SNOW AND ICE

Ulf Molau

Snow: Cover, Duration, and Disappearance

Introduction

Snow melt procedure during the summer is one of the most important and powerful ecological determinants in the Arctic, and has a huge impact on phytosociological differentiation within any particular area, as well as on reproductive success within species (Billings & Bliss 1959, Holway & Ward 1963, Bell & Bliss 1979, Isard 1986, Galen & Stanton 1991, Kudo 1991, Molau 1993). Climatic change is assumed to induce drastic changes in snow cover in the Arctic: its depth as well as duration (shifting of time for melt-off and onset of accumulation, i.e., changing the length of the vegetation period).

The response variables measured in ITEX plants in monitoring and manipulation experiments will partly be affected by the timing of the snow melt at the study plot or plant individual. Therefore, at any ITEX site, data on snow disappearance date for permanent plots or plant individuals will be most informative. Not all ITEX field parties will have the possibility to monitor snow disappearance, but as many as possible are encouraged to include this is their monitoring program.

Snow disappearance can be measured in two different ways in the field, either by (1) monitoring of disapperance date in permanent plots/points, or by (2) monitoring the progressive melt-off along a permanent snow accumulation transect, such as a north-facing slope, a snow-bed, or perpendicular to a standardized snow fence.

Permanent Plots or Sample Points

Permanent plots for monitoring flowering phenology of ITEX species are suitable also for monitoring of dates of snow disappearance in a number of years. The recommended ITEX norm for recording of the date when *stable* seasonal snow cover finally disappears in any given area or plot follows Foster (1989): ”The date of snow cover disappearance is given as the day when 1 inch of snow (2.5 cm) can no longer be measured at the reporting station (plot) and hence only a trace of snow is observed”. Any 1x1 or 2x2 m (or other size) squares are suitable for this method. In cases where monitoring is carried out on permanently tagged individuals or branches instead of plots, use the surrounding square meter at each point as the snow monitoring plots. In order to find plots when still snow-covered, mark the corners with sticks, irons, or plastic tubing, long enough to be found in early spring.

Actual date of disappearance of continuous snow cover is the most important measure in this context. However, even better resolution of effects of climatic fluctuation/change will be obtained if you are able to measure also snow depth in the plots prior to final melt-off. In that case, a subsample of 10 random probings should be taken in each plot at even intervals, preferable every third day.

Always when monitoring snow depth or disappearance date, note time (hour) of the day when measures are taken. In plant species with short prefloration periods (e.g., 8–10 days in *Saxifraga oppositifolia*) it is important to have this accuracy; a tolerance of ± 0.5 days of accumulation of solar radiation effect and cumulative degree days may entirely blur the relationship between microclimate and phenology.

Since the design of this kind of snow cover monitoring will vary among ITEX sites depending on the terrain and the species selection, no standard report forms are provided. Make up site- and species-specific report forms and communicate your annual data to the ITEX secretariat.

Permanent Transects

Monitoring of snow cover and disappearance along environmental transects (such as a slope or across a snow-bed) gives a lot more information than just a sample of plots. In flat tundra plain sites, snow gradients can be induced by putting up permanent snow fences. Along the study gradient, one or (preferably) two straight permanent transects should be marked. For example, in a 100 m long transect, permanent sample points are marked at every fifth meter. End points of transects and some of the sampling points in between should be marked with metal tubings or irons, high enough to be visible above the snow at any time of the year. Make a detailed map of your transect (orientation in degrees, level differences profile); use a theodolite for this survey (no need to buy one, it is usually possible to borrow one from collegues at geology, glaciology, or geography departments).

Once the transect is established, it can be used for monitoring of (1) snow depth until final disappearance at each sample point, (2) the progressive movement of the snow front during the season, and (3) the progressive movement of the flowering and fruiting fronts in various species during the season. Prefloration time, the time lag between snow-melt and flowering in a species, can then be correlated with climatic parameters, e.g., integrated solar radiation and growing degree days (GDD). Snow depth should only be recorded at every third day (otherwise the snow cover will be too disturbed); snow and flowering/fruiting fronts should be recorded daily throughout the season. An example of a protocol developed for a 100 m transect belt at Latnjajaure, Sweden, is added to this manual.

Lake Ice

Introduction

Freeze-up and break-up dates of lakes provide useful estimates of air temperature early and late in the seasons. The applicability of this method was thoroughly tested by Palecki and Barry (1986) in an analysis of data for 63 Finnish lakes. Monitoring of ice conditions and surface water temperature requires little extra effort if there are lakes of sufficient size and depth, and located close to an ITEX site. On the other hand, such records, even if incomplete, will provide useful data for seasonal comparison of temperature regime at the site. Melting of lake ice is a relatively inert process, well buffered against short-time temperature fluctuations within the season, and could be a powerful tool for reliable detection of climate change (in any direction). Running 5-year means of break-up dates or the duration of the annual open-water period tend to sufficiently insensitive to the often large differences between consecutive seasons (see Fig. 1–2).

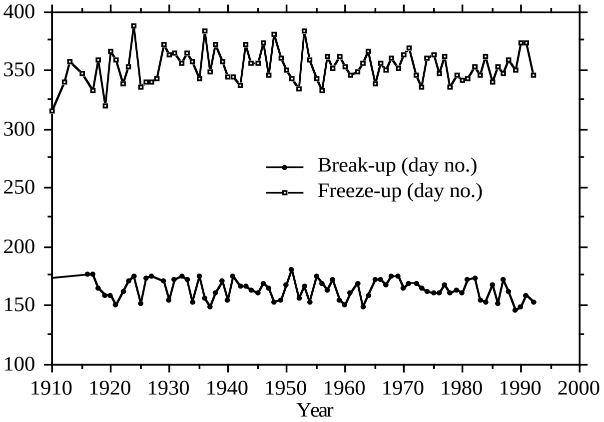

Fig. 1. Ice break-up (lower curve) and freeze-up dates (upper) for Lake Torne, N Sweden, in the years 1910–92. Data from Abisko Scientific Research Station.

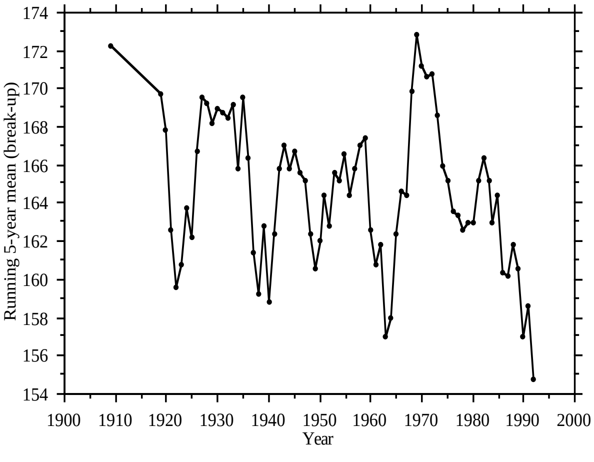

Fig. 2. Running 5-year means of ice break-up in Lake Torne, N Sweden, in the years 1908–92. Data from Abisko Scientific Research Station.

Lake ice break-up and freeze-up dates are primarily governed by average ambient temperature, but distortions may result from thick snow cover in spring and prevailing strong winds in autumn. A good example is provided by the long record (almost 90 years of continuous observation) of Lake Torne, Abisko ITEX site, N Sweden (Fig. 1). The lake has a maximum depth of 169 m and a surface area of 317 km^2; it is long and narrow, and situated at 340 m alt. in a deep valley along the direction of the prevailing westernly winds in the area. The ice is usually snow-free long before break-up, causing little disturbance to the data. Freeze-up in lakes of this size and topographical situation is, however, highly influenced by wind conditions in late autumn and early winter, making those dates somewhat less informative (see Fig. 1).

The opposite conditions are met with at Lake Latnjajaure (at the main Swedish ITEX site), situated close to Lake Torne but at 986 m alt., the surface area is only 1 km^2 but the maximum depth is 43.5 m. Here, break-up dates vary strongly among years due to large variations in snow cover and the fact that much of the lake ice is still snow-covered at the time of break-up. In the autumn, the impact of strong winds retarding final freeze-up is more marginal. In the case of Lake Latnjajaure, there is little correlation between break-up and May and June air temperatures, but surface water temperature during the summer shows high and significant correlation with the climate of the entire season. We lack records for freeze-up, but it is probably strongly correlated with average autumn air temperatures. Thus, the identity of the most informative and reliable data source (i.e., break-up, freeze-up, surface water temperature) varies with size, depth, winter precipitation, and topographical situation of the lake. A pilot study using all variables during the first 2–3 years of monitoring will solve the problem.

Recommended Methods

Select a suitable lake close to the ITEX field site (recommended minimum size: 0.5 km^2 surface area, 5 m depth). Preferably, surface water temperature (uppermost 5 cm), break-up/freeze-up stage, and ice cover should be recorded daily as an addition to the manual weather observation at 1900 hours normal time. Ice cover of lake surface is normally reported with an accuracy of 5–10 percent. For very large lakes, observations are made only for a particular area of the lake in question. A protocol for ITEX lake ice monitoring is provided in Appendix VI. Use the following classification of lake ice stages (modified from Palecki and Barry 1986):

Break-up:	B0	No sign of break-up
	B1	Open water on shore
	B2	Open water offshore
	B3	Ice in movement
	B4	Final break-up
Freeze-up:	F0	No ice formation
	F1	Ice formation on shore
	F2	Ice cover on bays
	F3	Ice within visible range
	F4	Final freeze-up

The dates of final break-up (B4) and freeze-up (F4) are the most commonly used ones in seasonal comparisons. Palecki and Barry (1986) used simple linear regression with these events as dependent variables and mean air temperature the preceding month(s) as the independent ones. For the Finnish lakes, a 5-day displacement of break-up or freeze-up dates resulted from a change of the magnitude of 1.0–1.1°C in mean April and September temperatures, respectively.

References

Bell, K. L. & Bliss, L. C. 1979. Autecology of *Kobresia bellardii*: Why winter snow accumulation limits local distribution. — Ecol. Monogr. 49: 377–402.

Billings, W. D. & Bliss, L. C. 1959. An alpine snowbank environment and its effects on vegetation, plant development, and productivity. — Ecology 40: 388–397.

Foster, J. L. 1989. The significance of the date of snow disappearance on the arctic tundra as a possible indicator of climatic change. — Arct. Alp. Res. 21: 60–70.

Galen, C. & Stanton, M. L. 1991. Consequences of emergence phenology for reproductive success in *Ranunculus adoneus* (Ranunculaceae). — Amer. J. Bot. 78: 978–988.

Holway, J. G. & Ward, R. T. 1963. Snow and meltwater effects in an area of Colorado alpine. — Amer. Midl. Nat. 69: 189–197.

Isard, S. A. 1986. Factors influencing soil moisture and plant community distribution on Niwot Ridge, Front Range, Colorado, U.S.A. — Arct. Alp. Res. 18: 83–96.

Kudo, G. 1991. Effects of snow-free period on the phenology of alpine plans inhabiting snow patches. — Arct. Alp. Res. 23: 436–443.

Molau, U. 1993. Life history strategies in tundra plants: Does inference from mating systems apply in the Arctic? — Arct. Alp. Res.. (in press).

Palecki, M. A. and Barry, R. G. 1986. Freeze-up and break-up as an index of temperature changes during the transition seasons: a case study from Finland. — J. Clim. Appl. Meteor. 25: 893—902.