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Greenhouse cooling up high

Ralph J. Cicerone

CHANGES in the atmosphere's chemical composition are stimulating a lot of careful thought: how far will thinning of the ozone layer in the stratosphere proceed?; will radiative forcing, the growing greenhouse effect, accelerate in the troposphere? The consensus is that it is at least plausible that continued increases, due to human activity, in concentrations of carbon dioxide, methane and chlorofluorocarbons, will lead to measurable, if not damaging, environmental disturbances. Roble and Dickinson¹ now widen the debate by considering the effect of emissions of carbon dioxide and methane on the upper atmosphere. Dramatic consequences could ensue: the upper reaches may cool by tens of degrees and pressures will be reduced; concentrations of oxygen atoms will be reduced and those of hydrogen atoms increased.

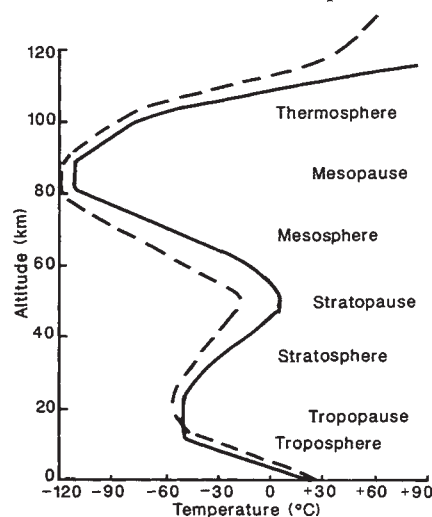
This is not a wild proposition, but rather a simple and direct one. The increased concentration of CO₂ in the stratosphere causes cooling because CO₂ is an efficient radiator to space of energy through infrared emissions (the obverse side of the greenhouse coin in which infrared activity causes tropospheric warming through radiation trapping). This is thought to be the surest consequence² of increased CO₂; this cooling should extend into the lower mesosphere³. The concentration of hydrogen atoms in the thermosphere is known to be sensitive to the amounts of water vapour and methane at the top of the stratosphere⁴.

Also, the link between the ground-level concentration of CH₄ and the stratospheric concentration of water vapour has been known for a while. Yet no one had looked at the very high atmosphere to see how its chemistry and physics might be affected by ground-level changes in CO₂ and CH₄. At times like these we see how fragmented are our scientific communities and our knowledge of the chemistry of the Earth's atmosphere.

The upper atmosphere is an arena for a rich variety of phenomena, much studied, such as visible aurorae over the polar regions, airglow optical emissions and electrical current flows due to charged particles. Commercial and military communication through radio waves reflected by the ionosphere, starting at the mesosphere, added to the scientific interest in the upper atmosphere. Intensive scientific research has focused on the atmosphere above about 100 km altitude. Instruments flown by satellites have probed the ionosphere and the upper atmosphere with remote sensing by ultraviolet and visible light and *in situ* mass spectrometers, as have ground-based

radars and optical airglow sensors. Its gross morphology (temperature, degree of ionization and chemical composition) and variations have been mapped. Atomic and molecular atmospheric processes such as those involved in photoionization of gases and recombination of ions have been studied in the laboratory, and macroscopic collective phenomena have been modelled and observed, such as gravity waves, plasma waves and electrical currents.

Numerical models of the ionosphere and upper atmosphere have progressed dramatically. Fluid dynamical, thermal balance and chemical kinetic equations are solved for winds and temperatures,



Variation of temperature with altitude in the atmosphere (solid line) revealing the various strata. Precise details vary with latitude and season. The temperature of the thermosphere rises to over 700 °C at 250 km. Above the mesopause, solar radiation ionizes atmospheric gases to create the ionosphere, divided into sub-layers D, at 90 km, E, at 110 km, F, above 200 km, defined by differing behaviour. Roble and Dickinson are the first to study the effect of CH₄ and CO₂ on the upper reaches of the atmosphere. The broken line shows the predicted effect of increased CO₂, which extends to cooling by 50°C at the top of the thermosphere.

given fairly basic input data for solar input and the major chemical species in air. Roble and Dickinson and their colleague, E.C. Ridley, and others can now calculate reasonably realistic dynamical patterns, ion types and numbers and temperature variations, for example, from solar-activity maxima to minima. Although some boundary conditions for the equations are still specified too rigidly, many of the phenomena are simulated amazingly well and the coupling of fluid dynamics, radiation, charged-particle dynamics and chemical reactions in

modern models is becoming very realistic.

Roble and Dickinson have introduced into such a model changes from the reference-state concentrations of CO₂ and CH₄ of the 1950s; they doubled and halved the observed values at the model's lower boundary (62 km). Higher concentrations for these gases cause the computed temperatures to fall by 50 K near 400 km altitude as compared to the reference state, whereas lower concentrations cause temperatures there to rise by 35 K. Concentrations of the dominant gas, oxygen atoms, fall by almost 40 per cent near 400 km when CO₂ and CH₄ are doubled and they rise by the same amount when the driving gases are halved. Hydrogen atom concentrations either rise by 50 per cent or fall by 20 per cent for the same changes.

The potential consequences of such perturbations are numerous. Roble and Dickinson mention some of them for the case of increasing CO₂ and CH₄: atmospheric drag on orbiting satellites will be reduced as the density of the upper atmosphere decreases and noctilucent clouds in the mesosphere will become more common as mesospheric water vapour quantities increase and temperatures decrease simultaneously. Ionospheric ion densities would be reduced near the E- and F-region peaks, and topside plasma scale heights will shrink. Global circulation and spatial morphology of the thermosphere may also change.

All of these and other perturbations must be analysed more thoroughly; Roble and Dickinson have made only the beginning. Various interactions in the system could lead to altered predictions; effects could be larger or smaller. For example, wave propagation and dynamical heating through the mesosphere and thermosphere could be altered as vertical temperature profiles change. One notable inconsistency in the paper leads to underestimated effects. The authors held the water-vapour mixing ratio fixed at 6 parts per million (p.p.m.) at 62 km; it should have risen to 9 p.p.m. when methane was doubled. Thus, hydrogen-containing species should increase in concentration even more than the authors predicted and hydrogen escape rates will increase (at least that part of the escape flux that is thermal^{5,6}) and the ratio of hydrogen/deuterium escape rates will change⁷. Further, these larger amounts of mesospheric H₂O and simultaneously lower temperatures will increase the regularity of noctilucent clouds⁸ and possibly alter D-region ion chemistry. It is also conceivable that the added water could lead to more cloud formation in the polar stratosphere, thus priming the system for ozone destruction⁹, but the size of this effect remains to be determined. In the thermosphere, as the H/O ratios must change by perhaps a factor of three, the redox state

of the high atmosphere would tend to reducing rather than oxidizing. Results could depend also on the phase of solar activity.

The driving perturbations and the proposed effects do deserve more study. CO₂ and CH₄ should be simulated separately to isolate mechanisms of change, the sizes of the changes in temperature, pressure and mixing ratios of chemicals should be compared to corresponding ranges of natural variability so that trends can be extracted from observations, and inconsistencies in the calculations should be removed (mesospheric concentrations of CO₂ were closer to 300 than to 330 p.p.m. in the 1950s). Also, further attention should be paid to low CO₂ and CH₄ amounts; concentrations of these species have been as low as 190–280 p.p.m. (ref. 10) and 0.35 p.p.m. (ref. 11) respectively in the past 160,000 years and well outside this range for CO₂ at earlier times.

Roble and Dickinson's report opens our eyes to further disturbances to the global atmosphere that are primarily due

to human activities. These may turn out to be manageable or even insignificant. But like the ozone hole over Antarctica, they may be large enough to be seen from Mars or some other vantage point in space. □

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1. Roble, R.G. & Dickinson, R.E. *Geophys. Res. Lett.* **16**, 1441–1444 (1989).
2. Mahlman, J.D. *Testimony to US Senate Committee on Commerce, Science and Transportation, Subcommittee on Science, Technology and Space* 8 May 1989, 122–139 (US Govt Printing Office, 1989).
3. Brasseur, G.P. & Hitchman, M.H. *Science* **240**, 634–637 (1988).
4. Ehhalt, D.H. *J. geophys. Res.* **91**, 2843 (1986).
5. Hunten, D.M. & Strobel, D.F. *J. Atmos. Sci.* **31**, 305–317 (1974).
6. Liu, S.C. & Donahue, T.M. *J. Atmos. Sci.* **31**, 2238–2242 (1974).
7. Yung, Y.L. *et al. J. geophys. Res.* **94**, 14971 (1989).
8. Thomas, G.E., Olivero, J.J., Jensen, E.J., Schroeder, W. & Toon, O.B., *Nature* **338**, 490–492 (1989).
9. Blake, D.R. & Rowland, F.S. *Science* **239**, 1129 (1988).
10. Barnola, J.M., Raynaud, D., Korotkevich, Y.S. & Lorius, C. *Nature* **329**, 408–414 (1987).
11. Chappelaz, J., Barnola, J.M., Raynaud, D., Korotkevich, Y.S. & Lorius, C. *Nature* (in the press).

GENE TARGETING

Tapping the cellular telephone

Mario Capecchi

GENE targeting means that we now have the potential to generate mice of virtually any desired genotype. In the first instance, standard recombinant DNA technology is used to alter a cloned DNA sequence of a chosen locus; the modified DNA is then introduced into a pluripotent stem cell derived from a mouse embryo, and homologous recombination between the exogenous and endogenous chromosomal sequence transfers the mutation to the genome. Microinjection of the stem cells containing the modified locus into mouse blastocysts is used to generate germ-line chimaeras. Finally, interbreeding of heterozygous siblings yields animals homozygous for the desired mutation. This technology has already been used to create germ-line chimaeras containing targeted disruptions in the *HPRT*, *abl*, *en-2*, *n-myc*, β -2 microglobulin, *igf-2* and *int-1* genes. Despite these achievements, we know very little about the recombination mechanisms underlying gene targeting in mammalian cells. On page 170 of this issue¹, Zheng and Wilson provide an elegant demonstration of an unexpected feature not predicted by any simple recombination model, namely that the gene targeting frequency in mammalian cells is independent of the number of target sequences present in the genome. The authors report that the efficiency of targeting into the dihydrofolate reductase gene (*DHFR*) was identical in a normal and in an amplified Chinese hamster-

ovary cell line containing 400 copies of the *DHFR* gene. Each *DHFR* gene in the amplified cell line is presumed to be equivalent as the *DHFR* enzyme and messenger RNA levels are proportional to the number of modified genes.

This observation is unexpected because the exogenous DNA sequence must search an enormous number of DNA sequences to find the cognate chromosomal sequence and participate in homologous recombination. In addition, the gene targeting frequency is independent of the number of copies per cell of exogenous DNA molecules introduced into the recipient cell². This means that the search for the cognate chromosomal DNA sequence is probably not rate-limiting. Furthermore, because this gene targeting occurs at readily detectable frequencies, there is probably a cellular machinery for the efficient sampling of chromosomal sequences.

Interestingly, as the authors point out, in yeast the gene targeting frequency seems to be proportional to the number of target sequences in the genome^{3,4}. For example, targeting into the ribosomal RNA genes, which are present at 140 copies per genome, is 100–200 times more frequent than into the *leu-2* gene. Gene targeting in yeast and mammalian cells also differs in a number of other respects. The frequency depends more on the extent of homology between the exogenous and chromosomal sequences in mammalian cells than it does in yeast^{5–7}:

in yeast this dependence is linear, but in mammalian cells it is exponential. On the other hand, the presence of homologous ends in the targeting vectors is apparently more critical for gene targeting in yeast than in mammalian cells^{8,9}. But in spite of these differences, the absolute frequencies of gene targeting in yeast and mammalian cells are surprisingly comparable. The main difference between the two cell types is that when they are exposed to exogenous DNA, yeast mediates recombination events that are almost exclusively homologous, whereas recombination events in mammalian cells are predominantly non-homologous. So the problem in mammalian cells is to identify homologous recombination in a vast arena of scattered, non-homologous recombination activity.

In any organism, gene targeting exploits the cellular machinery to mediate homologous recombination between exogenous and endogenous DNA. What is the normal function of this machinery? One function must be DNA repair, but evidence is accumulating that all the DNA sequences in a cell may be continually in communication with one another. In yeast, gene conversion occurs between cognate DNA sequences on homologous or non-homologous chromosomes with comparable frequency¹⁰. In humans, examples are turning up in which the normal gene seems to have been mutated by gene conversion as a result of a pseudogene residing on non-homologous chromosomes. If all DNA sequences within a cell are continually talking to each other, then the function of the communication machinery could extend well beyond DNA repair. For example, it might participate in the generation, maintenance and divergence of gene families and in the shuffling of exons between genes sharing stretches of homologous DNA sequences.

At present there is a flurry of activity to employ gene targeting in pluripotent stem cells as a means to define the function of a wide range of genes in the living mouse. Our increasing understanding of the gene targeting reaction itself will continue to improve the design of such experiments. □

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1. Zheng, H. & Wilson, J.H. *Nature* **344**, 170–173 (1990).
2. Thomas, K.R., Folger, K.R. & Capecchi, M.R. *Cell* **44**, 419–428 (1986).
3. Petes, T.D. *Cell* **19**, 765–744 (1980).
4. Szostak, J.W. & Wu, R. *Nature* **284**, 426–430 (1980).
5. Capecchi, M.R. *Science* **244**, 1288–1292 (1989).
6. Szostak, J.W. & Wu, R. *Plasmid* **2**, 536–554 (1979).
7. Smolik-Utlant, S. & Petes, T.D. *Molec. cell. Biol.* **3**, 1204–1211 (1983).
8. Orr-Weaver, T.L., Szostak, J.W. & Rethstein, R.J. *Proc. natn. Acad. Sci. U.S.A.* **78**, 6354–6358 (1981).
9. Mansour, S.L., Thomas, K.R. & Capecchi, M.R. *Nature* **336**, 348–352 (1988).
10. Robertson, J.S. & Petes, T.D. *Proc. natn. Acad. Sci. U.S.A.* **82**, 3550–3554 (1982).