Disclosure log entry: Geo-engineering FAQs.

Context/Position statement-

The Met Office publishes a range of information including a summary of geoengineering, outlining what it is, why it is being discussed, what the current research shows, and the Met Office's position on geoengineering here Met Office position on geoengineering research - Met Office.

As outlined in the Met Office position on geoengineering above, the Met Office's contribution to scientific research in the field of geoengineering is **based on simulations using climate models and we do not advocate or provide context for real-world physical experiments**. Geoengineering describes interventions and technologies which could be deployed to alter aspects of the global climate system to help tackle some aspects of global warming.

Our position statement is consistent with the UK Governments position on geo-engineering, which states the Government is not deploying SRM, and has no plans to do so. The topic of geo-engineering was debated on the 23rd June 2025. The full debate, transcript, and supporting documentation can be seen here: Geo-engineering and the Environment - Hansard - UK Parliament.

The Met Office does not have authority to issue approvals, consents, licences, or authorisations of real-world physical experiments.

Q- What is geo-engineering?

A- Geoengineering is the deliberate large-scale manipulation of climate. Geoengineering describes interventions and technologies which could be deployed to alter aspects of the global climate system to help tackle some aspects of global warming. These methods are increasingly debated as people around the world consider how best to minimise the risks of climate change.

There are two key categories that fall under the term 'geoengineering':

- Greenhouse Gas Removal (GGR) is the use of natural and artificial means to take greenhouse gases from the atmosphere and sequester them for an extended period of time. This could include planting trees or encouraging marine phytoplankton growth, through to technology which can chemically remove CO2 from the atmosphere or employing a process known as bioenergy carbon capture and storage (BECCS) (where biomass is burnt for energy and the carbon dioxide captured).
- Solar Radiation Modification (SRM) is use of technologies to reflect some of the Sun's energy that reaches Earth back into space, thereby reducing the Earth's temperature to offset global warming. This could include strategies to brighten clouds over the ocean or injecting aerosols high into the atmosphere.

Further information on geo-engineering and what it is can be found on the page here Met Office position on geoengineering research - Met Office and here Atmospheric modification and geoengineering - Met Office.

Q- Have SRM technologies been implemented in an attempt to cool the planet?

A- Global-scale deployments of SRM or solar geoengineering to cool the planet are at present theoretical. Hypothetical scenarios are simulated within climate models to evaluate the potential impacts these might have on the climate system if the technologies and infrastructure required existed. We are not aware of any ongoing or planned real-world experiments with the intention or scale required to alter the Earth's climate themselves.

Q- Does the Met Office conduct SRM experiments in the real-world?

A- No. We have not conducted or collaborated with any other organizations on any physical real-world solar geoengineering (SRM) experiments and have no plans to conduct, advocate or provide context for real-world physical experiments.

Q- Are you aware of any geoengineering or related activities currently or recently taking place in UK?

A- The Met Office is aware of possible upcoming real-world small scale field experimentation undertaken by other organisations, such as ARIA. However, the Met Office does not have any involvement in these activities. For your information, ARIA have recently disclosed details of their SRM research plans on their website under the programme: Exploring Climate Cooling.

We are also aware that a group of scientists from the University of Reading conducted a small-scale field experiment in the UK during 2021 with an unmanned aerial vehicle to explore how electric charge can change water drops in fog. Whilst, they did not conduct cloud seeding, weather modification or create artificial precipitation, their research news summary explains the connection of their investigations to research on rain enhancement: Charging fog - University of Reading.

Q- Is the Met Office involved in weather modification such as cloud seeding?

A- As outlined in our guide to Atmospheric modification and geoengineering, the Met Office does not engage in adding substances to the atmosphere in order to modify it. The Met Office does not undertake any practical research into weather modification, all research into geoengineering is theoretical and based on simulations using climate models.

Q - Have weather modification experiments ever occurred in the UK?

A- Please see Met Office disclosures log references 029, that points to published information on historical investigations of cloud seeding during the early 1950's.

Q- Reports/studies on geo-engineering.

A- The list below includes publications that Met Office researchers have led and those that Met Office researchers have contributed to as co-authors. Our contribution to this research is not based on real life experiments, but climate model simulations and hypothetical scenarios.

We look at the possible value of the approaches and the potential trade-offs that may result from their enaction. We do not advocate for any particular approach to mitigation and our role is not to judge the most effective or promising technique.

Many of our climate simulations and associated publications have been coordinated with or followed the model simulation protocols of the Geoengineering Model Intercomparison Project (GeoMIP) project, an endorsed community coordinated project, as designated by the Working Group on Coupled Modelling (WGCM) of the World Climate Research Programme (WCRP). The Geoengineering Model Intercomparison Project (GeoMIP) is a coordinated international initiative that has provided a framework for geo-engineering modelling experiments and coordinating modelling intercomparisons.

Below is a list of publications that investigated/are **on the topic of SRM**:

- ACP - Comparing different generations of idealized solar geoengineering simulations in the Geoengineering Model Intercomparison Project (GeoMIP) (copernicus.org).
- Antipyretic Medication for a Feverish Planet | Earth Systems and Environment (springer.com).
- Evaluating climate geoengineering proposals in the context of the Paris Agreement temperature goals | Nature Communications.
- ACP - The climate effects of increasing ocean albedo: an idealized representation of solar geoengineering (copernicus.org).
- ACP - Response to marine cloud brightening in a multi-model ensemble (copernicus.org).
- Regional Climate Impacts of Stabilizing Global Warming at 1.5 K Using Solar Geoengineering - Jones - 2018 - Earth's Future - Wiley Online Library.
- Impacts of stratospheric aerosol geoengineering strategy on Caribbean coral reefs | Emerald Insight.
- Impacts of hemispheric solar geoengineering on tropical cyclone frequency | Nature Communications.

- ACP - Marine cloud brightening – as effective without clouds (copernicus.org).
- ACP - Climatic impacts of stratospheric geoengineering with sulfate, black carbon and titania injection (copernicus.org).
- GMD - The Geoengineering Model Intercomparison Project Phase 6 (GeoMIP6): simulation design and preliminary results (copernicus.org).
- Key factors governing uncertainty in the response to sunshade geoengineering from a comparison of the GeoMIP ensemble and a perturbed parameter ensemble - Irvine - 2014 - Journal of Geophysical Research: Atmospheres - Wiley Online Library.
- Arctic cryosphere response in the Geoengineering Model Intercomparison Project G3 and G4 scenarios - Berdahl - 2014 - Journal of Geophysical Research: Atmospheres - Wiley Online Library.
- Solar radiation management impacts on agriculture in China: A case study in the Geoengineering Model Intercomparison Project (GeoMIP) - Xia - 2014 - Journal of Geophysical Research: Atmospheres - Wiley Online Library.
- Haywood, J.M. and Bellouin, N. L'impact des éruptions volcaniques sur les précipitations au Sahel implique la prudence pour la géo-ingénierie planétaire (in French), La Researche, 482, 44-46.
- The impact of abrupt suspension of solar radiation management (termination effect) in experiment G2 of the Geoengineering Model Intercomparison Project (GeoMIP) - Jones - 2013 - Journal of Geophysical Research: Atmospheres - Wiley Online Library.
- Asymmetric forcing from stratospheric aerosols impacts Sahelian rainfall | Nature Climate Change
- Sea spray geoengineering experiments in the geoengineering model intercomparison project (GeoMIP): Experimental design and preliminary results - Kravitz - 2013 - Journal of Geophysical Research: Atmospheres - Wiley Online Library.
- The hydrological impact of geoengineering in the Geoengineering Model Intercomparison Project (GeoMIP) - Tilmes - 2013 - Journal of Geophysical Research: Atmospheres - Wiley Online Library.
- An overview of the Geoengineering Model Intercomparison Project (GeoMIP) - Kravitz - 2013 - Journal of Geophysical Research: Atmospheres - Wiley Online Library.
- Climate model response from the Geoengineering Model Intercomparison Project (GeoMIP) - Kravitz - 2013 - Journal of Geophysical Research: Atmospheres - Wiley Online Library.
- ACP - Sea-spray geoengineering in the HadGEM2-ES earth-system model: radiative impact and climate response (copernicus.org).
- A comparison of the climate impacts of geoengineering by stratospheric SO2 injection and by brightening of marine stratocumulus cloud - Jones - 2011 - Atmospheric Science Letters - Wiley Online Library.
- ACP - Geoengineering by stratospheric SO2 injection: results from the Met Office HadGEM2 climate model and comparison with the Goddard Institute for Space Studies ModelE (copernicus.org).
- Climate impacts of geoengineering marine stratocumulus clouds - Jones - 2009 - Journal of Geophysical Research: Atmospheres - Wiley Online Library.
- EGUsphere - A protocol for model intercomparison of impacts of Marine Cloud Brightening Climate Intervention (copernicus.org)
- EGUsphere - Projected future changes in extreme precipitation over China under stratospheric aerosol intervention (copernicus.org)
- Identifying Climate Impacts From Different Stratospheric Aerosol Injection Strategies in UKESM1 (wiley.com)
- GMD - G6-1.5K-SAI: a new Geoengineering Model Intercomparison Project (GeoMIP) experiment integrating recent advances in solar radiation modification studies (copernicus.org)
- ACP - Climate intervention using marine cloud brightening (MCB) compared with stratospheric aerosol injection (SAI) in the UKESM1 climate model (copernicus.org)
- Climate intervention on a high-emissions pathway could delay but not prevent West Antarctic Ice Sheet demise | Nature Climate Change
- ACP - Opinion: The scientific and community-building roles of the Geoengineering Model Intercomparison Project (GeoMIP) – past, present, and future (copernicus.org)
- ACP - Comparison of UKESM1 and CESM2 simulations using the same multi-target stratospheric aerosol injection strategy (copernicus.org)
- ACP - Climate response to off-equatorial stratospheric sulfur injections in three Earth system models – Part 1: Experimental protocols and surface changes (copernicus.org)

- ACP - Climate response to off-equatorial stratospheric sulfur injections in three Earth system models – Part 2: Stratospheric and free-tropospheric response (copernicus.org)
- ACP - Future changes in atmospheric rivers over East Asia under stratospheric aerosol intervention (copernicus.org)
- ACP - Assessing the consequences of including aerosol absorption in potential stratospheric aerosol injection climate intervention strategies (copernicus.org)
- ACP - The impact of stratospheric aerosol intervention on the North Atlantic and Quasi-Biennial Oscillations in the Geoengineering Model Intercomparison Project (GeoMIP) G6sulfur experiment (copernicus.org)
- ACP - Stratospheric ozone response to sulfate aerosol and solar dimming climate interventions based on the G6 Geoengineering Model Intercomparison Project (GeoMIP) simulations (copernicus.org)
- ACP - Identifying the sources of uncertainty in climate model simulations of solar radiation modification with the G6sulfur and G6solar Geoengineering Model Intercomparison Project (GeoMIP) simulations (copernicus.org)
- ACP - North Atlantic Oscillation response in GeoMIP experiments G6solar and G6sulfur: why detailed modelling is needed for understanding regional implications of solar radiation management (copernicus.org)

We have also contributed to two reports published by the United Nations Environment Program (UNEP) that reviewed aspects of geoengineering research:

- One Atmosphere: An Independent Expert Review on Solar Radiation Modification Research and Deployment | UNEP - UN Environment Programme, which was published in 2023.
- Scientific Assessment of the Ozone Layer Depletion: 2022 | UNEP - UN Environment Programme, which reviewed the potential consequences of Stratospheric Aerosol Injections for ozone depletion.

The Met Office undertakes numerical modelling research into a variety of mitigation pathways, as well as the impacts of solar radiation management, as part of the Hadley Centre Climate Programme (HCCP). This includes a workstream entitled "*Exploring the role of Climate Interventions in mitigation*", exploring the potential climate co-benefits and trade-offs for climate interventions to avoid overshoot, recover and stabilise temperature. Research into mitigation pathways is also part of the Research & Innovation strategy of the Met Office, which is publicly available on the Met Office website.

Q- What chemicals are being sprayed by you?

A- We are not involved in the spraying of any chemicals over the UK and therefore do not have any details on this. We do not carry out physical geo-engineering experiments. The following page contains more information on climate misinformation: Tackling climate misinformation - Met Office.

Q- Who do we collaborate with/what partnerships do we have?

A- The Met Office collaborates widely with international academic and research institutions on climate research, including studies analysing or reviewing climate model simulations of hypothetical solar radiation management geo-engineering scenarios.

Below is a list of national and international collaborations **relating to SRM research:**

- Arctic Centre, University of Lapland, Rovaniemi, Finland.
- Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, USA.
- Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden.
- Canadian Centre for Climate Modeling and Analysis, Environment Canada, Toronto, Ontario, Canada.
- Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Victoria, Canada.
- CAS Center for Excellence in Tibetan Plateau Earth Sciences, Beijing, China.
- Center for Global Change Science, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA, 02139, USA.

- Centre for Rediscovered and Redefined Natural Resources Research and Education (C4RE), Dhaka, Bangladesh.
- CICERO Center for International Climate and Environmental Research Oslo, Oslo, Norway.
- CICOES (Cooperative Institute for Climate, Ocean and Ecosystem Studies), University of Washington, Seattle, WA.
- Climate and Environmental Physics, Physics Institute, University of Bern, Bern, Switzerland.
- Climate Change Research Centre, University of New South Wales, Sydney, Australia.
- Climate Institute, Washington, D.C., USA.
- Climate System Analysis Group, University of Cape Town, Cape Town, South Africa.
- CNRM, Université de Toulouse, Météo-France, CNRS, Toulouse, France.
- College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, UK.
- College of Global Change and Earth System Science, Beijing Normal University, Beijing, China.
- Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado Boulder, Boulder, CO, USA.
- CSIRO Oceans and Atmosphere, Hobart, Australia.
- Danish Meteorological Institute, Copenhagen, Denmark.
- Department of Atmospheric Sciences, University of Washington, Seattle, WA, USA.
- Department of Earth and Atmospheric Science, Indiana University, Bloomington, IN, USA.
- Department of Energy and Process Engineering, Industrial Ecology Programme, Norwegian University of Science and Technology, Trondheim, Norway.
- Department of Environmental Sciences, Rutgers University, New Brunswick, NJ, USA.
- Department of Geology and Geophysics, Yale University, New Haven, CT, USA.
- Department of Geosciences, University of Oslo, Oslo, Norway.
- Department of Mathematics and Statistics, Faculty of Environment, Science and Economy, University of Exeter, Exeter, UK.
- Department of Meteorology and National Centre for Earth Observation, University of Reading, Berkshire, UK.
- Department of Meteorology, Stockholm University, Stockholm, Sweden.
- Dept. of Environmental and Geographical Science, University of Cape Town, Cape Town, South Africa.
- Downing College Cambridge, Cambridge, UK.
- Earth Sciences Division, NASA GSFC, Greenbelt, MD, USA.
- Earth Sciences, University College London, London, UK.
- Environment and Climate Change Canada, Toronto, Ontario, Canada.
- GESTAR-II University of Maryland Baltimore County, Baltimore, MD, USA.
- IMK-ASF, Karlsruhe Institute of Technology, Eggenstein–Leopoldshafen, Germany.
- Institut Pierre-Simon Laplace, Sorbonne Université/CNRS, Paris, France.
- Institute for Advanced Sustainability Studies, Potsdam, Germany.
- Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland.
- Institute for Atmospheric and Climate Science, ETH Zürich, Zurich, Switzerland.
- Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia.
- Institute for Science, Innovation and Society, University of Oxford, Oxford, UK.
- Institute of Environmental Sciences and Geography, University of Potsdam, Potsdam, Germany.
- Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan.
- Joint Center for Global Change Studies, Beijing, 100875, China.
- Kuopio Unit, Finnish Meteorological Institute, Kuopio, Finland.
- Laboratoire de météorologie dynamique, Université Pierre et Marie Curie, Paris, France.
- Laboratoire des Sciences du Climat et l'Environnement, CEA, CNRS, UVSQ, Gif-sur-Yvette, France.
- Max Planck Institute for Meteorology, Hamburg, Germany.
- National Centre for Atmospheric Research, USA.
- National Centre for Atmospheric Sciences, University of Leeds, Leeds, UK.
- NOAA Chemical Sciences Laboratory (NOAA CSL), Boulder, CO, US.
- Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland.
- School of Earth and Environment, University of Leeds, Leeds, UK.
- School of Earth and Ocean Sciences, University of Victoria, Victoria, British Columbia, Canada.

- School of Earth Sciences and Environmental Engineering, Gwangju Institute of Science and Technology, Gwangju, South Korea.
- School of Geographical Sciences, University of Bristol, Bristol, UK.
- School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, UK.
- School of GeoSciences, University of Edinburgh, Edinburgh, UK.
- Scripps Institution of Oceanography, La Jolla, CA, USA.
- Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca, NY, USA.
- State Key Laboratory of Earth Surface Processes and Resource Ecology, College of Global Change and Earth System Science, Beijing Normal University, Beijing, China.
- University of East Anglia, Norwich, UK.
- University of Geneva, Geneva, Switzerland.
- University of Hamburg, Hamburg, Germany.
- Whiting School of Civil Engineering, Johns Hopkins University, Baltimore, MD, USA.

Q- who funds this research/cost of doing this research?

A- Research on the topic of geoengineering is supported by the Department for Energy Security and Net Zero (DESNEZ) as part of the broader Hadley Centre Climate Program. More information on this Climate Program can be seen here: Met Office Hadley Centre Climate Programme: Chair of the Science Review Group - Met Office.

Q- Do you have a list of all experiments that have taken place over the UK by you?

A- We do not have a list of any experiments that have taken place over the UK as we are not involved in any physical geo-engineering experiments.

Q- What are ARIA doing?

A- Whilst the Met Office is aware of possible upcoming real-world small scale field experimentation undertaken by other organisations, such as ARIA, the Met Office does not have any involvement in these activities. For your information, ARIA have recently disclosed details of their SRM research plans on their website under the programme: Exploring Climate Cooling

Q- How does the Met Office contribute to coordinated modelling activities on geoengineering research?

A- Simulation outputs from climate model experiments (i.e. datasets) that assess hypothetical SRM scenarios are sometimes shared with collaborators in the scientific community to collaborate on this area of research. This has been both through Met Office Academic Partnerships that facilitate direct access to our model datasets, and via externally coordinated modelling research projects that facilitate modelling centres to share their data to undertake intercomparisons and joint research studies.

The principal external coordinator through which the Met Office has contributed model outputs has been GeoMIP. Indeed, many of our climate simulations and associated publications have been coordinated with or followed the model simulation protocols of the Geoengineering Model Intercomparison Project (GeoMIP) project, an endorsed community coordinated project, as designated by the Working Group on Coupled Modelling (WGCM) of the World Climate Research Programme (WCRP). The Geoengineering Model Intercomparison Project (GeoMIP) is a coordinated international initiative that has provided a framework for geo-engineering modelling experiments and coordinating modelling intercomparisons and is aligned with the CMIP - Coupled Model Intercomparison Project.

Another SRM modelling research project through which we have shared our model outputs since 2019 has been the ARISE project: Assessing Responses and Impacts of Solar intervention on the Earth system with Stratospheric Aerosol Injection (ARISE-SAI) | Community Earth System Model. Please see the following page for access to the ARISE project datasets: Dataset Record: UKESM1 ARISE-SAI climate simulations.

Please consult the following pages for internationally shared data sets: The CMIP6 GeoMIP datasets are available via ESGF MetaGrid and the ARISE dataset is available from the Centre for Environmental Data Analysis (CEDA) Archive: Dataset Record: UKESM1 ARISE-SAI climate simulations.

In order to provide advice and assistance, please consult the GeoMIP about page for further information about the GeoMIP project.

Q- Which climate models has the Met Office used or provided access to for geoengineering research?

A- On the Met Office infrastructure we host modelling systems that have been developed internally and through collaboration with our partners. Since 2019, SRM simulations have been undertaken with models that fall under the framework of the Met Office Unifed Model (UM) and with climate model configurations of the UM including the Hadley Centre Environment Model (HadGEM) and the UK Earth System Model (UKESM). For more information, see:
HadGEM1: Met Office climate prediction model - Met Office
HadGEM2 family: Met Office climate prediction model - Met Office
HadGEM3 family: Met Office climate prediction model - Met Office
New flagship climate models - UKESM1 and HadGEM3-GC3.1 - Met Office

Q- Does the Met Office research the impacts of contrails on climate?

A- Some research has been undertaken to quantify the potential contribution of contrails to climate change, as listed below. However, please note that as outlined in Atmospheric modification and geoengineering - Met Office, there is misinformation on social media suggesting the condensation trails (contrails) from high-altitude aircraft are visual signs of attempts to alter the atmosphere or for other nefarious purposes. The term chemtrails is sometimes used to suggest that the condensation contains added chemicals. Despite numerous claims, there is no evidence to support such suggestions.

Further information explaining what contrails are and how they form has been provided in Met Office disclosures log reference 029

Below is a list of publications that investigated the **contribution of contrails to climate change:**

- Zhang, W., Van Weverberg, K., Morcrette, C. J., Feng, W., Furtado, K., Field, P. R., Chen, C.-C., Gettelman, A., Forster, P. M., Marsh, D. R., and Rap, A.: Impact of host climate model on contrail cirrus effective radiative forcing estimates, Atmos. Chem. Phys., 25, 473–489, https://doi.org/10.5194/acp-25-473-2025, 2025.
- Jones, H. M., Haywood, J., Marenco, F., O'Sullivan, D., Meyer, J., Thorpe, R., Gallagher, M. W., Krämer, M., Bower, K. N., Rädel, G., Rap, A., Woolley, A., Forster, P., and Coe, H.: A methodology for in-situ and remote sensing of microphysical and radiative properties of contrails as they evolve into cirrus, Atmos. Chem. Phys., 12, 8157–8175, https://doi.org/10.5194/acp-12-8157-2012, 2012.
- Rap, A., P. M. Forster, J. M. Haywood, A. Jones, and O. Boucher (2010), Estimating the climate impact of linear contrails using the UK Met Office climate model, *Geophys. Res. Lett.*, 37, L20703, doi:10.1029/2010GL045161.
- Rap, A., P. M. Forster, A. Jones, O. Boucher, J. M. Haywood, N. Bellouin, and R. R. De Leon (2010), Parameterization of contrails in the UK Met Office Climate Model, *J. Geophys. Res.*, 115, D10205, doi:10.1029/2009JD012443.
- Haywood, J. M., R. P. Allan, J. Bornemann, P. Forster, P. N. Francis, S. Milton, G. Rädel, A. Rap, K. P. Shine, and R. Thorpe (2009), A case study of the radiative forcing of persistent contrails evolving into contrail-induced cirrus, *J. Geophys. Res.*, 114, D24201, doi:10.1029/2009JD012650.

Other information-

- Please see our guidance page providing an understanding what is meant by atmospheric modification and geoengineering and misinformation on these topics: Atmospheric modification and geoengineering - Met Office.
- Please see the information published on the Met Office disclosures log references 029 and 032, Disclosure Log - Met Office.
- We do not have any involvement with airlines on the subject of geoengineering.