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An Evaluation of Fog Forecasting Tools for a Fog Event and Non-Event at Salt Lake City International Airport

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Introduction

One of the more difficult weather phenomena to forecast is fog. Specific forecasting aspects to consider include: 1) predicting its formation, 2) onset and dissipation times, and 3) the degree of visibility restriction. Fortunately, several traditional fog forecasting methodologies are available to aid in the decision making process. These include local forecaster experience (e.g., pattern recognition, climatology, and persistence), model numerical and statistical guidance, and various local and regional studies. However, since the resolution of operational numerical guidance generally does not capture the small scale controlling factors responsible for fog, forecasters must often rely and apply local conceptual models and fog studies to adjust numerical guidance.

This case study evaluates the usefulness of two fog forecasting tools available for forecasters at the Salt Lake City (SLC), Utah, National Weather Service (NWS) Forecast Office. Two fog events will be used to demonstrate the utility of these tools in operational forecasting. The first case was a dense fog event that occurred at the SLC International Airport during the morning hours of 02 December 2003, from 1200 UTC until shortly after 1900 UTC – or between 500 AM and 1200 PM MST. The impact from this event on aviation was significant with 26 flights to SLC diverted and many more delayed. The second event – hereafter referred to as the "non-event" – occurred the following night on 03 December 2003. The tools examined include a local forecast tool developed by Watling (1989; hereafter referred to as the "Watling study"), along with a second, more generic nationwide based forecast tool developed by Baker et al (2002; hereafter referred to as the "UPS study") of the United Parcel Service. A brief description of northwest Utah topography is presented first, and then a synopsis and discussion of satellite imagery and meteorological observations of both the fog event and non-event are presented, followed by a conceptual overview of previous studies used in developing the fog forecasting tools. The application of data from both cases to conceptual models is then discussed, followed by a summary and conclusion.

Topography of Northwest Utah

The two primary terrain features that drive the mountain-valley circulations across most of northwest Utah are the Great Salt Lake desert and the Wasatch Mountains that border to the east and extend from the Idaho border to south of SLC (Fig. 1). More subtle features that influence diurnal patterns of the Salt Lake Valley include the Oquirrh Mountains to the southwest of SLC, and the slightly higher terrain that bridges across the south end of the Salt Lake Valley between the Oquirrh Mountains and the Wasatch Mountains.

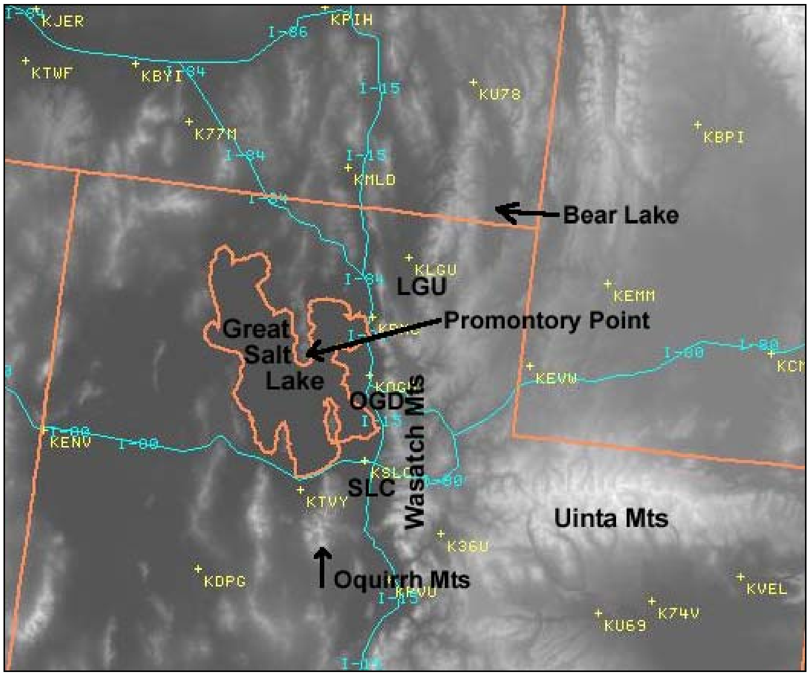

Fig. 1. High resolution terrain map of northern Utah. The darker shade of gray represents the lowest elevations. Note that Salt Lake City International Airport (SLC) is located between the Oquirrh Mountains to the southwest, and the higher Wasatch mountains to the east. Other reference points noted are Logan (LGU) and Ogden (OGD).

Synopsis, Satellite, and SLC observations

Fog Event - 02 December 2003

The overall meteorological conditions leading up to the commencement and continuing through dissipation of the dense fog were investigated. The general 700 mb synoptic flow at 0000 UTC 02 December was southwest at 15-25 kt (except 40 kt at SLC) between a ridge over Colorado and a trough over the California coast (Fig. 2a). The strength of this approaching trough was considered weak (moderate at best) based on the difference of only 5°C between SLC and Reno, NV (RNO). By 1200 UTC (time of fog onset), SLC experienced a trough passage, with the 700 mb trough axis over eastern Utah (Fig. 2b). In the wake of this transient trough, a ridge moved to near the Nevada-Utah border by 0000 UTC 03 December (Fig. 2c).

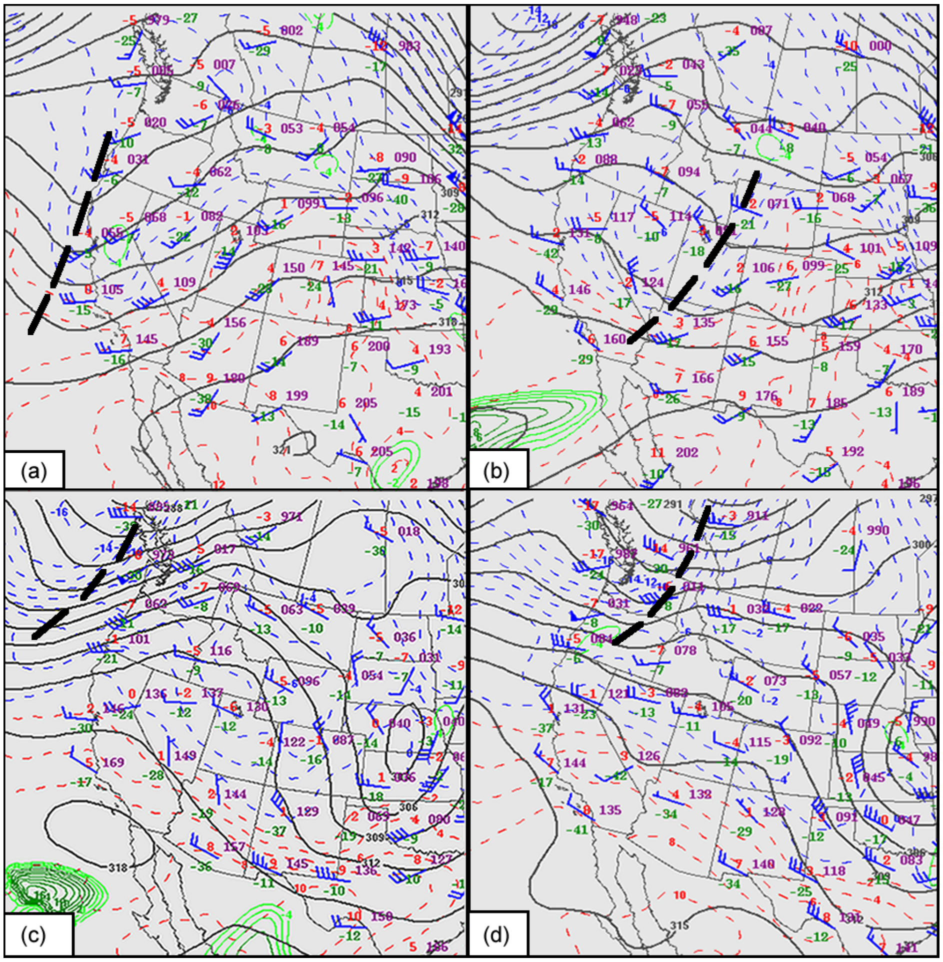

Fig. 2. Analyses of 700 mb wind (full barbs 10 kts), temperature (dash lines every 2°C), and geopotential heights (solid lines every 30 m). (a) 0000 UTC 02 December, (b) 1200 UTC 02 December (onset of fog), (c) 0000 UTC 03 December, (d) 1200 UTC 03 December.

While this general synoptic pattern was not favorable for what forecasters at SLC consider for a typical fog pattern, surface conditions and the SLC sounding showed otherwise. Surface conditions across the intermountain region indicated that this approaching trough was weak, with a rather flat pressure gradient northwest of SLC from 0900 UTC through 1800 UTC 02 December (Fig. 3). In fact, the actual difference between the surface pressure observations from several Automated Surface Observing System (ASOS) and Automated Weather Observation System (AWOS) sites across northern Utah varied less than 0.50 mb between 0600 UTC and 1800 UTC 02 December. Although this flat gradient would not have enhanced the typical nocturnal southeast drainage flow out of the Wasatch Mountains and into the Salt Lake Valley, it is not known whether it was the sole inhibitor. Other micro-meteorological processes may have occurred, that are beyond the scope of this paper, which allowed the surface winds to reverse to a northerly direction.

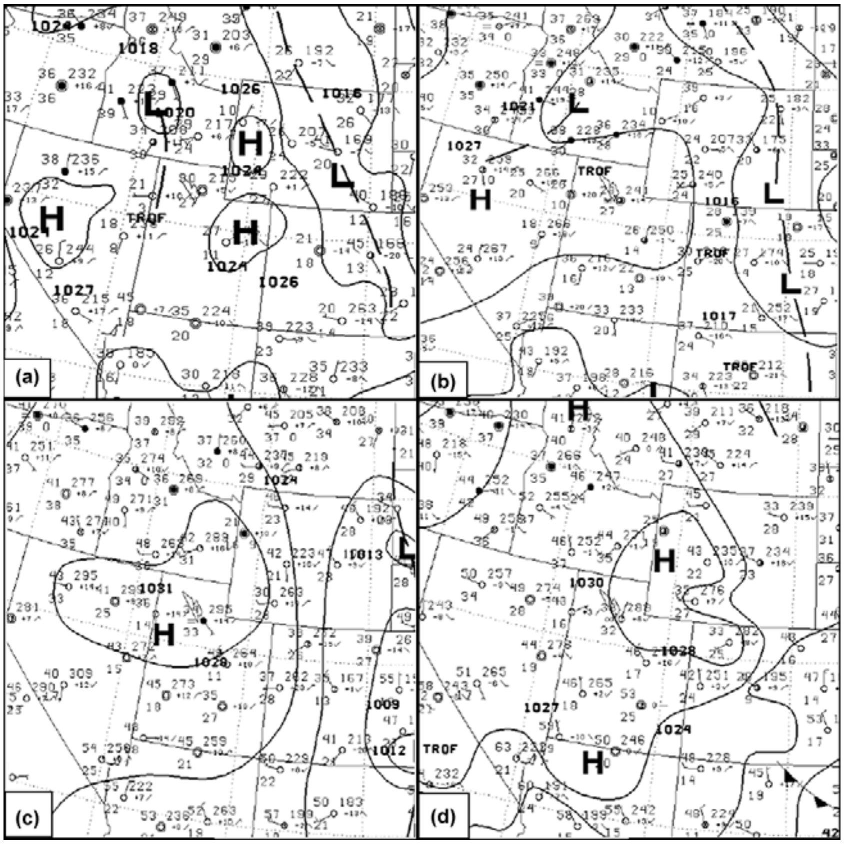

Fig. 3. Sea level pressure (every 4 mb) on 02 December 2003. (a) 0900 UTC , (b) 1200 UTC, (c) 1800 UTC. And (d) 0000 UTC 03 December.

This non-descipt pressure gradient pattern is quite opposite of what typically occurs with an incoming trough over the Great Basin, whereby the surface pressure gradient is southeast-to-northwest along the Wasatch Front. This subtle but important difference in surface pressure gradient was critical to fog development at SLC. Due to the lack of snow cover or very recent precipitation, the typical nocturnal southeast drainage advects in either slightly drier air or at least keeps the more moist valley air associated with the Great Salt Lake (GSL) itself and its marshes northwest of the SLC airport.

An inversion below 800 mb formed over the SLC valley the previous night (01 December), and persisted through the daytime hours of 01 December due to extensive cloud cover that allowed little if any mixing. Soundings collected at SLC between 1200 UTC 01 December (Fig. 4a) through 1200 UTC 02 December show that this surface-based inversion strengthened and lowered below 850 mb between 0000 UTC (Fig. 4b) and 1200 UTC 02 December (Fig. 4c), while the winds above the inversion – stronger at 0000 UTC – shifted to the northwest and relaxed by 1200 UTC.

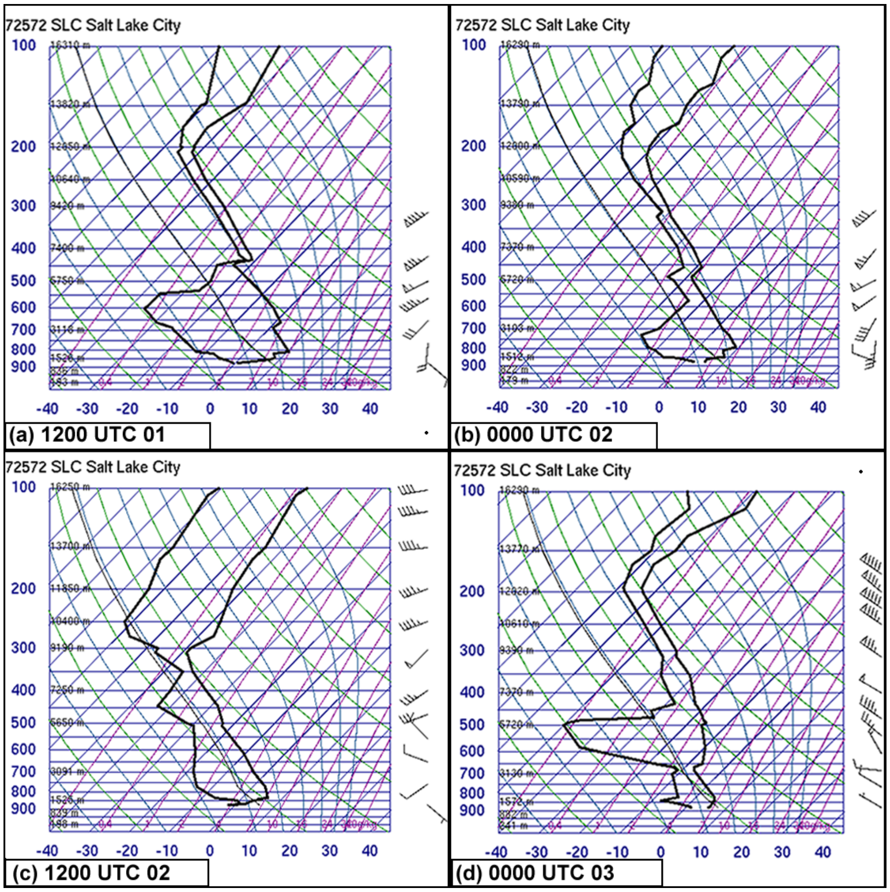

Fig. 4. SkewT-log*p* at SLC (T and Td). winds (full barbs 10 kts). (a) Strong inversion with low level moisture valid 1200 UTC 01 December, (b) northwest flow off GSL below inversion valid 0000 UTC 02 December, (c) trough passage between 500-700 mb and strong low level inversion with lowest 15 mb saturated valid 1200 UTC 02 December, and (d) 0000 UTC 03 December.

Winds at Promontory Point mesonet site (6926 ft msl and 45 miles northwest of SLC - see Fig.1 for location), were above the inversion at approximately 2700 ft above Great Salt Lake valley floor. These winds veered from west to northwest, then to the north between 0900 and 1300 UTC 02 December. The 1200 UTC the SLC sounding (Fig. 4c) did not show this wind shift below 700 mb. This can be expected since, 1) SLC soundings are released at approximately 1100 UTC, and 2) SLC is about 1h downstream from Promontory Point under a typical northwest flow regime. These wind shifts above the inversion with the trough passage were not reflected in the wind pattern at the surface.

At 1132 UTC 02 December the SLC winds shifted to light northwest (<6 kt), while the temperature dropped to the dew point temperature of 27°F. Dense fog was observed at the SLC airport within 20 minutes of this wind shift (Fig. 5). This trend is consistent with climatology associated with onset of fog at SLC according to a fog climatology study performed by Slemmer (2004). Once the dense fog settled in, the on-duty aviation forecaster was faced with the question of how long the fog would persist. Arguments for visibility improvement by 1700 UTC were two-fold: 1) climatological breakup time typically is between 1600 and 1700 UTC, and 2) mid to high level clouds were moving across the area which would act to limit the outgoing radiation loss. The latter argument had already proven itself in the Cache Valley at LGU (see Fig. 7. for location and relationship to high clouds to the west), where the onset of higher clouds after 0430 UTC resulted in a visibility increase at LGU from <=1SM BR to >=2 SM BR. Thus, in theory, these visibilities were expected to also occur at SLC. Other than a brief 13 minute increase to 1 SM BR from 1243 to 1256 UTC, dense fog was persistent at SLC through the morning hours. Even with the southeast surface winds occurring after 1500 UTC – which typically helps advect moisture away from SLC – the visibility at SLC decreased to 1/16 SM FG between 1700 and 1800 UTC. This is a time and associated wind direction that climatologically favors an increase in visibility according to Slemmer's study.

KSLC

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DEC 02 11:32UTC 32005KT 2 1/2 BR CLR 27 27 100 30.20 TWR VIS GTR THAN FOUR
DEC 02 11:40UTC 31004KT 1 BR VV007 28 27 93 30.22 TWR VIS GTR THAN FOUR RVRNO
DEC 02 11:49UTC 00000KT 1/4 FZFG VV003 28 28 100 30.21 TWR VIS GTR THAN FOUR RVRNO
DEC 02 11:56UTC 00000KT 1/4 FZFG BKN003 BKN008 28 27 96 30.21 1024.1 34 26   TWR VIS GTR THAN
FOUR RVRNO
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DEC 02 12:23 UTC 11004KT 1/4 FZFG BKN001 OVC008 27 25 93 30.22 TWR VIS GTR THAN FOUR RVRNO
DEC 0212:43 UTC 00000KT 1 BR SCT001 SCT006 27 27 100 30.24 TWR VIS GTR THAN FOUR RVRNO
DEC 02 12:56 UTC 28004KT 1/4 FZFG BKN003 26 26 100 30.25 1025.6 TWR VIS GTR THAN FOUR RVRNO
DEC 02 13:48 UTC 00000KT 1/8 FZFG VV001 28 28 100 30.28 SFC VIS RVRNO
DEC 0213:56 UTC 00000KT 1/8 FZFG VV001 28 28 100 30.29 1027.0 SFC VIS RVRNO
DEC 02 14:56 UTC 15004KT 1/8 FZFG OVC001 29 29 100 30.32 1028.1 SFC VIS 1 RVRNO
DEC 02 15:56 UTC 17006KT 1/8 FZFG VV001 31 31 100 30.34 1028.7 RVRNO
DEC 02 16:56 UTC 13006KT 1/16 FG VV001 33 33 100 30.36 1029.3 SFC VIS RVRNO
DEC 02 17:56 UTC 13007KT 1/16 FG OVC001 34 33 96 30.37 1029.5 34 25 SFC VIS RVRNO
DEC 02 18:37 UTC 12003KT 3/4 BR BKN001 BKN020 36 36 100 30.36 RVRNO

Fig. 5. SLC surface observations from onset of north winds at 1132 UTC 02 December until dense fog dissipation at 1837 UTC 02 December. Observation at 1243 UTC italicized to indicate only non-dense fog observation for over six consecutive hours.

Satellite imagery clearly captures the fog evolution for this event. Dense high clouds shrouded the region through the day (01 December), then moved east during the evening ahead of high clouds that were associated with the upstream trough. In the clear slot at 0600 UTC 02 December (Fig. 6), two main areas of fog were observed over Utah at Bear Lake and Logan (LGU) with a hint of fog over the eastern arm of the GSL - just west of Ogden (OGD).

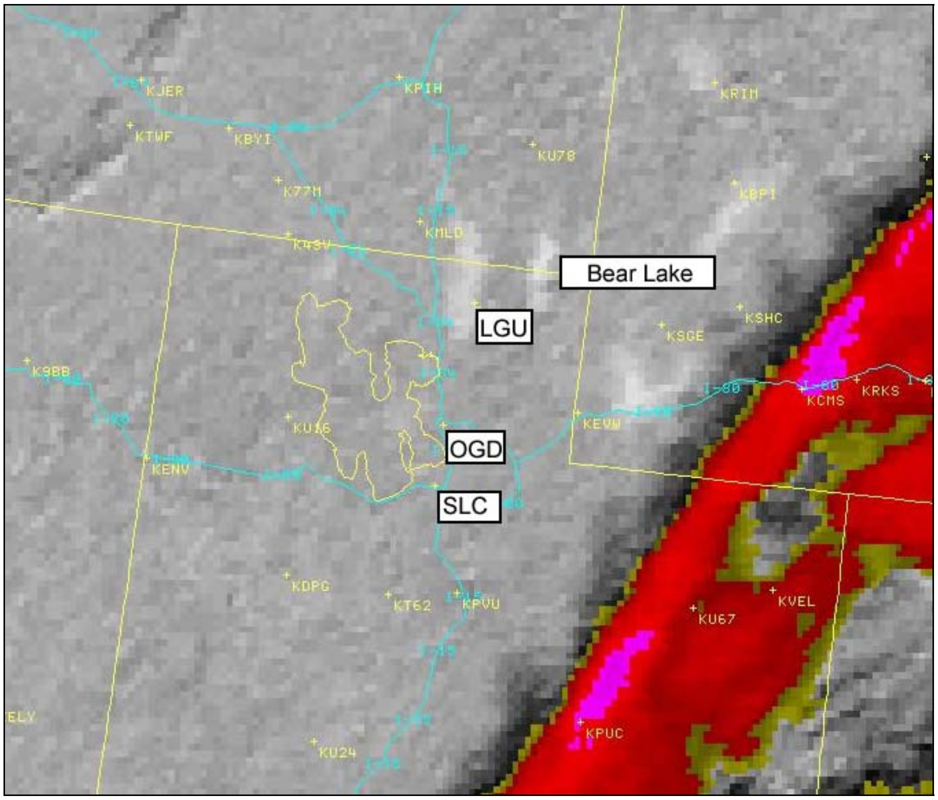


Fig. 6 GOES-IR Satellite valid 0600 UTC 02 December. Extensive dense fog (white tone) in the Bear Lake valley and in the Cache valley where Logan (LGU) is located. There is a hint of fog (light gray) over the eastern arm of the GSL- just west of OGD. High clouds (red) are over eastern Utah and southwest Wyoming. The yellow crosshairs at the top left corner of each three-letter city identifier is the exact location of that city.

After 1030 UTC this area thickened into a noticeable fog bank over the marshlands along the eastern flank of the GSL between Ogden and SLC

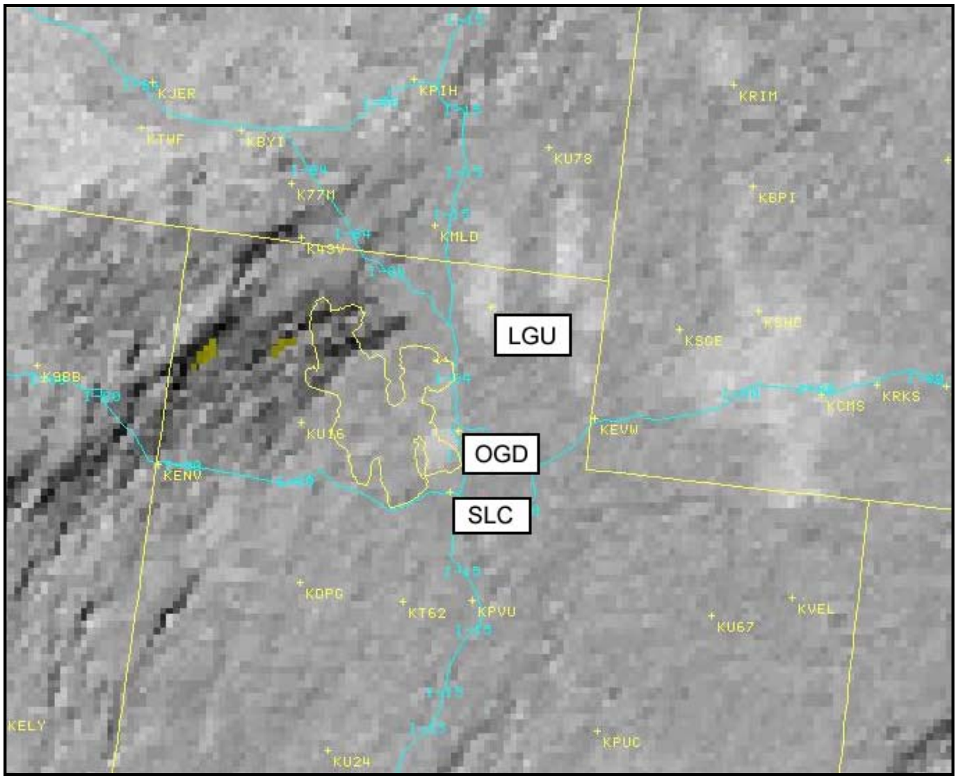


Fig. 7. GOES-IR Satellite valid 1030 UTC 02 December. City locations as same as in Fig. 6. Fog thickened (light gray to white tones) southwest of OGD and expanded southward toward SLC. Note mid or high clouds (dark gray, black and yellow pixels) over northwest Utah.

The fog expanded and drifted southward into SLC at 1149 UTC. During the following hour, the tower visibility remained above 4SM. (It is important to note that the SLC tower is considered a "super tower" at a height of 374 ft AGL.) At 1348 UTC (648 AM MST), the fog thickened to at least a depth of the tower, [note- the tower visibility was no longer reported (Fig. 5)]. At 1530 UTC (Fig. 8a), GOES visible satellite imagery was utilized to reveal the extensive fog from the Salt Lake Valley northward along the eastern shoreline of the GSL. By 1700 UTC (Fig. 8b), fog was clearly defined in a narrow band from the northeast edge of GSL southward through SLC across the eastern half of the Salt Lake valley to a point where higher terrain – seen in the high resolution topo map in Figure 1 – impeded its southward progress. Fog movement and dissipation during the late morning and early afternoon hours is clearly shown in GOES visible satellite imagery (Figs. 8c and 8d). Note the fog retreated back to the northwest and actually appeared to be advected westward across the southern arm of the GSL, rather than dissipating after 2000 UTC.

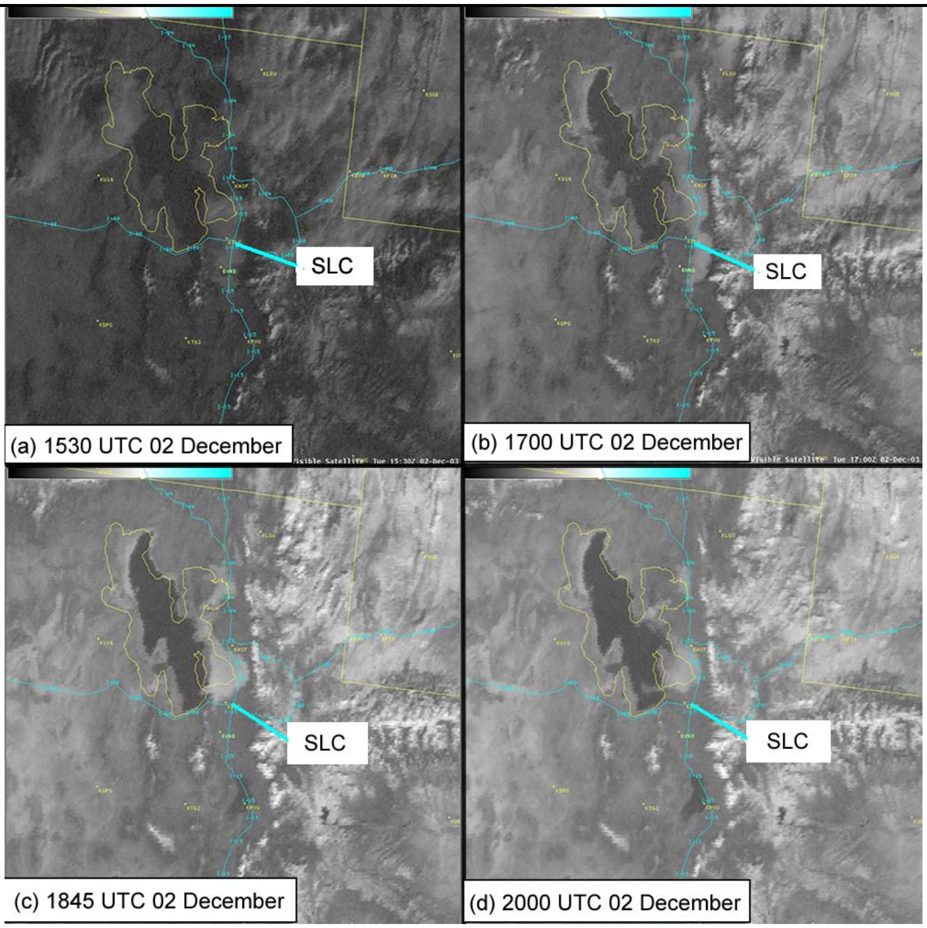
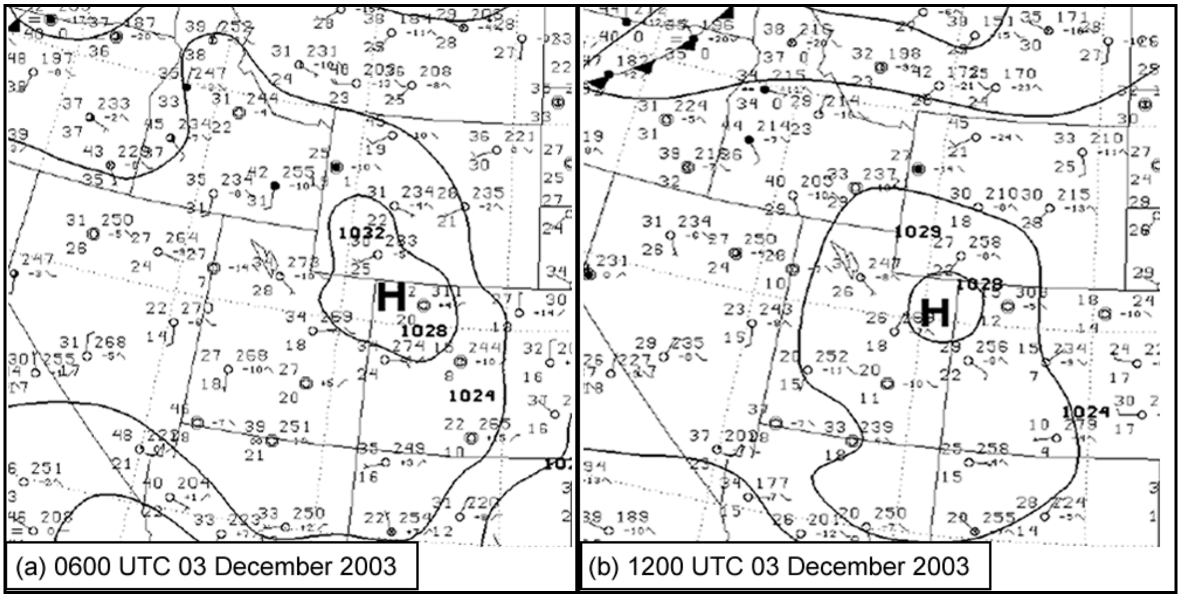


Fig. 8. GOES-Visibility Satellite. (a) 1530 UTC, (b) 1700 UTC, (c) 1845 UTC, (d) 2000 UTC. Note: Registration errors caused the satellite imagery to be offset by about 15 km too far east as easily seen by the shoreline displacement of the GSL.

The SLC observations indicate that the strength of southeast winds nearly doubled between 1900 UTC and 2100 UTC, which resulted in the rapid visibility and ceiling improvement by early afternoon.

Fog Non–Event - 03 December 2003

The general 700 mb synoptic flow between 0000 and 1200 UTC 03 December was west at 10-15 kt under a generally flat Great Basin ridge. By the end of this period, a trough was forecast to extend across eastern Washington and Oregon (Fig. 2d). The MSLP responded to this incoming trough as the surface high centered near the tri-state area of ID-WY-UT at 0000 UTC moved east of SLC by 0600 UTC (Fig. 9a), and southeast of SLC by 1200 UTC 03 December (Fig. 9b). This allowed favorable conditions for the southeast drainage flow to be enhanced across the SLC valley.

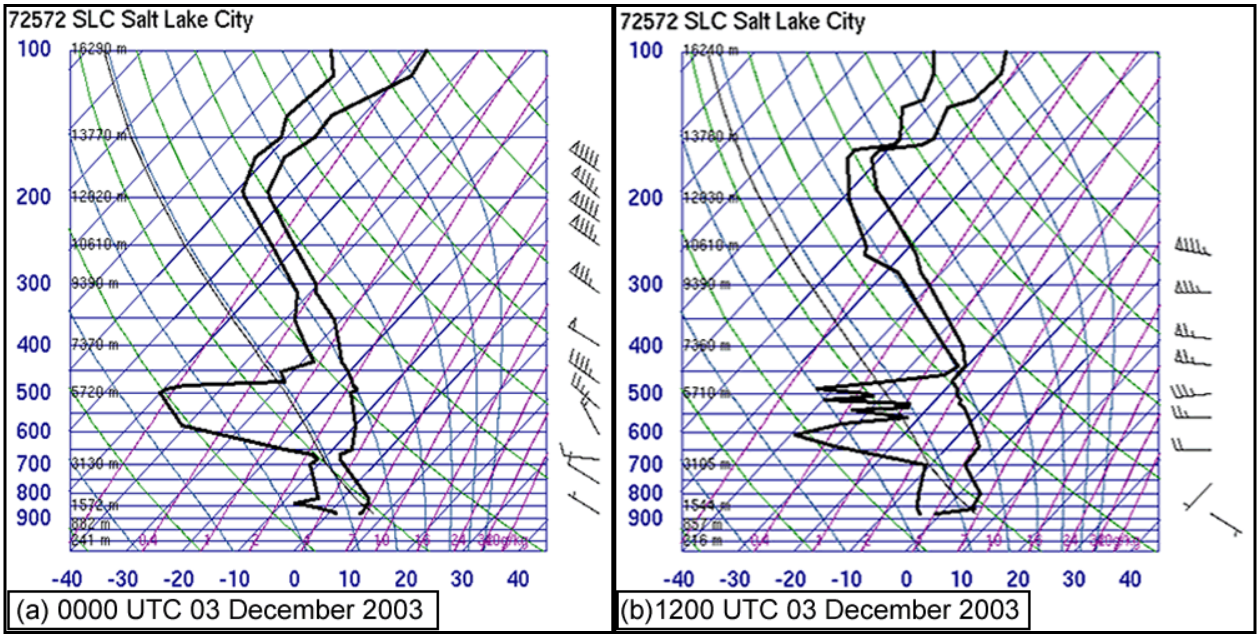


(a) 0600 UTC 03 December 2003

(b) 1200 UTC 03 December 2003

Fig. 9. Sea level pressure (every 4 mb) on 03 December 2003. (a) 0600 UTC and (b) 1200 UTC.

The vertical profile also changed as seen by the significant low level drying that occurred between 1200 UTC 02 December (Fig. 4c) and 0000 UTC 03 December (Fig. 10a). This drying trend continued through the night despite a strong inversion that redeveloped by 1200 UTC 03 December (Fig. 10b).



(a) 0000 UTC 03 December 2003

(b)1200 UTC 03 December 2003

Fig. 10. SkewT-log*p* for SLC (T and Td), winds (full barbs 10 kts)..(a) 0000 UTC 03 December. Weak surface inversion under a predominant northwest flow throughout the profile and (b) 1200 UTC 03 December. Surface boundary no longer saturated.

There was a strong surface inversion, but the lowest 15 mb of the profile was not saturated. An overcast or broken cloud deck is likely based on the near saturated conditions at 450 mb.

Conceptual overview of studies

The UPS Study

The UPS study is an all encompassing nationwide study from over 80 airports for which the UPS provides a fog/visibility forecast. It primarily examines vertical processes in the potential fog layer. More specifically, the UPS study examines the low-level hydrolapse (humidity) profile of the atmosphere. Since humidity observations above the surface are limited to radiosonde observations – which are only collected twice per day – the UPS study infers a humidity profile by correlating the observed dew point temperatures during the warmest, and typically deepest well-mixed portion of the day. If the dew point remains constant or increases during the afternoon, it is implied that moisture is not decreasing with height, and the probability of fog forming the subsequent night is greater. Assuming there is some degree of mixing, this conceptually represents the dew point temperature of the air at approximately 200 ft AGL. The lowest observed dew point temperature during the warmest part of the day is considered the cooling threshold, or the so-called crossover temperature (*Txover*; see below). The UPS study suggests that the visibility will lower to 1-3 statue miles (SM) when the shelter height temperature (T) cools to equal Txover or to within 2°F below Txover. If T cools 3°F or more below Txover dense fog of one-half SM or less will form. Stated in another manner:

When T = Txover , expect 1-3 SM visibility
When T =< Txover - 3°F, expect ½ SM or lower visibility

For example, if the lowest afternoon dew point is 40°F, Txover and the forecast nighttime minimum is 40°F, then expect the visibility to decrease to between 1 and 3 SM. If the forecast minimum is 37°F or lower, then expect the visibility to drop to one-half SM or less.

The Watling Study

The Watling study is a local SLC study which performed multiple linear regressions on candidate fog forecasting parameters at SLC. It was found that no single parameter in combination with another exhibited a strong enough relationship to *reliably* forecast dense fog. However, of the variables examined, surface visibility and relative humidity from the previous afternoon were the most important, followed by the forecast lapse rate. The Watling Chart, which provides probabilities of fog formation, is based on the relationship between the lapse rate (surface - 1000 ft AGL temperature (°F) on the1200 UTC RAOB), and average surface relative humidity between 1900 and 2100 UTC. This relationship should only be applied when the current day's visibility is below 7 SM. A steep lapse rate combined with moderate relative humidity has the equivalent probability of dense fog forming as a lesser lapse rate has with high relative humidity.

It should be noted that in the original Watling study, only 3 of 98 dense fog cases (less than 5%)

occurred when the average previous afternoon visibility was greater than 7 SM. The lapse rate vs. RH chart used for determining fog development was based on the remaining 95 positive cases. An example of a Watling Chart can be viewed in figure 13.

Additional statistics and limitations are as follows: the Watling technique has a Probability of Detection (POD) of 0.50 and a False Alarm Ratio (FAR) of 0.29. Although these are not the best statistics, especially the POD, the FAR score can have value in adding confidence to the forecaster's decision making process. A significant limitation of the Watling study is that it relies heavily on the previous afternoon visibility. This can be very misleading since it can change sharply even if the liquid water content of the air remains constant. For a given volume of water, Watling reminds forecasters that many small droplets will reflect more light than fewer large droplets due to the greater combined surface square area, thus reducing the visibility. Consequently, the visibility criteria used in the Watling study should be used loosely, with more emphasis placed on the more consistent RH predictor.

Application of data to conceptual models

Precursor conditions from the afternoon of 01 December are applied to each of the forecasting tools. Of utmost importance to the UPS study is the surface dew point and its trend. From the following list of SLC observations (Fig. 11), the lowest dew point observed during the warmest portion of the afternoon was 34°F. This is the UPS Txover.

KSLC

DEC 01 18:56 UTC 34003KT 10 BKN120 OVC200 41 33 73 30.17 1021.8
DEC 01 19:56 UTC 29003KT 9 FEW090 SCT130 OVC180 43 36 76 30.14 1020.6
DEC 01 20:56 UTC 30008KT 9 FEW090 BKN130 OVC180 42 36 79 30.14 1021.1
DEC 01 21:56 UTC 32006KT 10 BKN130 OVC180 43 *34* 70 30.11 1019.8
DEC 01223:56 UTC 28005KT 10 BKN130 OVC180 42 *34* 73 30.11 1019.9
DEC 01 23:56 UTC 30005KT 10 BKN130 OVC180 40 35 83 30.12 1020.3 44 38
Dec 01 00:56 UTC 27003KT 10 BKN130 OVC180 39 36 89 30.11 1020.0

Fig. 11. SLC surface observations during the afternoon prior to fog event between 1900 UTC 01 until 0100 UTC 02 December. Lowest dew point (34°F) is italicized

The minimum temperature forecast for the upcoming night at SLC was 30°F (4°F less than Txover), which supports expected visibilities of one-half SM or lower. The following observations indicate that this threshold (Txover = 34°F) was surpassed by T at SLC by 0736 UTC (T = 30°F), and remained 3°F or more (and as much as 5°F) below Txover through 1100 UTC (Fig. 12). Despite this, dense fog *did not* form. Although the RH reached 100% twice during this period, the visibility remained in the 2-3 SM range. This is more in line with what should be expected when T is equal to Txover. Finally, at 1149 UTC (Fig. 5) dense fog formed at a T of 28°F and dewpoint of 28°F (Txover - 6°F).

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KSLC
DEC 01 05:56 UTC 36003KT 7 FEW150 33 31 92 30.14 1020.3 40 32
DEC 01 06:56 UTC 27007KT 5 BR CLR 33 31 92 30.15 1021.4
DEC 02 07:36 UTC VRB03KT 2 1/2 BR CLR 30 28 93 30.16 TWR VIS GTR THAN FOUR
DEC 02 07:56 UTC 16004KT 3 BR CLR 31 30 96 30.15 1021.5 TWR VIS GTR THAN FOUR
DEC 02 08:44 UTC 13006KT 2 1/2 BR CLR 30 28 93 30.17 TWR VIS GTR THAN FOUR
DEC 02 08:56UTC 15006KT 3 BR CLR 30 29 96 30.17 1021.2 TWR VIS GTR THAN FOUR
DEC 02 09:35 UTC 00000KT 2 BR CLR 30 28 93 30.17 TWR VIS GTR THAN FOUR
DEC 02 09:56 UTC 00000KT 2 BR CLR 29 29 100 30.20 1022.2 TWR VIS GTR THAN   FOUR
DEC 02 10:56 UTC 13004KT 3 BR CLR 30 28 92 30.19 1021.9 TWR   VIS GTR THAN FOUR
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Figure 12. SLC surface observations between 0600 UTC 02 December and 1100 UTC 02 December.

The Watling study requires the visibility to remain below 7 SM throughout the afternoon prior to the night in question. The afternoon visibility on 01 December 2003 exceeded this visibility criterion, thus potentially rendering the Watling study ineffective in this case. Watling found that when the average afternoon (1900 to 2100 UTC) visibility is greater than 7 SM, heavy fog should not be forecast at the Salt Lake Airport for the following 18 hours, with less than a 5% chance it will occur. However, even though it technically should not have been used, it was utilized in a *what if* scenario.

The average RH of 76% between 1900 UTC and 2100 UTC 01 December, combined with the 24 h forecast (valid at SLC 1200 UTC 02 December) lapse rate of -9°F (surface minus the 1000 ft temperature) resulted in a Watling chart value of 0.78 (Fig. 13). This value converts to a 78% probability that dense fog will occur, consequently boosting the forecaster's confidence that a fog event was possible.

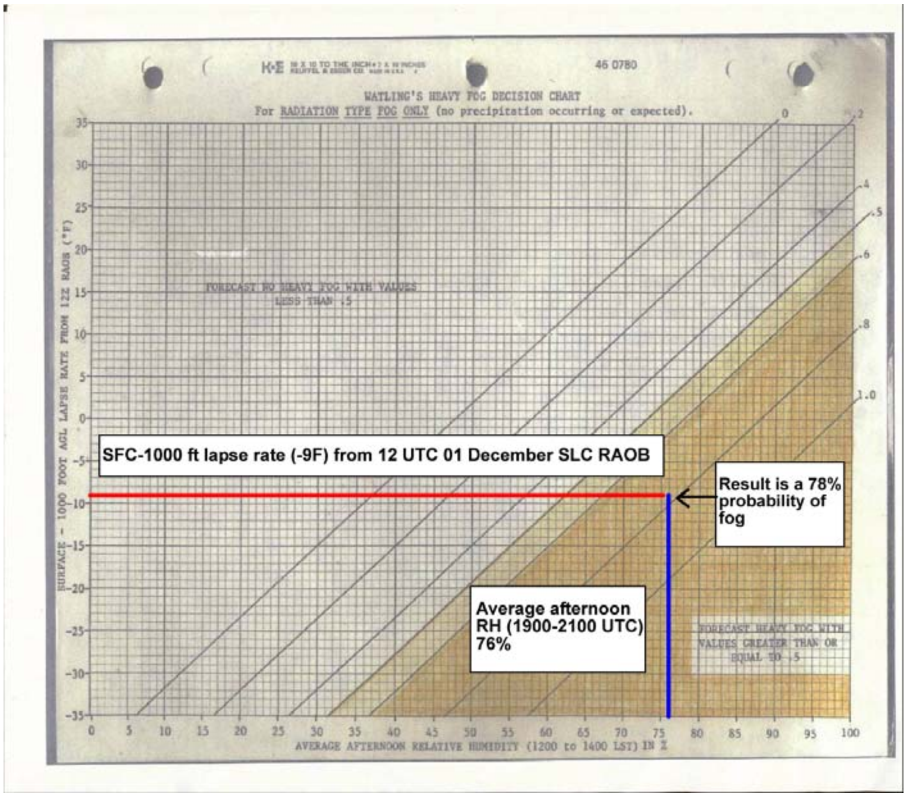
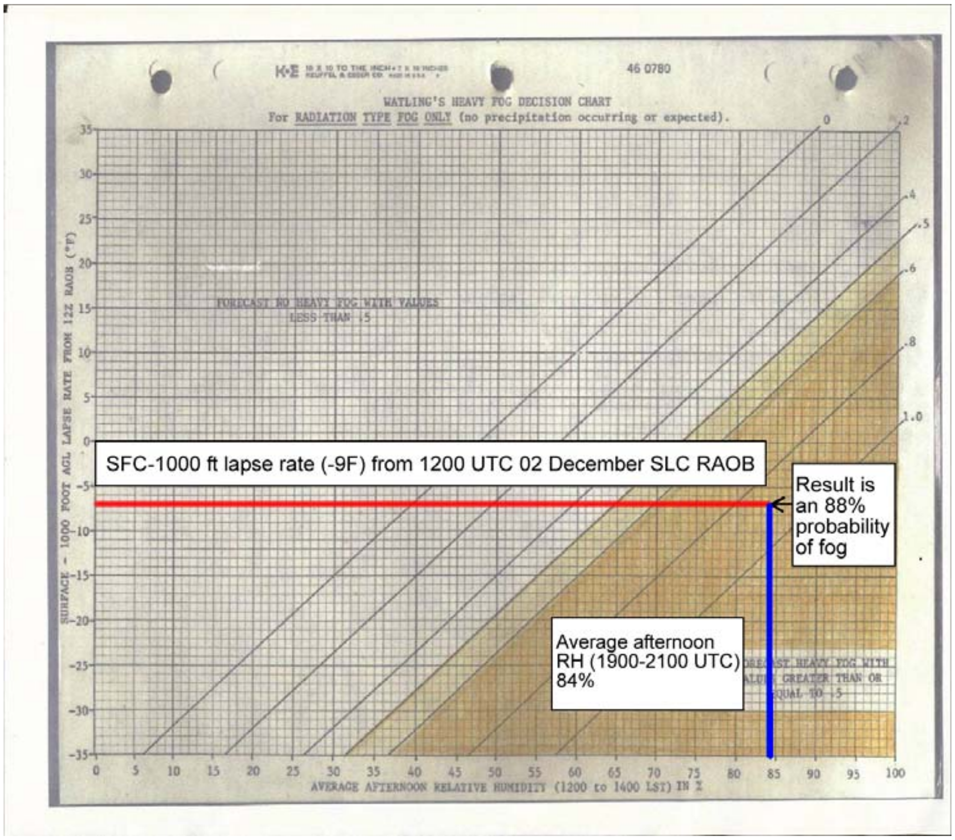


Fig.13. Watling Heavy Fog Decision Chart used for radiational fog only. The X-axis is the average afternoon relative humidity (1900-2100 UTC) in percent. The Y-axis is the SLC 1200 UTC sounding lapse rate computed as [surface temperature (°F) minus 1000 foot AGL temperature (°F)]. Diagonals are probabilities of fog forming (multiply by 100 for percentage). Greater than 50% probabilities are shaded.

Knowing the sequence of events and to what degree the fog forecasting tools performed during the early morning of 02 December fog episode, the on-duty aviation forecaster was faced with the question whether fog would form during the morning of 03 December. From the following list of observations (Fig. 15), the UPS study Txover was 35°F. This threshold for developing fog was easily surpassed with a forecast low of 27°F. The 0000 UTC 03 December (Fig. 10a) GFS forecast sounding indicated that the inversion below 820 mb was expected to remain, thus trapping the low level moisture. Therefore, based on the UPS study, several of the necessary ingredients were present. Evaluating the Watling criteria, the RH and visibility between 1900 and 2100 UTC 02 December were 84% and below 3 SM BR, respectively. The 1200 UTC 02 December sounding indicated about a -6 to -7°F lapse rate, which resulted in a probability of fog occurrence of about 88% (Fig. 14). Consequently, the results from both studies indicate that fog was likely.



SFC-1000 ft lapse rate (-9F) from 1200 UTC 02 December SLC RAOB

Result is an 88% probability of fog

Average afternoon RH (1900-2100 UTC) 84%

Fig.14. Same as in Fig. 13 but for conditions on 02 December

KSLC

DEC 02 18:56 UTC 00000KT 1 1/2 BR SCT001 BKN020 36 35 96 30.35 1028.8 SFC VIS 1
DEC 02 19:02 UTC 00000KT 1 1/2 BR FEW001 SCT020 SCT075 37 36 93 30.35 SFC VIS 2
DEC 02 19:56 UTC 29004KT 1 1/2 HZ FEW075 SCT250 41 35 79 30.33 1027.0 SFC VIS 2
DEC 02 20:56 UTC 34004KT 2 1/2 HZ FEW080 SCT250 42 35 76 30.33 1026.8 SFC VIS 4
DEC 02 21:56 UTC 35003KT 3 HZ FEW075 BKN250 44 35 70 30.33 1027.5 SFC VIS 5

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DEC 02 22:56 UTC 31005KT 4 HZ FEW070 SCT250 44 35 70 30.34 1028.0
DEC 02 23:56 UTC 01004KT 6 HZ FEW070 SCT250 38 32 79 30.35 1028.9 44 34
DEC 02 00:56 UTC 02005KT 6 BR FEW150 SCT250 33 32 96 30.34 1029.1
DEC 02 01:56 UTC 12004KT 6 BR FEW150 SCT250 36 32 85 30.34 1028.7
DEC 02 02:56 UTC 15006KT 6 HZ SCT250 35 30 82 30.34 1028.8
DEC 02 03:56 UTC 14008KT 6 HZ SCT250 35 30 82 30.33 1028.3
DEC 02 04:56 UTC 15008KT 7 FEW250 34 29 82 30.31 1027.6
DEC 02 05:56 UTC 13007KT 8 FEW250 34 28 79 30.30 1027.3 38 32
DEC 02 06:56 UTC 14008KT 10 FEW250 33 27 78 30.29 1026.7 400671039
DEC 03 07:56 UTC 14009KT 10 CLR 32 26 78 30.27 1025.6
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Fig.15. SLC surface observations between 1856 UTC 02 December and 0756 UTC 03 December.

As revealed by the observations above, fog *did not* occur. Rather, the visibility continued to increase through the evening hours. This was likely due to the steady southeast drainage winds of 6-9 kt that persisted from 0300 until 0800 UTC 03 December. These winds were forecast to remain steady, if not increase, toward morning as the surface high moved southeast of SLC. This was in stark contrast to the previous night when there were flat surface pressure gradients that failed to eradicate the surface inversion and variable surface high pressure centers that at times counteracted the drainage wind and resulted in light and variable winds.

Summary

Two fog forecasting tools were applied to two potential fog events from December 2003 at the SLC International Airport. Their results were evaluated and compared to the traditional fog forecasting techniques available to the SLC forecasters at that time. The traditional means of forecasting fog at SLC on the first night, when fog occurred, was divided between a synoptic pattern at mid and high levels that argued against a fog event, while low level conditions argued for an event. The synoptic pattern at 700 mb and above indicated a weak trough moving over northern Utah. However, below 700 mb a strong inversion was present, and the center of the surface high was mainly positioned north northeast of SLC, thus inhibiting the typical southeast drainage at SLC and consequently favored fog formation.

During the second night, when fog did not occur, conditions were once again divided. The synoptic pattern of a ridge overhead favored fog formation early on, but by morning was forecast by the GFS to move east due to a strong upper-level low entering the Pacific Northwest. The center of the surface high developed southeast of SLC, which enhanced the southeast drainage at SLC and consequently did not favor fog formation. This traditional methodology of evaluating whether fog would occur, as well as comparing how the forecasting tools utilized in this event and non-event aided in the forecast process, are summarized in Fig. 16.

Traditional Evaluation of Fog Potential

Fog Event	Fog Non-event
Fog favorable • Surface inversion • Light, north surface wind • Low level moisture present	Fog favorable • Surface inversion • Upper level ridge • Low level moisture present
Fog not favorable • Mid and upper level trough • Some high clouds	Fog not favorable • Drainage flow • Increasing high clouds

Applying the Watling Tool

Negative factors italicized

Fog Event	Fog Non-event
• Average afternoon RH 76% • 1200 UTC 01 Dec lapse rate_-9°F • *Afternoon visibility > 7SM* • Fog probability 80%	• Average afternoon RH 84% • 1200 UTC 02 Dec lapse rate -7°F • Afternoon visibility < 7SM • Fog probability 88%

Applying the UPS Tool

Fog Event	Fog Non-event
• Hydrolapse constant with height • Afternoon dew point trend constant • (T) forecasted < 4°F (Txover) • (T) actual < 5°F (Txover) • Supported dense fog	• Hydrolapse constant with height • Afternoon dew point trend constant • (T) forecasted < 7°F (Txover) • (T) actual < 4°F (Txover) • Supported dense fog

Fig. 16. The preceding tables compare traditional methods of evaluating both the fog event and non-event with the application of both the Watling and UPS tools to each event. The striking feature in the fog event is that it occurred with an upper level trough moving through the region, which traditionally does not support fog. While the UPS tool supported fog formation both nights the Watling tool favored the non-event night.

As viewed in the table, all aspects of the UPS study supported fog formation both nights. However, the minimum temperatures had to cool several degrees below the crossover temperature before a reduction in visibility occurred. The Watling study as originally designed divided the nights; in that it did not support fog the first night due to not meeting the required criteria of previous afternoon visibility below 7 SM, while it supported fog the second night having met the necessary requirements. However, the Watling study supported fog both nights when altered to use prevailing visibility below 7 SM.

Conclusion

This paper examined the applicability of two fog forecasting tools; one developed locally and a second more generic nationwide based forecast tool. Both use various precursor conditions from the morning or afternoon to generate a forecast prior to the period in which fog development is a concern, namely 1200 UTC SLC sounding, afternoon visibility and dew point trend, and comparison of minimum temperature forecast to current afternoon dew point temperature. However, other factors, such as observations and forecasts of the broad synoptic situation and resultant mesoscale circulations, warrant consideration. The main deficiencies found in the

Watling tool and to a certain degree the UPS tool are not incorporating changes in the synoptic pattern or considering local effects. Understanding how each parameter is weighed in the tool and their potential drawback, is also critical. Therefore, strict application of these decision making tools is not advisable.

In addition, one of the more valuable fog forecasting tools is derived from the local fog climatology at each forecast site. Because several of the fog formation factors are from stationary local effects – such as the effects of terrain and local bodies of water – comparing atmospheric conditions to those of previous fog events can effectively aid in the decision making process for forecasting onset, duration and dissipation of dense fog.

Finally, several lessons were learned in the evaluation of these decision making tools. They are as follows:

- Know the antecedent conditions
- Understand the forecasting tool's capabilities and limitations
- Tools must be well tested before utilized unilaterally
- Tools are just one piece in the forecast process – need to evaluate total picture
- Incorporate local fog climatology
- Forecaster experience – pattern recognition – "Best tool"

References

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