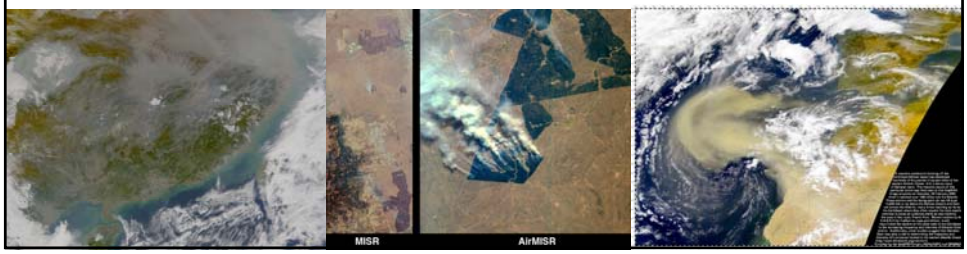
**MODULE 3: Atmospheric Aerosols**

Lecture 5: Health and Climatic Impacts of Atmospheric Aerosols: Importance of particle properties and implications

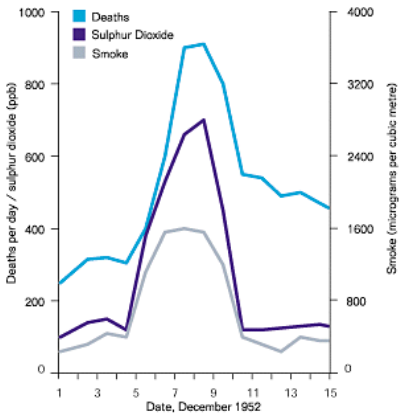



# 1. Health Impacts of Atmospheric Aerosols

# Air pollution and human health

**1952: the "London smog disaster"**

**Air pollution**
**$O_3$, CO, $NO_2$, $SO_2$**
**aerosol**




**1950s: Los Angeles smog**

Buildings in Los Angeles' Civic Center are barely visible from 1st and Olive Street on September 14, 1955. (Los Angeles Times via Getty Images)


A woman takes advantage of a "fresh air task force" supplying air from outside Los Angeles in 1958. (Bettmann Archive via Getty Images)


As many as 6,000 people attended a meeting to protest smog levels in Pasadena in 1954. (Allan Grant/The Life Picture Collection via Getty Images)

**1950s-1960s: New York City smog**

The 1966 smog wasn't the first time that New Yorkers were forced to brave dangerous smog. The infamous smog emergency of 1953 also took place in the fall.

A photo of the 1966 New York City smog as seen from the Empire State Building on November 24, 1966 at 8:30 a.m. The photo, taken by Neal Boenzi, was published on the front page of *The New York Times*.

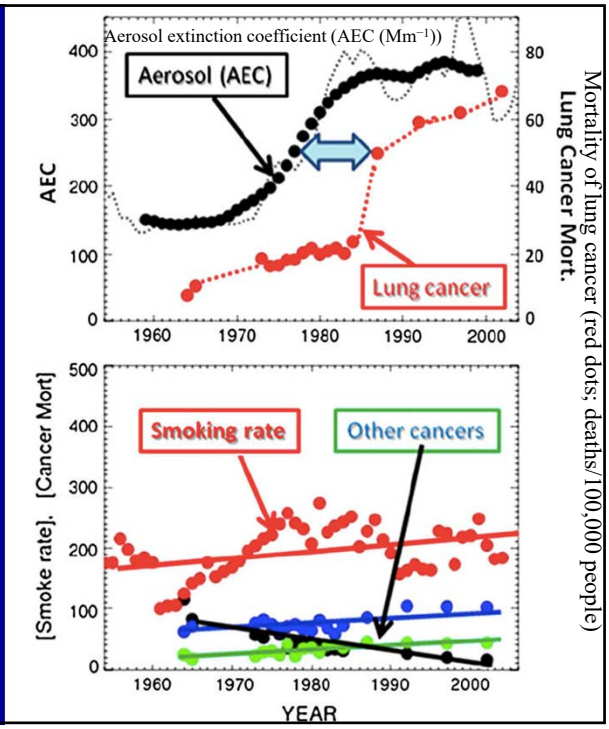
## Air Pollution Linked to 1.2 Million Premature Deaths in China in 2010


Aly Song/Reuters

Shanghai in January. Researchers said the toll from China's pollution meant the loss of 25 million healthy years in 2010.

Tie, Wu, and Brasseur, Atmos. Environ., 2009

"the dramatic increase in the occurrence of air pollution events between 1954 and 2006 has been followed by a large enhancement in the incidence of lung cancer"




## Association between size-segregated particles in ambient air and acute respiratory inflammation

Yiqun Han [a,*], Tong Zhu [a,**], Tianjia Guan [a], Yi Zhu [a], Jun Liu [a], Yunfang Ji [b], Shuna Gao [b], Fei Wang [b], Huimin Lu [b], Wei Huang [c]

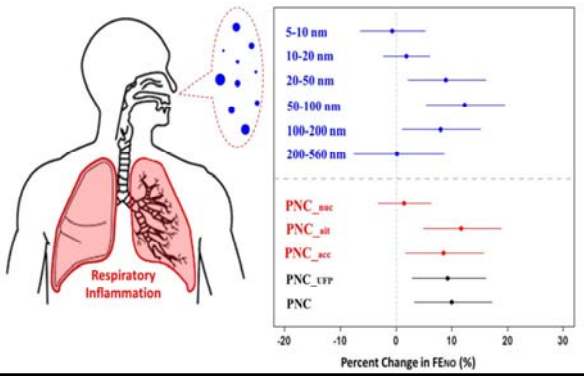
Science of the Total Environment 565 (2016) 412–419

[a] College of Environmental Sciences and Engineering and Centre for Environment and Health, Peking University, Beijing 100871, China
[b] The Center for Diseases Control and Prevention of Huangpu District, Shanghai, China
[c] College of Occupational & Environmental Health, School of Public Health, Center of Health Sciences, Peking University, China

HIGHLIGHTS

- $FE_{NO}$, a biomarker of respiratory inflammation, was positively associated with almost all ambient air pollutants.
- The significant associations occurred within hours.
- The association between $FE_{NO}$ and fine particulates depended on particle size. Aitken-mode particles have the most robust association.

GRAPHICAL ABSTRACT



Science of the Total Environment 542 (2016) 841–844

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Short communication

# Association of urban particle numbers and sources with lung function among children with asthma or allergies

Ya-Ru Li [a,1], Li-Ting Feng [b,1], Bing-Yu Chen [c,d], Ho Kim [e,f], Seung-Muk Yi [e,f], Yue Leon Guo [a,c,d,*], Chang-Fu Wu [a,b,g,**]

[a] Institute of Occupational Medicine and Industrial Hygiene, College of Public Health, National Taiwan University, 17 Xu-Zhou Road, Taipei 10055, Taiwan
[b] Institute of Environmental Health, College of Public Health, National Taiwan University, Taipei, Taiwan
[c] Department of Environmental and Occupational Medicine, College of Medicine, National Taiwan University, Taipei, Taiwan
[d] National Taiwan University Hospital, Taipei, Taiwan
[e] Department of Epidemiology and Biostatistics, School of Public Health, Seoul National University, Seoul, Republic of Korea
[f] Institute of Health and Environment, Seoul National University, Seoul, Republic of Korea
[g] Department of Public Health, College of Public Health, National Taiwan University, Taipei, Taiwan

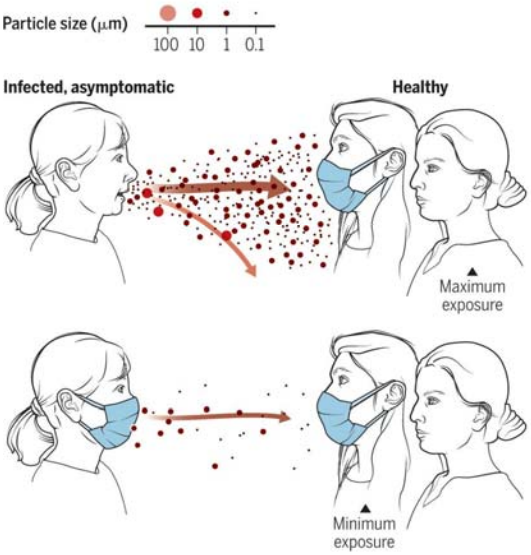
## HIGHLIGHTS

- Particle numbers and sources were used for examining particle-induced health effects.
- Secondary particle is most responsible for deterioration in childhood lung function.
- Analyses that rely on only particle number may underestimate risks of particles.

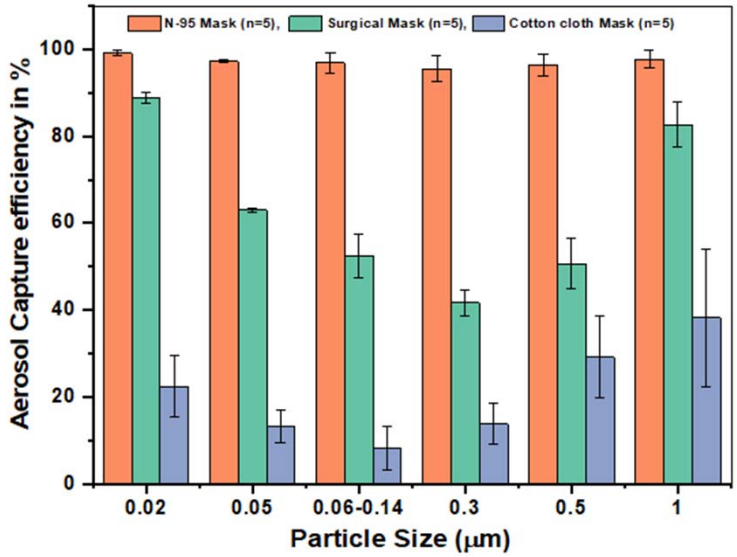
## GRAPHICAL ABSTRACT

## Masks reduce airborne transmission

Infectious aerosol particles can be released during breathing and speaking by asymptomatic infected individuals. No masking maximizes exposure, whereas universal masking results in the least exposure.




GRAPHIC: V. ALTOUNIAN/*SCIENCE*




Aerosol capture efficiencies of the test specimen for nano and sub-micron sizes estimated under sealed fit condition on the full mask sampler.

Joshi et al., 2021, DOI: https://doi.org/10.21203/rs.3.rs-32527/v1

## 2. Effects of aerosols on radiation, cloud, climate and weather

# Aerosol Direct and Indirect Climate Effects

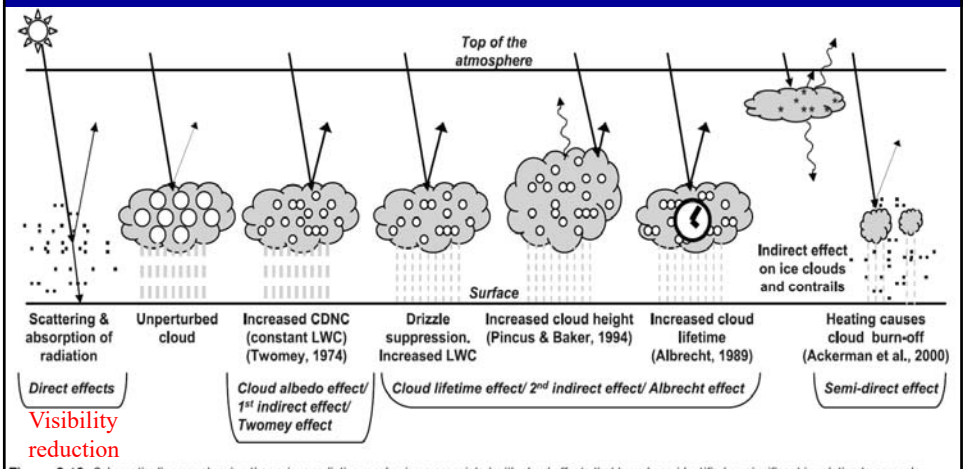
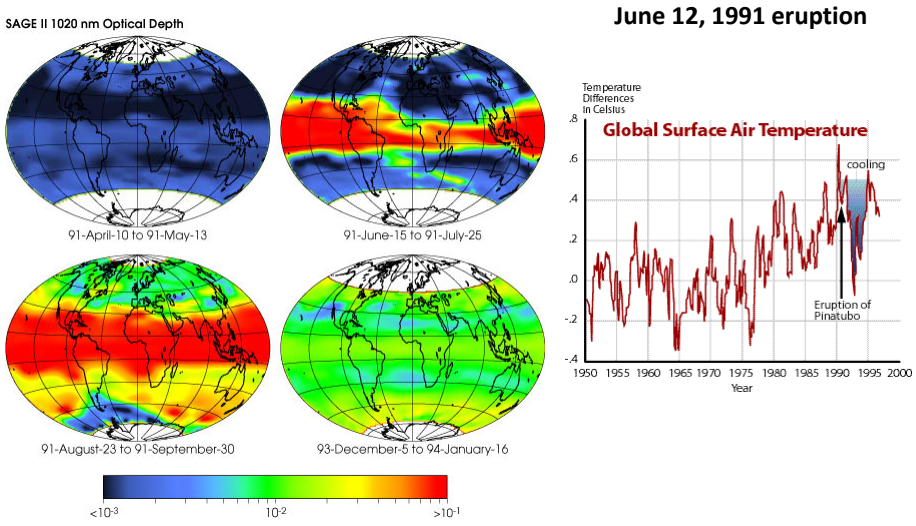



**Figure 2.10.** *Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.*

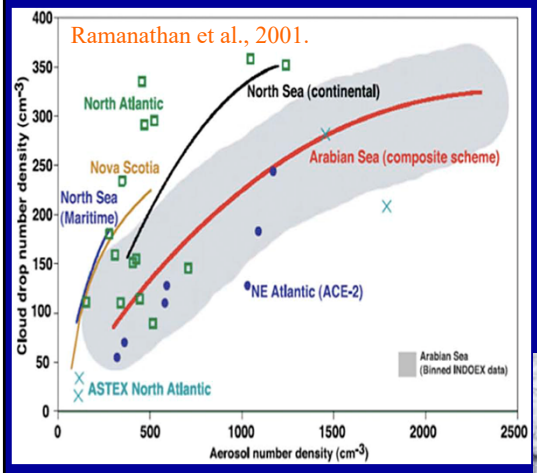
IPCC, 2007

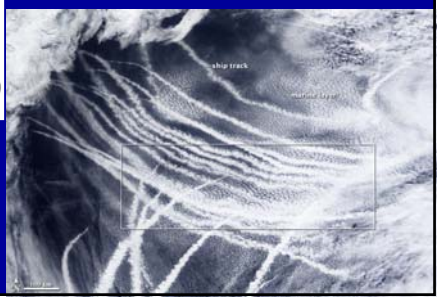
## Mt. Pinatubo June 1991

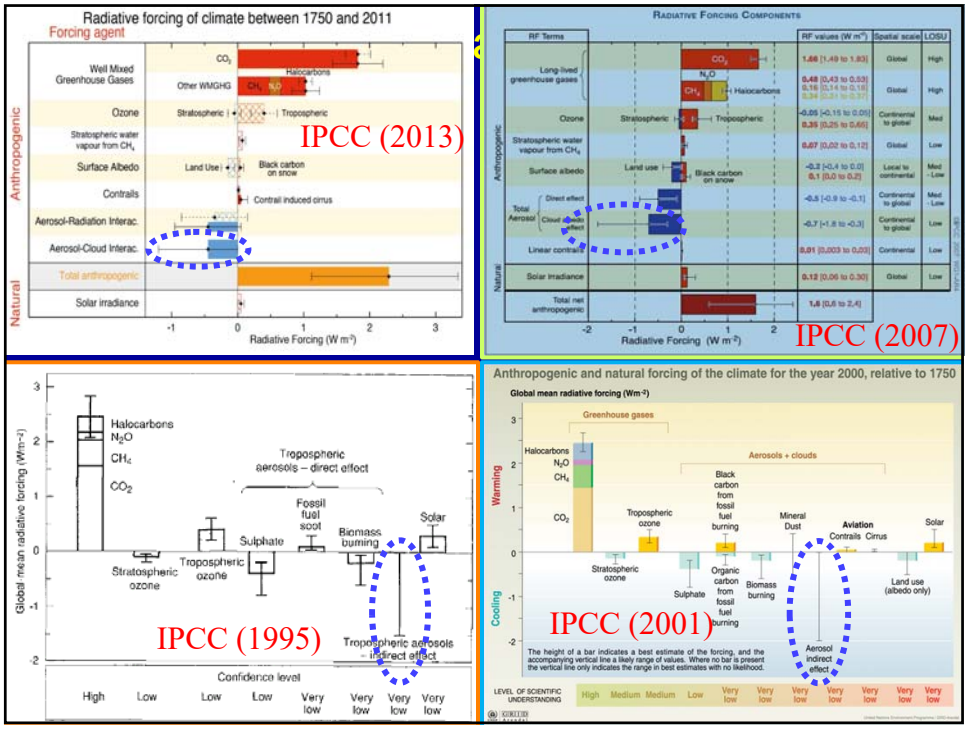
## Impact of Pinatubo aerosols on average global surface air temperature: ~0.5 °C!

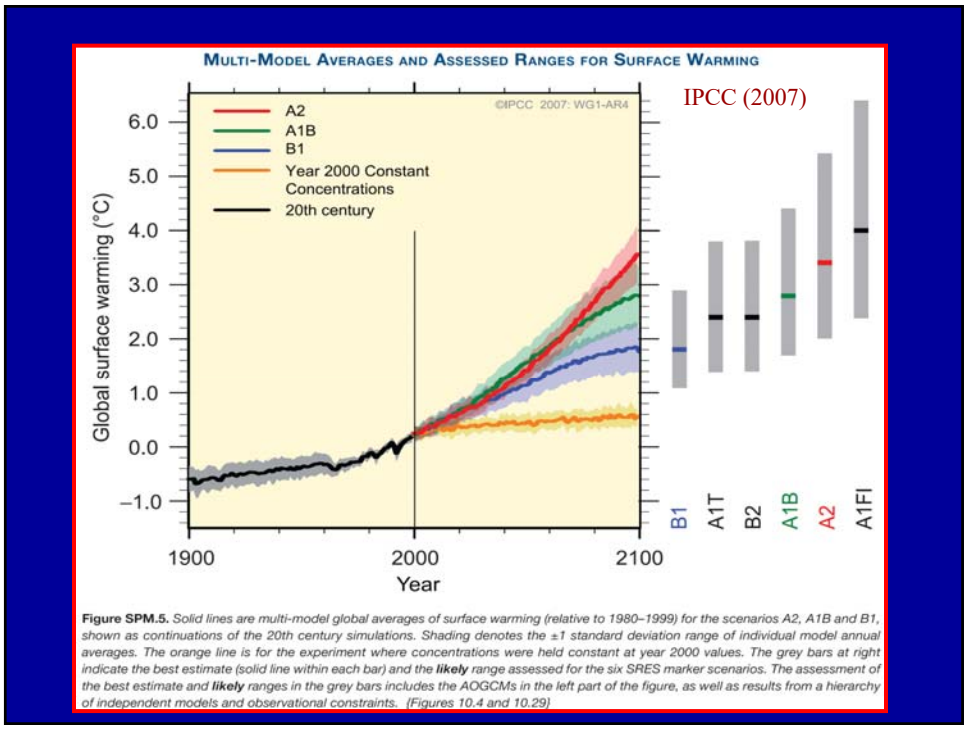



## Aerosol Indirect Climate Effects




Radiative forcing of climate between 1750 and 2011
Forcing agent
Anthropogenic
Natural
Well Mixed Greenhouse Gases
Other WMGHG
Halocarbons
Ozone
Stratospheric
Tropospheric
Stratospheric water vapour from CH4
Surface Albedo
Land Use
Black carbon on snow
Contrails
Contrail induced cirus
Aerosol-Radiation Interac.
Aerosol-Cloud Interac.
Total anthropogenic
Solar irradiance
Radiative Forcing (W m-2)
IPCC (2013)
Radiative Forcing Components
RF Terms
Long-lived greenhouse gases
Linear contrails
Total net anthropogenic
Radiative Forcing (W m-2)
IPCC (2007)
Global mean radiative forcing (Wm-2)
Halocarbons
N2O
CH4
CO2
Stratospheric ozone
Tropospheric ozone
Tropospheric aerosols – direct effect
Sulphate
Fossil fuel soot
Biomass burning
Solar
Tropospheric aerosols – indirect effect
Confidence level
High
Low
Very low
IPCC (1995)
Anthropogenic and natural forcing of the climate for the year 2000, relative to 1750
Global mean radiative forcing (Wm-2)
Greenhouse gases
Aerosols + clouds
Warming
Cooling
Tropospheric ozone
Black carbon from fossil fuel burning
Mineral Dust
Aviation
Contrails
Cirrus
Solar
Stratospheric ozone
Sulphate
Organic carbon from fossil fuel burning
Biomass burning
Land use (albedo only)
Aerosol indirect effect
LEVEL OF SCIENTIFIC UNDERSTANDING
IPCC (2001)


Multi-Model Averages and Assessed Ranges for Surface Warming
©IPCC 2007: WG1-AR4
A2
A1B
B1
Year 2000 Constant Concentrations
20th century
Global surface warming (°C)
Year
B1
A1T
B2
A1B
A2
A1FI
IPCC (2007)
Figure SPM.5. Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. (Figures 10.4 and 10.29)

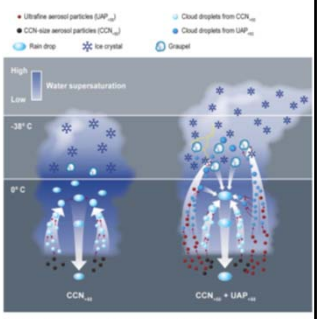
Fan *et al.*, *Science* **359**, 411–418 (2018) 26 January 2018

RESEARCH ARTICLE

ATMOSPHERIC PHYSICS

# Substantial convection and precipitation enhancements by ultrafine aerosol particles

Jiwen Fan,[1*] Daniel Rosenfeld,[2] Yuwei Zhang,[1,3] Scott E. Giangrande,[4] Zhanqing Li,[3,5] Luiz A. T. Machado,[6] Scot T. Martin,[7] Yan Yang,[1,8] Jian Wang,[4] Paulo Artaxo,[9] Henrique M. J. Barbosa,[9,10] Ramon C. Braga,[6] Jennifer M. Comstock,[1] Zhe Feng,[1] Wenhua Gao,[1,11] Helber B. Gomes,[12] Fan Mei,[1] Christopher Pöhlker,[13] Mira L. Pöhlker,[1] Ulrich Pöschl,[13,14] Rodrigo A. F. de Souza[15]

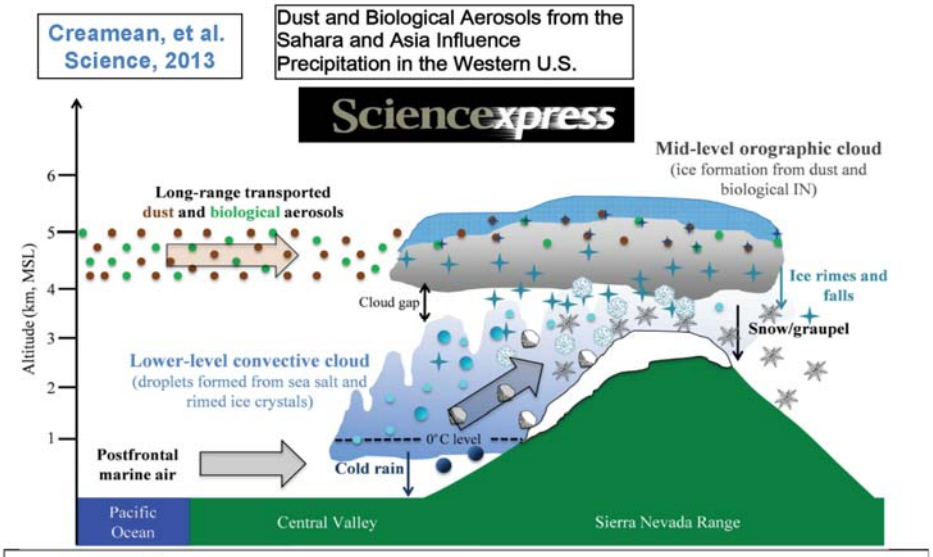



Aerosol-cloud interactions remain the largest uncertainty in climate projections. Ultrafine aerosol particles smaller than 50 nanometers ($UAP_{<50}$) can be abundant in the troposphere but are conventionally considered too small to affect cloud formation. Observational evidence and numerical simulations of deep convective clouds (DCCs) over the Amazon show that DCCs forming in a low-aerosol environment can develop very large vapor supersaturation because fast droplet coalescence reduces integrated droplet surface area and subsequent condensation. $UAP_{<50}$ from pollution plumes that are ingested into such clouds can be activated to form additional cloud droplets on which excess supersaturation condenses and forms additional cloud water and latent heating, thus intensifying convective strength. This mechanism suggests a strong anthropogenic invigoration of DCCs in previously pristine regions of the world.

Creamean, et al. Science, 2013

Dust and Biological Aerosols from the Sahara and Asia Influence Precipitation in the Western U.S.

Sciencexpress




CalWater-2011 field observations showed days with dust and bioparticles experienced extensive snowfall

# High resolution WRF simulations of Hurricane Irene: Sensitivity to aerosols and choice of microphysical schemes

A. Khain *, B. Lynn, J. Shpund

*Department of Atmospheric Sciences, The Hebrew University of Jerusalem, Jerusalem 91904, Israel*

Atmospheric Research 167 (2016) 129–145

ABSTRACT

Recent studies have pointed to the possible sensitivity of hurricanes to aerosols via aerosol effects on microphysical and thermodynamic processes in clouds. Hurricane Irene, occurring in August 2011, is an excellent case study for investigating aerosol effects on tropical cyclone (TC) structure and intensity: it moved northward along the eastern coast of the United States, and weakened much faster than was predicted by the National Hurricane Center. Moreover, the minimum pressure in Irene occurred, atypically, about 40 h later than the time of maximum wind speed. In this study, we simulate Hurricane Irene with 1-km grid spacing using Spectral Bin Microphysics (SBM) and various bulk microphysical schemes in WRF. Simulations with SBM showed that aerosols penetrating the eyewall of Irene from the Saharan Air Layer (SAL) led to an intensification of convection at Irene's eyewall and to a deepening of the hurricane. When Irene moved along the eastern coast of the United States, continental aerosols led to an intensification of convection at Irene's periphery, which interfered with the re-forming of the inner eyewall and to Irene weakening. Sensitivity tests using different "bulk" microphysics schemes indicated a large dispersion of simulated minimum pressure and maximum wind between different simulations. This showed that the simulated hurricane intensity was very sensitive to microphysical processes. Moreover, in consequence,

**Geophysical Research Letters**

**RESEARCH LETTER**
10.1002/2015GL064479

**Key Points:**
- Aerosols contribute to flooding by "aerosol-enhanced conditional instability"
- Reducing pollution (particularly BC) in the Sichuan Basin mitigates floods
- Coupling aerosols with meteorology may improve weather forecasts

## Substantial contribution of anthropogenic air pollution to catastrophic floods in Southwest China

**Jiwen Fan[1], Daniel Rosenfeld[2], Yan Yang[1,3], Chun Zhao[1], L. Ruby Leung[1], and Zhanqing Li[4,5]**

[1]Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, Washington, USA, [2]Institute of Earth Sciences, Hebrew University of Jerusalem, Jerusalem, Israel, [3]Chinese Academy of Meteorological Sciences, Beijing, China, [4]Department of Atmospheric and Oceanic Science and ESSIC, University of Maryland, College Park, Maryland, USA, [5]State Key Laboratory of Earth Surface Processes and Resource Ecology and Joint Center for Global Change Studies, Beijing Normal University, Beijing, China

**Key Points:**

- Aerosols contribute to flooding by "aerosol-enhanced conditional instability"
- Reducing pollution (particularly BC) in the Sichuan Basin mitigates floods
- Coupling aerosols with meteorology may improve weather forecasts

J Atmos Chem
DOI 10.1007/s10874-015-9300-x 2015

**Sensitivity of convection to observed variation in aerosol size distributions and composition at a rural site in the southeastern United States**

T. L. O'Halloran · J. D. Fuentes · W. K. Tao · X. Li

aerosol composition over short time scales. Variations in the aerosol size distribution and composition resulted in substantial variation in the total number of cloud condensation nuclei (CCN) produced in the four case studies. Cases with high CCN concentrations developed larger, more vigorous clouds with more precipitation generated by both warm and cold rain processes. Greater numbers of drops were propelled aloft and formed an extensive ice anvil that produced a large area of stratiform rain. Convection was enhanced by increasing aerosols despite decreases in precipitation efficiency. In contrast, lower CCN concentrations developed smaller clouds with suppressed cold rain processes and less total precipitation. The relatively

**Key parameters controlling atmospheric new particle formation and implications for climate feedback processes**

$J_{BHN} = J([H_2SO_4], RH, T)$

$J_{THN} = \ldots + [NH_3]$

$J_{ATHN} = \ldots + [\text{Amines}]$

$J_{IMN} = J([H_2SO_4], RH, T, Q, S_0)$

$J_{TIMN} = J([H_2SO_4], [NH_3], RH, T, Q, S_0)$

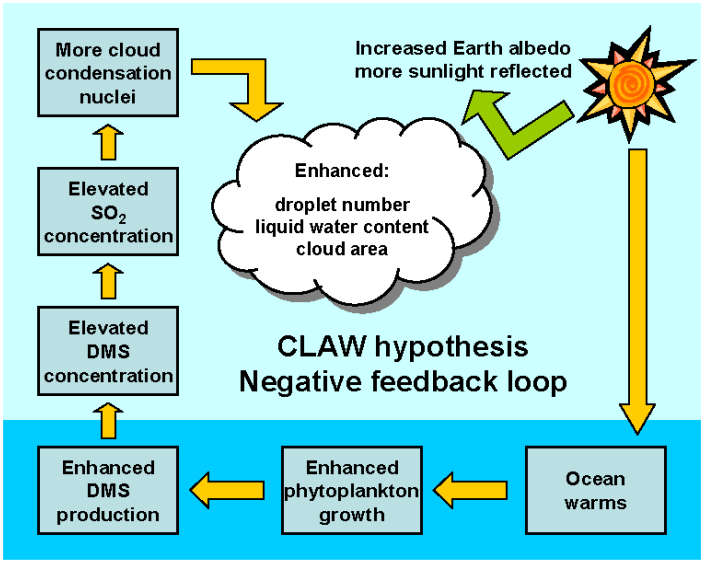
$J_{nucl\_org} = \ldots + [\text{Organics}]$

$J_{pure\_org} = [\text{Organics}] + \text{ions}$

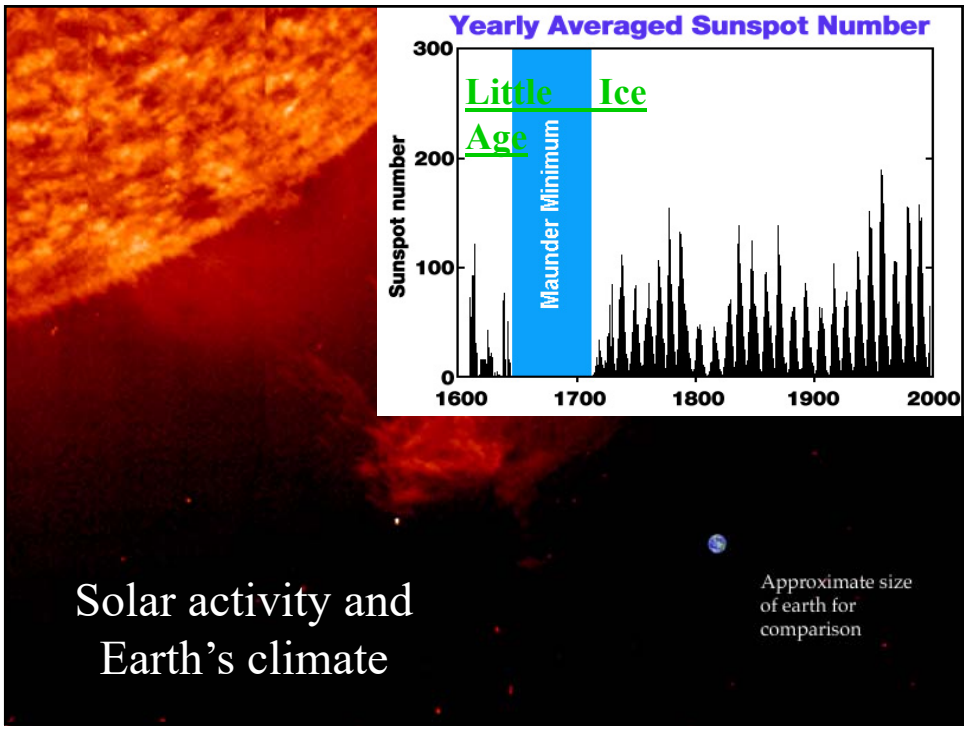
…

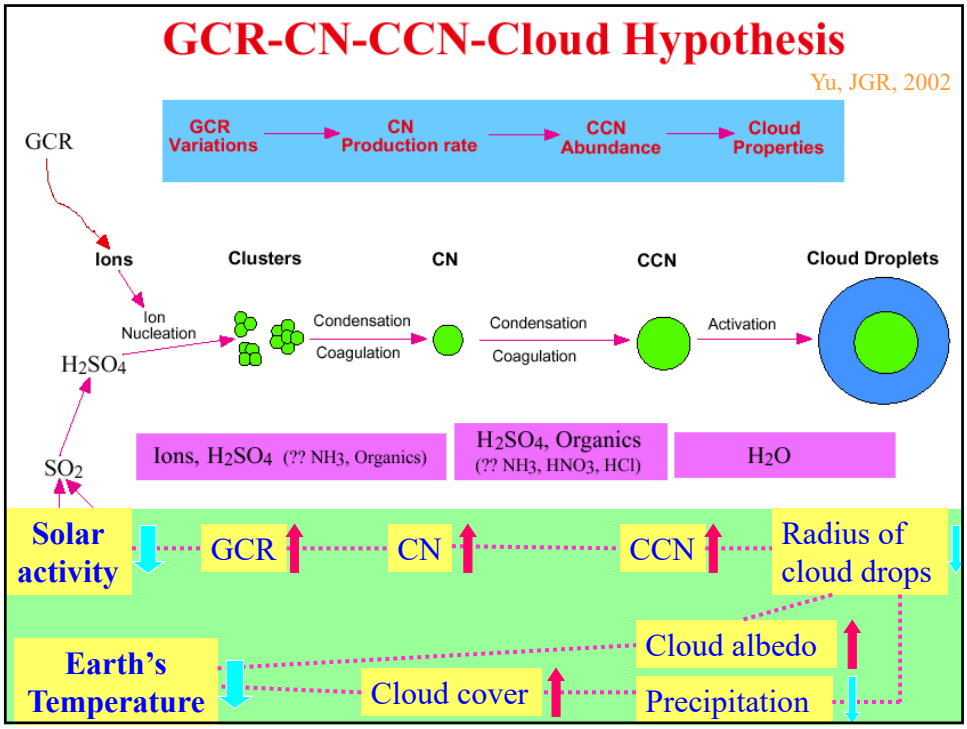
24

## Negative climate feedback mechanism: CLAW hypothesis



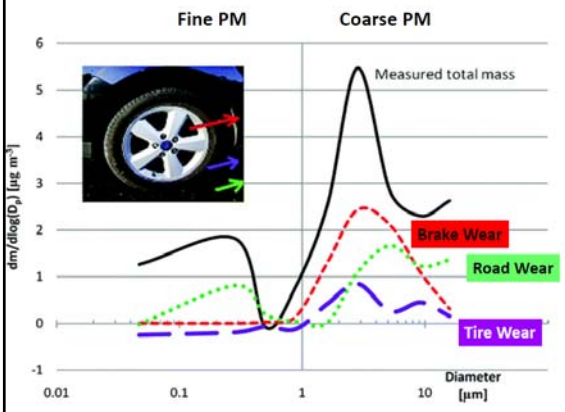

Charlson, R. J., J. E. Lovelock, M. O. Andreae, S. G. Warren, Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate, Nature, 326, 655-661, 1987.






## 3. Other emerging research topics related to particles

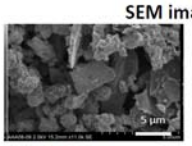
# Non-tailpiple emissions



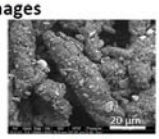

(Harrison et al. EST 2012)

- Primary/directly emitted particles
- Mechanical abrasion → larger particles!
- Composition:
  - Brake Wear: metals (Fe, Cu, Zn, …)
  - Tire Wear: microplastics, Zn
  - Road wear: crustal (Si, Al, Fe, Ca …)
  - Resuspended road dust: Crustal

SEM images




Brake wear

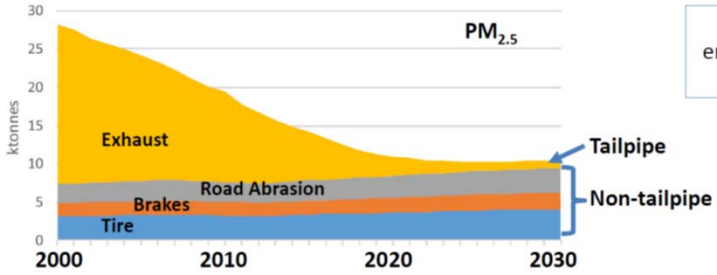



Tire/Road wear

(Kukutschová et al. Env Pol. 2011)

(Panko et al. AE 2019)

## Non-tailpipe emissions now exceed tailpipe emissions?




On-road vehicle emissions in United Kingdom

Could be even more skewed is very substantial electrification of the fleet.

https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1907101151_20190709_Non_Exhaust_Emissions_typeset_Final.pdf

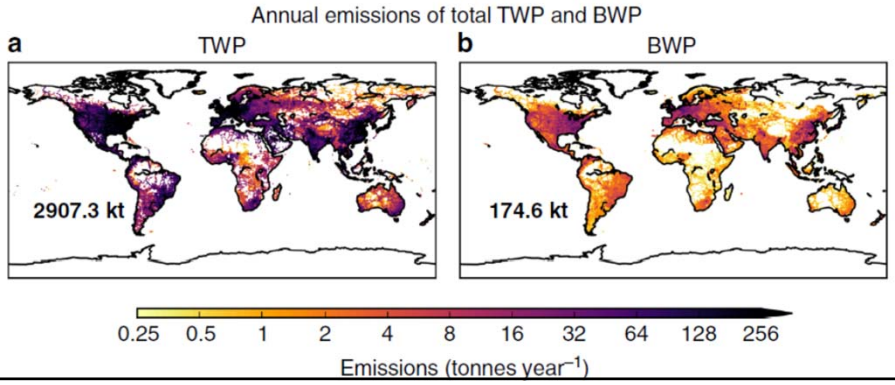
**Are non-tailpipe emissions more toxic than other types of PM?**

nature COMMUNICATIONS
ARTICLE
https://doi.org/10.1038/s41467-020-17201-9

"Here, we present global simulations of atmospheric transport of microplastic particles produced by road traffic (TWPs – tire wear particles and BWPs – brake wear particles), a major source that can be quantified relatively well. We find a high transport efficiencies of these particles to remote regions."

# Atmospheric transport is a major pathway of microplastics to remote regions

N. Evangeliou[1✉], H. Grythe[1], Z. Klimont[2], C. Heyes[2], S. Eckhardt[1], S. Lopez-Aparicio[1] & A. Stohl[1,3]

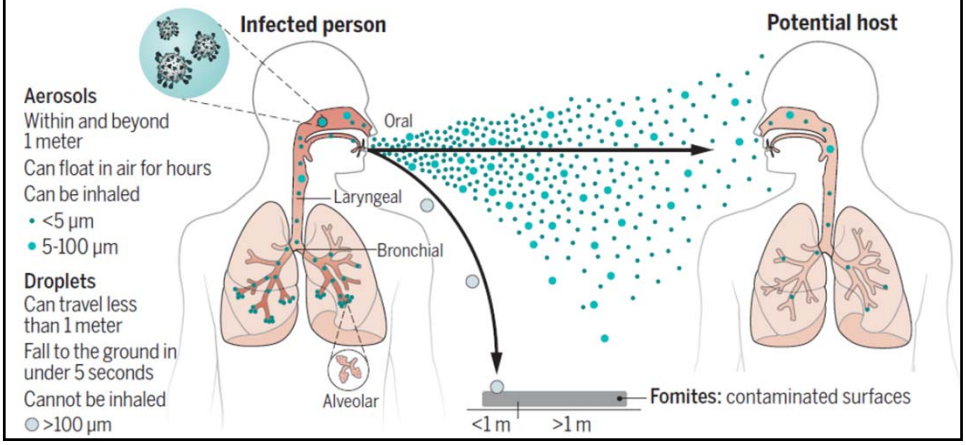


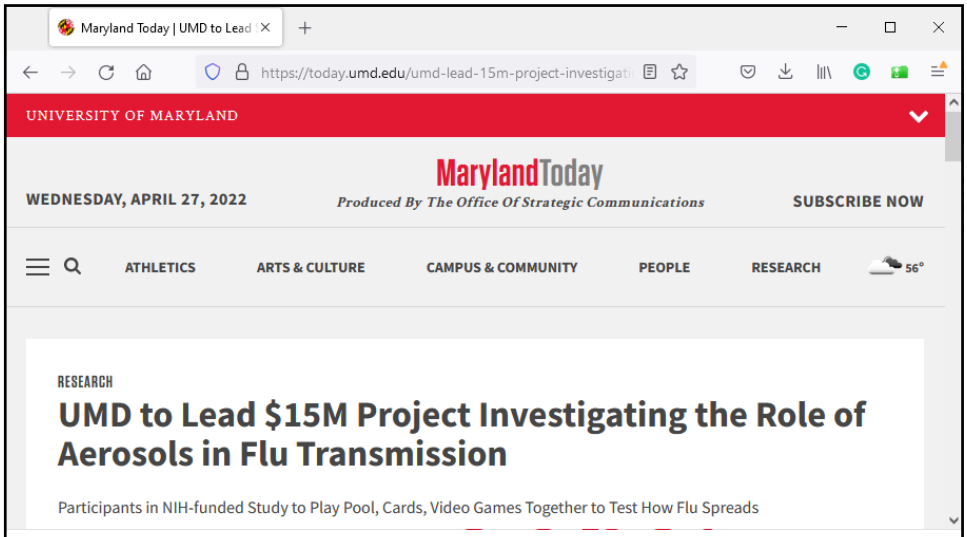

REVIEW SUMMARY
Wang *et al.*, *Science* **373**, 981 (2021)

CORONAVIRUS

# Airborne transmission of respiratory viruses

**Chia C. Wang*, Kimberly A. Prather*, Josué Sznitman, Jose L. Jimenez, Seema S. Lakdawala, Zeynep Tufekci, Linsey C. Marr**

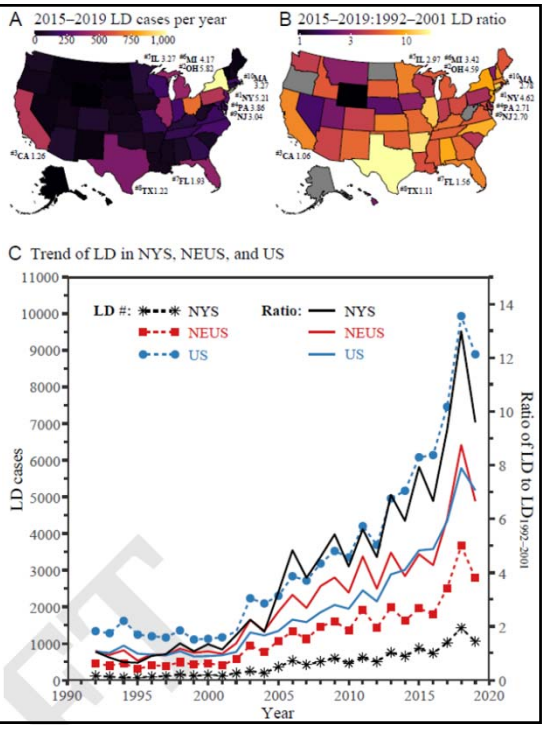





"The medical community doesn't yet fully understand aerosols and has been waiting for more evidence from a trial like this one," said Milton, who will lead the project. "My hope is that we can address this persistent controversy that has held up our ability to respond to respiratory pandemics."

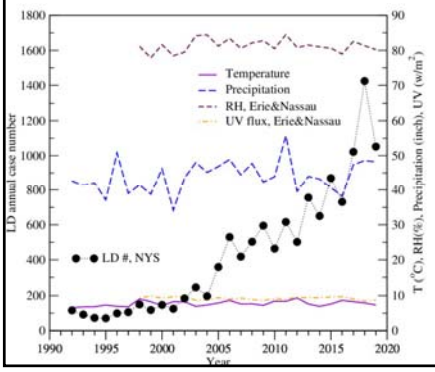
**Legionnaires' disease has been increasing rapidly but the reasons are unknown!**

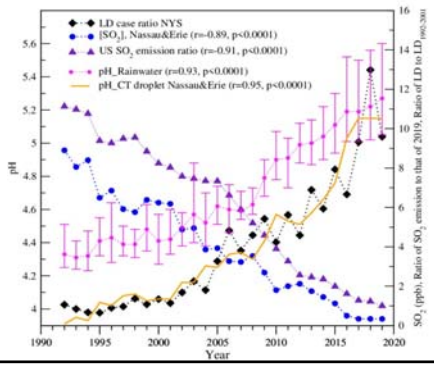
Possible reasons?

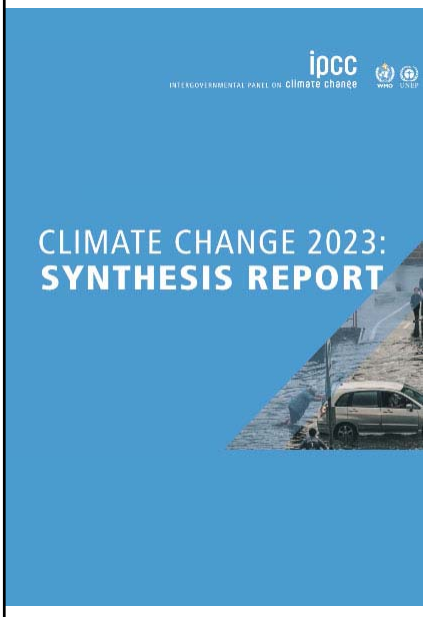


## Legionnaires' disease has been increasing rapidly but the reasons are unknown!

Interactions of **aerosolized** droplets with weather and environments




The Washington Post
Democracy Dies in Darkness
Subscribe

**World is on brink of catastrophic warming, U.N. climate change report says**

A dangerous climate threshold is near, but 'it does not mean we are doomed' if swift action is taken, scientists say

By Sarah Kaplan

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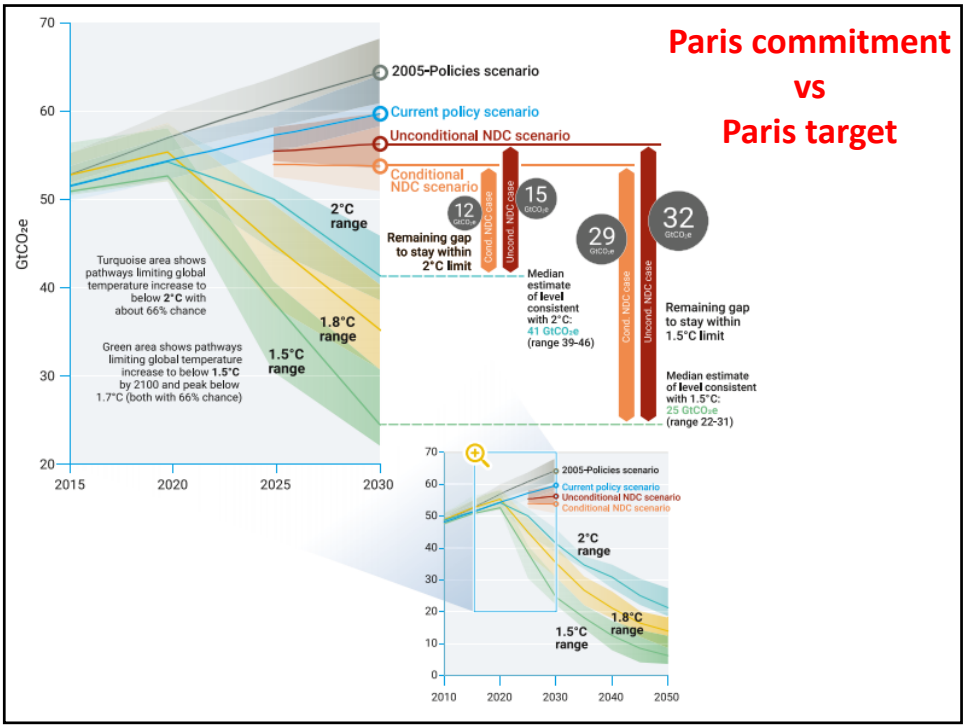
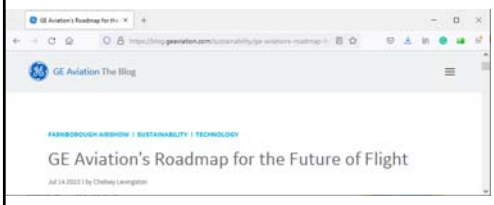
A Chinese state-owned coal-fired power plant under construction in 2017 in Huainan, Anhui province, China. (Kevin Frayer/Getty Images)

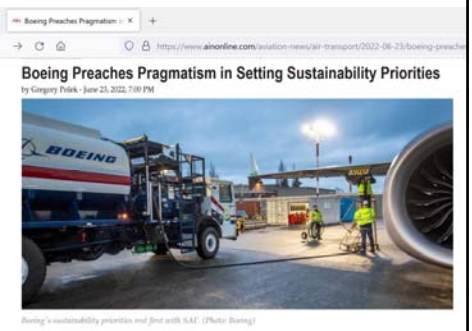
**Paris commitment**
**vs**
**Paris target**




| 1.5°C (2.7°F) | VS | 2°C (3.6°F) |
|---|---|---|
| 8.5-30 inches of sea level rise by 2100 | Sea Level Rise | Additional 4 inches of sea level rise and 10.4 million more people exposed |
| Loss of **70-90%** of coral reefs | Ecosystems | Loss of **99%** of coral reefs |
| **350 million people** in urban areas exposed to severe drought | Extreme Weather | **410 million people** in urban areas exposed to severe drought |
| At least one sea-ice-free Arctic summer **after 100 yrs** | Arctic Ice | At least one sea-ice-free Arctic summer **after 10 yrs** |




- Multiple ground and flight tests planned for the **mid-2020s**;
- Entry-into-service of a zero-emission aircraft **by 2035**;
- Net-zero carbon emissions for commercial flight **by 2050**.



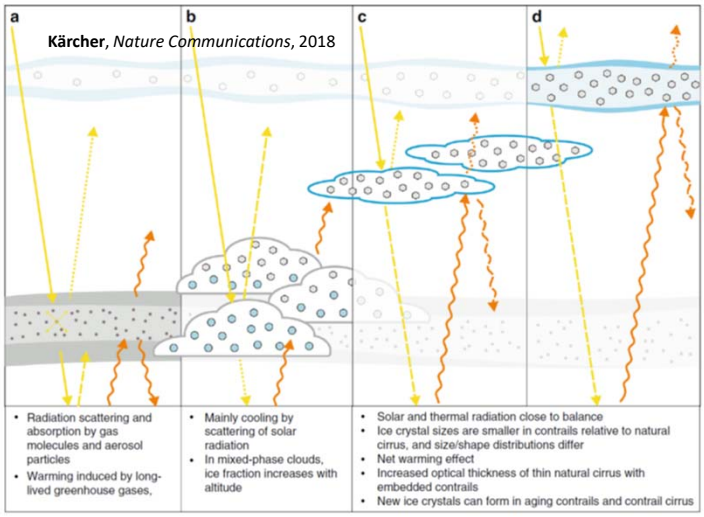

Boeing chief sustainability officer Chris Raymond:

"… We have to understand how to deal with contrail formation on a hydrogen fuel cell airplane. And we're studying that."


**Fig. 1 The NASA DC8 research aircraft probing contrails from the DLR A320 burning sustainable aviation fuel blends.** Photo showing the DC8 chasing a contrail from the A320 burning a sustainable aviation fuel blend above Germany on 24 January 2018.

of LW radiation at cold temperatures. Contrary to low clouds composed mainly of liquid water droplets (**b**), high ice clouds are often optically thin (**c**, **d**), i.e., partially transparent to solar radiation ($\lambda \approx 0.2$–$4\,\mu m$), meaning their ability to scatter SW radiation back to space (albedo forcing) is small. The greenhouse forcing is stronger for higher and colder clouds, in which ice crystals are increasingly abundant. The net average diurnal RF due to thin cirrus and contrails is a small positive residual from the wavelength-integrated SW and LW forcings. RF contributions due to thickening of natural cirrus by embedded contrails and new ice crystal formation in contrail areas with low ice crystal concentrations, blurring the distinction between natural cirrus and contrail cirrus, have not yet been determined.

**Kärcher**, *Nature Communications*, 2018




REVIEW ARTICLE NATURE COMMUNICATIONS | DOI: 10.1038/s41467-018-04068-0

**Kärcher**, *Nature Communications*, 2018

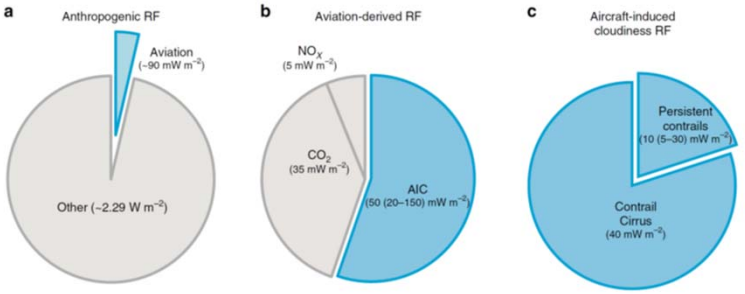
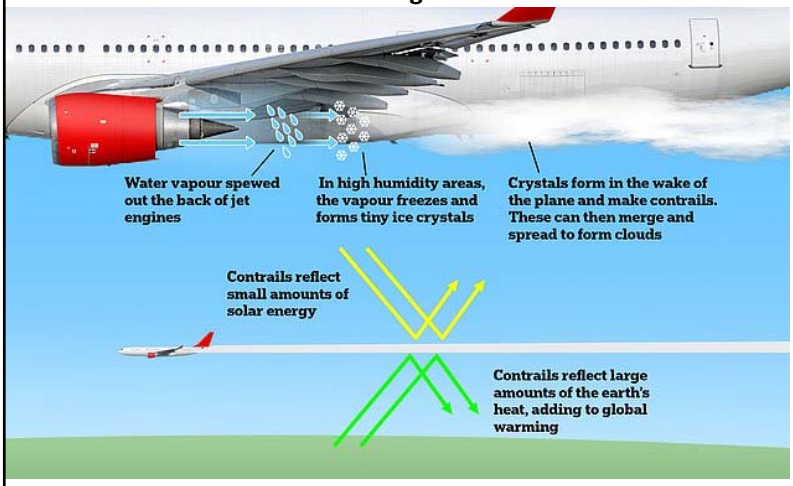


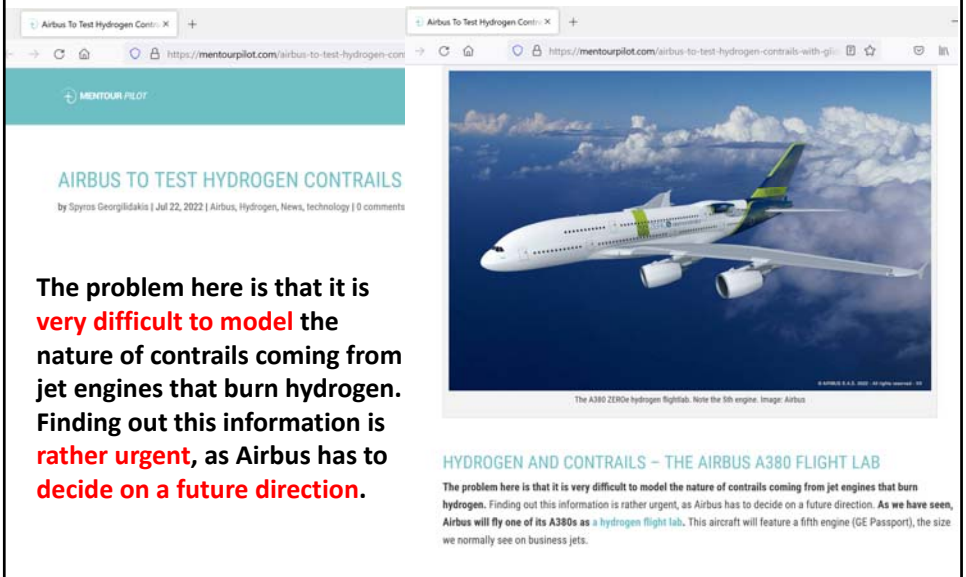

**Fig. 1** Aviation radiative forcing components. **a** Aviation as a percentage of total global radiative forcing (RF) due to human activities in the year 2011 relative to pre-industrial times, 2.29 (1.13–3.33) W m$^{-2}$ (ref. [7]). **b** Forcing components within the aviation fraction, of which aircraft-induced clouds (AIC) account for more than half. AIC and carbon dioxide ($CO_2$) estimates represent 2011 emission levels[10]; the latter contribution has been obtained by extrapolating the year 2005 value[11] using the corresponding increase in scheduled air traffic distance (Table 7.SM.2 in ref. [10]). RF estimates for all aviation components together for the same year and emission levels superseding 2005 values are not available[13]. Aircraft emissions of nitrogen oxides ($NO_x$) cause positive and negative RF contributions, values here calculated based on refs. [107,139]. Small direct RF contributions from aircraft water vapour[140] and particle emissions[14] together nearly cancel out and are therefore not shown. No scientific consensus has been reached regarding the sign of RF due to modification of natural clouds by particle emissions. Therefore, the RF caused by those 'indirect' effects is not considered here, but may be of opposite sign and as large as that of AIC. **c** Breakdown of AIC radiative forcing into contrail cirrus and persistent contrails based on ref.[10]

## Formation and radiative forcing of contrails: Media version of description




Contrails form when the soot from the engine gets coated in water vapour and then freezes in the atmosphere. In high humidity regions this then leads to crystals which create contrail and these merge with clouds to form 'contrail cirrus' clouds. These clouds prevent heat from escaping and reflect it back to Earth, acting like a huge blanket.

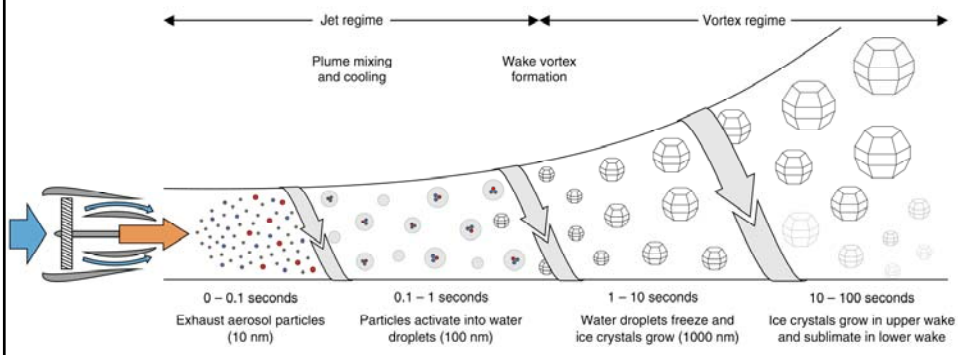
By Joe Pinkstone, 4/12/2021, From https://www.dailymail.co.uk/sciencetech/article-9461243/British-company-building-software-eradicate-contrails.html



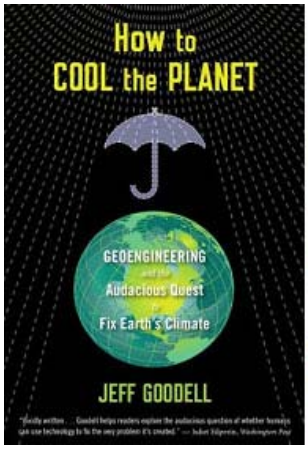

**The problem here is that it is very difficult to model the nature of contrails coming from jet engines that burn hydrogen. Finding out this information is rather urgent, as Airbus has to decide on a future direction.**

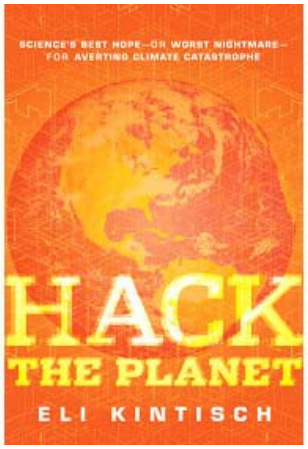
**Formation and radiative forcing of contrails: Scientist version of description**

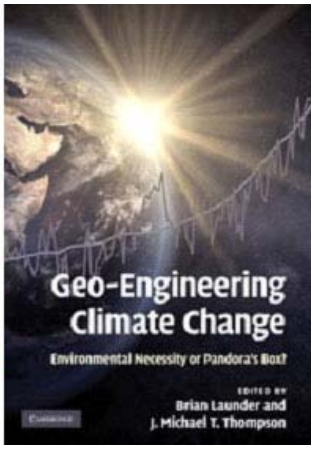
**Kärcher**, *Nature Communications*, 2018




# Geo-Engineering



**Paris commitment**
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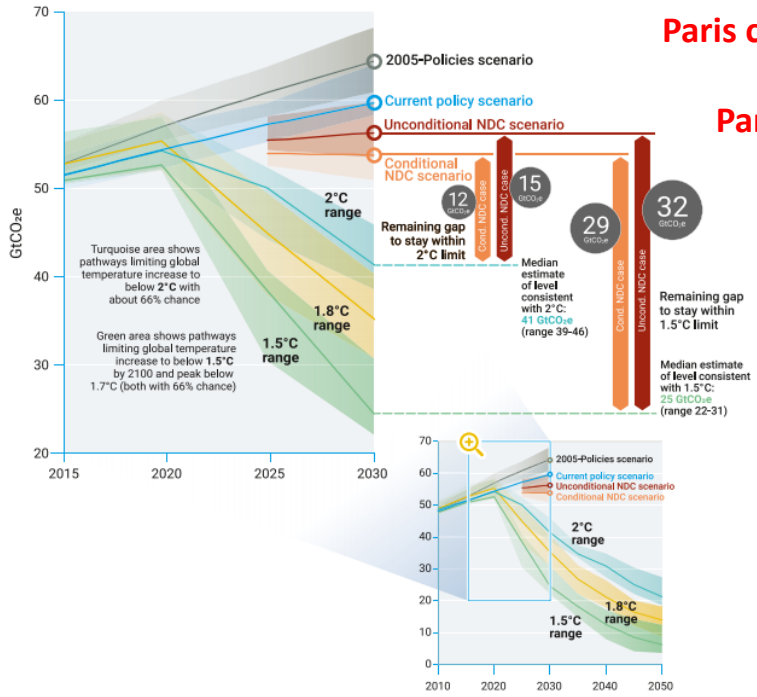
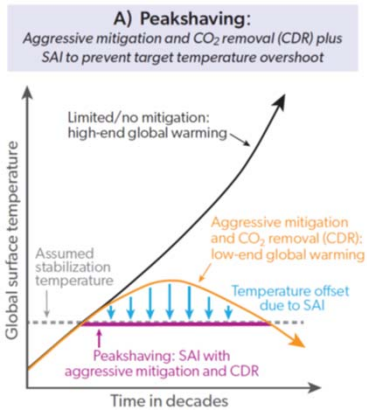




**First time chapter on SAI**

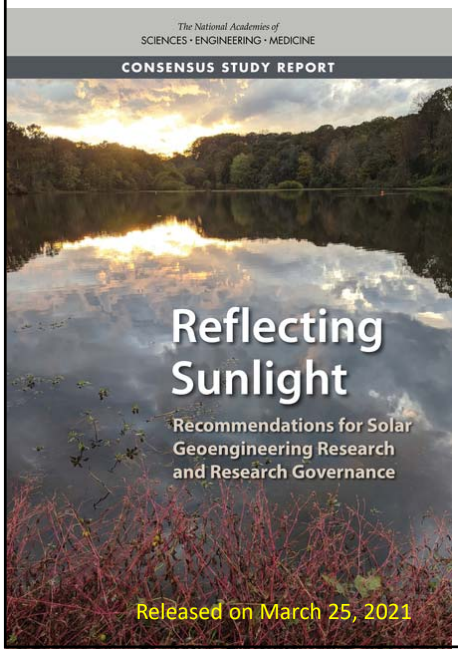
Chapter 6:
Stratospheric Aerosol Injection and Its Potential Effect on the Stratospheric Ozone Layer




"SAI and other solar radiation modification (SRM) approaches may therefore be the only option to keep the global surface temperature below the limit of 1.5 °C."

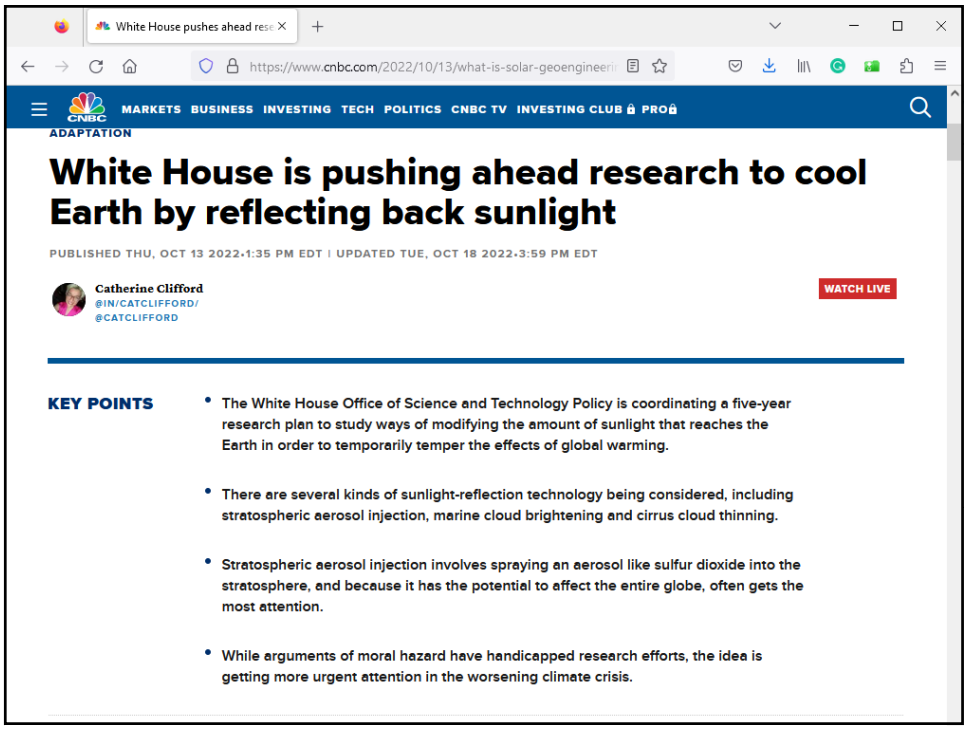
"Multi-model comparisons reveal large uncertainties in forcing and surface cooling per unit of sulfur injected, which are attributed to differences in model complexity in representing key processes and details of SAI strategies."

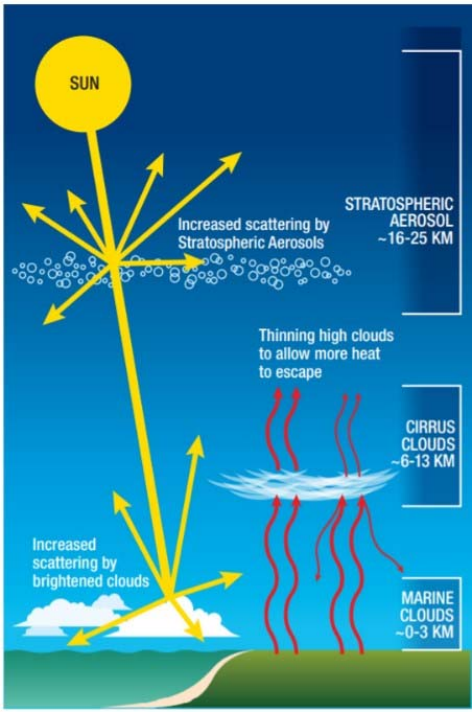
# Geo-Engineering




"Given the urgency of the risks posed by climate change, the U.S. should pursue a research program for solar geoengineering — in coordination with other nations, subject to governance, and alongside a robust portfolio of climate mitigation and adaptation policies, says a new report from the National Academies of Sciences, Engineering, and Medicine. The report emphasizes that solar geoengineering is not a substitute for reducing greenhouse gas emissions."

"The report says the U.S. Global Change Research Program (USGCRP) should lead the effort to establish and coordinate a solar geoengineering research program across federal agencies and scientific disciplines, with funding in the range of $100 million-$200 million over the first five years."



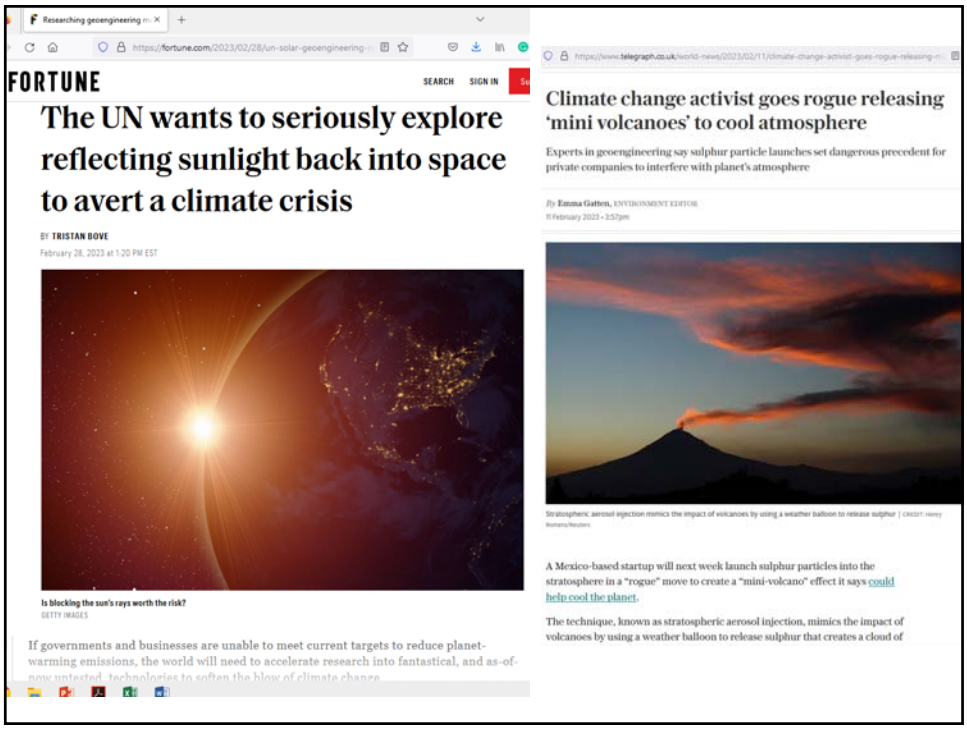



## Discussion:

Based on what we have learned about aerosols in this module,

(1) What are the possible approaches to implement these?

(2) What specific attentions that one needs to take care of?



FORTUNE

SEARCH SIGN IN

The UN wants to seriously explore reflecting sunlight back into space to avert a climate crisis

BY TRISTAN BOVE

February 28, 2023 at 1:20 PM EST

Is blocking the sun's rays worth the risk?

GETTY IMAGES

If governments and businesses are unable to meet current targets to reduce planet-warming emissions, the world will need to accelerate research into fantastical, and as-of-

Climate change activist goes rogue releasing 'mini volcanoes' to cool atmosphere

Experts in geoengineering say sulphur particle launches set dangerous precedent for private companies to interfere with planet's atmosphere

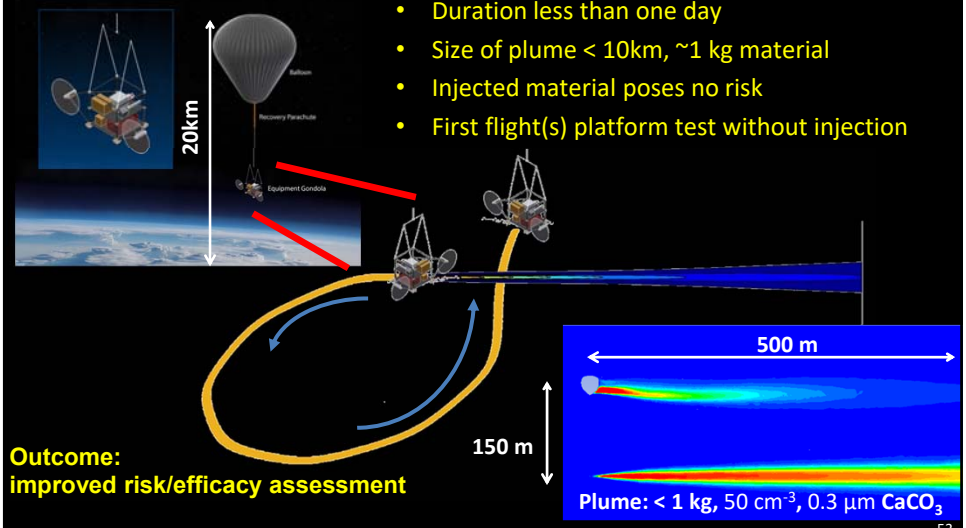
By Emma Gatten, ENVIRONMENT EDITOR

A Mexico-based startup will next week launch sulphur particles into the stratosphere in a "rogue" move to create a "mini-volcano" effect it says could help cool the planet.

The technique, known as stratospheric aerosol injection, mimics the impact of volcanoes by using a weather balloon to release sulphur that creates a cloud of

## Small Scale Stratospheric Controlled Perturbation Experiment (SCoPEx)

- Experiment at 20 km altitude in stratosphere
- Duration less than one day
- Size of plume < 10km, ~1 kg material
- Injected material poses no risk
- First flight(s) platform test without injection




**Outcome:**
**improved risk/efficacy assessment**

For comparison: 747 flight 1-2 kg aerosol / minute

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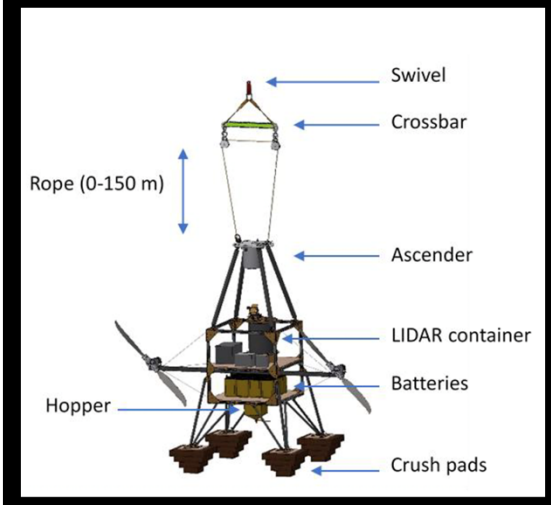
## Small Scale Stratospheric Controlled Perturbation Experiment (SCoPEx) Operational Ground Tests

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## Key knowledge points of Lecture 5:

1. Air pollution associated with atmospheric particles is known to impact human health. Air or aerosol transmission of coronavirus plays a role in the present pandemic and other diseases.

2. The non-linear and complex dependence of new particle formation rates on key parameters may lead to important climate feedback processes that require further study.

3. Geo-engineering of Earth's climate is an emerging research topics and many proposed methods involve aerosols. A clear understanding of key processes controlling relevant particle properties can help to design the cost-effective geo-engineering approaches.

4. Aerosol particles play an important role in a number ongoing or emerging research topics.