Convective Available Potential Energy (CAPE)

Convective Available Potential Energy is the maximum energy available to an ascending, buoyant saturated parcel. On a SkewT, it's the "positive area" between the Level of Free Convection (LFC) and the Equilibrium Level (EL). This assumes no water loading (all condensate falls out immediately) and no dry air entrainment. In particular, if the layer of atmosphere is relatively dry (often using Precipitable Water as a guide), cumulus clouds could form but most will not reach thunderstorm status.

Also, it's only meaningful if a parcel can be lifted to its LFC. Therefore, a lifting mechanism must be available.

The LFC is the level a lifted parcel's temperature first becomes the same as the environment. Above the LFC, the air parcel's temperature (T_{parcel}) will be warmer than the environment temperature (T_{env}) in a finite layer. The EL is the top of that layer where T_{parcel}=T_{env} again. Above the EL, the air is negatively buoyant (T_{parcel}< T_{env}) but will overshoot until it loses its momentum by deceleration.

CAPE is expressed in units of J kg^{-1}. As a rule of thumb, the following applies:

CAPE value	Convective potential
0	Stable
0-1000	Marginally Unstable
1000-2500	Moderately Unstable
2500-3500	Very Unstable
3500 +	Extremely Unstable

You will frequently see CAPE with different kind of prefixes. The prefixes "sb", "mu", and "ml" in forecast discussion products identify which air parcels are being used to calculate CAPE. SB = the surface-based parcel, MU = the most unstable parcel found in the lowest 300 mb of the atmosphere, and ML = the mean conditions in the lowest 100 mb. In automated programs, the mean layer is often used more than surface based. MUCAPE is often a stand-alone product in case here is instability aloft, and compared to a lower-level (SB or ML) CAPE.

You may also see NCAPE (Normalized CAPE). This is CAPE that is divided by the depth of the buoyancy layer (units of ms^{-2}). Values near or less than .1 suggest a "tall, skinny" CAPE profile with relatively weak parcel accelerations, while values closer to .3 to .4 suggest a "fat" CAPE profile with large parcel accelerations possible. Normalized CAPE and Lifted Indices are similar measures of instability.

SkewT exercise

Compute CAPE for Omaha's 00Z sounding for September 5, 2016.

Calculations

In z coordinates and pressure coordinates, CAPE is

$$CAPE = \int_{LFC}^{EL} g\left(\frac{T_{parcel} - T_{env}}{T_{env}}\right) dz = -\int_{LFC}^{EL} R\left(T_{parcel} - T_{env}\right) \mathrm{dln}p$$

In applications, we have to approximate this interval. Many numerical integration techniques are available such as Simpson's Rule and the Trapezoid Method. For class purposes, we will simply perform a summation over several layers:

$$CAPE \approx \sum_{i=1}^{ni-1} g\left(\frac{\overline{T_{parcel}} - \overline{T_{env}}}{\overline{T_{env}}}\right)(z_{i+1} - z_i) \approx -\sum_{i=1}^{ni-1} R\left(\overline{T_{parcel}} - \overline{T_{env}}\right)(\ln(p_{i+1}) - \ln(p_i))$$

where $\overline{T_{parcel}}$ is the average parcel temperature in each layer and $\overline{T_{env}}$ is the average environmental temperature in each layer. The gas constant is R=287 J kg^{-1} K^{-1}, and g is gravity (9.8 ms^{-2}).

Answers:

In this exercise, we will choose coarse layers for simplicity and clarity. In reality, computer programs can perform this at high vertical resolution.

The LFC is at about 600 mb, where T_{parcel}=T_{env}=-6°C. Above, a lifted saturated is marginally buoyant. The values of the parcel and environment are shown on the graphic. The EL indicates where the buoyancy stops when T_{parcel}=T_{env} again.

The vertical levels are chosen to be 600, 500, 400, 300, and 220 mb. The procedure is to first take the average value of T_{parcel} and T_{env} in each layer. For example, between 600 and 500 mb

$\overline{T_{parcel}} = \frac{(-6)+(-14.5)}{2}$=-10.25°C=262.9°K.

$\overline{T_{env}} = \frac{(-6)+(-15)}{2}$=-10.5°C=262.65°K.

Details are in the spreadsheet. Then, for z coordinates, CAPE is approximately:

$$CAPE \approx \frac{(9.8)(262.9 - 262.65)}{262.65}(5870 - 4506.5)$$
$$+\frac{(9.8)(253.65 - 253.15)}{253.15}(7580 - 5870)$$
$$+\frac{(9.8)(240.9 - 239.65)}{239.65}(9680 - 7580)$$
$$+\frac{(9.8)(220.65 - 219.65)}{219.65}(11832 - 9680)$$

Which gives CAPE≈249 J kg^{-1}. In practical terms, this is very low CAPE and one could anticipate little convection, at least in the short-term.

CAPE is also computed in the spreadsheet in pressure coordinates. It gives a similar value of 273 J kg^{-1}.

In contrast, a sounding is also shown in the graphics for North Platte, NE on the same day and hour. A radar figure is also shown, consistent with obviously high CAPE. Can you compute its CAPE?