can then engage distinct protein modification pathways. While such a mechanism would be unusual, it is not completely unprecedented. Recent work on the eukaryotic signal recognition particle also points to the potential importance of nascent proteins folding within the ribosomal tunnel (*11*). Whatever the exact mechanism, the discovery of Zhang *et al.* that synonymous codon changes can so profoundly change the role of a protein adds a new level of complexity to how we interpret the genetic code.

References and Notes

1. S. Seppälä, J. S. Slusky, P. Lloris-Garcerá, M. Rapp, G. von Heijne, *Science* **328**, 1698 (2010).
2. F. Zhang. S. Saha. S. Shabalina. A. Kashina, *Science* **329**, 1534 (2010).
3. A. Kaji, H. Kaji, G. D. Novelli, *Biochem. Biophys. Res. Commun.* **10**, 406 (1963).
4. C. C. Wong *et al.*, *PLoS Biol.* **5**, e258 (2007).
5. R. Rai *et al.*, *Development* **135**, 3881 (2008).
6. M. Karakozova *et al.*, *Science* **313**, 192 (2006).
7. A. S. Kashina, *Trends Cell Biol.* **16**, 610 (2006).
8. T. Tuller *et al.*, *Cell* **141**, 344 (2010).
9. G. Cannarozzi *et al.*, *Cell* **141**, 355 (2010).
10. G. Kramer, D. Boehringer, N. Ban, B. Bukau, *Nat. Struct. Mol. Biol.* **16**, 589 (2009).
11. U. Berndt, S. Oellerer, Y. Zhang, A. E. Johnson, S. Rospert, *Proc. Natl. Acad. Sci. U.S.A.* **106**, 1398 (2009).
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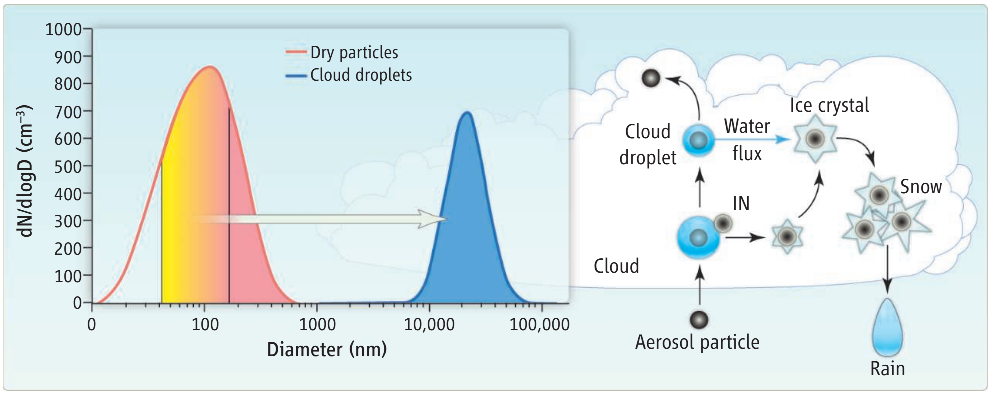
ATMOSPHERIC SCIENCE

Aerosols in Clearer Focus

Two studies provide insight into aerosol characteristics and cloud formation in regions with widely different aerosol concentrations.

Urs Baltensperger

Atmospheric aerosols—microscopic liquid or solid particles suspended in Earth's atmosphere—can harm human health (*1*) as well as influence climate by absorbing and reflecting solar radiation and modifying cloud formation (*2*). Our ability to fully describe the role of aerosols in the climate system, however, has been limited by uncertainty surrounding aerosol distribution and characteristics. Two papers in this issue help reduce this uncertainty by providing data from two regions where coverage was poor. On page 1488, Clarke and Kapustin (*3*) detail aerosol profiles from both relatively pristine and polluted areas over the Pacific Ocean. On page 1513, Pöschl *et al.* (*4*) report on aerosols and cloud formation over the Amazon, where conditions may approximate those that existed in preindustrial times.



Aerosols into cloud droplets. (Left) The red curve presents a typical number size distribution of dry aerosol particles from the mountain site Jungfraujoch, Switzerland (*11*). The red shaded area represents particles that are activated to cloud droplets at a very low supersaturation (0.1%); orange and yellow areas represent activated particles for increasing supersaturation up to 1%. Critical diameters for Jungfraujoch aerosols can vary slightly with water solubility, surface tension, or mixing state (*12*); however, size is the most important parameter (*13*). The blue distribution represents an example of the size distribution of cloud droplets measured at the Jungfraujoch (*7*). **(Right)** When ice crystals are formed, water vapor is transported from the cloud droplets to the ice crystals because of the lower saturation vapor pressure over ice than over liquid water. This eventually results in evaporation of the cloud droplets, and the radiative properties of the cloud are no longer influenced by the number of CCN but only by the properties of the ice nuclei (IN) and ice crystals.

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Health-related monitoring typically focuses on measuring aerosol mass concentrations, but a suite of additional variables comes into play when dealing with climate issues. Climate researchers, for instance, want to know how aerosols scatter or absorb light to calculate aerosol optical depth (AOD), an important measure of atmospheric transparency, which can directly affect climate. They also want to know how many cloud condensation nuclei (CCN) are available to form cloud droplets; the radiative properties of clouds are influenced by the CCN concentration, an effect known as the indirect aerosol effect on climate (*5*). Clarke and Kapustin present data on AOD and a CCN proxy (the number of particles surviving a 1- to 2-s exposure to 300°C) from about 1000 vertical profiles collected over 13 years. The data show that, in the Pacific regions most influenced by anthropogenic activities such as the burning of fossil fuels and biomass, AOD, CCN, and all other measured aerosol variables are higher—by more than an order of magnitude—than in cleaner regions. They conclude that increased aerosols from combustion are directly and indirectly influencing climate.

Andreae (*6*) argues that prehuman aerosol levels were very similar over continents and oceans. He concludes that, before the onset of human-induced pollution, the microphysical properties of clouds that formed over the continents resembled those that formed over the oceans. Today, however, cloud processes over most continents are shaped by the effects of human perturbation.

Pöschl *et al.* report on cloud formation over one region where preindustrial conditions may still occur: the Amazon during the wet season. They characterized aerosols in air masses that moved over the region for an 11-day period in March 2008. They found that the majority of CCN were composed of secondary organic material formed by oxidation of gaseous biogenic precursors (apparently from forest biota). They showed that aerosol-cloud interactions in this environment are distinctly different from those in polluted regions. In particular, they suggest that cloud formation over the pristine Amazon is limited by the number of available aerosol particles; in contrast, in polluted regions the formation of cloud droplets is limited by the velocity of the updrafts that carry particles into the

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higher atmosphere, where they "activate" into cloud droplets.

Pöschl *et al*. report that low aerosol concentrations resulted in cloud droplet number concentrations that were nearly independent of the updraft velocity of a convective cloud, and substantially higher supersaturation levels than found in polluted areas. This in turn meant that particles could activate to cloud droplets at a lower (smaller) critical diameter than in polluted areas. This modeling result is confirmed by measurements at the high-altitude (3580 m) station Jungfraujoch, Switzerland. There, the median of the activation diameter decreased from about 100 nm for particle concentrations (with diameter $D >$ 100 nm) greater than 100 cm^{-3} to about 65 nm for particle concentrations below 100 cm^{-3} (*7*). The effect of varying supersaturation is illustrated in the figure: At high supersaturation, a much higher fraction of the aerosol particles is activated to cloud droplets than at low supersaturation.

Pöschl *et al*. also report on ice nuclei (IN), particles that initiate ice formation at a temperature considerably above the freezing temperature of water (roughly –40°C). Supermicron-sized particles over the Amazon consisted mostly of primary biological aerosol particles that showed substantial IN activity. Precipitation occurs when these supermicron particles act as "giant" CCN (in warm rain) or IN (when ice formation is involved). The impact of aerosol particles on precipitation is different for warm and cold clouds. In warm clouds, increased CCN concentrations slow the conversion of cloud droplets into raindrops by nucleating larger concentrations of smaller drops, which are slower to coalesce into raindrops (*8*). In cold clouds, the situation is much more complex. The saturation vapor pressure is lower over ice than over liquid water; this transports water vapor from the cloud droplets to the ice crystals as soon as ice crystals form in liquid clouds (the so-called Wegener-Bergeron-Findeisen process) (*9*). This results in evaporation of the cloud droplets and a very low fraction of activated CCN (*10*). In these clouds, the radiative properties of the cloud are no longer influenced by the number of CCN but only by the properties of the IN and ice crystals. These processes are important for both the hydrological cycle and the radiative properties of clouds and clearly call for more research.

References

1. C. A. Pope, D. W. Dockery, *J. Air Waste Manage. Assoc.* **56**, 709 (2006).
2. IPCC, *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon et al., Eds. (Cambridge Univ. Press, Cambridge, UK), www.ipcc.ch/ipccreports/ar4-wg1.htm (2007).
3. A. Clarke, V. Kapustin, *Science* **329**, 1488 (2010).
4. U. Pöschl *et al.*, *Science* **329**,1513 (2010).
5. S. Twomey, *J. Atmos. Sci.* **34**, 1149 (1977).
6. M. O. Andreae, *Science* **315**, 50 (2007).
7. S. Henning *et al.*, *Tellus* **54B**, 82 (2002).
8. D. Rosenfeld *et al.*, *Science* **321**, 1309 (2008).
9. W. Findeisen, *Meteorol. Z.* **55**, 121 (1938).
10. B. Verheggen *et al.*, *J. Geophys. Res.* **112**, D23202 (2007).
11. E. Weingartner, S. Nyeki, U. Baltensperger, *J. Geophys. Res.* **104**, 26809 (1999).
12. G. McFiggans *et al.*, *Atmos. Chem. Phys.* **6**, 2593 (2006).
13. U. Dusek *et al.*, *Science* **312**, 1375 (2006).

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BIOCHEMISTRY

A Never-Ending Story

Britt-Marie Sjöberg

Revealing another way cells make DNA building blocks, this time with manganese.

More than 50 years ago, Reichard and colleagues elucidated how cells make their DNA building blocks—the deoxyribonucleotides or dNTPs (*1*). They found that the enzyme ribonucleotide reductase (RNR) converts ribonucleotides (RNA building blocks) to corresponding dNTPs. One would expect that such a central pathway for all living cells would be meticulously mapped by now. Yes—and no. Researchers have described several classes and subclasses of RNRs (see the figure) that appear to have the same evolutionary origin (*2*–*5*), but involve different chemical cofactors, and so enable cells to construct dNTPs under different environmental conditions. Whenever the field seems settled, however, fascinating new aspects appear (*1*, *2*). On page 1526 of this issue, Boal *et al*. (*3*) report crystal structures of RNR complexes from the bacterium *Escherichia coli* that, together with earlier studies, confirm and neatly illuminate yet another way cells can construct dNTPs, this time with the help of manganese (Mn).

Early researchers initially identified two classes of RNR: class I, which is characterized by a nonheme diiron center and a protein-derived tyrosyl radical (Fe^{III}_2-Tyr•); and class II, which involve the vitamin B_{12} coenzyme 5′-deoxyadenosylcobalamin (AdoCbl). Both of these RNR classes operate when oxygen is present (aerobic conditions). Later, investigators identified an anaerobic class III RNR, which involves a glycyl radical cofactor (Gly•) generated by an iron-sulfur cluster that cleaves S-adenosylmethionine (AdoMet). Despite structural differences and the involvement of different cofactors (see the figure), all RNR classes have a common origin and generate a transient thiyl radical (Cys•) in the active site.

In 1988, investigators isolated a Mn–dependent RNR from *Corynebacterium ammoniagenes* (*6*). It was not recognized as its own class, however; gene sequencing classified it as part of RNR class Ib, a subclass of class I. In addition, the role of Mn was unclear, since the new RNR was active in vitro with an iron cofactor (Fe^{III}_2-Tyr•) (*7*). Now, Boal *et al*., together with Cox *et al*. (*8*), highlight the importance of the Mn form of the class Ib RNR in *C. ammoniagenes* and *E. coli*. The work also highlights the role of the protein NrdI, a flavodoxin that is a crucial player in the formation of Mn-RNR. NrdI is encoded in the same operon as NrdE and NrdF, the two components of the known class Ib RNR. NrdI is essential for the formation of Tyr• in Mn-NrdF (*9*).

The NrdIs are unusual flavodoxins. They are smaller than classical flavodoxins, with one notable variation in the loop that interacts with the flavin mononucleotide (FMN) (*3*, *10*). Recent structures for NrdIs from *Bacillus anthracis* (*10*), *Bacillus cereus* (*11*), and *E. coli* (*3*) cover the three redox forms of FMN (oxidized, semiquinone, and hydroquinone). Whereas the two redox potentials of classical flavodoxin differ by more than 100 mV (*12*), *E. coli* NrdI maintains two almost identical redox potentials (*9*). The semiquinone form is thus transient in *E. coli* NrdI, which probably functions as a two-electron donor. Several NrdIs differ markedly from classical flavodoxin in their isoelectric points (pIs). Whereas flavodoxins have very similar pIs (4.5 ± 0.6), those of *E. coli* and *C. ammoniagenes* NrdIs are much higher, and *B. cereus* and *B. anthracis* NrdIs have pIs like those of flavodoxins (*11*). Both *B. cereus* and *B. anthracis* NrdIs

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