Linsky asserts, it predicts a temperature in much better agreement with the Colorado group's measurement.

"All the local interstellar clouds seem to be moving away from the Sco–Cen association," Bruhweiler told us. "The LIC appears to be part of an expanding complex of clouds on the boundary of a cavity about 700 light-years across, excavated by the stellar winds and supernova shock waves from the association of hot young stars at its center."

Bertram Schwarzschild

References

1. J. Linsky, S. Redfield, B. Wood, N. Piskunov, Astrophys. J. **528** (10 Jan. 2000). S. Redfield, J. Linsky, Astrophys. J., to be published (2000).
2. R. Lallement, P. Bertin, Astron. Astrophys. **266**, 479 (1992).
3. http://casa.colorado.edu/~sredfiel/ColoradoLIC.html.
4. M. Wolfire *et al.*, Astrophys. J. **443**, 152 (1995).
5. C.-H. Lyu, F. C. Bruhweiler, Astrophys. J. **459**, 216 (1996).

The Decreasing Arctic Ice Cover

New studies indicate that the Arctic Ocean's ice cover is about 40% thinner than it was 20 to 40 years ago, and the area of its perennial ice could be shrinking at a rate of about 7% per decade.

Ongoing monitoring of Earth's north polar region has been turning up numerous signs of change in its atmosphere, waters, and ice pack (see Physics Today, November 1998, page 17). Such studies have revealed that the Arctic ice mass is shrinking, but now, it seems, the rates of decline are much more rapid than previously thought.[1,2] Such changes are of concern because the polar region is expected to amplify any change in Earth's climate.

Ice thickness

The data on sea-ice thickness come primarily from submarine-borne instruments. In the 1990s the US Navy welcomed civilian scientists and their instruments aboard its Sturgeon-class submarines for five data-taking cruises in the Arctic. Sonar beams were directed upward from the subs to determine the ice draft—that is, the depth of sea ice below sea level. D. Andrew Rothrock, Yanling Yu, and Gary Maykut of the University of Washington have so far analyzed the data from the first three cruises (1993–97) and found that mean drafts in the central Arctic Ocean varied between 1 m and 3 m.

We don't know how these ice thicknesses compare to those in the 1980s because much of the submarine data remains classified. However, Rothrock, Yu, and Maykut found two publicly available data sets taken during naval cruises between 1958 and 1976. They looked for data taken at roughly the same locations and time of year as in the 1990 cruises; they found 29 such sites in roughly six geographical regions covering most of the deep-water portion of the Arctic Ocean. In each of those regions, the ice drafts had dropped, by amounts ranging from 0.9 to 1.8 m. The mean ice draft decreased 1.3 m, from 3.1 m to 1.8 m. (See the figure at right.) As noted in the report,[1] "The changes are striking both in the uniformity of their sign and in their magnitudes."

The 1990s data were all collected in the months of September and October while the 1958–76 data were taken during cruises ranging from July to October. One expects seasonal variation in the ice draft as summer heat melts some ice and winter freezing replenishes it. Rothrock, Yu, and Maykut used a model of this seasonal variation to adjust all the data to 15 September. In the accompanying figure, the circles represent the actual measurements and the colored symbols are the adjusted values.

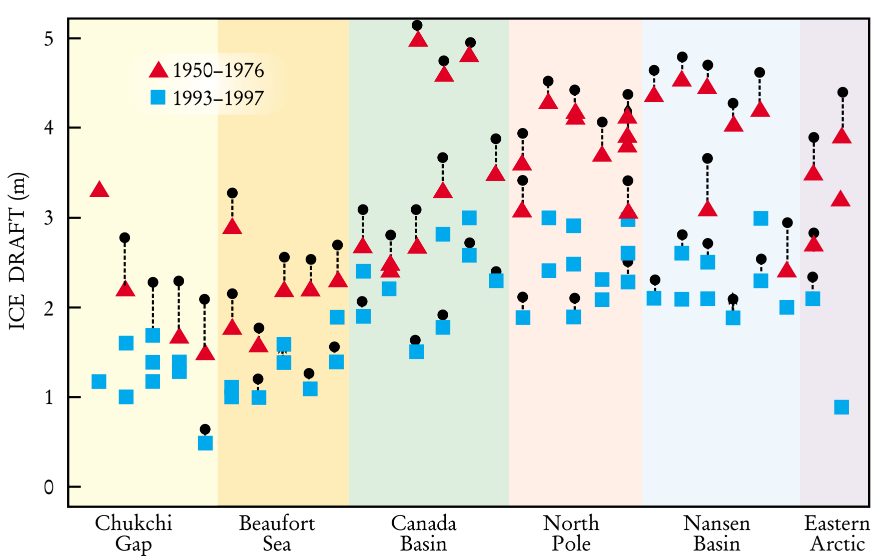
Other researchers have also studied trends in ice thickness, but their studies were more restricted in spatial extent.

Sea-ice coverage

The polar sea ice has been monitored since 1978 by satellite-borne sensors that detect low-frequency microwave radiation. Previous analyses of these microwave data found a drop of 3% per decade in the areal extent of the sea ice. Those results applied to the total ice, including both the perennial, or multiyear, ice—which doesn't melt in summer—and the more seasonal first-year ice. The area of multiyear ice alone was recently teased out of the same data by Ola Johannessen and his colleagues from the twin Nansen Environmental and Remote Sensing Centers, one in Bergen, Norway, and the other in Saint Petersburg, Russia.[2]

In theory, one can distinguish among multiyear ice, first-year ice, and open water based on the wavelengths of microwaves that each tends to emit. In practice, it's not so easy, largely because melting ice on the surface of multiyear ice, especially in summer, can confuse the readings. So Johannessen and his colleagues determined the extent of multiyear ice by looking only at the data from five winter months. From 1978 to 1998, the multiyear ice cover shrunk by 0.031×10^6 km^2/y, corresponding to a drop of 7% per decade, or more than twice the percentage decrease in total ice extent.

The Nansen group compared its data to ice thickness values deduced



Arctic ice thickness declined between 1958–76 (red triangles) and 1993–97 (blue squares). The ice drafts (thickness below the sea surface) were measured by sonar soundings from US Navy submarines. The triangles and squares represent data adjusted for season; circles are raw data points. (Adapted from ref. 1.)

by Russian scientists from the propagation through the Arctic ice of waves caused by ocean swells. The interannual variability of the ice-area and thickness data correlates well over the time period of the Russian measurements (1972–91).

What's causing the change?

Does the melting of the ice cap stem from a multidecadal cycle, or is it a downward trend? The years from 1989 through the 1990s, when the Arctic ice was found to be melting at a particularly rapid rate, were a period when a regional atmospheric circulation pattern known as the Arctic Oscillation (AO) was in an extreme phase, during which it tends to pump more warm air into the Arctic and blow more thick, multiyear ice out. Some wonder whether the downward trends in ice extent and thickness might be reversed if the AO swings back to a more normal state. Johannessen's team found that the North Atlantic Oscillation, which is correlated with the AO, accounted for 25% of the variability in the multiyear ice data.

On the other hand, some feel, the apparent melting may also result from the increased burden of anthropogenic greenhouse gases and tropospheric sulfate aerosols being added to the atmosphere. Konstantin Vinnikov of the University of Maryland and eight collaborators from seven other institutions recently conducted a comparison between the data on sea-ice coverage and the results of two global climate models that were simulating Earth's response to atmospheric contaminants.[3] Although one model underestimates the ice coverage, both seem to follow the observed temporal trends. Vinnikov and his colleagues found that the melting trends are greater than one would expect from natural variability as simulated by a 5000-year run of one of the models.

Whatever the cause, the thinning of the Arctic sea ice and shrinking of its coverage is a major climatic signal that needs to be better understood. To provide improved time series for the ice-draft data, Arctic researchers are hoping that the US Navy will find a way to declassify considerably more of the submarine sonar data covering the 1980s, and that the supporters of the Submarine Science Ice Experiment (the US Navy, the National Science Foundation, the Office of Naval Research, and NASA) will find a way to continue the data-gathering cruises.

BARBARA GOSS LEVI

References

1. D. A. Rothrock, Y. Yu, G. A. Maykut, Geophys. Res. Lett. **26**, 3469 (1999).
2. O. M. Johannessen, E. V. Shalina, M. W. Miles, Science **286**, 1937 (1999).
3. K. Y. Vinnikov, A. Robock, R. J. Stouffer, J. E. Walsh, C. L. Parkinson, D. J. Cavalieri, J. F. B. Mitchell, D. Garrett, V. F. Zakharov, Science **286**, 1934 (1999).

What Really Gives a Quantum Computer Its Power?

A closer look at quantum computation experiments in liquid-state nuclear magnetic resonance raises questions about what's really going on.

Quantum computers have been predicted to be exponentially faster than their classical counterparts for some computations, such as the factoring of large numbers. (See the article by Charles Bennett in PHYSICS TODAY, October 1995, page 24.) Whereas classical computers perform operations on information stored as classical bits, which can be in one of two discrete states, quantum computers perform operations on quantum bits, or "qubits," which can be put into any superposition of two quantum states.

Ideally, a quantum computer will have qubits that are isolated from their environment, so that there is sufficient time to perform computations before the qubits lose their coherence. To process the quantum information, researchers also need a way to control the interactions among the qubits. Experimenters are exploring various physical systems that may provide the necessary isolation and control for implementing a quantum computer, including trapped ions, cavity quantum electrodynamics, and nuclear magnetic resonance.

Experiments exploiting room-temperature liquid-state NMR have received much of the attention, and they have resulted in reports of quantum teleportation,[1] quantum searching,[2] quantum error correction,[3] and simulation of a quantum mechanical system.[4] Recently, however, a team of researchers in the UK and US—Samuel Braunstein (University of Wales, Bangor), Carlton Caves (University of New Mexico), Richard Jozsa and Noah Linden (recently moved to the University of Bristol), Sandu Popescu (now at Bristol and at Hewlett-Packard), and Rüdiger Schack (Royal Holloway College, London)—have shown[5] that the NMR experiments done thus far have all lacked entanglement—thought by many to be a crucial element for quantum computation. Their conclusion has prompted questions about the role of entanglement and the origins of the power of quantum computation.

Pseudo-pure states

The experiments addressed by Braunstein and company have all been carried out in liquid samples at room temperature. The samples have molecules containing a number N of spin-$^1/_2$ nuclei—such as ^{1}H and ^{13}C—that act as qubits for the calculations: The up and down orientations of the spins in an external magnetic field form the basis states for storing the information. Spin-$^1/_2$ nuclei can have very long relaxation times in solution, on the order of hundreds of milliseconds to seconds—long enough for hundreds of computational steps.

The random tumbling in the liquid washes out the intermolecular coupling between spins—but not the *intra*molecular couplings—so each NMR sample essentially consists of about 10^{22} identical samples in parallel. Techniques that have been honed over decades for use in NMR spectroscopy provide exquisite coherent control over the evolution of the nuclear spins. Individual spins—and the effective interactions between them—can be manipulated by applying appropriate RF pulses.

But in a typical magnetic field of about 10 tesla, the Zeeman splitting of the nuclear spin energy levels is only a very small fraction of the thermal energy at room temperature, and so the nuclear polarization is only a few parts per million. Thus, the N spins on each molecule cannot be described by a single, pure quantum state. Instead, spins on the molecules are distributed among all the possible energy states with a Boltzmann distribution, and the ensemble as a whole—as well as each individual molecule—can be described quantum mechanically only by a density matrix with just a tiny deviation from that of a maximally mixed, totally unpolarized ensemble.

In spite of the precise manipulations available with NMR, it is not possible to transform a thermally polarized ensemble into a pure state. Obtaining a pure state would require millikelvin temperatures; at such