P2.25 EXAMINING HIGH WIND EVENTS USING SATELLITE CLOUD COVER COMPOSITES OVER THE CHEYENNE, WY REGION

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1. INTRODUCTION

Very strong westerly surface winds occur throughout the cool season over much of southeastern Wyoming. These winds frequently gust over 70 mph, causing property damage, closed roads, and overturned trucks and trains. High wind events are a frequent forecast consideration for the Cheyenne National Weather Service (NWS) Forecast Office from October through May. Over the past decade considerable local knowledge has been gained to understand and predict these events.

High winds, as defined by the National Weather Service, are sustained winds of 40 mph or greater or gusts to 60 mph or greater. In mountainous areas above 7500 feet Mean Sea Level, the criteria becomes sustained winds of 50 mph or greater or gusts to 70 mph or greater. An average of fifteen to twenty-five high wind events occur in southeast Wyoming annually, with the majority of these occurring from December through February. These events can be grouped into two major categories; gap winds and chinook winds. Strong westerly winds are supported by an upper level jet stream over Wyoming. The extreme terrain of the Rocky Mountains also plays a major role in enhancing the low level wind field.

Gap winds (Marwitz 1984) generally occur in south central and central Wyoming. These winds result as a tight surface pressure gradient develops between high pressure west of the Continental Divide and low pressure or a lee trough on the east side of the Rocky Mountains. A strong polar jet over the region will force cooler air over the red desert and through gaps in the Rocky mountains. This type of wind event will typically begin in the late evening or early morning hours and tend to diminish with atmospheric mixing in the mid to late morning.

Mountain wave or Chinook winds (Whiteman 2000) generally occur along the front range of the Rockies from Colorado to Montana. Boulder and Fort Collins, Colorado, Cheyenne, Wheatland, and Cody, Wyoming and Livingston, Montana commonly experience Chinook winds during the fall and winter months. Chinook winds are strong and warm downslope winds generally found on the lee sides of mountain ranges. Along the lee side of the Rocky mountains chinook winds can reach speeds of over 100 mph. A strong westerly polar jet over the region generates a deep wind field normal to the mountains. A mountain wave will develop just east of the Continental Divide. Interaction between the mountain wave and an approaching surface warm front from the west often aids in creating a stable layer over the peaks, thus enhancing the mountain wave and triggering chinook winds. This type of wind event usually starts after midnight and persists through the next day because atmospheric mixing actually helps support the strong downslope winds.

In this study, we investigate whether satellite cloud cover percent composites can add new information to forecasting high winds for Cheyenne NWS office. In a previous study, Connell et al (2001) have shown that hourly cloud frequency composites divided into various wind regime categories are useful in forecasting sea breeze convection in the Florida Panhandle. In another study, Combs et al (2001) showed that wind regime cloud climatologies aided Wakefield, VA forecasters in determining some persistent cloud features under certain wind conditions. Now cloud percent composites have been developed over the Rocky Mountains and high plains to see if there are any persistent cloud patterns before, during or after Cheyenne area high wind events.

2. DATA AND METHODOLOGY

For this project, images for channels 1-5 from the Geostationary Operational Environmental Satellite

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(GOES) were obtained from an archive collected at CIRA. The GOES 10 images were collected every other hour for September through May, 1998-2002, cover the western U.S., and are sampled to 4-km resolution. Each image was previously quality checked, then sectorized to cover the Rocky mountains and the high plains, including all of the Cheyenne County Warning Area (CWA). Then the data were grouped by hour for further processing.

In the Wakefield project mentioned above, a threshold method using only the visible (channel 1) was utilized to study convection during daylight hours. Unfortunately for this project, wind events often occur at night during the winter months. While composites of cloud cover percent using the visible channel were produced, the effects of the snowy mountain terrain overshadowed the cloud signatures, making the products unusable for this study.

To overcome this problem, clouds were determined by a channel 4 (10.7 µm) threshold method used in the Climatological and Historical Analysis of Clouds for Environmental Simulations (CHANCES) project (Vonder Haar et al (1995)). (For more on CHANCES, see P1.2, Development and applications of regional cloud products from the CHANCES global cloud database by Reinke et. al. at this conference.) First, the channel 4 images were divided into hour and ten day period sets. Then for each pixel location within the sector, all the images in the set are compared to find the maximum value. The results are combined into an image called a "background". It provides later algorithms with an assumed warmest ground value for clear conditions.

The next step is to categorize each image by wind regime. For each day, the 1000 - 700mb Mean Layer Vector Wind (MLVW) is determined. First, the 12 UTC ETA model analysis fields are used to derive a 'sounding' over the Wakefield, VA vicinity. The MLVW is then calculated using PC-Gridded Interactive Display and Diagnostic System (PC-GRIDDS) software. Using the MLVW value, the image is then designated into one of nine generalized regimes. These cover the eight points of the compass and a calm (< 5 m/s) regime, as listed in table 1.

The cloud frequencies within a given wind regime are determined by comparing each image with the previously determined background image for that hour over a ten day period. For each pixel location, the image value is compared to the background plus a twelve degree threshold. If the image pixel is colder than the background and threshold, that pixel is tagged as cloudy. If the image value is less, it is considered clear. As the images from the set are processed, the number of cloudy pixels for each pixel location are tallied. Then the number of cloudy pixels is divided by the total number of pixels considered for that location to produce a cloud cover percentage.

This procedure was implemented for each hour and wind regime within a given three month period. To investigate high wind events, we divided the data into three periods: September-November, December-February, and March-May. Since the largest number of high wind events for Cheyenne area occurred during December through February (44 cases during 1998-2002), we will focus on this period. After the composites for this period were completed, three subsets were pulled from the December-February data consisting of hours during high wind events, the twelve hours before each event, and twelve hours after each event. The subsets were determined from high wind data collected at the Cheyenne office for their CWA.

Table 1

	Wind regimes
1	Calm (< 5m/s)
2	North
3	Northeast
4	East
5	Southeast
6	South
7	Southwest
8	West
9	Northwest

3. PRELIMINARY ANALYSIS

This study includes data from five winter seasons (1998-2002), split into the above wind regimes. Table 2 shows the range for the number of cases per hour for each wind regime. The vast majority of the cases for the entire period fall into the west wind regime, which is reasonable given the prevailing wind is from the west and the gap wind conditions for the area. In addition, the west regime is dominant for both pre-event and wind event hours. The post-event hours have more cases in the southwest and northwest regimes, but largest number still fall into the west category.

Table 2: Range for Number of Cases Per Hour
during December-February, 1998-2002

Period	Calm	North	NE	East	SE	South	SW	West	NW
Dec-Feb	44-57	5-6	1	0-2	1	1-2	23-28	179-215	72-88
Wind event	0	0	0	0	0	0	2-3	21-35	3-8
Pre-event 12 hours	0-3	0	0	0	0	0	0-1	8-16	1-4
Post-event 12 hours	0-4	0-1	0	0	0	0	0-2	2-13	2-8

To determine the average conditions for comparison, the hourly cloud cover percent from the December-February 1998-2002 period for available wind regimes was examined. Figure 1 is an example from the west regime for 2200 UTC or 1500 MST. Much of the sector shows cloud cover in the 30-50% range, with areas of 10-30% in west central Colorado, and 50-70% range in western Idaho, northern Nevada, and central Montana.

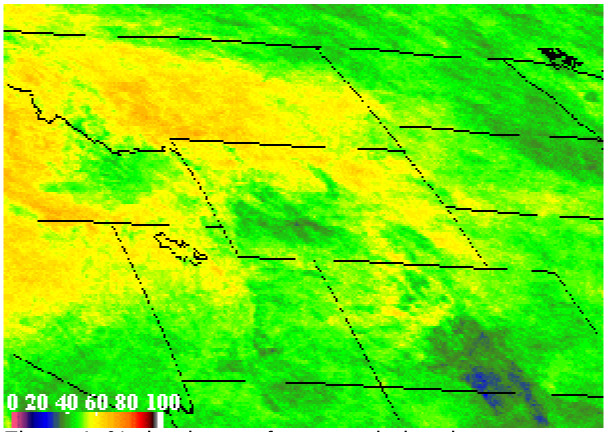

Figure 1: % cloud cover for west wind regime, December-February, 1998-2002, 2200 UTC, 211 cases

Next, only images during high wind event periods are processed into hourly composites within the Cheyenne CWA at 1500 MST (see figure 2). While there are fewer days for the wind event composite (35 compared to 211 for the entire period), there are some significant differences. Cloud percentages in central Colorado have dropped, as well as a small area around the Montana/Saskatchewan border. In addition, percentages have increase in Idaho and Montana, with an area of 90% or greater in central Idaho. Also, there is an increase of clouds over the Rocky mountains between Wyoming and Colorado, with a decrease in clouds on either side. This could indicate mountain wave clouds that often form streets over and around the mountains during high wind events.

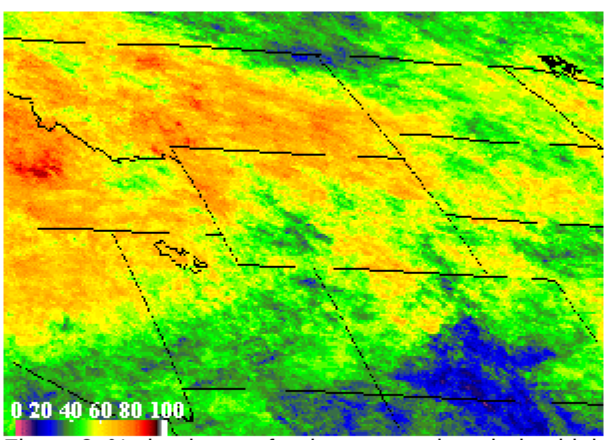

Figure 2: % cloud cover for the west regime during high wind events, Dec-Feb, 1998-2002, 2200 UTC, 35 cases

To determine if there are any precursors for Cheyenne's high wind events, the twelve hours before each event were processed into hourly composites. Figure 3 shows the pre-event composite for 0000 UTC or 1700 MST. When compared to the previous figures, one feature stands out. There is a streak of very high (80-100%) cloud percentages over the Rocky Mountain region in western Montana. We suspect that this is due to either jet streaks or baroclinic leaves occurring in that area prior to the wind event in the Cheyenne CWA. Another point of interest is that the cloud percentages in central Idaho are in the 20-30% range. That is much lower than the same area in the event composite. This also warrants further investigation.

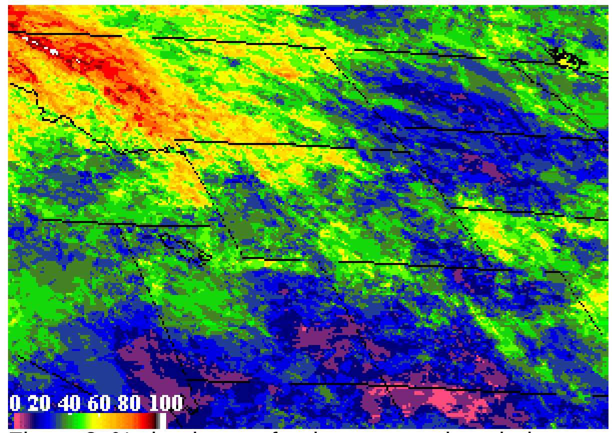

Figure 3: % cloud cover for the west regime during pre-event period, Dec-Feb, 1998-2002, 0000 UTC, 15 cases

To examine the idea of jet streaks in the pre-event composite further, we decided to 'slice' the composite according to cloud top temperature, as determine from channel 4. Figure 4 is the percent cloud cover when cloud tops under –10 °C, Figure 5 for tops under -20 °C, Figure 6 for -30 °C and Figure 7 for –40 °C. While there is not much difference between original pre-event composite and the under –10 °C, there is significant

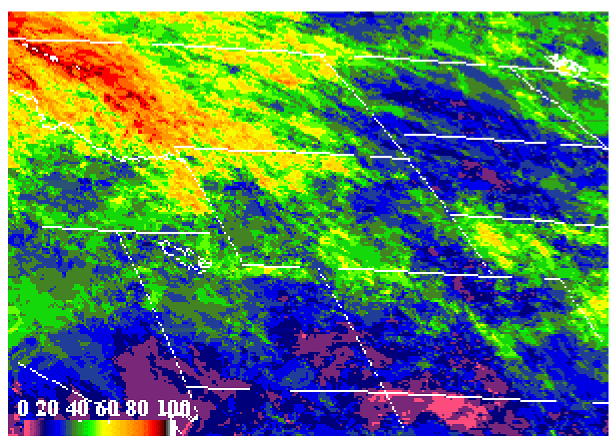

Figure 4: % cloud cover under –10 °C for west wind regime during pre-event period, Dec-Feb, 1998-2002, 0000 UTC, 15 cases

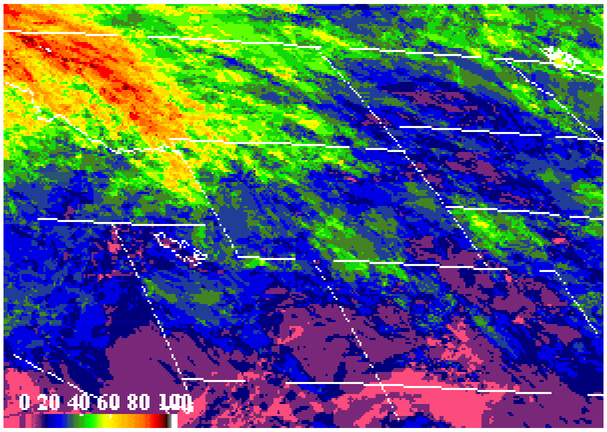

Figure 5: % cloud cover under –20 °C for west wind regime during pre-event period, Dec-Feb, 1998-2002, 0000 UTC, 15 cases

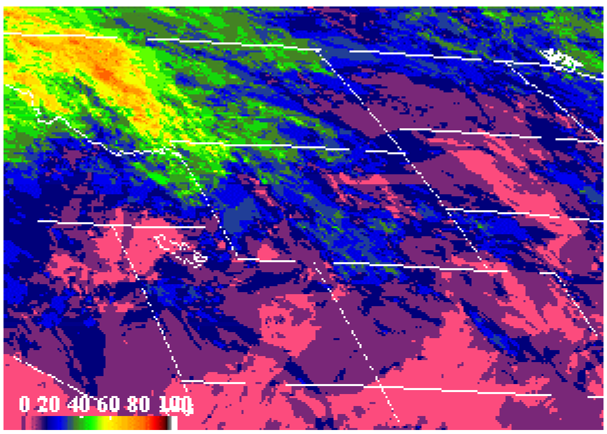

Figure 6: % cloud cover under –30 °C for west wind regime during pre-event period, Dec-Feb, 1998-2002, 0000 UTC, 15 cases

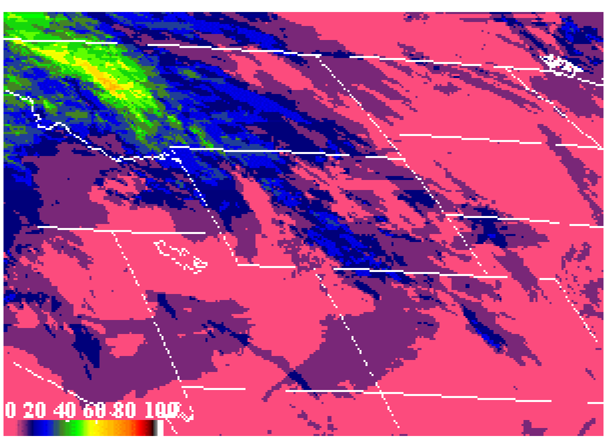

Figure 7: % cloud cover under –40 °C for west wind regime during pre-event period, Dec-Feb, 1998-2002, 0000 UTC, 15 cases

reduction between the other levels. This appears to indicate that while many of the clouds in the original pre-event composite are mid-level, the main feature of interest is associated with a significant proportion of high clouds. This adds evidence that the feature could be due to jet streaks.

Next, the twelve hours after each wind event were processed into hourly composites. Figure 8 shows an example for 1700 MST. There is no obvious pattern as there was for the pre-event composite. More study is needed to determine what, if any, information can be found.

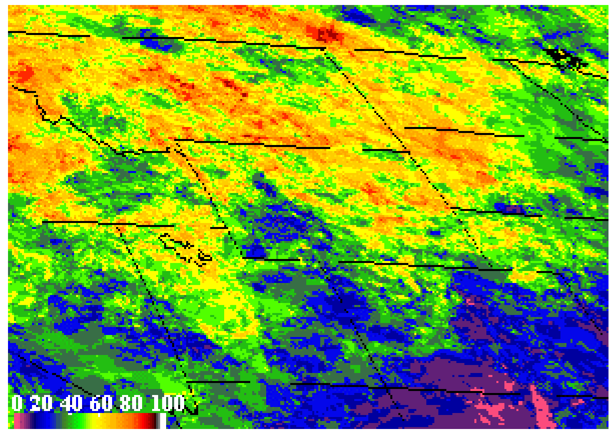

Figure 8: % cloud cover for west wind regime during post-event period, Dec-Feb, 1998-2002, 0000 UTC, 13 cases

4. CONCLUSIONS AND FUTURE WORK

There are definite patterns in the cloud frequency composites for the high wind event and pre-event cases that are different from average conditions. The obvious feature in the pre-event case of a jet streak or baroclinic leaf may be a pre-cursor to high wind events that the Cheyenne forecasters can utilize. Further analysis and study is needed to determine if this idea is practical.

There are several more avenues we wish to pursue. One is to continue investigating which features in the composites are composed of high, middle or low cloud, both by the slice method and others. One possible method would be to utilize the shortwave product which combines channels 2 (3.9µm) and 4. An algorithm using the shortwave product to produce high and low cloud composites is under development. Such methods may clarify the post-event composites.

In addition, an average of the water vapor channel (6.7µm) is being processed to determine if there is a signal similar to the one for channel 4 in the pre-event cases.

Another avenue to pursue is to examine whether wind events in different locations within the Cheyenne CWA produce different cloud patterns in the event and pre-event composites. It would also be interesting to investigate how these patterns differ from hour to hour, and in comparison to the other three month periods (September-November, and March-May).

5. ACKNOWLEDGMENTS

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6. REFERENCES

Combs, C. L., N. A. Stuart, M. DeMaria, and T. H. Vonder Haar: Wind regime GOES cloud cover composites for the Wakefield, VA county warning area. Preprints, *11th Conf. On Satellite Meteorology and Oceanography,* Madison, WI, Amer. Meteor. Soc., 165-167.

Connell, B. H., K. J. Gould, and J. F. W. Purdom, 2001. High resolution GOES-8 visible and infrared cloud frequency composites over northern Florida during the summers 1996-1999. *Wea. Forecasting*, **16**, 713-724.

Marwitz, John D., and P. Dawson, 1984: Low-Level Airflow in Southern Wyoming during Wintertime. *Mon. Wea. Rev.*, **112**, 1246-1262.

Reinke, D. L., C. L. Combs, S. Q. Kidder, and T. H. Vonder Haar, 1992: Satellite cloud composite climatologies: A new high-resolution tool in Atmospheric research and Forecasting. *Bull. Amer. Meteor. Soc.* **73**, 278 - 285.

Vonder Haar, T.H., D.L. Reinke, K.E. Eis, J.L. Behunek, C.R. Chaapel, C.L. Combs, J.M. Forsythe, and M.A. Ringerud, 1995: Climatological and Historical Analysis of Clouds for Environmental Simulations (CHANCES) Database. Final Report prepared for Phillips Laboratory under Contract No. F-19628-93-C-0197, July 1995.

Whiteman, C. David, 2000: Mountain Meteorology, Oxford University Press, 146-152.