ASSESSING THE SIGNIFICANCE OF EVAPO-SUBLIMATION IN NORTHERN ARIZONA

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Abstract

Climatic data for twenty-one winters was used to construct an index in order to assess the significance of evapo-sublimation at Flagstaff, Arizona. Large intra- and inter-annual variability was noted in the record using both *un*corrected monthly index values and values corrected for the relative importance of snow. 1967-68 *un-* corrected sublimation opportunity index (SOI) values and similar values for both 1982-1983 and 1984-1986 appear to indicate that those winters either had unusually high snowpack evapo-sublimation losses, or were years of low "basin efficiencies". Evapo-sublimation opportunity might be tracked as a climate element for high elevational snowzones which contribute significantly to a regional water supply.

Introduction

The disappearance of a snow cover from the landscape is due to either the melting and/or the evapo-sublimation of the snowpack and it is proposed that an awareness of, if not a concern with, the evapo-sublimation component of snow ablation should be included in snow management considerations or snow enhancement schemes. Figure One illustrates some pathways by which snow can evapo-sublimate: it also underscores the reality that not all the snowpack's water always enters the soil as melt.

<Figure One>

Probably for many reasons evapo-sublimation is given only a slight treatment outside of definitional considerations in the published literature.

Moreover not the least of the difficulties in resolving the issue of its importance is the separating of sublimation losses from other "measurement uncertainties". In the 1960-1970 period a number of significant papers called

for definitive measurements of evapo-sublimation in order to assess its significance to (total) ablation [Schmidt, 1991] but in general most forecasting techniques have been "improved" by the observation that basin efficiencies can be increased as evapo-sublimation losses are reduced and so the direct measurement of factors assumed responsible for evapo-sublimation was proposed [Peak, 1969]: to date no methodology for determing total seasonal sublimation loss has been forthcoming.

A review of published sublimation literature underscores the wide range of importance that has been given this process and therefore a recent effort was made to assess the probable significance of sublimation to snowpack disappearance on northern Arizona watersheds.

Background

Sublimation is defined as the conversion of a solid substance into its gaseous state. While for many substances the vapor pressure of the solid material is extremely small, others, like water and carbon dioxide, have an appreciable vapor pressure, and, if the vapor is not contained, the solid form can be converted to the gaseous form in a relatively short time. The often-cited "triple-point" expresses that place on the temperature-vapor pressure curve where all three phases can co-exist: for water that point is found at 4.6 millimeters (Hg) pressure and at 0.01 degrees (C) temperature. The process of evapo-sublimation (ie: the conversion of a solid to its vapor phase either directly or through the liquid phase requires that the latent energy needed both for vaporization and for melting be supplied to the surface. As there is uncertainty regarding the partitioning of the energy balance into the fractions for latent energy and for sensible energy at the freezing point it remains unclear whether a sufficiently steep vapor pressure gradient and/or sufficient net radiation is (are) the driving force(s) in this process.

Objectives & Methods

The objective of this work was to assess the variability and significance of evapo-sublimation to snowpack ablation in northern Arizona. The approach we took for this assessment was to develop a "Sublimation Opportunity Index" based on available archived climatic data for Flagstaff, Arizona. Although indices are imprecise aggregations of assumed factors, their utility is not without recognizable value and wide acceptance (ie: the Palmer Drought Severity Index) and the rational construction of an index may lead to clarifying some otherwise obscure relationships. We determined to construct

an evapo-sublimation algorithm based four factors which we could reasonably derive from the National Weather Service three-hourly observations for the period 1965-1986. These four factors are;

1. vapor pressure gradient
2. wind run
3. radiation

and 4. air temperature.

As we also had access to the data in the monthly climatic summaries, and we were required-due to an absence of certain data values- to approximate several components needed to formulate the above-noted factors [namely, snow depth, snow surface temperature and all radiant energy values], we also decided to use that set's daily observed value for morning " snow-on-the-ground" to control the Sublimation Opportunity Index.

From the data available to us we constructed an approximately even-weighted 3-hourly index value that was set to zero in the absence of morning snow-on-the-ground values for any day in the 21-year record. The index values were summed over each valid day and for each of the eight months (October-May) in the year at hand. Figure Two illustrates this procedure and the scaling factors used to weight the values.

<Figure Two>

Results & Discussion

From the 21-year data sets we developed two distinct indices: the first, a monthly *un*corrected value and the second, a monthly index value corrected for the actual days in the month which had snow. The results are indicated by Figure Three and Table One.

<Figure Three> <Table One>

The between-year variability illustrated by Figure Three is further expanded by Figure Four and Figure Five which, respectively, demonstrate the intra-year variability by months as a function of the percentage of each month with snow. The years chosen for these figures were years with exceptional snowfall and little runoff (1967-68) and low snowfall but average runoff (1984-85). Note that Figure Four uses the corrected values, while Figure Five uses *un* corrected SOI values. Tables One (above) and Two list the values used to construct these figures and their statistics.

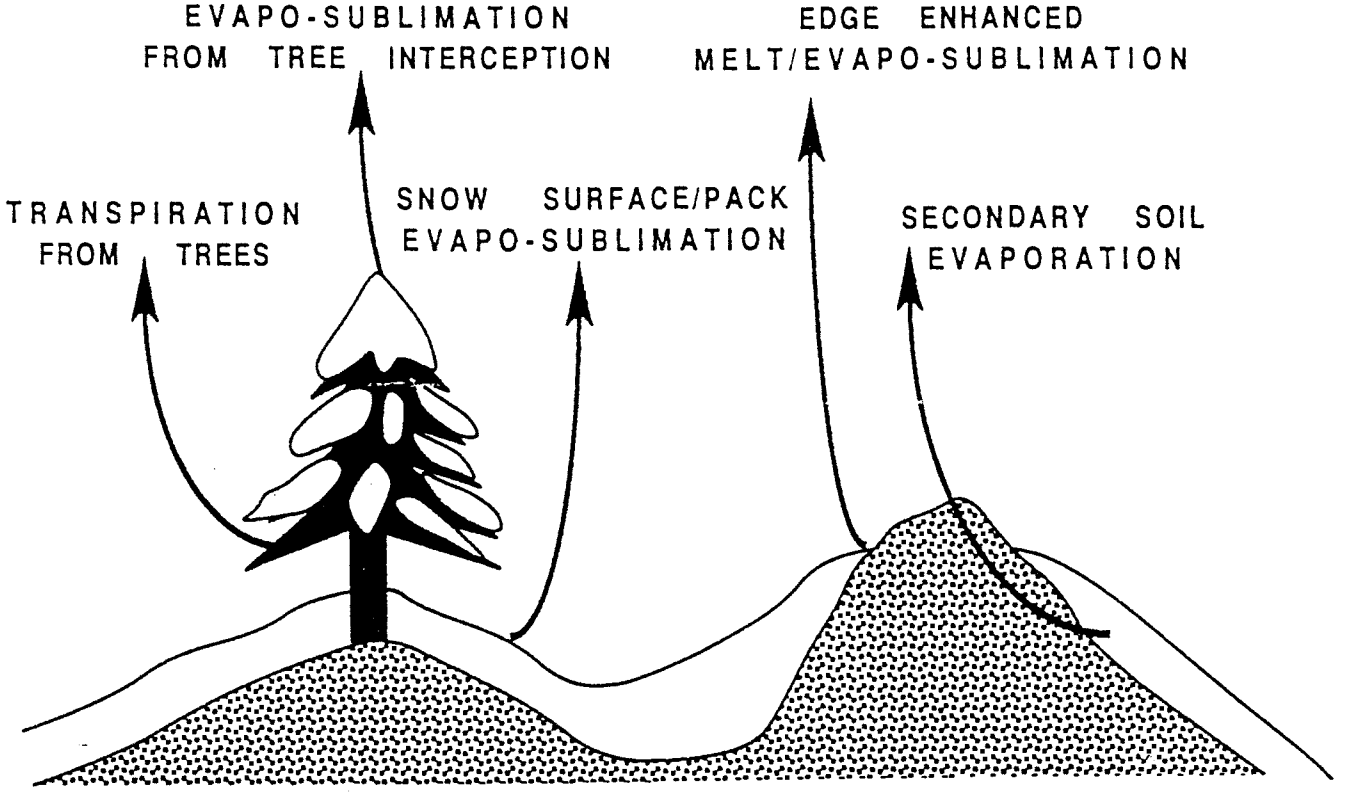

FIGURE ONE: Possible Routes for Abstractions Before Snowmelt Runoff, Emphasing Evapo-Sublimation and Excluding Inflitration.

SUBLIMATION OPPORTUNITY INDEX ALGORITHM

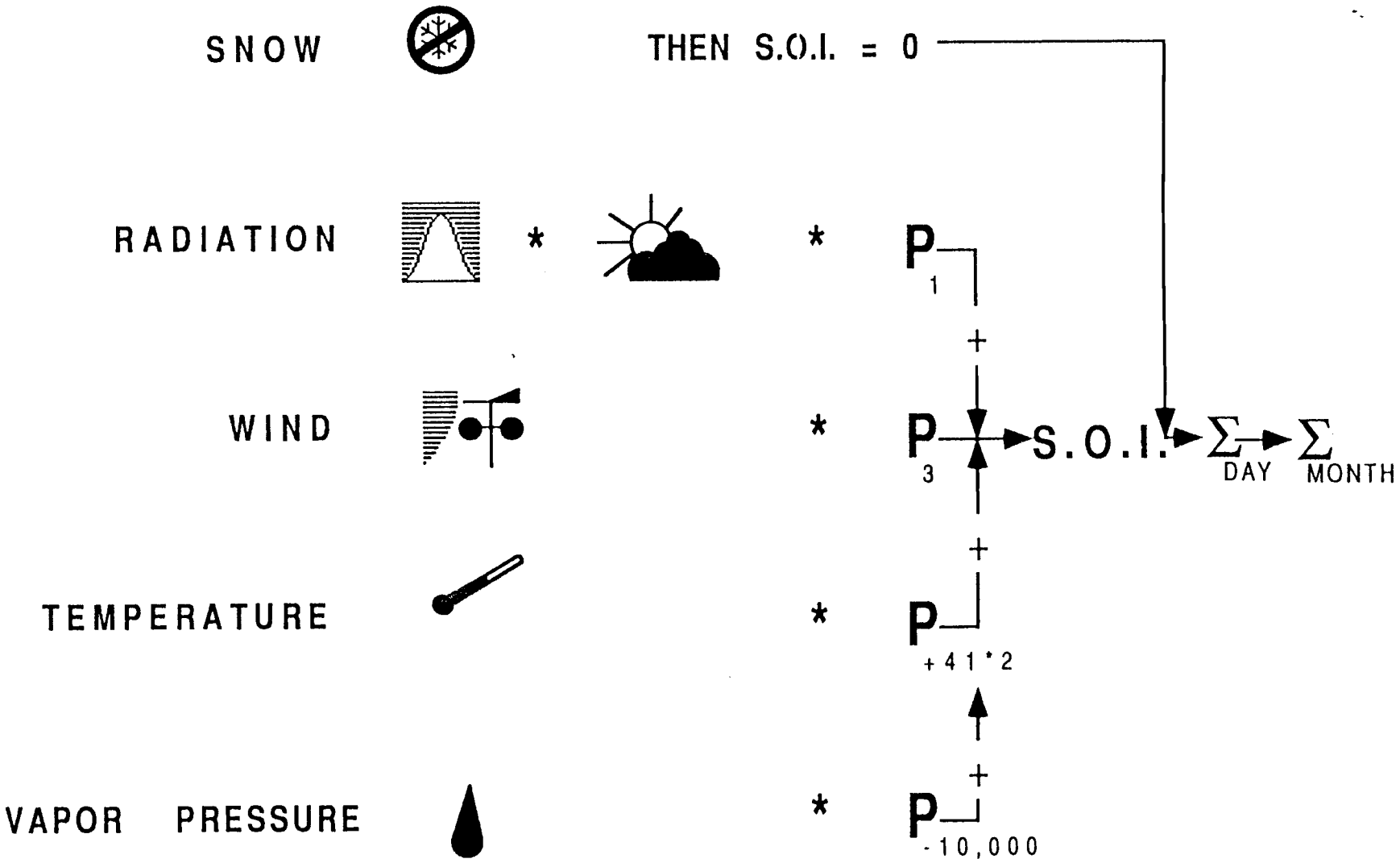

FIGURE TWO: Schematic Representation of the Sublimation Opportunity Index (S O I) Algorithm

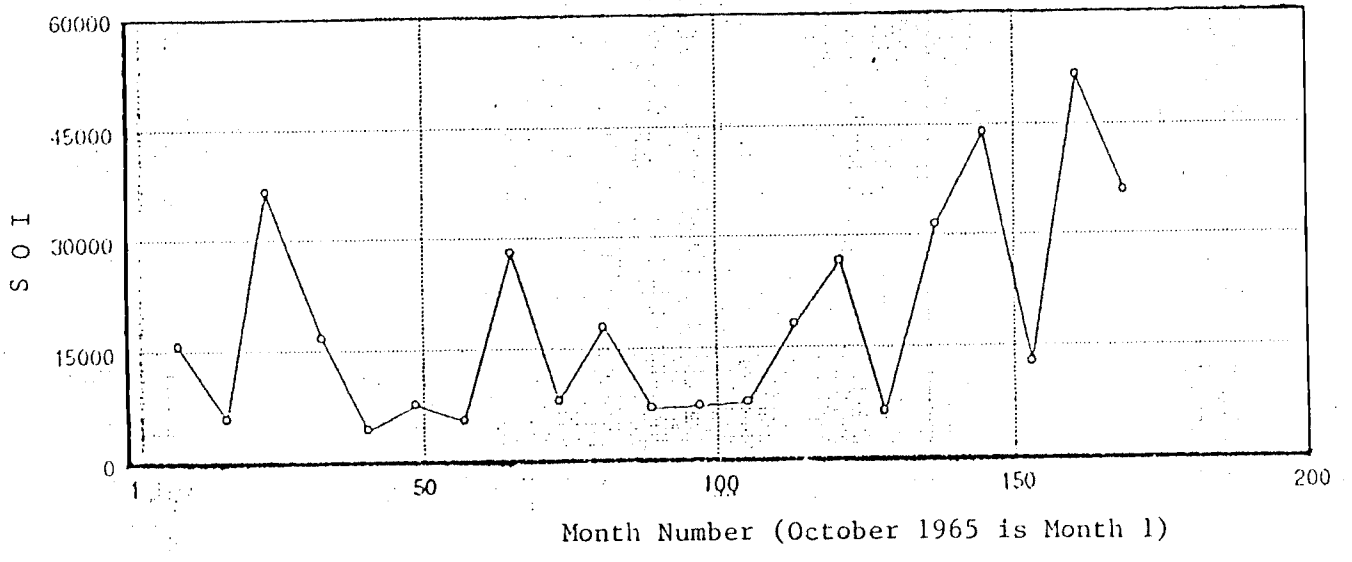

Figure 3: Sublimation Opportunity Index by Month

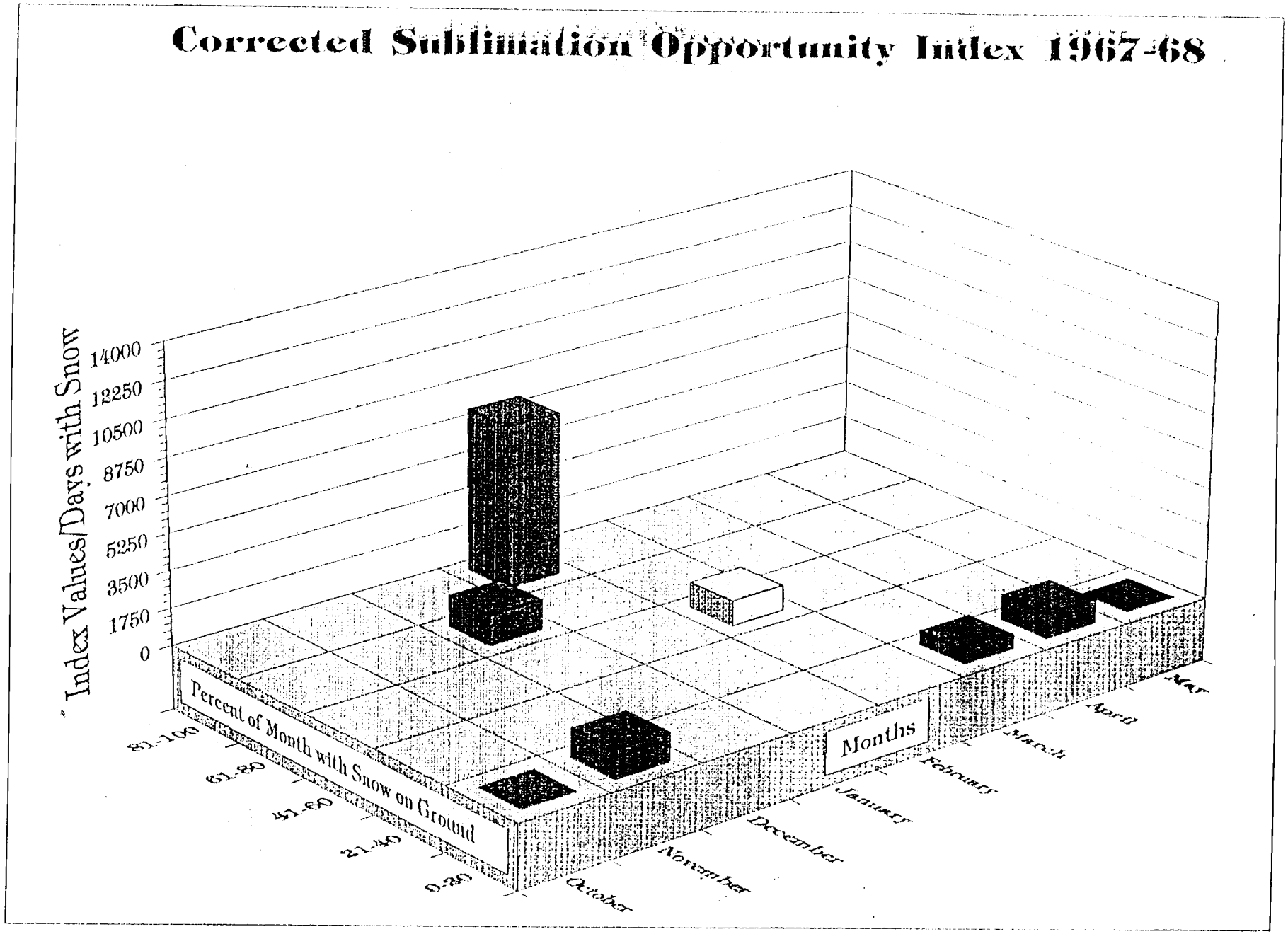

Figure 4: Corrected Sublimation Opportunity Index 1967-1968

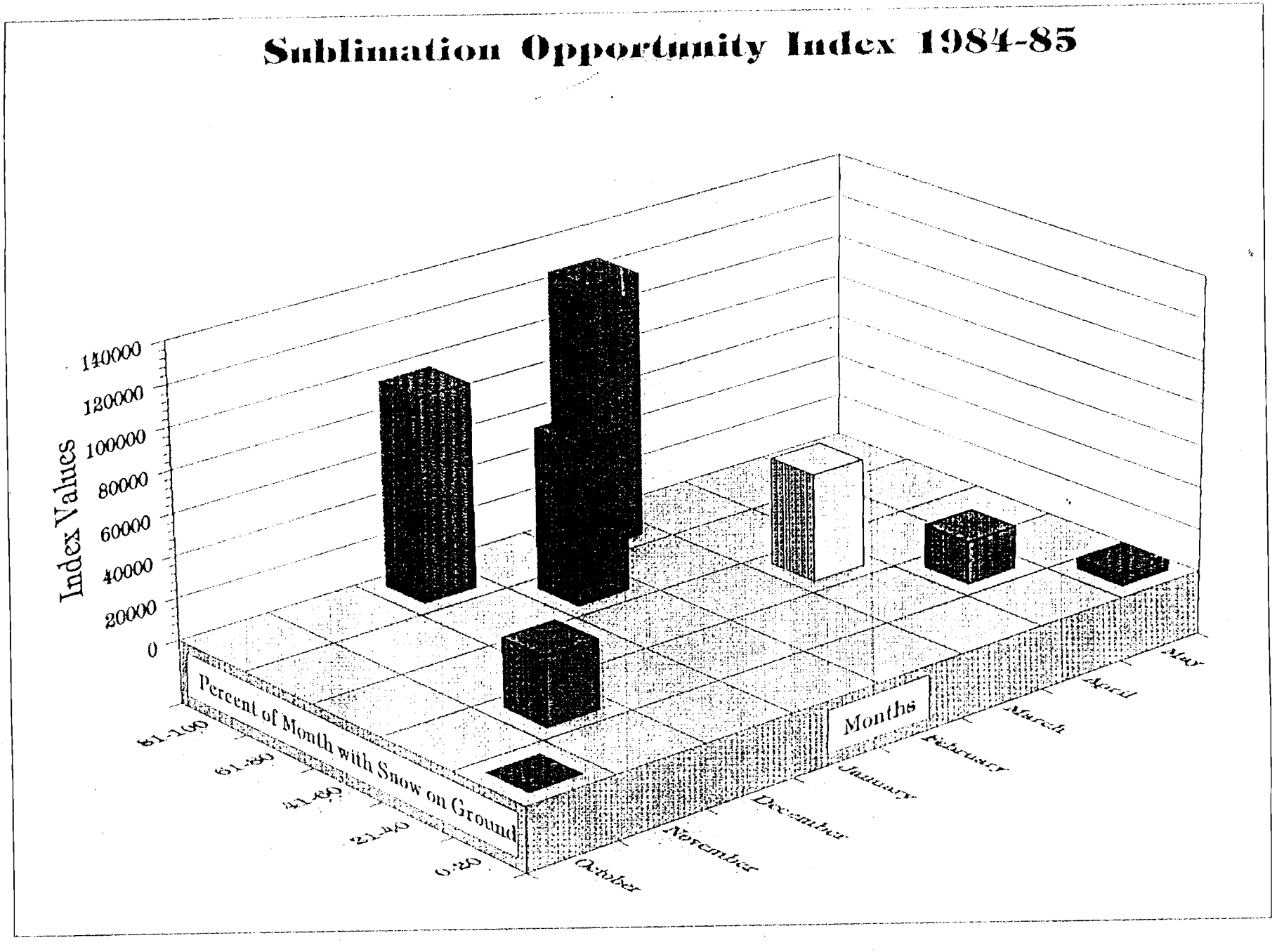

Figure 5: Sublimation Opportunity Index 1984-1985

DATE	UNCORRECTED SUBLIMATION OPPORTUNITY INDEX	% DAYS WITH SNOW ON GROUND IN MONTH
OCT 65-66	0.00	0.00
NOV	1898.00	3.33
DEC	27428.71	70.97
JAN	43163.23	87.10
FEB	39828.21	75.00
MAR	10981.94	19.35
APR	2170.00	3.33
MAY	0.00	0.00
OCT 66-67	0.00	0.00
NOV	4590.00	10.00
DEC	7072.26	12.90
JAN	24162.58	45.16
FEB	0.00	0.00
MAR	5143.27	9.44
APR	5497.00	13.33
MAY	0.00	0.00
OCT 67-68	0.00	0.00
NOV	2648.31	6.67
DEC	27807.49	61.29
JAN	238723.26	100.00
FEB	20295.00	58.62
MAR	1343.09	6.45
APR	2312.93	6.67
MAY	0.00	0.00
OCT 68-69	0.00	0.00
NOV	444.00	3.33
DEC	28307.42	51.61
JAN	19060.65	41.94
FEB	40048.93	78.57
MAR	45655.16	74.19
APR	0.00	0.00
MAY	0.00	0.00
OCT 69-70	0.00	0.00
NOV	0.00	0.00
DEC	0.00	0.00
JAN	1327.74	3.23
FEB	0.00	0.00
MAR	20119.35	45.16
APR	12748.00	20.00
MAY	0.00	0.00
OCT 70-71	0.00	0.00
NOV	998.00	3.33
DEC	18244.12	45.16
JAN	30860.80	58.06
FEB	0.00	0.00
MAR	10825.95	16.13
APR	1356.69	3.33
MAY	0.00	0.00
OCT 71-72	11739.92	25.81
NOV	2526.96	6.67
DEC	30340.83	61.29
JAN	0.00	0.00
FEB	0.00	0.00
MAR	0.00	0.00
APR	0.00	0.00
MAY	0.00	0.00
OCT 72-73	3218.71	6.45
NOV	20418.00	40.00
DEC	49224.45	80.60
JAN	49733.23	100.00
FEB	40492.50	100.00
MAR	32347.74	100.00
APR	28687.00	50.00
MAY	0.00	0.00
OCT 73-74	0.00	0.00
NOV	12797.00	40.00
DEC	4700.32	9.68
JAN	37476.77	96.77
FEB	3893.57	7.14
MAR	5063.23	12.90
APR	0.00	0.00
MAY	0.00	0.00
OCT 74-75	1533.87	6.45
NOV	8674.00	23.33
DEC	15196.45	29.03
JAN	37766.13	67.74
FEB	49969.29	92.86
MAR	19940.32	38.71
APR	10401.00	23.33
MAY	1324.84	3.23
OCT 75-76	0.00	0.00
NOV	4657.00	10.00
DEC	51186.29	100.00
JAN	0.00	0.00

Table 1: Tabular Values of Uncorrected Sublimation Opportunity Index (part 1)

FEB	0.00	0.00
MAR	0.00	0.00
APR	0.00	0.00
MAY	0.00	0.00
OCT 76-77	0.00	0.00
NOV	0.00	0.00
DEC	0.00	0.00
JAN	16198.06	67.74
FEB	22401.43	17.86
MAR	9658.80	12.94
APR	6656.00	13.33
MAY	4459.35	0.00
OCT 77-78	0.00	999.00
NOV	0.00	999.00
DEC	0.00	999.00
JAN	22712.90	70.97
FEB	34072.50	77.86
MAR	2755.16	9.55
APR	1180.00	3.33
MAY	0.00	0.00
OCT 78-79	0.00	0.00
NOV	11173.00	30.00
DEC	34000.65	67.74
JAN	23360.32	58.06
FEB	50211.43	100.00
MAR	26189.03	48.39
APR	0.00	0.00
MAY	0.00	0.00
OCT 79-80	0.00	0.00
NOV	5809.00	10.00
DEC	13039.35	32.26
JAN	39483.87	87.10
FEB	50217.93	96.55
MAR	102400.65	25.81
APR	3759.00	6.67
MAY	0.00	0.00
OCT 80-81	966.77	3.23
NOV	0.00	0.00
DEC	2246.13	6.47
JAN	3870.00	9.68
FEB	12078.21	28.57
MAR	17349.68	51.61
APR	5802.00	10.00
MAY	0.00	0.00
OCT 81-82	0.00	0.00
NOV	2820.00	3.33
DEC	27111.58	32.34
JAN	103867.74	100.00
FEB	80728.93	78.57
MAR	32763.87	29.03
APR	4220.00	3.33
MAY	0.00	0.00
OCT 82-83	0.00	0.00
NOV	11332.00	10.00
DEC	118853.23	100.00
JAN	57668.71	41.94
FEB	103328.57	78.57
MAR	54410.32	45.16
APR	6901.00	10.00
MAY	0.00	0.00
OCT 83-84	0.00	0.00
NOV	41620.00	33.33
DEC	28530.00	25.81
JAN	23410.65	16.13
FEB	0.00	0.00
MAR	0.00	0.00
APR	8468.00	6.67
MAY	0.00	0.00
OCT 84-85	0.00	0.00
NOV	32793.00	26.67
DEC	98080.65	93.55
JAN	76814.52	67.61
FEB	126863.57	85.71
MAR	51033.87	41.94
APR	20457.00	20.00
MAY	5594.52	6.45
OCT 85-86	0.00	0.00
NOV	88150.00	66.67
DEC	36431.61	32.26
JAN	0.00	0.00
FEB	77786.79	67.14
MAR	83766.11	70.97
APR	0.00	0.00
MAY	0.00	0.00

Table 1: Tabular Values of Uncorrected Sublimation Opportunity Index (part 2)

SOI	Mean	Median	Max	Min
OCT	831 -		11740	0
NOV	12064	4590	88150	0
DEC	29419	27429	118853	0
JAN	40460	24163	238723	0
FEB	35820	34073	126864	0
MAR	25321	17350	102401	0
APR	5744	3759	28687	0
MAY	542	0	5594	0

Annual Mean	Median	S=	K=
18775.0	4623.0	3.2	17.9

CORR SOI

OCT	990	0	1610	0
NOV	1831	1323	4407	0
DEC	1914	1619	3834	0
JAN	2151	1466	7701	0
FEB	2150	1793	5286	0
MAR	2431	1746	12798	0
APR	1829	1486	4231	0
MAY	1100	0	2798	0

Annual Mean	Median	S=	K=
1799.0	1301.0	3.6	23.7

Table 2: Monthly Values and Statistics for SOI and Corrected SOI, 1965-1986