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HAINES INDEX CLIMATOLOGY FOR THE WESTERN UNITED STATES

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Introduction

For years, atmospheric instability and dry air have been associated with the development of large wildland fires in the United States. Brotak and Reifsnyder (1977) analyzed characteristic values of low-level atmospheric lapse rates on a number of large wildland fires in the eastern United States. They found that a majority of the major fire runs occurred on days when the atmospheric lapse rate in the vicinity of the fire exceeded the standard atmospheric lapse rate. Haines (1988) conducted a rudimentary comparison of atmospheric lapse rates and dry air during or immediately before large wildland fires with those expected climatologically. Results from his study provided further evidence of a strong relationship between environmental lapse rates, dry air, and large fire growth. More recently, Potter (1996) conducted a detailed statistical analysis on a number of atmospheric properties to determine which parameters varied significantly from climatology on days with large wildfire growth. He concluded surface temperature, surface dew-point depression, and surface relative humidity differed significantly from climatology on days with large wildfire growth.

However, Haines (1988) was the first researcher to devise a national fire-weather index based on the stability and moisture content of the lower atmosphere. Originally called the Lower Atmospheric Severity Index (LASI), it is now commonly referred to as the Haines Index, as a tribute to the pioneering work done by Haines in the field of fire and forest meteorology.

Due to large differences in elevation across the United States, three combinations of atmospheric layers were used to construct the index. The layer chosen for each Region was thought to be high enough above the surface to avoid major diurnal changes in temperature and relative humidity caused by solar insolation, or the effects of surface-based inversions on temperature and humidity. Figure 1 shows a map of the United States divided into the three regional areas based on surface elevation. In the mountainous Region of the western United States, the index uses the 70-50 kPa (~10,000-18,000 feet) temperature difference and the temperature-dew point spread at 70 kPa (~ 10,000 feet).

The Haines Index is calculated by adding a temperature term (A) to a moisture term (B). Values from 1 to 3 are assigned the temperature term depending on the magnitude of the temperature difference within the predefined layer for each Region. The moisture term also receives values from 1 to 3, depending on the dryness of the layer's lower level. The resultant Haines Index varies from 2 to 6. A 2 indicates moist, stable air while a 6 indicates dry, unstable air. The potential for large fire growth or extreme fire behavior is very low when the index is 2, but high when the index is 6. Table 1 shows the temperature and moisture limits used to compute the high-elevation Haines Index.

Land management agencies and fire weather meteorologists have used the Haines Index operationally since the early 1990s as an indicator of the potential for extreme fire behavior, e.g., high rates of spread, extensive spotting, prolific "crowning", or the development of large convection columns. Research by Werth and Ochoa (1990) found correlation between a Haines Index of 5 or 6 and large wildfire growth in central Idaho. Other fire weather meteorologists and fire managers in the western United States have also associated a Haines Index of 5 or 6 with extreme fire behavior.

Haines developed a Haines Index climatology for the high-elevation West using radiosonde data from Winslow, Arizona for the 1981 fire season. He concluded atmospheric conditions during the 1981 fire season were representative of the long-term climate, since fire activity (number of fires and acres burned) in the U.S. national forest was near normal that year. Preliminary results from his study indicated 6% of all fire season days fall within the high-index category (6) with 62% in the very low-index category (2 or 3).

This study establishes a more detailed, high-elevation Haines Index climatology for the western United States based on 1990-1995 upper-air data from the 20 radiosonde sites located in the western United States. National figures for both the number of fires and the number of acres burned were near normal during the period with an average of 74,963 fires and 2,891,966 acres per year. This compares with the 10 year average (1987-1996) of 73,914 fires and 3,2270,669 acres burned per year. Nationwide, fire activity was near normal in 1991 and 1992, below normal in 1993 and 1995, and above normal in 1990 and 1994.

Maps and frequency tables of the observed Haines Index are constructed for June through October for 1200 UTC (0500 PDT or 0600 MDT) and 0000 UTC (1700 PDT or 1800 MDT) upper-air soundings. Some of the questions this study attempts to answer are:

1. What is the frequency of Haines 5 and 6 days in the western United States?

2. Does the frequency of Haines 5 and 6 days vary by location?

3. Is there a significant diurnal difference in the frequency of the Haines Index between 1200 UTC and 0000 UTC?

4. Are there monthly variations in the Haines Index?

5. Is the frequency of Haines 5 and 6 days unusually high in California as many California fire weather meteorologists claim?

Methods

Daily upper-air data were collected for the 20 radiosonde sites (Fig. 2) located in the western United States for the period June through October from 1990 to 1995. For each station, the Haines Index was calculated using the high-elevation limits described in Table 1. Separate data sets were constructed for 1200 UTC and 0000 UTC. Each data set included 600 to 700 days of Haines Index values for each site. Seasonal (June through October) frequency distribution tables were constructed for each radiosonde site (Table 2).

Individual data sets were developed for each station using 0000 UTC Haines Index data for the same time period. Data for each station were further stratified by month to show monthly trends in the Haines Index. Table 3 summarizes the monthly frequency distribution for each radiosonde site. Afternoon upper-air data were utilized in this portion of the study since 0000 UTC is either during, or just after the most active burning period (usually mid- to late-afternoon) for non-winddriven fires in the western United States. It was also consistent with data used in Haines' study.

Additional data sets were created for a smaller subset of stations using June through September 0000 UTC data for 1994. For each site, calculated values of the Haines Index were separated into their individual components, i.e., moisture and stability. Data were then entered into spreadsheets for further statistical analysis.

Results

a. Haines Index Frequency by Site

Haines' original research indicated a high-elevation Haines Index of 6 should occur about 6% of the fire season days in the western United States. However, this study found large differences in the frequency of Haines 6 days across the western United States at 0000 UTC. It varied from less than 1% at UIL, GEG, GGW, and SLE to over 30% at ELY (Fig. 3).

A statistical analysis of the 0000 UTC data showed a correlation of 0.83 between radiosonde site surface elevation and the frequency of Haines 6 days at 0000 UTC (Fig. 4).

b. Diurnal Variation of the Haines Index

Haines speculated indices calculated from the morning (0500 PDT or 0600 MDT) upper-air soundings might be more useful in predicting large wildfire growth later in the day during the most active portion of the burning period. The question then arises, "Are there significant differences between Haines Index frequencies calculated from morning upper-air soundings and late afternoon or evening soundings?" Results from this analysis indicated the frequency of Haines 6 days at 1200 UTC varied from less than 1% at UIL, GEG, GGW, SLE and MFR to over 10% at SLC, DEN and GJT (Fig. 5). Large increases in the frequency of Haines 6 days were noted in the Great Basin and the Rocky Mountains south of Montana, while little or no change was noted elsewhere (Fig. 6). The increase was most pronounced in Nevada, Utah, Colorado, Wyoming, northern Arizona, and northern New Mexico where surface elevations generally exceeded 1000 meters M.S.L.

Holtzworth (1972) found that afternoon mixing heights in this area of the United States are climatologically between 4,000 and 5,500 meters during the summer (Fig. 7). At these sites, convectively-driven thermals of buoyant surface air rise to great heights in the atmosphere, transporting sensible heat throughout the depth of the mixed layer. Figure 7 shows that at most of the high-elevation sites in the west, the depth of the mixed layer encompasses most, if not all, of the layer used to calculate the high-elevation Haines

Index. Therefore, as the day progresses, the temperature difference within this layer increases, eventually equaling or surpassing 22°C, the limit defined by Haines for unstable air (category 3). Diurnal increases in the temperature at 70 kPa (~10,000 feet) would also modify the dew-point depression, resulting in a higher frequency of days with very dry air (category 3) at these sites. Figures 8, 9, and 10 illustrate this principle by showing the frequency distribution of the 70-50 kPa temperature difference at three radiosonde sites in the western United States for the summer of 1994. Plots of both 1200 UTC and 0000 UTC frequency distribution curves are included in each graph. Thin vertical lines with arrows at each end mark the temperature difference limits defined by Haines for high elevation stations.

The frequency distribution for the low-elevation site of UIL approached a normal distribution curve with equal tails to the right and left of intermediate values (Fig. 8). There was little change in the frequency distribution from morning (0500 PDT) to afternoon (1700 PDT). On most days, the temperature difference fell within category 1, indicating stable air which would tend to restrict large-scale, vertical motion. As shown in Fig. 8, there were no days with category 3 temperature differences at UIL during the summer of 1994.

The frequency distribution for the mid-elevation site of BOI also approached a normal distribution (Fig. 9). However, in this sample, a majority of the days fell within category 2 with smaller percentages in categories 1 and 3. Again, there was no significant change in the frequency distribution between morning (0600 MDT) and late afternoon (1800 MDT).

At the high-elevation site of ELY, there were large changes in the frequency distribution of 70-50 kPa temperature difference from morning to afternoon (Fig. 10). The graph approached a normal distribution curve for the morning soundings (0500 PDT), but was highly skewed towards category 3 temperature differences for the late afternoon (1700 PDT) soundings. The average temperature difference increased from 20.4°C in the morning to 22.8°C in the afternoon.

Sites with average afternoon mixing heights below 4,000 meters msl showed only minor changes in the 70-50 kPa temperature difference from morning to afternoon, and little or no change in the frequency of Haines 6 days from morning to afternoon. Figures 7, 8, 9, and 10 provide strong evidence that the diurnal increase in the frequency of Haines 6 days at high-elevation radiosonde sites in the West was the result of diurnal increases in the frequency of category 3 temperature differences, caused by very high, afternoon mixing heights during the summer.

Monthly Variations of the Haines Index

During the month of June, the frequency of Haines 5 and 6 days was 70% in northern Arizona and northern New Mexico, but decreased to only 5 or 6% along the Canadian/U.S. border (Fig. 11). The low occurrence of Haines 5 and 6 days in the north was primarily due to the location of the polar jet stream and the occasional passage of Pacific frontal systems, or closed, upper-level low-pressure systems over the Pacific Northwest and the northern Rockies. In July, the maximum shifted north into Nevada, Utah, and western Colorado, while the minimum continued along the United States-Canadian border. Further south, over southern Arizona and southern New Mexico, the frequency of category 5 and 6 days dropped dramatically, from nearly 50% in June to around 15% in July (Fig. 12). The influx of monsoonal moisture from Mexico was responsible for the large decrease at ELP, TUS, INW, and ABQ in July.

Idaho and Wyoming had their highest frequency of Haines 5 and 6 days in August (Fig. 13). A maximum extended from central Nevada into western Wyoming. Frequencies in the southern Great Basin continued to be high, but were much lower than July, due to the occasional northward surge of monsoonal moisture. A minimum frequency of 2% extended across southern Arizona and southern New Mexico as the southwest monsoon intensified and pushed further north (see ELP, ABQ and INW in Fig. 18).

Data showed that Oregon, Washington and northern California had their highest frequency of Haines 5 and 6 days during the month of September (Fig. 14), resulting from the high frequency of days with large dew-point depressions (very dry air) associated with foehn type winds in the Cascade and Sierra Nevada Mountains. A maximum continued across central California and central Nevada, while a minimum (<5%) remained across southern Arizona and southern New Mexico.

In October, the frequency of days with a Haines Index of 5 or 6 diminished significantly in most areas of the West (Fig. 15). During this time of the year, jet stream winds begin to sag further south again, allowing moist, Pacific frontal systems to move further inland across the northern tier states. However, at the same time, the frequency of Haines 5 and 6 days increased again over the desert southwest as the effects of the summertime monsoon ended. In southern California there was a marked increase in the frequency of Haines 5 and 6 days due to the drying effects of strong Santa Ana winds associated with the occasional development of high pressure systems over the Great Basin.

When the seasonal frequency of the Haines Index was stratified by month, large variations by area were readily apparent. Monthly variations in the index resulted from changes in the location and strength of the polar jet stream, the onset of the Desert Southwest monsoon, and the occurrence of foehn type winds in the Pacific Northwest and California in the late summer and early fall.

California Haines Index

The final question answered by this study was whether or not California experiences a high frequency of Haines 5 and 6 days. Both OAK and NKX have fewer than 4% of the days with a Haines Index of 6 (Figs. 3 and 5). However, the frequency of Haines 5 days is the highest for both morning and afternoon (Fig. 16). A closer look at the individual components of the Haines Index for OAK (Figs. 17 and 18) revealed that low moisture values, not temperature differences, were responsible for the high number of Haines 5 days in California. The high frequency of dry air resulted from synoptic-scale subsidence associated with subtropical high pressure systems, which usually reside off the California coast during the summer months.

Conclusions

The frequency of days with a Haines Index of 5 or 6 varies significantly from that observed by Haines in his original study. It is much higher in the Great Basin and the central and southern Rockies and much lower in the Pacific Northwest, the northern Rockies, and the California coast.

Large monthly variations in the Haines Index were also noted, resulting from changes in the location and strength of jet stream winds, the development and decay of the Desert Southwest monsoon, and the occurrence of foehn type winds in the Pacific Northwest and California. Monthly charts and tables included in this study should aid fire weather meteorologists and fire managers in assessing when their districts are climatologically most susceptible to days with a high Haines Index.

The data show a significant diurnal increase in the frequency of category 6 days from 1200 UTC to 0000 UTC, especially at high-elevation radiosonde sites in the Great Basin, and the central and southern Rocky Mountains. Similar increases in the frequency of category 5 days can be noted in Table 2. Thus, Haines Indices calculated from 1200 UTC soundings appear to be a better measure of synoptic-scale, atmospheric stability and moisture conditions in the western United States.

High-elevation Haines Indices measured at the coastal, lowland sites of Oakland and San Diego, show the climatological frequency of category 6 days is very low in California, but category 5 days are quite frequent. This suggests that low- or mid-elevation Haines Indices may better reflect the potential for large fire growth in the coastal lowland and interior lowland areas of California, as well as Washington and Oregon. However, high-elevation Haines Indices measured at UIL, SLE, OAK, and NKX may still be appropriate for high elevation areas of the Cascades, Sierra Nevada, and the coastal mountain ranges in Washington, Oregon, and California.

The Haines Index has shown some skill over traditional stability indices in predicting large wildfire growth or extreme fire behavior. However, this study indicates the need for further refinement, to better identify those days from climatology which have a high potential for extreme fire behavior, or large wildfire growth, in the western United States. Modifications to the Haines Index are already being researched by the authors in preparation for a second paper on this topic.

Acknowledgments

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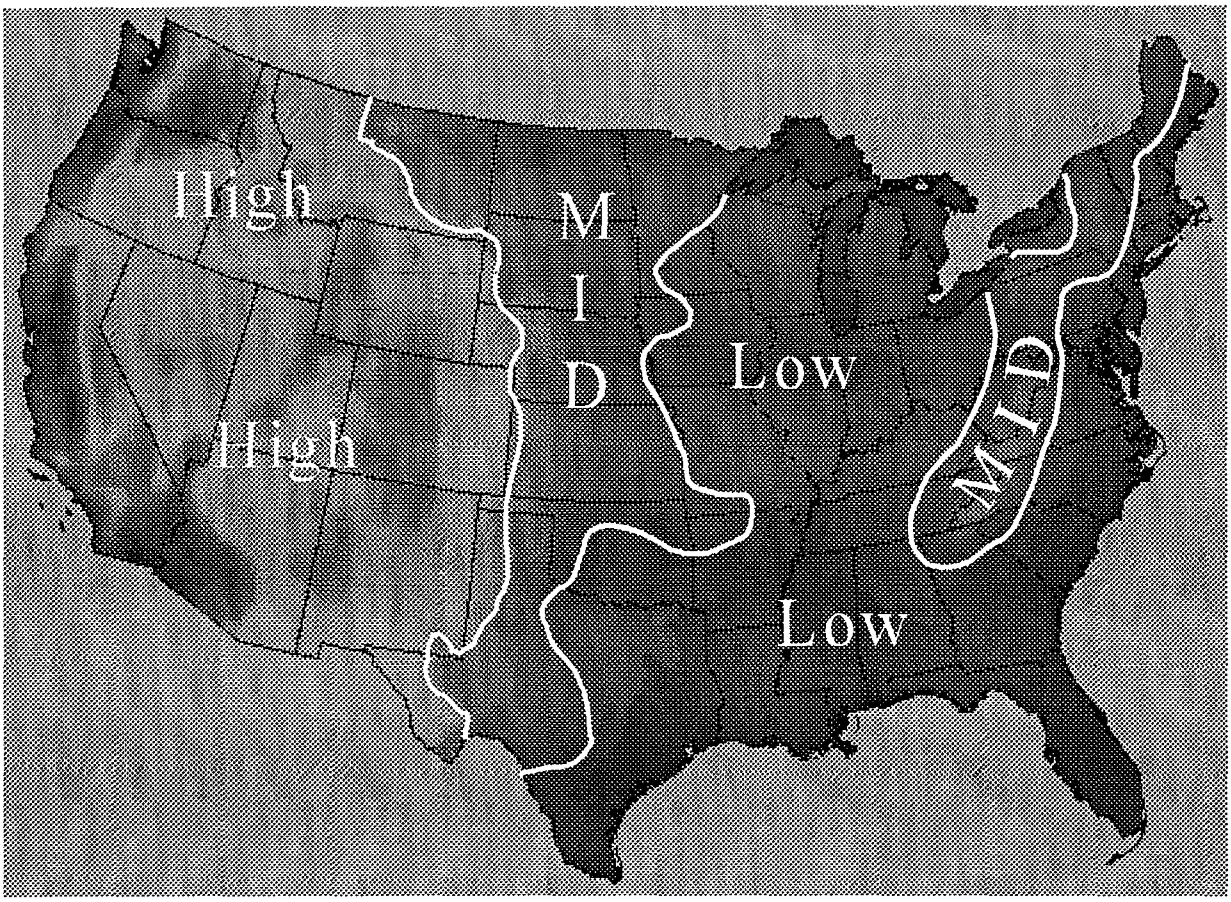

Figure 1 - Haines Index elevation map.

Station Legend

SITE ID	LOCATION
UIL	Quillayute, Wa
GEG	Spokane, Wa
GTF	Great Falls, Mt
GGW	Glasgow, Mt
SLE	Salem, Or.
MFR	Medford, Or
BOI	Boise, Id
LND	Lander, Wy
OAK	Oakland, Ca
WMC	Winnemucca, Nv
ELY	Ely, Nv
DRA	Desert Rock, Nv
SLC	Salt Lake City, Ut
GJT	Grand Junction, Co
DEN	Denver, Co
NKX	San Diego, Ca
INW	Winslow, Az
TUS	Tuscon, Az
ABQ	Albuquerque, NM
ELP	El Paso, Tx

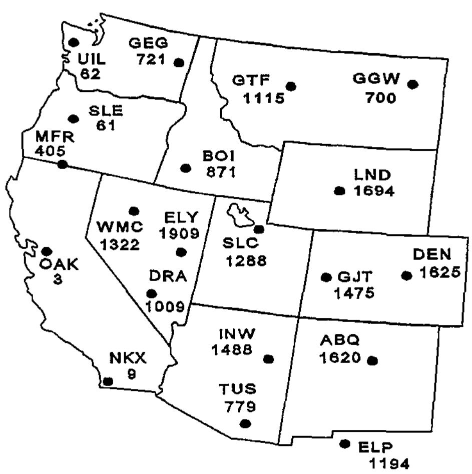

Figure 2 - Upper air stations with station elevation in meters.

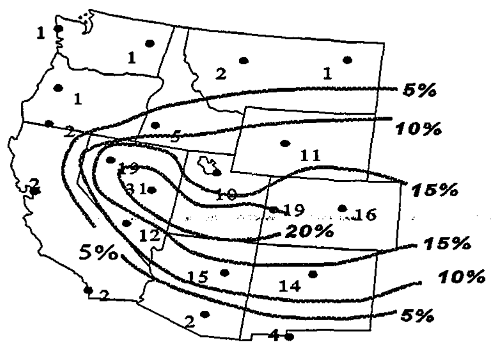

Figure 3 - Frequency of Haines 6 days June-October at 0000 UTC.

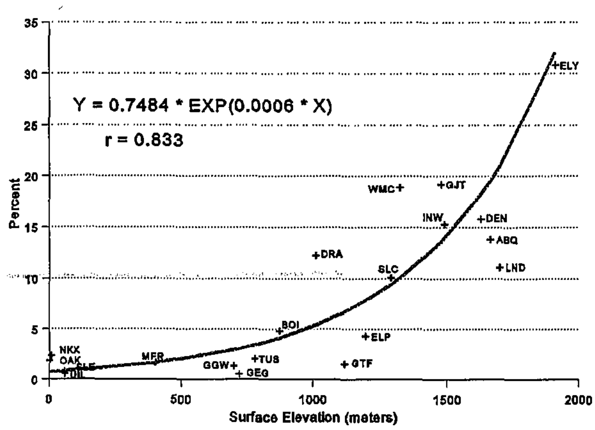

Figure 4 - Station elevation versus frequency of Haines 6 days at 0000 UTC.

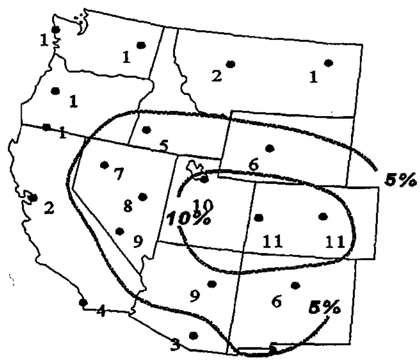

Figure 5 - Frequency of Haines 6 days (June-October) at 1200 UTC.

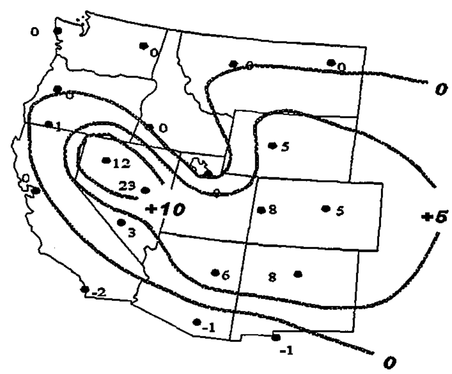

Figure 6 - Change in frequency of Haines 6 days 1200 UTC to 0000 UTC.

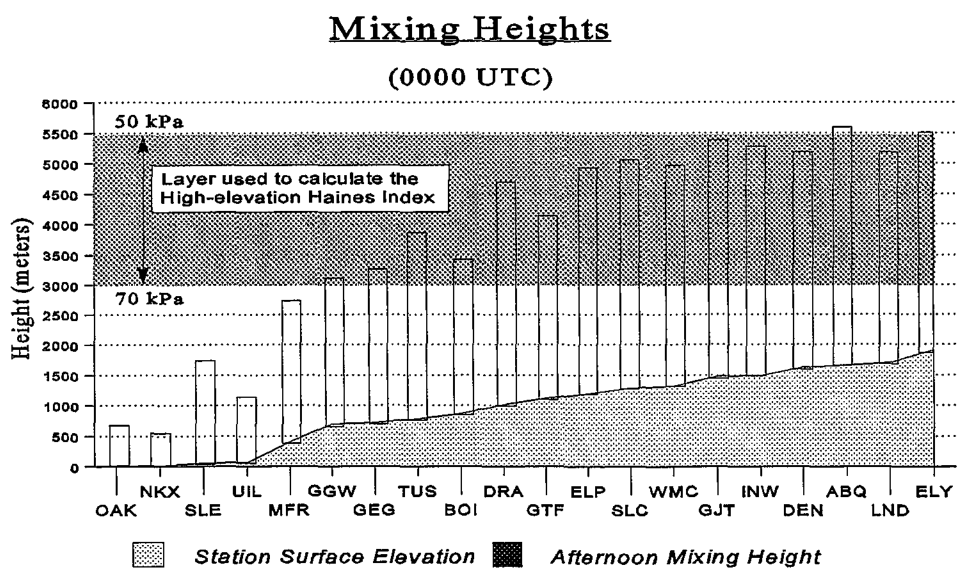

Figure 7 - Surface elevation and mean summer afternoon mixing heights of western U.S. radiosonde sites in meters M.S.L.

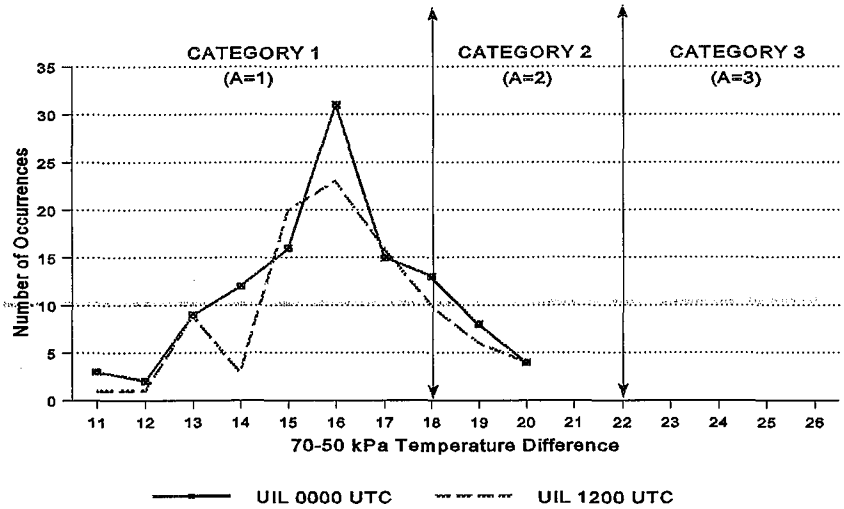

Figure 8 - Frequency distribution of 70-50 kPa temperature difference at UIL.

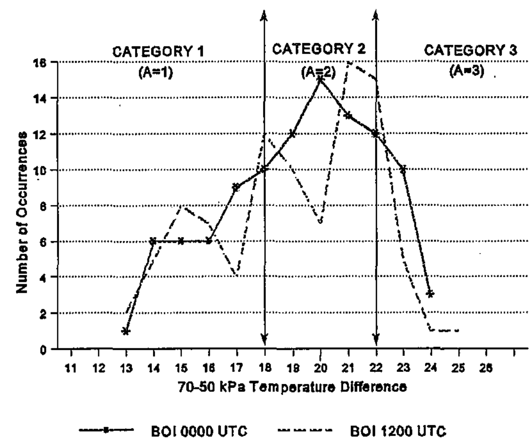

Figure 9 - Frequency distribution of 70-50 kPa temperature difference for BOI.

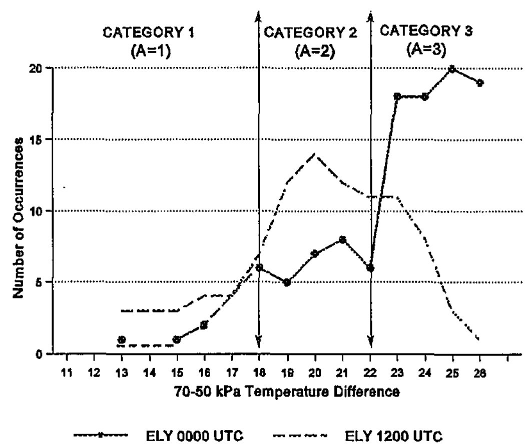

Figure 10 - Frequency distribution of 70-50 kPa temperature difference for ELY..

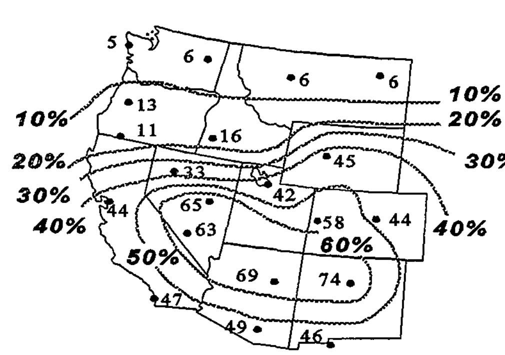

Figure 11 - Frequency of Haines 5 and 6 days June.

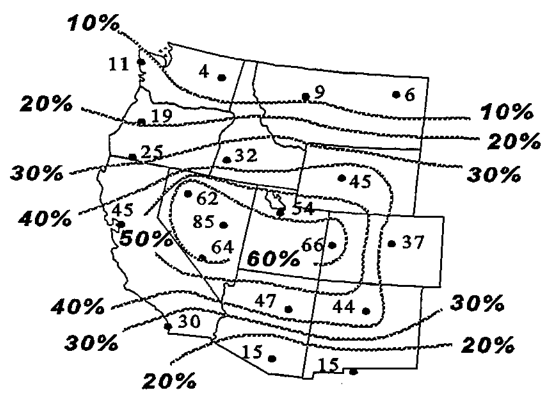

Figure 12 - Frequency of Haines 5 and 6 days July.

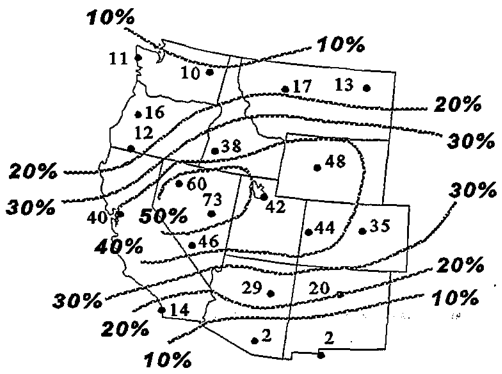

Figure 13 - Frequency of Haines 5 and 6 days August.

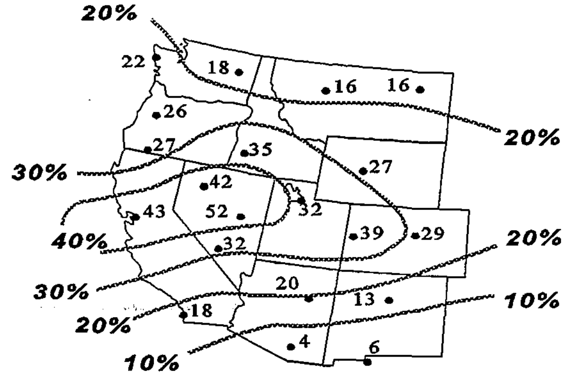

Figure 14 - Frequency of Haines 5 and 6 days September.

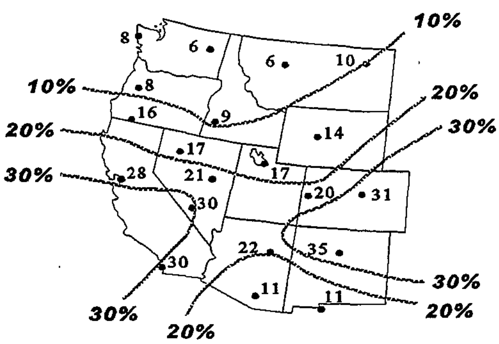

Figure 15 - Frequency of Haines 5 and 6 days in October.

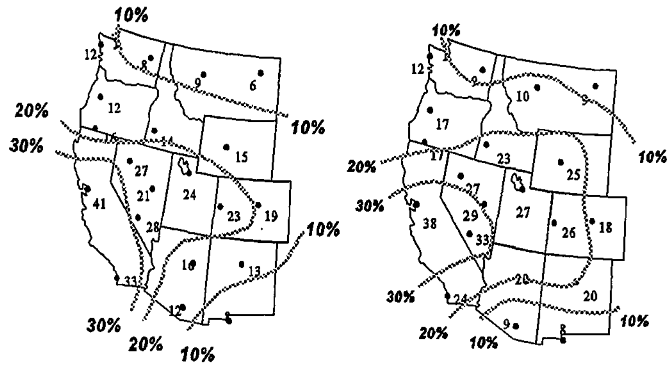

Figure 16 - Frequency of Haines 5 days at 1200 UTC (left) and 0000 UTC (right).

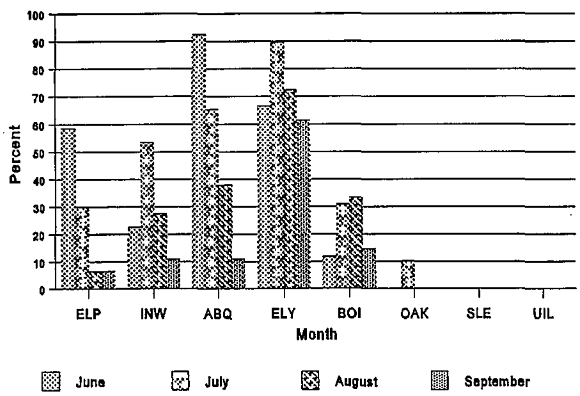

Figure 17 - Frequency of category 3 temperature difference (A=3) at selected upper-air stations.

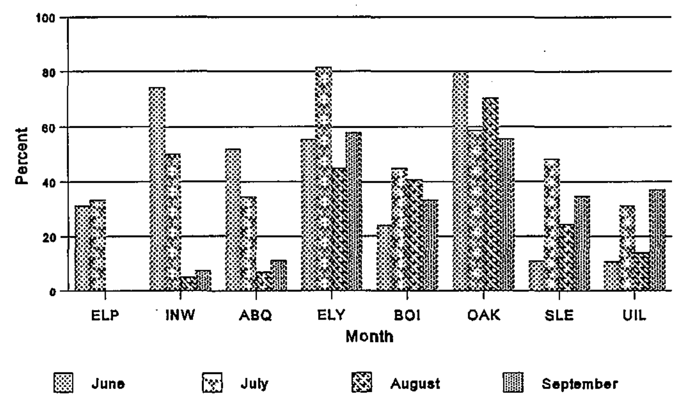

Figure 18 - Frequency of category 3 moisture days (B=3) at selected upper-air stations.

Haines Index = Temperature Term + Moisture Term

= (A) + (B)

Temperature Term (70-50 kPa Temp Difference)	**Moisture Term** (70 kPa T - Td)
A=1 when <18°C	B=1 when <15°C
A=2 when 18-21°C	B=2 when 15-20°C
A=3 when >=22°C	B=3 when >=21°C

Table 1 - Limits for high-elevation Haines Index.

Site	Haines 2		Haines 3		Haines 4		Haines 5		Haines 6		Haines 5 & 6	
	1200 UTC	0000 UTC	1200 UTC	0000 UTC	1200 UTC	0000 UTC	1200 UTC	0000 UTC	1200 UTC	0000 UTC	1200 UTC	0000 UTC
UIL	46	44	14	20	28	24	12	12	1	1	13	13
GEG	50	49	26	27	16	16	8	9	1	1	9	10
GTF	49	41	29	35	12	13	9	10	2	2	11	12
GGW	51	48	31	29	12	13	6	9	1	1	7	10
SLE	36	35	24	22	27	26	12	17	1	1	13	18
MFR	29	30	27	26	27	26	16	17	1	2	17	19
BOI	31	23	28	24	22	25	14	23	5	5	19	28
LND	30	16	33	27	17	21	15	25	6	11	21	36
OAK	10	10	13	17	34	33	41	38	2	2	43	40
WMC	21	14	22	19	23	22	27	27	7	19	34	46
ELY	15	9	29	16	27	16	21	29	8	31	29	60
DRA	11	10	27	23	24	22	28	33	9	12	37	45
SLC	19	14	24	25	23	24	24	27	10	10	34	37
GJT	19	10	23	26	18	18	23	26	11	19	34	45
DEN	22	17	32	30	16	19	19	18	11	16	30	34
NKX	10	17	19	26	33	31	33	24	4	2	37	26
INW	22	12	36	32	17	21	16	20	9	15	25	35
TUS	34	37	39	38	12	15	12	9	3	2	15	11
ABQ	26	12	40	37	15	17	13	20	6	14	19	34
ELP	43	37	33	39	12	11	8	8	5	4	13	12

Table 2 - Seasonal frequency table of Haines Index 2 through 6 for 1200 UTC and 0000 UTC.

	2/3	4	5	6	2/3	4	5	6	2/3	4	5	6	2/3	4	5	6	2/3	4	5	6
	UIL				GEG				GTF				GGW				SLE			
JUN	77	19	4	1	88	6	5	1	82	13	5	0	84	11	6	0	77	10	13	0
JUL	66	23	11	0	87	9	4	0	86	6	9	0	87	7	4	2	53	29	18	1
AUG	68	21	11	0	76	15	10	0	67	16	15	2	73	14	12	1	60	24	16	0
SEP	46	32	21	1	58	25	16	1	66	18	13	3	65	19	13	3	42	32	24	2
OCT	68	24	7	1	75	19	6	0	85	9	5	1	78	12	10	0	65	27	8	0
	MFR				BOI				LND				OAK				WMC			
JUN	73.	17	8	2	67	17	12	5	39	17	28	17	27	30	40	4	47	19	14	19
JUL	53	22	24	2	42	26	26	6	33	22	32	13	23	32	43	2	15	23	29	34
AUG	60	28	11	1	31	31	29	10	32	20	31	17	23	37	39	2	24	16	37	23
SEP	44	29	23	4	40	25	32	2	51	22	20	7	27	31	42	1	34	24	30	13
OCT	53	32	16	0	68	23	8	1	63	24	11	3	38	34	27	2	54	29	13	4
	ELY				DRA				SLC				GJT				DEN			
JUN	20	15	31	35	21	16	38	25	38	20	31	11	29	17	25	33	36	20	15	29
JUL	7	8	32	53	18	19	43	21	23	23	35	19	12	17	34	32	50	13	16	21
AUG	15	12	36	38	32	23	31	15	33	26	29	13	37	19	27	17	49	15	24	12
SEP	28	20	27	25	39	29	27	5	43	25	27	6	40	21	25	13	51	20	16	13
OCT	55	25	20	1	53	17	28	2	62	22	15	2	60	20	17	3	43	26	18	13
	NKX				INW				TUS				ABQ				ELP			
JUN	21	32	44	4	17	13	27	43	32	19	37	12	11	15	31	43	29	25	20	27
JUL	33	36	24	6	34	19	19	29	72	11	11	3	43	13	19	25	76	9	11	5
AUG	61	26	14	0	49	22	21	8	91	7	2	0	64	16	17	3	91	7	2	0
SEP	52	30	17	1	53	27	17	3	77	19	4	0	66	21	12	1	90	4	5	1
OCT	38	33	28	2	58	20	19	3	61	18	11	0	45	19	28	7	64	25	11	0

Table 3 - Monthly frequency table of Haines Index 2 through 6 at 0000 UTC.