PHYSICAL CHEMISTRY

Ice niceties

The molecules in ice crystals normally form a hexagonal lattice, which is why all snowflakes are six-sided (pictured). But on page 218, Lupi *et al.* report that the tiniest ice crystals prefer a different arrangement — a finding that has implications for climate models (L. Lupi *et al.* *Nature* **551**, 218–222; 2017).

The authors used computational simulations to investigate how nanoscale ice crystals form from water. They found that a molecular arrangement consisting of randomly ordered layers of hexagonal and cubic arrays is the most thermodynamically stable arrangement in crystallites of up to 100,000 molecules.

The findings disagree with the classical theory of crystallite formation, which is used to predict the rates at which ice crystallites form in the atmosphere — a variable that influences cloud formation. The authors conclude that the classical theory must be corrected to improve climate and weather forecasts. [Andrew Mitchinson](#)

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OCEANOGRAPHY

Mixed up at the sea floor

Circulation of the ocean's densest waters modulates millennial-scale shifts in climate. Contrary to conventional wisdom, a study finds that the shape of the sea floor constrains where these waters rise towards the surface. [SEE ARTICLE P.181](#)

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A network of ocean currents known as the global overturning circulation has a central role in Earth's climate^{1,2}. The deepest branch of this circulation consists of cold, dense waters that originate from near Antarctica and spread northward, eventually rising towards the surface through turbulent mixing with overlying waters³. Over periods of hundreds to thousands of years, variations in the deep branch modulate oxygen supply and carbon dioxide storage in the deep ocean^{4,5}. Yet the pathways of the circulation remain uncertain because of a paucity of measurements in the deepest parts of the ocean^{3,6}. On page 181, de Lavergne *et al.*⁷ report that the shape of the sea floor, combined with intensification of turbulent mixing close to the ocean bed, requires these waters to return southward at a much

greater depth than was previously estimated^{3,6}.

The upper branch of the global overturning circulation has received particular attention because of its prominent role in heat transfer between the Southern and Northern hemispheres, and is the subject of an international monitoring effort¹. By contrast, there have been few direct measurements of the deep branch. Oceanographers rely instead on global inverse models, which use sparse measurements of the ocean's temperature, salinity and dissolved gases to estimate the deep branch's structure^{3,6}.

Partly because of these observational limitations, our conception of the deep branch has changed little since 1966, when oceanographer Walter Munk proposed that these waters sink at high latitudes and rise throughout the ocean interior⁸. As they rise, the waters become less dense through turbulent mixing with lighter

waters — a mechanism known as water-mass transformation. This mechanism is integral to theories of the deep branch's structure, comprehensive climate models and global inverse models^{6,9}.

However, the turbulent flows that facilitate mixing result from tides and other deep currents interacting with the rough sea floor, and tend to be most intense close to the bottom of the ocean¹⁰. Bottom-intensified mixing, combined with geothermal heating through the ocean bed, implies that water-mass transformation should be concentrated close to the sea floor¹¹. In turn, this suggests a pattern of circulation that involves deep waters rising near the sea floor, in contrast to Munk's model of waters rising throughout the ocean interior^{10,12} (Fig. 1).

De Lavergne and colleagues have investigated the implications of bottom-intensified turbulent mixing for the structure of the overturning circulation's deep branch. Globally, the shape of the sea floor varies gradually at depths greater than 2.5 kilometres (see Fig. 2 in the paper⁷). This allows waters that have a relatively small range of densities to access a disproportionately large fraction of the sea floor, and thereby undergo faster water-mass transformation than would otherwise occur. Using calculations that take into account bottom-intensified mixing, the authors show that the shape of the sea floor strongly favours water-mass transformation at a depth of about 4 km. Their results imply that the sea floor's