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On Convective Indices and Sounding Classification

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I. INTRODUCTION

Convective indices have been a cornerstone in the forecasting of convection for many decades, and often are used in the research literature, as well. By convective indices, I am limiting my discussion to parameters derived from the data contained in a single rawinsonde ascent. The introduction of an index by Showalter (1953) represents a watershed moment, beyond which we have seen a steady proliferation of indices, a representative sampling of which can be found in Table 1. Many of these indices are keyed to mandatory pressure levels, with Showalter's proto-type, for example, being tied exclusively to 850 and 500 mb. (As a stubborn person, I refuse to believe that science has been advanced in any detectable way by insisting on hPa instead of mb!!) A primary reason for this, historically, is that receipt of significant level data used to be delayed substantially compared to the mandatory level data. This was a historical artifact of manual raob processing and meant that indices derived solely from mandatory levels would be available much earlier than those using the significant level data. Obviously, this artifact that has no meaning in today's world of automated sounding processing.

Index	T	D	M	Reference
Showalter	X		Y	Showalter (1953)
Lifted	X		H	Galway (1958)
Pickup	X		Y	Pickup (1982)
EHI	X	X	C	Davies and Johns (1993)
BRN	X	X	C	Weisman & Klemp (1982)
SWEAT	X	X	Y	Miller (1972)
K	X		Y	George (1960)
dT	X		Y	Doswell et al. (1985)
SRH			N	Davies-Jones et al. (1990)
BRN shear		X	N	Weisman & Klemp (1982)
CAPE	X		N	Moncrieff and Green (1972)
Total-Totals	X		Y	Miller (1972)
Boyden	X		Y	Boyden (1963)

Table 1. A selection of indices related to convection. The common name is indicated in the first column; an "X" in the "T" column means it involves thermodynamic variables, an "X" in the "W" column means it involves the wind profile data, a "Y" in the "M" column means it uses mandatory level data only, an "H" means it involves both mandatory and significant level data, a "C" means it uses a combination of wind and temperature data, and "N" means it is not restricted to mandatory level data.

This is by no means pervasive, however. Galway's Lifted Index lifts a parcel having the (forecast) average properties of the lowest 100 mb in the sounding, but still measures buoyancy relative to the 500 mb level temperature. The CAPE is perhaps the index least dependent on mandatory pressure levels, since it involves an integration between levels of some physical significance (the LFC and the EL - in the interest of saving space, I am not going to define all my terms).

A careful reader will note that I have included some indices that are perhaps not normally included in such lists. Specifically, I have included indices that consider not only the thermodynamic stratification, but also the structure of the vertical wind profile, either by itself or in combination with the thermodynamic variables. The development of such indices has been fairly recent, with the realization that buoyancy did not contain all the relevant physics for some applications of sounding analysis.

Various arguments have been made, mostly outside the formal literature, in favor of one index or another. Forecasters have their favorites and so do the research scientists; all index users tend to have a host of reasons why the other pretenders are flawed. My primary thesis is going to be that *all* indices are basically flawed. I am going to try to clarify what indices are intended to provide and I am going to try to make a convincing argument that indices are almost certainly useless for achieving most of those objectives, and in fact end up being misleading and perhaps even counterproductive for many of those objectives.

2. OBJECTIVES

So what are convective indices all about? There are at least two more or less independent goals for producing an index.

The first is as an aid to forecasting deep, moist convection (hereinafter DMC; its occurrence, its intensity, the likelihood of the convection resulting in some specified weather event, etc.). An ideal index would, presumably, delineate space-time domains inside which the forecast events occur, outside of which the forecast events do not occur. In many senses, this is the core of the arguments advanced for any particular favored index; examples usually are shown illustrating how well the index has depicted the occurrence of a particular event (e.g., Fig. 1). Naturally, examples where the index failed miserably are provided only occasionally, and often are buried in a heap of statistics, where their failures are obscured by the numbers. If failures occur, the adherents of a particular index are quick to rush to its defense, often arguing that the data were undersampled, or that certain mitigating factors were ignored, or that no one intended the index to stand alone as a forecasting tool. To me, these have begun to sound uncomfortably like rationalizations preventing us from a serious examination of the merits of indices, in general.

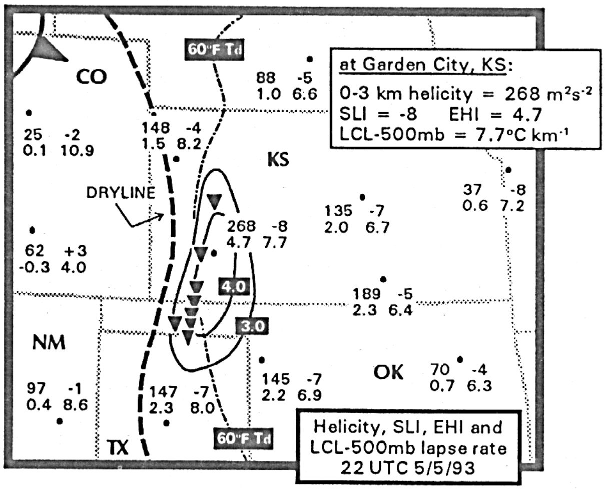

Fig. 1. Example of the comparison between and index and the event it purports to "forecast." Contours depict Energy-Helicity Index values of 3.0 and larger (from Davies 1993)

I observe that if a *perfect* index (i.e., one that forecast some event perfectly, with no failures to detect and no false alarms) ever were to be found, forecasters of the phenomenon delineated by that index would then be out of a job! One would need merely to calculate the index and the forecast would be done. The implausibility of this is so obvious that virtually no one expects to find such an ideal index. Rather most folks argue that an index is at most a necessary ingredient but is not by itself sufficient.

If a perfect index is beyond achievement, what else can an index do? A common argument is that it can focus attention on places and times where the forecast events are likely to occur. Since I am considering "events" to refer to *convective* events, let's take a look at how helpful indices can be at focusing our attention. I begin with my standard litany about the ingredients for deep, moist convection: moisture, conditional instability, and lift. (I am not considering *forced* convection, which is an issue in its own right, of course.) Virtually all of the thermodynamic stability indices consider, explicitly or implicitly, the behavior of a rising parcel. That is, they consider the *combined* effects of moisture content and conditional instability. If either moisture or conditional instability is absent, the index indicates benign conditions. As discussed in Doswell et al. (1985), by the time the index reveals instability, this may no longer be a forecast but has become a statement of what is evident by what is already happening! Moisture and conditional instability (e.g., as measured by a lapse rate) can evolve more or less independently and be brought together only just before DMC initiation. In my view of the DMC forecasting problem, an index keyed to the simultaneous presence of both moisture and conditional instability is not very helpful!

Moreover, indices keyed to particular mandatory levels can give an egregiously inadequate picture of the situation. The scenarios by which this flaw in an index multiply rapidly; a single example suffices to illustrate the problem (Fig. 2). All it takes is some not altogether unlikely circumstance, and the index fails to convey a proper sense of the situation.

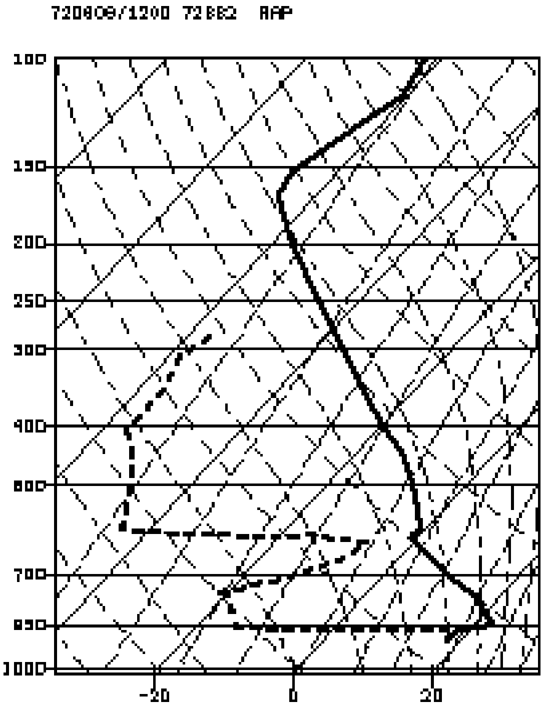

Fig. 2. Example of a sounding where the moisture cuts off just below 850 mb, so parameters like the Showalter Index may not reveal an accurate picture of the impending events (this was the morning of a 1972 flash flood event later in the day in Rapid City, South Dakota.

The advent of computerized analysis has meant that computation of indices no longer requires one even to look at the sounding. This perhaps is the most insidious threat associated with indices. Now one merely need look at the index numbers plotted on a map or plopped into a table and never have to sully one's mind with such complexities as a sounding. The programs blindly compute the numbers, no matter what the sounding itself looks like (Fig. 3) and when the plotted numbers show up on the screen, who is able to tell *what* that sounding looked like? Indices are an all-too-convenient mechanism to avoid looking at the wealth of information contained in a sounding. They are a zero-dimensional representation of the complexity and value associated with a rawinsonde ascent.

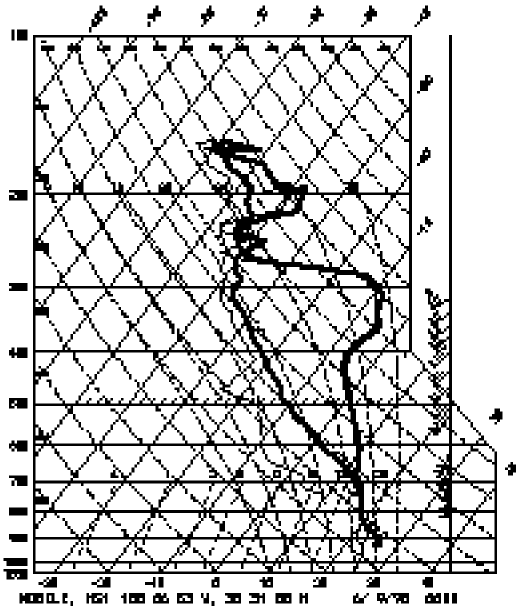

Fig. 3. Example of a "strange" sounding (during VORTEX) where the sonde entered an updraft shortly after release and then descended after becoming coated with ice.

Similar arguments can be mounted for indices relating to all of the events *produced* by convection. The problem with any index is that to be reasonably competent, it must attempt to be inclusive of all of the physically meaningful ingredients. But to do so means the index becomes not a forecast tool but a diagnostic tool. It tells you where and when the conditions *have been* brought together for the event in question, not where they are *going* to be brought together. The paper by Collier and Lilley (1994) exemplifies the popular but erroneous notion that indices comprise a *forecast* of convection.

To complete the thread this section began with, the second goal of indices is to <u>characterize the environments</u> in which DMC events occur. In a scientific sense, as distinguished from a forecasting sense, this means that indices can be offered as a means of representing something physically relevant about the environment. This use is the predominant one in the scientific literature; one merely need say that the such-and-so index had a particular value, and everyone is supposed to be able to infer something about the situation. In effect, however, this application of indices is not much different from the forecasting uses!! That is, the use of indices in forecasting DMC presupposes they have some pertinence in representing the DMC environment. Therefore, almost all of the problems I have enunciated with respect to forecasting applications of indices can be used to suggest that this application of indices is flawed, as well. To the extent that an index is, in fact, competent at characterizing the DMC environment, its diagnostic role might be of some value. However, the problems of representativeness, use of mandatory levels, etc. will plague indices in this context as well. Furthermore, a given value of an index can be obtained in environments that are quite different (e.g., the EHI); index values are not unique descriptors of the environments they purport to represent.

3. DESIGN

Yet another problem with indices has recently been suggested by Tudurí and Ramis (1996). When indices are used, as they often are, in situations *outside of their original intentions and in geographical locations outside of their original development*, they often prove to be of little or no value in dealing with the DMC problems in the new domain. To some extent, it may be that "tuning" the interpretive threshold values of the index, which no doubt were formulated by the original author in a particular context, can fix the problem, after a fashion. This indicates that each potential new application of an index must include a careful study of the climatology of that index relative to the events in question. Of course, one conclusion from such a study might be that it is necessary to develop some *new* index to deal with the location/situation-specific problems at hand.

Furthermore, it may be that the topography of the region dictates a reassessment of the mandatory levels used. For example, it is difficult to imagine using the Showalter Index unmodified in Denver, Colorado, where the 850 mb surface is often underground! So what was Showalter's intent in picking 850 mb? Perhaps he wanted to be out of the surface boundary layer but still within the domain of low-level moisture? What mandatory level would serve that purpose in Denver? 700 mb is the next up, but it might be too high to function in the same way as 850 mb does in the Showalter Index. What about using 500 mb as the reference level for the lifted parcel in the Showalter Index? If we use 700 mb as the level from which we lift, should we raise the level to which we lift to 400 mb? There is no 350 mb mandatory level, so we can't maintain the same δp used in the Showalter Index. What about sites near sea level? Is 850 mb the right level or should it be lowered to 925 mb (a new mandatory level)? If it is, should we lower the upper reference level to 700 mb? If we start changing the levels all over the map, how can we compare values at different stations?

As Tudurí and Ramis have noted, indices developed to deal with certain types of DMC can be virtually useless in some geographic locations, simply because those environments are not observed frequently enough in those locations to merit inclusion in an analysis to be used in forecasting.

Calculating such an index is basically a waste of effort. To be of value in forecasting, an index should be capable of discriminating the types of weather events that are important. It is interesting to observe that hail events observed by Tudurí and Ramis are characteristically a cool-season phenomenon. This suggests that indices designed to capture large hail events of the warm season almost certainly will be useless in defining environments charac-teristic of cool-season small hail. It would be necessary to develop a new index for the latter, rather than using the existing ones.

4. ALTERNATIVES

If an index is basically a flawed approach to the problem of characterizing DMC environments, what is the alternative? An empirical approach, designed with specific forecast problems and geography as a basis, has been suggested by Tudurí and Ramis (1996). Basically, their scheme aims to relate specific forecast events to the soundings by means of a sounding classification scheme. This is a powerful method for creating forecast-relevant sounding analysis that can be generalized to any forecast event and any geographic region. Assuming that the events are correlated with some characteristics contained in sounding data, once the classification is done, a forecaster merely needs to know into which category a specific sounding fits to have some idea of what sorts of events to expect. Knowledge of the "climatology" associated with development of the scheme even permits some estimation of the uncertainty associated with particular events when the sounding falls in a given class.

The advantage to this scheme, or any other of sufficient generality, is that it is relatively easy to do and can be tuned to the problem and area of interest. The disadvantage is that the method is essentially statistical; it is not necessary to employ much physical understanding during the development of the sounding classifications.

Moreover, schemes based on sounding classification, in general, invariably have difficulties (comparable to those of indices, perhaps) with the *representativeness* of the input soundings. Since all the information being applied to the problem is contained in vertical ascents, the "synoptic situation" information is not included. The ideas of Schaefer and Doswell (1984) are related to those developed in Tudurí and Ramis, but are 3-dimensional; this is "map typing" instead of "sounding classification" and is considerably more complex, but potentially more valuable since such a method includes more interconnected information about the environment of the event than a single sounding.

Nevertheless, even map typing has severe limitations. The ingredients suppor-ting some physical process can be brought together in some atypical way; an example is discussed in Bosart and Lackmann (1995). Some failures of parameters and indices can be understood in terms of unconventional processes giving rise to a certain event. Others failures of parameters and indices might not be understandable in terms of what is known currently. In either case, given my biases, I must advocate a *physical* approach to the maximum extent possible. Brooks et al. (1994) have noted that to be useful, either in research or in forecasting, parameters have to be well-matched to the physical processes associated with the event. SRH, originally developed as a tornado forecasting tool, appears to be best suited for forecasting the occurrence of supercells. It appears that the physical processes associated with tornadogenesis are quite different from those tied to mesocyclogenesis. Thus, if parameters and indices are to be used, and I am reluctantly willing to concede that they almost certainly will be, then I am urging that the primary argument in favor of a parameter's selection should be its *physical relationship to the events* being considered.

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