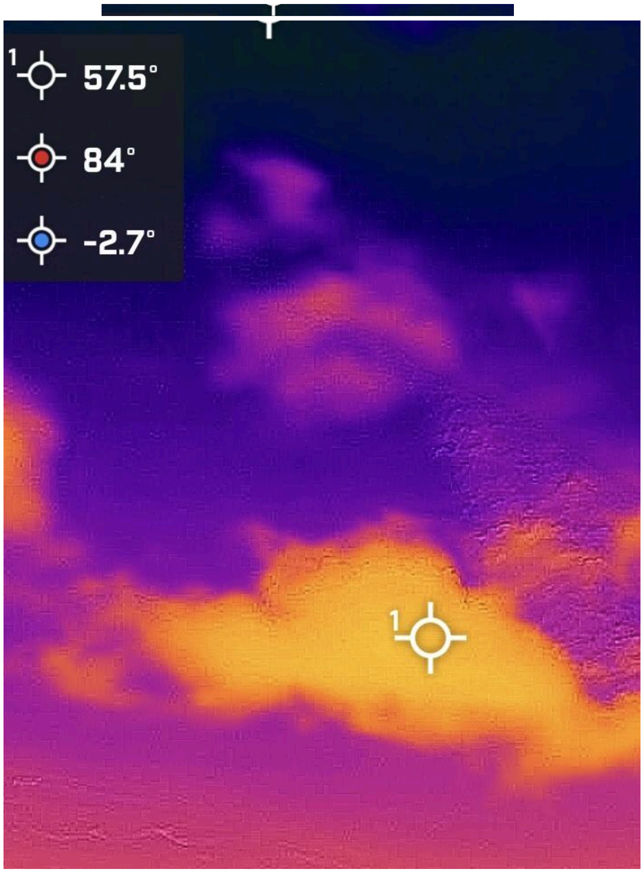	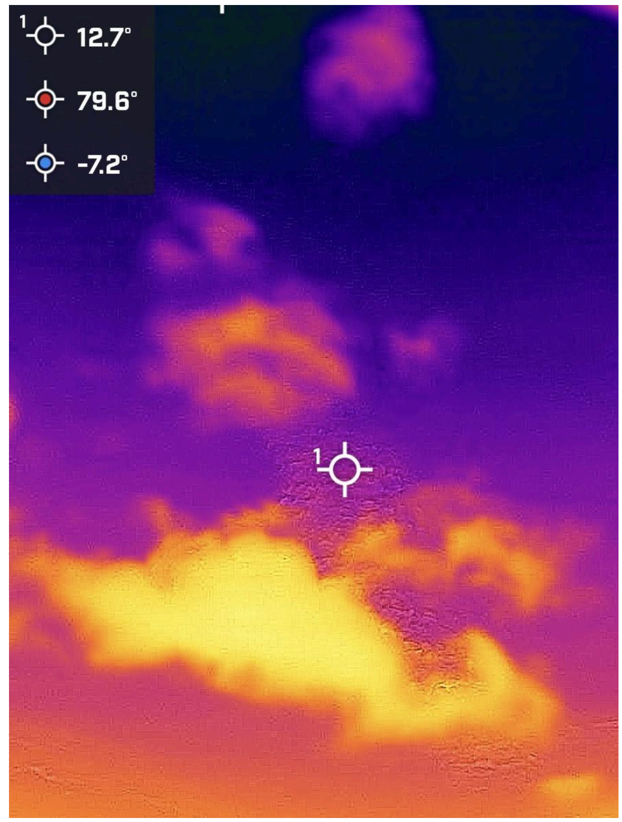
The temperature of the low altitude cloud (at the bottom) is measured at 57^0 F with my infrared camera.	The temperature of the high altitude cloud is around 12^0 F.

And, just to check my calibration….

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	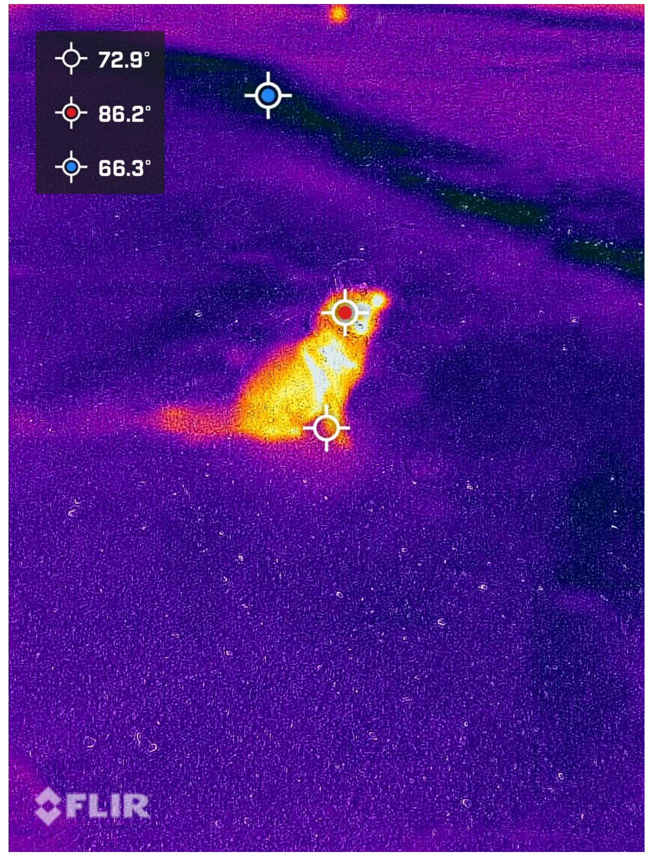

Finally: How does this help inform our understanding of human effects:

- **jet plane contrails;**

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Planes create their mesmerizing contrails as they soar **high in the thin, cold air**. Water vapor quickly condenses around soot from the plane's exhaust and freezes to form cirrus clouds, which can last for minutes or hours. These high-flying clouds are too thin to reflect much sunlight, but ice crystals inside them can trap heat. Unlike low-level clouds that have a net cooling effect, **these contrail-formed clouds warm the climate.**

A 2011 study suggests that the net effect of these contrail clouds contributes more to atmospheric warming than all the carbon dioxide ($CO2$) produced by planes since the dawn of aviation.

https://www.science.org/content/article/aviation-s-dirty-secret-airplane-contrails-are-surprisingly-potent-cause-global-warming

- **ship exhaust plumes;**

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The magnitude of the effect of anthropogenic aerosols on the formation of clouds is **an important unknown about how humans are affecting climate**. Studies of stratocumulus cloud tracks that are formed by ship exhaust have been used to estimate the radiative impact of this process, but Glassmeier *et al.* now show that **this approach overestimates the cooling effect of aerosol addition by up to 200%.** These findings underscore the need to quantify stratocumulus cloud responses to anthropogenic aerosols to understand the climate system.
https://www.science.org/doi/10.1126/science.abd3980

Jim Hansen et al. have brought a lot of focus to these ship tracks, noting significant reduction in reflectivity as the fuels have been cleaned up over the last decade.
https://academic.oup.com/oocc/article/3/1/kgad008/7335889

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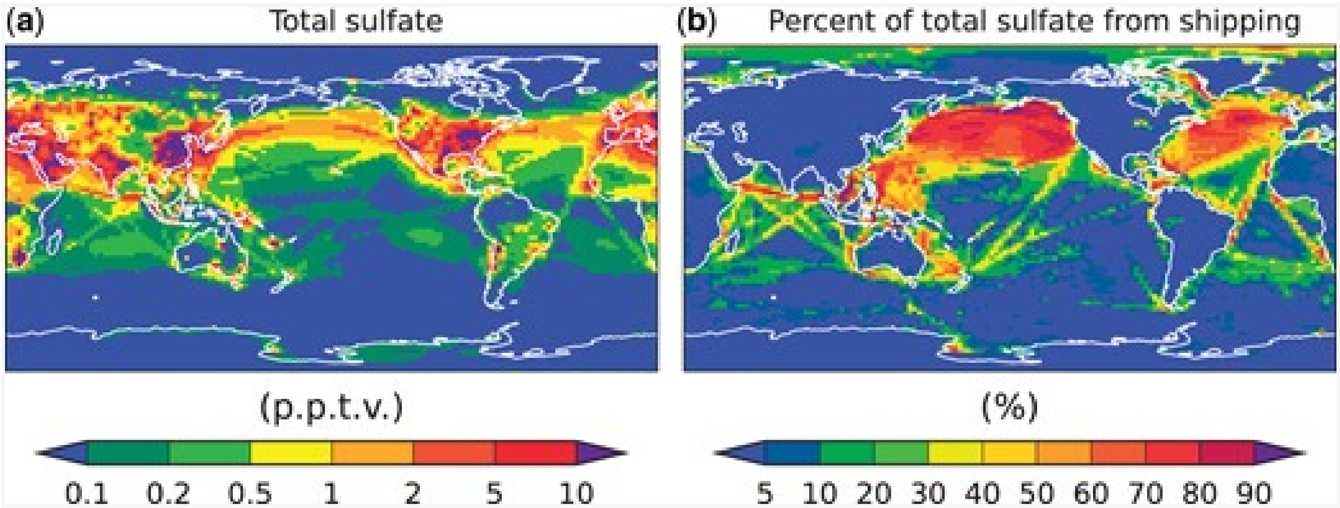
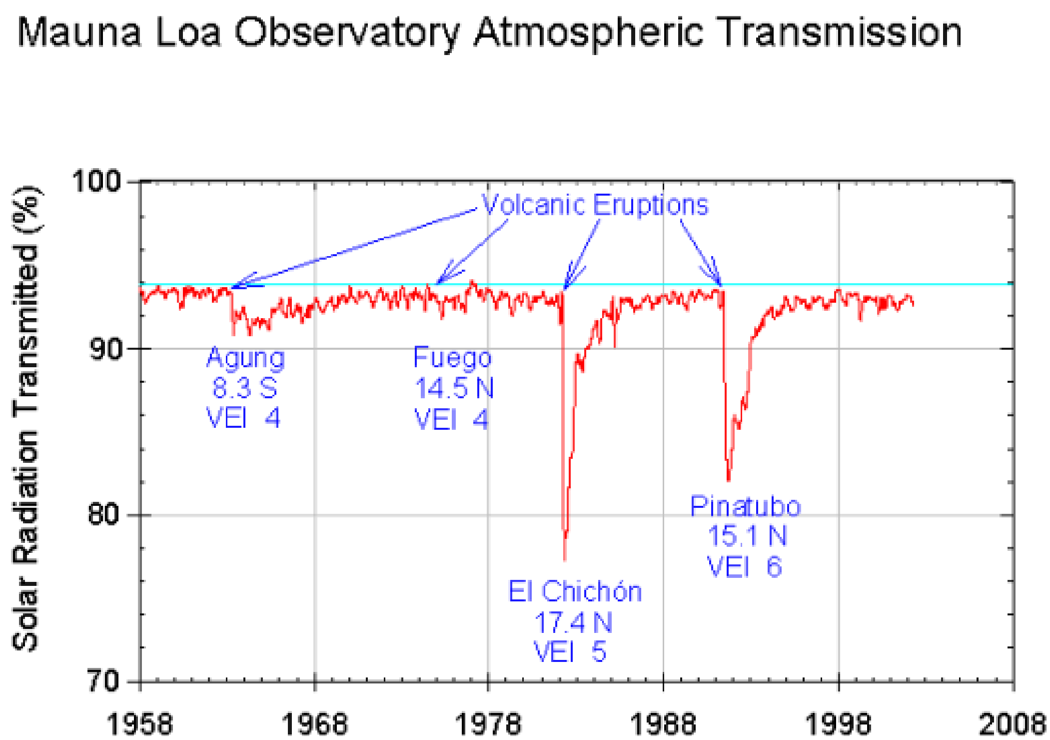


Changes of IMO (International Maritime Organization) emission regulations provide a great opportunity for insight into aerosol climate forcing. Sulfur content of fuels was limited to 1% in 2010 near the coasts of North America and in the North Sea, Baltic Sea and English Channel, and further restricted there to 0.1% in 2015 [163]. In 2020 a limit of 0.5% was imposed worldwide. **Following the additional 2020 regulations [165], global ship-tracks were reduced more than 50% [**166].

- ## geoengineering concepts of aerosols in the Stratosphere

This approach is less cloud-like because it is introducing solid particles in the dryer environment of the Stratosphere. The particles absorb little infrared heat, and reflect a lot of visible incoming light - both in the right direction. A new study finds that injecting SO_2 at higher latitudes, rather than in the tropics, could mitigate some undesirable side effects of SAI – but all options come with trade-offs.

One such potential method of climate intervention, known as stratospheric aerosol injection (SAI), aims to mimic the planet cooling effects of volcanic eruptions by injecting sulfur dioxide (SO_2) directly into the stratosphere where it forms sunlight-reflecting sulfate aerosols.



So, this looks a lot like the reflective clouds from above, but little moisture is involved.

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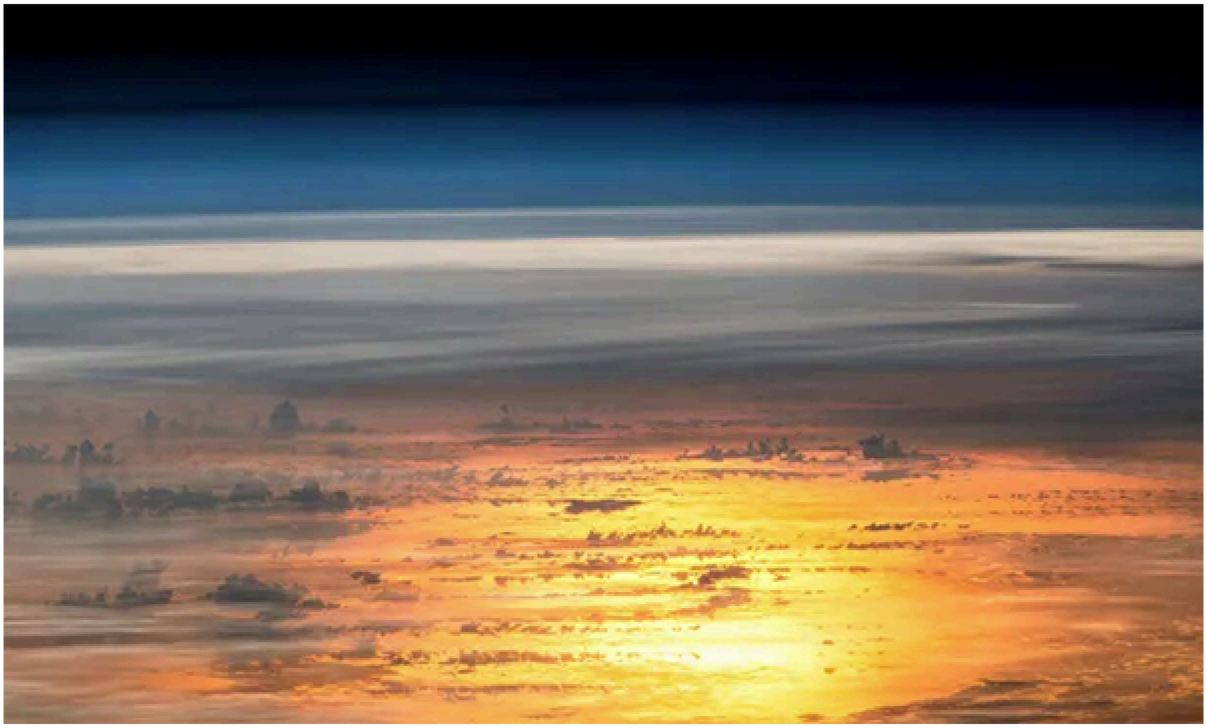

Stratospheric aerosol injection mimics the effect of a volcano by pumping gas into the sky that turns into aerosols, reflecting part of the sun's heat. Photo: ISS/NASA

https://csl.noaa.gov/news/2023/390_1107.html#:~:text=One%20such%20potential%20method%20of,forms%20sunlight%2Dreflecting%20sulfate%20aerosols.

There are reasons this approach is controversial - it is complicated!

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Table 1. Benefits and Risks of Stratospheric Geoengineering [a]

Benefits	Risks
1. Cool planet	1. Drought in Africa and Asia
2. Reduce or reverse sea ice melting	2. Continued ocean acidification from CO_2
3. Reduce or reverse land ice sheet melting	3. Ozone depletion
4. Reduce or reverse sea level rise	4. No more blue skies
5. Increase plant productivity	5. Less solar power
6. Increase terrestrial CO_2 sink	6. Environmental impact of implementation
	7. Rapid warming if stopped
	8. Cannot stop effects quickly
	9. Human error
	10. Unexpected consequences
	11. Commercial control
	12. Military use of technology
	13. Conflicts with current treaties
	14. Whose hand on the thermostat?

a The right column is an update of *Robock* [2008a].

https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2009gl039209

- **and throwing <u>salt water</u> up into the Troposphere.**

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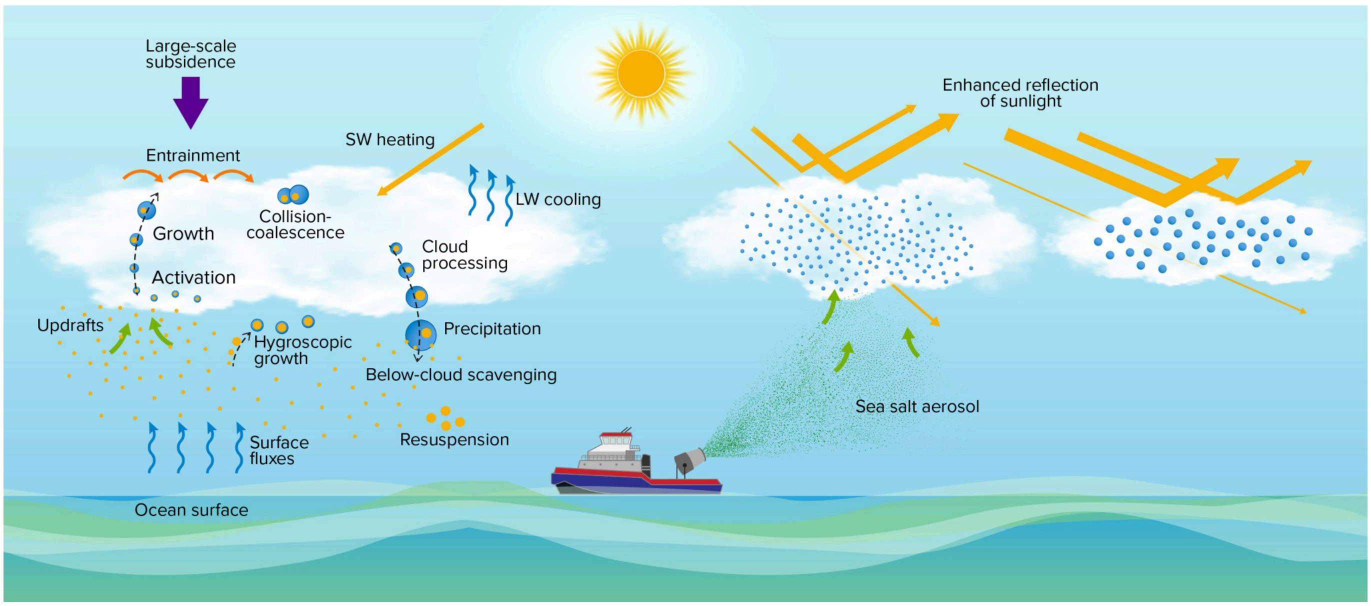
Marine cloud brightening (MCB) is the deliberate injection of aerosol particles into shallow marine clouds to increase their reflection of solar radiation and reduce the amount of energy absorbed by the climate system. From the physical science perspective…MCB will ultimately depend on …the scale-up of local-to-global brightening in today's climate and identify strategies that will **ensure an equitable geographical distribution of the benefits and risks** associated with projected regional changes in temperature and precipitation. https://www.science.org/doi/10.1126/sciadv.adi8594



Scientists are **even more unsure of the effects of marine cloud brightening than they are of stratospheric aerosol injection**. So it's no surprise that the authors of the new MCB paper want to proceed with caution. https://apple.news/A91FqHx2hQ5O2n69s6dau7g

Punchlines: Clouds are the result of many factors: temperature, thickness, size of droplets, aerosol content, altitude, etc.
Human effects can determine and influence how the atmosphere lets energy through or contains it.

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