DOE/ER/60245--2

DE93 001431

ANNUAL PROGRESS REPORT
for
January 16, 1986 through January 15, 1987

RESEARCH ON THE SEASONAL SNOW OF THE ARCTIC SLOPE

from

Professor Carl S. Benson
Geophysical Institute
University of Alaska
Fairbanks, Alaska 99775

ep

INTRODUCTION

This project deals with the seasonal snow on Alaska's Arctic Slope. Although it is concentrated on snow of the R_4D project area, it is important to relate the snow cover of this area with the rest of the Arctic Slope. The goals include determination of the amount of precipitation which comes as snow, the wind transport of this snow and its depositional pattern as influenced by drifting, the physical properties of the snow, the physical processes which operate in it, the proportions of it which go into evaporation, infiltration and runoff, and the biological role of the snow cover.

SEASONAL SNOW IN ALASKA

Alaska is famous for its glaciers which cover an area of nearly 10^5 km^2. However, glaciers cover only 5% of Alaska's total area (1.5×10^6 km^2) all of which is subjected to seasonal snow. The physical properties of this snow, its thickness, the length of time it remains on the surface, and the physical processes which occur within it, above it, and below it, are of fundamental importance to the physical and biological environment. Alaskan snow varies significantly within its four climatic zones, but can be described according to three extreme types (Benson, 1982).

1. Tundra Snow - primarily above timberline and on the entire arctic slope.
2. Taiga Snow - primarily in the interior, between the Brooks Range and the Alaska Range
3. Maritime Snow - primarily in the coastal mountains of southeastern and southcentral Alaska.

TUNDRA SNOW OF THE ARCTIC SLOPE

Alaska's seasonal snow lasts longest on the Arctic Slope where it is present for three quarters of the year. It differs from the hydrologically important snow of the Western United States in that its temperatures are lower, steeper temperature gradients occur in it, and, except in the maritime region, there is less of it per unit area, but it lasts longer and enters more directly into the ecology (including most human activity) as snow itself rather than serving primarily as a cold storage water reservoir. This snow plays an essential role in physical and biological processes on the Arctic Slope.

In addition to protecting the tundra from damage by vehicles, snow also provides vital protection for microtine rodents during most of their lives. Furthermore, since the Arctic Slope is underlain by permafrost, its hydrology is significantly different from non-permafrost regions where snow dominates the hydrology (such as in parts of the western U.S.).

The importance of snow on the Arctic Slope as a dominant feature of the environment is being increasingly recognized. The U.S. Soil Conservation Service (SCS) has the prime responsibility for snow surveys in Alaska. It began with a network of ten snow courses in 1961 and now operates over 150 of them. The first snow-course measurements in the Arctic began with a Wyoming gage installed by the Geophysical Institute of the University of Alaska in 1975, today 10 or 12 of these gages operate in the Arctic. In spite of this, the SCS currently receives more requests for information about snow on the Arctic Slope than for any other region in Alaska.

From a scientific point of view, there is much to learn about snow on the Arctic Slope. Among the primary questions are:

(1) Quantity

Most precipitation on the Arctic Slope comes in the form of snow and its quantity has been underestimated in the Weather Bureau records by a factor of about three. Overall means, in the Weather Bureau records, from 1961 to 1979 are 11.3 cm for Barrow and 14.4 cm for Barter Island; our corrected values are 25 cm for Barrow and 32 cm for Barter Island (Benson, 1982; Clagett and Benson, 1983).

(2) Wind action

Snow on the Arctic Slope is moved by the wind to a significant but largely unknown extent. The directions of movement, the quantity of mass moved, the distance of movement and the formation of snow drifts are all subjects which need to be studied. As seen by the distribution of snow drifts, two wind directions, one from east-northeast, and the other nearly in opposition from the west, transport virtually all of the wind-blown snow on the Arctic Slope. In the west, at Atkasook, measurements indicate that the flux of wind blown snow from the eastern winds is about twice that from the western winds, and that the values vary significantly from year to year (Benson, 1982). In the southern part of the Arctic Slope, katabatic winds from the Brooks Range blow from the south; this is most pronounced in large river valleys such as the Killik River valley. Wind transport of snow in the R_4D research area is also from the south. The location of the boundary between the two wind systems across the Arctic Slope is not yet known.

(3) Distribution of snow

Significant precipitation gradients exist. From west to east, the snowfall at Barrow is about 80% of that at Barter Island. From north to south, the snowfall at Barter Island is about 60% of the 50 cm measured on the McCall Glacier 100 km south in the Romanzof Mountains. There are regions with minimum snow cover which lie on the slope between the foothills and the Arctic coast (Holmgren, Benson and Weller, 1975). The boundaries of these regions, and the reasons for their existence need to be investigated. They are of special interest because of their use as prime calving ground by caribou (Kuropat and Bryant, 1980).

(4) Physical Properties

The tundra snow on the Arctic Slope is dry and its wind-blown sastrugi surface strongly resembles the year-round surfaces of the Greenland and Antarctic Ice Sheets, or the winter snow surface of the adjacent Arctic Ocean. In many places the structure of the tundra snow resembles the top annual stratigraphic unit of the dry-snow facies of an ice sheet. It consists of a hard, wind-packed layer overlying a low density depth hoar layer. Perhaps the most important feature of the snow pack is its control of the radiation balance by its simple presence or absence. The virtually unbroken tundra snow surface has an albedo (surface reflectivity) of about 80%. When the snow melts, in late May or early June, it disappears rapidly and the albedo drops to about 15% (Holmgren et al., 1975). This five-fold decrease in albedo occurs at the same time when the amount of incident radiation is rapidly increasing, and results in a dramatic change in the amount of absorbed radiation at the surface (Weller et al., 1972; Benson et al., 1975). Similar observations were made on the Canadian tundra by McFadden and Ragotski (1967) who estimated a sixfold increase in absorbed radiation at the surface when the snow melted away.

(5) Physical processes

The snow, the overlying air and the underlying soil and vegetation form a three-layer system in which heat and mass transfer processes are active. These processes lead to hard, wind-packed layers (wind slabs) and soft, low-density depth hoar layers (Benson, 1969). These extreme formations are of special biological significance because animals which live under the snow (like lemmings) depend on the soft depth hoar when they make tunnels, and are partially protected from predators by the wind slabs. Animals which feed by digging through the snow (like Caribou) avoid the wind slabs and depend on the depth hoar to yield food more easily than would hard-packed snow.

Especially interesting phenomena accompany the presence and movement of trace gases in the snow. The most important of these gases is, of course, water vapor because its movement in the snow is essential for metamorphism of the snowpack. The water vapor moves by diffusion and convection (Benson and Trabant, 1972), along vapor pressure gradients which accompany temperature gradients in the snow. This process forms the depth hoar layers and contributes to the formation of wind slabs as well. Another interesting gas is CO_2 which is more concentrated within the snow pack (with highest values at the bottom) than in the overlying ambient air. Not only are the values higher, but they show short-term increases by a factor of two or three in the springtime (Kelley, Weaver and Smith, 1968; Coyne and Kelley, 1974). The reasons underlying these phenomena are not understood.

A significant, but unknown, part of the snow deposited on the Arctic Slope is lost directly to the atmosphere by sublimation and evaporation. Much of this loss occurs while the blowing snow is airborne (Schmidt, 1972; Tabler, 1976), the rest is lost from the surface, especially during spring after vegetation perforates the snow surface (Benson et al., 1975; Dingman et al., 1980). Our research on the 1985 melt season indicates that at least 15% of the snowpack in the R_4D area was lost by evaporation (Liston, 1986).

Because the underlying ground is frozen, infiltration is severely limited and runoff in the streams which are not fed by glaciers is characterized by a large, single pulse during spring breakup (Dingman et al., 1980).

The above phenomena are involved in questions relating to the abiotic environment of natural biological systems and to man-made disturbances of the tundra. Roads and buildings interact with winds to cause variations in the pattern of snow drifts; this in turn modifies temperature and moisture conditions at the base of the snow pack. In particular, drifts formed along roads produce ponding or wet areas parallel to the roads, and the physical processes associated with this require attention. Impurities on the snow, such as road dust, will affect melting and evaporative rates. Unfortunately, we do not understand the undisturbed melt and evaporative losses. In order to deal with these problems it is necessary to know how much snow falls, and how it is moved by wind. In general, this is a difficult problem which requires continued development of theoretical models of snow transport and depositon (Schmidt, 1972; Tabler and Schmidt, 1973; Tabler, 1980), in addition to more field research.

ORIGINAL OBJECTIVES

The original objectives of this research included a regional study of snow on the entire Arctic Slope. During the first year the scope was restricted to the R_4D area. In the second year the primary focus was also on the R_4D area, but measurements were made at Prudhoe Bay, Atkasook and Wainwright to determine the flux of windblown snow on a wider scale. Additional broadening of scope was discussed at the San Deigo R_4D meetings in April 1986. Our plans to accomplish this are discussed below.

MAPPING

Topographic and Orthophoto Maps

The need for accurate topographic maps of the R_4D research area was apparent in this project as well as for all other R_4D projects. A mapping project was added to this project because of the investigator's experience with preparation of aerial photogrammetric maps. Ground control for aerial photogrammetry was established by precision surveying done by Glen Liston and helpers during July and August of 1984. A total of 50 points were surveyed, 13 of which were pre-marked for aerial photogrammetry.

Vertical aerial photographs were taken after all the pre-marked survey points were established. Both black-and-white and color Infra Red (I.R.) photography was done. Because of persistent bad weather in August and September 1984 it was difficult to complete the surveying and the aerial photography. The black and white photos were flown twice before a usable set, free of snow cover, was obtained. The color I.R. photos were not as good as they could be because the time of maximum chlorophyll had passed. Therefore, color I.R. photos were taken again in the summer of 1985 with excellent results.

We worked closely with the photogrammetrists at North Pacific Aerial Surveys (NPAS) in Anchorage to construct stereomodels for the photogrammetry. All survey points were verified on the internally-consistent stereo models. This permitted us to make several products:

1. Orthophoto negatives were prepared and orthophoto maps were made at the scales of 1:6000 and 1:1000.
2. Topographic contour maps were made of the overall area at scale of 1:6000 with 5 m contour interval. These contour maps were printed on top of the orthophoto maps. Two map sheets at this scale cover the overall area.
3. Topographic contour maps were made of the intensive study area at scale of 1:1000 with 1 m contour interval. These contour maps were printed on the 1:1000 scale othophoto maps. Four map sheets at this scale cover the intensive area.

Figure 1a shows the location and relative positions of the six maps which were available for the 1985 spring and summer field season. A report describing the maps was distributed at the R_4D meeting in San Diego during April 1986. The report identifies the U.S.G.S. bench marks used to locate the map and to define a true North azimuth, and lists the coordinates of the 50 control points in the mapped area.

Digitized Topographic Map

A digitized Elevation model (DEM) was prepared by Dr. Gary Petersen of Penn State University for most of the area covered by Map 2 of the 1:6000 series. The area covered corresponds to that identified as the Snow Research area (Fig 1a). A three-quarter image of this model (Fig 1b) helped reveal surface features which were useful when we interpreted photographs of the melting snow cover. We plan to combine the DEM with the digitized snow cover maps, described below. This will be done in cooperation with Dr. Garry Peterson with support from the DOE REFLEX program.

Aerial Photography

At the R_4D meetings in San Diego during April 1986 it was decided that vertical aerial photographs, that could be printed to a scale of 1:500, were needed over the intensive study site. Financial authorization to do this was delayed until the end of August. The photography was done on 6 Sept. Two sets of photos were taken:

(a) Photos at scale 1:3000 for enlargement to scale of 1:500 over the intensive site

(b) Photos at scale 1:9000 for enlargement to 1:1500 over an extended area within Map No. 2 of the 1:6000 series described above.

The delayed date of photography may have resulted in washed-out conditions for the color I.R. imagery. We have not yet seen the processed film.

SUMMARY OF RESEARCH ON SEASONAL SNOW DURING 1984, 1985 AND 1986

During the 1984-85 and 1985-86 snow seasons the snow cover was observed in detail. In addition to measuring its total quantity we determined its distribution as a function of wind action and topography. Observations of meteorological parameters and snowpack characteristics during winter and spring allowed description of the seasonal evolution of the snow in quantitative terms. A method of determining melt rates over large regions was developed and progress was made on a model describing energy flux sources which control snow melting. A strong control is exerted by air mass advection on a broad scale. This combines with local effects as tundra is exposed, absorbs radiation and warms the air. During the 1985 melt period, at least 15% of the winter snow cover was lost by evaporation. The results of this research were summarized in Glen Liston's (1986) MS Thesis completed in Sept. 1986.

Distribution of snow across the R_4D area was measured by combining several techniques. Snow depths were measured along selected traverses and pit studies were made to measure snow density, temperature and hardness profiles. In addition to providing water equivalent of the snow pack, the pit studies allowed us to measure extreme snow types such as wind-slab and depth-hoar layers. Photographs were taken from control points at selected time intervals during each melt season. Three sets of oblique aerial photos were also taken during each melt season. The photography permitted us to extrapolate detailed measurements made at points and on traverses to broad areas. by this means three maps of snow cover during the 1985 spring were made (Fig 2abc). A map showing the maximum water equivalent of the 1984-85 snow pack was constructed from the above described data. This map was digitized and plotted by the North Slope Borough Geographic Information System. It will be presented at the November R_4D meeting in San Diego. It is now in a form where it can be digitally combined with the DEM prepared by Penn State. A reduced version of it is presented in Figure 3.

In the R_4D area snow transport is produced primarily by winds from the south. The sensitivity of snow distribution to topography is pronounced. Accumulation on lee slopes was about 65% more than on windward slopes, even though the slope angles were only 2 to 3 degrees. Some of the variability would not have been so clearly related to topography if our detailed topographic maps were not available. Wind slabs were better developed in the 1984-85 snow pack than in 1985-86. The two melt seasons differed markedly. In Spring 1986 the melt season was delayed by nearly two weeks by advection of cold air from the Arctic Ocean. When it did get underway melting was very rapid and the snow pack disappeared in only half the time taken in 1985.

END

DATE FILMED

12/1/92