ATMO 352
Severe Weather and Mesoscale Forecasting
Spring 2007

Laboratory #3: NSHARP, more on CAPE, NCAPE, CIN and stability indices

Section 502, Friday
2-2-07

Due: By beginning of next lab session (2-9-07)

Introduction:

The purpose of this laboratory assignment is to 1) introduce you to NSHARP (National-Centers [AWIPS] Skew-T Hodograph Analysis and Research Program), 2) explore the variability of CAPE (and CIN) to assumptions regarding the origins of air parcels at low levels using NSHARP, 3) calculate CIN (Convective Inhibition), NCAPE (Normalized CAPE), and various stability indices such as the lifted index, K index and Total totals using NSHARP, 4) interpret all of the sounding parameters above and make a convective probability and intensity "forecast," 5) define radar reflectivity and describe how it is related to convective intensity, and 6) verify your "forecast" using animations of radar reflectivity.

Data:

1. Upper-air sounding data from Omaha, NE (OAX), Chanhassen, MN (MPX), and Green Bay, WS (GRB) at 1800 UTC (or 1300 CDT, CDT = UTC – 5 hours) on 30 May 1998.
2. Level III WSR-88D reflectivity composites (1-km resolution) over the general region covered by the soundings above.

Background:

1. CAPE – including the effects of moisture and latent heat release

In order to include the effects of a saturated air parcel and the latent heat of condensation on buoyancy, most calculations of CAPE replace the temperature (T) with the virtual temperature (T_v) in the equation presented in class. Virtual temperature is defined as the temperature at which dry air would have the same density as moist air if at the same pressure. Virtual temperature can be approximated by

$$T_v \approx T(1+0.61*w) \qquad [1.1]$$

where w is the mixing ratio. The mixing ratio (w) is essentially a ratio of the mass of water vapor to the mass of dry air in a moist air parcel. It typically has units of grams of water vapor per kg of dry air, or g kg^{-1} (see AWS TR-79 manual for a detailed review). From [1.1], we can see that $T_v \geq T$.

CAPE is then written as

$$\text{CAPE} = g \int_{Z_{LFC}}^{Z_{EL}} \left(\frac{(T_{vp} - T_{ve})}{T_{ve}} \right) dz \qquad [1.2]$$

where T_{vp} and T_{ve} represent the virtual temperature of the parcel and environment, respectively.

NSHARP utilizes an equation similar to [1.2] when calculating CAPE. The utilization of virtual temperature in [1.2] provides a more representative estimate of CAPE and is therefore routinely used for operational forecasting and research. (Note: The same is true for NCAPE and CIN).

2. CAPE – sensitivity to assumptions regarding the origins of air parcels at low levels

As you will demonstrate in this lab, estimation of CAPE is very sensitive to the origin of the air parcel and hence the near surface structure of temperature (T) and moisture (e.g., such as dewpoint temperature, T_d). The sensitivity of CAPE arises from its dependence on the Z_{LFC} and $T_{vp}(z)$ in [1.2] (i.e., or the parcel path as defined by the pseudo-moist-adiabat the parcel follows on a skew-T diagram) on the low-level T and T_d.

In lecture and lab #2, we assumed that air parcels come from a parcel originating at the surface (i.e., surface air parcel). In these calculations, CAPE is often called "surface based CAPE" or (**SBCAPE**). Since forecasters often only have a 12z (i.e., morning) sounding from which to extrapolate the days convective potential, it is often appropriate to replace the low-level surface temperature with the *forecasted* maximum temperature for the day to get a more representative estimate of CAPE.

In a well-mixed boundary layer, the assumption of an air parcel originating from the surface may not be representative. Instead, CAPE is calculated using the lowest 100 mb AGL (above ground level) mean layer temperature and moisture. CAPE calculated in this manner is often called the mean layer CAPE (**MLCAPE**) or (mean) mixing layer CAPE.

Air parcels in convective thermals may often originate at pressure levels above the surface (i.e., elevated convection). To determine the potential for elevated convection, forecasters often calculate the most unstable CAPE (**MUCAPE**). This is CAPE calculated by using a parcel from a pressure level, which results in the most unstable (i.e., largest) CAPE value possible, in the lowest 300 mb AGL. Alternatively, if the forecaster has a priori knowledge of the pressure level from where convection is expected to originate, then that pressure level (e.g., 850 mb) can be used as the originating air parcel for the estimation of CAPE.

NSHARP can calculate CAPE with any of the above assumptions regarding the origin of the air parcel.

3. CIN – Convective Inhibition

Convective inhibition is a measure of the negative area on a sounding between the surface and the LFC. CIN is the amount of work required to lift a parcel through the layer that is warmer than the parcel. The parcel must be forced upward sufficiently to overcome the negative buoyancy. This negative area is often referred to as the “lid” or “cap” because, in the absence of sufficient lifting or modification of the sounding, the negative area will prevent parcels from reaching the LFC and stop convection from triggering. As discussed in class, CIN is calculated in an analogous fashion to CAPE. However, NSHARP calculates CIN using virtual temperature to include the effects of a moist air parcel and latent heat release. As discussed for CAPE above, the origin of the air parcel will also affect the calculation of CIN.

4. Stability Indices

There are a number of different indices that estimate the convective instability or the air parcel’s virtual temperature excess over the environment. These indices are convenient and easy to compute. However, the indices should be used with caution because they attempt to estimate the full vertical instability of the thermodynamic profile with data from assumed levels. As a result, each index has its strengths and weaknesses and may be misleading in certain circumstances. We will gain more experience with these indices as we progress in the lab. Forecasters use indices as a “red flag” to identify full soundings that require further scrutiny. NSHARP computes several stability indices. In this lab, you will explore the 1) lifted index, 2) total totals and 3) K-index. Refer to the lecture notes or the reading assignment in *Chapter 5 of AWS TR-79 (Sections 5.24.0, 5.24.2, 5.24.9, 5.24.12, and 5.24.17, which can be found on pages 5-33-5.35, 5.38-5.39, and 5.42-5.43)* for definitions, explanations on how these indices are computed, and guidelines (or “rules of thumb”) for convective weather forecasting.

5. NCAPE

As discussed in lecture, Normalized CAPE (NCAPE) is calculated by dividing the CAPE by the vertical depth (Δz) over which it is integrated. Physically speaking, NCAPE is equivalent to the mean buoyancy acceleration in the layer and therefore has units of acceleration (m s^{-2}). As with CAPE, the standard definition of NCAPE integrates buoyancy from the LFC to the EL. In this case, NCAPE is useful for determining the “shape of the CAPE.” In other words, it can be used to distinguish between “long skinny” (lower NCAPE) and “short fat” (higher NCAPE) positive areas on a SKEW-T. The latter case is less susceptible to entrainment and water loading effects and therefore more associated with intense convection and severe weather. Of course, NCAPE can be calculated over any arbitrary vertical depth by changing the limits of integration of CAPE and normalizing by the appropriate depth. The vertical profile of NCAPE may be a useful tool in severe storm forecasting.

6. Radar Reflectivity

Radar reflectivity (z) is a measure of the size and amount of precipitation. For most conditions, it is the “sixth moment of the precipitation size distribution,” meaning that it is proportional to diameter of the particle size to the sixth power. More specifically, radar reflectivity can be defined as

$$z = \sum_{D\min}^{D\max} N(D) \bullet D^6 \qquad [\mathrm{mm}^6\ \mathrm{m}^{-3}]$$

Where N(D) is the precipitation concentration per size bin (i.e., particle size distribution with units of # m^{-3}) and D is the diameter (mm). Thus, the units of radar reflectivity are usually mm^6 m^{-3}). Since z can range from 0.1 to 10,000,000 mm^6 m^{-3}, radar meteorologists typically report radar reflectivity in a logarithm scale called dBZ (i.e., decibels [dB] of radar reflectivity [Z]).

$Z = 10*LOG_{10}(z)$ [dBZ]

Typical values for Z range from -10 to 70 dBZ. In general, increasing radar reflectivity indicates increasing storm intensity and precipitation amounts.

Loading Case Study Data into NSHARP:

To load archived case study data for this lab exercise, please follow the following instructions:

1. select load
2. select observed soundings
3. select file
4. select uair
5. place your cursor in the "filter" box and delete the directory path
6. replace the above path with "/h/metr352/cases/spencer/" and enter
7. select (double-click) on the "/h/metr352/cases/spencer/upperair" directory from the list
8. select (highlight) the file "smot12105980530_upa.gem" for data from 5/30/1998.
9. select OK
10. select the appropriate date time, "980530/1800"
11. select the appropriate "red diamond" for the upper air sounding site you require in the CONUS map to the right

NOTE: You may find the following NSHARP overview useful for interpreting various aspects of the display and output - http://www.unidata.ucar.edu/software/gempak/tutorial/nsharp.html

Exercises: (100 points)

1. *(18 points)* Load sounding data from OAX on 30 May 1998 from 1800 UTC into NSHARP. Using NSHARP, estimate the CAPE using 1) current surface conditions, 2) forecasted surface conditions, 3) mean mixed layer and 4) most unstable conditions. How different are the four estimates of CAPE? Explain the differences based on the properties of the low-level sounding. Repeat the procedure but for the MPX and GRB soundings. Place all of your results for OAX, MPX and GRB in a table for easy comparison. Comment on the values at each location. Are they low, moderate or high?
2. *(6 points)* In your own words, describe the lifted index, total totals index and k-index.
3. *(16 points)* Using NSHARP, construct tables that contains the lifted index (LI), total totals index (TT), k-index, and 700-500 mb ΔT for OAX, MPX, and GRB. Comment on the values at each location. Note that the lifted index (LI) will vary as a function of

parcel assumption (see #1), because it includes the *parcel's* temperature. You should record LI for each parcel type listed in #1 above.

4. *(4 points)* Using data provided by NSHARP, calculate NCAPE from the LFC to the EL in units of m s^{-2} for each sounding (OAX, MPX, and GRB). Use the "most unstable" parcel in your calculation.
5. *(12 points)* Provide a brief forecast of convective potential and likely intensity after 18z given the results in #1, #3, and #4 above for the regions surrounding OAX, MPX and GRB. Justify your forecast using known rules of thumb and the results from #1, #3, and #4 above.
6. *(6 points)* Load garp for this case. In a terminal window, type and enter "Spencer" first then execute "garp" as you did before. In GARP, load a loop (animation) of LEVEL III radar reflectivity composites (1 km resolution) from about 30/2200z to 31/0200 z. To make this go faster, load the animation with about 1 hour of data at a time (roughly 5-6 frames or files). Describe what you see in the radar reflectivity loops in the vicinity of OAX, MPX and GRB. You will want to zoom into the vicinity of South Dakota, Minnesota, and Wisconsin. What convection developed in each region? What are typical and maximum values of radar reflectivity in each region?
7. *(8 points)* By assuming 1) $V_t \sim D^{1/2}$ where V_t is the terminal fall speed and D is the diameter of a precipitation particle and 2) a balance level argument (i.e., the particle is balanced by the updraft, w, or $V_t = w$), show that $z \sim w^{12} \sim CAPE^6$, where z is radar reflectivity as defined above. This demonstrates that radar reflectivity, updraft strength and CAPE are positively correlated. A small change in CAPE should result in a large change in radar reflectivity. Radar reflectivity is typically reported in units of dBZ, where $Z = 10*\log_{10}(z)$. Using the above relation, a doubling of CAPE should increase the radar reflectivity (Z) by how much (dBZ)?
8. *(8 points)* Assuming radar reflectivity is positively correlated to updraft strength and CAPE as shown in 7 above, use the radar reflectivity to validate your "forecast" from #5 above. What index (CAPE, LI, TT, K-index, 700-500 mb ΔT) worked and what did not for each locale? How did your forecast do?
9. *(9 points)* Use NSHARP, to calculate the CIN for each sounding (OAX, GRB, MPX) at 18z using the four different parcel methods (current surface, forecast surface, mean layer, and most unstable. Explain why CIN also varies with the parcel method used. Construct a table and comment on the values of CIN (low, moderate, high) at each location.
10. *(6 points)* By using the interactive aspect of NSHARP (i.e., click and drag temperature and dewpoint values to change), demonstrate how the low-level sounding (i.e., in the low-level moist layer below the cap) can be modified to overcome the negative buoyancy represented by CIN in the OAX sounding? Describe and explain what you find. What are the implications of CIN for convective triggering? Assuming CIN was overcome in the manner demonstrated above, about what value of CAPE would result and what are the implications for convective intensity?
11. *(7 points)* Following from the prior question, list two primary aspects of the temperature profile that can be modified to increase or decrease CAPE. Explain how the change in temperature profile increases or decreases CAPE by using the definition given above. List potential meteorological processes that could cause each type of change.