P8.2 THE IMPORTANCE OF PARCEL CHOICE AND THE MEASURE OF VERTICAL WIND SHEAR IN EVALUATING THE CONVECTIVE ENVIRONMENT

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1. INTRODUCTION

Convective parameters from both observed and model-derived soundings weigh heavily in the thunderstorm forecasting process [along with climatology and pattern recognition; Johns and Doswell (1992)]. There is a multitude of options one can chose from to compute many of these parameters, which further complicates the already difficult problem of forecasting convective initiation and thunderstorm evolution. For example, in the computation of convective available potential energy (CAPE), one may chose to lift the surface parcel (SBCAPE), the most unstable parcel in the lower atmosphere (MUCAPE), or a mixed parcel of some predetermined depth (MLCAPE). The virtual temperature correction (Doswell and Rasmussen 1994) may or may not be applied. Furthermore, CAPE is used in derived parameters such as the bulk Richardson number (BRN; Weisman and Klemp 1982), energy helicity index (EHI; Hart and Korotky 1991), and vorticity generation parameter (VGP; Rasmussen and Blanchard 1998), allowing for a wide array of results depending only upon parcel choice.

In addition to the parcel choices for these thermodynamic parameters, there are also several measures of vertical wind shear one can use, including the bulk, total, positive, and negative shear. The differences among these measures of vertical wind shear are not trivial, and they can lead to different forecaster interpretations of the potential for supercells and bow echoes, for example. In light of these observations, the present investigation attempts to better document these differences through a climatology of soundings in the central United States. Some of the literature that has applied variants of these parameters is also discussed.

2. PARCEL CHOICE FOR COMPUTING CAPE

2.1 *Methodologies to Compute CAPE*

The SBCAPE uses the surface air and dewpoint temperatures to determine the parcel ascent path. As such, calculations can be highly volatile on small time and space scales when these thermodynamic parameters display significant variations. However, the SBCAPE does give a better representation of surface-based convection than does, for example, the MUCAPE. This is very important when assessing the potential for tornadoes and damaging thunderstorm winds—both of which are hindered when the instability is elevated. The SBCAPE and MUCAPE are often equal to each other during the afternoon and early evening hours when the surface parcel has become the most unstable parcel (e.g., Fig. 1), but the SBCAPE typically falls to zero overnight after a surface-based inversion develops.

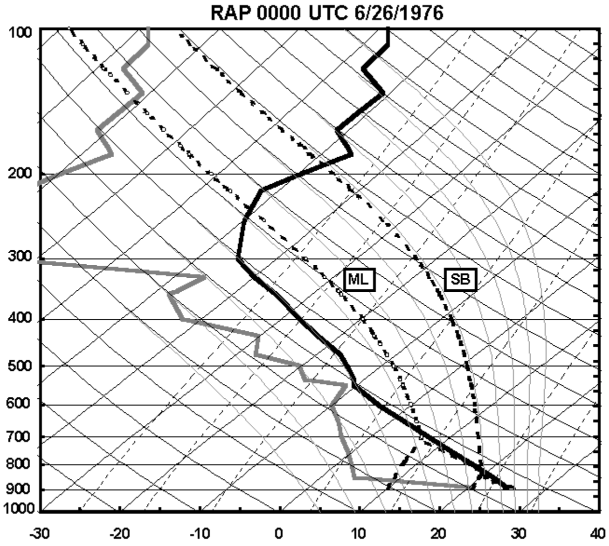

Fig. 1. SkewT-logP sounding for Rapid City, SD on 0000 UTC 26 June 1976. Bold dashed lines indicate ascent paths for the surface-based (SB) and 1000-m mixed-layer (ML) parcels.

The MUCAPE will always produce the largest estimate of buoyancy among the three measures introduced above. It is most effectively used to assess the potential for elevated convection (Rochette et al. 1999)—thunderstorms that develop in an unstable air mass situated above a stable surface layer. In these cases, the SBCAPE and MLCAPE will be relatively small (perhaps zero), thus failing to reveal the true convective potential. The MUCAPE is especially useful overnight when the surface layer cools and stabilizes, but elevated instability still exists. It is also effective for evaluating the convective potential on the cold side of a warm front. Doswell and Rasmussen (1994) and Rochette et al. (1999) suggested calculating MUCAPE by lifting the most unstable parcel (containing the highest equivalent potential temperature) in the lowest 300 hPa of the sounding.

The MLCAPE is computed by lifting a "parcel" constituting a well-mixed layer of constant potential temperature and mixing ratio. This layer is usually surface-based, but it may also be an elevated layer. [Computing the MLCAPE using an elevated layer is yet a fourth variant of CAPE, combining the MUCAPE and MLCAPE attributes (e.g., the Eta model).] There is less consistency in the calculation of MLCAPE when compared to the other two variants of CAPE, mainly because there is not a universally accepted depth of the surface-based layer to mix. For example, Bluestein and Jain (1985) used the lowest 500-m layer, weighted by pressure, to compute the MLCAPE; Wakimoto and Wilson (1989) used the lowest 50-hPa layer; Johns et al. (1993) used the lowest 100-

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hPa layer; Rasmussen and Blanchard (1998) used the lowest 1000-m layer; and Weisman and Klemp (1982, 1984) used the lowest 1000-m layer. The 100-hPa (50-hPa) and 1000-m (500-m) layers are quite similar in depth, since to a first-order approximation, 1 hPa $\approx$ 10 m near the earth's surface.

Due to the averaging properties of MLCAPE, it is less variable in time and space than SBCAPE. Additionally, values of MLCAPE are typically smaller than those of SBCAPE during the afternoon and early evening hours; however, these values are often slightly larger than the SBCAPE values in the nighttime and early morning hours, especially when a shallow surface-based inversion exists. The MLCAPE and SBCAPE will be equal when the boundary layer is well mixed throughout the lifting layer. This is the case in the Weisman and Klemp model soundings, which have uniform potential temperature and mixing ratio throughout the lowest 1000 m. There is some debate whether SBCAPE or MLCAPE is a better estimate of surface-based deep moist convection. In cases of shallow moisture (or perhaps erroneous surface data), the SBCAPE may be much larger than the MLCAPE, perhaps leading to an overestimation of the buoyancy (e.g., Fig. 1). When a shallow surface-based inversion is present, the SBCAPE will be considerably less than the MLCAPE, this time potentially underestimating the buoyancy. In these cases, it appears that MLCAPE (and MUCAPE in the latter case) is superior to the SBCAPE. A climatology of cloud base heights in comparison to sounding-derived lifted-condensation level (LCL) heights would be useful to this end.

It is also very important to note that the virtual temperature correction can produce significant differences in the computed CAPE (and other derived parameters), especially at the lower end of the buoyancy spectrum (Doswell and Rasmussen 1994). There is some disagreement among operational meteorologists whether or not to use this correction, but meteorologists should be aware if it is being used, as CAPE calculations will be affected (in addition to the convective inhibition, level of free convection, etc.). For a more thorough treatment of the virtual temperature correction, refer to http://www.nssl.noaa.gov/~doswell/virtual/virtual.html.

2.2 *Some Observations of Central United States CAPE*

In order to further illustrate some of the differences between the SBCAPE and MLCAPE, a climatological analysis was performed using all observed soundings for the period 1948 to 2000 from four sites in the northern High Plains (NHP: Rapid City, SD; Bismarck, ND; Glasgow, MT; Great Falls, MT) and from four sites in the central/southern Plains (CSP: Springfield, MO; Topeka, KS; Norman, OK; Fort Worth, TX). Furthermore, only those soundings assumed to be associated with environments capable of producing deep moist convection were analyzed; chosen thresholds were SBCAPE > 50 J kg^{-1} and surface-based convective inhibition (SBCIN) < 50 J kg^{-1} (using the virtual temperature correction). Furthermore, the MLCAPE was calculated with a 1000-m mixed layer parcel. A modification of the C program described in Bunkers (2002) was used for this sounding analysis.

It is evident that the median ratio of SBCAPE to MLCAPE is much higher across the NHP, with an order-of-magnitude difference during the spring and fall when moisture is much shallower across the NHP (Fig 2). During the peak severe weather season across the NHP (June–August), when boundary layer moisture is most prevalent, the median CAPE ratio gets a little closer to that in the CSP, with SBCAPE 4 to 8 times the MLCAPE. Across the CSP, the SBCAPE typically ranges from 2 to 3 times the MLCAPE from March through October. These results are simply a reflection of the greater frequency of deeper moisture across the CSP, relative to the NHP. In summary, two conditions will lead to relatively large differences between the SBCAPE and MLCAPE: (i) shallow surface moisture, and (ii) choosing a deep mixing parcel.

When one looks at the ratio of SBBRN to MLBRN—both parameters which employ CAPE in the numerator—a similar picture to that of the CAPE ratio emerges (Fig. 3). This can have dramatic consequences for forecasting the convective mode. As an example, assume that for a given sounding the SBCAPE is 4500 J kg^{-1} and the MLCAPE is 1500 J kg^{-1} (which is reasonable given Figs. 1 & 2). If the BRN shear—the denominator of the BRN—is 70 m^2 s^{-2}, then the SBBRN is 64 and the MLBRN is 21. As a result, an operational forecaster using the SBBRN might expect multicellular convection, but a forecaster relying on the MLBRN would anticipate supercells (assuming they both rely only on this single parameter). Similar examples could be presented for the EHI and VGP. It can be seen that confounding solutions can readily emerge depending upon the parcel used for parameters to forecast deep moist convection (underscoring the need to look at all available data).

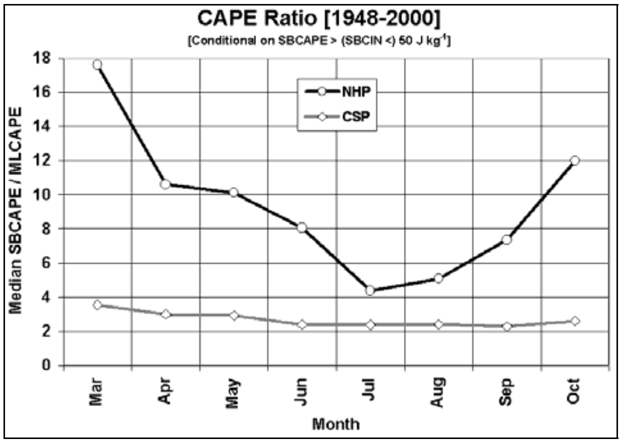

Fig. 2. Median ratio of the SBCAPE to the MLCAPE across the NHP (bold with open circles) and the CSP (shaded with open diamonds).

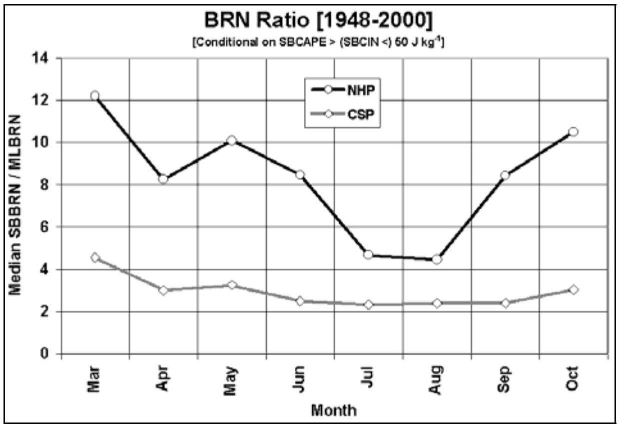

Fig. 3. Same as Fig. 2 except for the median ratio of the SBBRN to the MLBRN.

3. MEASURES OF VERTICAL WIND SHEAR

3.1 *Methodologies to Compute Vertical Wind Shear*

Similar to the thermodynamic parameters discussed in the previous section, there are several measures of vertical wind shear. The bulk shear is the most commonly employed, and is represented by the vector difference between the winds at two different levels. [Technically, this difference is divided by the depth of the layer, thus giving wind shear units of s^{-1}; however, wind shear is often represented operationally simply as a vector difference.] For example, the 0–3-km bulk shear is the difference between the surface and 3-km winds. On occasion, the surface wind may be replaced with a boundary layer average in order to smooth out variations in the low-level winds (e.g., Rasmussen and Blanchard 1998). Evans and Doswell (2001) recently applied measures of bulk shear in their examination of derecho environments.

A second measure of shear, the total (also called cumulative) wind shear (similar to mean shear, Rasmussen and Wilhelmson 1983) is represented by a summation of the shear segments across shallow sublayers between two different levels. In effect, one calculates the bulk shear at relatively small intervals over a given layer, and then sums these results to get the total shear. For example, the 0–6-km total shear can be calculated as the summation of the bulk shear segments across each 0.5-km sublayer from 0 to 6 km. This is a measure of hodograph length, and is analogous to "stretching out" the hodograph and calculating the bulk shear. For a purely unidirectional hodograph that does not fold back on itself, the bulk shear and total shear must be equal; and for a curved hodograph, the bulk shear will always be less than the total shear, at times by several factors (e.g., Fig 4). Weisman and Klemp (1982, 1984) and Rotunno et al. (1988) used the total wind shear in their modeling studies of supercells and squall lines.

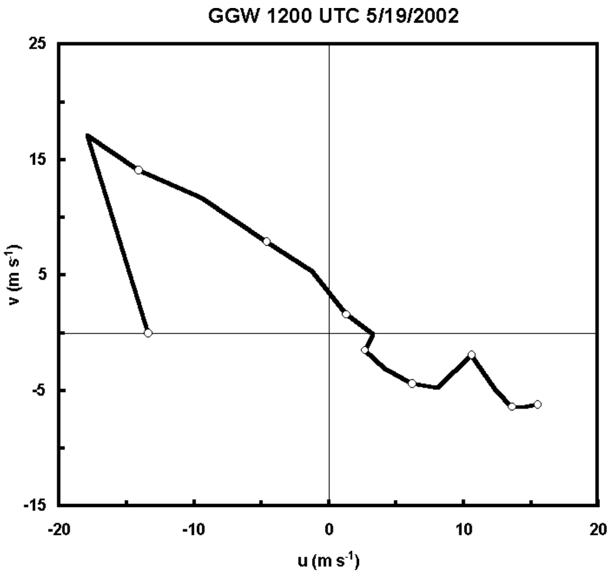

Fig. 4. Observed 0–8-km hodograph for Glasgow, MT on 1200 UTC 19 May 2002. Open circles are plotted every 1 km AGL. The 0–3-km bulk (total) shear is 15 m s^{-1} (43 m s^{-1}), and the 0.5–3-km bulk shear is 25 m s^{-1}.

Positive shear is similar to the total shear, except that only the neutral and clockwise-curving shear segments are summed, which is then normalized by the depth of the shear layer (Johns et al 1990; Hart and Korotky 1991). Conversely, negative shear uses the neutral and counterclockwise-curving shear segments. For a unidirectional hodograph, the total, positive, and negative shear would be similar. For a purely clockwise (counterclockwise) curving hodograph, the total and positive (negative) shear would be similar, and the negative (positive) shear would be zero. In the Fig. 4 example, the 0–6-km positive (negative) shear is 56 m s^{-1} /6km (38 m s^{-1}/6km), with the large difference due primarily to the shear vector turning in the lowest 1 km. Large positive shear, relative to negative shear, is typically associated with environments of large storm-relative helicity. Johns et al. (1990) and Monteverdi et al. (2001) used positive/negative shear to assess tornadic potential.

As a final comment, all but the bulk shear calculation are dependent on the resolution of the wind data used (e.g., Markowski et al. 1998). Therefore, as the resolution of the wind data becomes coarser, the total, positive, and negative shear values generally decrease, and as the resolution becomes finer, shear values get larger. For example, hodographs obtained from high resolution sounding data often display many "wiggles" which can make the total shear much larger than the bulk shear. In an attempt to circumvent this, some researchers have opted to use the bulk shear in lieu of the total shear when analyzing observed soundings (e.g., Evans and Doswell 2001).

3.2 *Some Observations of Central United States Shear*

In general, as the depth of the shear layer increases, the ratio of the total to bulk shear increases (Fig. 5; obtained from the same sounding data used in section 2.2). There are, however, regional differences such that this ratio is smaller over the NHP vs. the CSP. In the NHP, the median value of this ratio remains just below two for all of the layers, although it is near two for the 0–6-, 0–7-, and 0–8-km layers (Fig. 5a). Across the CSP, the median value of the shear ratio equals two for the 0–3-km layer, and exceeds two for all layers deeper than this (Fig. 5b).

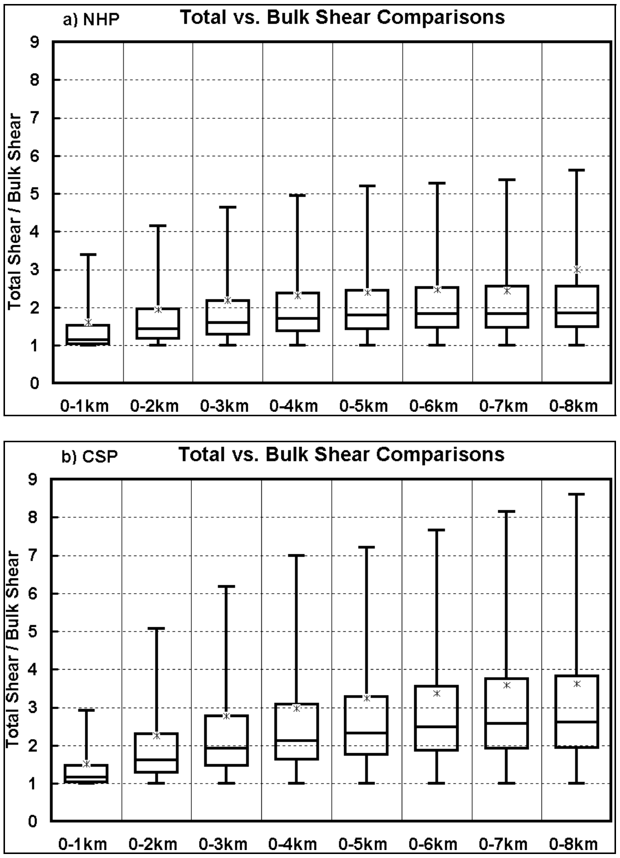

Fig. 5. Box-and-whiskers plots (Wilks 1995) of the ratio of the total shear to the bulk shear for the 0–1-, 0–2-, …, 0–8-km layers for the (a) northern High Plains (NHP) and the (b) central/southern Plains (CSP). Asterisks denote average values.

As noted in the previous section, the bulk and total shear will be similar for unidirectional hodographs (i.e., a ratio near one), but the total shear will be much larger than the bulk shear for hodographs with significant shear vector turning (i.e., a ratio much greater than one; e.g., Fig. 4). Therefore, one can infer from Fig. 5 that hodographs from the NHP have a tendency to be more linear, whereas there is a tendency for greater shear vector turning in the CSP hodographs. As a result of this, hodographs with similar bulk shear from geographically different regions may be rather dissimilar in their shape, with the bulk shear underestimating the overall shear (e.g., Fig. 4).

4. RAMIFICATIONS FOR DERIVED PARAMETERS

As mentioned in the Introduction, CAPE and measures of shear (along with parameters derived from them) are used extensively in thunderstorm forecasting. For example, the VGP, which is used as a tornado forecasting parameter, utilizes CAPE and 0–4-km mean shear (Rasmussen and Blanchard 1998). In their study, Rasmussen and Blanchard used the virtually corrected 1000-m MLCAPE—applied to observed 0000 UTC soundings. So what are some pitfalls that operational forecasters may fall into when applying just this one parameter? First, the VGP has been applied extensively in operations using the SBCAPE, and without the virtual temperature correction. Second, it is quite possible that some have used a measure of bulk shear in place of the mean shear. Third, the VGP has been calculated from 1200 UTC soundings and from model soundings. Fourth, wind data of differing vertical resolutions have likely been applied to the mean shear calculation. And finally, the mean shear may have been calculated over a different layer than 0–4-km. After following this convoluted path to obtaining the VGP, its relationship to the results of Rasmussen and Blanchard becomes somewhat meaningless. From this example, operational forecasters are urged to understand both the definitions of the parameters they are using, as well as the base data that go into their computation.

5. CONCLUSIONS

Following are the conclusions of the present study.

- SBCAPE can be several times to an order-of-magnitude larger than MLCAPE.
- Total wind shear can be several times up to an order-of-magnitude larger than bulk shear.
- The differences in SBCAPE vs. MLCAPE are larger across the NHP relative to the CSP, but the differences in total shear vs. bulk shear are larger across the CSP relative to the NHP.
- Care should be taken when comparing convective parameters between two studies (e.g., one study may have used bulk shear and the other may have used total shear), and between operational forecasting and various studies (e.g., operational forecasters may use SBCAPE and the applied research may have used MLCAPE).
- All available parameters should be consulted when making a convective forecast.

Since many of the studies cited herein used some form of MLCAPE, this may be the most appropriate buoyancy measure for anticipating surface-based convection, with MUCAPE desired for elevated convection. On the other hand, both total and bulk shear have been used extensively in various research, and each has some utility in forecasting applications. These two measures should not be confused, however, as this can lead to misleading outcomes.

6. ACKNOWLEDGMENTS

We would like to thank Dave Carpenter and Bill Read for supporting this work.

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