Fog Effect of the Great Salt Lake

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ABSTRACT

The effect of the Great Salt Lake on the frequency and geographical extent of wintertime fog is analyzed by use of fog reports, precipitation, and temperature records over a 25-yr period, during which time the size of the lake has more than doubled. Fog reports at Salt Lake City on days when precipitation other than snow grains did not occur are analyzed to find a relationship between lake size and fog frequency. While a large winter-to-winter variability is found, there is also a strong relationship with lake size.

To analyze the geographical effect of the lake on fog, the daily range of temperature is first related to the occurrence of persistent fog; it is shown that when fog is present throughout a day the difference between the maximum and minimum temperature will be low. Analysis of the geographical distribution of these persistent fog days shows the strong effect of the lake. Also, the occurrence of persistent fog was much less when the lake was small compared to when the lake was large.

1. Introduction

With the dramatic rise of the Great Salt Lake over the past few years, there is an increased interest in its weather effects, particularly any possible increases in precipitation and fog during the winter. The recent size of the lake has more than doubled since 1962, and with the West Desert Pumping Project designed to increase evaporation, the lake size has tripled. In this article the fog effect of the Great Salt Lake is examined. Other weather effects will be described in a subsequent article.

Any lake-effect fog will be masked considerably by the large natural variations in atmospheric conditions. Fog often occurs when there is a high pressure system present with light winds, clear skies, and a temperature inversion. Under these conditions, moisture evaporating from the surface is trapped under the inversion. At the same time the clear skies permit strong radiation from the surface, thereby cooling the temperature to the dewpoint. The resulting fog is thickest in the early morning hours. During the daytime the fog may "burn off," or, in some instances, the sun's radiation will not penetrate the fog, but is mainly reflected upward from the top of the fog layer. The presence of a snow-covered surface will add to the overall cooling of the surface by reflecting more solar radiation and increasing ground radiation to the sky.

Superimposed upon these factors, which may vary greatly from year to year, is the effect of the Great Salt Lake. Whether this effect is minimal, highly significant, or moderate, is the subject of this study.

A number of previous studies have documented a well-defined precipitation lake effect. For example, Dunn (1983) and Carpenter (1985) have clearly demonstrated that precipitation is increased by the presence of the Great Salt Lake. Studies of the Great Lakes have revealed large early winter increases in precipitation on the windward shores (Jiusto and Kaplan 1972).

The only available study on fog which might be related to the size of the Great Salt Lake is an unpublished one recently presented by Alder [National Weather Service (1986)]. He states that the number of days with heavy fog at Salt Lake City has varied widely over several decades, and is unrelated to the size of the lake. It is noted here that if the visibility falls below ¼ mile, even momentarily, a day is classified as having heavy fog.

Our review of these data on a year-by-year basis confirms his findings. In fact, it may well be that these heavy fog occurrences are an indicator of favorable fog-forming conditions rather than any possible lake effect. Heavy fog very close to the lake and typically occurring in the early morning may not necessarily indicate whether an increased lake size will cause fog to persist throughout the day or to spread 100 km or more.

To resolve these uncertainties, an analysis of the distribution of fog around the lake is needed for various lake sizes. Similarly, analysis of the occurrence of persistent fog at Salt Lake City, or other locations, is also needed. While detailed fog data for Salt Lake City are available, there are few if any long-term records of fog at other locations around the lake. In this study, both

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actual fog data and other related data will be used to assess lake-effect fog.

A detailed analysis of fog reports at the Salt Lake City International Airport is made herein for winter months during the period of available data, 1962–86. To obtain an analysis of fog distribution in the general vicinity of the Great Salt Lake, extensive use of the diurnal temperature range (ΔT) is made. Additional analysis is carried out first to show when and how ΔT is related to fog occurrence. Then the appropriate values of ΔT are used to identify the occurrence of fog in places where no fog reports are available.

2. Relationship of fog with other meteorological data

Before proceeding with analysis of fog data and lake size, it will be useful to establish certain meteorological relationships. One meteorological variable which will be shown to be very valuable in analyzing the distribution of fog is the diurnal temperature range, i.e., the difference between the temperature maximum and minimum over an entire day, (ΔT). On a clear day, ΔT will normally be large, typically 15° to 20°C (27° to 36°F)[1] but on a stormy or very foggy day, ΔT will be much less, perhaps only a few degrees. Precipitation records are needed to identify the stormy days. Furthermore, if ΔT is large in the mountains to the east, then there is an indication of clear skies above the low-level inversion.

The relationship of ΔT to actual fog reports is examined by using records of weather data compiled in the National Weather Service publication of Local Climatological Data (Monthly Summary). These data are listed at 3-h intervals.

To make maximum use of ΔT information, it is important to understand its limitations as well as its utility. For example, a fog layer lasting only a few hours with otherwise clear conditions will affect ΔT only slightly. On the other hand, if fog were to persist throughout the day, the effect on ΔT will be to keep it low. Consequently, a persistent fog day is defined as having fog reported on at least six out of eight 3-h observations on a given day. Such a day would generally be considered to be a gloomy one.

To aid in establishing what ΔT is indicative of persistent fog, a comparison between ΔT and ceiling/visibility reports is made. Thus, a quantitative assessment can be made of the strength of the fog as it affects ceiling and visibility.

A plot of ΔT and ceiling for all days during the winters of 1982–85, inclusive, having the required number of fog reports is shown in Fig. 1. When the ceiling is unlimited, it is plotted above 3000 m (10 000 ft), because it makes little difference for the present purpose. It is noted, also, that each of these persistent fog days is represented by one datapoint, and that the precipitation at Salt Lake City did not exceed a trace, except when snow grains were reported. The ceiling used in this figure is the next to the highest of the eight reports. Points marked with a "U" indicate that the highest ceiling was unlimited.

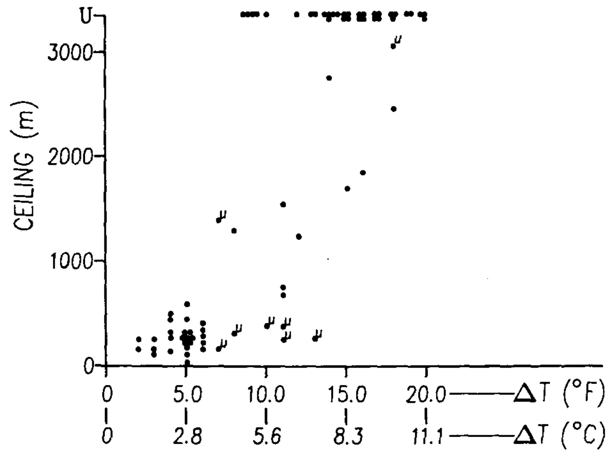

FIG. 1. Ceiling and ΔT at Salt Lake City for days with fog present 75% or more of the day. (Ceiling shown is second highest reported out of eight 3-h observations; U indicates the highest ceiling is unlimited; unlimited ceilings are shown at 3300 m.)

It is evident from the figure that when ΔT is 3°C (6°F) or less, the next to the highest ceiling is restricted to less than 600 m (2000 ft). Between 4°C (7°F) and 6°C (11°F), the ceiling is somewhat restricted but either the highest or the next to the highest ceiling is unlimited in most cases. However, in the five cases with unlimited or high ceiling, four of the five ceilings drop to below 300 m (1000 ft) for the third highest ceiling. Thus, a 4°C (7°F)–6°C (11°F) ΔT may be regarded as intermediate, but with a definite indication of a generally foggy day. Above 6°C (11°F), these (next to the highest) ceilings increase greatly.

A similar picture emerges when (horizontal) visibility is related with ΔT, but with one important difference. When smoke is present, and reported, the visibility is further reduced. To examine the effect of fog on visibility, the smoke cases are removed from this part of the analysis. In Fig. 2, persistent fog days are plotted according to ΔT and the second highest visibility. A "U" is shown for the cases when either of the highest or next to the highest ceiling was unlimited. In these cases with reports of unlimited ceiling, the fog is more shallow than otherwise, even though the horizontal visibility may be low. Again, three regimes are defined according to the value of ΔT. Above 6°C (11°F), six of the fog days have low visibilities; however, four of these have three or more reports of unlimited ceiling. In one case with ΔT of 7°C (13°F) the fog remained heavy for most of the day.

[1] Temperatures are given in this article in both celsius and fahrenheit; the original data were in units of the latter.

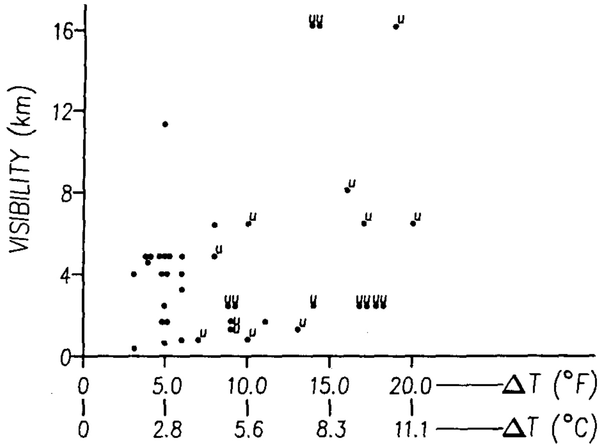

FIG. 2. Visibility and ΔT at Salt Lake City for days with fog present 75% or more of the day, and no smoke reports during the time of three greatest visibilities. (Visibility is second greatest reported out of eight 3-h observations; U indicates the highest ceiling is unlimited.)

While the exact cutoff of ΔT used to identify persistent fog may vary slightly in different situations, it is evident that a ΔT of 6°C (11°F) or less is a near certain indication of persistent fog and that a ΔT of 3°C (6°F) or less is similarly indicative of heavy persistent fog, provided that precipitation does not occur (in excess of a trace). An exception to this is the occurrence of snow grains, which often develops from the fog layer itself.

As noted previously, the ΔT's in the mountains are expected to be high when there is persistent fog at Salt Lake City. On all 41 days but 1, the ΔT at Silver Lake Brighton (elev. 2652 m, 8700 ft) exceeded 11°C (20°F). The average ΔT for Silver Lake Brighton was 15.3°C (27.5°F) while the average ΔT at Salt Lake City was only 3.5°C (6.3°F).

3. Fog frequency according to lake size

The size of the Great Salt Lake increased from 604 000 acres in 1962 to 1 539 000 acres in 1987, with an overall average of 1 071 500 acres. The lake levels in the years 1962–75 and 1978–82, inclusive, were below the 25-yr average lake level and 1976–77 and 1983–87 were above the 25-yr average. During these two periods, the average number of persistent fog days found from actual fog data at Salt Lake City (SLC) increased from 4.1 to 12.7 per year during the lower to higher lake levels, respectively. Persistent fog was defined less stringently to include more cases, i.e., six or more fog reports, but as many as four reports of unlimited ceiling.

A breakdown of total fog days by month for November–March over the 25-yr period is 6, 78, 62, 16 and 2, respectively. Since most of the persistent fog days occur in December and January and, to a lesser extent, in February, only data in these 3 months will be utilized in the following analyses.

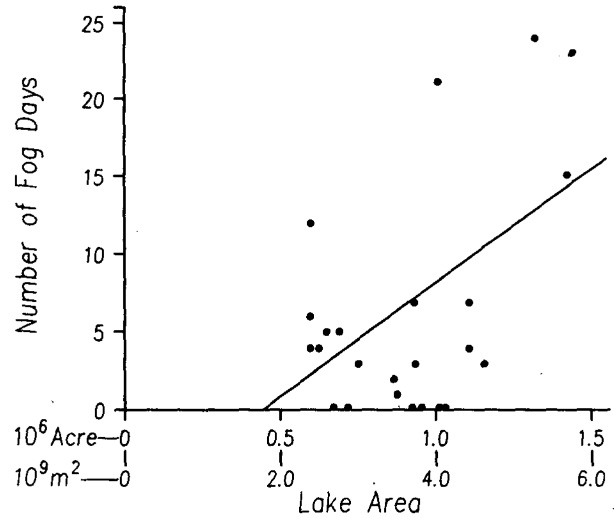

FIG. 3. Number of fog days (six or more fog reports on days with no precipitation and no more than four reports of ceiling above 3000 m) versus the size of the Great Salt Lake.

Persistent fog days (as defined above) are found directly from fog reports at Salt Lake City. The number of these days per 3-month winter season is shown in Fig. 3, according to lake size measured on 1 January. Two main factors are revealed by these data. One is that there is a large variation in (persistent) fog frequency for a given lake size. This variability is to be expected, because the overall meteorological conditions often vary greatly from year to year. The other factor is that superimposed upon this high variability is a strong trend toward increased fog frequency as the lake size increases. According to these data there are about 1.5 more persistent fog days for every 100 000 acre

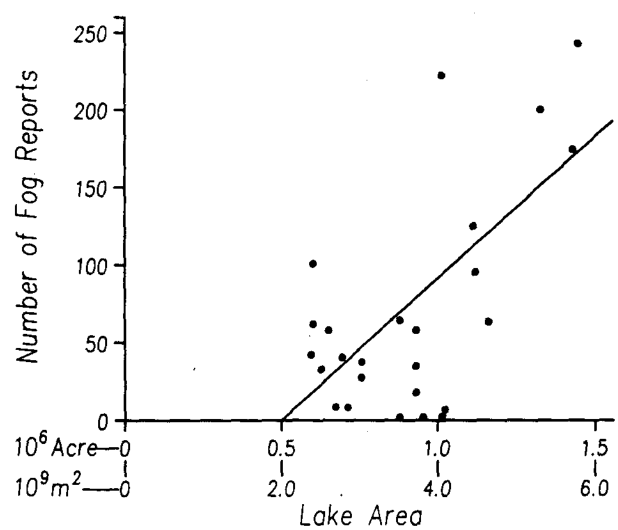

FIG. 4. Number of 3-hourly reports of fog on days with no precipitation versus the size of the Great Salt Lake.

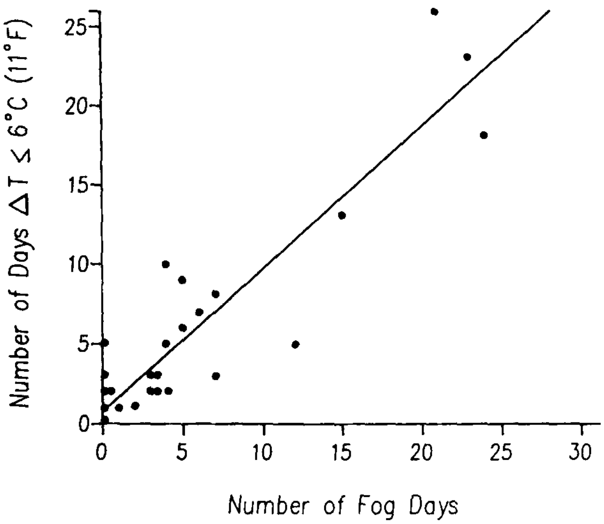

FIG. 5. Number of persistent fog days (ΔT at SLC ≤ 6°C (11°F) ΔT at Silver Lake Brighton ≥ 13°C (20°F) and no precipitation at SLC) versus number of fog days as defined in Fig. 3.

increase in lake size. (For a net increase of 300 000 acres by the West Desert Pumping Project, an increase of 4.5 persistent fog days per winter may be expected; however, this number of increased fog days decreases over subsequent years while pumping continues. When pumping is stopped, a corresponding sudden improvement in weather will occur and then gradually return to what would have occurred had the pumping project not existed. The reason for this pattern is that when pumping is occurring, evaporation exceeds what would have occurred without the pumping project and when pumping is stopped, evaporation is below what would have occurred in the absence of the pumping project. These departures in rates of total evaporation act strongly to restore the lake to the size it would have been had the pumping project not existed.)

Another analysis is made by using the *number* of 3-h reports of fog on days with no precipitation other than snow grains as the only restrictive criterion. This method allows an estimate of the lake-effect fog even though it may not be classified as persistent. These data are shown in Fig. 4. Again there is a large variability in fog frequency for a given lake size, but there remains a strong increase in fog occurrence with increasing lake size. There is an increase of about 54 h (18 × 3) for an increase of 100 000 acre ft. Expressed in terms of days, this is an increase of 2.25 days as compared with an increase of 1.5 days of persistent fog.

While the utilization of the ΔT and precipitation criteria are primarily useful in a geographical analysis of fog distribution, analysis can also be made of persistent fog frequency versus lake size. Before making this analysis it is of interest to compare the number of actual persistent fog days with the number of persistent fog days found solely by the use of ΔT and precipitation criteria, i.e., ΔT at SLC ≤ 6°C (11°F), ΔT at Silver

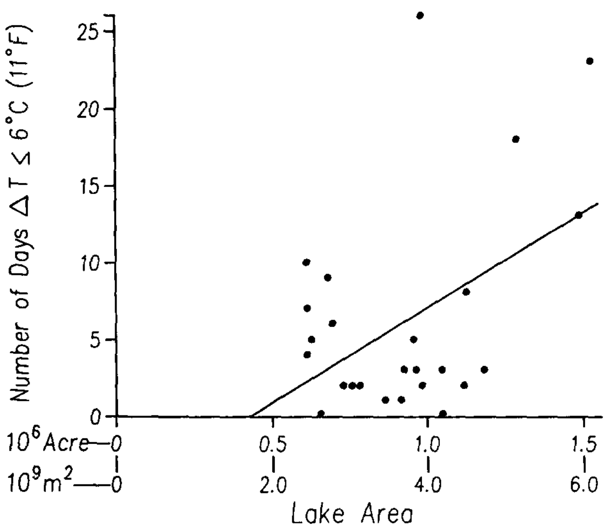

FIG. 6. Number of persistent fog days as defined by ΔT in Fig. 5 versus the size of the Great Salt Lake.

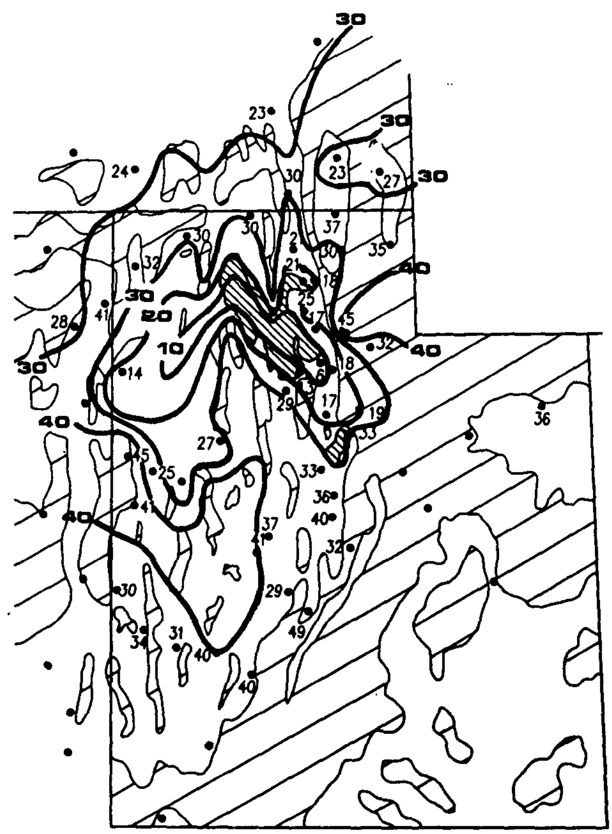

FIG. 7. Distribution of ΔT on 17 December 1962. Contours are every 10°F. Hatched areas within light contours are above 1830 m (6000 ft).

Lake Brighton ≥ 11°C (20°F), and no precipitation other than snow grains at SLC. The number of persistent fog days per winter season found by each of the two independent methods is shown in Fig. 5. The correlation coefficient is $r = 0.90$ with a slope of very near unity. It appears that the use of ΔT data along with an absence of precipitation yields a reasonable estimate of the number of persistent fog days.

In terms of ΔT, with $\Delta T \leqslant 6$°C (11°F), (which corresponds to six or more fog reports and no more than two unlimited ceilings) there were 2.7 persistent fog days in the "low" lake period and 8.0 persistent fog days in the "high" lake period, compared to 4.1 and 12.7 days of actual slightly less persistent fog, respectively. The number of persistent fog days found on a year to year basis is shown in Fig. 6 according to lake size. A similar variability is found as before, along with a strong increase in fog frequency with lake size.

4. Geographical distribution of ΔT during fog episodes

When persistent fog is observed in northern Utah, a minimum in ΔT is nearly always found in the immediate vicinity of the Great Salt Lake. In the more prolonged episodes, the low values of ΔT may extend well away from the lake. In Fig. 7 a very typical example

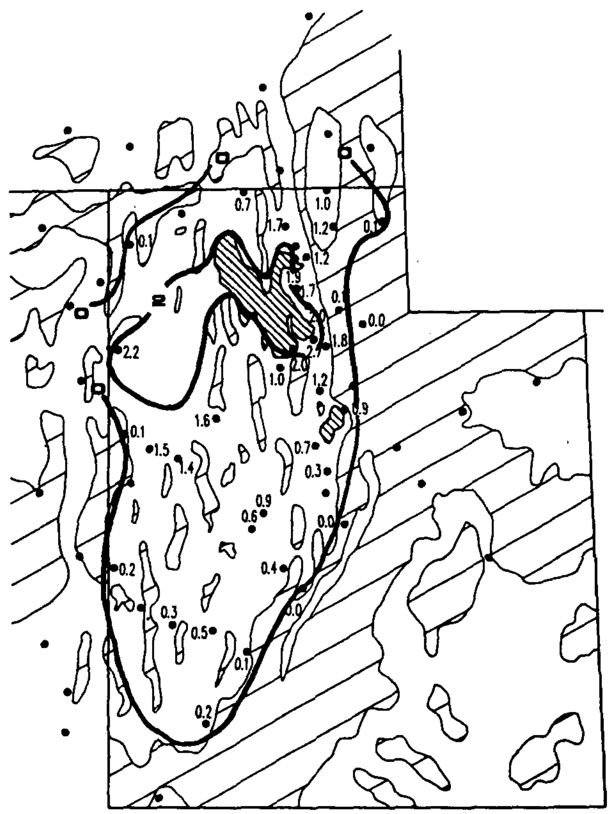

FIG. 9. Average number of persistent fog days per season with $\Delta T \leqslant 6$°C (11°F) when persistent fog was observed at SLC as defined in Fig. 3 for the 19 yr when the lake area was *below* the recent 25-yr average. Contours at intervals of 2 fog days. Hatched areas within light contours are above 1830 m (6000 ft).

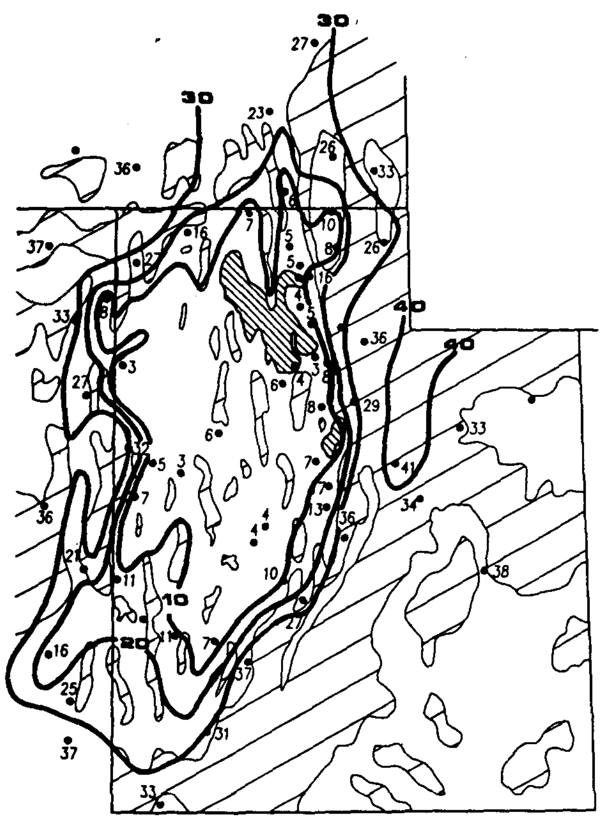

FIG. 8. As in Fig. 7 except distribution of ΔT on 14 January 1981. Contours are every 10°F.

is shown of the pattern of ΔT when fog is persistent in Salt Lake City. Low ΔT's are confined to the vicinity of the lake and the west desert. Well away from the lake and in the mountains to the east the ΔT's are often as much as 22°C (40°F). These high values of ΔT are a strong indicator of clear skies above the low-level fog.

In Fig. 8, a more extended fog episode is shown. On this day, low ΔT's covered the entire western Utah region, except for the mountains. High values of ΔT are found further away from the lake at low elevations and in the mountains to the east. It is noted that in all of the maps drawn for the actual fog days in the period 1962–86 the same general pattern shown in these two figures is found. A search for days with persistent fog centered elsewhere in western Utah revealed no other episodes. It is also noted that the contours of equal ΔT varied in a very consistent manner and that practically no spatial averaging was needed. Such consistency in the data is the result of fog being centered over the lake and extending outward so that the fog is bounded by mountains, and at low elevations the fog gradually becomes weaker further away from the lake. Although the strong geographical connection between fog and

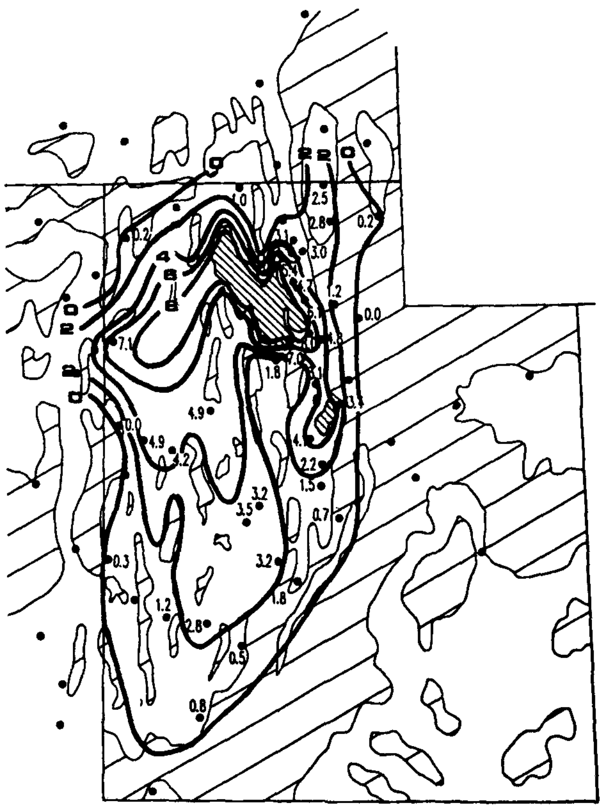

FIG. 10. As in Fig. 9 but for the 6 yr when the lake area was *above* the recent 25-yr average. Contours at intervals of 2 fog days.

the lake is evidence of a lake effect, further evidence of a lake-effect fog follows.

The geographical effect of the changing lake size on fog is found by mapping ΔT for days when persistent fog (at SLC) was actually observed. There were 77 such days in the low lake years (19) and 76 such days in the high lake years (6). Maps of the average number of days per season when $\Delta T \leq 6°C$ (11°F) for the persistent fog days are shown in Figs. 9 and 10. When the lake was low there were about 2–3 such days per season in the immediate vicinity of the lake, whereas during the high lake years, the number increased to more than 8, which amounts to an increase of a factor of about 3. This factor is typical throughout northwestern and west-central Utah. These data may be compared with the grouped fog data of the previous section, which also yielded a factor of about 3.

During the 25 winter-season periods for which data were analyzed there were 164 cases of persistent fog according to the ΔT method. The overall average ΔT at Salt Lake City was 7.0°F; for Silver Lake Brighton the average was 29.0°F. This large contrast is a result of the persistent valley fog with generally clear skies above the inversion. Further to the south in valley locations the fog diminishes gradually. For example, at Dugway the average ΔT was 12.7°F and at Delta it increased to 18.5°F. The 164 fog episodes consisted of 75 at Dugway and 54 at Delta.

5. Conclusion

It is evident from the foregoing that persistent fog is initiated over the Great Salt Lake and spreads outward from there. Although fog would occur at times even in the absence of a lake, the important role of the Great Salt Lake as a controlling factor is evident.

From the foregoing analyses, it is estimated that there will be about 600 h per winter season (December–February) with fog reported at Salt Lake City (Airport) if the lake were to remain at the 1 January 1987 level. There will be about 16 days per winter season when fog remains persistent at Salt Lake City. This amount of fog may be expected to continue until the lake level decreases substantially. West Desert Pumping will initially cause an additional increase of 165 h and 4.5 days. This initial addition in fog frequency will diminish rapidly over 2 or 3 yr as the modified lake (lake plus added pond) approaches equilibrium with the size of the lake had no pumping taken place.

Finally, it is emphasized that there is a large year-to-year variability in fog occurrence, so that in any one season the actual number of hours of fog or days with persistent fog may differ greatly from those estimated above.

In localities well away from the lake, but within the areas of lower elevation in western and northwestern Utah, persistent fog may be expected much more frequently than when the lake was half or less of the present size.

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