Western Region Technical Attachment
No. 93-28
September 21, 1993

THE EFFECTS OF VERTICAL SPEED SHEAR ON THUNDERSTORM GROWTH

INTRODUCTION

In the western United States, the initiation and life cycle of thunderstorms varies significantly from those areas located east of the Continental Divide. For the most part these differences arise due to topography and the large variation in local thunderstorm environments. One of the main ingredients in thunderstorm morphology and the progression into deep, sustained convection, is environmental wind shear. Since highly localized (and varying) boundary layer wind profiles (i.e., thunderstorm inflow regimes) exist over small areas in the West, the prediction of storm type commonly used over the eastern two-thirds of the United States is seldom possible. The inability to determine the exact inflow profile of a given thunderstorm is compounded by the low density of surface observing sites in the West. However, vertical speed shear is both obtainable through the current data network (i.e., proximity soundings) and important to the production of severe convection in the West. This Technical Attachment will discuss the importance of vertical speed shear in the production of severe convection and specifically hail. Directional environmental shear will be discussed in a future Technical Attachment. Additionally, a case example will be used to highlight the operational significance of recognizing favorable speed shear environments. The kinematic and thermodynamic analyses in the case study were computed exclusively from the SHARP workstation.

VERTICAL SPEED SHEAR AND CELL DEVELOPMENT

Significant strides in research have been made within the last 10 years on the interaction of environmental wind shear and its relation to both buoyancy and storm type. In years prior to this, theories explained that strong vertical speed shear can be detrimental to updraft growth in weakly buoyant environments, thereby inhibiting the convective plume. This is rare; however, in environments where instability is marginal to strong (i.e., Lifted Indices $< +2$), the vertical speed shear can actually play an additive role and be conducive to cell growth and development. Schaefer and Livingston (1982) investigated the amount of change in vertical shear within a given environment (or "shear of the vertical shear") and found that layers in which the vertical speed increases rapidly are not conducive to convection. In this scenario, drastically varying kinematic fields can literally "shear off" the tops of rising convective plumes. Again, this is rare and usually does not occur in moderate to strongly unstable environments. Thus, moderately increasing speed shear in the vertical is most preferred.

One of the main impacts of vertical speed shear of the horizontal wind upon the evolution of a convective storm is the enhanced outflow boundaries generated through a downward momentum flux. The ability to transfer momentum to the surface (through downdraft processes such as precipitation drag and evaporative cooling) allows the generation of new cells on the downshear flank (i.e., ahead) of the storm. Also, the entrainment of mid-level ambient air into the precipitation region of the thunderstorm evaporates and cools the downdraft creating more negatively buoyant air. As the entrainment of ambient air increases (and the drier it becomes), which depends on the vertical speed shear, the development and existence of the downdraft improves. Thus, the life cycle of the parent thunderstorm is sustained over a longer duration, allowing it to fully mature.

Another important feature created in a strong vertically sheared environment is the tilted updraft. The tilted updraft allows for the adjacent, yet separate, location of the downdraft on the upshear side of the storm and, more importantly, prevents precipitation particles from falling through the updraft itself. Thus, the "pulse" type thunderstorm is avoided and; therefore, the vertical shear promotes further cell initiation and evolution. In concert with the processes described above, this again leads to the increased likelihood of the evolution towards severe thresholds.

VERTICAL SPEED SHEAR AND HAIL GENERATION

Numerous studies dating back to the early 1950s (Fawbush and Miller, 1953; Ludlam, 1963) relate the production of hail stones to favorable vertically sheared environments. In most cases, the generation of larger hail stones occurred in strongly sheared environments that create parent thunderstorms which support the growth. Although strong wind shear is <u>not</u> necessary for hail growth, a strong correlation does exist between the two. The formation of hail strongly relies on a mature, long-lived, and self-perpetuating thunderstorm which is favored in a strong vertically sheared environment. Both the tilted updraft and co-existing updraft/downdraft couplet are key factors which aid hail growth. It is also important to mention other factors which enhance the probability of hail formation, such as the wet-bulb zero height, moisture properties of mid-level entrained air, and environmental instability or Convective Available Potential Energy (CAPE).

CASE STUDY - 8 AUG 1993

On two consecutive days in northern Utah, 7-8 AUG 1993, convective development occurred in very similar, unstable thermodynamic air masses. However, the wind profile (i.e., vertical wind shear) drastically changed over the 24-hour period. On 7 AUG 1993, the National Severe Storms Forecast Center issued a severe thunderstorm watch box to include most of northern Utah and northeastern Nevada. Convection developed over most of Utah; however, only heavy rains and up to pea-sized hail were reported. Thus, the thunderstorm watch box did not verify. The following day (8 AUG), northern Utah experienced many severe hail reports with up to 1.5" hail accumulating to 3" deep. Numerous cells tracked over the southern portion of Salt Lake City, UT, with many places reporting repeat hail occurrences.

Figures 1 and 2 illustrate the thermodynamic profiles on the 7-8 AUG 1993, respectively. The temperature profile at 1200 UTC 8 AUG was very similar to the previous day; however, the 500 mb temperature had cooled approximately 2.5°C, which translated to a Lifted Index of -2 (compared to +1 the day before). The largest difference in the moisture profile occurred above 500 mb where much drier air (Dwpt Dep >20°C versus <3°C) was apparent at 1200 UTC 8 AUG. Thus, the convective instability increased over the two days as the equivalent potential temperature difference from the surface to 500 mb had also increased from -10 to -21°C. As expected, the CAPE also increased from approximately 1000 to 1300 JKg^{-1}.

Figure 3 is a modified vertical wind profile for the each of the two days. The net vertical shear had increased dramatically in the lowest 5 km (from 3.0×10^{-3} to 5.7×10^{-3}) over northern Utah by 1900 UTC 8 AUG. Using the actual storm motion and the SHARP workstation, the storm relative inflow at approximately 500 mb (4712 m AGL) had increased from 4.8 to 33.0 kts (Table 1). Thus, the entrainment of drier ambient air at mid-levels supported well-maintained downdrafts within the parent thunderstorms and favored hail maturation.

DISCUSSION

Although a slight increase in convective instability occurred from 7-8 AUG 1993, the most appreciable change in the mesoscale thunderstorm environment over northern Utah was the vertical speed shear. In concert with drier air aloft, the doubling of the 0-5 km mean shear led to the development and sustenance of very mature thunderstorms, favoring the evolution of hail embryos. In assessing the mesoscale environment, the SHARP workstation can be both quick and helpful operationally. The workstation provides a detailed wind shear and thermodynamic analysis, while providing a medium to display an altered (forecasted) storm environment. The vertical speed shear of the horizontal wind, and its analysis, is an important variable in the thunderstorm severity equation and the production of hail.

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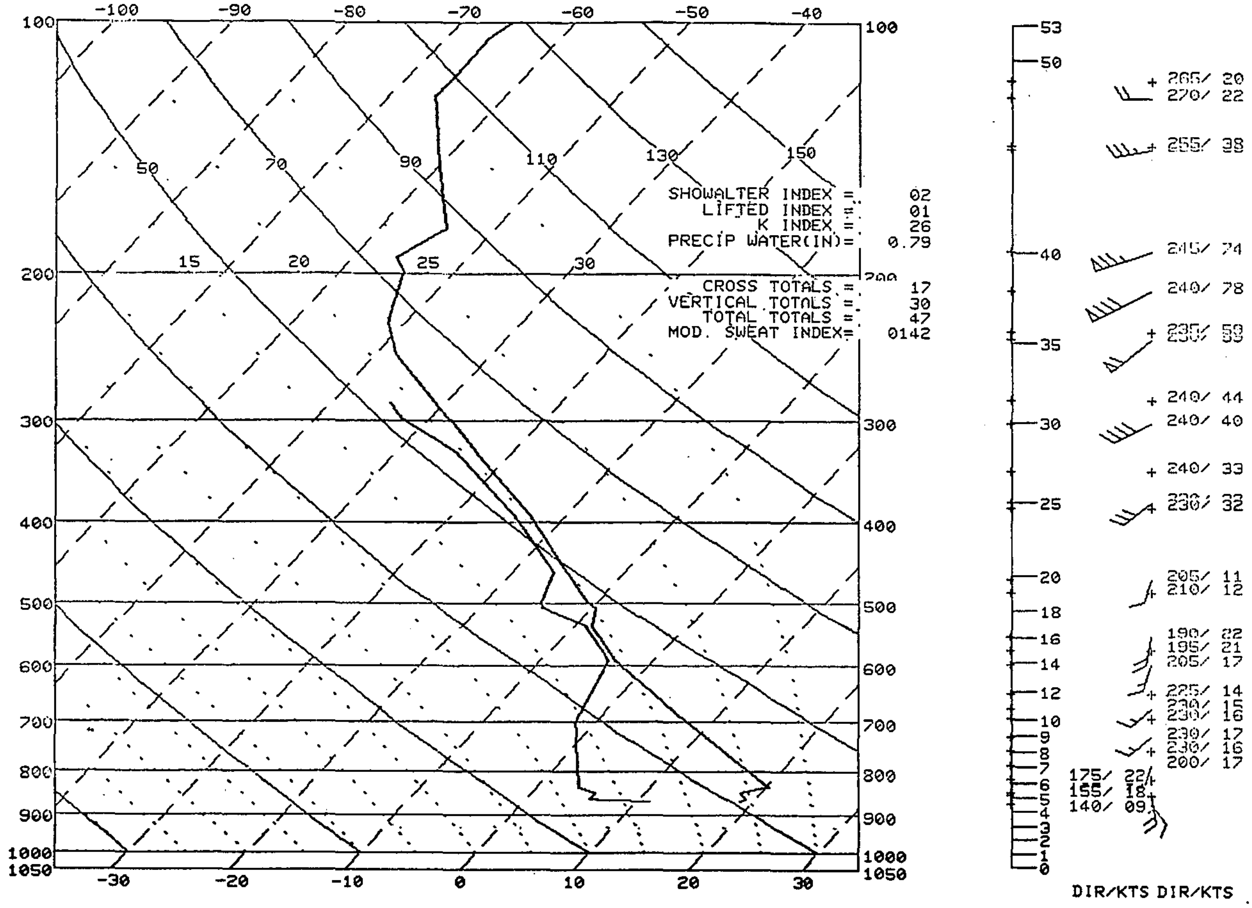

Figure 1. SkewT-lnP sounding for Salt Lake City, UT at 1200 UTC 7 AUG 1993.

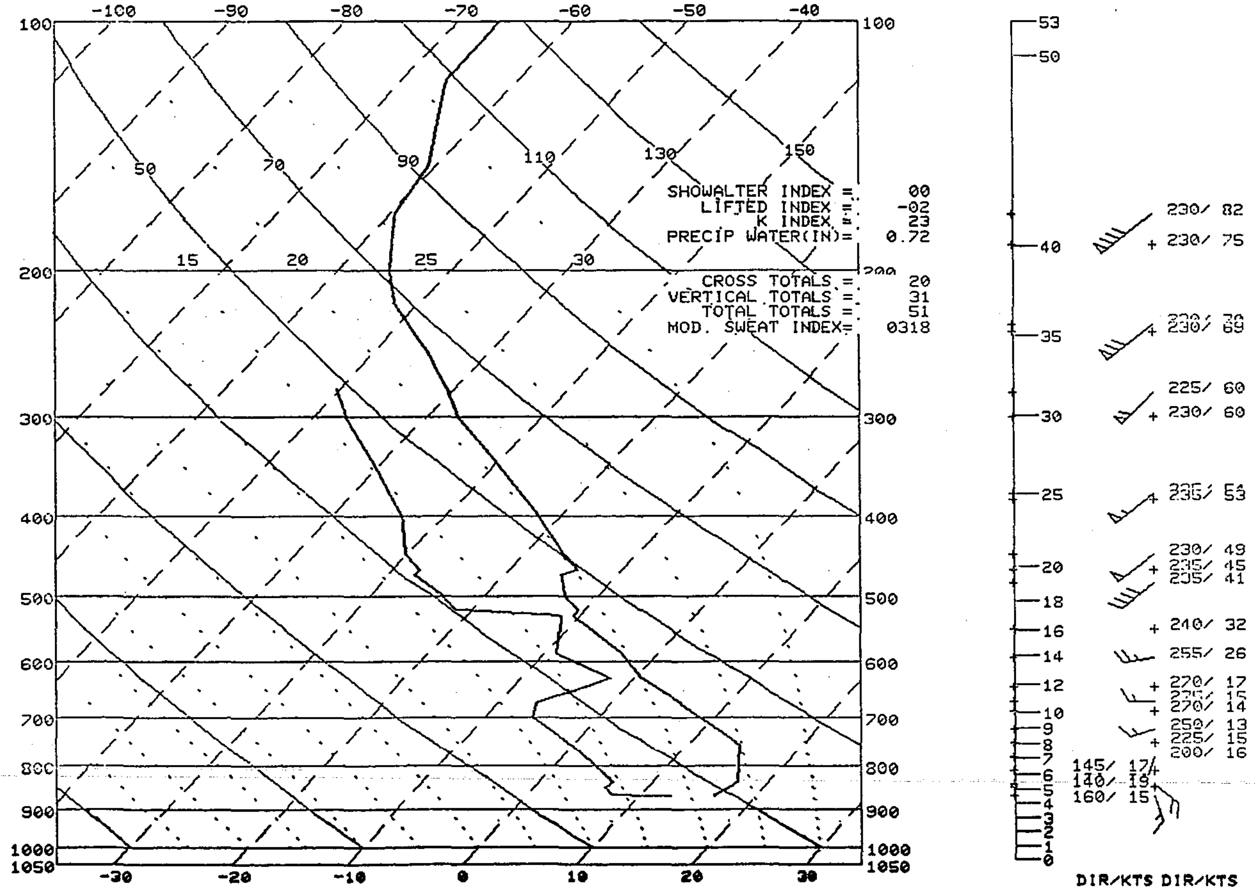

Figure 2. SkewT-lnP sounding for Salt Lake City, UT at 1200 UTC 8 AUG 1993.

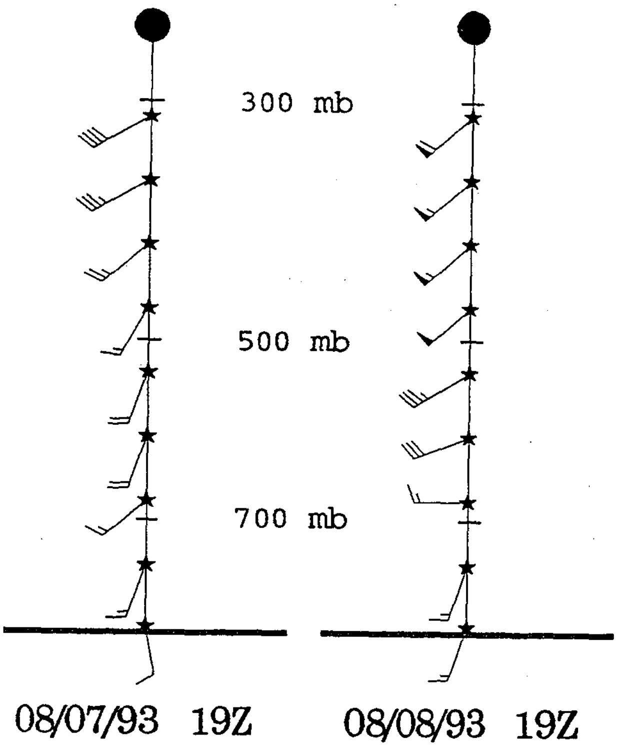

Figure 3. Modified vertical wind plot for 7-8 AUG 1993 at 1900 UTC at SLC. Winds are plotted every 1 km (kts).

HEIGHT	STORM RELATIVE					
	dir	speed		dir	speed	
AGL (m)		kt	m/s		kt	m/s
0.0	90.5	14.5	7.4	117.7	15.4	8.0
212.0	132.5	21.0	10.8	126.0	13.8	7.1
712.0	152.3	13.7	7.0	128.3	12.9	6.6
1212.0	225.6	5.0	2.6	226.3	3.0	1.5
1712.0	225.6	5.0	2.5	315.4	7.7	3.9
2212.0	213.8	3.1	1.6	315.2	10.6	5.4
2712.0	175.1	5.8	3.0	283.3	13.5	6.9
3212.0	167.1	12.7	6.5	258.4	17.8	9.1
3712.0	162.6	14.4	7.4	243.0	22.2	11.4
4212.0	154.2	8.1	4.2	238.0	27.1	13.9
4712.0	129.5	4.8	2.5	236.3	33.0	17.0
5212.0	195.2	6.9	3.5	229.7	38.0	19.6
5712.0	221.0	13.1	6.7	233.5	40.0	20.6
6212.0	229.0	21.0	10.8	236.0	42.0	21.6
6712.0	238.1	21.0	10.8	234.7	44.0	22.7
7212.0	243.6	24.2	12.4	232.2	46.0	23.7
7712.0	243.1	28.1	14.5	229.8	48.0	24.7
	AUG 7			AUG 8		

Table 1. Storm relative wind for 7-8 AUG 1993 at 1900 UTC at SLC.