COLD REGIONS SCIENCE AND MARINE TECHNOLOGY

Hayley H. Shen
Clarkson University, Potsdam, NY 13699, USA

Keywords: Earth system, polar meteorology, air-ice-sea interaction, snow and ice, permafrost, glaciers, thermo-mechanical properties, structure-ice interaction, modeling, remote sensing.

Contents

Summary

Cold regions are part of the earth system characterized by the presence of snow and ice at least part of the year. Roughly divided into polar and sub-polar regions, historically a majority of these cold regions is sparsely populated with minimum human impact to nature. Due both to the pressure of population and economic development, this picture is changing. Global warming may accelerate the pace of change. The theme on cold regions science and marine technology in the *Encyclopedia of Life Support Sciences* (EOLSS) is developed to cover a cross-section of topics in fundamental science and practical engineering for cold regions. The definition of cold regions is given first, followed by their key characteristics, i.e. the presence of snow, ice, permafrost and glaciers. Climate change has modified the distribution of cold regions around the world. These modifications also come from economic developments. Human activities, especially those of grand scales, have potential to greatly impact cold regions environment. Sound technology development in and for the cold regions can only come from sound scientific understanding of many inter-related processes. Synthesis of these processes using sophisticated mathematical modeling is often needed. Issues discussed in this theme demonstrate the breadth of knowledge required to address the natural phenomena and engineering challenges in cold regions.

1. Introduction

Definition of a cold region varies. A broadly accepted definition is to use the $0^{o}C$ isotherm in the coldest month of the year (Bates and Bilello (1966)). For North

America, this definition roughly coincides with the area above the 40^{o}N latitude. As the technology improves, regions previously too cold for human activities become more accessible. The lure of uncovered natural resources in the Arctic and Antarctic, for example, further attracts humans to develop the cold regions.

Geologically cold regions may be loosely categorized as the Polar and sub-Polar regions. Human activities existed in sub-Polar regions long before written history started. In the Polar regions, historical events of human activities predating the 1970's were largely from explorations and adventures, such as Nansen in the Arctic and Scott in the Antarctic. Native residents of the cold regions include the Inuit, the Sami, and the Mongol. They subsisted on hunting and fishing. Population of these tribal communities was low. With the exception of events such as the (hypothetical) overkill leading to extinction of North America woolly mammoth (Scott 2010), the impacts of human on nature were minimal. The picture has been changing gradually and will pick up speed in this century.

Chronologically speaking, cold regions human activities have three periods: exploration, engineering development, and most recently scientific research. These three major activities have not been mutually exclusive. For instance, being a professor in zoology and oceanography, Nansen contributed in the development of neurology and fluid dynamics. The most noteworthy in light of cold regions studies were the Nansen bottles he devised to collect ocean water sample at different depths, as a means to map out the ocean current structure. In case of Scott, a research institute was established after his death. The Scott Polar Research Institute, founded in 1926 in Cambridge, England, is fully dedicated to polar research. Nonetheless, the evolution of human activities in cold regions has been quite clear. It is fair to say that we humans first coped within the cold regions, then exploited it, and finally tried to understand it.

Data from the pre-historical time are available only through coring samples of the soil or ice, tree trunks, and direct indigenous knowledge. As the technology advances, more accurate and higher temporal and spatial data have become available. These data can be categorized into atmosphere, lithosphere, biosphere, hydrosphere, and cryosphere. The interaction between all these different 'spheres' makes up our entire earth system. Collecting data is the first step in any scientific study. Worldwide there are many institutions dedicated to archive cold regions data (e.g. US Army Cold Regions Science and Engineering Laboratory, established in 1961.) Events not directly related to science and technology can be valuable data sources. For instance, the Iditarod dog sled race started from 1973 is a good source for the evolution of spring conditions in Alaska.

Large engineering projects in the cold regions included both on land and in a freshwater or marine environment. These projects included dams, bridges, air and sea ports, offshore platforms, highways and railroads. In nearly all cases, these projects were built to enable economic development. In the past, when our knowledge of adverse environmental implications was limited, the challenges for these projects were to find a way to confront the nature. With increased knowledge, we face the additional challenge to evaluate the potential long term impact. The problem is no longer whether we can do it, but also whether we can do it right.

The impact of global warming is amplified in the cold regions of the world. In these regions snow and ice are present for at least part of the year. The existence of this frozen water defines a broad range of nature and human activities from bird population to winter recreation. A few degrees of warming can greatly alter the spatial and temporal extent of the freezing season. In fact, changes in frozen ground have already been observed in historically permafrost zones. Precipitation shifts will soon produce measurable changes in the bio-environment of the cold region habitats. The full impact of climate change on the globe is a topic that concerns scientists, politician, and the general public. For instance, the mineral resources under the sea ice cover in the Arctic may become accessible. To claim the ownership of these resources will no doubt generate political discussions.

Many of the existing basic science and technology do exist to help future development and preservation of the cold regions. To apply this basic knowledge and develop strategies that can strike a balance between these two competing demands requires both academic and public education.

Academic curriculum specifically developed for cold regions is not part of the civil, environmental, or mechanical engineering yet. These disciplines include soil mechanics, hydraulics, heat flow, materials, construction, energy, transportation, and many others. This theme covers scientific disciplines relevant to study the natural forces in cold regions, and potential changes that can be brought by either climate or human developments. These topics are organized in this theme as:

- The atmosphere – Polar Meteorology, Air Pollution
- The land – Thermo-mechanical Properties of Materials, The Physics and Structure of Snow and Ice, Snow and Ice Loads on Structures and Their Controls, On Land the Offshore Oilfield Development
- The water – Models of Air-Ice-Sea Interaction, Snow and Ice Loads on Structures and Their Controls, River Ice Processes, Ice Growth on Water Surfaces and Modeling of Ice Drift, On Land and Offshore Oilfield Development, Design of Ice Breaking Ships.
- Man-made structures on land and in water – Snow and Ice Loads on Structures and Their Controls, On land and Offshore Oilfield Development, Design of Ice Breaking Ships.
- Impact of human development to nature – On Land and Offshore Oilfield Development, Air Pollution

Many of these topics have overlapping targets, as seen by their multiple listing. The topics covered in this theme are by no means exhaustive. Many other topics that are relevant to cold regions studies will be developed in the future. In this theme, a cross-section of existing science and engineering topics provides a starting point for understanding the complexities of cold regions.

2. Various Definitions of Cold Regions

Defining cold regions is the first step to put a boundary for this theme. There are three accepted ways to define a “cold region”:1) Air temperature; 2) Ice cover in lakes, rivers, and harbors (on land) and sea ice extend (over the ocean); and 3) Permafrost (permanently frozen ground).

1)Based on air temperature:

Cold winter – mean air temperature during the coldest month is between 0^{o}C and –17.8^{o}C.

Very cold winter – mean temperature during the coldest month is between –17.8^{o}C and –32^{o}C.

Extremely cold winter – mean temperature during the coldest month is between –32^{o}C and –62.2^{o}C.

Under this definition, the southern limit of the cold regions marked by the 0^{o}C isotherm for the coldest month of the year is shown in Figure 1.

Figure 1. Climate zones of the cold regions of the northern hemisphere (from Gerdel 1969).

2)Based on ice covers over water:

Mild cold regions – Boundaries where lakes, rivers, and harbors become, on the average, un-navigable for 100 days per year.

Severe cold regions – the above condition extends to 180 days per year.

This classification is shown in Figure 2.

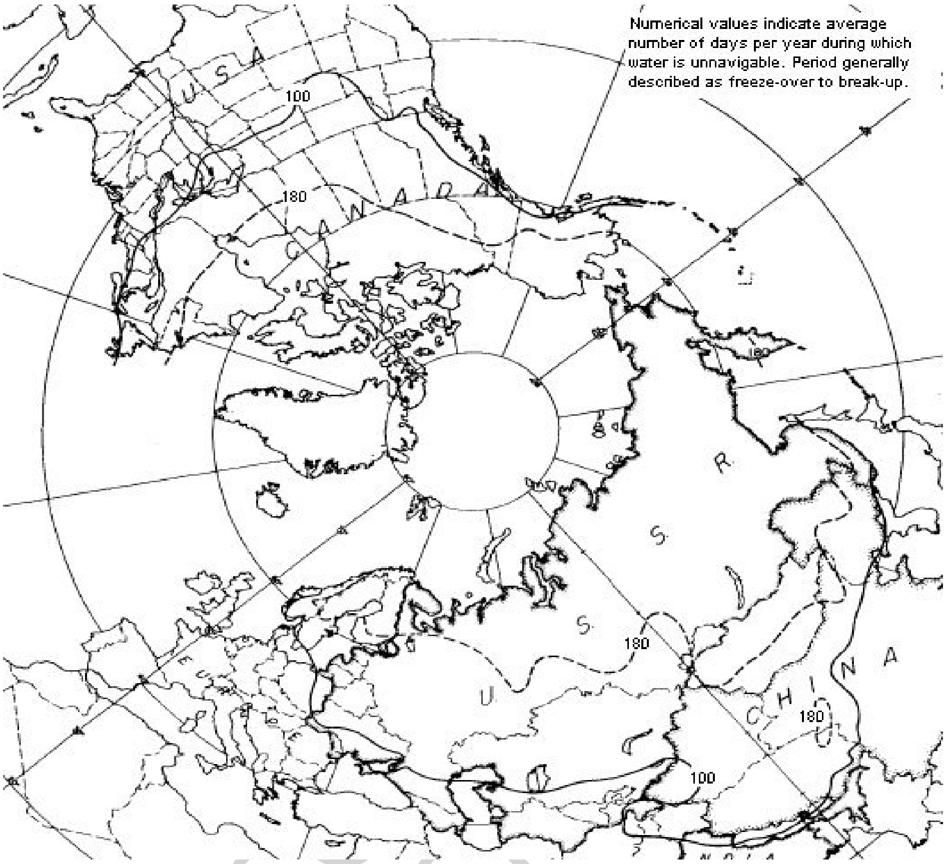

Figure 2. Cold region boundaries as determined by days with ice cover (from Bates and Bilello 1966).

3)Based on permafrost:
Permafrost that exists in an unbroken fashion over an entire region is called "continuous permafrost", and permafrost that is patchy is called "discontinuous permafrost". The lines of continuous and discontinuous permafrost correspond roughly to the Arctic and sub-Arctic regions. Permafrost can also exist far south of these zones in small patches dependent on the local climate, vegetation, and soil conditions. Distribution of permafrost is shown in Figure 3. A much more recent map based on the work from Brown et al. (1997) of permafrost distribution in the Northern Hemisphere can be found at the US National Snow and Ice Data Center. (http://nsidc.org/data/google_earth/images/permafrost.jpg.) However, it should be noted that the more recent map published in 1997 was an effort to unify many existing maps up to that point. The original maps were based on data sets obtained in different years and thus changes might have taken place between the original maps and the unified map.

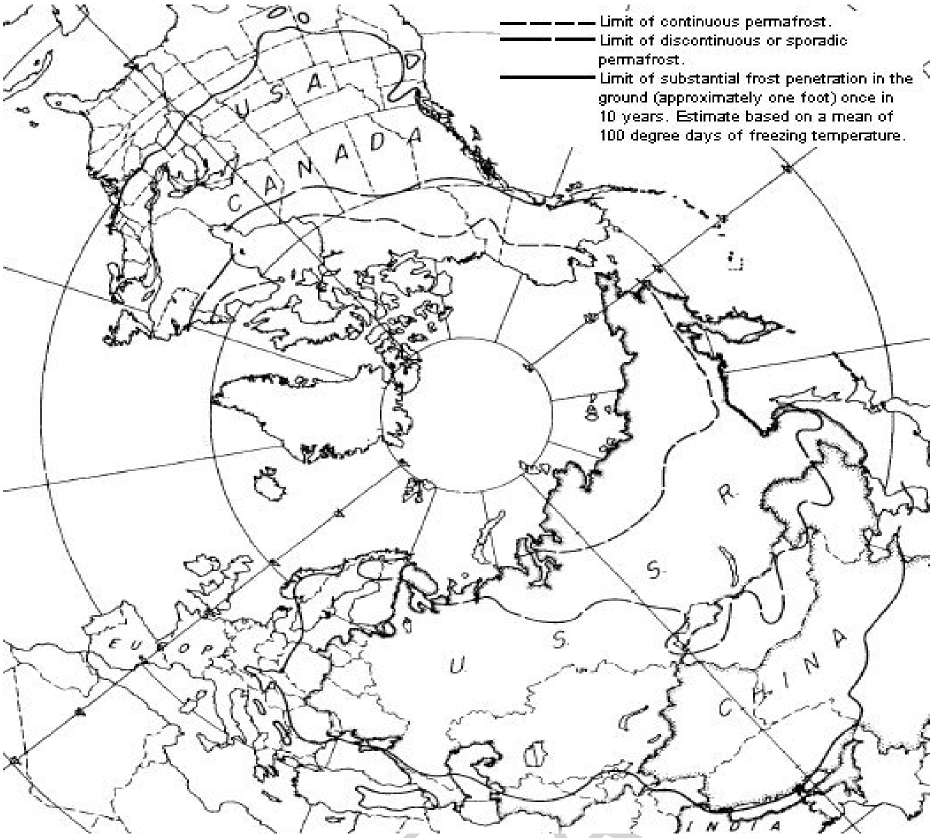

Figure 3. Cold region boundaries as determined by frozen ground (from Bates and Bilello 1966).

From these three definitions it is clear that the same location may be classified differently under different criteria. A systematic comparison of the extent of cold regions using one of the above criteria may show that different definitions yields different quantitative measure of the climate change trend. Such comparison can reveal the complexity of climate change, with different effects on different parameters.

The most direct measurement of climate change is using the annual average of air temperature. From an engineering viewpoint, the accepted delineation of cold regions includes those regions north of the 40^{o}N latitude in North America. This coincides roughly with the freezing isotherm definition. In general, a cold climate environment exists wherever frost affects engineering systems; ice on rivers, lakes, and harbors interferes with transportation or damages structures; snow load must be considered in the design of structures; low temperatures affect the efficiency of man or machines; safety of roadways and power lines; the manifestations of low temperature affect the economics of engineering design.

-
-
-

Bibliography

Arctic Climate Impact Assessment (2005) Cambridge Press, Project Director: John E. Walsh, Director, Cooperative Institute for Arctic Research (CIFAR), Project Manager: Patricia A. Anderson, Consultant' Indexer and Editor: Lelani Arris. 1019pp. [A comprehensive summary of past and present state of the Arctic and projected climate impact.]

Arctic Transitions in the Land-Atmosphere System, Reprinted from the Journal of Geophysical Research and published by American Geophysical Union. [A collection of papers on Arctic conditions in recent years due to climate change.]

Bates, R.E. and Bilello, M.A. (1966). Defining the cold regions of the northern hemisphere. Hanover, NH: CRREL, Technical Report 178. [Definition and characterizations of cold regions.]

BBC documentary (2007). *The Ice King*. [A documentary of Fridtjof Wedel-Jarlsberg Nansen and his Arctic expedition].

Bokushi, S. (1986) *Snow Country Tales – Life in the other Japan.* Translated by Hunter J. and Lesser, R. ISBN 0-8348-0210-4. 336pp. [A collection of art work and stories in the early 19^{th} century western Japan.]

Brown, J., Ferrians, O.J. Jr., Heginbottom, J.A. and Melnikov, E.S., (1997) *Circum-Arctic Map of Permafrost and Ground-Ice Conditions.* US Geological Survey, for the International Permafrost Association, USGS Circum-Pacific Map Series, Map CP-45, scale 1:10,000,000. [A map of permafrost distribution with areal coverage from 20^{o}N to the North Pole.]

Brown, T. G. (1997) The Confederation Bridge: analysis of environmental impacts related to ice. *Can. J. Civ. Eng.* 24, 908–914. [Discussions on principal environmental concerns derived from possible effects that the bridge would have on the ice regime in Northumberland Strait.]

CEOS (Committee on Earth Observation Satellites) International Directory Network – A comprehensive directory of Earth science and global change data. http://idn.ceos.org/portals/Home.do?Portal=ceos&MetadataType=0 [A comprehensive collection of data obtained via the use of satellite mounted sensors on all aspects concerning the natural and human dimensions on Earth.]

Dean R. Freitag and Terry McFadden (1996) Introduction to Cold Regions Engineering, ASCE Press, ISBN 0-7844-0006-7. [Comprehensive information on issues, problem, and technological solutions concerning cold regions.]

Du, M., Kawashima, S., Yonemura, S., Zhang, X., Chen, S., (2004). Mutual influence between human activities and climate change in the Tibetan Plateau during the recent years. *Global and Planetary Change*, 41(3–4), pp. 241–249. [A study of warming effect on biomass increase and likelihood of overgrazing, positive feedback, and grassland degredation.]
Ealing Studios (1948). *Scott of the Antarctica.*[A film based on Robert Falcon Scott's ill fated expedition to reach the South Pole].

Gerdel, R.W. (1969). Characteristic of the cold regions. CRREL, monograph 1-A. 51pp.

Goersen, P. Campbell, W.J. Cavalieri, D.J., Comiso, J.C., Parkinson, C.L., and Zwally, H.J. (1992) *Arctic and Antarctic Sea Ice, 1978-1987: Satellite Passive-Microwave Observations and Analysis*. Scientific and Technical Information Program, NASA -511. [Collection of data from satellite sensors in the period stated for both Arctic and Antarctic sea ice.]

Johannessen, O.M., Bengtsson, L., Miles, M.W., Kuzmina, S. I., Semenov, V.A., Alekseev, G.V., Nagurnyi, A.P., Zakharov, V.F., Bobylev, L.P., Pettersson, L.H., Hasselmann, K., and Cattle, H.P. (2004)

Arctic climate change: observed and modelled temperature and sea-ice variability, *Tellus A*: *Dynamic Meteorology and Oceanography*, 56(4): 328-341.

Kalnay, E. and Cai, M. (2003) Impact of urbanization and land-use change on climate. *Nature* 423, pp. 528-531. [Evaluation of urbanization impact on climate.]

Kasting, J.F. (2004) When methane made climate, *Scientific American*, 291(1), pp. 78-85 [Discussion on the multiple roles played by methane on the earth climate.]

Kiefer, F. (1972) *Naturkunde des Bodensees*, ed. Thorbecke Verlag, Sigmaringen, Germany. [History of Lake Constance.]

Lunardini, V.J. (1981). Heat transfer in cold climates, Van Nostrand Reinhold Co. [Definition, theory, and mathematical modeling of thermal mechanisms in cold regions.]

Magnuson, J. J., Robertson, D. M., Benson, B. J., Wynne, R. H., Livingstone, D. M., Arai, T., Assel, R. A., Barry, R. G., Card, V., Kuusisto, E., Granin, N. G., Prowse, T. D., Stewart, & K. M., Vuglinski, V. S. (2000) Historical Trends in lake and river ice cover in the Northern Hemisphere. Science 289: pp. 1743-1746. [Summary of lake and river ice observations as the title indicated.]

Rahmstorf, S. (2006) Thermohaline Ocean Circulation. *Encyclopedia of Quaternary Sciences*, (Ed. Elias. S. A., Elsevier, Amsterdam 2006). [Mechanisms of ocean circulations and outlooks of their inter-relationship with climate change.]

Scott, E. (2010) Extinctions, scenarios, and assumptions: Changes in latest Pleistocene large herbivore abundance and distribution in western North America. *Quaternary International*, 217(1-2):pp. 225-239. doi:10.1016/j.quaint.2009.11.003 [Examination of different theories concerning the extinction of large mammal in North America at the end of Pleistocene Epoch.]

Seidov, D., Barron, E., and Haupt, B.J. (2001) Meltwater and the global ocean conveyor: northern versus southern connections. *Global and Planetary Change*, 30(3-4), pp. 257-270.

Stearn, S.R. (1965) Selected aspects of geology and physiography of the cold regions. CRREL, 1-A-1. [Classifications and definitions of the cold regions.]

Stone, G.S. (2003) *Ice Island: The Expedition to Antarctica's Largest Iceberg.* Bunker Hill Publishing, 80pp. [A story of a scientific expedition studying an iceberg the size of Texas.]

Symon, C. (lead editor), Arris, L., and Heal, B. (2005) *ACIA (Arctic Climate Impact Assessment) report*. Cambridge University Press, 1039pp. [A thorough report of climate changes in the Arctic.]

Watson, R.T. and the Core Writing Team (eds.) (2001) IPCC, 2001: *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp. [A comprehensive assessment of climate change via data, scientific questions, and outlooks.]

Wright, E.A. (1986) *CRREL's First 25 Years*, Technical Publications Writer-Editor, Technical Information Branch, Technical Services Division, U.S. Army Cold Regions Research and Engineering Laboratory. 61pp.

Zhang, T., Barry, R.G., Knowles, K., Heginbottom, J.A. and Brown, J. (2008a) Statistics and characteristics of permafrost and ground-ice distribution in the Northern Hemisphere, *Polar Geography*, 31(1-2):47-68.

Zhang, T., T. Harry, W. Baker, G.-D. Cheng, and Q. Wu. (2008b) The Qinghai–Tibet Railroad: A milestone project and its environmental impact. *Cold Regions Science & Technology* 53(3): 229-240, doi:10.1016/j.coldregions.2008.06.003. [A summary of the construction and its potential long term impact of the Qinghai-Tibet Railroad.]

In addition, three sources have extensive literature concerning the cold regions:

National Science Foundation (NSF) Polar Research Program [http://www.nsf.gov/home/polar/]

Cold Regions Research and Engineering Laboratory (CRREL) [http://www.crrel.usace.army.mil/]

Scott Polar Research Institute (SPRI) [http://www.spri.cam.ac.uk/]

The CRREL Library and NSF's Polar Research Program provide many sources for the Antarctic Bibliography and the Bibliography on Cold Regions Science and Technology. In addition, through a cooperative agreement with AGI, the Scott Polar Research Institute (SPRI) provides information on the Antarctic materials housed in the SPRI Library at the University of Cambridge.

Biographical Sketch

Hayley H. Shen received her B.S. degree in mathematics from the National Taiwan University in 1972, and a Ph.D. in applied mathematics from the University of Iowa in 1976. All of the mathematics was intended to prepare her for her real interest: the physical laws behind the universe. After completing a Ph.D. in Engineering Sciences in 1982 from Clarkson University she began teaching and doing research in the Civil and Environmental Engineering Department at Clarkson University up to the present.

Her research areas include granular materials, in particular, the mechanical laws governing moving granular materials, and sea ice, in particular, the rheology of fragmented ice fields and wave-ice interaction. She started her study in cold regions problem during her visit at the US Army Cold Regions Research and Engineering laboratory in 1983, when the marginal ice zone was intensely investigated under the MIZEX campaign. Her first project in cold regions was to apply the granular materials knowledge to determine the constitutive laws for moving and deformation fragmented ice fields typically found in the marginal ice zone. From there, her work expanded to wave induced ice movement, attenuation of wave energy due to ice interactions, formation of pancake ice, and limiting size and thickness of pancake ice fields. She participated in field studies in the Greenland Sea in 1991 with researchers from the Norwegian Polar Institute and on the Ross Island in 1994 with researchers from the Otago University.

Dr. Hayley H. Shen has been fortunate to have had collaborations with many international scientists and engineers around the world, visited outstanding institutions in many countries. The intellectual journey into the cold regions through these colleagues world-wide has been exhilarating. The physical journeys into the cold regions have been humbling. Dr. Shen is a member of the American Geophysical Union, the International Association of Hydraulic Research, and the Engineering Mechanics Institute.