BOREAL FOREST SNOWPACK RESEARCH FOR GLOBAL CHANGE

by

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ABSTRACT

Discontinuous-permafrost landscapes are highly vulnerable to potential global change. The seasonal snowpack in northern boreal forest settings will respond to and will influence global warming, predicted to be earliest and of greatest magnitude at high latitudes. Research toward assessing global change is being conducted at a Taiga Long-Term Ecological Research facility in central Alaska. Baselines of snow accumulation, ablation and chemistry are being developed, building on more than two decades of ecosystem research and monitoring. Complementary research is conducted on ecological and hydrological processes in forest stands from lowland floodplain through upland slopes (both cold, permafrost-underlain and warm, permafrost-free) to treeline.

INTRODUCTION

The circumpolar northern boreal forest -- the discontinuous permafrost zone of North America, Fennoscandia and Eurasia -- extends beyond 70°N in Siberia, and to below 50°N in Mongolia, northeast China and south of Hudson Bay in eastern Canada. The boreal forests of central Alaska exist under a cold continental climate characterized by long, cold winters and short, warm summers (Van Cleve et al., 1986), occupying over 100 million acres with a heterogenous cover of white spruce, paper birch, quaking aspen, balsam poplar, black spruce and larch intermixed with extensive peatlands, wetlands and tall shrub communities. Alaska's boreal forest is strongly influenced by wildfire, and vegetation patterns are inextricably linked with fire history (Viereck, 1973; Dyrness et al., 1986).

CONSEQUENCES OF WARMING

General Circulation Models indicate that global warming will be detected earlier and will be of greater magnitude at high latitudes (Hansen et al., 1988). Landscapes of Alaska's northern boreal forest are extremely sensitive to thermal disruption: permafrost temperatures range from -1/2 to -2°C, while GCM's predict as much as 8°C warming over the next 50 years. Warming may result in widespread thermal and physical degradation of terrain, altered rates and patterns of vegetation succession, and damage to engineered facilities. CO_2 and CH_4 sequestration or release to/from the extensive carbon store found in northern boreal forests and peatlands has the potential to drastically alter rates of global change (Gorham, 1991). Altered flux of water, minerals and nutrients from atmosphere to landscape to fluvial systems under potentially changed conditions will affect productivity and stability of terrestrial and aquatic ecosystems (Kane et al., 1992; Oswood et al., 1991). A changing climate might alter disturbance regimes of the northern boreal forest, including frequency and severity of wildfires and infestations by insects and pathogens, and could alter forest patterns which have been fairly stable over at least the past six millennia (Billings, 1992).

High-latitude landscapes are occupied by seasonal snow and ice for six to eight months of the year (Slaughter and Benson, 1986); the snowpack will both reflect and influence changing climate. The soil mantle of northern landscapes is seasonally or perennially frozen, affecting surface and groundwater regimes (Kane et al., 1992). Seasonal snow alters landscape albedo while holding water in "detention storage" prior to its release to the landscape and stream system at spring melt. The swift increase of albedo consequent to snowfall in autumn coincides with rapidly decreasing sun angle and decreased day length; the onset of spring snowpack ablation as result of rapidly increasing day length, sun angle and ambient temperature, coincides with rapid decrease in albedo as snowmelt progresses. Weller (1992) suggests that a doubling of atmospheric CO_2 may lead to greater temperature increase in winter than in summer, an increase in winter precipitation, and an increase of up to three weeks in growing season in central Alaska; this implies more snow over a shorter season, and perhaps accelerated spring snowmelt and river breakup. Presence of permafrost in a watershed affects runoff regime; permafrost-dominated catchments have greater "flashiness," higher peak flows, lower base flows and steeper flow recessions than do permafrost-free basins (Slaughter et al., 1983). Alteration of snowpack mass, accumulation/ablation regime and seasonal duration could influence the surface energy balance under changing climate. Net energy balance change which alters distribution of permafrost in boreal forest landscapes will therefore affect biogeochemical and hydrologic regime of those landscapes.

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SNOWPACK RESEARCH AND MONITORING

Long-term snow investigations are integral to interdisciplinary ecosystems research being conducted in the Bonanza Creek Experimental Forest/Caribou-Poker Creeks Research Watershed (Figure 1) of central Alaska. The Bonanza Creek Experimental Forest (BCEF) is a 5000-ha site 30 km west of Fairbanks, Alaska. BCEF encompasses environments of the floodplain of the Tanana River (120 m msl) and adjacent uplands, to a maximum elevation of 490 m msl. Current research in BCEF addresses vegetation succession in floodplain and uplands, herbivory, and resource availability to specific vegetation communities in relation to climate, nutrient availability and biogeochemical processes. The emphasis is on the floodplain where primary succession is initiated by periodic flooding, and on uplands where secondary succession is strongly influenced by periodic wildfire. Caribou-Poker Creeks Research Watershed (CPCRW) is a 10,400 ha upland research site 45 km north of Fairbanks, dedicated to multidisciplinary long-term research and associated environmental monitoring of the boreal stream/landscape biophysical system. CPCRW encompasses more than a dozen first-, second-, and third-order subdrainages over an elevation range from 210 to 826 m msl, allowing analysis of a stream system continuum from headwaters through fourth-order streams. The BCEF/CPCRW Taiga Long-Term Ecological Research site is the only boreal forest terrain in Alaska dedicated to sustained ecosystem research. The 150 km^2 BCEF/CPCRW lies in the zone of discontinuous permafrost with south-facing slopes generally free from permafrost while valleys and north-facing slopes are underlain by frozen ground at shallow depth; it includes an elevational gradient from floodplain to treeline and spans a hydrologic continuum from ephemeral and first-order drainages to sixth-order rivers.

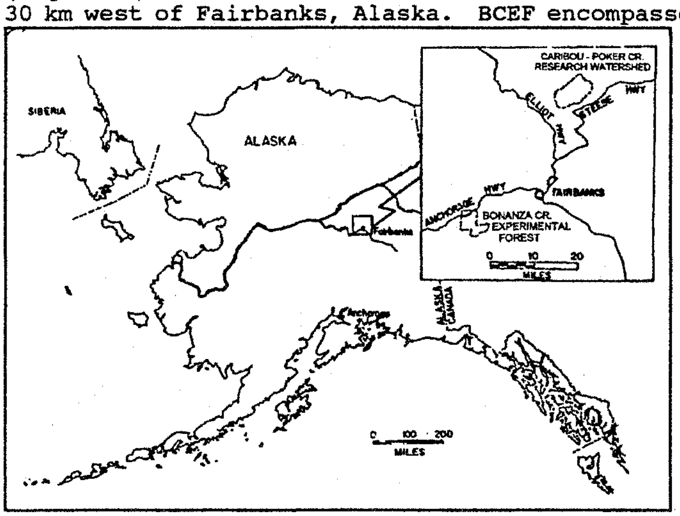

Figure 1. Bonanza Creek Experimental Forest/Caribou-Poker Creeks Research Watershed, Alaska.

This range of taiga environment provides opportunity for study of the two major snow "types" occuring in central Alaska: "tundra" snow is characterized by extensive reworking by wind and a high-density wind slab underlain by low-density depth hoar, and is found at higher elevations in CPCRW and at some exposed sites on the Tanana River floodplain in BCEF; "taiga" snow is characterized by extremely low density at initial deposition (0.05 to 0.15 g cm^{-3}, lack of reworking by wind, extensive depth hoar formation, and low snowpack density at spring snowmelt (Trabant and Benson, 1972; Slaughter and Benson 1986).

Table 1. Snow research and monitoring installations, Bonanza Creek Experimental Forest/Caribou-Poker Creeks Research Watershed Taiga Long-Term Ecological Research.

Installation	Parameter	Data Base
Bonanza Creek Snow Course	Cumulative snowpack	1966 - present
Caribou Creek Snow Course	" "	1970 - present
Haystack Snow Course	" "	1970 - present
CC Snow Pillow Snow Course	" "	1970 - present
BCEF-LTER-1 Snow Course	" "	1988 - present
BCEF-LTER-2 Snow Course	" "	1988 - present
Caribou Creek Snow Pillow	Accumulation/ablation	1970 - present
LTER1 Snow Pillow	Accumulation/ablation	1989 - present
BCEF-LTER Forest Succession Stands, flood plain and upland	Snow depth, weekly or monthly	1987 - present
IWAES Aerometric Station - CPCRW	Monthly bulk snow chemistry	1993 - present
NADP - CPCRW	Weekly bulk snow chemistry	1992 - present
Stream Gages: Seven in CPCRW	Streamflow - hourly during open-water season	1969 - present

Snowpack studies at BCEF/CPCRW were initiated in the late 1960's (Table 1). Snowpack measurements at four standard (SCS) snow courses are augmented by continuous snow pillow operation to monitor snowfall and ablation in both BCEF and CPCRW. Intensive snow depth/density measurements are conducted in selected floodplain and upland forest stands at BCEF. Precipitation chemistry (rain and snow) is monitored in the Caribou Creek valley (230 m elevation) through the National Atmospheric Deposition Program (NADP). Composite precipitation samples are collected weekly for determination of Ca, Mg, K, Na, NH_4, NO_3, Cl, SO_4, PO_4, pH, and conductivity. The NADP program in CPCRW is complemented by operation at treeline (762 m elevation) of a "Remote Aerometric Station*" which records standard climatic variables and monitors UV-B radiation (280-330 nm); continuous air samples are pumped through a filter pack which is changed monthly and analyzed for SO_4, SO_2, NO_3, HNO_3, NH_4, and O_3. Bulk precipitation samples (composited monthly) from this treeline station are analyzed for Na, Ca, K, Cl, Mg, SO_4, NO_3, NH_4, pH, and electrical conductivity. These inputs complement measurements of water (snowmelt and summer streamflow) in first- and second-order streams in CPCRW which have been monitored (not necessarily continuously) for more than a decade; analysis of streamwater has included determination of NO_3-N, NH_3-NK, ortho-P, total P, Ca, Mg, Na, K, Mn, Fe, As, Cl, Si, specific conductance, pH, and alkalinity. The BCEF/CPCRW snowpack record of more than two decades indicates wide variability in seasonal snow patterns (Figure 2), from maximum accumulation of less than 5 cm SWE (1970) to more than 30 cm SWE (1971, 1991, 1993). The spring ablation period commonly spans two to three weeks (see example in Figure 3) and at CPCRW has been initiated as early as April 8 or as late as April 29. The 2 1/2-decade record at BCEF/CPCRW appears to represent much of the between-year variability in seasonal snowpack in this region, from the low-snow 1970 water year to the extended snow cover (and short snow-free season) of 1992, when spring snowmelt at BCEF concluded May 26 and first permanent snowfall occurred September 10 (Figure 4). This variability under present climate underscores the need for maintaining and extending long-term data bases, to provide a foundation for assessing future change in seasonal snow under altered climate conditions.

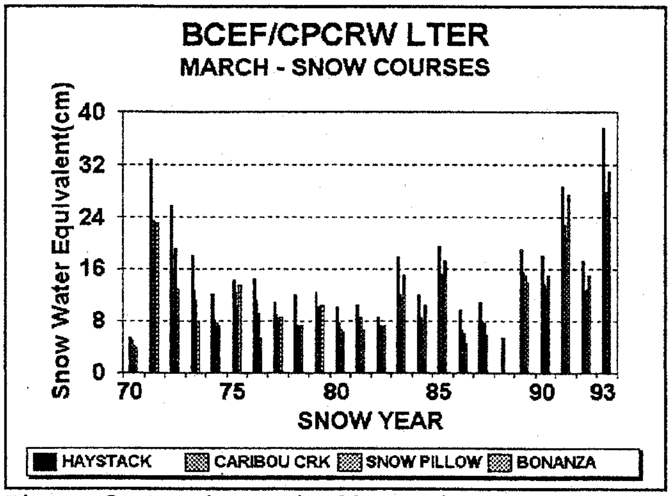

Figure 2. March (typically maximum accumulation) snowpack for BCEF/CPCRW.

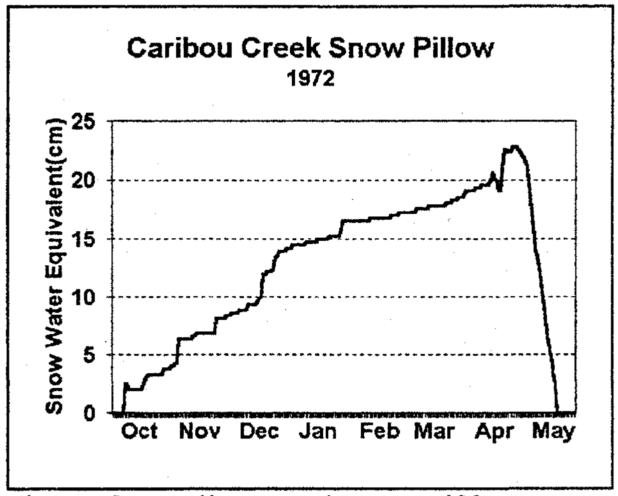

Figure 3. Caribou Creek Snow Pillow record showing typical short, rapid ablation period.

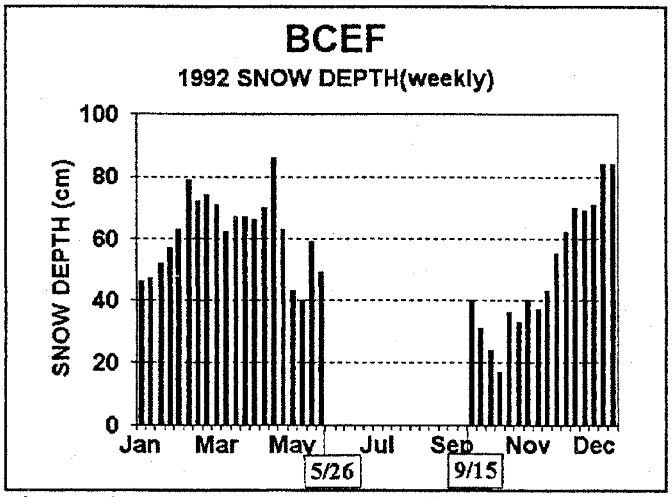

Figure 4. Snow cover at BCEF for 1992.

The long-term and evolving information archive developed in this program constitutes a baseline for evaluation of changing climate in boreal forest ecosystems. The initial value of this work lies in defining threshold conditions under current climate and land use, and providing a basis for future evaluation of change in snowpack regime, landscape conditions, hydrologic response and taiga ecosystem stability. The BCEF/CPCRW Taiga Long-Term Ecological Research facility offers an appropriate field laboratory for research addressing ecological and hydrologic terrestrial/aquatic ecosystem attributes and functioning relating to climate change in the northern boreal forest.

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