

Seeding Feasibility Analysis of Storm Periods in the Gunnison, CO Seeding Project Area

An analysis was conducted using daily precipitation records from four SNOTEL sites in the 9600 - 10600 foot elevation range in the mountains northwest and northeast of Gunnison, Colorado. Days with approximately 0.4" or more of precipitation during the October-April season were identified and an analysis was made of the associated meteorological conditions. Results show that approximately 12 or 13 .4-inch or greater storm days occur during the October-April season on average. April had the highest frequency of these events (2.7 per season), followed by November and February (2.1 per season). December had the lowest frequency with approximately 1 half-inch or greater storm day per season. An average of one inch or greater amounts at these SNOTEL sites occurred on only about 10% of these storm days. Table 1 shows a breakdown of the data by month, and Table 2 breaks the data down by 700-mb wind direction sectors.

Storm Types

Over 30 of the identified storm events were analyzed to determine the weather patterns and types of storm systems likely to produce significant snowfall during the winter season. It was found that these heavier precipitation amounts occur during a variety of weather patterns, which tend to vary according to the time of year. During the winter period (December-February), many of these precipitation events resulted from strong zonal flow, with mid- and high-level Pacific moisture moving over Colorado. Satellite images during these events were often very impressive, with high cloud cover (very bright on the IR imagery) covering large portions of the western U.S. Deep trough situations were also responsible for some of the precipitation events, with storm systems over the SW U.S. and southern Rockies favoring the spring and fall seasons. Typically the more significant precipitation amounts were found to occur in southwesterly flow in advance of a storm system (sometimes well in advance), although some did occur in northwesterly flow behind a trough. A thick shield of high-level cloud cover was evident in most of these significant precipitation events, suggesting a large amount of high-level moisture. Strong upper-level winds and a jet core near Colorado were very often associated with these precipitation events.

700-mb Wind Flow and Temperature Characteristics

Upper-air soundings from Grand Junction, Colorado (GJT) were used to determine the 700-mb wind velocity and temperature, as well the stability of the atmosphere. Although Denver is approximately the same distance away from the project area, the Grand Junction soundings were primarily used because of the greater similarity of terrain than Denver, which frequently experiences air mass affecting the Great Plains. Denver soundings were used in a few cases when the sounding from Grand Junction was not available. The 700-mb wind flow is used to represent the transport of potential seeding material, and 700-mb temperature is used to gauge the seedability of the atmosphere.

The results of the analysis are summarized in Table 1. The 700-mb wind during these storm events strongly favored a southwesterly direction, with a direction between southerly and

westerly in approximately 64% of the 166 soundings examined. Wind direction was between north and west about 23% of the time, between north and east in 8% of the soundings, and between south in east in only 5% of the soundings. March and April had the greatest variety in wind directions, but even then, when upslope storms are common on the front range, the Gunnison project area rarely received amounts over 0.5" from easterly-type events. November - February events were almost exclusively from a westerly direction. Many of the soundings were dry below 650 or 700 mb. Some showed only a 100- or 200-mb thick moist layer, usually found between 500 and 700 mb.

Of the soundings examined, the 700-mb temperature was -5C or below slightly less than half of the time, with the average being -4.1 C. However, the 700-mb temperature was -2C or colder approximately 80% of the time. Although a -5C temperature is commonly used as a maximum threshold for wintertime seeding projects, much of the Gunnison project area is above the 700-mb level (with some peaks rising to near 600 mb) and thus the seeding material can be expected to rise significantly higher than 700 mb if targeted correctly. This means that seeding is likely to be effective even when the 700-mb temperature is as warm as 0C or -2 C, in which case the vast majority of these events are cold enough to be seeded.

Stability

This approach has some limitations regarding stability analysis in the lower levels of the atmosphere, since the soundings from Grand Junction are in an area of different topography from that of the project area. Stability below about 600 mb (~14,000 feet) was examined in these soundings, and the results summarized in the table. The atmospheric temperature profile was well-mixed in 72 cases, or about 43% of the time; there were minor stable layers or slight static stability in 49 cases, or about 30% of the time; and a more definitely stable atmosphere was observed in 45 cases, or 27% of the time. The atmosphere was most stable during the soundings observed in January, with half of the soundings quite stable and over three-quarters having some stability. March and April soundings had the least stability, with over half being well-mixed. Positive CAPE was noted in at least three soundings, one in November and two in April.

A stability analysis comparing wind direction sectors does not seem to show a clear relationship between stability and 700-mb wind direction, although the atmosphere was perhaps most well-mixed when 700-mb winds were westerly. Of the few cases with an easterly component, most had at least some stability below 600 mb.

Table 1. Results by Month

First Portion: Number of events with 700-mb wind direction in each sector; winds and temperature all at 700 mb; Stability – # well-mixed, # slight stability, # stable; Total seedable – 700-mb temp of -2C or colder, and not in “stable” category

	Oct-Apr	Oct	Nov	Dec	Jan	Feb	Mar	Apr
700-mb dir								
0-22 degrees	9	2	0	1	0	0	3	3
23-45	4	0	0	0	0	0	2	2
46-68	0	0	0	0	0	0	0	0
69-90	0	0	0	0	0	0	0	0
91-112	1	0	0	0	0	0	0	1
113-135	0	0	0	0	0	0	0	0
136-158	2	0	0	0	0	0	0	2
159-180	5	0	0	0	1	0	1	3
181-202	15	4	2	1	0	0	2	6
203-225	25	2	4	2	4	8	3	2
226-248	32	2	5	4	3	12	6	0
249-270	35	3	6	0	7	8	5	6
271-292	10	2	3	0	2	0	1	2
293-315	18	1	4	0	2	1	3	7
316-337	3	0	0	0	1	0	1	1
338-359	7	2	0	1	2	0	0	2
Total Sndgs	166	18	24	9	22	29	27	37
Total Storm Days	141	17	23	10	17	23	21	30
Mean wind	21.3	16.5	23.0	24.9	25.5	26.3	18.3	17.2
Mean temp	-4.1	-1.6	-3.5	-6.0	-6.2	-5.0	-4.3	-4.1
% < or = -5C	46%	28%	38%	78%	64%	62%	37%	35%
% < or = -2C	81%	50%	75%	100%	95%	90%	93%	70%
Stability	72, 49, 45	5, 9, 4	10, 5, 9	4, 2, 3	5, 6, 11	12, 11, 6	16, 6, 5	20, 10, 7
# Per Season								
Total	12.8	1.5	2.1	0.9	1.5	2.1	1.9	2.7
# -5C or colder	5.9	0.4	0.8	0.6	1.0	1.3	0.9	1.0
# -2C or colder	10.4	0.8	1.6	0.8	1.4	1.9	1.6	1.9
Seedable	7.6	0.6	1.1	0.5	0.9	1.4	1.3	1.5

Table 2. Results by 700-mb Wind Direction Sector
See Table 1 for description of parameters

700-mb dir	Total	0-22	23-45	46-68	69-90	91-112	113-135	136-158
# Sndgs	166	9	4	0	0	1	0	2
Mean wind	21.3	19.2	19.8	n/a	n/a	n/a	n/a	n/a
Mean temp	-4.1	-4.7	-5.5	n/a	n/a	n/a	n/a	n/a
% < or = -5C	46%	67%	50%	n/a	n/a	n/a	n/a	n/a
% < or = -2C	81%	78%	100%	n/a	n/a	n/a	n/a	n/a
Stability	72, 49, 45	3, 3, 3	0, 2, 2	0	0	0, 0, 1	0	0, 2, 0
# Per Season								
Total	12.8	0.7	0.3	0.0	0.0	0.1	0.0	0.2
# -5C or colder	5.9	0.5	0.2	0.0	0.0	0.0	0.0	0.1
# -2C or colder	10.4	0.6	0.3	0.0	0.0	0.1	0.0	0.1
Seedable	7.6	0.4	0.2	0.0	0.0	0.0	0.0	0.1

700-mb dir	159-180	181-202	203-225	226-248	249-270	271-292	293-315	316-337
# Sndgs	5	15	25	32	35	10	18	3
Mean wind	16.6	20.3	19.9	26.3	23.3	22.7	15.6	21.7
Mean temp	-8.0	-2.2	-2.7	-4.6	-4.7	-3.9	-4.1	-6.3
% < or = -5C	40%	13%	28%	56%	51%	60%	50%	67%
% < or = -2C	80%	47%	76%	91%	100%	70%	72%	100%
Stability	0, 1, 4	8, 2, 5	8, 10, 7	17, 8, 7	17, 13, 8	7, 1, 2	9, 5, 4	2, 0, 1
# Per Season								
Total	0.3	1.2	1.9	2.5	2.7	0.8	1.4	0.2
# -5C or colder	0.1	0.3	0.7	1.2	1.4	0.4	0.7	0.1
# -2C or colder	0.2	0.7	1.5	2.3	2.5	0.7	1.0	0.2
Seedable	0.1	0.5	1.1	1.8	2.0	0.6	0.8	0.2

700-mb dir	338-359
# Sndgs	7
Mean wind	18.9
Mean temp	-3.0
% < or = -5C	43%
% < or = -2C	57%
Stability	3, 4, 0

Per Season

Total	0.5
# -5C or colder	0.3
# -2C or colder	0.4
Seedable	0.3