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Policy brief

From uncertainty to action:

Addressing aerosol-cloud interactions for climate resilience

EC - ESA
Aerosol Cloud Cluster

Introduction

Limiting global warming requires rapid and sustained reductions in greenhouse gas emissions. Yet, **our ability to predict the pace and regional pattern of climate change remains dominated by uncertainties linked to aerosols and their interactions with clouds.** These tiny airborne particles are often emitted together with greenhouse gases, and influence how sunlight and heat are reflected or absorbed in the atmosphere, shaping cloud formation, rainfall, and temperature extremes.

Uncertainties in how air pollution interacts with clouds (so-called aerosol–cloud interactions, or ACI) are now the largest source of uncertainty in projecting near-term climate evolution and risk. Because aerosols respond quickly to emission changes, their effects unfold over years to decades, the timescales most relevant for adaptation and mitigation planning.

Reducing these uncertainties is therefore essential to guide effective climate action, improve confidence in regional projections, and ensure that mitigation and clean-air policies deliver their intended climate benefits.

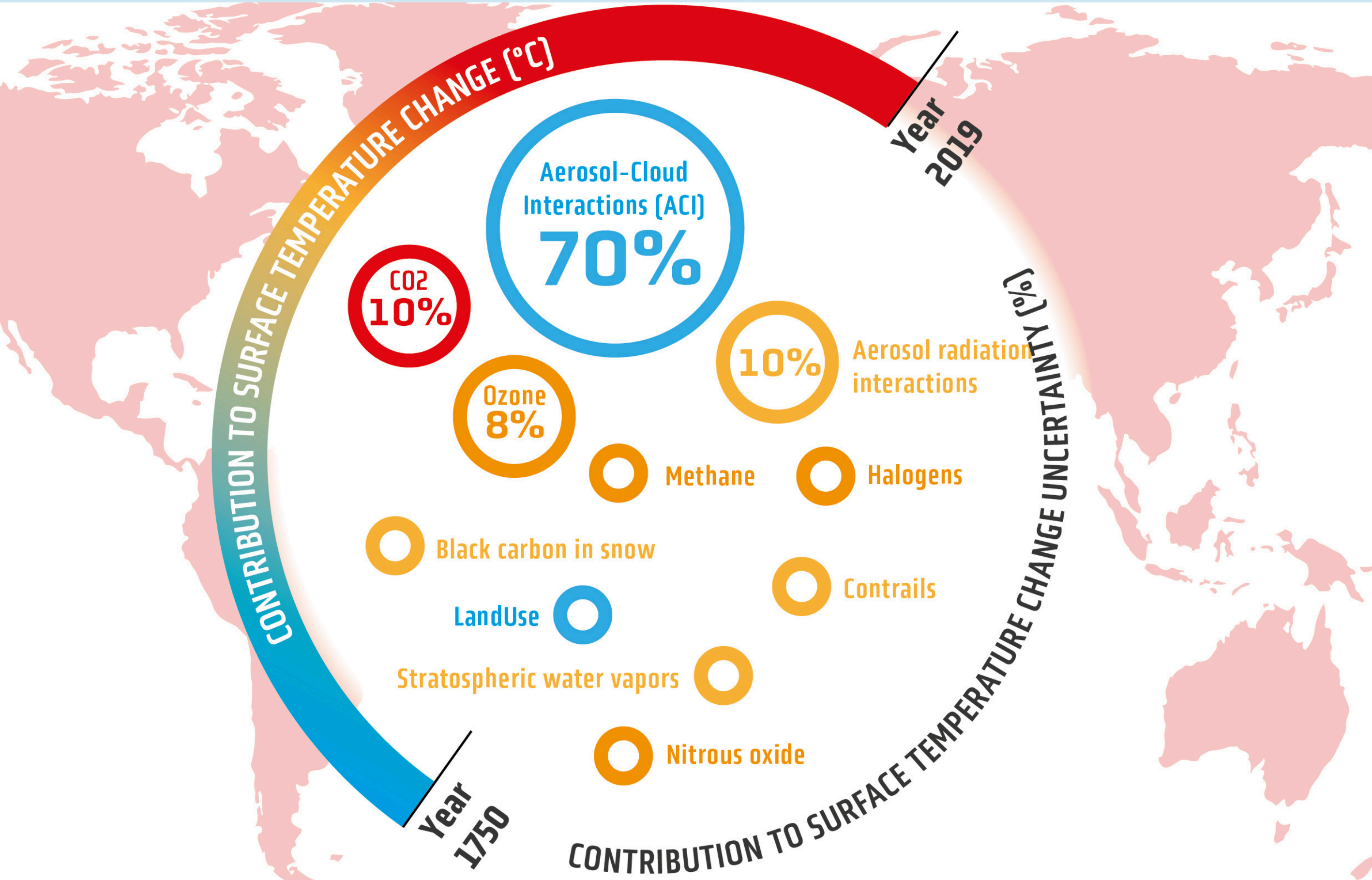


Figure 1. Aerosol–cloud interactions (ACI) represent the largest source of uncertainty on the estimated anthropogenic temperature change (Im. et al., 2025)

How ACI uncertainty affects policy

Accelerating warming and extreme events demand more reliable near-term projections. In addition to greenhouse gas driven warming, recent record global temperatures have been influenced by air pollution related factors such as reduced sulfur emissions from shipping and China, low Saharan dust, and volcanic effects.

Untangling their influences is however very challenging, because of poorly constrained ACI. As a result of these uncertainties, policymakers cannot yet know how much recent warming stems from cleaner air policies versus greenhouse gases. This complicates estimates of the remaining carbon budget and of near-term regional climate change. Aerosols currently mask some greenhouse-gas warming, but as air quality improves, this hidden warming will be revealed. It also limits confidence in climate sensitivity estimates, which determine how much the planet will warm for a given rise in CO_2, leaving open the possibility of both moderate and high-risk futures.

At the regional level, ACI uncertainty prevents reliable projections of rainfall, monsoons, and extreme weather, undermining adaptation planning and evaluation of interventions such as Solar Radiation Management.

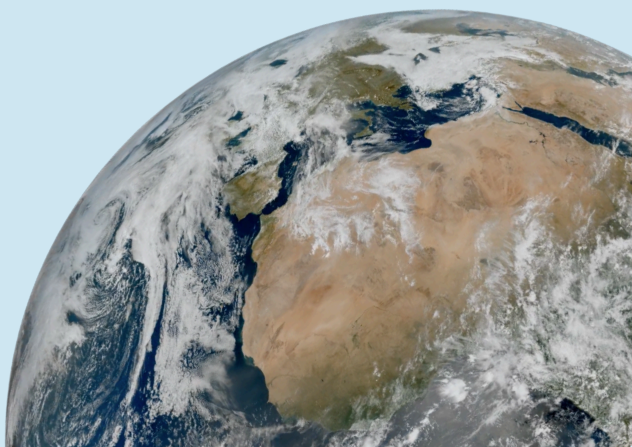
Finally, it blurs the balance between public health gains from cleaner air and the climate risks of reduced aerosol cooling.

The challenges

- Magnitude of uncertainty: Current IPCC estimates of ACI's radiative forcing range from −1.7 to −0.3 W/m², representing the largest uncertainty in human-induced climate change (since pre-industrial times).
- Changing aerosol regimes: Clean air policies are reducing anthropogenic aerosols, shifting cloud–aerosol dynamics and amplifying greenhouse gas warming, while natural aerosol types such particles produced by wildfires, as well as mineral dust and sea spray grow more common in a warmer world.
- Unequal impacts: Different regions will experience distinct aerosol-cloud-climate regimes, complicating adaptation and mitigation planning.
- Gaps in evidence: Remote regions (especially the Global South) remain undersampled; cloud microphysics and extreme precipitation processes are poorly captured in models.

Opportunities for progress

- New satellite missions (e.g. ESA EarthCARE, NASA PACE) will deliver breakthrough aerosol–cloud data.
- Ground networks (e.g. ACTRIS, ARM) expand long-term aerosol and cloud observations, especially needed in the Global South.
- High-resolution models at km-scale capture storms and extremes more realistically.
- Machine learning accelerates model development and improves data interpretation.
- Collaboration across disciplines and countries is key to rapid progress



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Policy recommendations

1 Prioritize investment in satellite and ground-based observational infrastructure, with emphasis on underserved regions (especially Global South).

2 Accelerate high-resolution and aerosol-aware climate modeling, including investment in computing infrastructure, that can better represent clouds and extreme events.

3 Integrate new satellite mission data rapidly into climate assessments and IPCC reports.

4 Support interdisciplinary research integrating atmospheric science, data science, and climate impacts.

5 Promote global collaboration to ensure rapid, open sharing of data and methods.

6 Explicitly incorporate aerosol-cloud interactions uncertainty into climate policies, carbon budget and adaptation & mitigation strategies.

Conclusion

Reducing uncertainties in aerosol–cloud interactions is not just a scientific priority, it is a prerequisite for sound climate policy. Investing in this research will directly enhance our ability to project near-term climate changes, strengthen resilience to extreme events, and support effective mitigation strategies.

Reference

Im, U., Samset, B.H., Nenes, A., Thomas, J.L., Kokkola, H., Dubovik, O., Amiridis, V., Arola, A., Bellouin, N., Benedetti, A., Blichner, S., Decesari, S., Ekman, A.M.L., García-Pando, C.P., Gross, S., Gryspeerdt, E., Hasekamp, O., Kahn, R.A., Laakso, A., Lohmann, U., Marelle, L., Massling, A.H., Myhre, C.L., Pöhlker, M., Quaas, J., Raatikainen, T., Riipinen, I., Schmale, J., Seifert, P., Skov, H., Smith, C., Sporre, M.K., Stier, P., Storelvmo, T., Tsigaridis, K., van Diedenhoven, B., Virtanen, A., Wandinger, U., Wilcox, L.J., Zieger, P., 2025. Aerosol-cloud interactions: Overcoming a barrier to projecting near-term climate evolution and risk. AGU Advances

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