WESTERN REGION TECHNICAL ATTACHMENT
No. 76-14
June 15, 1976

GUSTY SURFACE WINDS AND HIGH LEVEL THUNDERSTORMS

This Technical Attachment discusses how high level thunderstorms cause strong surface gusts, and suggests a simple method for assessing the potential for such gustiness.

High level thunderstorms, with bases between 12 and 18 thousand feet, are fairly common over the Western Region from May through September. Experience has shown that these storms are often associated with strong gusty surface winds and "dry lightning". While most thunderstorms are noteworthy for having heavy rains, this variety often has little or no precipitation reaching the ground. They are identifiable by their high bases, and by the appearance of virga. Viewed from a distance, a heavy rain curtain from the cloud base (giving an opaque bluish or greyish appearance) will often evaporate out to a thin curtain (which can be seen through) near the surface. Below the cloud base the air is originally quite dry. This results in considerable evaporation of the rain produced by the cumulonimbus clouds (CBs).

The resultant evaporational cooling is considered to be the main cause of the strong gusty surface winds which are often observed under the base of these CBs. To see how these winds are generated consider Figure 1. In Fig. 1a, a strong upper-level thunderstorm has developed, and a rain shaft is just beginning to drop out of the base. For purposes of example we assume an ambient air sounding the same as that taken for Salt Lake City, August 27, 1975 at 12 GMT (Fig. 1b). The moist layer based at 550 mb with a top above 400 mb is close to being convectively unstable, thus it would not be surprising to see a high level thunderstorm develop in this situation. Note also that the convective condensation level is quite high (close to 160 MSL) and only small surface heating is needed to destroy the surface inversion and warm the surface to the convective temperature.

For our purposes the most important factor is the very dry layer centered at 700 mb. The heavy rain shaft would fall rapidly toward the ground (due to large droplet size) as shown in Fig. 2a. In the rain shaft evaporation of liquid water droplets into the dry air rapidly brings each level to its wet bulb temperature. Those of you who have used a sling psychrometer can appreciate that this is a rapid and efficient cooling process. Thus a sounding, taken in the rain shaft, would look like that shown in Fig. 2b.

Comparing Figures 1b and 2b it is apparent that the air above the surface in the rain shaft is much colder and therefore heavier than the surrounding air. As a consequence the surface pressure rises; actually other effects are important (such as the weight of the rain drops, etc.) but it can be taken as an observational fact that surface pressure can jump up rapidly, often as much as several millibars, in a rain shaft. The small but intense meso-high that develops produces a strong divergent wind due to the resultant pressure gradient force (see Fig. 3). Since strong gusty winds are so common when the sub cloud layer is dry, it can be inferred that evaporational cooling causes a much more intense meso-high than would otherwise occur. The important thing to remember is this: When there is dry air in the lower 10 to 15 thousand feet, evaporational cooling-(due to rain shafts which fall into it) will cause very strong gusty surface winds near thunderstorms. In the case of the example shown (August 27, 1975) Hill Air Force Base near Salt Lake City experienced gusts to 50 knots in a thunderstorm which occurred about six hours after the sounding was taken.

There are two requirements for strong gusty thunderstorms:

(1) The upper level (above 120 MSL) must be convectively unstable, and
(2) The lower level must be dry.

A good measure of the lower level moisture is the 700 mb dew-point depression. To determine upper level stability a parcel index is suggested similar to the Showalter Index (which is based at 850). A parcel at 500 mb is assumed lifted to its lifting condensation level (LCL) and followed up the moist adiabat through the 400 mb level to 300 mb. The index is the sum of the algebraic difference between the ambient temperature and the temperature of the lifted parcel at 400 and 300 mb. An example of this computation is shown in Fig. 4.

Fig. 5 is a plot of surface-wind gust occurrence based on two independent variables determined from Salt Lake City soundings:

(1) Upper level instability index (a measure of high-level thunderstorm potential) and

(2) 700-mb dew-point depression (a measure of the evaporational potential of the air).

The small circles indicate no convective gusts within 18 hours after the sounding was taken. Convective gusts within 18 hours which were greater than 30 knots are shown as solid dots. The max gust is given after the "G". Period of the developmental sample is May 1975 through September 1975, and part of May 1976.

The graph is divided into four main areas. Area 1, sub cloud layer, is relatively moist; i.e., 700 mb depression less than 10. Thunderstorms occur, often with heavy rain, but strong surface gusts are usually not observed. Area 2, the upper level, is convectively stable; i.e., upper level stability index is greater than 5. No upper level thunderstorms develop to cause the gusts. Area 3, a transition zone where fairly strong gusts are likely to occur, and area 4, the strong gust zone where severe convective gusting is strongly indicated.

[Ed. Note: This study was accomplished recently by A. MacDonald while on two weeks active duty at Hill AFB, Utah. It is based on a similar method developed by Maj. Edward J. Perantoni and Capt. Robert E. Wilt.]

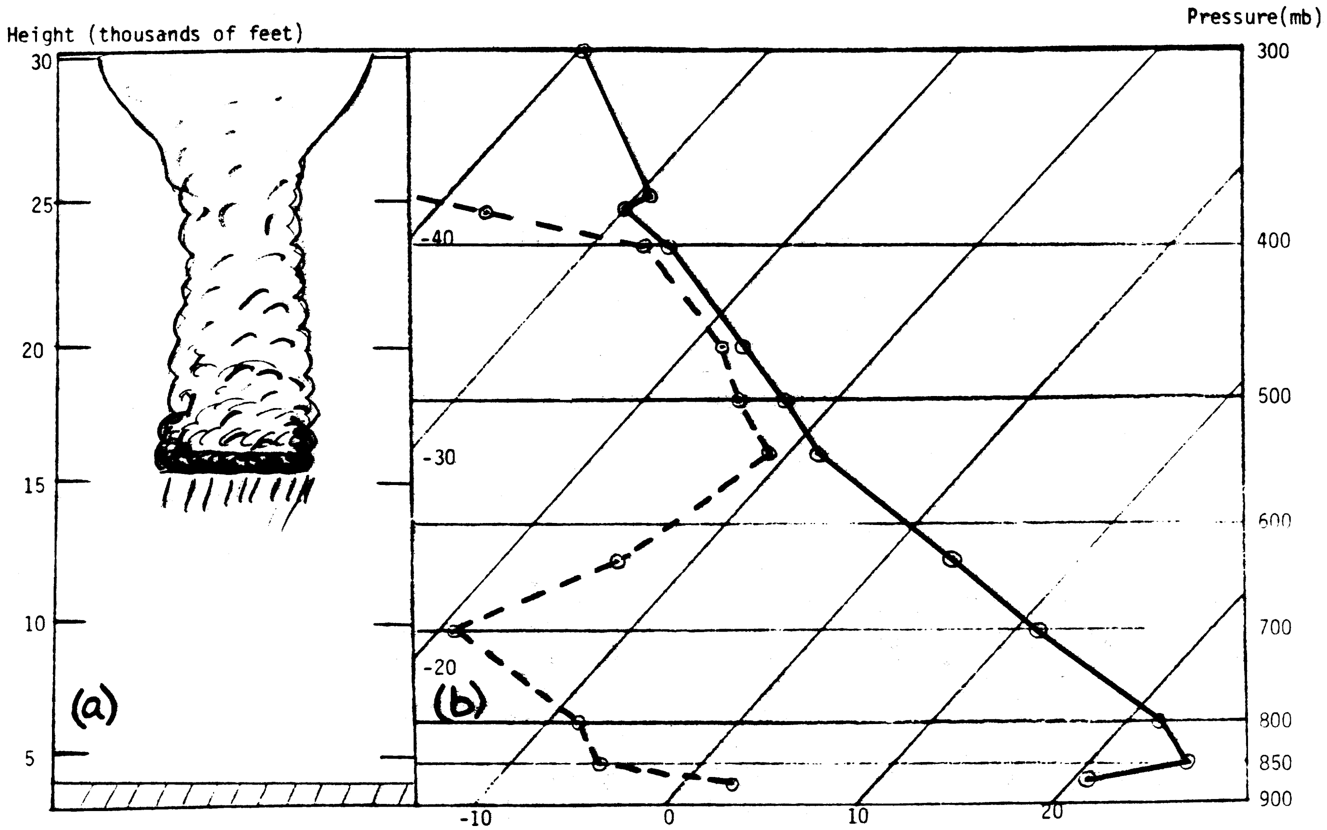

Fig. 1. A high level thunderstorm, based near 150 MSL, (Fig. 1a) due to convective instability which is evident in the Salt Lake City sounding for 12 GMT August 27, 1975 (Fig. 1b). Note the very dry layer at 700 mb.

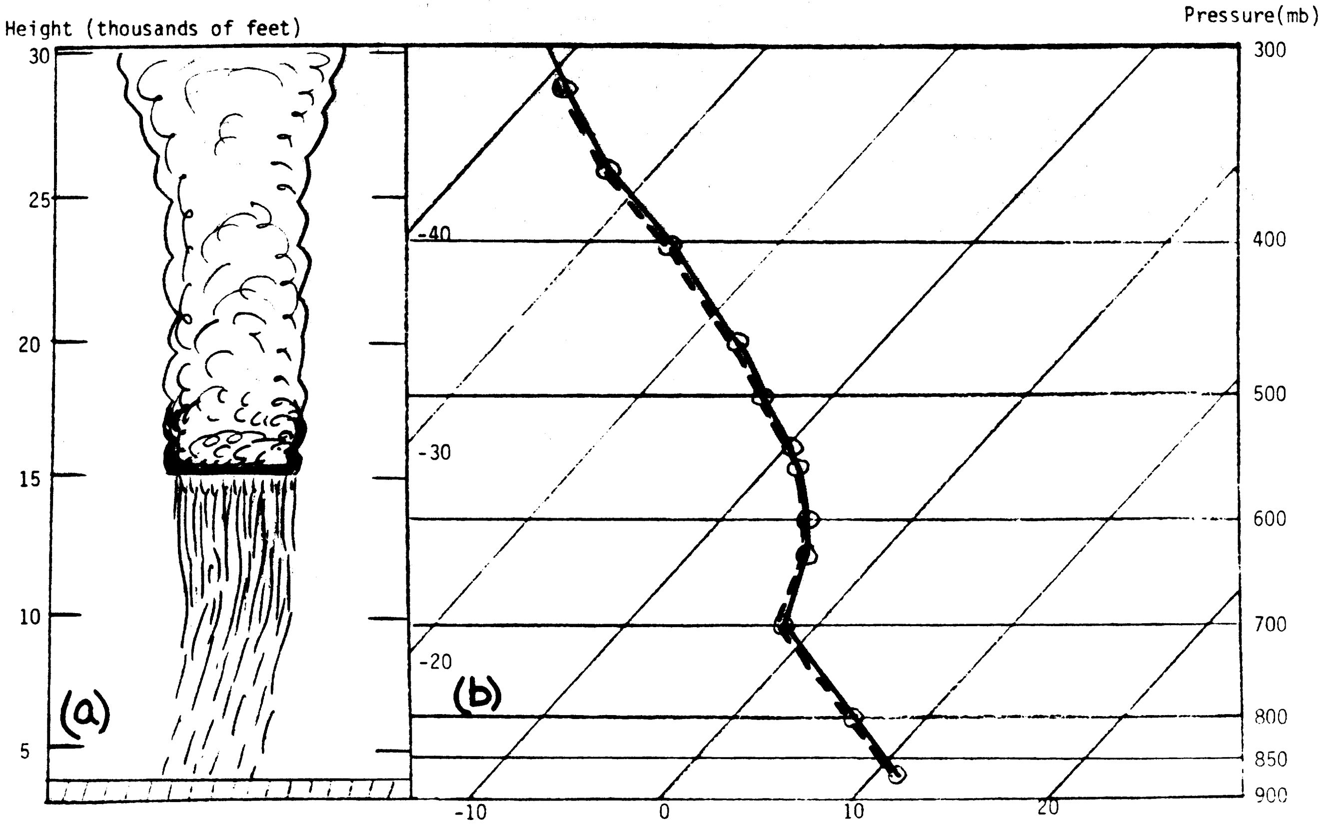

Fig. 2. The presence of liquid water in the rain shaft (Fig. 2a) would rapidly modify the air in the rain shaft to its web bulb temperature at each level. Note the strong cooling in the rain shaft by comparing Figures 1b and 2b.

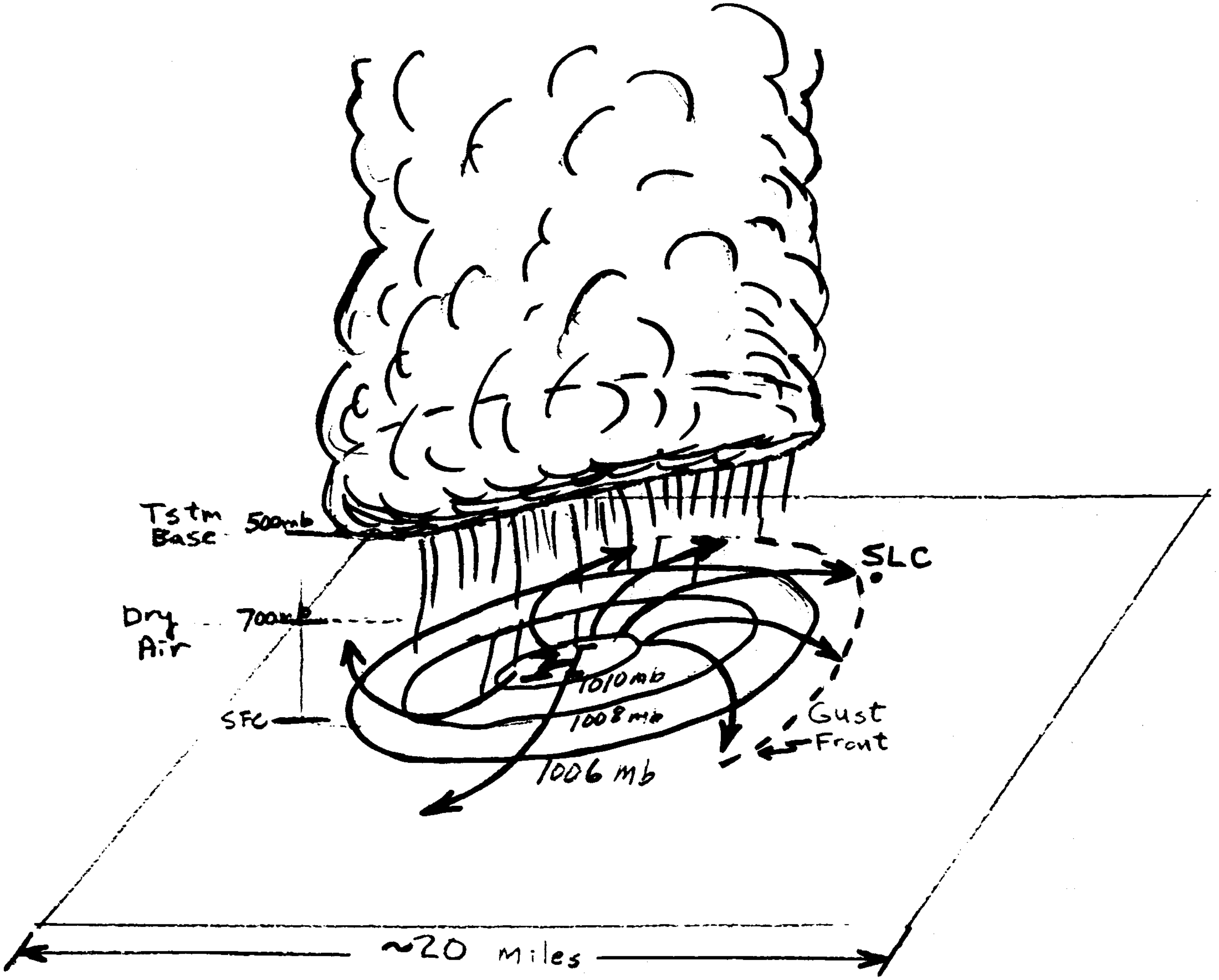

Fig. 3. The evaporationally cooled air in the rain shaft below the CB creates a meso-high with associated strong gusty winds.

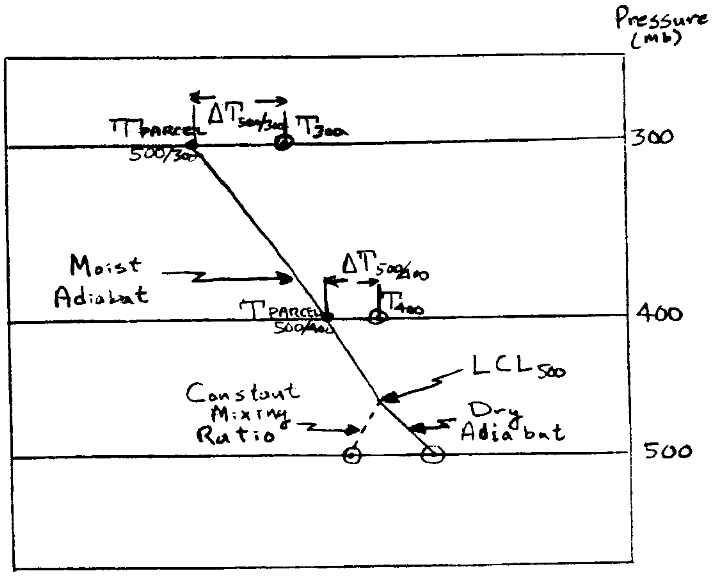

Fig. 4. To compute the upper level instability (UI), find the LCL for a parcel lifted from 500 mb and go up the moist adiabat past 400 mb to 300 mb. UI is equal to the sum of the temperature differences of the lifted parcel from the ambient temperatures at 400 mb and 300 mb:

$$UI = (T_{400\,mb} - T_{500\,mb\ parcel}) + (T_{300\,mb} - T_{500\,mb\ parcel})$$

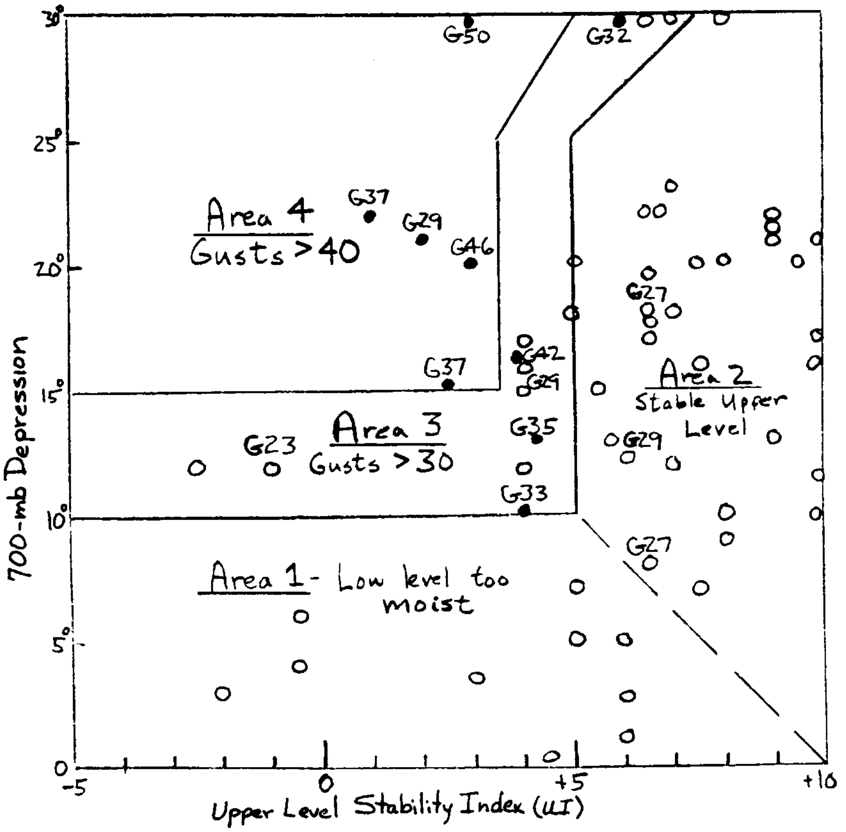

Fig. 5. Plot of upper level instability (UI) vs 700 mb dew point depression. Circles indicate convective gusts less than 30 knots (or none). It is apparent that dry air at 700 mb and upper level instability are a sufficient condition for strong gusty winds with thundershowers.

CONVECTIVE GUST POTENTIAL FORECAST PROCEDURE

[Ed. Note: This page is designed to be detached for operational use.]

Step 1. Multiply the 500-mb dew-point depression by three and subtract from it the 700-mb dew-point depression. If this number is negative, proceed; if it is positive, there is no gust potential. This step is optional.

Step 2. Compute the upper level instability index (UI) by lifting a parcel from 500 mb to its LCL and then up the moist adiabat through 400 mb to 300 mb.

$$UI = \left(T_{400\,mb} - T_{500\,mb\,parcel}\right) + \left(T_{300mb} - T_{500mb\,parcel}\right)$$

Step 3. Locate the point on the graph below, using 700 mb depression and UI.

Area 1. Too moist for strong convective gusts even though thunderstorms may occur.

Area 2. Too stable for upper level thunderstorms.

Area 3. Issue Met Watch Advisory for gusts above 30 knots for the period when thunderstorms are expected.

Area 4. Issue Weather Warning for gusts above 40 knots for the period when thunderstorms are expected.