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EQUIVALENT POTENTIAL TEMPERATURE (THETA-E) APPLICATIONS

Mike Campbell - WSFO Boise

Introduction

This Technical Attachment is a brief overview of some operational applications of equivalent potential temperature. The use of equivalent potential temperature, or theta-e (θe), as a diagnostic tool is a good compliment to standard constant pressure analyses. The conservative property of theta-e also allows it to be used as a forecast tool. Recent work by Dr. Roderick Scofield (NESDIS Satellite Applications Laboratory) has yielded recognition of favorable theta-e fields for development and propagation of organized convection. Although his work was focused on mesoscale convective systems (MCSs), his methods still have application for convection in general. Vertical cross sections of both theta-e and moisture provide another diagnostic view that can be used to determine favored areas of convection.

What is Equivalent Potential Temperature?

Equivalent potential temperature is a thermodynamic property dependent on temperature and moisture. The equivalent potential temperature of a parcel of air is the potential temperature of the parcel when its mixing ratio is zero. When the parcel's mixing ratio is brought to zero (via condensation), the resultant latent heat warms the parcel. A greater value of low-level theta-e implies greater convective available potential energy (CAPE), energy released if the environmental lapse rate is greater than the moist adiabatic lapse rate. This makes the parcel buoyant with respect to its environment and allows the parcel to be accelerated upward.

Equivalent potential temperature for any given level can be easily calculated from a thermodynamic diagram. In the high terrain country of the western U.S. the 700mb level probably works best. You want to choose a level that is above the surface but still at low levels of the atmosphere. Starting then at the 700mb level, compute the lifted condensation level (LCL) by lifting the 700mb dew point along the saturation mixing ratio line until it intersects the 700mb temperature lifted along the dry adiabat. From the 700mb LCL, raise the parcel along a moist adiabat until it parallels the dry adiabat (this is analogous to condensing all the moisture out of a parcel at 700mb by lifting it). From this point, lower the parcel to 1000mb along a dry adiabat. This value is the 700mb theta-e.

Equivalent potential temperature is a particularly useful atmospheric parameter since it is conservative with respect to **both** dry and saturated adiabatic processes. A parameter which remains constant during certain atmospheric transformations is said to be "conserved". Since theta-e is conserved during both dry and saturated atmospheric processes, it is a valuable diagnostic tracer. The equivalent potential temperature of a parcel can be changed by adding or removing moisture, or by diabatic heating or cooling.

Uses of Theta-E Analyses

A high value of theta-e in the lower levels of the atmosphere (700mb in most Western Region locations) usually implies a large amount of CAPE. To be sure that the CAPE is indeed high, the low-level moisture must be more than just a very shallow layer right at 700mb (or whatever the analysis level is), and the lapse rate must be fairly steep as well. With high lapse rates and a fairly deep layer of low-level moisture, theta-e analyses can be quite useful for determining favored areas of convection. Since high values of low-level theta-e imply high CAPE (assuming the other ingredients are present), ridges and maxima in the theta-e field are favored areas for convection. Synoptic scale or mesoscale forcing mechanisms need to be considered as well. A lifting mechanism within a favored theta-e area will enhance convection. If a lifting mechanism is strong enough outside a favored area then convection can certainly develop outside the favored area. At the same time, a strong capping inversion or subsidence aloft may suppress convection within a favored area. Synoptic scale subsidence can often be seen on water vapor imagery as a darkening area.

Scofield and others have found some relationships between low-level theta-e patterns and convection, many of which are most useful when synoptic scale forcing (positive or negative) is at a minimum. Figures 1 and 2 show examples of typical theta-e patterns associated with the following relationships:

1. Theta-e ridges and maxima are favored areas for convective development if other favorable ingredients are also present. Downward vertical motion inhibits convective development, even with a favorable theta-e pattern.

2. Convection often develops or is located at the extremities of theta-e ridge axes.

3. Convective systems often propagate toward theta-e maxima.

4. Theta-e gradients are favored areas for convective development in the presence of moderate to strong upward vertical motion.

5. Theta-e axes and maxima usually change little (conserved) in a 12-24 hour period and therefore can be tracked from analysis to analysis. Large mesoscale convective systems can modify the theta-e field.

6. Convection can develop in secondary (minor) ridge axes. These axes are often subtle and are not always trackable.

7. In winter storms, "thunder snowbursts" can occur when the theta-e ridge axis and the main precipitation area of the cyclone overlap.

8. Heavy rainfall can develop when a "tropical connection" feeds into organized convection in a theta-e ridge. Water vapor imagery is helpful to determine if this kind of connection exists.

Theta-E Cross Sections

Vertical cross sections of equivalent potential temperature combined with momentum and moisture cross sections are another valuable diagnostic tool for determining areas of convection. These cross sections offer a three-dimensional look at the atmosphere and allow the forecaster to diagnose features and instability which may not be present on standard isobaric analyses.

An important application of theta-e cross sections is the analysis of slantwise convection. As the name implies, slantwise convection contains components of vertical (buoyant) and horizontal (inertial) stability. Slantwise, or symmetric, instability occurs when vertical stability is weak and horizontal instability is also weak. Since inertial instability decreases as absolute vorticity does, areas of anticyclonic vorticity are favored for weak horizontal stability. The orientation of lift in slantwise convection is assumed to be along a line of constant momentum. If theta-e decreases upward along a constant momentum surface, symmetric instability exists. Figure 3 shows a cross section of theta-e and momentum. The shaded areas show where the atmosphere theta-e decreases as constant momentum lines are followed upward - where the atmosphere is symmetrically unstable. If moisture is also present in this area, then slantwise convection can occur. For a complete discussion of symmetric instability see Sanders and Bosart (1985); for a good discussion on the operational use of slantwise convection see Lussky (1987).

The ideas and methods discussed in this paper are not new ones, but they have received little attention in operational meteorology, especially in the western U.S. Since application programs are available on AFOS to create all of the analyses discussed in this paper, forecasters may wish to explore the use of equivalent potential temperature as a diagnostic tool for determining areas of convection.

References

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PATTERNS OF LOW-LEVEL θ_e RIDGE AXES AND MAXIMA ASSOCIATED WITH THE DEVELOPMENT AND PROPAGATION OF ORGANIZED CONVECTION

...from work by Dr. Roderick Scofield, NESDIS Satellite Applications Lab.

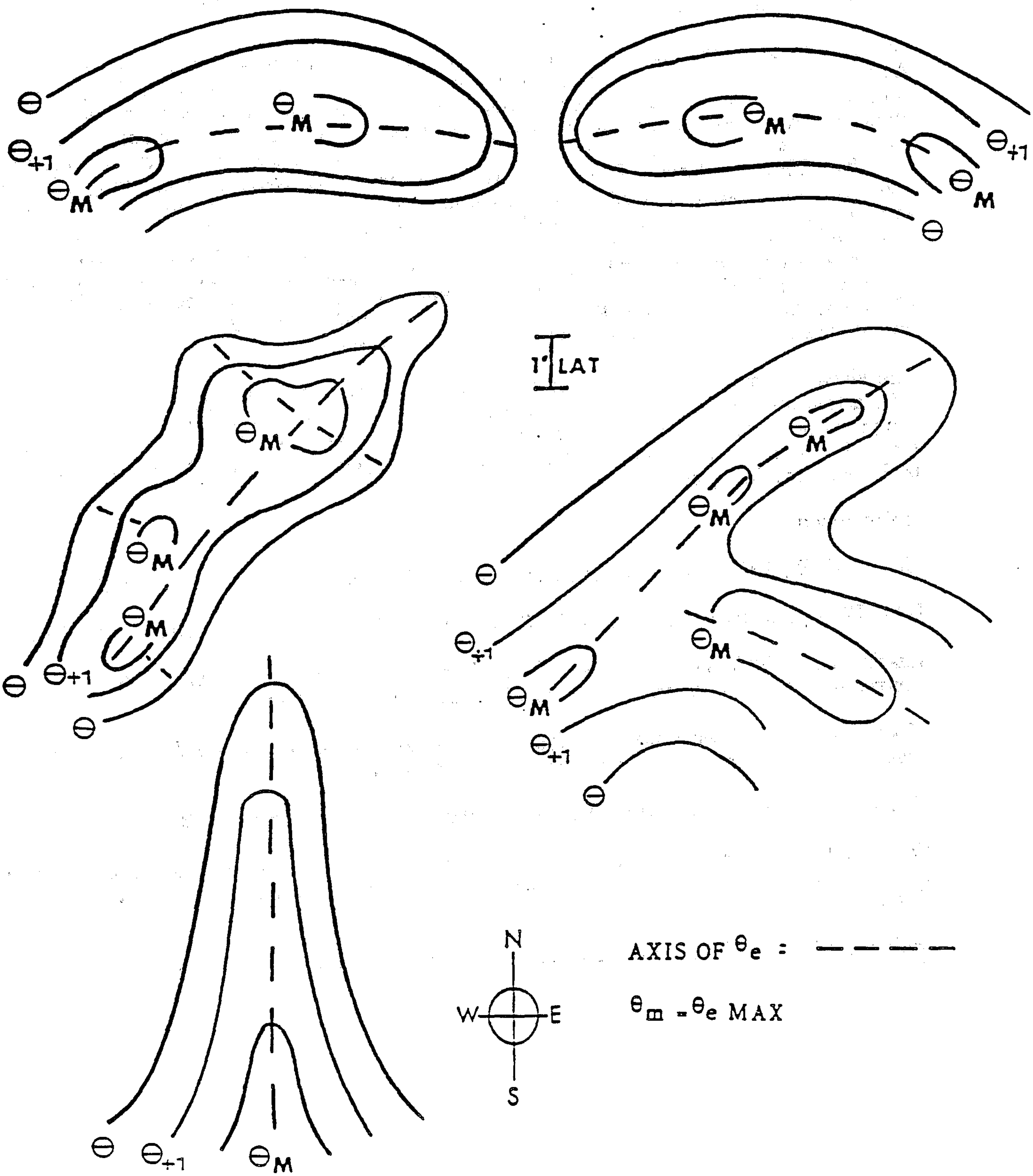


Fig. 1

ADDITIONAL θ_e PATTERNS

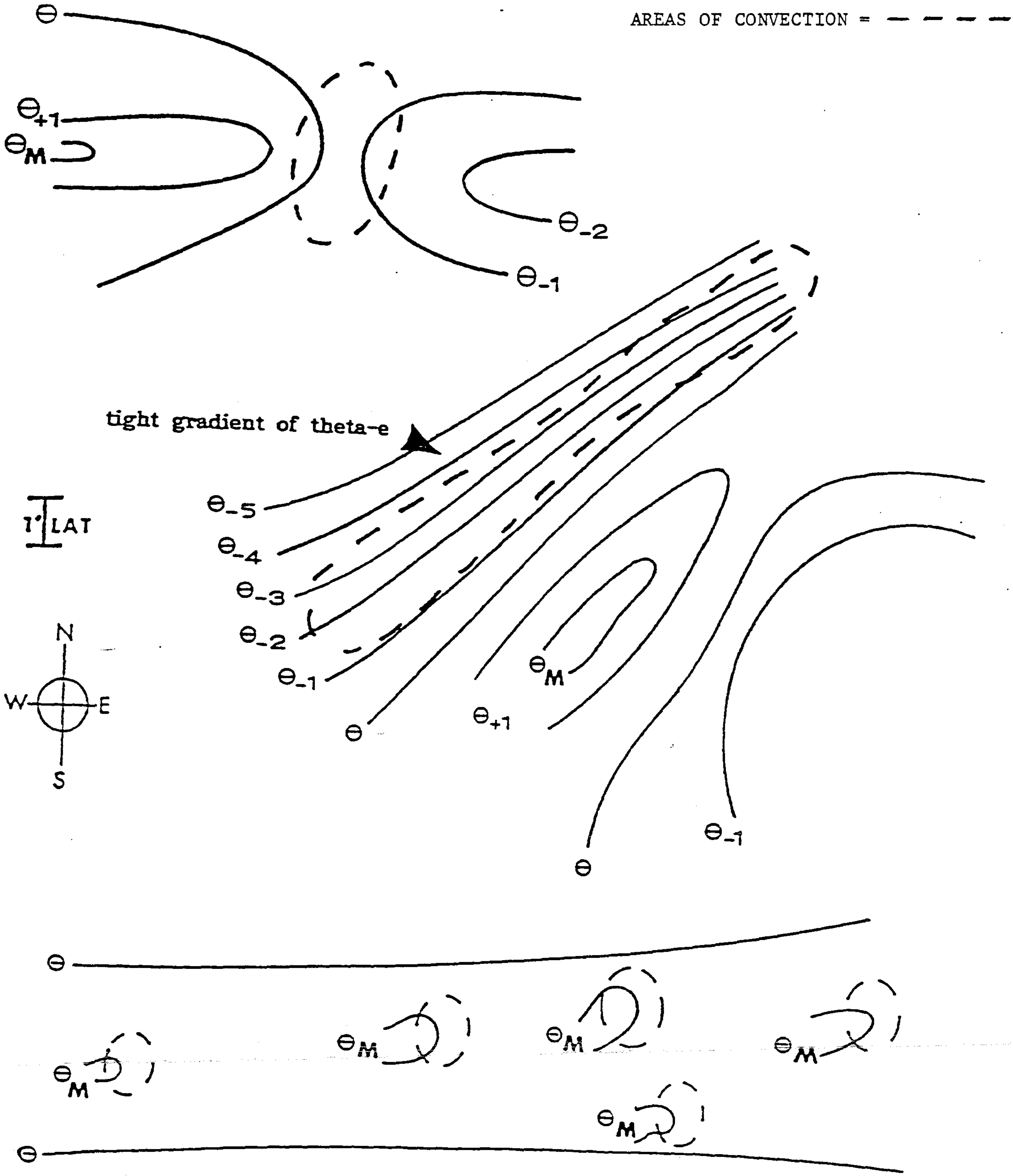
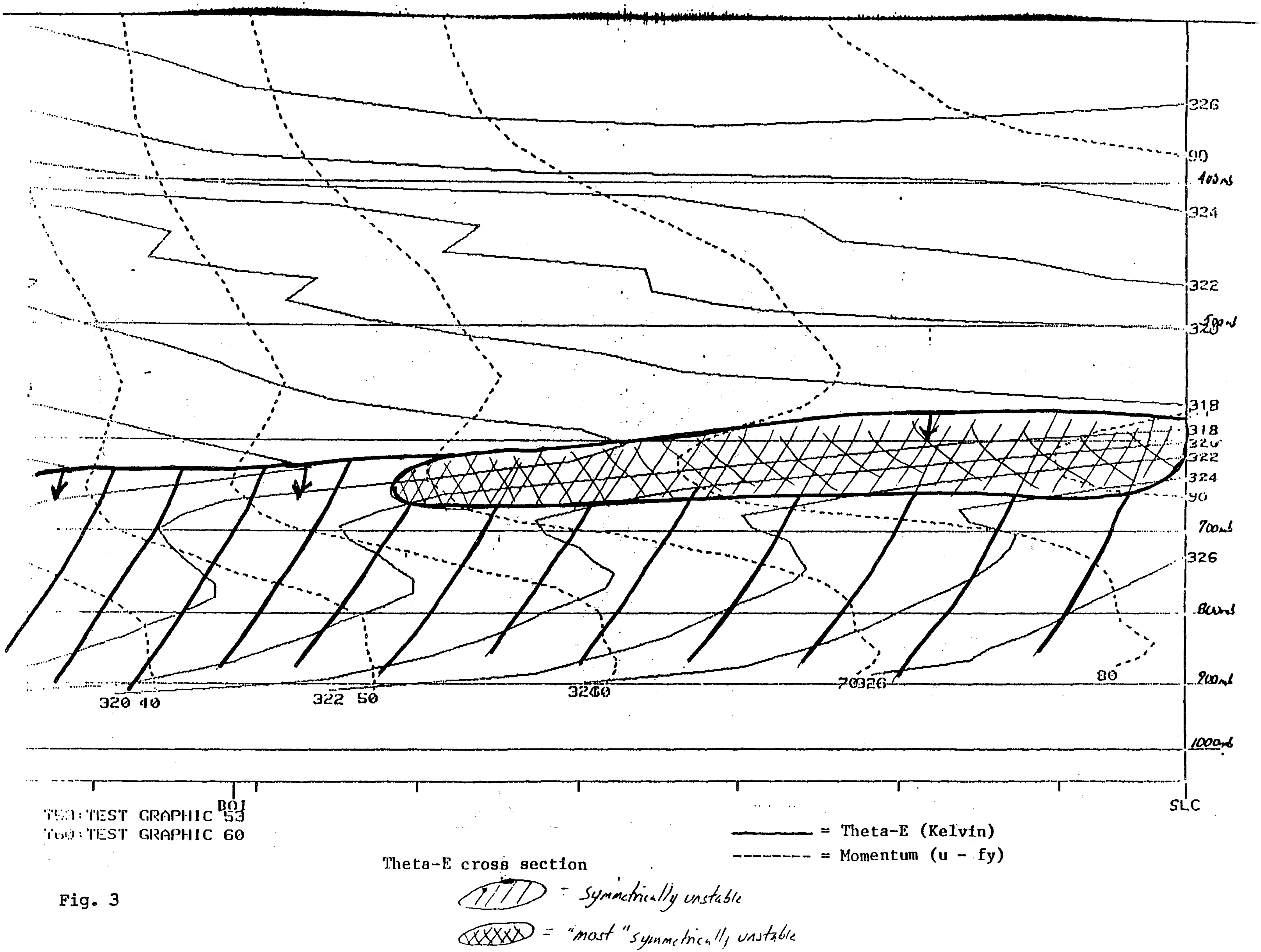


Fig. 2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322 50
3260
70326
80
BOI
SLC
T53:TEST GRAPHIC 53
T60:TEST GRAPHIC 60
= Theta-E (Kelvin)
= Momentum (u - fy)
Theta-E cross section
= Symmetrically unstable
= "most" symmetrically unstable

Fig. 3