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GLOBAL WARMING

The soot factor

The surface warming due to emissions of black-carbon aerosols over the second half of the twentieth century has been identified in observations. These findings will inform debate over the climatic effects of controlling such emissions.

JOHANNES QUAAS

Anthropogenic emissions affect global climate. In a paper published in *Atmospheric Chemistry and Physics*, Jones *et al.*[1] add to understanding of this 'forcing' of climate in a study of one of the factors involved — black carbon, or soot.

Greenhouse gases, most prominently carbon dioxide, warm the planet by trapping infrared radiation. A less-recognized, but important, climate forcing is that caused by aerosols, small particles emitted during the combustion of fossil fuel and biofuel such as wood[2]. The additional anthropogenic aerosols reflect sunlight, and also act as cloud-condensation nuclei — particles on which water vapour can condense and form clouds, which reflect more sunlight if they are formed from greater numbers of droplets. Both processes cool the Earth's surface.

Black carbon, however, is a special aerosol because it also strongly absorbs sunlight (Fig. 1) — precisely the reason it looks black. The immediate effect of this absorption of sunlight is to warm the atmosphere and cool the surface. But because the Earth system as a whole absorbs sunlight rather than reflecting it, the overall result is a warming. Clouds may serve as a medium that strongly enhances this effect: if the atmosphere is heated as a result of the absorption of radiation, clouds may dissolve, which would probably constitute a further net warming. Aerosols quickly settle through gravity and are washed out by precipitation. Their typical lifetime in the lower atmosphere is thus relatively short (up to one week), so they are concentrated near their sources. The pattern of the forcing by anthropogenic aerosols thus reflects their main source regions.

Jones *et al.*[1] now identify the pattern of surface warming produced by anthropogenic black carbon in the observational record for the second half of the twentieth century. The analysis involved performing a set of climate-change simulations for the twentieth century, using a coupled atmosphere–ocean general circulation model and considering various combinations of individual forcings (greenhouse gases, aerosols including black carbon, ozone and land-use changes, as well as natural forcings such as volcanic emissions and changes in solar irradiation).

The authors split the temperature responses as estimated using these simulations into four groups — temperature changes due to natural forcings; changes due to anthropogenic greenhouse gases; changes due to other anthropogenic factors (aerosols other than black carbon, ozone, and land-use alteration); and changes due to black carbon. The 'detection and attribution' method to identify a temperature signal due to a specific forcing was then applied to try to discern the corresponding simulated patterns of temperature change in the observational record.

Focusing on the second half of the twentieth century (1950–99), Jones *et al.* find that natural forcing did not contribute significantly to the temperature trends, whereas all three groups of anthropogenic forcings did contribute significantly. This was previously known for the warming by greenhouse gases and the relative cooling by aerosols. But Jones *et al.* for the first time show that black carbon has warmed Earth by a statistically significant amount.

Their study[1] is particularly timely given the recent revival of discussion about whether control of black-carbon emissions might help to mitigate global warming. The scientific debate on this topic focuses on the net effect of a reduction in anthropogenic black carbon because, in addition to the warming caused by absorption of sunlight, black carbon may affect climate by other means. When mixed with other aerosols, black-carbon aerosols may serve as cloud-condensation nuclei, altering cloud reflectivity and probably having a cooling influence. By contrast, when deposited on snow, black carbon may act as a warming agent. The amount of sunlight reflected is reduced if a snow surface polluted by soot is less bright, an effect that may become stronger if the snow is heated so much that it melts.

These two contrasting effects of black carbon were not included in Jones and colleagues' model. However, if either the cooling effect by enhanced cloud reflectivity was large enough to compensate for the warming due to the absorption of sunlight plus potential dissolution of clouds, or the warming by pollution of snow was greater than the other effects, the simulated pattern of temperature change probably would not have been detectable in the observations. Thus, this study is also a notable contribution to the debate about which of black carbon's impacts on climate is most important.

In quantitative terms, considerable uncertainty remains. In Jones and colleagues' study, this is most manifest in the fact that a substantial warming of 0.21 kelvin due to black carbon was detected for 1950–99, whereas it is only 0.14 kelvin for a slightly shifted period, 1957–2006. The likely reasons are that this second period was more strongly affected by the 1991 eruption of Mount Pinatubo, and that the relative importance of black carbon diminished after the late 1990s in many regions. It is also noteworthy that other anthropogenic climate forcings had a much stronger impact on the global

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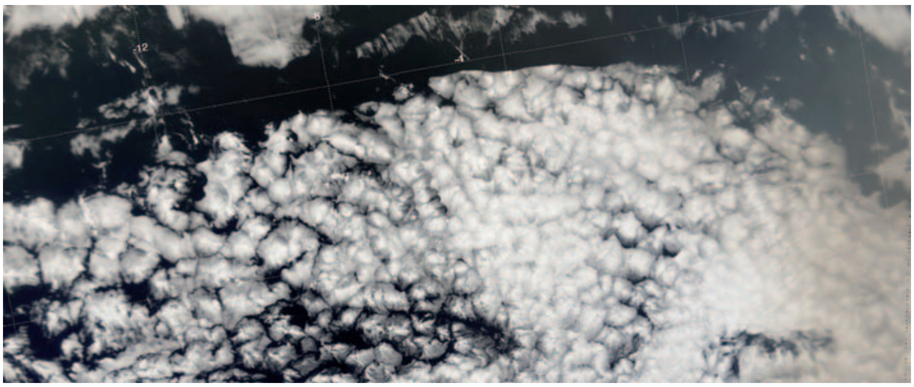

Figure 1 | Plume of soot aerosol overlying clouds above the eastern Atlantic Ocean. This image, taken by NASA's MODIS satellite instrument, shows a black-carbon plume (lower right) that emanated from biomass burning in west-central Africa. The aerosol absorbs radiation and so reduces the radiation being reflected back into space from the underlying clouds. Jones *et al.*[1] show that anthropogenic emissions of black-carbon aerosols have warmed Earth's climate to a statistically significant level over the period 1950–99. (Faint vertical lines are lines of longitude; the image is about 2,200 kilometres across.)

temperature — Jones *et al.* find a three to four times greater warming by greenhouse gases. In the context of mitigation of climate change, a further consideration is that black carbon is usually co-emitted with other aerosols, such as sulphate, that cool the climate. Reductions in total aerosol output might be desirable for public-health purposes. In the context of climate change, however, appropriate technical means would have to be applied to reduce the warming influence of black carbon but not the (probably larger) cooling effect of other aerosols.

Finally, it is also necessary to remember that anthropogenic aerosols, including black carbon, have a very short atmospheric lifetime compared with that of greenhouse gases. The gases typically have lifetimes of centuries and longer[3], compared with days for aerosols. This implies that, if implementation of emission-reduction strategies were indeed to be feasible, climate-change mitigation by cutting black-carbon emissions could be effective fast. But it also suggests that the relative importance of black carbon will in any case gradually diminish, given that greenhouse gases are long-lived and that they will continue to accumulate in the atmosphere as long as anthropogenic emissions of these gases continue. ■

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DEVELOPMENTAL BIOLOGY

A mouse is not a cow

Early cell-lineage decisions during embryonic development differ between mice and cows. This finding calls for a re-examination of developmental variations across mammals, but does not undermine use of the mouse as a model organism.

JANET ROSSANT

The mammalian blastocyst is a thing of beauty. Over a period of a few days after the union of an egg with sperm, the fertilized egg divides to generate this tiny hollow sphere of cells, which has a cluster of enclosed cells at one end of the fluid-filled cavity. The outer cells are called the trophectoderm and the inner cells are, inventively, named the inner cell mass. But when do cells commit to becoming one or the other, and how? Writing in *Developmental Cell*, Berg *et al.*[1] show that the answers to these questions are not the same for mice and cattle.

Pluripotency — a cell's ability to differentiate into all cell types of the body — is a common property of the inner cell mass (ICM) of all mammalian blastocysts and is always associated with the expression and function of the transcription factor Oct4. The trophectoderm, which later generates all of the specialized layers of the placenta, also expresses a number of lineage-restricted transcription factors, most notably Cdx2.

In mice, deletion of either the *Oct4* gene (also known as *Pou5f1*) or the *Cdx2* gene leads to the formation of abnormal blastocysts: ICM cells of *Oct4*-mutant blastocysts express trophectoderm markers and lose pluripotency[2], whereas the outer cells of *Cdx2*-mutant blastocysts express pluripotency markers such as Oct4 ectopically and fail to differentiate further down the trophectoderm lineage[3]. This suggests a model — albeit an overly simplistic one — whereby restricted expression of Oct4 and Cdx2 leads to reciprocal repression of the opposing lineage and establishes cell fate.

Berg *et al.*[1] asked whether this model applies to cell-fate decisions in cows. They find that, unlike in mice, Oct4 expression is not restricted only to the ICM during the early stages of cow blastocyst development. Instead, Oct4 is co-expressed with Cdx2 in the trophectoderm for some time after the beginning of blastocyst formation. This observation is consistent with previous reports and has also been made for pig and human embryos (for example, see refs 4, 5). Even in the mouse, Oct4 expression overlaps with Cdx2 expression during the late cleavage and early blastocyst stages of embryonic development, and is restricted to the ICM only by the fully expanded blastocyst stage[3].

So why is Oct4 expression maintained for longer in the cow trophectoderm than in its mouse equivalent? Through experiments involving cow blastocysts engineered to express a fluorescently tagged version of mouse *Oct4* (the mouse *Oct4–GFP* transgene), Berg and co-workers show that the factors that restrict Oct4 expression to the ICM are not available, or not functional, in the cow blastocyst (Fig. 1a). Cdx2 could be one such factor, but the authors' data suggest that this protein has a role only later during cow embryonic development. However, Berg and colleagues do not investigate whether the role of Cdx2 in restricting Oct4 expression is simply delayed in the cow embryo, nor whether Oct4 is ectopically expressed later during development in embryos treated to express reduced levels of Cdx2.

The paper[1] shows that a mouse *Oct4–GFP* transgene containing the bovine Oct4 regulatory elements is expressed in both the ICM and trophectoderm in fully expanded blastocysts of both the cow and the mouse (Fig. 1b). This suggests that Cdx2, which is active in mouse blastocysts, is not the only factor that affects the timing of Oct4 repression. It also indicates that bovine regulatory elements do not respond to the factors that downregulate Oct4 in mouse blastocysts.

Of the four evolutionarily conserved regulatory regions around the Oct4 locus, CR4 shows the most sequence divergence between the mouse and the cow. When Berg *et al.* replaced mouse CR4 with the cow version in the mouse *Oct4–GFP* construct, it behaved like the cow gene in the mouse blastocysts (Fig. 1c). Thus changes in both DNA

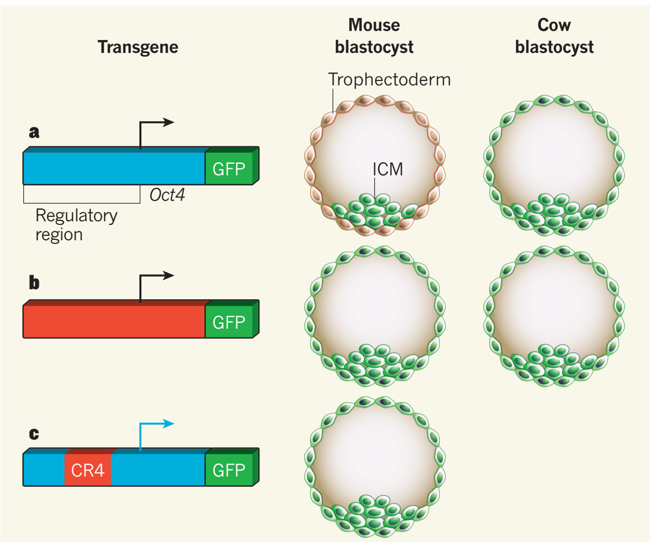

Figure 1 | Oct4 regulation in mouse and cow blastocysts. a, Berg *et al.*[1] find that the expression of a *GFP* fluorescent reporter transgene controlled by the regulatory elements of the mouse *Oct4* gene (blue) is restricted to the inner cell mass (ICM) in mouse blastocysts but not cow blastocysts. **b**, The same transgene, but containing the bovine Oct4 regulatory elements (red), is not restricted to the ICM in either cow or mouse blastocysts. **c**, The authors narrow down this effect of bovine regulatory elements to the CR4 region.