SEASONAL SNOWPACK DYNAMICS AND CHEMISTRY IN THE SIERRA NEVADA (CALIFORNIA, USA) AND THE TIEN SHAN (XINJIANG PROVINCE, CHINA)

by

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INTRODUCTION

As part of NASA's Earth Observing System (EOS) we are investigating the hydrology and hydrochemistry of seasonally snow-covered basins. Two of our high-elevation, headwater study sites are the Emerald watershed (ELW) on the western slope of the Sierra Nevada, California (2800 m) and the headwaters of the Ürümqi River in the Tien Shan, Xinjiang Province, northwestern China (3800 m).

The objective of this research is to understand the physical and chemical dynamics of seasonally snow-covered regions of the Earth in an effort to detect changes in global hydrologic and biogeochemical cycles. To realize this objective we are studying drainages ranging from 1 sq km to 1000 sq km in area. Field surveys will be used in conjunction with remote-sensing data to monitor and forecast the impact of global change on both hydrology and hydrochemistry.

STUDY SITES

The Emerald Lake watershed is located in Sequoia National Park in the southern Sierra Nevada of California, about 5 km from the nearest road, with access by trail. This basin has been studied since 1983 by both the California Air Resources Board and the National Park Service to collect baseline data on ecosystems sensitive to acid deposition.

The Emerald Lake watershed is a north-facing, glacial cirque located in the drainage of the upper Marble Fork of the Kaweah River, on the western slope of the Sierra Nevada. The rugged basin is 1.2 sq km in area, ranges from Emerald Lake (2800 m a.s.l.) up to Alta Peak (3416 m a.s.l.), and has a median slope of 31°, although some slopes in the basin are considerably steeper [Dozier et al., 1989]. Exposed rocks make up about 30% of the surface area of the watershed, with unconsolidated clays, sand, gravel, and talus about 50%. There are four major geologic intrusions: the granite of Lodgepole, granodiorite of Emerald Lake, granodiorite of Castle Creek and aplite [Clow, 1987]. Poorly developed soils cover about 20% of the basin, and these are shallow and acidic. Vegetation covers less than 20% of the basin area, with only about 3% of the total area covered by trees (primarily western white pine, *Pinus monticola*). Less than 3% of the basin area contains open water.

The hydrology of the Emerald watershed is dominated by snowfall and snowmelt runoff during the period of March-June [Kattelmann and Elder, 1991]. Two main inflows drain about 60% of the basin and account for more than two-thirds of the annual inflow to the lake. One outflow carries water from the lake through a series of stream reaches and ponds that drain into the Marble Fork of the Kaweah River. During peak runoff there is unchannelized overland flow into the lake. Groundwater seepage from the lake has been investigated and not observed to occur.

The southern Sierra Nevada has a Mediterranean-type climate, with most precipitation falling in the winter. In this region of the Sierra, precipitation is distributed approximately as: 18% in September through November, 50% in December through February, 30% in March through May, and 2% in June through August [Stephenson, 1988]. Precipitation amounts from individual storms can vary from a trace to more than a meter and interannual

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variability in precipitation amount can be great (WY86 SWE of 2000 mm vs. WY88 SWE of 630 mm). During the period of study, precipitation amount varied from a low value of 959 mm (WY 87) to a high value of 2625 mm (WY 86) [Williams and Melack, 1991(a)]. During the summer, occasional rainfall is associated with convective storms either of local origin or associated with subtropical monsoon patterns.

The study watersheds in western China are located in the Daxigou Valley, at the source of the Ürümqi River that runs north to the provincial capital city of Ürümqi. The Tien Shan extends 2000 km west into the Soviet Union and is surrounded on three sides by large deserts, the Gobi to the east, the Taklimakan to the south, and the Junggar Basin to the north. In May 1990 we studied four of the basins located in this study area, three which are covered by glaciers (Glacier #1, east lobe; Glacier #1, west lobe; Glacier #2) and one that is dry when not covered by seasonal snow (Dry Cirque). Watershed areas of these four are in the range of 1-2 sq km, with elevations ranging from 3800 to 4480 m a.s.l. These basins have been studied since 1959 by researchers from the Lanzhou Institute of Glaciology. Data on precipitation, streamflow and meteorological conditions have been collected by a number of provincial agencies.

Central Asia is characterized by a continental climate, with most of the the precipitation falling between June and August. At the site in the Tien Shan annual precipitation ranges from 450-500 mm, all of it snow. A shallow snowpack is present in the spring and runoff begins in early April. During this ablation season meltwater does not immediately enter stream channels. This is due to: (1) refreezing of the snowcover, (2) creation of basal ice layers at the soil/snow interface, (3) growth of superimposed ice in the glaciers of the basin, (4) ice formation in stream channels, and (5) frequent snow storms in spring [Kattelmann and Yang, 1991].

METHODS

At ELW we measured snowpack composition in March-April by taking integrated samples from four to six snowpits located throughout the watershed. We collected 40-cm increment cores (in duplicate) to within 10 cm of the bottom of the pit. Snow cores were transferred to polyethylene bags and kept frozen until measurements could be made in the laboratory. Snow water equivalence (SWE) was measured using a 1-L stainless steel cutter [Elder et al., 1991(a)] and a digital scale. Once the snow samples were melted, we measured pH and conductance with standard meters, ammonium by colorimetry and major anions and cations by ion chromatography and atomic absorption spectrophotometry (on filtered samples) [Williams and Melack, 1991(b)].

In the Tien Shan we collected snow samples from four pits in each of the four test basins, with four snow cores collected per pit. Techniques used were similar to those described for work at ELW. However, snow samples were melted at the Upper Glacier Research Station, and pH, conductance and acid neutralizing capacity (ANC, by titration) determined on site. Samples were filtered and kept cold during transport back to the U.S. Duplicate samples are being analyzed at the Lanzhou Institute for major anions and cations.

Glacier mass balance measurements have been made by Chinese researchers for a number of years because of the importance of the runoff as a water source for agriculture and municipal use in Xinjiang Province. We participated in a comparison of techniques for estimating SWE on Glacier #1 by taking snow density measurements at four pit locations and depth measurements along transects of the glacier area.

Total precipitation at the Tien Shan site has been collected using Belfort weighing rain gauges. At ELW we used Belforts to measure rainfall; snowfall was estimated by measuring either snow events or total snowpack at maximum accumulation.

RESULTS

Two site comparisons are presented here. Additional data on the hydrology and hydrochemistry of the Sierra Nevada are available in the cited references. Details of the Tien Shan glacier mass balance comparison are available in Elder et al. [1991(b)]; hydrochemical information is provided in Williams et al. [1991].

Figure 1 presents the average precipitation depth for ELW and the Tien Shan. The seasonal differences in precipitation are a function of the different climate regimes. At the study site in the Tien Shan all precipitation is snow; in the Sierra Nevada 80-95% of annual precipitation is snow.

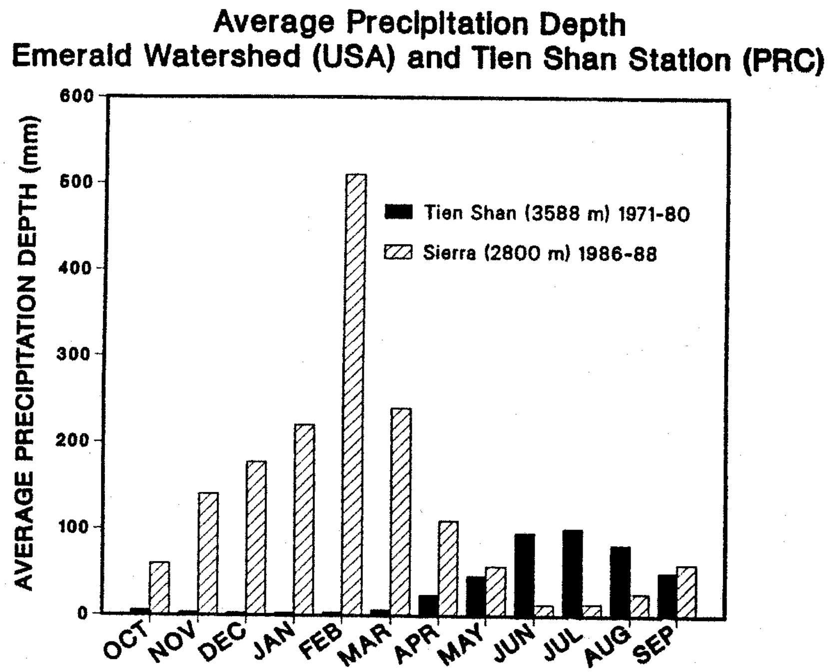

FIGURE 1

Table 1 provides a comparison of the range of chemical values measured in the snowpack of ELW and the Tien Shan basins. In general the snowpack of ELW is more dilute than that of the Tien Shan for all chemical species measured, including ANC (trace conc. vs. approx. 50 ueq/L). These chemical differences may be attributed to the presence of dust layers found throughout the Tien Shan snowpack. Snowpack concentrations of calcium, ANC, and hydrogen ion differ significantly from that of new snow in the Tien Shan, indicating the dissolution of particles and buffering of acidity in situ.

Snow Chemistry

Sierra Nevada (USA) and Tien Shan (PRC)

Chemical Concentration	Emerald Watershed Sierra Nevada	Glacier No. 1 Ürümqi Valley Tien Shan
pH	5.1 - 5.4	6.4 - 7.2
Conductance (μS/cm)	2.2 - 3.9	3.1 - 11.3
Ca^{2+} (μeq/ℓ)	1.3	60.7
Na^{+} (μeq/ℓ)	1.3	27.9
NO_3^{-} (μeq/ℓ)	2.3	3.7
SO_4^{2-} (μeq/ℓ)	2.0	23.3

TABLE 1

FUTURE WORK

We will continue regular monitoring of snow hydrology and chemistry at ELW and the larger watershed of the Marble Fork of the Kaweah throughout the ten-year EOS Interdisciplinary Investigation. During summer 1991 we will collaborate with Chinese researchers to set up a permanent hydrochemical monitoring program in the Tien Shan. In addition, snow properties will be measured at both locations for "ground truth" to verify remote sensing information collected during EOS using such instruments as HIRIS (High-Resolution Imaging Spectrometer), SAR (Synthetic Aperture Radar), and MODIS (Moderate-Resolution Imaging Spectrometer).

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