Assessing Applicability of the UPS Airlines Radiation Fog Forecasting Method for the J.C. Harris Regional Airport in Elko, Nevada

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Introduction

A study was conducted assessing applicability of the United Parcel Service Radiation Fog Forecasting Method for forecasting fog at the J.C. Harris Regional Airport in Elko Nevada. Data was gathered from the ASOS unit (Automated Surface Observing System), analyzed, and then compared to the UPS study to form a basis for determining if accurate fog prediction could be realized far enough in advance to be useful for aviation customers.

Overview of UPS Study

Traditional fog forecasting methods normally use only surface-based data such as dew-point temperature to access the potential for fog development. However surface based approaches fail to take into account key information above the surface such as the vertical distribution of humidity in the potential fog layer (surface to 500 feet). The UPS study was undertaken to take into account these non-surface-based factors that are important in fog formation.

The importance of the vertical profile of humidity, or hydrolapse, in fog formation has long been known but largely ignored. This has been due to the lack of observations above the surface at most airports. The UPS study uses a method to indirectly infer the hydrolapse. If during the afternoon hours, when mixing is usually at its maximum, the dew point falls at the surface, this infers that moisture is decreasing with height and the fog risk will be reduced. However if the dew point remains constant or increases during the afternoon, this implies that moisture is not decreasing with height and the risk of fog development is more favorable. This information is incorporated into the forecast process using the "crossover temperature" (T_{xover}), which is equal to the minimum dew point observed during the warmest part of the afternoon. The UPS study suggests that the visibility will lower to between 1 and 3 statute miles (SM) when the shelter-height temperature (T) either cools down to T_{xover} or to within 2˚F below T_{xover}. If T cools 3˚F or more below T_{xover}, dense fog of ½ SM or less will form.

Equation 1: $T = T_{xover}$, expect 1-3 SM visibility

Equation 2: $T \leq (T_{xover} - 3^\circ F)$, expect $\leq$ ½ SM visibility

Data

For the purpose of this study, a fog event is determined to have occurred when visibility (VIS) at the Elko airport decreased to 3 SM or less, a critical aviation threshold that requires pilots to transition from Marginal Visual Flight Rules (MVFR) to Instrument Flight Rules (IFR). Data for 26 "potential" fog events was collected and analyzed between March 2001 and December 2005.

Each case was evaluated using the Crossover Temperature Method, as defined in the UPS study, to determine the temperature at which fog would form (T_{fog}). After initial review of each case, four datasets were created; three based on fog formation in relation to the crossover temperature (T_{xover}) and one dataset in which no fog formed. Datasets are shown in Tables 1 through 4 in the Analysis section below. Specifically, the first dataset includes cases when fog formed 0-4˚C below T_{xover}, the second dataset covers cases when fog formed above $T_{xover,}$ and the third dataset is comprised of "delayed" fog events when formation of fog occurred well-below T_{xover}. Finally, the fourth dataset contains cases for which fog may have been expected but an event did not occur. This last dataset was included to strengthen the confidence in parameter relationship for the first three datasets for which fog did form. See Appendix A, figure 1 for explanation of parameters used in Tables 1 through 4 shown in the analysis section.

Analysis

For the purpose of this paper only the Crossover Temperature Method of the UPS Fog Study was used to determine if fog formation would occur. It was assumed that other factors conducive to fog formation are present such as a subsidence inversion, little or no turbulence at the top of the boundary layer, and clear, partially clear or rapidly clearing skies. With only one exception, an element common to the cases in which fog formed was that measurable precipitation (P) had occurred within the last 5 days, an expected relationship since moisture availability in the near-surface layer is critical to fog formation.

Dataset #1. Ten cases were assigned to the first dataset shown in Table 1, when fog formed between 0˚C and 4˚C below T_{xover} (see $T_{\mathbf{dev}}$). Eighty percent of the cases in this first dataset declared a most-recent maximum temperature (T_{max}) above 0˚C. In the two cases that T_{max} failed to exceed the freezing mark, 9 and 10 inches of snow depth (S_{depth}) was reported compared to no more than a trace (T) for any of the other events. Measurable precipitation (P) occurred within the previous 2 days in 70% of the cases. Although winds were deemed light (≤ 7 kts) in all cases, half of the dataset is comprised of events displaying an easterly component to the wind (W_{3hr}) and dense fog developed in more than half of the events assigned to this dataset as well.

Fog formation 0˚- 4˚C below T_{xover}
Dataset #1

Case #	VIS (SM)	T_{max} (ºC)	T_{min} (ºC)	T_{xover} (ºC)	T_{diff} (ºC)	T_{fog} (ºC)	(T_{dev}) (ºC)	S_{depth} (in.)	W_{3hr} (kts)	P (time)
1	1/2	- 1	- 3	- 2	1	- 2	0	10	NE 0-4	2 days
2	3/4	4	- 12	- 6	10	- 8	- 2	T	var. 0-4	2 days
3	1/4	11	- 4	- 4	15	- 4	0	0	calm	10 hrs
4	1/4	9	- 5	- 2	11	- 5	- 3	0	calm	4 days
7	<1/4	11	1	5	6	2	- 3	0	E 0-5	10 hrs
8	3/4	3	- 5	- 1	4	- 3	- 2	0	E 0-6	4 days
18	1/4	- 4	- 14	- 6	2	- 8	- 2	9	var. 3	3 hrs
22	1/4	11	- 2	2	9	2	0	0	var. 3	7 hrs
23	1/4	2	- 8	- 4	6	- 7	- 3	T	E 0-5	8 days
25	1/2	4	- 4	2	2	- 1	- 3	0	E 4-6	2 days

Table 1. Cases when fog formed 0˚- 4˚C below T_{xover}.

Dataset #2. Five cases were assigned to the second dataset, shown in Table 2. Dense fog formed in these cases between 1˚C and 3˚C above T_{xover} (see T_{dev}). There was no recognizable easterly component to the wind for any event in this dataset and wind (W_{3hr}) ranged from calm to 5 kts. In four of these cases, measurable precipitation (P) had occurred within 5 hours of fog formation. With abundant moisture in the boundary layer and little mixing of the near-surface environment, fog was able to form before T_{xover} was attained.

Dense fog formation above T_{xover}
Dataset #2

Case #	VIS (SM)	T_{max} (ºC)	T_{min} (ºC)	T_{xover} (ºC)	T_{diff} (ºC)	T_{fog} (ºC)	(T_{dev}) (ºC)	S_{depth} (in.)	W_{3hr} (kts)	P (time)
5	1/4	17	1	2	15	3	1	0	calm	5 hrs
6	1/4	10	- 2	- 1	11	1	2	0	var. 3	5 hrs
17	1/4	- 6	- 13	- 9	3	- 7	2	9	var. 0-5	2 days
19	1/4	4	- 13	- 7	11	- 5	2	2	var. 3	5 hrs
20	1/4	6	- 8	- 7	13	- 4	3	T	W 0-3	5 hrs

Table 2. Cases when dense fog formed above T_{xover}.

Dataset #3. Six cases were assigned to the third dataset shown in Table 3, when fog formed between 5˚C and 8˚ C below T_{xover}. Commonalities in this third dataset were that in 4 of 6 cases, the most recent minimum temperature (T_{min}) was below -10 ˚C and T_{max} was 0˚C or lower with snow on the ground (S_{depth}). It must be stated here that S_{depth} ranged from 2 to 9 inches in these 4 cases, and is comparable to the S_{depth} / T_{max} relationship evident in Tables 1, 2 and 4.

Delayed onset…fog formation 5˚-8˚C below T_{xover}

Dataset #3

Case #	VIS (SM)	T_{max} (ºC)	T_{min} (ºC)	T_{xover} (ºC)	T_{diff} (ºC)	T_{fog} (ºC)	T_{dev} (ºC)	S_{depth} (in.)	W_{3hr} (kts)	P (time)
9	1/4	- 3	- 21	- 11	8	- 17	- 6	4	calm	21 hrs
13	< 1/4	0	- 13	- 4	4	- 12	- 8	2	calm	2 days
15	1 1/2	- 4	- 16	- 8	4	- 16	- 8	9	E 3-7	5 days
16	2 1/2	- 5	- 15	- 8	3	- 15	- 7	9	var. 4	4 days
21	1/4	9	1	7	2	2	- 5	0	calm	6 hrs
26	< 1/4	11	- 5	3	8	- 3	- 6	0	var. 0-4	2 days

Table 3. Cases when fog formed 5˚-8˚C below T_{xover}.

Dataset #4. Table 4, the fourth dataset, is comprised of non-events when fog may have been expected, but no fog formed. In none of these cases did T_{max} exceed 0˚C. In 4 out of 5 cases in this dataset (case #'s 10,11, 12, 14), an inversion episode had been in effect for at least 4 days where T_{max} did not reach the freezing mark and T_{min} dropped to near -17 ºC. There was at least a trace of snow on the ground in each case. Winds (W_{3hr}) displayed a defined easterly direction with maximum wind speed ranging from 5 to 7 kts, generally higher than in the other three datasets, and allowed for mixing of the near-surface layer.

No fog

Dataset #4

Case #	VIS (SM)	T_{max} (ºC)	T_{min} (ºC)	T_{xover} (ºC)	T_{diff} (ºC)	S_{depth} (in.)	W_{3hr} (kts)	P (time)
10	7	- 1	- 17	- 9	8	2	E 0-7	5 days
11	10	- 2	- 17	- 9	7	1	E 0-6	7 days
12	10	- 2	- 17	- 9	7	2	E 3-7	6 days
14	9	- 8	- 18	- 11	3	5	E 3-7	3 days
24	6	0	- 11	- 6	6	T	E 0-5	10 days

Table 4. Cases when no fog developed.

Conclusions

Based on analysis of local data collected between March 2001 and December 2005, the UPS Crossover Temperature Method of forecasting fog, with modification, will be helpful to forecasters at WFO Elko in assessing fog potential for the J.C. Harris Regional Airport in Elko Nevada. There were three primary determining factors that needed to be addressed in the fog forecast process: the speed and direction of the wind; and the length of time since the last reported precipitation. Four tables were developed and analyzed in order that decision tree tools could be constructed for use as an aid in forecasting fog.

Light winds are critical to fog development in the vicinity of the airport due to low-level mixing and drainage aspects. Analysis of the data revealed that when W_{3hr} approached 7 knots, no fog occurred.

A substantial dry period prior to an anticipated event reduces moisture in the lower layers of the atmosphere, and diminishes the probability that fog will occur. In general, the longer the time period since the last precipitation event, the drier the near-surface layer of air becomes, reducing the likelihood that fog will form. During wintertime inversion events, when temperatures remain below freezing for an extended period of time, most of the moisture in the boundary layer sublimates out and the near-surface layer becomes too dry to support fog formation. In some cases, even though a snow layer was present, icing-over of the snowpack may have limited moisture release and thus prevented saturation of the near-surface layer to the extent that fog did not form. If measurable precipitation (P) had not occurred within 8 days, no fog developed. Similarly, data reflected that if P exceeded 5 days, there was a mere 4% probability that fog would form.

Actual fog events for this study were placed into three categories: fog formation 0º- 4ºC below T_{xover}; dense fog formation above T_{xover}; and delayed-onset fog. Fog usually formed during the first few days of an inversion episode. In cases when P occurred within five days and ended before noon on the day preceding a fog event, fog generally formed between 0ºC and 4ºC below T_{xover}. In cases when T_{max} did not exceed freezing and dropped to -13˚C or below at night for at least the two previous nights, fog generally formed between 5ºC and 8ºC degrees below T_{xover}, classified as delayed onset. When P ended during the previous late afternoon or evening, fog generally formed overnight between 1ºC and 3ºC above T_{xover}.

The six cases in the third dataset, when fog formed 5º- 8ºC degrees below T_{xover}, were instances where application of the UPS method would have been less effective as a forecast tool. It is theorized that on very cold nights, moisture is sublimated from the layer of air near the surface and deposited on the snowpack. Hence the temperature has to drop well-below T_{xover} before the near-surface environment becomes saturated and fog forms. This is especially true when you are well into an inversion event where the moisture in the boundary layer has had a chance to sublimate out onto the snow pack during the preceding nights. To accommodate these cases, modification of the UPS method is necessary to forecast the onset of fog at the Elko airport.

It has been determined that the UPS fog study has applicability for fog forecasting for the J.C. Harris Regional Airport in Elko Nevada. Of the 26 cases involved in this study, fog could have been forecast with a 96% probability of detection (POD). Data derived from this study has led to the development of two decision trees (see Appendix B) that has been made available to WFO Elko forecasters to be used as an aid for fog prediction. One decision tree is a shortened version (FOGCAST Basic) that will give forecasters a quick-decision tool to evaluate whether fog should form (see figure 2, Appendix B). The development of a more detailed decision tree (FOGCAST Enhanced) is comprised of two parts (charts A and B) and may help the forecaster decide whether the fog will most likely become dense overnight and possibly yield a more precise time of occurrence (see figures 3 and 4, Appendix B). Although this is a limited dataset, the resulting decision trees have proved useful during the 2006-2008 "fog" seasons.

Appendix A

Description of table parameters

VIS................. lowest visibility occurrence in statute miles (SM)
T_{max}................most recent maximum temperature
T_{min}................. .most recent minimum temperature
T_{xover} ....dewpoint temperature at time of T_{max}
T_{diff}.................T_{max} - T_{xover}
T_{fog} ....temperature when visibility first lowered to 3 SM or less
T_{dev}.................T_{fog} - T_{xover}
S_{depth}...............snow depth at time of event (T = trace)
W_{3hr}................general wind characteristic for 3 hours prior to anticipated event
P .... last occurrence of measurable precipitation (at least 0.01 in.)

Figure 1. Parameters used within the fog datasets.

Appendix B

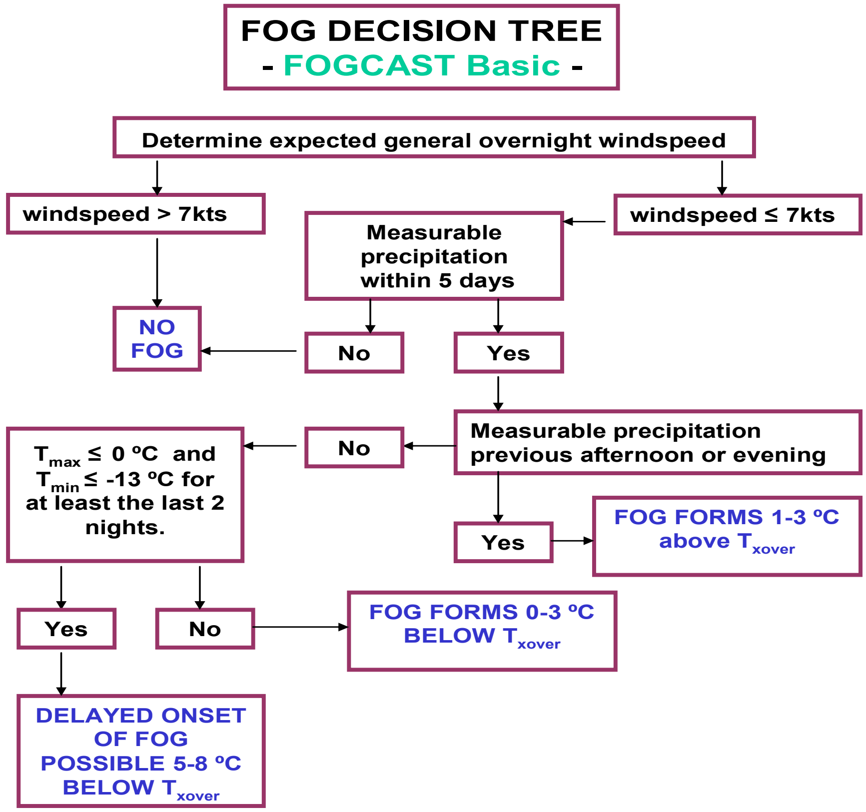


Figure 2. Fog Decision Tree (FOGCAST Basic).

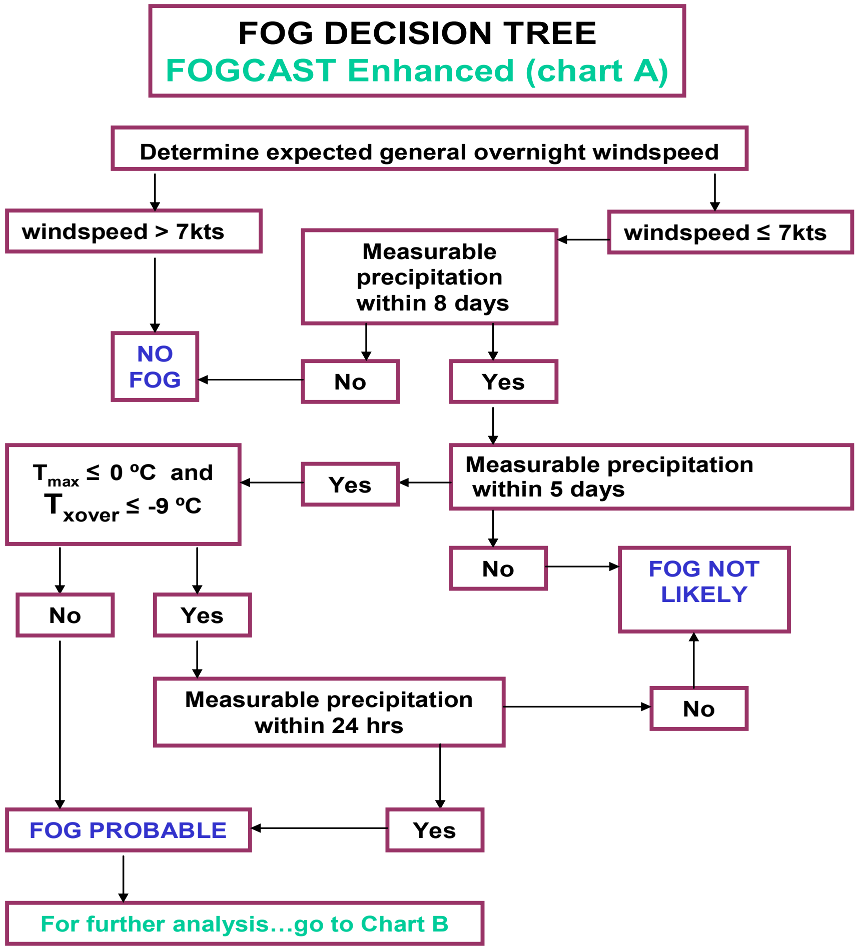
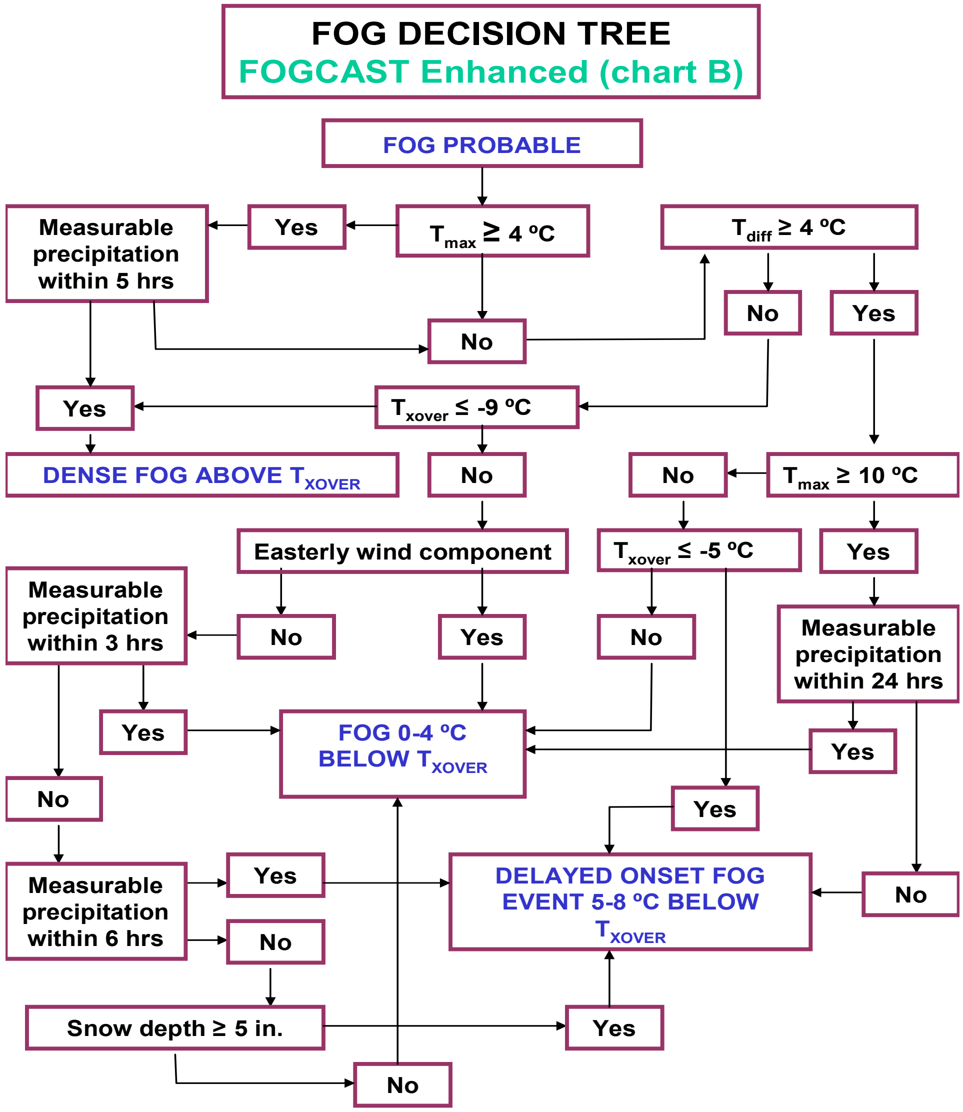


Figure 3. Fog Decision Tree (FOGCAST Enhanced - chart A).



T_{xover} = dewpoint temperature at time of T_{max}
$T_{diff} = T_{max} - T_{xover}$

* for description of other parameters, see Appendix A, figure 1.

Figure 4. Fog Decision Tree (FOGCAST Enhanced - chart B).

References

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