mean that more recipients received injections containing Aβ seeds. However, it is important to stress that the subjects of this study died of CJD, not of Alzheimer's disease. Whether those with Aβ lesions would eventually have manifested clinical Alzheimer's disease cannot be known with certainty.

Continued surveillance of surviving c-hGH recipients will be essential to determine whether they are at unusually high risk of developing Alzheimer's disease. An earlier study[8] suggests that, as of 2008, c-hGH-treated patients in the United States are not more likely to develop Alzheimer's disease than people in the general population, although an incubation period of 30 years or more is possible. Interestingly, the subjects in the current study lacked tauopathy, an essential feature of Alzheimer's disease[6]. Whether tauopathy would have emerged over a longer incubation period is unknown.

This transmission of Aβ pathology occurred in the uncommon context of long-term c-hGH therapy. So far, there is no indication that Alzheimer's disease can be transmitted between people under ordinary circumstances. Furthermore, the replacement of c-hGH by genetically engineered growth hormone has eliminated the risk that growth-hormone treatment will inadvertently transmit brain disorders between humans. However, it is conceivable that the human transmission of Aβ seeds can occur under other conditions, which must now be carefully defined. Jaunmuktane and colleagues' findings should stimulate new research in this direction, and, more generally, will inspire further investigation into the mechanisms that govern the formation, transmissibility and toxicity of misfolded protein seeds in neurodegenerative diseases. ■

Mathias Jucker *is at the Hertie Institute for Clinical Brain Research, University of Tübingen, and at the German Center for Neurodegenerative Diseases (DZNE), D-72076 Tübingen, Germany.*
Lary C. Walker *is at the Yerkes National Primate Research Center and Department of Neurology, Emory University, Atlanta, Georgia 30322, USA.*
e-mails: mathias.jucker@uni-tuebingen.de; lary.walker@emory.edu

1. Gajdusek, D. C. *Science* **197,** 943–960 (1977).
2. Brown, P. *et al. Emerg. Infect. Dis.* **18,** 901–907 (2012).
3. Prusiner, S. B. *N. Engl. J. Med.* **310,** 661–663 (1984).
4. Jaunmuktane, Z. *et al. Nature* **525,** 247–250 (2015).
5. Will, R. G. *Br. Med. Bull.* **66,** 255–265 (2003).
6. Holtzman, D. M., Morris, J. C. & Goate, A. M. *Sci. Transl. Med.* **3,** 77sr1 (2011).
7. Jucker, M. & Walker, L. C. *Nature* **501,** 45–51 (2013).
8. Irwin, D. J. *et al. JAMA Neurol.* **70,** 462–468 (2013).
9. Prusiner, S. B. *Annu. Rev. Genet.* **47,** 601–623 (2013).
10. Eisele, Y. S. *et al. Science* **330,** 980–982 (2010).
11. Tousseyn, T. *et al. J. Neuropathol. Exp. Neurol.* **74,** 873–888 (2015).
12. Ye, L. *et al. Nature Neurosci.* http://dx.doi.org/10.1038/nn.4117 (2015).

ATMOSPHERIC SCIENCE

Sea-spray particles cause freezing in clouds

Ice clouds in marine regions at high latitudes might form in warmer and drier air than was previously believed because of freezing induced by airborne particles that contain organic materials from ocean surface waters. SEE LETTER P.234

LYNN M. RUSSELL

The oceans cover two-thirds of Earth's surface and are almost entirely, and rather uniformly, composed of water and inorganic salts[1]. The remaining fraction of a per cent of ocean water contains organic material. This has a variable concentration in space and time[2] and is largely uncharacterized, but might be a key component in driving ice formation in the atmosphere. On page 234 of this issue, Wilson *et al.*[3] report that organic material concentrated in the topmost millimetres of the ocean has the essential crystal-forming properties needed to freeze water and form ice clouds in the atmosphere — a process called ice nucleation. The findings might help to refine predictions of future climate.

Ice formation in clouds is central to precipitation processes because it affects whether, when and where rain, snow or ice falls out of clouds. Climate models calculate the timing and location of ice clouds and the associated precipitation partly on the basis of the particle types and concentrations that are thought to be present in the atmosphere. For example, air temperature must drop to almost −40 °C, and the humidity relative to that at which ice can form at that temperature must be well above 100%, for water to freeze in the atmosphere when no ice-nucleating particles are present[4,5]. But different types of particle can promote freezing when the air is not as cold or as humid as that — by contact with, or immersion in, supercooled water droplets (that is, liquid droplets cooled to below the ideal freezing temperature), by condensation of water onto particles or by direct deposition of ice from water vapour on the particles (Fig. 1).

Wilson *et al.* provide evidence that marine particles could support ice-cloud formation at locations (or at times of the year) where dust is too sparse to freeze ice efficiently. To do this, they sampled surface seawater using a variety of

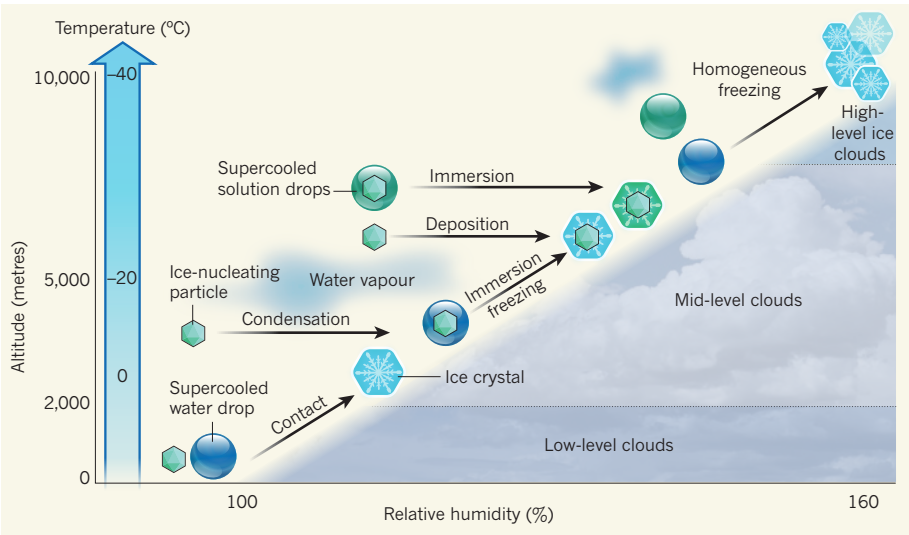

Figure 1 | Ice formation in clouds. The predominant processes for ice formation in the atmosphere depend on temperature (which changes with altitude) and the relative humidity with respect to that at which ice can form. In low-level mixed-phase clouds (composed of water droplets and some ice particles), freezing may occur most effectively when supercooled water droplets come into contact with ice-nucleating particles (INPs). In mid-level mixed-phase and ice clouds, water vapour condenses on INPs, or INPs become immersed in water droplets, after which ice crystals form. Ice crystals can also form when INPs are immersed in supercooled drops of solutions (of salts or of organic compounds, for example), or by direct deposition of ice on the particles. High-level ice clouds include ice that forms 'homogeneously' when supercooled droplets freeze or water vapour crystallizes in the absence of INPs. Wilson *et al.*[3] report that particles from the ocean surface can act as INPs. (Figure adapted from refs 4 and 5.)

techniques, used X-ray microscopy to chemically characterize organic material in the water, and observed droplet freezing (both *in situ* and in samples returned to the laboratory).

Bubbles bursting at the ocean surface incorporate some of this surface-ocean organic material into particles that are lofted into the atmosphere, and these particles may have a larger role in forming ice clouds than was previously calculated in climate models. Indeed, Wilson and colleagues show that, when the measured ice-forming abilities of organic materials are represented in a model[6] that calculates the effects of sea-spray particles in global atmospheric simulations, marine particles contribute more to ice nucleation in high-latitude regions, where airborne dust is sparse, than was previously thought. If these results are representative of airborne marine-derived particles around the world, the occurrence of ice clouds in climate simulations could change substantially. The authors' models suggest that the changes will be most evident at high latitudes that have few continents and little desert area, such as the northern Pacific and Atlantic oceans and the Southern Ocean.

Because few measurements of ice-nucleating properties have been taken from ocean surface layers, the model used by the authors necessarily extrapolates the global picture from a limited number of samples in the surface waters of the Arctic and the northern Pacific and Atlantic oceans. To refine things further, it will be necessary to determine the degree to which organic particles from surface waters of, for example, the Southern Ocean differ from marine particles sampled at other latitudes. The simulations could also be improved by characterizing the seasonal and biogeochemical drivers that change the freezing properties of marine organic material and the particles that it forms. Longer-term observations are needed to assess how year-to-year variability in weather and in ocean-nutrient availability affects the formation of organic material that induces freezing.

Wilson and co-workers' findings could also have implications for our understanding of how climate will change in the coming decades. For instance, as global warming occurs, ice clouds might form less frequently in warmer air near the ocean's surface, but stronger surface winds could produce more marine particles to initiate freezing. These two effects may cancel out each other. But if phytoplankton populations decline, then fewer organic ice-freezing particles could be formed, which would exacerbate the reduction in ice-cloud formation.

The authors' work also reveals that marine-derived particles containing organic material were part of the natural mixture of atmospheric particles that made ice freeze in pre-industrial times, but further work is needed to address fundamental questions about marine particles in general: how many of them form, and what fraction contains ice-freezing organic material? And how do surface winds, ocean ecosystems and the state of the sea change both of these quantities?

Finally, little is known about what controls the size and composition of particles formed as bubbles burst at the ocean surface, but understanding the basic physical processes involved is crucial. Limited measurements and semi-empirical parameterizations provide only a rough basis for climate models to calculate the distribution of such particles in the atmosphere. Satellite observations provide some constraints on the present-day distributions of airborne particles, but without an understanding of the mechanisms of ocean-particle formation, the accuracy and certainty of future and past contributions from marine particles to changing climate will continue to be limited. ■

Lynn M. Russell *is at the Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California 92093-0221, USA.*
e-mail: lmrussell@ucsd.edu

1. Holland, H. D. *The Chemistry of the Atmosphere and Oceans* (Wiley, 1978).
2. Hansell, D. A., Carlson, C. A., Repeta, D. J. & Schlitzer, R. *Oceanography* **22**(4), 202–211 (2009).
3. Wilson, T. W. *et al. Nature* **525,** 234–238 (2015).
4. Hoose, C. & Möhler, O. *Atmos. Chem. Phys.* **12,** 9817–9854 (2012).
5. Wendisch, M. & Brenguier, J.-L. (eds) *Airborne Measurements for Environmental Research: Methods and Instruments* (Wiley, 2013).
6. Burrows, S. M., Hoose, C., Pöschl, U. & Lawrence, M. G. *Atmos. Chem. Phys.* **13,** 245–267 (2013).

ASTROPHYSICS

Glimpse into a primitive stellar nursery

The first well-resolved images of local-galaxy stellar nurseries that are poor in elements heavier than helium give the best picture yet of the conditions in which stars may have formed in the early Universe. SEE LETTER P.218

ADAM LEROY

Astronomers dub elements heavier than hydrogen and helium 'metals', and these make up only trace amounts of all matter by mass. For example, about 2% of the interstellar matter in the neighbourhood of the Sun comprises metals, the most abundant of which are oxygen and carbon. These elements have a role in catalysing the birth of stars that is far out of proportion to their low abundance. On page 218, Rubio *et al.*[1] present the first well-resolved pictures of metal-deficient stellar nurseries found in a nearby dwarf galaxy, by recording the spectral lines emitted by carbon monoxide (CO). The results open up CO spectroscopic imaging as a diagnostic for exploring the relationship between metal content and star formation for substantially metal-deficient systems.

Stars form out of cold, dense clouds of molecular hydrogen (H_2). In these clouds, metals act as coolants, helping the gas to reach low temperatures and facilitating its collapse into pre-stellar condensations. Metals also form interstellar dust, which shields stellar nurseries from starlight that would otherwise break molecules apart and heat the gas.

These metals are produced in stellar interiors. When stars die and explode, some of the newly produced metals are mixed into the interstellar gas. Thus, successive generations of stellar birth and death lead to a gradual enrichment of heavy elements in the interstellar medium. These, in turn, aid the subsequent formation of new stars. Following this logic backwards, early generations of stars probably formed in stellar nurseries that contained few metals compared with the Milky Way or similar present-day galaxies. Thus, to understand the build-up of the first stars and galaxies, astronomers must measure how a dearth of metals (low metallicity) affects the star-formation process.

To study star formation in metal-poor gas, astronomers study the least-massive galaxies in the present-day Universe. These dwarf galaxies are not believed to be truly young, and so they are imperfect analogues of distant primordial systems. But because of a combination of their inefficient star-formation activity and weak gravity (exploding stars can blow heavy elements entirely out of a small galaxy), they are deficient in heavy elements. Therefore, researchers use them as local 'laboratories' to investigate how a lack of metals affects the formation of stars in interstellar gas clouds.

Direct observation of the H_2 that makes up most of the cold, dense gas in these clouds is difficult. This forces astronomers to observe molecular tracers that are mixed with the H_2, and whose spectral signatures are used to infer the abundance of H_2 indirectly. The workhorse tracer is CO, the second most abundant interstellar molecule[2]. CO survives in the interstellar medium mainly in regions