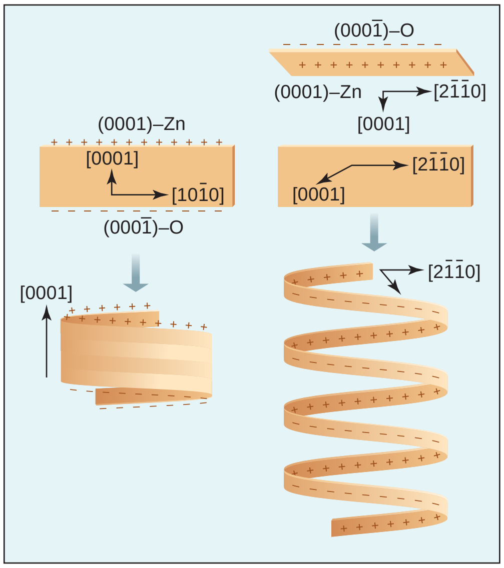
growth by serving as a nucleation site that promotes the anisotropic crystallization (*2*).

The long-range forces that direct nanoribbon coiling are electrostatic (see the figure). The wurtzite ZnO crystal structure consists of alternating stacked planes of tetrahedrally coordinated Zn^{2+} and O^{2-} ions oriented perpendicular to the *c* axis of the crystal. An uncompensated (0001) surface of the unit cell can consist of exposed zinc, giving rise to a net positive charge. The $(000\bar{1})$ surface exposes oxygen, giving rise to a net negative charge. In most materials, these charged surfaces are highly unstable and rapidly undergo reconstruction or rearrangement to neutralize the net charge. The situation for ZnO nanoribbons, however, is different, and uncompensated charged (0001)-Zn and $(000\bar{1})$-O surfaces are relatively stable (*8*). The growth direction determines which nanoribbon surfaces will exhibit these charged faces and can be controlled synthetically. Therefore, the third requirement for nanoribbon coiling relates to the nanoribbon growth direction. If the nanoribbon grows in the $(2\bar{1}\bar{1}0)$ direction, the (0001)-Zn and $(000\bar{1})$-O surfaces will be exposed orthogonal to the nanoribbon plane (*6*). These nanoribbons form helices with the positive charged surface orienting toward the interior of the ring and the negative charge toward the outside. If the nanoribbon grows in the $(10\bar{1}0)$ direction, the (0001)-Zn and $(000\bar{1})$-O surfaces orient in the plane of the nanoribbon, perpendicular to the growth direction. This is the orientation necessary to induce the observed coiling process (*2*). Because the nanoribbon coils back upon itself, the positive surface contacts the negative surface and minimizes the electrostatic charge on the nanoribbon.



Self-coiling nanoribbons. The structure of ZnO nanocoils depends on the crystallographic orientation of the charged (0001)-Zn and $(000\bar{1})$-O surfaces in the ribbon. **(Left)** When the (0001) planes extend along the ribbon edge, the compact cylindrical structure results. **(Right)** When the width of the ribbon exposes the charged planes, electrostatic repulsion between coiled segments directs the formation of extended helices.

Kong *et al.* have also imaged an extraordinary epitaxial sintering between the coiled wires. Under high-resolution transmission electron microscopy, neighboring nanoribbons appear to interface in the cylinder wall with atomic precision. Therefore, the polar interactions between the oppositely charged ribbon edges provide not only a long-range force that induces the ribbons to wrap back upon themselves, but also a short-range "zippering" effect in which charge appears to be most effectively neutralized by epitaxial interfacing between the (0001)-Zn and $(000\bar{1})$-O surfaces.

New materials chemistry and synthetic approaches—for example, high temperature, new precursors, additives, surfactants, and various growth media—continue to surprise us with unexpected results. The self-coiling ZnO nanoribbons presented here demonstrate the complexity that nature can offer and provide a glimpse of outstanding problems remaining in materials science. Compared to living systems—which are self-assembled "factories" of macromolecular building blocks, with not only secondary structure, but tertiary and quaternary complexity—these coiled ZnO nanoribbons are extremely simple. However, in the context of our ability to understand and attempt to replicate in artificial inorganic materials–based systems the structural complexity found in natural systems, the self-assembly of coiled ZnO nanoribbons represents a significant milestone and advance in both our fundamental understanding of and continued improvement in synthetic capabilities.

References

1. Z. W. Pan, Z. R. Dai, Z. L. Wang, *Science* **291**, 1947 (2001).
2. X. Y. Kong, Y. Ding, R. Yang, Z. L. Wang, *Science* **303**, 1348 (2004).
3. S. Amelinckx *et al.*, *Science* **265**, 635 (1994).
4. S. T. Lee, N. Wang, C. S. Lee, *Mater. Sci. Eng.* **A2862**, 16 (2000).
5. T. Hanrath, B. A. Korgel, *Adv. Mater.* **15**, 473 (2003).
6. X. Y. Kong, Z. L. Wang, *Nano Lett.* **3**, 1625 (2003).
7. X. D. Bai, E. G. Wang, P. X. Gao, Z. L. Wang, *Appl. Phys. Lett.* **82**, 4806 (2003).
8. Z. L. Wang, X. Y. Kong, J. M. Zuo, *Phys. Rev. Lett.* **91**, 185502 (2003).

ATMOSPHERIC SCIENCE

The Complex Interaction of Aerosols and Clouds

Hans-F. Graf

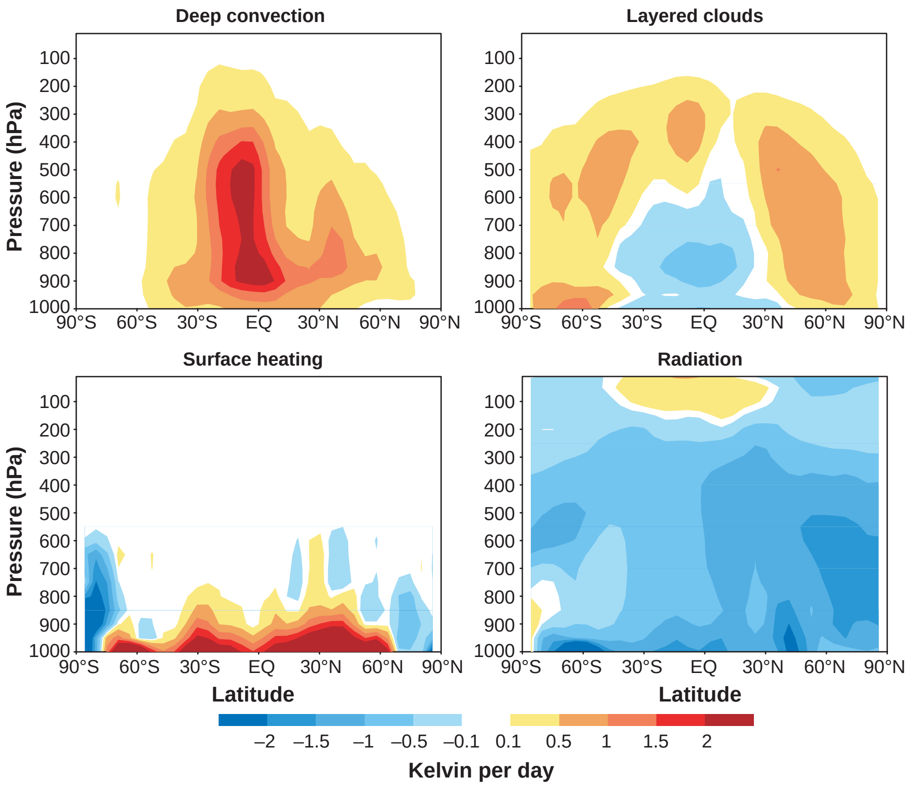
Aerosols have an important effect on atmospheric chemistry throughout the troposphere and lower stratosphere. They influence the radiative budget of Earth directly and indirectly by the modification of the cloud droplet size spectrum and precipitation at the surface (*1*). Researchers are beginning to incorporate these effects into the most sophisticated climate models for shallow clouds. This is because aerosol-cloud interactions are seen as one of the most important single forces that drive climate change, but there are big uncertainties in the current understanding of these processes. Two reports on pages 1342 and 1337 of this issue concern the interaction of aerosols in smoke from biomass burning with clouds in Amazonia, describing additional effects that potentially have significant impact on climate at the regional to continental scale. Koren *et al.* (*2*) report on the suppression of boundary layer clouds (BLC, shallow clouds that form on top of the turbulent planetary boundary layer, which is typically some 100 m to 1 or 2 km thick, often called "fair-weather clouds") in smoky areas during the dry season, and Andreae *et al.* (*3*) study clouds that appear to emit smoke during the transition between the dry and the wet season in Amazonia**.**

Koren *et al.* show that the primary effect of light-absorbing and light-scattering aerosols is to decrease the supply of water from the forest canopy. This decrease occurs because of surface cooling and stabilization of the turbulent boundary layer. At the same time, the temperature of the aerosol layer increases and, together with the competition of the hygroscopic aerosols for water vapor, this prevents the formation of BLC. Hence, the cooling of

---

The author is in the Department of Geography, Centre for Atmospheric Science, University of Cambridge, Cambridge CB2 3EN, UK, and at the Max-Planck-Institute for Meteorology, Hamburg, Germany. E-mail: hfg21@cam.ac.uk

CREDIT: PRESTON HUEY/*SCIENCE*



The hot zone. Winter heating rates from the ECHAM4 (*9*) climate model. (**Bottom left**) Solar radiation heats the surface, and this heat is distributed to the planetary boundary layer by turbulent motions. (**Bottom right**) Radiative processes lead to effective cooling in the troposphere, where longwave irradiance dominates absorption of shortwave radiation. Only in the tropical stratosphere does absorption of solar radiation in the ozone layer results in weak heating. (**Upper right**) Radiation and latent heat release connected to layered clouds lead to slight warming in large parts of the troposphere, but not in the lower tropical troposphere. (**Upper left**) The main positive energy source in the troposphere is the latent heat released from precipitating deep convective clouds, the tropical "hot towers."

Earth's surface is reduced to less than half of the smoke effect alone. Once aerosol pollution in a stably stratified atmosphere is strong enough, its radiative forcing may be reduced by a negative feedback loop with BLC formation.

Andreae *et al.* report that deep convective clouds (DCC, convective clouds that have a larger vertical than horizontal extent, reaching depths of 1 or 2 to more than 10 km, and sometimes may even penetrate into the lower stratosphere) can be an effective means of tracer transport from the smoke-polluted lowest troposphere to the upper troposphere and the tropopause region. Rain formation is not affected at low pollution, but where pollution is heavy, rainfall is significantly reduced and the convective transport of pollutants is enhanced. Pollution, once it passes a critical threshold, produces its own transport path to higher atmospheric layers if the potential of deep convection is given. In Amazonia, this results in clouds that appear to be generating their own layers of smoke, as reported by Andreae *et al.* (*3*).

Although these two reports concentrate on aerosols from biomass burning in Amazonia, the importance of their findings may well go beyond this specific case. Other aerosol types cause different effects on clouds, depending on the background situation and on the aerosol properties and mixing. Although insoluble, many mineral dust particles also act as condensation nuclei. They are, in addition, effective nuclei for ice formation and intense precipitation, and thus will ultimately influence cirrus cloud formation. Large ice nuclei and many small condensation nuclei can lead to the suppression of heterogeneous freezing, with the result that many small droplets remain liquid down to temperatures at which homogeneous freezing occurs (*4*). Small ice nuclei may have the adverse effect of increasing the rainfall rate from single clouds, which is the principle of cloud "seeding." The vertical transport of pollutants may be even more effective in the dryer subtropics and higher latitudes, where less water vapor may prevent the formation of precipitation and washout at lower aerosol concentrations. If precipitation is suppressed in DCC, more water vapor is injected into the upper troposphere from the cloud tops, and this influences cirrus cloud formation and even stratospheric water content (*5*).

If formation of warm rain is suppressed in the polluted DCC, mixed water-ice clouds become more common—and these produce lightning. Lightning may induce wildfires and thus more smoke, and it certainly increases the production of nitrogen compounds in the free troposphere relevant to atmospheric chemistry. Aerosols will have a bigger impact on clouds over the continents because the contribution of sea salt to the aerosol mixture over the oceans provides a wider spectrum of cloud droplet size (*6*). However, this is highly dependent on the production and vertical transport of sea salt particles to the cloud base and, hence, on wind and turbulent mixing in the planetary boundary layer.

One aspect has been overlooked so far: Deep tropical convection and the formation of rainfall lead to the release of enormous amounts of latent heat, which drives the general circulation of the atmosphere. The contribution of surface heating, radiative processes, and latent heat release in the mean over latitude belts proves that the only strong source of heating in the tropical free troposphere is the latent heat released from the tropical "hot towers" (see the figure). If aerosols, mainly from biomass burning in the tropics, affect the efficiency of precipitation and latent heat release in these latitudes, one must also expect changes in the general circulation of the atmosphere, namely of the tropical systems of Hadley and Walker circulation. The only global sensitivity study with a simple parameterized aerosol effect on warm (that is, excluding the ice phase) rain formation in deep convective clouds (*7*) in fact showed significant shifts in the tropical circulation and rainfall patterns.

Depending on vertical profiles of temperature, humidity, and wind shear, aerosols may produce different effects in DCC and BLC. The cloud-aerosol interaction is a nonlinear process and can lead to (multiple) bifurcation in the routes of cloud development. The suppression of warm rain below a weak temperature inversion may be enough to prohibit further vertical development of the cloud, whereas a temperature lower by a few degrees Celsius would allow freezing and the formation of mixed-phase precipitation. The released latent heat could then allow the cloud to break through the stable layer and further development of the cloud. Cloud-aerosol interaction is tied to critical values and potentially has strong effects on many relevant processes. Therefore, changes on the scale of individual aerosol particles lead to changes in cloud dynamics, regional cloud fields, and large-scale atmospheric energetics. The process of formation of BLC in climate models must include the effects of aerosols on radiation, on turbulent mixing, and on evapotranspiration from surface and vegetation canopies. These phenomena have very short time scales, which may make it necessary to include time dependence instead of quasi-equilibrium. The variability of aerosol and background properties, and their impact on cloud formation and development, puts a big question mark on the usefulness of observation-based statistical parameterizations in global models. Because there is no reasonable "mean" influence of aerosols on clouds, aerosol-cloud interactions must be parameterized at the process level, including microphysics and chemistry.

Current climate models operate with vertical resolutions of more than 1 km in the free troposphere, implying temperature steps between the model layers on the order of at least 6 to 7 K. This is not enough to account for the complexity of DCC and their interaction with different kinds of aerosols. In the past, it was common practice to use simplified mass flux schemes as a proxy of DCC, describing one mean DCC and a coverage factor in a single column of a global climate model. DCC did not contribute to radiative effects, and the microphysics in the model were rudimentary at best. This approach underestimated by far the importance and complexity of DCC. Currently several scientific communities are trying to improve their deep convection modeling (*8*), but it is not yet clear which additional effects will finally go into the standard climate (and weather forecasting) models. Will it be simple "spectral" parameterizations that are adjusted to observations, or will it be a "superparameterization" where a comprehensive cloud-resolving model including microphysical processes is used to describe DCC? In any case, the current vertical resolution is not sufficient and must be improved. Given the wide spectrum of impacts, it would be wise to devote at least as many research and computer resources to the problem of DCC and their interaction with aerosols as are given, for example, to radiative processes or atmospheric chemistry.

References

1. V. Ramanathan, P. J. Crutzen, J. T. Kiehl, D. Rosenfeld, *Science* **294**, 2119 (2001).
2. I. Koren, Y. J. Kaufman, L. A. Remer, J. V. Martins, *Science* **303**, 1342 (2004).
3. M. O. Andreae *et al.*, *Science* **303**, 1337 (2004).
4. D. Rosenfeld, W. L. Woodley, *Nature* **405**, 440 (2000).
5. S. Sherwood, *Science* **295**, 1272 (2002).
6. D. Rosenfeld, R. Lahav, A. Khain, M. Pinsky, *Science* **297**, 1667 (2002).
7. F. J. Nober, H. F. Graf, D. Rosenfeld, *Global Planet. Change* **37**, 57 (2003).
8. W. K. Tao, D. Starr, A. Hou, P. Newman, Y. Sud, *Bull. Am. Meteorol. Soc.* **84**, 1055 (2003).
9. E. K. Roeckner *et al.*, Max-Planck-Institut für Meteorologie, Report No. 218 (Hamburg, Germany, 1996).

MOLECULAR BIOLOGY

HNFs—Linking the Liver and Pancreatic Islets in Diabetes

Rohit N. Kulkarni and C. Ronald Kahn

Type 2 diabetes is a complex and heterogeneous disease caused by both environmental and genetic factors. The pathophysiology of the common polygenic form of type 2 (late-onset) diabetes results from early-onset insulin resistance coupled with functional defects in insulin secretion by pancreatic islet β cells. However, the precise factors leading to this disease are not known. In contrast, the monogenic form of diabetes—maturity-onset diabetes of the young (MODY)—primarily results from defects that affect the functioning of islet β cells. Of the six known forms of MODY, one form (MODY2) is due to mutations in the glucokinase gene and the others are secondary to mutations in genes encoding β-cell transcription factors. MODY4 and MODY6 are caused by mutations in genes encoding the pancreatic homeodomain transcription factor (PDX-1) and a transcription factor required for the normal development of pancreatic islets, NeuroD1/BETA2, respectively. Three forms of the disease—MODY1, MODY3, and MODY5—are caused by mutations in genes encoding the respective hepatocyte nuclear family (HNF) transcription factors HNF4α, HNF1α, and HNF1β (*1*). On page 1378 of this issue, Odom *et al.* (*2*) report their genome-scale analysis of the genes regulated by three HNF transcription factors in liver and pancreatic islet tissue from human donors. Their findings suggest that defects in one of these transcription factors, HNF4α, may contribute to late-onset type 2 diabetes.

By regulating the expression of specific groups of genes, transcription factors define specificity and maintain tissue diversity in most organisms, including mammals. The HNF transcription factors regulate the development and function of the liver and of other tissues, including pancreatic islets. Three HNFs—HNF1α, HNF4α and HNF6—are known to work cooperatively in a connected network in liver cells (hepatocytes), but their relative importance in human pancreatic islet β cells has not been ascertained. In the new work, Odom *et al.* combined chromatin immunoprecipitation assays with promoter microarrays to systematically identify the transcriptional regulatory circuits of HNF1α, HNF4α, and HNF6 in liver and pancreatic islet tissue (*2*). They discovered that HNF1α and HNF6 bound to the promoters of target genes expressed in human hepatocytes and islets, consistent with the role of HNF1α in the regulation of hepatic and islet function (*3*, *4*). By contrast, HNF4α bound to the promoters of ~12% of the hepatocyte and islet genes represented on the microarray. HNF4α activated a much larger number of hepatocyte and β-cell genes than did HNF1α, suggesting that HNF4α has broad activities in these two tissues.

These findings gain significance in the light of recent reports describing a link between the HNF4α gene and late-onset type 2 diabetes. For example, a missense mutation (T130I) affecting a conserved amino acid in a DNA binding domain of the HNF4α gene is associated with late-onset type 2 diabetes in Japanese subjects (*5*). In addition, a haplotype of HNF4α is associated with increased insulin secretory capacity and substantially reduced disease risk in a group of Caucasians in the United Kingdom (*6*). Two independent studies, one in a Finnish population (*7*) and another in individuals of Ashkenazi Jewish origin (*8*), also report an association between the risk of type 2 diabetes and single nucleotide polymorphisms in the primary promoter of the HNF4α gene in pancreatic β cells.

The new work clearly shows HNF involvement in the transcriptional regulatory loops that control the activity of human hepatic and islet cells. However, further investigation is needed to identify the factors that switch on these transcriptional regulatory circuits and the mechanisms underlying temporal defects in these networks. It is

---

The authors are in the Department of Cell and Molecular Physiology, Joslin Diabetes Center and Department of Medicine, Harvard Medical School, Boston, MA 02215, USA. E-mail: rohit.kulkarni@joslin.harvard.edu