ATMOSPHERIC CARBON REMOVAL COMPETITION

INTRODUCTION:

Large scale application of the Atmospheric Vortex Engine (AVE) is arguably the only way in which humankind can manage to affect Earth's climate on a scale large enough to reverse the processes which have led to our current crisis.

The use of AVEs will be:

- Highly cost-effective
- Environmentally benign in terms of eliminating carbon-based emissions in the medium term
- Able to substantially reduce environmental pollution which is causing the deaths of millions of people per year in third-world nations
- Having a significantly increased amount of precipitation local to the updraft system

STRATEGY:

- To reduce emissions of CO2 by generating power using Convective Available Potential Energy inherent in the atmosphere
- To reduce the level of atmospheric pollution, specifically black carbon, by
  - Reducing emissions of black carbon particulates
  - Using vortex-induced precipitation to "scrub" particulates from the local atmosphere
- To utilise waste flare gas from oil/natural gas production for electrical power generation <u>in the short term</u> until the use of fossil fuels is able to be fully eliminated
- To enhance atmospheric convection by
  - Increasing local circulation within the Intertropical Convergence Zone, where it is otherwise low
  - Overcoming inversion layers
  - Overcoming the convection inhibition caused by the Atmospheric Brown Cloud
- To substantially increase the albedo of the Earth's atmosphere by transporting water vapour to form clouds at the top of the troposphere

THE PROBLEM – AN IMBALANCE BETWEEN SOLAR RADIATION INFLOW TO EARTH AND INFRARED RADIATION BACK TO SPACE:

Earth's Heat Balance:

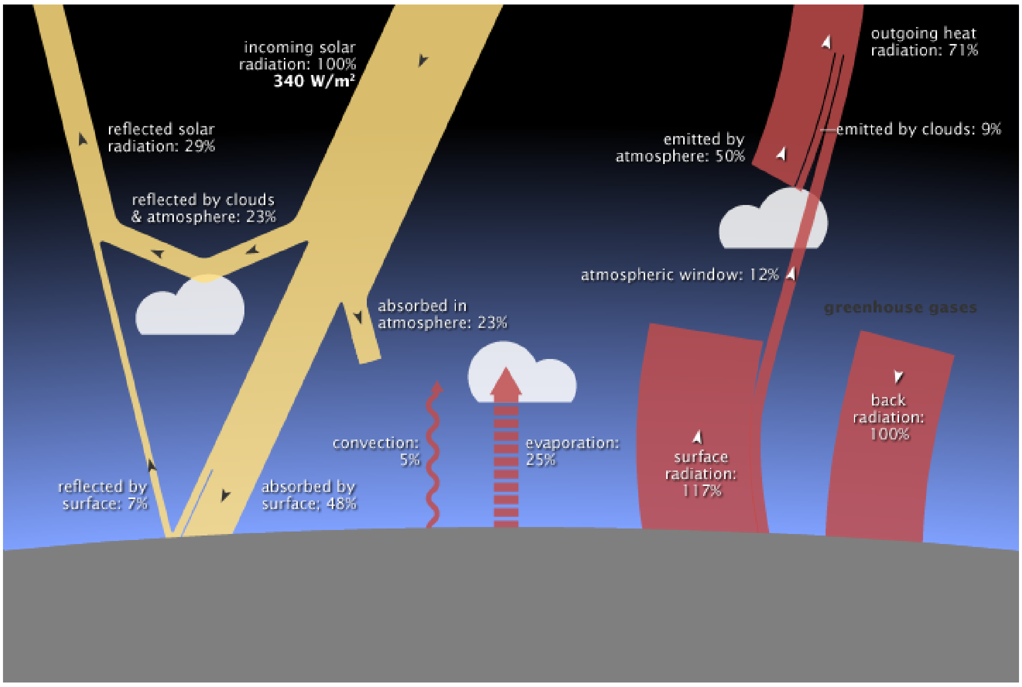


Fig. 1 https://earthobservatory.nasa.gov/features/EnergyBalance/page6.php

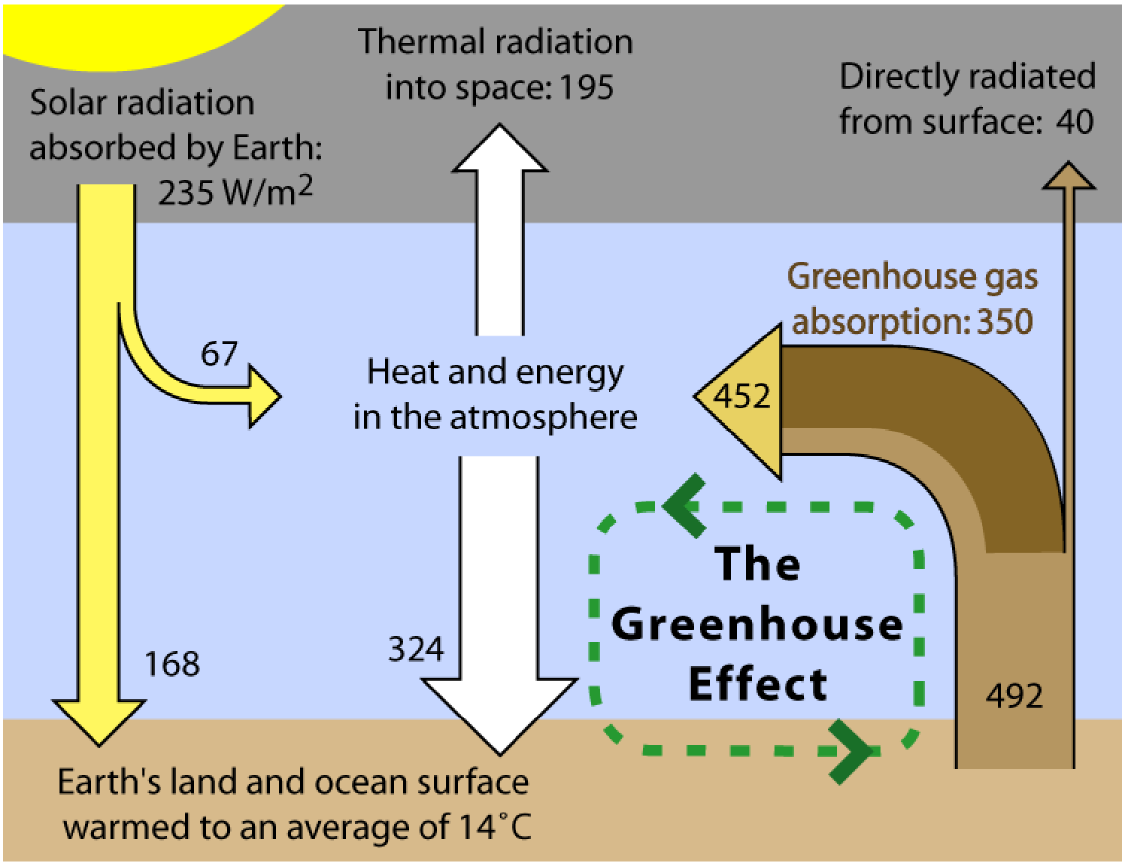


Fig. 2 Diagram illustrating the greenhouse effect.

Credit: *Image created by Robert A. Rohde, courtesy of the Global Warming Art project.*

CALCULATIONS:

Average Global Insolation = 340 W/m^2.

(From Fig. 1)

Earth's surface area **(A)** = 510 x 10^{12} m^2

Therefore, total Global insolation:

Q = 340 x 510 x 10^{12}

= 1.734 x 10^{17} Watts solar radiation.

= 1.734 x 10^{17} x 8760 x 3600 J/yr

= **5.47 x 10^{24} J/yr**

Percent of heat absorbed by Earth's surface Q':

= **48%**

(From Fig. 1)

Q' = 2.63 x 10^{24} J/yr.

Moist convection through Troposphere:

Earth's average annual precipitation = 100 cm

(ref: https://hypertextbook.com/facts/2008/VernonWu.shtml)

= 1.0 m

Total precipitation/ annum (M) = 510×10^{12} m^3 of water

M = 510×10^{15} kg/yr.

Enthalpy differential between ground level ambient and the top of the Troposphere:

Δh water between 30C and -70C $\simeq 3.5 \times 10^6$ J/kg

Global enthalpy differential in moist convection:

ΔH = M * Δh

= $510 \times 10^{15} * 3.5 \times 10^6$

= **1.785×10^{24} J/yr.**

[$\Delta H/A$ (= 111 W/m^2 average)]

What percentage of the heat absorbed at the Earth's surface is transferred to Space by moist convection?

$\Delta H/Q'$ = $(1.785/2.63) \times 10^{24}$

= 0.678

= 68%

Similarly by dry convection: = 5%

<u>Total Convective Heat Transfer: = 73%</u> **Item 1**

<u>Miscellaneous heat transfer and interception, based on values from Fig.1, in which 48% of the incoming solar radiation is absorbed at the Earth's surface:</u>

Absorbed by atmosphere: = 23 x 0.48%

= 11 % **Item 2**

Reflection from Clouds/atmosphere: = 23 x 0.48%

= 11% **Item 3**

Reflection from surface: = 7 x 0.48%

= 3.3% **Item 4**

Net radiative flux: = 12 x 0.48%

= 5.8% **Item 5**

The total percentage of the Earth's surface heat returned through items 1 to 5 is very slightly over 100%, probably due to a combination of roundoff error and estimation error.

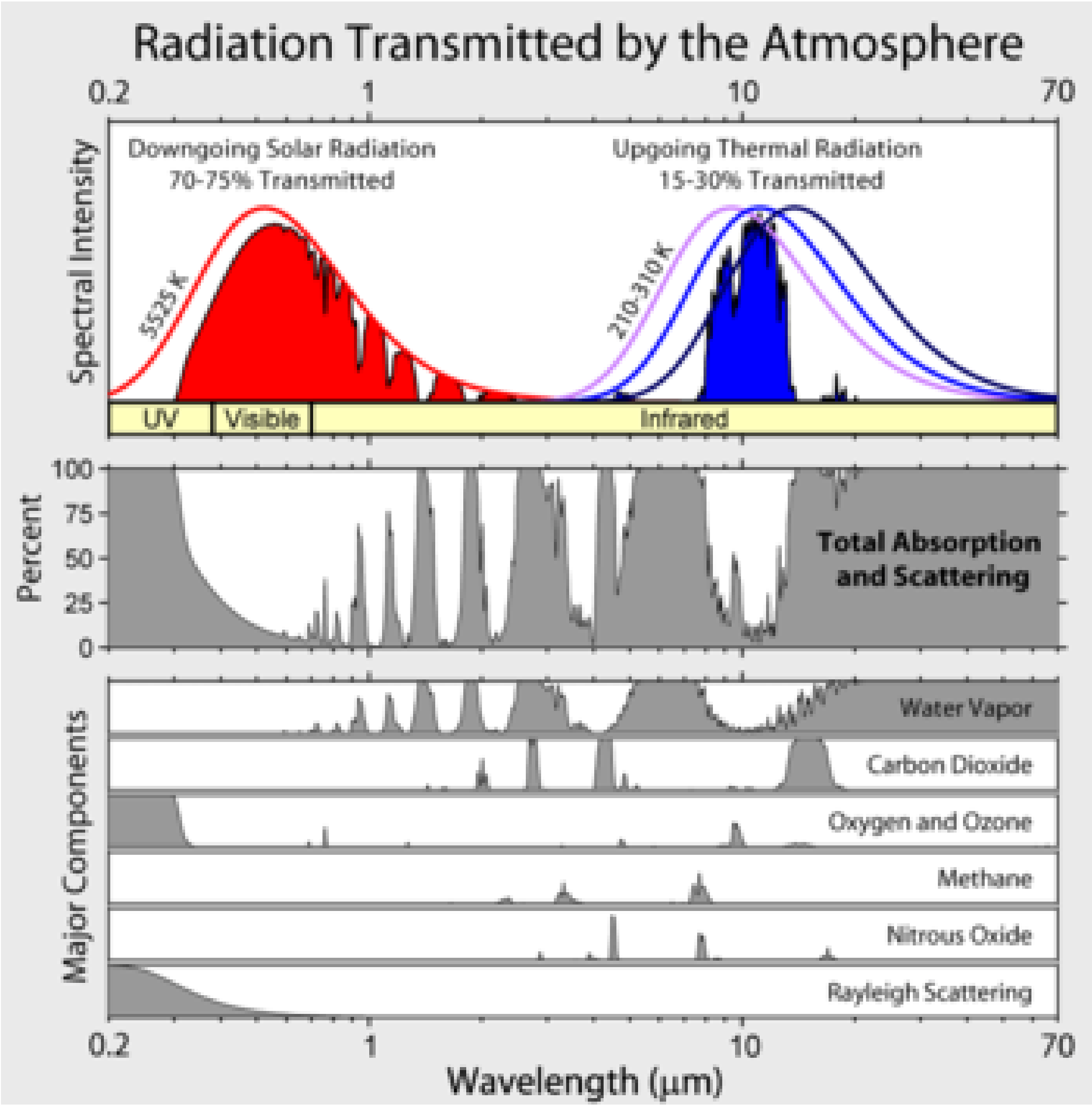


Fig. 3 Greenhouse gas interaction with Earth's energy flux. *Credit: NASA*

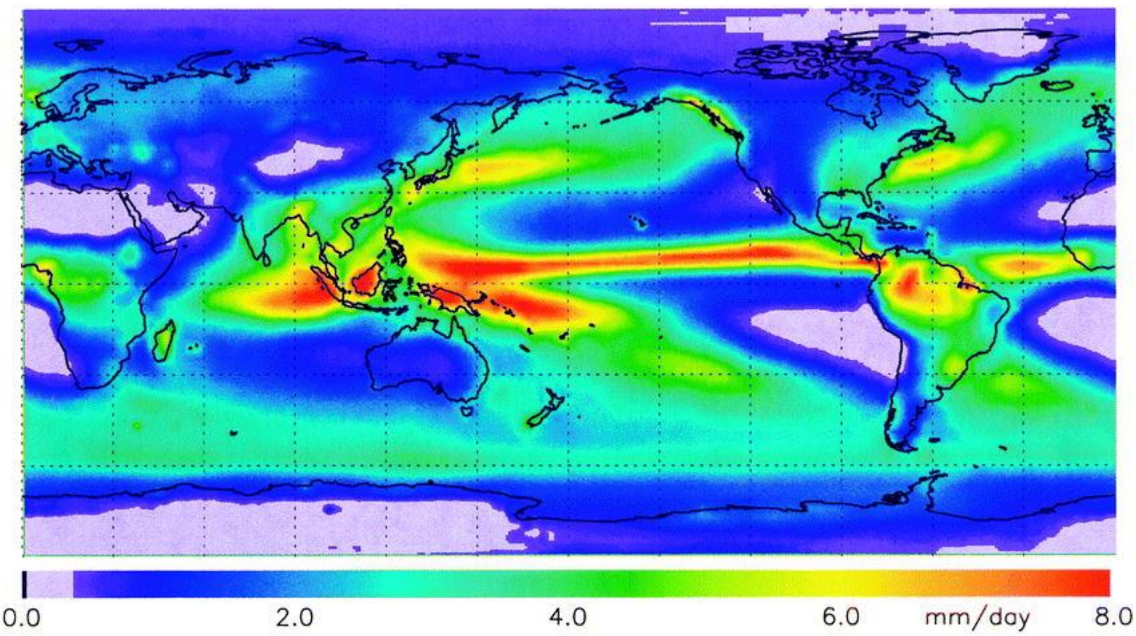


Fig. 4 The 23-yr (1979–2001) annual mean precipitation (mm day^{-1})

https://journals.ametsoc.org/view/journals/hydr/4/6/1525-7541_2003_004_1147_tvgpcp_2_0_co_2.xml

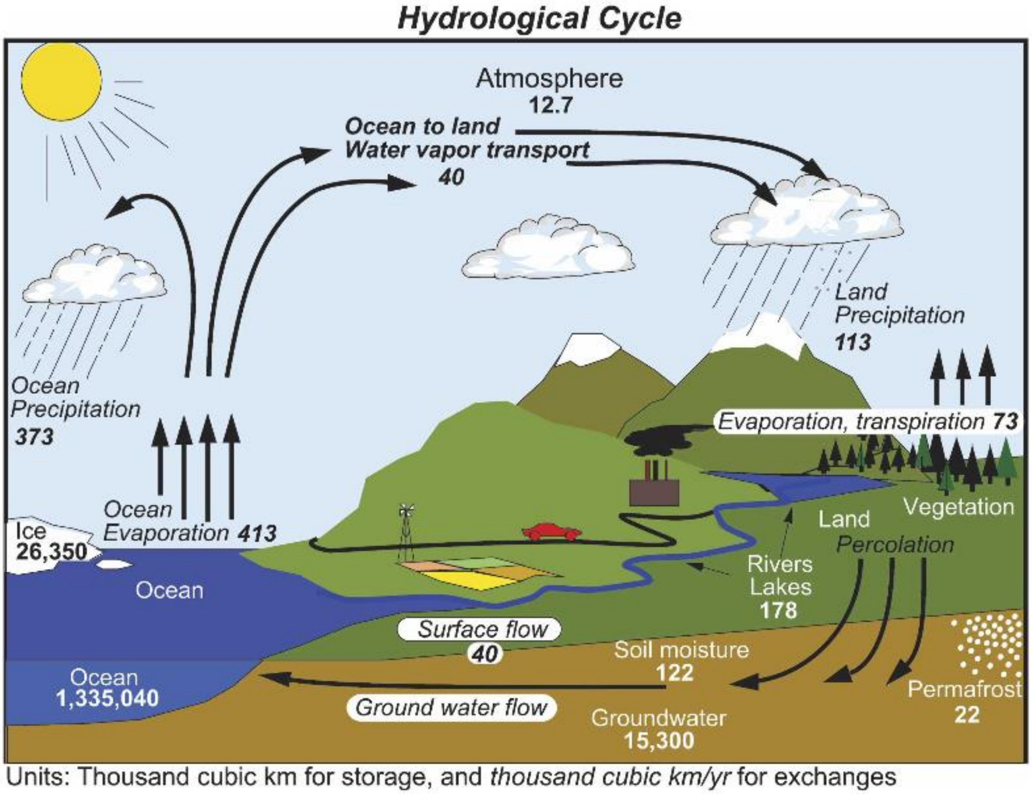


Fig. 5 The hydrological cycle. Estimates of the main water reservoirs, given in plain font in 10^3 km^3, and the flow of moisture through the system, given in italics (10^3 km^3/yr.)

Source: Trenberth, K. E., L. Smith, T. Qian, A. Dai and J. Fasullo, 2006. Estimates of the Global Water Budget and Its Annual Cycle Using Observational and Model Data, Journal of Hydrometeorology, 8:758-769

The percentage of precipitation which occurs over land is then:

= (113/(413 + 73)) x 100**%**

= 23%.

This is well below the percentage of Earth's surface covered by land, 30%. Hence Land is getting around 77% as much rain intensity as the oceans.

Earth's total precipitation is a function of the global surface temperature. Despite global warming, this is unlikely to vary more than a few percentage points.

What **can** be affected by the vortex engine is arguably:

- The percentage of precipitation falling on land
- A reduction in the difference between the extremes of flooding and drought

These would both be extremely valuable in terms of general human welfare, and in overcoming global warming. Each would aid in carrying out re-afforestation and hence increasing global photosynthesis and natural convection. It has been shown that for the Amazon rainforest:

> *"…This shallow convection moisture pump (SCMP) preconditions the atmosphere at the regional scale for a rapid increase in rain-bearing deep convection, which in turn drives moisture convergence and wet season onset 2 – 3 months before the arrival of the Intertropical Convergence Zone (ITCZ). Aerosols produced by late dry season biomass burning may alter the efficiency of the SCMP. Our results highlight the mechanisms by which interactions among land surface processes, atmospheric convection, and biomass burning may alter the timing of wet season onset and provide a mechanistic framework for understanding how deforestation extends the dry season and enhances regional vulnerability to drought..."*

https://www.pnas.org/content/114/32/8481 .

The vortex engine can arguably be employed in conjunction with existing rainforests to enhance their Global cooling ability. The Amazon rainforest and river system acts to remove twenty billion tonnes of greenhouse gas (i.e. water vapour) per day. Ninety five percent of the greenhouse warming effect is due to water vapour. The effect of water vapour is usually neglected because it is regarded as being a *symptom* of global warming, rather than a *cause*. Dr. Veerabhadran Ramanathan's ground-breaking research would argue strongly counter to this. Through the Atmospheric Brown Cloud, humans are having a profound effect on atmospheric convection and hence the build-up of water vapour in the atmosphere.

> *"…In 2019, total global anthropogenic GHG emissions were 52.4 Gt CO_2e…"*

https://css.umich.edu/factsheets/greenhouse-gases-factsheet

Greenhouse Gases:

Gases that absorb radiation, particularly infrared radiation, typically trap solar radiation in Earth's atmosphere. The principal such gases are water vapour, CO2, methane

Water Vapour:

From Fig. 3, it can be seen that atmospheric water vapour is the most important greenhouse gas. It can be minimized by enhancing convection within the troposphere. Convection is currently being inhibited by human activity:

> *"…What we see in the observations is that when air picks up water vapour from the ocean surface and rises up, it often only rises a few kilometres before it begins its descent back to the surface," Sherwood said. "Otherwise it might go up 10 or 15 kilometres."*
>
> *"And those shorter trajectories turn out to be crucial to giving us a higher climate sensitivity because of what they do to pull water vapour away from the surface and cause clouds to dissipate as the climate warms up..."*

https://www.voanews.com/a/study-warmer-world-will-produce-fewer-clouds/1822952.html

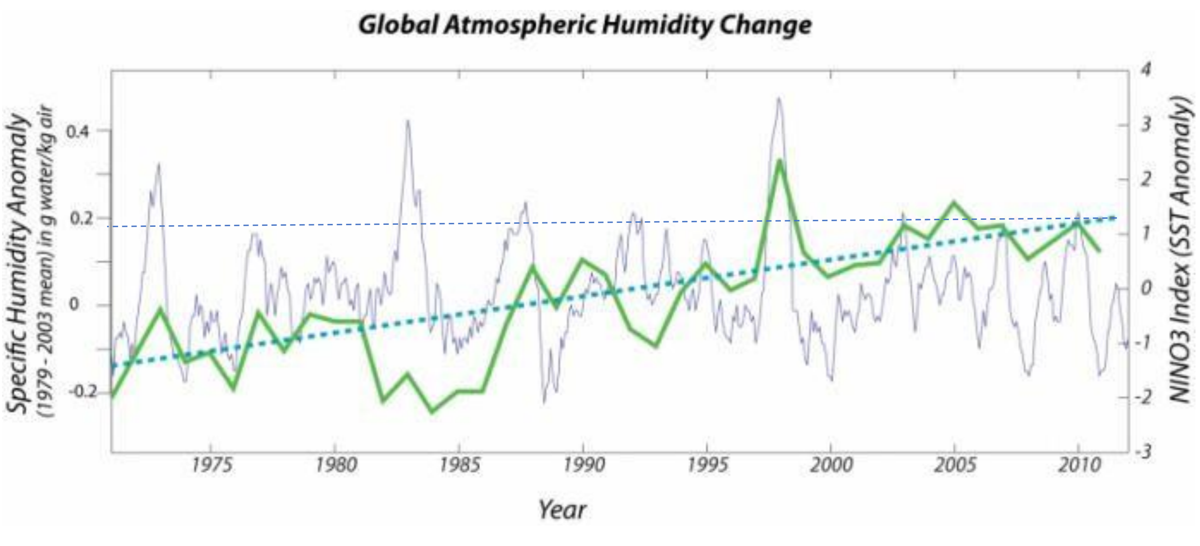


Fig. 6 Change in Global humidity over the last 40 years.

Credit: David Bice © Penn State University is licensed under CC BY-NC-SA 4.0

The thick green line in the figure above is the global specific humidity anomaly (data from NOAA), with its best fit linear trend as the blue dashed line. Over this time period, the water content has risen by about 5%. The thin blue line is the history of the El Niño - La Niña oscillation. The water vapour increase represents 650 billion tonnes over 40 years, or 16 x 10^9 tonnes per year, based on the accepted figure of 13,000 billion tonnes (13,000 cubic kilometres) of atmospheric water vapour.

*(Alternatively on the above indicated variation of 0.33g water/kg air, and mass of air in the atmosphere 101.3 kN/m^2 * 510 x 10^{12} m^2/9.8, the change of water vapour mass is then 1.74 x 10^{12} tonnes in 40 years, or 43 x 10^9 tonnes/yr.)*

As expected, the highest water vapour level in the Troposphere is in the tropics, specifically the Inter-Tropical Convergence Zone (ITCZ):

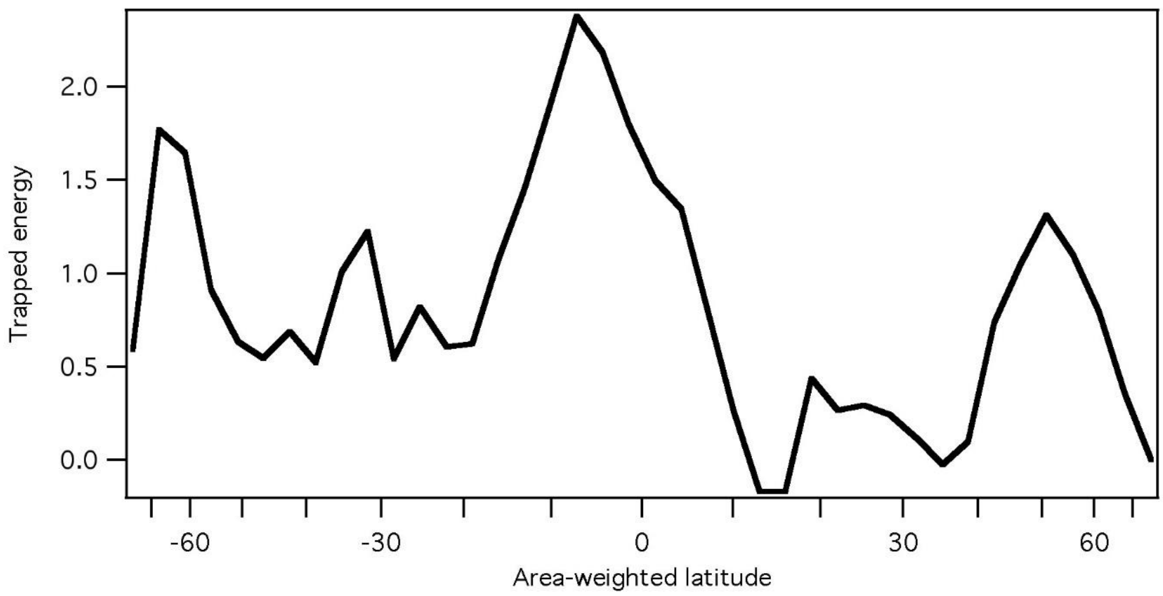


Fig. 7 Based on climate variations between 2003 and 2008, the energy trapped by water vapor is shown (L – R) from Southern to Northern latitudes, peaking near the equator.
Credit: Prof. Andrew Dessler Texas A&M University.
https://www.nasa.gov/topics/earth/features/vapor_warming.html

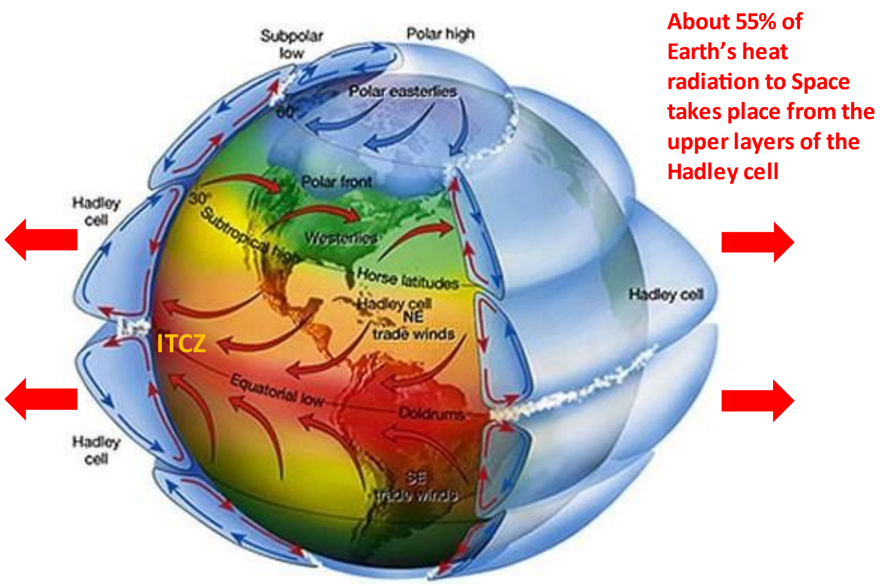


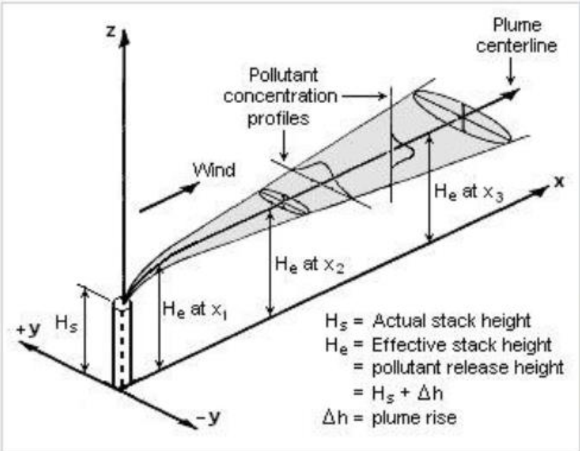
Fig. 8 Efficient operation of the Hadley Cell is crucial for maintaining Earth's heat balance.

For effective convection within the Hadley Cell:

- Deforestation must be stopped
- The atmospheric brown cloud must be eliminated (or bypassed with the aid of the vortex engine)

These are eminently doable in the order of one or two decades if given adequate priority.

The AVE can help maintain convection during the transition period.



Visualization of a buoyant Gaussian air pollutant dispersion plume

PD (Photo) U.S. EPA

Industrial emissions plume

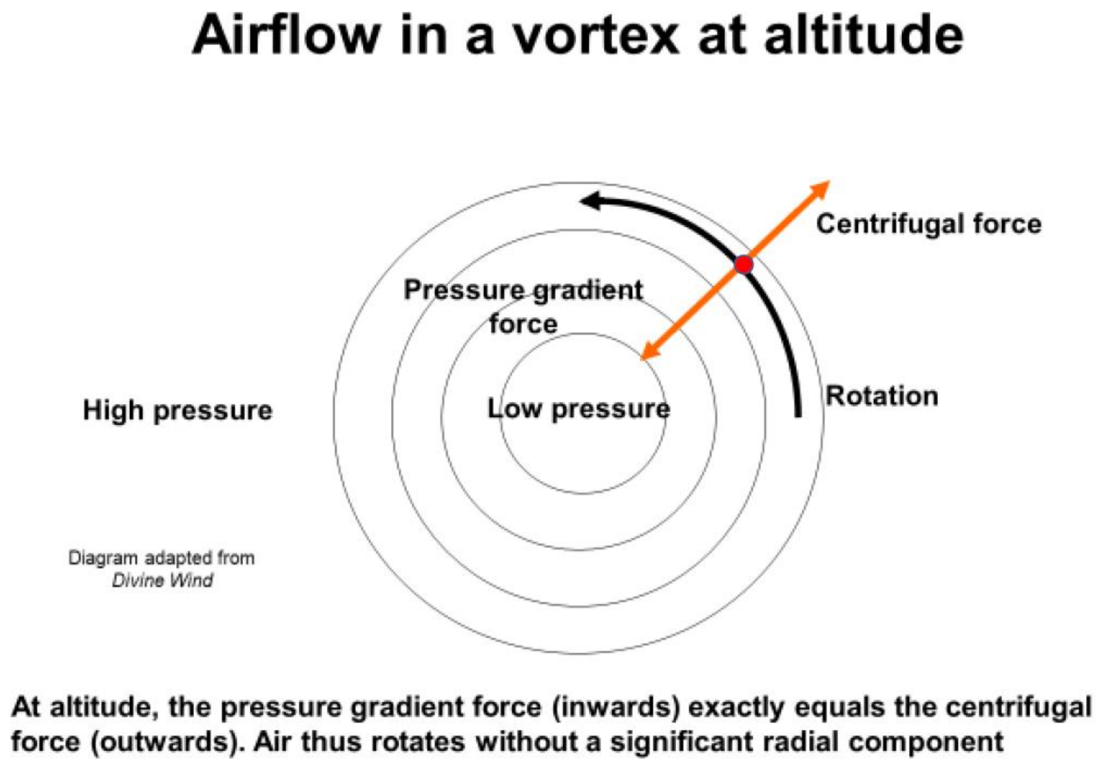
Fig 9. Non-rotating updrafts tend to entrain the surrounding air and lose vertical momentum.

Visualization of a buoyant Gaussian air pollutant dispersion plume Briggs, (1971); & Briggs, (1972)

Because of the dynamics of the vortex, rotating updrafts are 'quarantined' from the surrounding atmosphere, lose very little vertical momentum, and hence are much more efficient in terms of convection:

Fig 10. The tornado is a highly effective mechanism through which Nature acts to convey humid boundary layer air to the top of the troposphere where precipitation is initiated. The "anvil" is formed when it reaches the tropopause (ca. 10 km), the interface with the stratosphere.

The high efficiency of the vortex “virtual chimney” in terms of the facilitation of convection is the key factor in terms of the utility of the vortex engine:



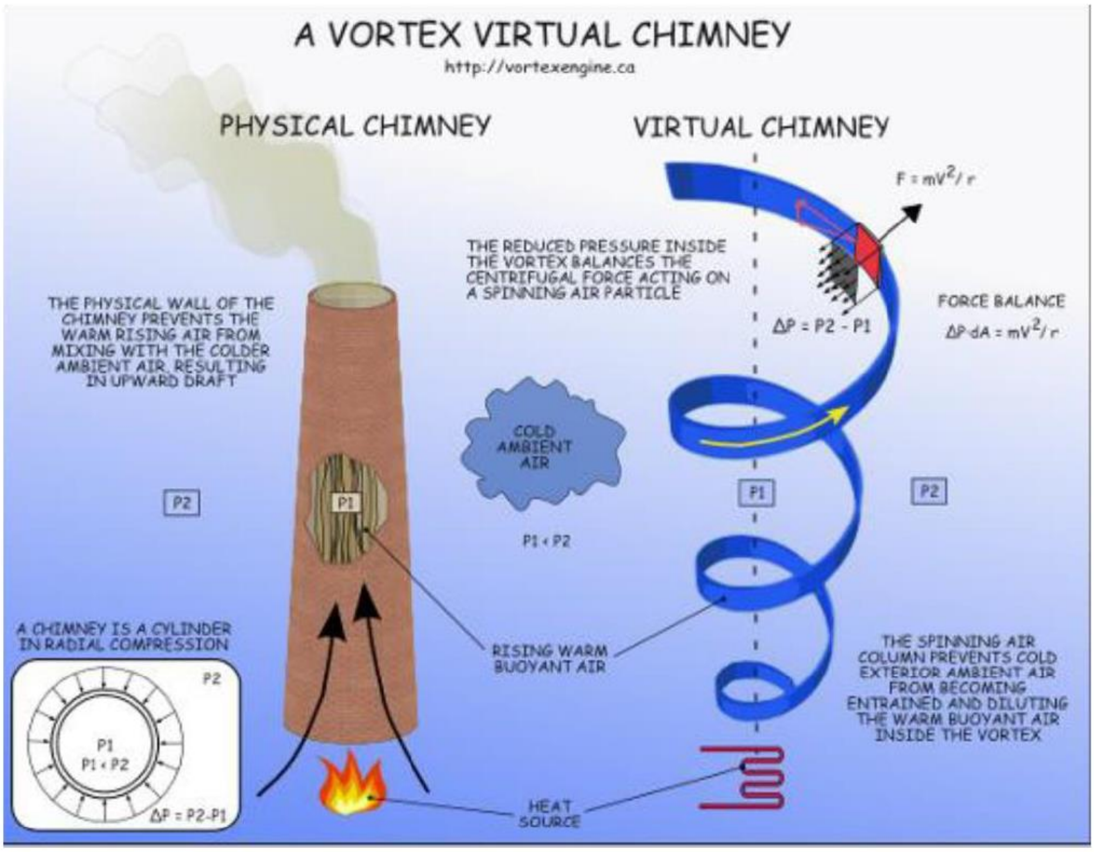


Fig. 11. The mechanism of the “virtual chimney.”

Carbon Dioxide:

The vortex engine cannot remove carbon dioxide from the atmosphere, but in its geothermal or solar energy input form, it will be completely carbon emissions free and hence would justifiably be classified as renewable energy.

Methane:

> *"Cutting methane emissions is the fastest opportunity we have to immediately slow the rate of global warming, even as we decarbonize our energy systems."*
>
> *"It's an opportunity we can't afford to miss."*
>
> *"Methane has more than 80 times the warming power of carbon dioxide over the first 20 years after it reaches the atmosphere. Even though CO_2 has a longer-lasting effect, methane sets the pace for warming in the near term."*
>
> *"At least 25% of today's warming is driven by methane from human actions. One of the largest methane sources is the oil and gas industry…"*

https://www.edf.org/climate/methane-crucial-opportunity-climate-fight

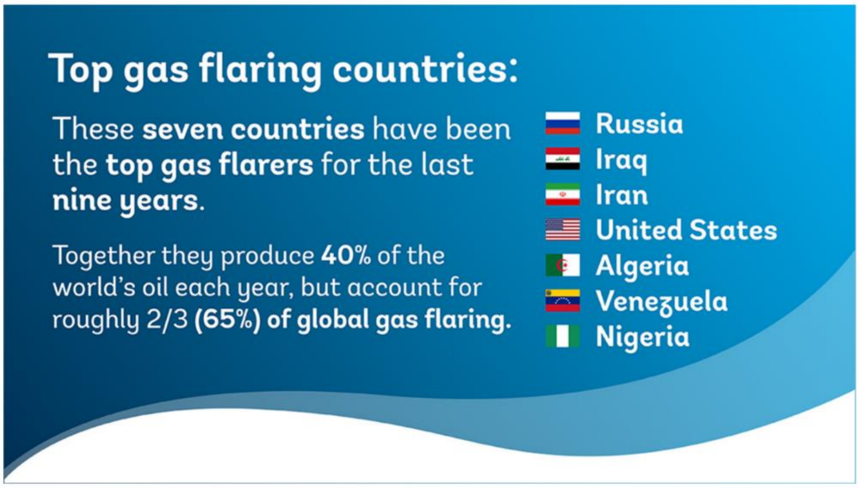
Global Warming Potential

GHG	GWP for 100 years
CO_2	1
CH_4	23
N_2O	296
HFC - 23	12 000
HFC – 134a	1 300
SF_6	22 200

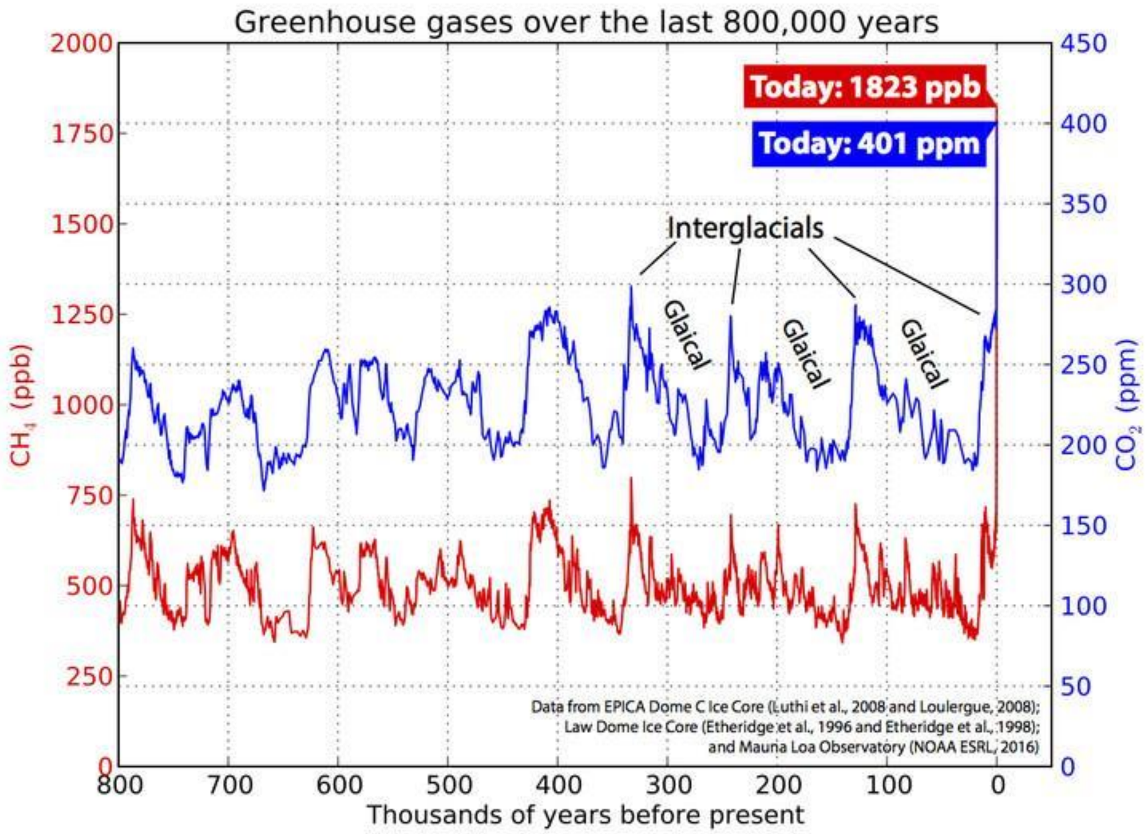
Source: *IPCC Third Assessment Report* (2001).

https://www.economist.com/leaders/carbon-dioxide-is-by-far-the-most-important-driver-of-climate-change/21803535

Due to the fact that methane is an unwanted by-product at many production well-heads, there is a strong incentive to flare the gas off, or even worse, vent the gas covertly:



The build-up of CO2 and atmospheric methane is absolutely unsustainable:



Sulphur Dioxide:

While sulfur dioxide isn't a direct greenhouse gas like carbon dioxide or methane, it is considered an indirect greenhouse gas because, when coupled with elemental carbon, it forms aerosols, or particles which interfere with tropospheric convection. As with black carbon, the precipitation induced by the vortex engine will help "scrub" the atmosphere of these aerosols.

OTHER EFFECTS:

Solar-geoengineering: increasing Earth's albedo:

The Earth's albedo is dropping due to the melting of ice, particularly in the Arctic.

"…Arctic sea ice minimum extent is now declining at a rate of 13.1% per decade. The pace is likely to accelerate because of climate change-induced warming and the ice-albedo feedback cycle. The albedo effect describes the white ice surface's ability to reflect Earth-bound sunlight back to space. Redirecting solar energy away from the ocean keeps the seawater beneath the ice cooler. When sea ice melts, darker-colored liquid water is left exposed to absorb sunlight. That warmer water then melts additional ice, creating the ice-albedo feedback cycle…"

To counter this effect to some extent reflection from clouds can be enhanced by using the vortex engine principle to lift humid air to the top of the troposphere to where the reflective clouds can form :

Historically, around 26% of incoming solar energy has been reflected off clouds and the atmosphere in general. This is diminishing, arguably due to inhibition of atmospheric convection by the Atmospheric Brown Cloud.

The "shorter trajectories" are a result of atmospheric brown cloud inhibition to convection.

Fig. 12. Cloud cover and albedo

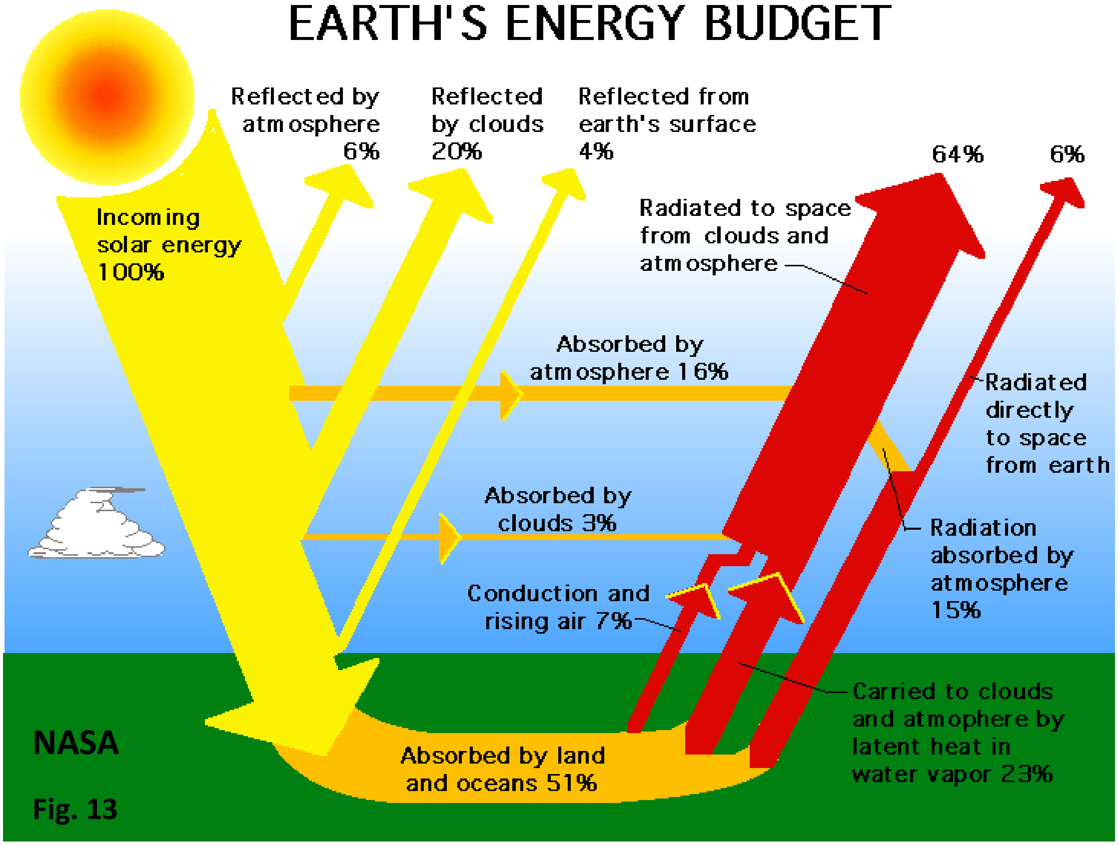


Fig. 13

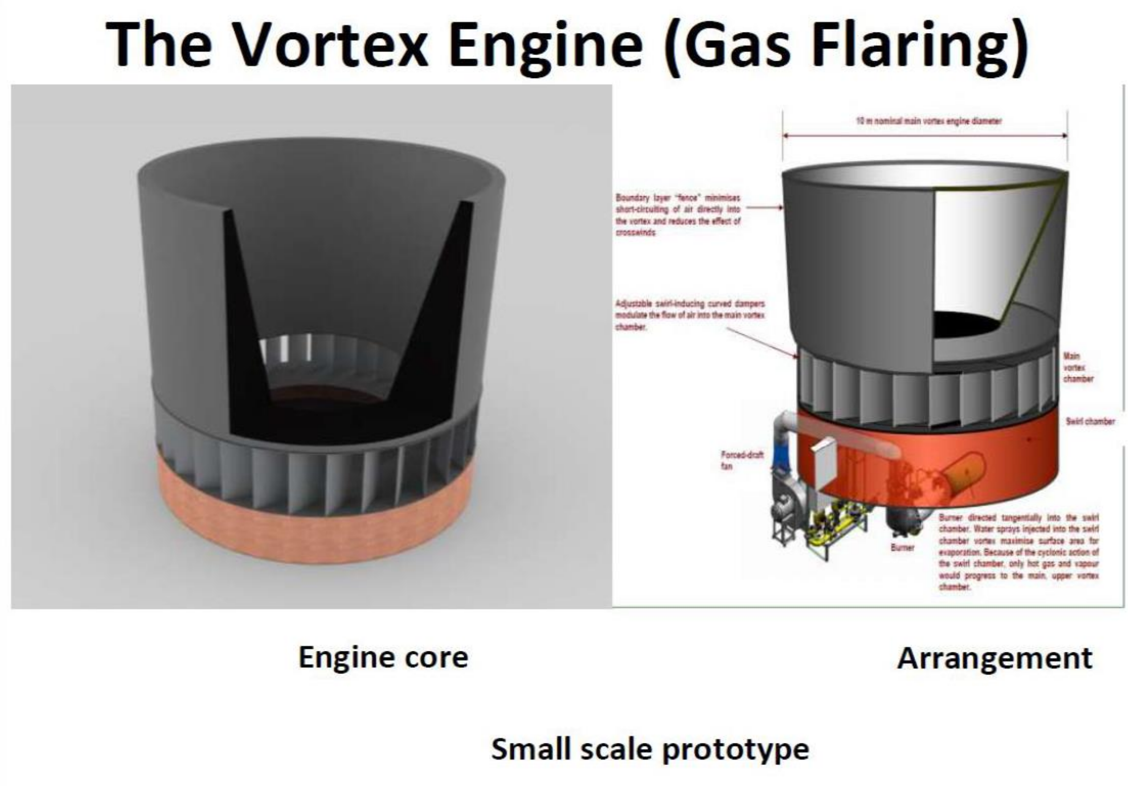

Fig. 14

If the process of convection is relatively fast, the heat lost by radiation is minimised and the resulting efficiency in reaching high altitudes is maximised. The updraft can generate:

- A “cloud umbrella” which can reduce local ground temperatures.
- Increased infra-red radiation from the top of the troposphere to Space, and hence global cooling

THE STRATEGY:

The Vortex Engine (AVE) Prototype:



Vortices can be generated and controlled as easily as that which we do when emptying the bath. As long as a vortex is of the same scale or less than that of a typical waterspout or tornado, it can be arranged to rotate in either direction as desired. The vortex engine can be the vehicle through which this control can be effected.

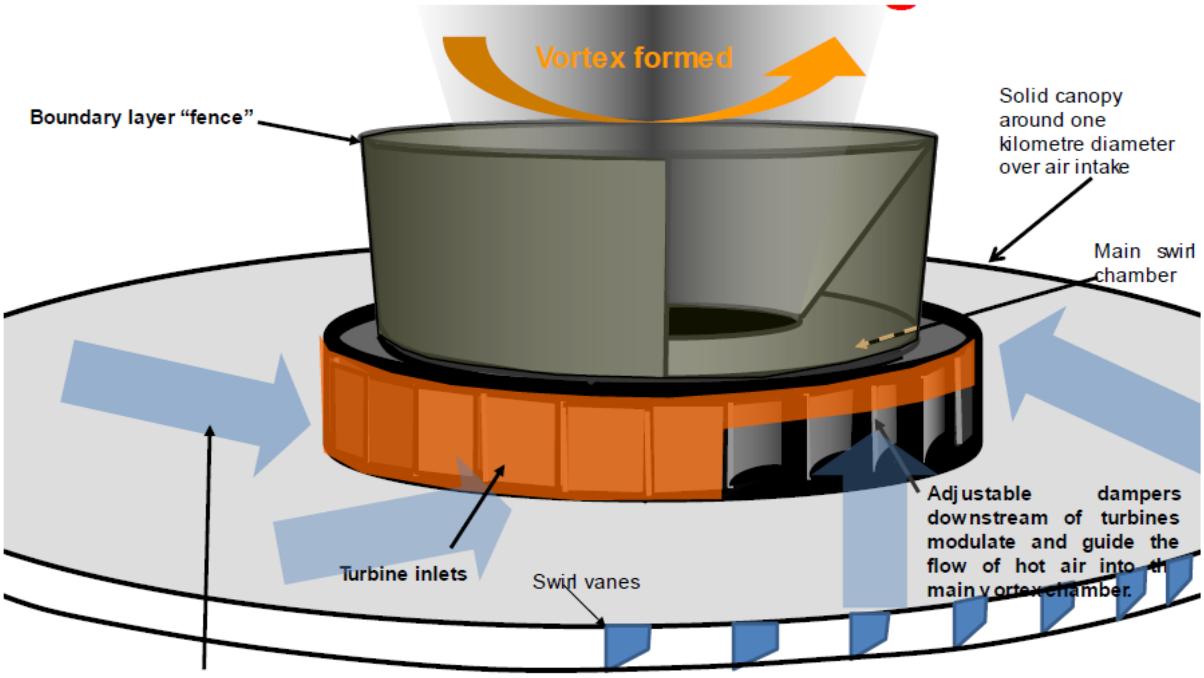
Flaring of waste natural gas absolutely must be stopped. In the short transition period until this is achieved, it is suggested that we "make a virtue of necessity" and generate electrical power from the waste flare gas:

Ref: **Vortex engine business plan** *https://www.vortexengineer.com/vortex-engine-business-plan.html*

The business plan relates to a proposal to utilise waste flare gas during the vortex engine research phase. This will allow "boot-strapping" of the project by generating income for further development.

In the longer term, it is proposed that low-grade geothermal energy from hot sedimentary aquifers be utilised to initiate the vortex updraft.

Geothermal energised vortex engine



Air picks up heat from pipes beneath a canopy creating a water-to-air heat exchanger, before entering the vortex engine main swirl chamber

As Professor Nilton Renno, of the department of atmospheric, ocean and space sciences at the University of Michigan, has put it:

> *“…‘The science is solid,’… ‘Once you induce circulation nearby, the vortex can be self-sustaining.’ ”*

Discovery, Feb 28 2013

Pareto’s Law:

We arguably need to “Pareto” our way out of the Climate crisis:

> *The **Pareto principle** states that for many outcomes, roughly 80% of consequences come from 20% of causes (the “vital few”). Other names for this principle are the **80/20 rule**, the **law of the vital few,** or the **principle of factor sparsity.***

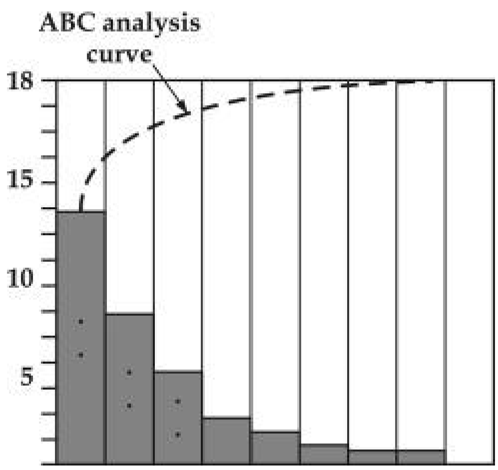


Fig. 15 https://www.sciencedirect.com/topics/engineering/pareto-principle

The elimination of methane emissions, short lived climate forcers such as black carbon, and other particulates can be far more cost-effective in the short term than the exclusive elimination of CO2 emissions. See **"Best path to net zero: Cut short-lived super-pollutants."** *https://thebulletin.org/2020/04/best-path-to-net-zero-cut-short-lived-super-pollutants/*.

> *"…At first glance, taken overall, these [CO2removal] trends generally sound promising. But the climate battle could be lost long before 2050; it might even be lost by 2035."*
>
> *"Consequently, it is time for fast climate mitigation, especially in the form of reductions of the short-lived so-called "super-pollutants"—black carbon, methane, tropospheric ozone, and hydrofluorocarbons, abbreviated as HFCs. (Black carbon is the sooty, dark material emitted by coal-fired power plants, gas and diesel engines, and other sources. Its heat-trapping power is twice what was thought only a few years ago, a report in the* Journal of Geophysical Research *found.) Speed must become the key measure of all climate mitigation strategies: a speedy reduction of global warming before it leads to further, self-reinforcing climate change feedbacks and tipping points; a speedy deployment of mitigation actions and technologies; and getting this all up to scale in a speedy manner…"*

The AVE can not only work directly against the warming aspects of climate change, but also be harnessed to work in synergy with Nature to increase local precipitation and hence agricultural productivity.

THE MECHANISM ENERGISING ATMOSPHERIC CONVECTION:

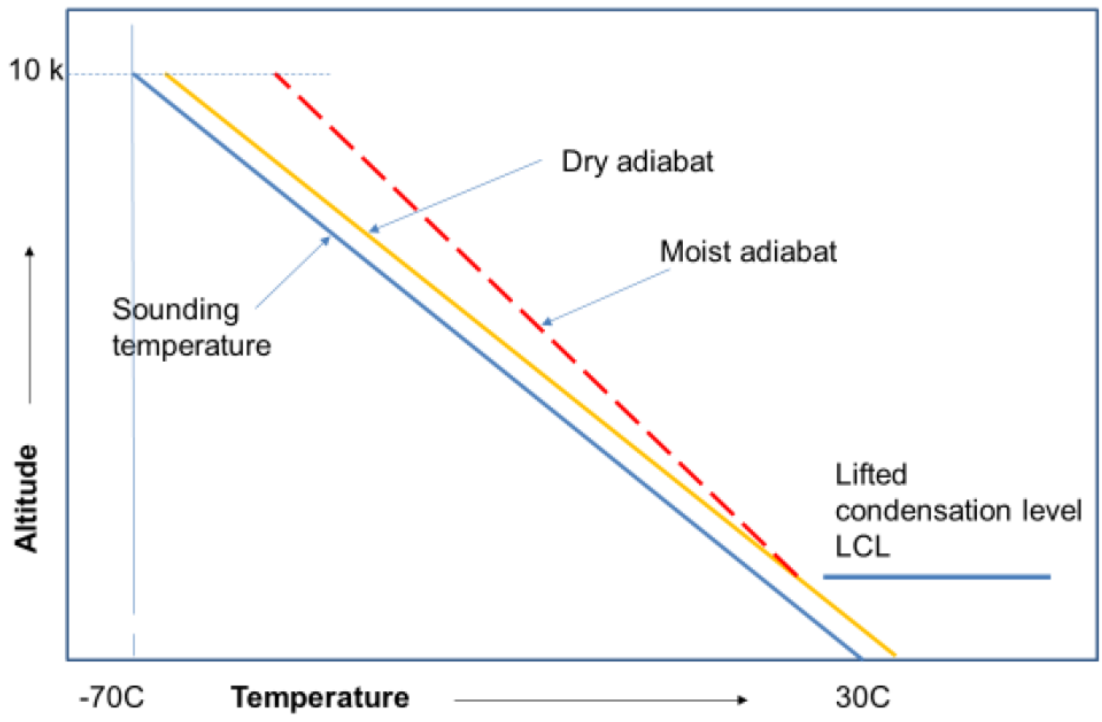


Fig. 16

The Vortex Engine can leverage heat transfer by use of the energy of atmospheric water vapour

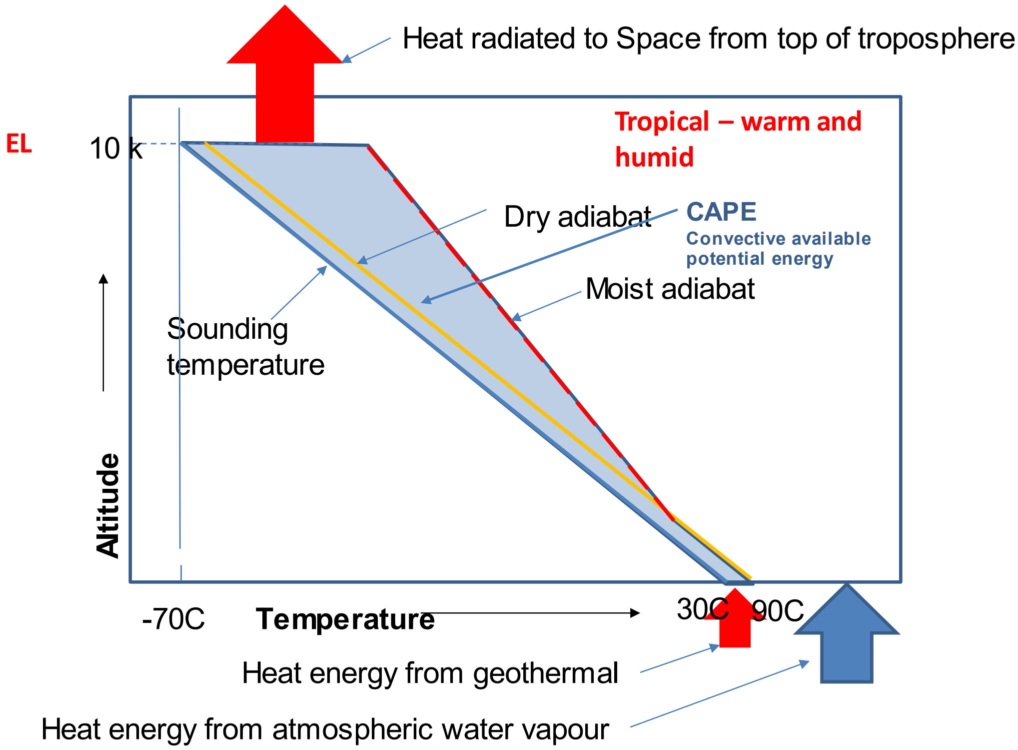


Fig. 17

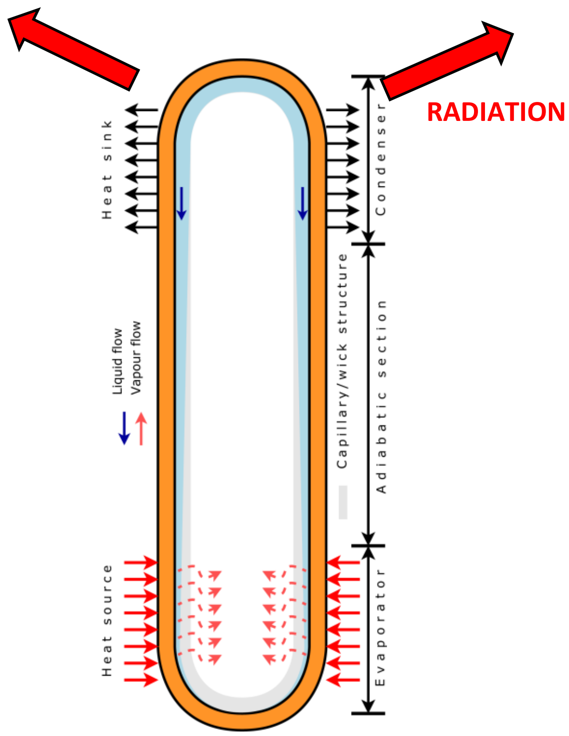


Fig. 18 The Principle of the Heat Pipe – using a vapour as the vehicle for conveying heat energy

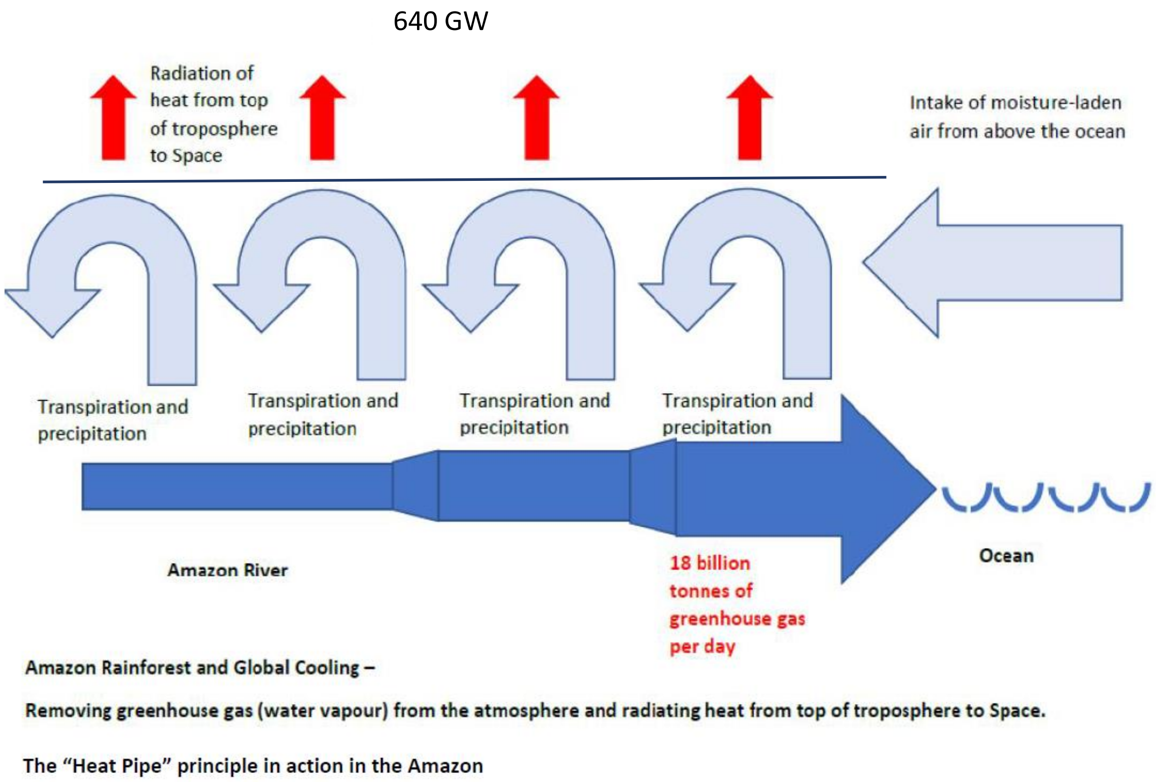


Fig. 19.

Fig. 20. The efficient operation of the Hadley Cell is crucial for Earth's heat budget.

From Fig 8, the highest precipitation regions are also those in which the heat transfer needs to be most efficient.

The Atmospheric Brown Cloud:

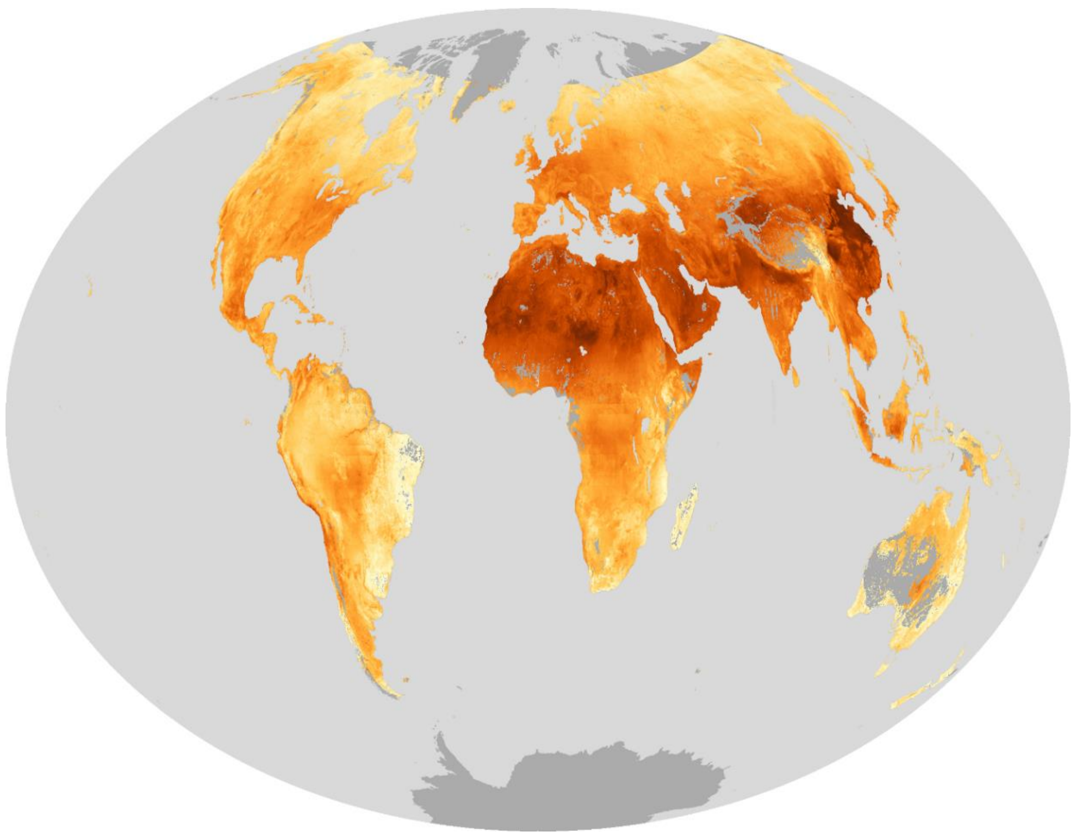


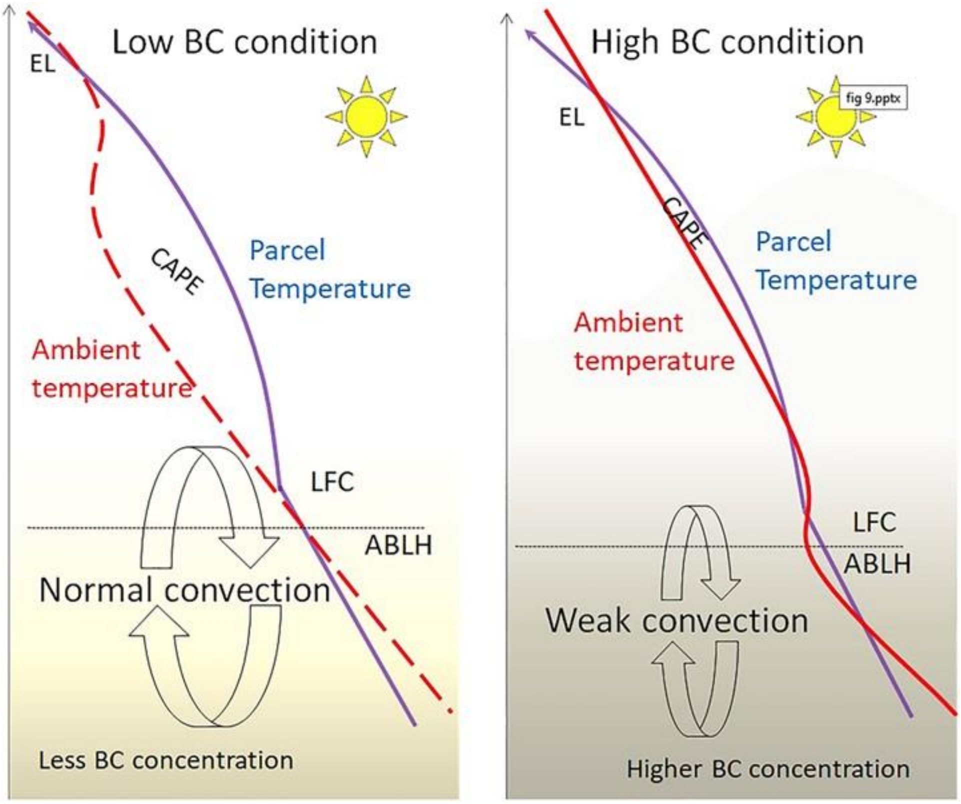
Fig. 21. Global View of Fine Aerosol Particles January 1, 2001 - December 31, 2006

NASA Earth Observatory [*https://earthobservatory.nasa.gov/images/46823/global-view-of-fine-aerosol-particles*](https://earthobservatory.nasa.gov/images/46823/global-view-of-fine-aerosol-particles)

Entities such as inversion layers and bends in the tropospheric sounding temperature effectively inhibit convection within the Troposphere:

"...The rainfall pattern in Asia is regulated by the monsoon system. The rainfall trend observed from 1950 to 2002 in Asia and Africa reveals that the monsoon of the Indian subcontinent and South-East Asia is weakening, with a decrease in the level of rainfall in India and South-East Asia by about 5-7 per cent (Figure 5) (Chung and Ramanathan, 2006; ABC Assessment Report, UNEP 2008). A shift in rainfall pattern from North to South in China, an increase in drought-prone conditions in Asia and Africa, and an increase in intense rain events in India and China have been observed (ABC Assessment Report, UNEP 2008). The decreasing rainfall levels in Asia affecting the food and water security and increase disaster risk..."

Convection is absolutely critical for maintaining Earth's heat balance between incoming solar radiation and outgoing infrared radiation from the top of the troposphere.



BC = black carbon **CAPE = Convective available potential energy.**

Influence of Black Carbon Aerosol on the Atmospheric Instability.

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018JD029611

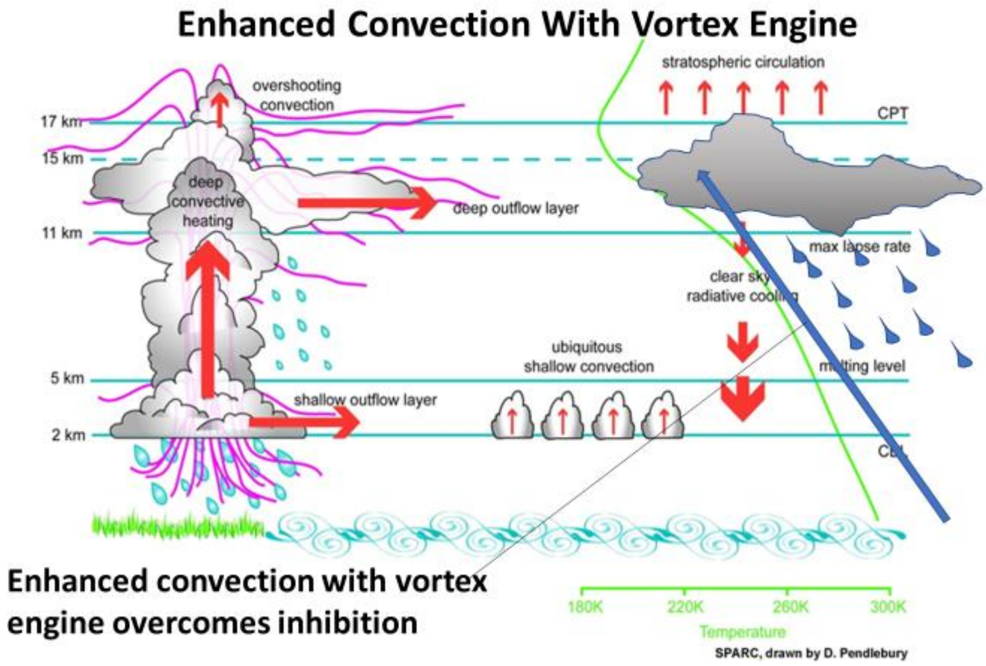


Fig. 22.

By blocking convection, the atmospheric brown cloud is effectively:

- Locking heat energy into the mid-altitude atmosphere, and hence preventing it being dissipated via infrared radiation to Space.
- Amplifying the tropospheric greenhouse gas level. In this case the greenhouse gas is water vapour, the principal greenhouse agent:

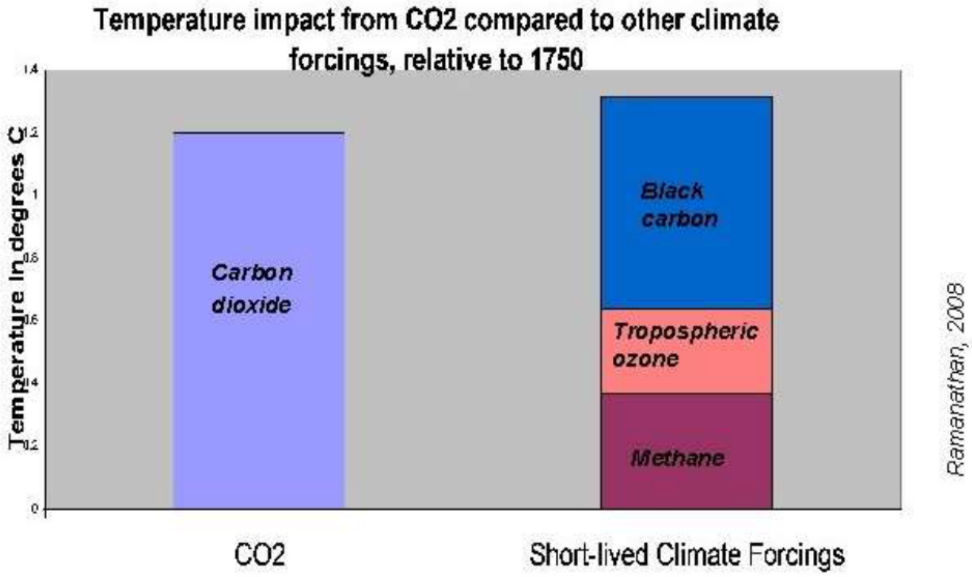
"…After the scientists had taken into account all of these effects, they tallied them up to calculate how much extra energy was being stored in the atmosphere thanks to black carbon. Climate scientists typically express that energy as watts per square meter of the Earth's surface. The number they got — 1.1 watts — was enormous. Carbon dioxide, the biggest heat-trapper in the atmosphere, is responsible for an estimated 1.56 watts per square meter. Black carbon takes second place. "It took a while to convince ourselves it was correct," says Doherty."

"If black carbon is responsible for trapping so much heat, then reducing soot may be an effective way to slow down the planet's warming. It's even more attractive because black carbon washes quickly out of the atmosphere, and so reducing soot emissions would lead to a fast fall in the concentration of black carbon in the atmosphere. Carbon dioxide, by contrast, lingers for centuries in the atmosphere…"

https://e360.yale.edu/features/carl_zimmer_black_carbon_and_global_warming_worse_than_thought

Role of Short Term Forcers in General:

Role of Short-Term Forcers Globally



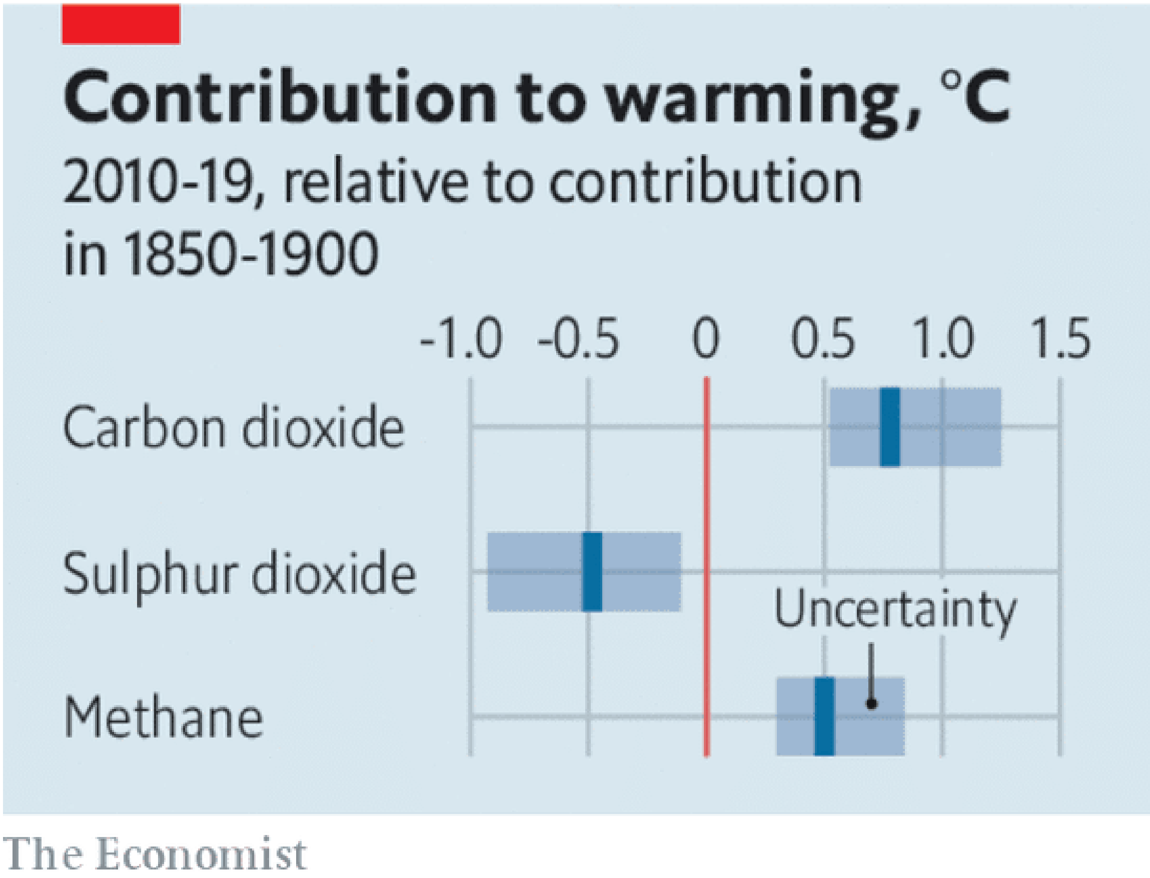
Role of Short-term forcers Globally: Carbon dioxide, Tropospheric ozone, Methane. Ramanathan, 2008 Black carbon

The influence of methane on global warming is now realised to be very substantially greater than that estimated in 2008, and hence is recognised as being only marginally behind that for CO2. This indicates how fast climate change theory is advancing, but the fact to be noted is that the effects of CO2 is less critical in the short term than it was once thought:

The World Gets Serious About Methane:

"In August, the Intergovernmental Panel on Climate Change warned that we cannot reach the Paris climate goals by tackling only carbon dioxide. Cutting methane from fossil fuels, livestock production and other industries is the fastest way to slow today's warming, even while we continue to decarbonize our energy systems.
"Fortunately, this urgency is finally being recognized at the highest levels in ways it hadn't before, setting the stage for real progress..."

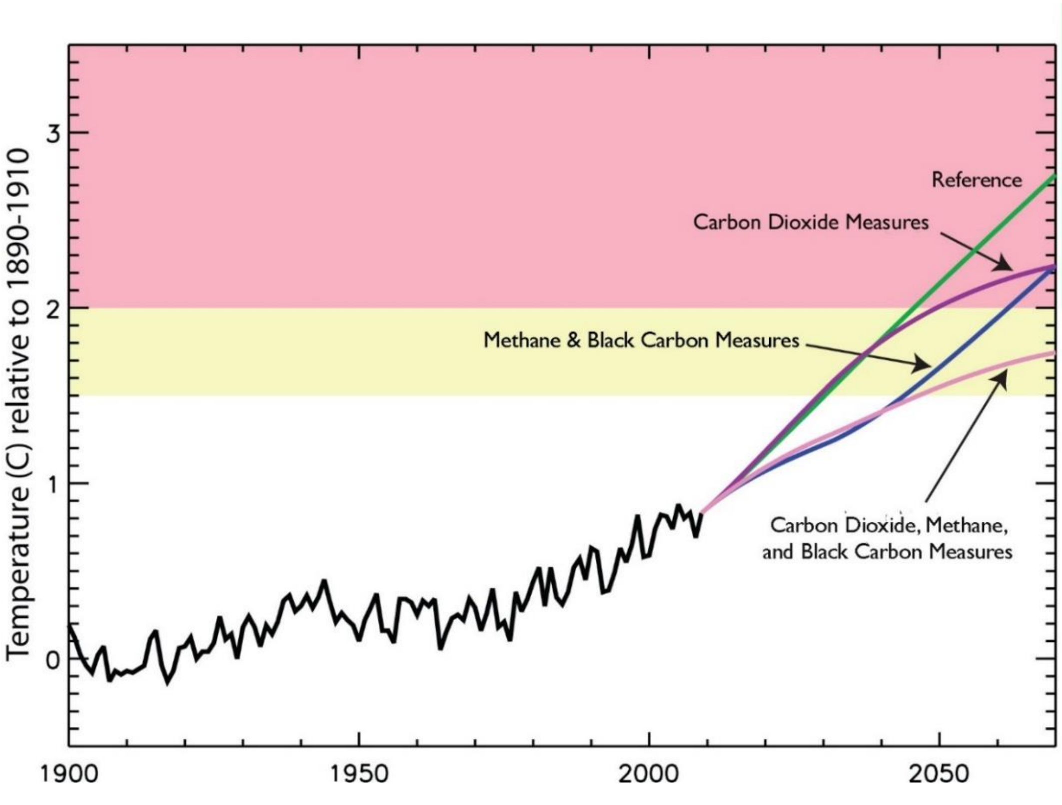
https://www.edf.org/blog/2021/10/26/world-gets-serious-about-cutting-methane-pollution



https://www.economist.com/leaders/carbon-dioxide-is-by-far-the-most-important-driver-of-climate-change/21803535

Published August 14, 2021

Urgent action to reduce methane and short-lived climate forcers in the short- to medium-term is now coming to be seen as a vital part of the strategy to mitigate global warming:



According to modelling conducted by the Goddard Institute for Space Studies and the European Commission's Joint Research Center, controlling emissions of carbon dioxide (purple line) is the only way to limit global warming in the long-term. In the next two decades, however, limiting emissions of black carbon and methane (blue line) could have a significant impact. Limiting emissions of carbon dioxide, black carbon, and methane (pink line) would have an even stronger short- and long-term impact. Credit: UNEP/Shindell

COST OF IMPLEMENTING THE GLOBAL VORTEX ENGINE STRATEGY:

The most important objectives for the project, in order of priority, would be to:

1. Benignly radiate heat to Space from the top of the troposphere by enhancing tropospheric convection within the Hadley Cell.
2. Scrub black carbon (in the atmospheric brown cloud) from the atmosphere.
3. Deliver cheap fossil-free energy to the World, generated as locally as possible to the customer.
4. Increase the proportion of global precipitation which takes place over land while minimizing the extremes of drought and flooding. Improve Global agricultural productivity.

It is estimated that the capacity required for objective one and two alone would be in the order of 100 terawatt (100,000 GW). The cost of a bare 1 GW vortex engine *without any electrical power infrastructure* is estimated to be in the order of $100 million. On that basis, the overall cost for only meeting the tropospheric convection enhancement objectives would be in the order of $10 trillion.

A small percentage of the installed vortex engines would need to be enhanced to generate electrical power.

CONCLUSIONS:

As 73% of heat at the Earth's surface is transmitted by convection through the troposphere (see item 1 in the calculations), maintaining and enhancing this process is critical for the prevention of global warming.

Convection is being increasingly inhibited by several atmospheric mechanisms and other causes including:

- Inversion layers.
- Atmospheric brown clouds.
- Global atmospheric stilling, thought to be at least partly due to increased surface roughness.
- Deforestation.

The atmospheric vortex engine can arguably help to overcome these inhibitory factors and in doing so yield:

- Significant energy.
- Additional local precipitation. A boost to agricultural productivity.
- Cooling of the global atmosphere through enhanced convection.
- Reduced atmospheric pollution by
  - Eliminating the use of fossil fuels.
  - Scrubbing particulates from the atmosphere.
- Increased local solar shading giving
  - Lower local (approx. 100 sq. km) evaporation rates.
  - Lower local and eventually global atmospheric temperatures.

It is argued that no strategy other than the AVE can achieve the cost-effectiveness and broad spectrum of benefits in the mitigation of global warming and hence the solving our current climate crisis. It must be used in concert with a number of other strategies. As Mario Molina, Veerabhadran Ramanathan, and Durwood J. Zaelke put it:

"…Of course, in addition to cutting super-pollutants, other things could help us achieve fast mitigation—such as halting deforestation so that existing forests can grow to their full ecological potential as carbon sinks. Similarly, improved land management could increase carbon storage or avoid greenhouse gas emissions;

together they may be able to provide more than a third of the cost-effective carbon dioxide mitigation needed through 2030 to give us a reasonable chance of limiting warming to less than 2 degrees Celsius…"

https://thebulletin.org/2020/04/best-path-to-net-zero-cut-short-lived-super-pollutants/

"…[Global warming is] perhaps the most consequential problem ever confronted by Mankind. Like it or not, we have been handed Phaeton's reins, and we will have to learn how to control climate if we are to avoid his fate..."

Professor Kerry Emanuel MIT