PERSPECTIVES: OCEANOGRAPHY

Patterns of Arctic Circulation

Lawrence A. Mysak

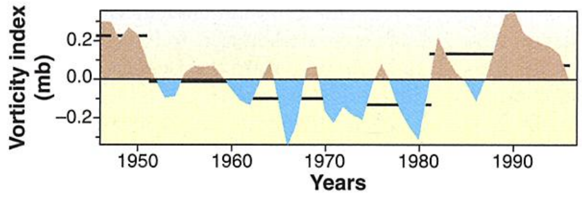
On page 1301 of this issue, Gobeil *et al.* (*1*) elegantly present a picture of the ocean transport pathways of contaminant lead originating from Western Europe and Russia into the Arctic Ocean. They further suggest that the Arctic Ocean circulation patterns involved in these transports—the inflowing Atlantic water currents and the Transpolar Drift Stream—have been relatively stable over the past 50 years.

Enhanced online at www.sciencemag.org/cgi/content/full/293/5533/1269

The inflowing Atlantic water currents and the Transpolar Drift Stream are mainly wind driven. Given that there are notable decadal and multidecadal oscillations in the large-scale atmospheric circulation in high northern latitudes (*2–4*), will Gobeil *et al.*'s description of the pathways for contaminant lead and other pollutants flowing into and around the Arctic Ocean also apply in the future? To answer this question, we must examine the nature and variability of the atmospheric circulation and sea-ice drift patterns in this region during the past 50 years or more.

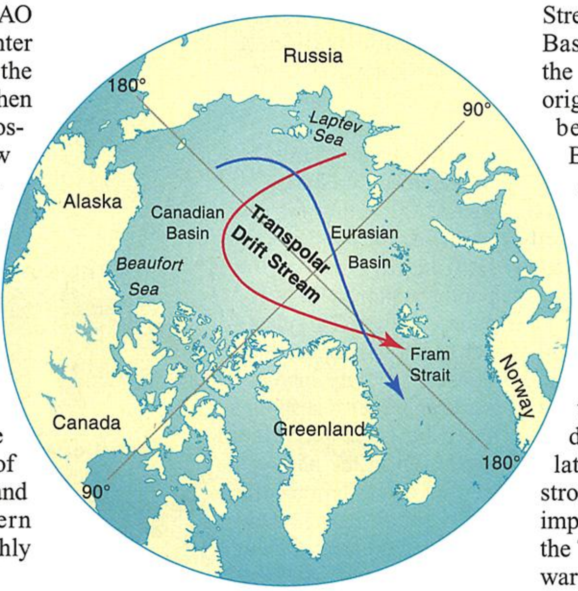
The North Atlantic Oscillation (NAO) is perhaps the best known mode of atmospheric variability outside the tropics. It consists of a north-south fluctuation of air mass over the North Atlantic sector whose time evolution is characterized by the NAO index (*5*), that is, the standardized winter sea level pressure difference between the Azores High and the Icelandic Low. When the NAO is in a positive mode (index positive, NAO+), a deepened Icelandic Low causes strong westerlies over the eastern North Atlantic, strong southerly winds over the Norwegian Sea, and strong northerly winds over the Labrador Sea. In the negative mode (NAO–), the Icelandic Low and the Azores High tend to be weak and the winds are reduced in the above areas.

Another wintertime oscillation closely associated with the NAO is the Arctic Oscillation (AO), which consists of fluctuations in air mass between mid- and high latitudes all around the Northern Hemisphere. The AO index (*2*) is highly correlated with the NAO index. Because the largest north-south air mass exchanges associated with the AO occur over the North Atlantic sector, the NAO is regarded (*6*) as the regional representative of the AO.



Multiple phases. Annual mean vorticity index (*7*) for the central Arctic Ocean computed from sea level pressure data. Brown (blue) regions show positive (negative) phases of decadal variability. The heavy horizontal black lines show decadal means. Also evident is a multidecadal (40- to 60-year) oscillation (*3, 4*), with mainly positive phases of the vorticity index in the late 1940s to early 1950s and late 1980s to 1990s and a mainly negative phase in the 1950s to 1980s.

On decadal and longer time scales, the NAO and AO indices over the past 50 years closely resemble a third index: the vorticity index (*7*) (see the first figure). This index characterizes the wind patterns over the central Arctic. When the vorticity index is positive (corresponding to AO+ and NAO+), there is a weak Arctic High and the associated winds tend to produce anticlockwise ice drift motion in the eastern Arctic (the Eurasian Basin). Conversely, when the index is negative (corresponding to AO– and NAO–), there is a strong Arctic High and the ice drift motion is clockwise in the Eurasian Basin (*3, 8*). In the first case, the Transpolar Drift Stream, which transports ice and relatively fresh surface water from the Laptev Sea to Fram Strait (see the second figure), is curved toward the Beaufort Sea before exiting the Arctic Ocean (*3, 8, 9*). In the second case, the Drift Stream flows directly from the Laptev Sea to Fram Strait (see the second figure).



The two paths for the Transpolar Drift Stream. Clockwise (blue curve) and anticlockwise (red curve) paths are associated with negative and positive phases, respectively, of the vorticity index (first figure).

CREDIT: ADAPTED FROM (3)

When these atmospheric and ice drift variations are placed in the context of when Gobeil *et al.* (*1*) collected the sediments used in their analyses, an interesting story emerges. The sediment cores were collected in 1994. The top 10 cm was analyzed for contaminant lead and its isotopic composition. If we allow for lead transit times of several years and residence times in the upper ocean of up to 5 years (*1*) and if we assume that most of the contaminant lead was released from its sources after World War II, then the ocean/ice circulation patterns inferred by Gobeil *et al.* apply to an ~30-year period from the 1950s to the 1980s.

Remarkably, the vorticity index was mainly negative during this 30-year period (see the first figure). As explained above, this means that the Transpolar Drift Stream flowed straight across the Eurasian Basin toward Fram Strait (blue curve in the second figure). Any contaminant lead originating in the Laptev Sea would thus be deposited mainly in the Eurasian Basin, as shown in figure 3 of Gobeil *et al.* (*1*). This could be one reason why, as proposed by Gobeil *et al.*, the Eurasian Basin is decoupled from the Canadian Basin, which shows little contaminant lead.

Since the early 1980s, the NAO and AO have been mainly in a strongly positive mode (*10*), as was the vorticity index (see the first figure; the drop in 1996 was short lived, and in the late 1990s, all three indices were again strongly positive). This atmospheric state implies that during the past 15 years or so, the Transpolar Drift Stream has curved toward the Beaufort Sea before exiting the Arctic (see the second figure). Consequently, contaminant lead and other pollutants that would emanate from Russia and enter the Laptev Sea would be transported into the Canadian Basin and Beaufort Sea.

The author is in the Department of Atmospheric and Oceanic Sciences and Centre for Climate and Global Change Research, McGill University, Montreal, QC H3A 2K6, Canada. E-mail: mysak@zephyr.meteo.mcgill.ca

The Canadian and Eurasian basins would be "coupled."

Furthermore, under the current atmospheric state, there are strong southerly winds over the Norwegian Sea, and hence the wind-driven inflow of warm Atlantic water into the Arctic is relatively strong, penetrating far into the central Arctic Basin (*11*). Any pollutants entering the ocean from Western Europe could thus penetrate far into the Arctic and might even reach the Canadian Basin. In contrast, during the 1950s to 1980s, when the three indices were mainly negative, the Atlantic inflow would not have penetrated very far into the Arctic Basin.

A useful perspective on the past history of the Transpolar Drift Stream has been provided by an analysis of Canadian Arctic Archipelago driftwood records for the past 8500 years (*12*), which showed that century- to millennial-scale changes in the Drift Stream must have occurred. A sea-ice model study (*13*) indicated that these changes are due to long-term changes in the phase of the NAO (and AO). In the model, the Drift Stream was relatively straight when the NAO was in a negative mode (similar to the blue curve in the second figure), whereas it followed a cyclonic path curved toward the Beaufort Sea when the NAO was positive.

It is clear that in response to atmospheric circulation fluctuations, the Arctic Ocean current and sea-ice drift patterns vary on a wide range of time scales. Gobeil *et al.* (*1*) were fortunate in analyzing sediments that accumulated over a period of several decades when the high-latitude atmospheric circulation was mainly in one (negative) state. It would be exciting to collect further sediment samples and redo their analyses some years after the atmospheric circulation has remained in the other (positive) mode to determine whether different flow pathways prevail.

References

1. C. Gobeil, R. W. Macdonald, J. N. Smith, L. Beaudin, *Science* **293**, 1301 (2001).
2. D. W. Thompson, J. M. Wallace, *Geophys. Res. Lett.* **25**, 1297 (1998).
3. I. V. Polyakov, M. A. Johnson, *Geophys. Res. Lett.* **27**, 4097 (2000).
4. S. A. Venegas, L. A. Mysak, *J. Clim.* **13**, 3412 (2000).
5. J. W. Hurrell, *Science* **269**, 676 (1995).
6. T. L. Delworth, K. W. Dixon, *J. Clim.* **13**, 3721 (2000).
7. J. E. Walsh, W. L. Chapman, T. L. Shy, *J. Clim.* **9**, 480 (1996).
8. A. Yu. Proshutinsky, M. A. Johnson, *J. Geophys. Res.* **102**, 12493 (1997).
9. R. W. Macdonald, personal communication.
10. H. Wanner *et al.*, *Surv. Geophy.*, in press.
11. R. R. Dickson *et al.*, *J. Clim.* **13**, 2671 (2000).
12. A. S. Dyke *et al.*, *Arctic* **50**, 1 (1997).
13. L.-B. Tremblay, L. A. Mysak, A. S. Dyke, *Geophys. Res. Lett.* **24**, 2207 (1997).

PERSPECTIVES: BIOCHEMISTRY

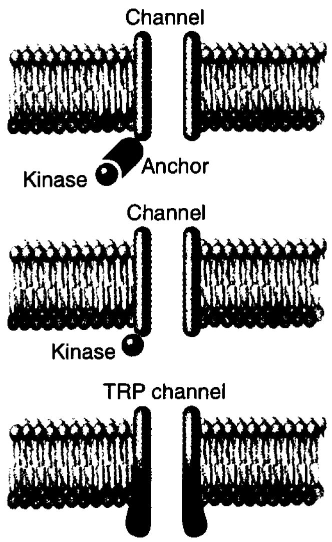
TRP Ion Channels—Two Proteins in One

Irwin B. Levitan and Susan M. Cibulsky

It is no longer a rarity to come across a protein that performs more than one activity, but membrane ion channels do not seem to feature among these multifunctional proteins. However, a cluster of recent papers (*1–5*) reveal that two members of the long TRP (transient receptor potential) cation channel family—LTRPC7 and LTRPC2—are not only ion channels but also have enzymatic activity. LTRPC7 is both an ion channel and a protein kinase, and its kinase activity may influence its channel properties. Similarly, LTRPC2, an ion channel activated by ADP ribose (ADPR), has ADPR pyrophosphatase activity (*4, 5*). These intriguing findings—a surprise to many ion channel biologists—have important implications for the regulation of cell membrane excitability and for many other cellular processes in which ion channels participate.

Ion channels are a specialized class of membrane proteins that form hydrophilic pores through which ions move down their electrochemical gradients. The current carried by ions flowing through these membrane channels is responsible for such fundamental cellular phenomena as the resting membrane potential in all cells, the generation of action potentials in neurons, and neurotransmission at synapses. Ion fluxes through membrane channels also alter the intracellular concentration of ions, most notably Ca^{2+}, that influence signaling pathways. Channels, however, are far more than passive pores—they can shift rapidly back and forth between a nonconducting (closed) conformation and a conducting (open) conformation, a process known as channel gating.

The first member of the TRP channel family to be identified was a Ca^{2+}-permeable channel responsible for the depolarization of *Drosophila* photoreceptor cells in response to light. This channel opens when phospholipase C activity increases, which in turn is stimulated by light-activated rhodopsin in the photoreceptor cells. Numerous TRP channels are now known, and many of them are associated with the transmission of sensory information (*6*). Members of one subfamily, the long TRP channels, have an extended carboxyl-terminal domain at the end of the predicted membrane-spanning portion of the protein, and their gating is not well understood.



Ion channel or enzyme? (Top) An ion channel (blue) may associate with a protein kinase (red) with the help of an intermediary anchoring protein (green). **(Middle)** Alternatively, an ion channel may physically interact with a protein kinase directly. **(Bottom)** Two ion channels, LTRPC7 and LTRPC2, have been identified with both channel and enzyme activities within the same protein.

Reports by three separate groups (*1–3*) describe the cloning and characterization of LTRPC7 (also called ChaK or TRP-PLIK), a new member of the long TRP channel family that exhibits both ion channel and protein kinase activities. LTRPC7 is expressed widely in mouse tissues (*1*) and is crucial for cell survival (*2*). When LTRPC7 is expressed in cultured cells, single-channel and whole-cell currents characteristic of TRP channels can be readily recorded (*1, 2*), leaving no doubt that LTRPC7 is an ion channel. Intriguingly, the extended carboxyl-terminal domain of LTRPC7 contains a region with sequence similarity to certain serine-threonine protein kinases of the atypical α-kinase family. Indeed, this region of LTRPC7 does have protein kinase activity and is capable of phosphorylating the channel itself as well as at least one other substrate (*1*). Another surprise comes from the three-dimensional structure of the kinase domain, solved by x-ray crystallography (*3*). The structure of its catalytic core closely resembles that of more classical protein kinases (typified by the cAMP–dependent protein kinase, PKA) even though

The authors are in the Department of Neuroscience, University of Pennsylvania School of Medicine, Philadelphia, PA 19104, USA.