WESTERN REGION TECHNICAL ATTACHMENT
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AN EXAMPLE OF USING THE "SATELLITE FOG PRODUCT" IN PREDICTING DENSE FOG OVER SOUTH-CENTRAL AND SOUTHEAST MONTANA AND NORTH-CENTRAL WYOMING ON NOVEMBER 28, 1999

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[Note: Satellite imagery will appear only on the web version of the Technical Attachment.]

Introduction

During the late afternoon and evening of November 28, 1999, dense fog moved from southeast Montana into the Billings area. The fog was dense enough to close Billings Logan International Airport. Dense fog, defined as visibilities of 1/4 mile or less, is uncommon across NWSO Billings County Warning Area (CWA). NWSO Billings CWA incorporates south-central Montana, southeast Montana, and Sheridan County Wyoming. Based on National Climatic Data Center normals, dense fog during the month of November across NWSO Billings county warning area occurs on average one day during the month.

This Technical Attachment will show the utilization of satellite imagery, in particular the fog product, and the synoptic situation which allowed forecasters to accurately predict the fog. Dense Fog Advisories were issued well ahead of the occurrence of dense fog in the Billings area.

The Synoptic Situation

A surface low developed along the east slopes of the northern Rockies on November 26. The low migrated to eastern Wyoming late on the 26th. Temperatures were mild enough to support rain at Billings and Sheridan, mainly rain in Miles City, but cold enough to support snow in the extreme southeastern corner of Montana. Total precipitation at all three cities was 0.15" or less on the 26th (see table below). Skies cleared late on the 26th with no precipitation on the 27th or 28th.

Airport Location	Precipitation on November 26
Billings, Montana	0.14"
Miles City, Montana	0.15"
Sheridan, Wyoming	0.07"

A strong 1040 mb surface high was located over southern Saskatchewan and Manitoba on the evening of November 28. The surface weather analyses at 00Z and 03Z on November 29 showed slight pressure increases, with 3-hour pressure changes of less than 1.0 mb. Surface pressure gradients over south-central and southeast Montana were rather weak with a tendency for an upslope east to northeast wind. The upper-air data at Glasgow, MT for 00Z and 12Z on November 29 clearly indicated a very moist and stable layer below approximately 875 mb with an easterly component to the wind on both soundings (Figs. 1 & 2).

Importance of Satellite Fog Product Imagery

In viewing low clouds and fog, visible imagery (except with snow cover) is the most ideal method. Naturally, visible imagery is only available during daylight hours. Infrared imagery is a poor choice for night viewing because low clouds and fog are hard to detect. This is because low clouds and fog have a similar radiating temperature as the underlying land.

The best satellite imagery to use for identifying fog and stratus clouds during the night is commonly called the "fog product." The identification of fog and stratus at night is an application of the GOES Imagery data (CIRA - Cooperative Institute for Research in the Atmosphere tutorials, 1999). The GOES Imagery data utilizes bi-spectral satellite imagery (11μ - 3.9μ on AWIPS, i.e. fog product) since low clouds and fog have different emissive properties in the two wavelengths. The imagery is reduced by subtracting the 3.9 μ brightness temperatures from those at 10.7 μ. This imagery highlights low clouds and fog in white gray shades (a positive difference), clear conditions with little temperature variability shows up as a mid-gray shade, and high clouds in a dark shade (a negative difference). High clouds appear dark in this imagery since much of the sensed energy comes from the ground, and the 3.9 μ channel response to warm sub-pixel temperatures is greater than that at 10.7 μ. This is true even though the emissivity of an ice cloud is about the same as at the 3.9 μ and 10.7 μ. Using the AWIPS Image Properties the forecaster can colorize the "fog product" making it easier to identify the low clouds and fog. Additionally, putting these images in animation, fog and low clouds would be easily observed since the higher ice clouds would show more rapid movement.

There are limitations in viewing the fog product imagery at night. The "fog product" is also a "stratus product" since the satellite only observes the top of clouds, not the cloud bases. The forecaster must utilize additional data such as surface observations to differentiate between stratus and fog. At times, it will be difficult to distinguish between high clouds and land. This problem is alleviated by animating the product. During the daytime, the fog product uses the 1 km spatial resolution GOES visible data which would give the product a highly defined appearance. During the night, the product utilizes bi-spectral satellite imagery which has a resolution of 4 km. Therefore, fog product imagery at night will have less sharpness and definition.

The Event

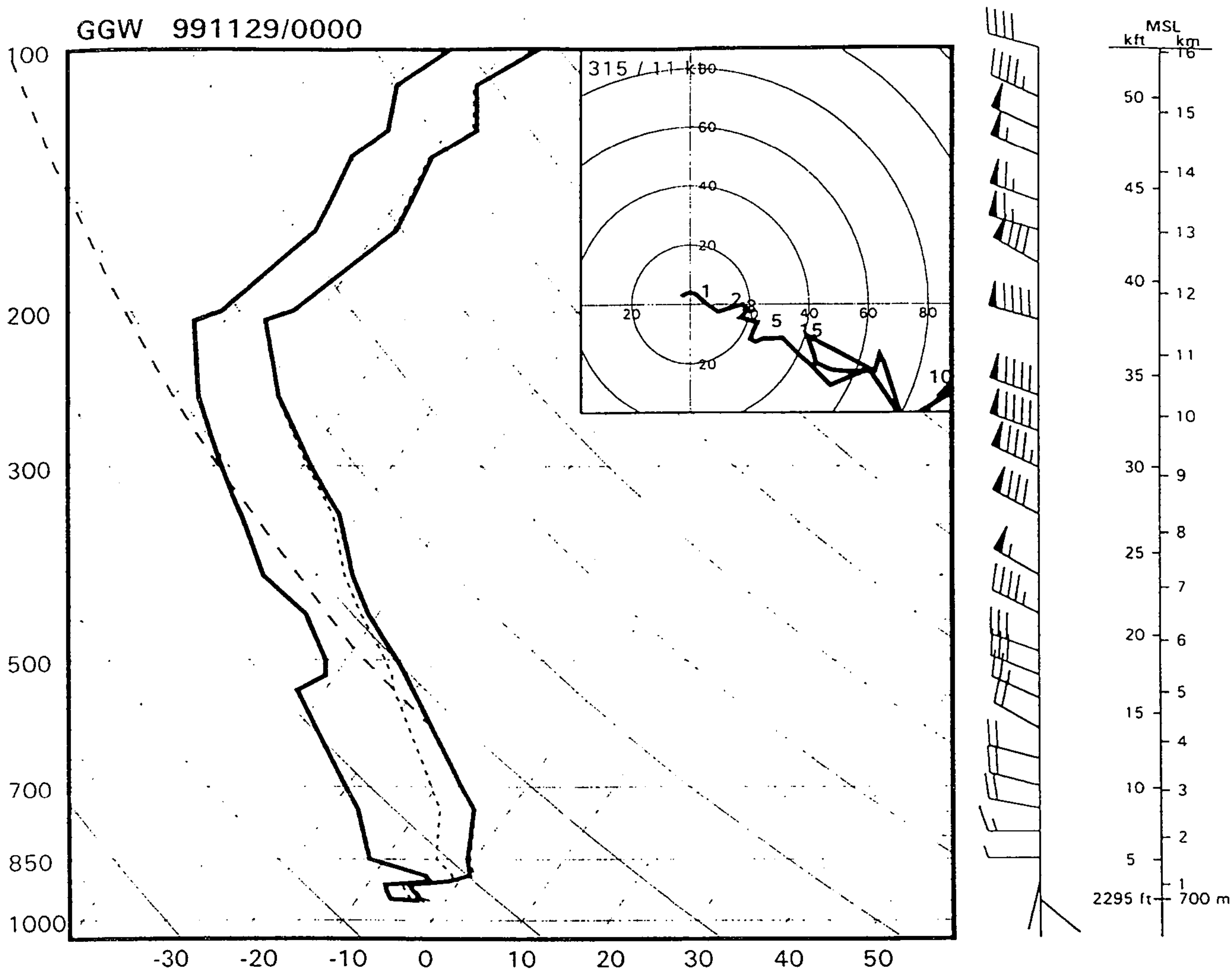
On November 28, the end of the Thanksgiving holiday weekend, dense fog persisted all day at Miles City, MT and to some degree at Sheridan, WY. The lower atmosphere mixed out enough during the day farther west with improved visibilities at Billings, MT. It is worth noting that prior to November 28, airport holiday traffic at Billings Logan International Airport had already been impacted with many flights delayed or canceled due to dense fog. With little mixing during the day over south-central Montana on the 28th, the lower atmosphere remained very moist and stable into the evening. Dense fog over southeast Montana began to expand and, with a persistent upslope wind component, advected westward in the Yellowstone and Tongue River valleys on the evening of the 28th (Fig. 3). Dense fog reached the Billings, MT airport (located approximately 400 feet higher than the city center) and lowered the visibility to less than 1/4 mile at 8:38 pm MST. Visibility remained very low overnight (Fig. 4). While the airport observed a very light northeast to northwest wind, there was a 10 to 15 knot easterly wind during the evening at Livingston, MT. The easterly upslope wind was directly supported by the slight pressure rises over southeast Montana during the evening of the 28th. By the morning of the 29th, pressure began to decrease along the east slopes (lee-side troughing) and a downslope, drier south to southwest wind developed. This completely eroded the fog before noon at Billings, MT, while visibilities gradually improved at Sheridan, WY and Miles City, MT.

Conclusion

Fog producing processes begin with a very moist and stable lower atmosphere with light mixing. In this case, rather light precipitation amounts over the area (0.15 inches or less) was sufficient to moisten the lower atmosphere. Other factors include slight pressure rises over south central and southeast Montana which resulted in an easterly upslope wind as far west as Livingston, MT, and a clear sky for radiational cooling processes.

Dense fog always results in some degree of impact on the livelihood of people, affecting travel both in the air and on the ground, especially if it occurs over a holiday when traffic volume dramatically increases. Fog is rare along the east slopes of the Rockies in south-central and southeast Montana, and north-central Wyoming. Moreover, it is very rare for dense fog to occur over such a widespread area for a long duration as reviewed in this example. When forecasters anticipate conditions favorable for fog development, in combination with other weather data, the satellite "fog product" becomes one of the most essential tools to use.

Figure 1. Upper Air Sounding for Glasgow, MT
00Z November 29, 1999



THERMODYNAMIC PARAMETERS

MOST UNSTABLE PARCEL

LPL: 601mb -15C/ -28C 5F/ -18F

CAPE:	0 J/kg	LI:	M
BFZL:	0 J/kg	LImin:	M
CINH:	0 J/kg	CAP:	M

LEVEL	PRES	HGT(AGL)	TEMP
LCL	485mb	16902ft	
LFC	M	M	M
EL	M	M	M
MPL	M	M	

Precip Water:	0.26 in	Mean RH:	40 %
Mean Q:	2.6 g/kg	Mean LRH:	67 %
Top of Moist Layer:		M / M	

700-500mb Lapse Rate:	17 C / 6.8 C/km
850-500mb Lapse Rate:	24 C / 5.9 C/km

Total Totals:	36	K-Index:	-1
SWEAT Index:	20	Max Temp:	50 F
ThetaE Diff:	24 C	*Conv Temp:	28 F
FRZ Level:	M	WBZ Level:	M

Output produced by:
SHARP (SkewT-Hodograph Analysis and Research Program) v3.0b
J Hart et.al., 1996, NWS/NCEP/Storm Prediction Center

KINEMATIC PARAMETERS

Sfc - 6 km Mean Wind:	286 / 18 kt	(9 m/s)
LFC - EL Mean Wind:	290 / 32 kt	(16 m/s)
850 - 300 Mean Wind:	291 / 28 kt	(14 m/s)

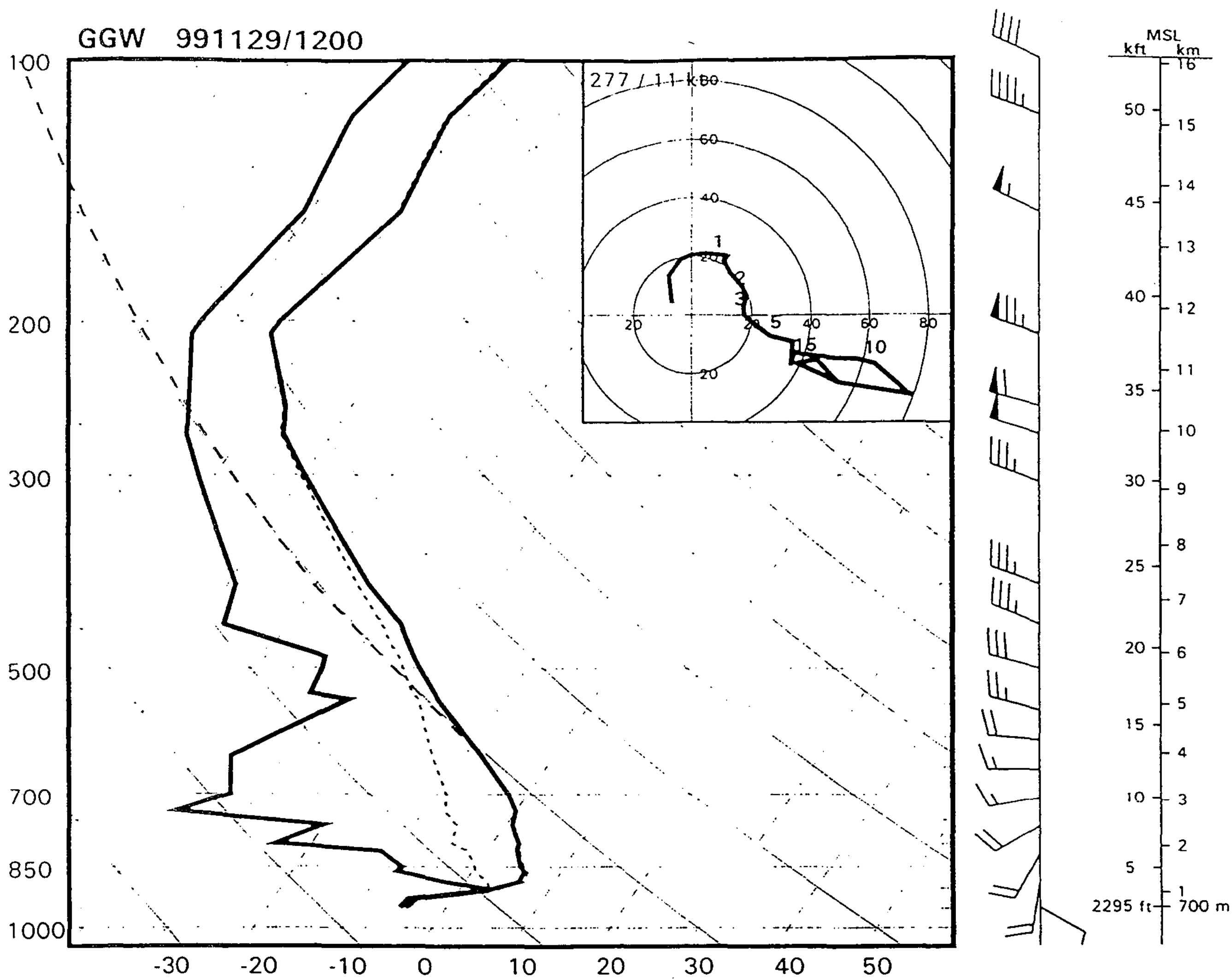
Sfc - 2km Shear:	17 kt	(8 m/s)
Sfc - 6km Shear:	48 kt	(24 m/s)
*BRN Shear:		46 m2/s2

STORM STRUCTURE PARAMETERS

Sfc - 3km SREH:	66 m2/s2
Effective SREH:	M

0-2 km SRW:	9 kt	EHI:	0.0
4-6 km SRW:	24 kt	BRN:	0
6-10 km SRW:	61 kt		

Figure 2. Upper Air Sounding for Glasgow, MT
12Z November 29, 1999



THERMODYNAMIC PARAMETERS

MOST UNSTABLE PARCEL

LPL: 631mb -8C/ -36C 17F/ -33F

CAPE:	0 J/kg	LI:	M
BFZL:	0 J/kg	LImin:	M
CINH:	0 J/kg	CAP:	M

LEVEL	PRES	HGT(AGL)	TEMP
LCL	400mb	21691ft	
LFC	M	M	M
EL	M	M	M
MPL	M	M	

Precip Water:	0.24 in	Mean RH:	24 %
Mean Q:	3.3 g/kg	Mean LRH:	48 %
Top of Moist Layer:		887 mb / 1702 ft	

700-500mb Lapse Rate:	20 C / 7.6 C/km
850-500mb Lapse Rate:	27 C / 6.5 C/km

Total Totals:	40	K-Index:	-12
SWEAT Index:	202	Max Temp:	61 F
ThetaE Diff:	26 C	*Conv Temp:	24 F
FRZ Level:	M	WBZ Level:	M

Output produced by:
SHARP (SkewT-Hodograph Analysis and Research Program) v3.0b
J Hart et.al., 1996, NWS/NCEP/Storm Prediction Center

KINEMATIC PARAMETERS

Sfc - 6 km Mean Wind:	250 / 18 kt	(9 m/s)
LFC - EL Mean Wind:	270 / 24 kt	(12 m/s)
850 - 300 Mean Wind:	267 / 22 kt	(11 m/s)

Sfc - 2km Shear:	18 kt	(9 m/s)
Sfc - 6km Shear:	45 kt	(23 m/s)
*BRN Shear:		19 m2/s2

STORM STRUCTURE PARAMETERS

Sfc - 3km SREH:	226 m2/s2
Effective SREH:	M

0-2 km SRW:	18 kt	EHI:	0.0
4-6 km SRW:	19 kt	BRN:	0
6-10 km SRW:	29 kt		

date/time	tmp F	dew F	rh %	wind mph	wnd chl	barom in	uncor press	vis mi	weather	clouds	max F	min F	max F	min F
29 05:56pm MST	47	30	52	S 8		30.30	26.543	10.00		BKN120 BKN220				
29 04:56pm MST	48	31	51	S 7		30.30	26.552	10.00		FEW085 BKN130 BKN220	51	32		
29 03:56pm MST	50	30	46	S 8		30.31	26.561	10.00		BKN130 BKN220				
29 02:56pm MST	49	32	52	SW 3		30.31	26.561	10.00		BKN130 BKN220				
29 01:56pm MST	49	31	50	SE 3		30.32	26.570	10.00		SCT120 BKN220				
29 11:56am MST	40	29	65	S 8		30.37	26.597	10.00		SCT120 BKN200				
29 10:56am MST	32	29	88	S 8		30.44	26.633	10.00		FEW100 BKN200	32	24		
29 09:56am MST	30	28	92	S 8		30.44	26.642	10.00		FEW100 BKN200				
29 08:56am MST	26	26	100	S 7		30.47	26.651	10.00		FEW100 BKN200				
29 07:56am MST	26	25	96	SW 7		30.47	26.660	10.00		FEW002 SCT100 SCT170				
29 06:56am MST	26	25	96	SW 10	11	30.47	26.660	10.00		FEW002 SCT090 SCT150				
29 05:56am MST	25	24	96	S 10	10	30.47	26.660	7.00		SCT001 BKN100				
29 05:41am MST	25	25	100	NW 3			26.669	3.00	BR	SCT001 BKN100				
29 05:31am MST	25	25	100	SW 3			26.669	0.75	BR	BKN001				
29 05:18am MST	25	25	100	S 8			26.660	0.50	FZFG	BKN002 BKN120				
29 04:56am MST	27	26	96	SW 8		30.48	26.678	8.00		FEW002 SCT120 BKN200	28	24		
29 04:21am MST	25	25	100	CALM			26.678	5.00	BR	FEW001 SCT007 BKN120				
29 03:58am MST	25	25	100	S 3			26.669	2.00	BCFG	SCT001 BKN180				
29 03:56am MST	25	24	96	S 5		30.47	26.669	3.00	BR	SCT001 SCT120 BKN200				
29 03:12am MST	25	25	100	S 7			26.687	5.00	BR	FEW001				
29 03:06am MST	25	25	100	S 7			26.678	2.50	BR	SCT001				
29 02:56am MST	25	24	96	S 6		30.48	26.687	0.25	FZFG	BKN001				
29 02:37am MST	25	25	100	S 7			26.696	0.25	FZFG	BKN001				
29 02:28am MST	25	25	100	S 8			26.696	0.75	BR	BKN001 BKN010				
29 02:20am MST	27	25	93	S 8			26.696	0.25	FZFG	BKN001 BKN008				
29 02:00am MST	25	25	100	SW 8			26.696	0.50	FZFG	BKN001 BKN008				
29 01:56am MST	25	25	100	SW 7		30.49	26.696	0.25	FZFG	BKN001 BKN007				
28 11:56pm MST	27	25	92	SW 7		30.51	26.705	0.25	FZFG	BKN001			42	26
28 11:36pm MST	27	27	100	SW 3			26.705	0.25	FZFG	BKN001				
28 11:27pm MST	28	27	93	SW 5			26.705	0.25	FZFG	SCT001				
28 11:08pm MST	27	25	93	SW 6			26.705	0.50	FZFG	SCT001				
28 10:56pm MST	28	27	96	S 5		30.51	26.705	6.00	BR	FEW001	35	27		
28 09:56pm MST	29	28	96	W 3		30.53	26.705	10.00	BCFG	FEW001 SCT005				
28 09:26pm MST	28	27	93	NW 5			26.705	6.00	BR	FEW001 SCT005				
28 09:18pm MST	28	27	93	NW 5			26.705	0.25	BR	SCT001 BKN005				
28 09:06pm MST	27	27	100	NW 5			26.705	0.75	BR	SCT001 OVC005				
28 08:56pm MST	28	27	96	NW 5		30.53	26.705	0.00	FZFG	BKN001 BKN005				
28 08:38pm MST	28	28	100	N 3			26.705	0.00	FZFG	OVC001				
28 08:31pm MST	28	28	100	N 5			26.705	0.50	FZFG	VV001				
28 07:56pm MST	30	29	96	NW 5		30.53	26.705	6.00	BR	CLR				
28 06:56pm MST	32	30	92	N 7		30.51	26.705	10.00		CLR				
28 05:56pm MST	33	30	88	N 3		30.50	26.705	10.00		FEW200				
28 04:56pm MST	35	32	88	N 3		30.49	26.696	10.00		FEW200	42	34		
28 03:56pm MST	39	33	79	NE 6		30.47	26.687	10.00		FEW070 SCT200				
28 02:56pm MST	40	31	70	NE 6		30.45	26.678	10.00		FEW070 SCT200				
28 01:56pm MST	41	30	65	VRB 3		30.45	26.678	10.00		FEW004 SCT200				
28 12:56pm MST	39	28	64	SW 6		30.45	26.678	10.00		FEW004 SCT200				
28 11:56am MST	37	28	70	S 5		30.48	26.696	10.00		FEW002 SCT220				
28 10:56am MST	34	28	79	CALM		30.49	26.696	10.00		FEW002 SCT190	34	26		
28 10:22am MST	32	27	80	CALM			26.687	8.00	BCFG	SCT001 SCT190				
28 10:07am MST	28	28	100	CALM			26.687	3.00	BCFG	BKN001				
28 09:56am MST	28	28	100	CALM		30.49	26.687	0.25	FZFG	BKN001 OVC150				
28 08:56am MST	26	26	100	CALM		30.48	26.669	0.00	FZFG	BKN001 OVC150				
28 07:56am MST	26	26	100	CALM		30.47	26.660	0.00	FZFG	VV001				
28 06:56am MST	29	29	100	CALM		30.45	26.651	0.00	FZFG	VV001				
28 05:56am MST	30	26	85	CALM		30.42	26.624	0.00	FZFG	VV001				
28 04:56am MST	30	27	88	CALM		30.40	26.615	0.00	FZFG	VV001	33	30		
28 03:56am MST	30	27	88	CALM		30.36	26.579	0.00	FZFG	VV001				
28 02:56am MST	31	28	89	CALM		30.35	26.570	0.00	FZFG	VV001				
28 01:56am MST	32	30	92	CALM		30.33	26.552	0.00	FG	VV001				
28 12:56am MST	32	30	92	CALM		30.32	26.543	0.00	FG	VV001				
27 11:56pm MST	33	31	92	CALM		30.30	26.534	0.00	FG	OVC001			34	28
27 10:56pm MST	32	31	96	CALM		30.29	26.525	0.00	FG	OVC001	34	32		
27 09:56pm MST	33	31	92	CALM		30.28	26.507	0.00	FG	OVC001				
27 08:56pm MST	34	31	88	CALM		30.26	26.489	0.00	FG	OVC001				
27 07:56pm MST	34	31	88	CALM		30.24	26.480	0.00	FG	OVC001				
27 06:56pm MST	33	32	96	CALM		30.24	26.471	0.00	FG	OVC001				

Figure 4. Surface Weather Observations for Billings, MT
Note the Duration of Dense Fog the Evening of November 28, 1999