# Out of the atmosphere

**Professor Ken Carslaw and Carly Reddington, of the University of Leeds, describes how particle formation over Europe is being studied to ascertain its effect on climate…**

Atmospheric aerosol particles strongly influence Earth's climate by scattering sunlight and affecting the brightness of clouds. However, there are many unanswered questions about the origin of the particles. Some originate from industrial and vehicle emissions, but there is also a significant natural source from chemicals emitted by vegetation. Picking apart the different sources of particles over Europe, and improving our understanding of their effects on climate, is a major aim of the EU 6th Framework Integrated Project EUCAARI (Aerosol, Cloud, Climate and Air-Quality Interactions).

Aerosols have had a substantial effect on Earth's climate over the industrial revolution, particularly over industrialised regions like Europe. Aerosol haze, as it appears from the ground, has had a significant cooling effect on the planet, and recent studies suggest that much of the warming due to greenhouse gases has been cancelled out by aerosol, at least until quite recently. It is now recognised that a large fraction of the particulate material is natural – even in polluted regions – deriving from chemical compounds emitted by trees and vegetation, and from dust and sea spray. It is essential to quantify the natural fraction of atmospheric aerosol if we are to understand their effects on climate. An important aspect of the EUCAARI project is to use advanced atmospheric models to quantify the different aerosol sources over Europe.

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To separate these different particle sources, EUCAARI is using advanced computer models of atmospheric transport and aerosols tested against observations made by aircraft and a network of ground stations. EUCAARI models, such as the Global Model of Aerosol Processes (GLOMAP), are using the latest knowledge developed in the project.

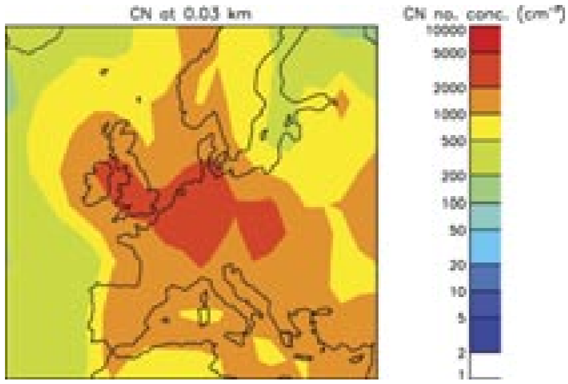



*Fig. 1: Map showing the concentration of particles at the surface over Europe from the GLOMAP global aerosol model. Particle concentrations like this are not a common feature of climate and air quality models. EUCAARI is developing such models to understand how different particle sources affect climate*

Aerosols can be emitted into the atmosphere directly (sea spray being a good example) or they can form in the air in a process known as nucleation, where new particles are formed at nanometre sizes from molecules like sulphuric acid vapour (partly from sulphur air pollution) and organic compounds emitted by trees. Thousands of new particles can be created every hour in each cubic centimetre of the atmosphere in nucleation events that occur almost every other day over pristine and highly polluted regions of Earth. The nucleation process is very uncertain and difficult to handle in models, but new insights from the EUCAARI laboratory and field experiments have enabled the process to be included realistically in the global and regional models.

EUCAARI's advanced model simulations have given us a new insight into global aerosol and climate. An important discovery has been the enormous importance of nucleation for climate. The model simulations show that about 45% of climate relevant particles at the Earth's surface are derived from nucleation, with the remainder coming from primary emissions (sea spray, combustion particulates, etc.). Climate relevant particles are those

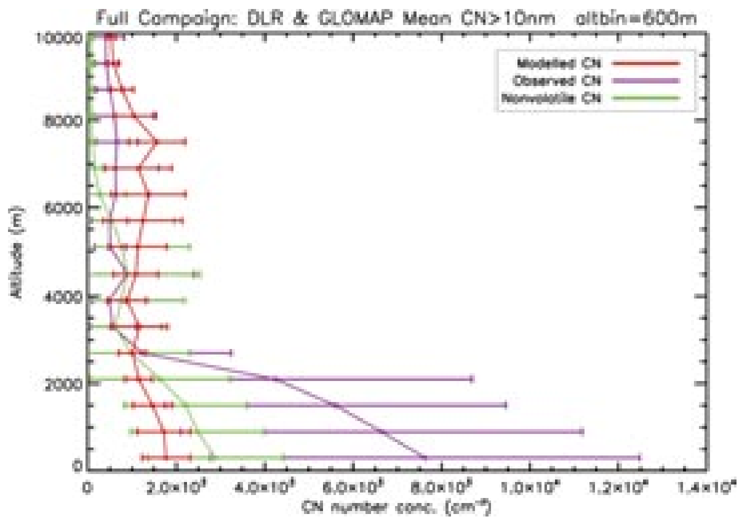



*Fig. 2: The vertical profile of particle concentrations (condensation nuclei, CN) over Europe from aircraft observations and the GLOMAP model. The observations are an average of eight flights of the DLR Falcon aircraft. The difference between the model and observations near the surface is due to neglecting important aerosol nucleation processes. The model under-predicts volatile particles, which probably come from nucleation*

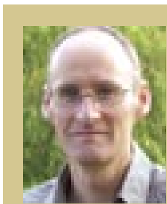
that are large enough (about 50-100 nanometres) to form cloud drops – so-called cloud condensation nuclei (CCN). This is a much larger contribution from nucleation than was previously thought. A further surprising discovery was that three-quarters of the CCN at the surface actually came from well above the surface (2-10km altitude). New particles are formed in the cold high atmosphere and then transported down by air motions. Such processes mean that pollutant emissions in one part of Europe can affect climate relevant particles several thousand kilometres away.

Over Europe and other polluted regions, the relative contributions from primary particles and nucleated particles were found to be quite different to the global average. Approximately 70% of the CCN are derived from particles emitted directly into the atmosphere from industrial and domestic sources. However, the research has shown that this contribution can change quite dramatically. When emissions of the primary particles are reduced (for example, to meet air quality targets), the models showed that nucleation increased in response, and the number of CCN didn't fall as much as expected.

EUCAARI has also tried to quantify the contribution to these processes from natural emissions. A second important discovery has been that forest emissions exert a very strong control on CCN. Using GLOMAP, we showed that the emission of organic vapours from high latitude (boreal) forests can double regional CCN concentrations (from about 100 to 200/cm$^3$). These vapours contribute to the rapid growth of new nuclei up to the size of CCN particles. These additional CCN have a substantial effect on cloud brightness. For example, we found that low level clouds will reflect an additional 1.8-6.7 watts of sunlight per square metre of forest when forest emissions are included in the model. This 'climate forcing' may be large enough to change the net effect of these high latitude forests on climate. While recent work has suggested that their net effect is to warm climate (because trees are dark and absorb lots of sunlight), our aerosol nucleation cloud effect suggests that the forests may have an overall cooling effect on climate.

This research on aerosol sources is important for climate. Firstly, understanding climate change requires an understanding of how aerosols and greenhouse gases change over decades. Nucleated aerosols behave quite differently to primary particles. While primary particles in the atmosphere should simply track the emissions, nucleated particles depend on many environmental factors like humidity, temperature, pollutant gas concentrations, emissions from trees, etc. So, long-term changes in climate relevant aerosols could be quite different to what is expected.

Another important aspect of EUCAARI is the use of such detailed knowledge of aerosol processes to improve climate models. GLOMAP is one of a new breed of global models that simulates the aerosol processes in much more detail than hitherto. However, many of the processes are too complex for full climate models, so EUCAARI is developing ways to simplify the processes. This is being achieved by running the simpler and more complex aerosol models side by side in the same atmospheric model, and comparing them both against the same observations. So far, the results look very encouraging.



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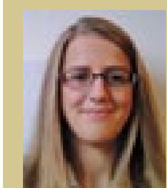

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