Comments on ‘‘Evaluation and Application of Conditional Symmetric Instability, Equivalent Potential Vorticity, and Frontogenetic Forcing in an Operational Forecast Environment’’

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After reading the paper by Wiesmueller and Zubrick (1998) on conditional symmetric instability (CSI) and equivalent potential vorticity (EPV), I agree with them that there has been a problem in getting operational forecasters to understand and properly use CSI concepts in their forecast routines. However, the problem is not entirely for a lack of model gridded data and tools to slice and dice them. The basic concepts for CSI have been poorly presented to forecasters. There are widespread misconceptions about CSI that appear in the Wiesmueller–Zubrick paper. CSI is a relatively easy concept for forecasters to grasp, so the confusion appears to be unnecessary. First I will provide an explanation for CSI that I have not seen anywhere in the literature. It was explained to me in this way at a scientific conference, and I apologize for forgetting the person’s name who offered me the explanation. Then I will point out some specific problems with the Wiesmueller–Zubrick paper with hopes that I can correct some of the misconceptions.

First I want to review some basic parcel dynamics. There are three major forces in the atmosphere that can act on a parcel. The forces in the vertical are the pressure gradient force and gravity. In the horizontal they are again the pressure gradient force and the Coriolis force. Meteorologists call the balance of these vertical forces ‘‘hydrostatic’’ balance and the balance of these horizontal forces ‘‘geostrophic’’ balance. Imbalances occur when the pressure gradient force changes for the parcel. For example, a parcel of air warmer than its environment will experience an imbalance of forces with the larger upward pressure gradient force accelerating the parcel upward. Under certain conditions, perturbed air parcels may be accelerated away from their previous positions in space. Meteorologists call those unbalanced force conditions ‘‘unstable.’’ The unstable condition in the vertical is called ‘‘static’’ instability and in the horizontal ‘‘inertial’’ instability. Note that this definition of inertial instability is not limited to the ‘‘classic’’ condition of the Coriolis force being larger than the pressure gradient force that leads to negative absolute vorticity.

Symmetric instability is a special combination of unbalanced forces in which parcels may be stable to solely horizontal or vertical displacements but still be unstable. It happens in baroclinic atmospheres because of the wind shear. Imagine an air parcel in geostrophic balance situated in a north–south horizontal temperature gradient (isotherms oriented east–west) that is displaced horizontally northward into the cool air. Because horizontal displacements are isothermal, the air parcel now is warmer than its environment and is accelerated upward. Now the initial northward displacement causes the Coriolis force on the parcel to increase, but the upward displacement causes an increase in the horizontal pressure gradient force on the parcel. (The geostrophic winds aloft are higher from the thermal wind relationship, so the pressure gradient force must be higher.) Depending on which horizontal force is greater (the Coriolis force on the parcel increases initially only because of a latitude change; it will slowly adjust to the increased wind), the parcel may accelerate more into the cold air or back into the warm air. And depending on the environmental temperature, the parcel may also accelerate upward or downward.

So there are two possibilities for the parcel depending on the relative strengths of the forces on it. 1) If the relative static stability is high, the forced downward displacement will move the parcel back toward its original level and the higher Coriolis force will move the parcel back to its original position. 2) The parcel will move upward if the static stability is negative. Its horizontal displacement depends on the relative strengths of the pressure gradient and Coriolis forces. A continued upward displacement will eventually place the parcel in high enough wind speeds to have the pressure gradient

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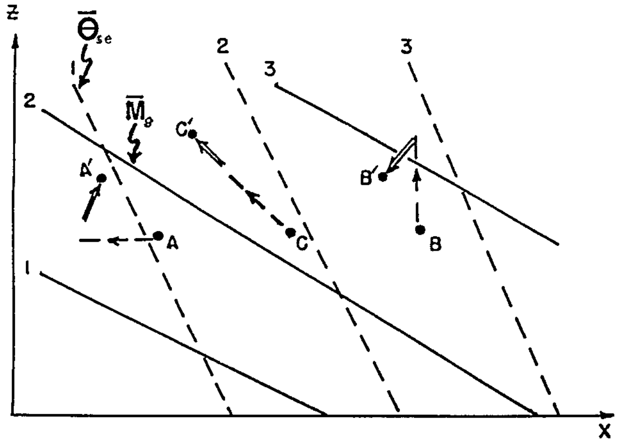

FIG. 1. A modified version of the Wiesmueller and Zubrick (1998) Fig. 1 schematic vertical cross section illustrating conditional symmetric instability. Solid contours represent absolute geostrophic momentum (M_g). Dashed contours represent saturated equivalent potential temperature (Θ_{se}). Lettered points show sample parcel displacements (dashed) and accelerations (arrowheads). Parcels at the "primed" locations will continue to accelerate leftward and upward. The original figure is from Sanders and Bosart (1985).

force the parcel into the cold air. Similarly, the parcel also will move upward and more into the cold air if the wind shear is high enough even under statically stable conditions if the horizontal motions can keep the parcel's temperature cooler than the environment's.

I could have described a similar situation for a parcel displaced vertically.

Up to this point I have not considered the parcel's moisture. If the parcel is saturated, the static stability is measured with respect to the moist adiabats and not the dry adiabats and is usually measured by examining the vertical distribution of the saturated equivalent potential temperature.

There are many possible scenarios for a saturated parcel. One way to sort it out is to examine cross sections of saturated equivalent potential temperature (Θ_{se}) and the so-called absolute geostrophic momentum (M_g). The parcel accelerations will be in relationship to its original equivalent potential temperature ($\Theta_{e\text{-pcl}}$) and to its original absolute geostrophic momentum ($M_{g\text{-pcl}}$).

I have modified Wiesmueller and Zubrick's Fig. 1 in two ways in my Fig. 1. First, I modified the labeling of the dashed lines to make them lines of equal Θ_{se} not lines of equal Θ_e. It is not necessary to assume a saturated environment, only a saturated parcel. Second, I have labeled the endpoints of the double arrows of each of their sample parcel displacements with a primed letter. Because of the slopes of the Θ_{se} lines are parallel to each other and the M_g lines are also parallel to each other, all the sample parcels in the figure have the same environmental static and inertial stabilities. Therefore, all the parcels will be accelerated away from their original positions; it does not matter how they are initially displaced.

Parcel A has the same M_g at A′ as it had at A, but the parcel, $\Theta_{e\text{-pcl}}$, is still warmer than the Θ_{se} of the environment so the parcel will continue upward. That will take the parcel into an environment with higher M_g, which will push the parcel more leftward. Because the Θ_{se} lines are sloped less than the M_g lines, the parcel $\Theta_{e\text{-pcl}}$ will always be warmer than the environment's Θ_{se}, and it will continue along a slantwise path similar to parcel C's. I invite the reader to examine the accelerations that the parcel at B′ must undergo and discover that B's path is also similar to C's.

Another way to examine the possible parcel accelerations is with an analysis of the environment's EPV. McCann (1995) derived a more general equation for EPV. In its vector form

$$\mathrm{EVP} = g\left[-\hat{k}\cdot\left(\frac{\partial \mathbf{V}_g}{\partial p}\times\nabla_p\Theta_{se}\right) - \zeta_g\frac{\partial\Theta_{se}}{\partial p}\right],$$

where g is the gravitational acceleration, $\hat{k}$ is the unit vector in the $-p$ (up) direction, $\mathbf{V}_g$ is the geostrophic wind, and ζ_g is the absolute geostrophic vertical vorticity. The two terms on the right-hand side define the relative strengths of the horizontal and vertical accelerations. Negative EPV implies instability with parcel accelerations away from its original position. McCann (1995) pointed out that the first term is proportional to the horizontal temperature gradient squared and so is always negative and "destabilizes" an environment. Therefore, the sign of the EPV depends on the sign and relative magnitude of the second term. A negative EPV can result from a negative second term (conditional static instability) or from a positive second term whose magnitude is less than the magnitude of the first term (conditional symmetric instability).

I have already pointed out corrections needed in Wiesmueller and Zubrick's Fig. 1 and in its analysis. Some other statements from their paper that need correcting or clarification include the following.

- "The term 'conditional' [in conditional symmetric instability] refers to an atmosphere near saturation."

The word "conditional" refers to an atmosphere that would force parcel accelerations if the parcel were saturated. The atmosphere may or may not be saturated. It is for this reason that I replaced Θ_e in their Fig. 1 with Θ_{se}. Their PCGRIDDS script in the appendix should also use Θ_{se} instead of Θ_e.

- "An equivalent criterion for CSI in a saturated environment is that the observed EPV be less than zero. . . ."

Negative EPV is a general criterion for conditional instability. CSI refers only to the condition of moist conditional instability in the presence of moist static stability.

- "These combined forces (gravitational and inertial) can be estimated from a single atmospheric sounding and by considering cross sections of pseudoangular momentum and equivalent potential temperature.''

Vertical gravitational forcing may be estimated to a high degree of accuracy from an atmospheric sounding by comparing the sounding lapse rates with the moist adiabats. However, inertial forcing is a function of the horizontal temperature gradient. The vertical wind shear in the sounding may give a clue, but that depends on how geostrophically balanced the atmosphere is. Analyses of the sounding wind shears [or the shears from other sources such as Weather Surveillance Radar-1988 Doppler (WSR-88D)] are no substitute for an analyses of horizontal temperature. Cross-sectional analysis as described above is only slightly better. To construct a cross section, the isotherms must be straight and not change orientation with height. Even if constructed correctly, estimating CSI is cumbersome (a good point from Wiesmueller and Zubrick) and subjective. The inconsistency in their Figs. 11 and 12 at the 900-hPa level between points C and A illustrates this point. Figure 12 shows high EPV values in this region, yet Fig. 11 shows the same region shaded as a region of weak symmetric stability. A much better approach is to compute EPV in three dimensions (a GEMPAK software capability) then display it in vertical profile at a single point or in cross section between points.

- ``Knowing that the atmosphere is conducive to CSI is one thing, but knowing where the (precipitation) bands will form remains one of the most difficult and challenging of forecast problems.''

I agree that the problem of forecasting precipitation bands in CSI is difficult and challenging, but it is no more challenging than forecasting thunderstorms. In fact, the forecasting techniques are identical. Thunderstorm forecasting is knowing where the conditionally unstable air masses are located and where any parcel within a conditionally unstable air mass may be lifted to its level of free convection (LFC; Johns and Doswell 1992). Since convection causes precipitation banding, CSI precipitation bands will be located where parcels are lifted to their slantwise LFC. Although difficult to forecast because of environmental subtleties, weak convection conceptually follows the same ``rules'' as strong convection. I suggest the following routine: Compute EPV in three dimensions because an EPV analysis will indicate more generally where conditionally unstable air masses are located. Since strong CSI situations are caused by strong horizontal temperature gradients, one likely important lifting mechanism is frontogenetic forcing. Wiesmueller and Zubrick's Fig. 8 shows large frontogenesis in the layer that happens to be the layer with the most unstable parcel. As they pointed out, the frontogenetic forcing and the precipitation banding were connected. Forecasters should note that a frontogenesis function analysis for frontogenetic forcing only gives one-half of the information. Keyser et al. (1988) give a generalized frontogenetic forcing that includes the forcing due to the rotation of isotherms. This technique can be computed on gridded data just as easily as the classic frontogenesis function.

- ``One cannot dispense with looking at the respective slopes of M_g and Θ_e in a cross section, since it is the vertical distribution of Θ_e that differentiates between convective and inertial instability.''

It is true that moist static instability is determined by the vertical distribution of Θ_{se}; however, it is the horizontal distribution of M_g that determines inertial instability. The combined moist potential stability is determined by the relative slopes of M_g and Θ_{se}. Whenever the slope of Θ_{se} is less than the slope of M_g, then there is total potential instability. This criteria is easily related to the EPV < 0 criteria algebraically. As a practical matter, perhaps forecasters should dispense with looking at slopes of M_g and Θ_{se} in a cross section. EPV is a much better generalized tool to evaluate layer potential instability. Computing it in three dimensions before displaying it eliminates the problems mentioned earlier. If a forecaster wants to distinguish CSI from more ``generic'' conditional static instability, just overlaying a cross section of Θ_{se} to examine its distribution with height is necessary.

- ``Whenever EPV is either zero or negative, and the atmosphere is nearly saturated, then the atmosphere is considered to have potential for CSI. In [the EPV equation], CSI occurs whenever term 1 dominates term 2 since both terms are usually negative.''

Whenever EPV is negative, the atmosphere is considered to have potential for convection (not just CSI). The atmosphere need not be saturated. In the EPV equation, term 2, the static stability term, may be positive or negative. Term 1, the inertial stability term, is always negative.

CSI is just another form of convective instability that arises from considering both horizontal and vertical instabilities. Most forecasters are already familiar with basic instability analysis, so CSI should not be that difficult to comprehend.

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