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Figure 1 **Clouds in the upper troposphere: their climatic effects depend on the frozen water content.**

predict accurately. Some observations show liquid droplets that persist until very low temperatures, suggesting that the freezing is homogeneous. In other studies, however, large quantities of ice form at relatively high temperatures, implying that heterogeneous freezing is taking place. This variability has prompted energetic speculation on the nature of 'ice nuclei' — pre-existing solid particles in clouds that are particularly efficient at catalysing freezing on their surfaces at relatively high temperatures.

Several studies have involved collecting cloud air and investigating the temperatures at which the particles in it can lead to droplet freezing. The most likely candidate nuclei include mineral dust and clays, particles of biological origin such as plant debris, and some products of industrial combustion. The experiments of Zuberi *et al.* suggest, however, that this approach, which is based on the idea that heterogeneous freezing of droplets requires pre-existing ice nuclei, may not always be sufficient to predict the eventual temperatures of droplet freezing. Rather, it seems that the formation of ice nuclei within droplets may sometimes be part of the freezing process itself.

There are, of course, many differences between conditions in laboratory experiments and those in the atmosphere, so the applicability of the results of these new experiments is likely to be limited. Nonetheless, as Zuberi *et al.* point out, there are times and places in the atmosphere at which analogous transformations of droplets occur, which might affect the freezing modes. Close to the boundaries between clouds and clear air, for example, aerosol particles and cloud droplets can be subjected to one or more cycles of condensation and evaporation, accompanied by large temperature fluctuations. If a droplet undergoes these processes at low temperatures it can freeze, and if it contains inorganic or organic materials of low solubility (such as some organics that are commonly found in atmospheric aerosol particles[4]), the freezing mode and temperature could depend on the droplet's history.

Some cases[5] of so-called 'ice multiplication' at temperatures above about −20 °C might also be explained in this way. This phenomenon, in which ice-particle concentrations far exceed the concentrations of known ice nuclei, may sometimes be due to heterogeneous freezing onto the solid inclusions in originally liquid droplets. Ideas such as these need to be investigated under realistic atmospheric conditions. If it turns out that droplet history is important in determining freezing temperatures, then that history must be taken into account in modelling and laboratory studies of tropospheric clouds.

The effects of upper-tropospheric clouds on climate are highly sensitive to the amount of frozen cloud water. For instance, according to the latest report from the Intergovernmental Panel on Climate Change[6], differences in assumptions about how much water is frozen lead to differences of up to 17 W m^{-2} in the global average flux of radiation entering or leaving Earth. For comparison, the change in flux due to the CO_2 increase over the past 200 years is less than 2 W m^{-2}. Droplet freezing is one of the central processes in cloud physics but also one of the least understood. We badly need new ideas in this area, and experiments such as those of Zuberi *et al.* are a great help in providing fresh approaches to the subject. ■

Marcia Baker is in the Departments of Atmospheric Science, and Earth and Space Sciences, PO Box 351650, University of Washington, Seattle, Washington 98195, USA.
e-mail: marcia@geophys.washington.edu

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Daedalus

Even more light

Artificial light is one of the few great inventions: it frees mankind from dependence on sunlight. Artificial light often depends on a hot object — a filament or gas mantle — as close as possible to the temperature of the Sun. In practice, 3,000 K is good. Alternatively, fluorescent materials can be excited by ultraviolet light or electric discharges, as in gas-discharge tubes. But both types of light are deplorably inefficient.

Daedalus now recalls the free-electron laser. A beam of electrons is fired along a tube, and set wiggling by magnets lining it. Electrons sent along a wiggly wire as an ordinary current should wiggle just as much, and their sideways oscillation should emit visible light. Modern micro-deposition can probably impose 10^{12} wiggles per metre on a conductive pathway, so a current of 10^3 metres per second should emit blue light at a frequency of 10^{15} Hz. A high-temperature superconductor may be needed, but the thing looks feasible: an amp is some 6×10^{18} electrons a second.

DREADCO engineers are therefore depositing cuprate superconductors, and even conducting metals such as silver, onto transparent quartz plates. They are packing as many wiggles as possible into the conductor. Transformer coupling to the wiggly element should let ordinary mains electricity drive the new light. It should compete strongly with existing lamps. It will be far more efficient than they are. It will hardly get warm; indeed, it may need to be cooled, but Daedalus hopes that room-temperature superconduction will be possible soon.

The new 'electrolamp' will emit a very pure light, its frequency defined by the speed of the electrons and the size of the wiggles. The first samples will go at a vast price for visible, infrared and even ultraviolet spectrometers; these will recover the heavy development costs. When the lamp reaches commercial production, several parallel 'filaments' will each have different number of wiggles, so as to emit a graded rainbow of colours approximating to white (as with gas-discharge tubes today).

Photographers will love a special electrolamp, whose three filaments are each tuned to one of the dyes in the film. It should combine great sensitivity with accurate colour rendition. The broader, whiter electrolamp should transform the domestic scene. Equally effective on mains or battery, it will complete our victory over fitful solar illumination.

David Jones