National Oceanic and Atmospheric Administration
U.S. Department of Commerce

JetStream Max: Severe Weather

Properties

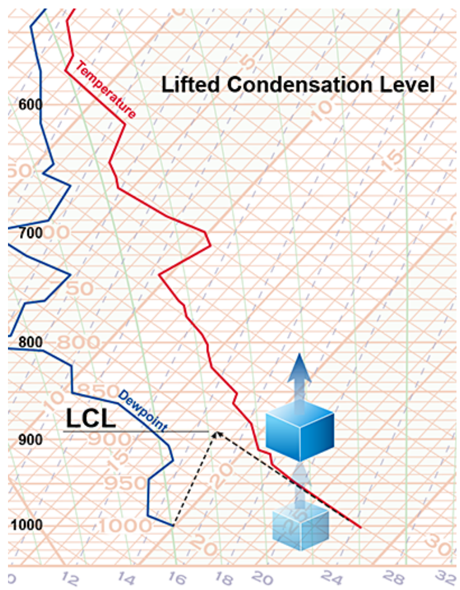
One of the primary functions of the radiosonde observation is to determine the stability of the atmosphere as this directly impacts the development of thunderstorms and tornadoes. There are many different properties and indices that provide a picture of the stability of the atmosphere that can be obtained via a Skew-T plot of a radiosonde observation.

Lifting Condensation Level (LCL)

A parcel with a humidity of less than 100% will cool at the dry adiabatic rate of 9.8°C/Km as it lifts from the surface. As it cools, the humidity will increase until it reaches 100%. The altitude at which the parcel reaches saturation when lifted dry adiabatically is called the lifting condensation level.

Therefore, the height of the LCL is dependent upon the surface moisture. As humidity increases, the height of the LCL decreases because it does not need to rise as much to become saturated. Conversely, drier conditions mean the LCL will occur higher in the atmosphere.

To obtain the LCL, start with the surface temperature and follow the dry adiabat on a Skew-T plot until it crosses the saturation mixing ratio of the surface dew point.



LCL CCL CT LFC

Convective Condensation Level (CCL)

The CCL is similar to the LCL and, under certain conditions, may even be the same. It is the height at which a parcel of air, specifically when heated from below (as opposed to force lifted by a front), will rise adiabatically until it is saturated (humidity equals 100%). This is the level of the flat bases of cumulus clouds. To obtain the CCL, start with the surface dew point and follow the saturation mixing ratio line up until it crosses the temperature curve.

Convective Temperature (CT)

This is the surface temperature at which convective clouds will begin to form from heating of the ground. To obtain the CT, begin at the convective condensation level (CCL) and follow the dry adiabat down to the surface level and read the temperature at that point.

Level of Free Convection (LFC)

LFC is the level at which a parcel of saturated air becomes warmer than the surrounding air and begins to rise freely. This refers back to buoyancy of the parcel, where if a parcel of air becomes warmer than the surrounding air mass, it will continue to rise until it cools to the same temperature as the air around it. The LFC is the level at which a rising parcel will continue to rise on its own without any additional force acting upon it.

To obtain the LFC, begin at the Lifting Condensation Level (LCL) and follow the moist adiabat up to where it intersects the temperature line. There are times when no LFC will occur as the parcel will always remain cooler than the surrounding atmosphere and therefore will never rise freely. When this occurs, the atmosphere is absolutely stable.

Stability Indices

Some of the more common stability indices are presented below, but caution is to be taken with all of these values as they represent conditions only at the time of observation. They are not necessarily predictive in nature. A radiosonde observation showing an unstable atmosphere does not necessarily imply thunderstorms will occur soon or at some time later.

Additionally, most of these indices are dependent upon the amount of moisture at specific pressure levels and may not necessarily provide a full understanding of the atmosphere's total moisture. There will be times when the moisture at 850 mb is very low, but just below this level, it's abundant. The dryness of the 850 mb level will suggest a more stable atmosphere and not provide a truer image of actual greater instability.

These are fairly rudimentary indices that have been around for decades. In the past 15 or so years, additional research has provided more refined indices that better identify storm initiation, structure, type, motion, and evolution of severe and tornadic thunderstorms. These advanced indices require knowledge and training that goes well beyond the scope of JetStream.

To learn about some of the more advanced indices, visit the Storm Prediction Center's Hourly Mesoscale Analysis help page and Sounding Help page.

Showalter / Lifted Indices

Likely the first published index for severe weather, A. K. Showalter developed his stability index (SI) in 1948 based upon two layers in the atmosphere, the 850 mb level and the 500 mb level. The SI is the difference between the temperature at the 500 mb level and the temperature of a parcel at 500 mb when lifted from the 850 mb level.

Stability	Showalter Index	Lifted Index
Stable	> 0	> 0
Slightly Unstable - Thunderstorms possible	-1 to -3	-1 to -3
Unstable - Thunderstorms probable	-4 to -6	-4 to -7
Extremely Unstable - Severe Thunderstorms possible	≤ -7	≤ -8

The Lifted index (LI) is similar to the Showalter Index, but the LI compares the 500 mb temperature to a parcel lifted from the surface instead of from the 850 mb level. Since the Lifted Index is highly sensitive to the surface temperature, which varies from night to day, it is best found using the forecast afternoon temperature and dewpoint.

Both of these indices are limited. They measure only one portion of the atmosphere, below about 18,000 feet (5,500 meters), and at discrete levels, but the air temperature and moisture content may be quite different at other levels between 500 mb, 850 mb, and the surface. Because of this, these indices can paint an incomplete picture of the atmosphere.

Totals Indices

Vertical Totals - This is the difference between the air temperature at 850 millibars (about 5,000 feet) and the air temperature at 500 millibars (about 18,000 feet). VT = T_{850} - T_{500}

Cross Totals - This is the difference between the dew point at 850 millibars and the air temperature at 500 millibars. CT = $T_{d(850)}$ - T_{500}

Total Totals - This is the sum of the **Vertical Totals** (T_{850}-T_{500}), and the **Cross Totals** ($T_{d(850)}$ - T_{500}), so that the sum of the two products is the total totals.

Thunderstorm occurrence
WEST of the Rockies
EAST of the Rockies

	Cross Total (CT)	Total Total (TT)	Vertical Totals (VT)	Cross Total (CT)	Total Total (TT)
Thunderstorms unlikely	<28	<48	≤25	<18	<44
Isolated or few thunderstorms	29-32	48-51	≥26	18-19	44-45
Scattered thunderstorms	52-54	≥33	≥26	20-21	46-47
Scattered thunderstorms (Isolated Severe)	≥33	55-57	≥26	22-23	48-49
Scattered thunderstorms (a few severe) w/Isolated Tornadoes	≥33	58-60	≥26	24-25	50-51
Scattered to Numerous thunderstorms (a few severe) w/Few Tornadoes	≥33	61-63	≥26	26-29	52-55
Numerous thunderstorms (scattered severe) Scattered Tornadoes	≥33	≥64	≥26	≥30	≥56

K-Index

This is a measure of thunderstorm potential based on the temperature difference between 850 mb and 500 mb, the dew point at 850 mb, and the difference between the temperature and dew point at 700 mb (called the dew point depression). The higher the K-index, the greater likelihood of thunderstorm development.

$K = T_{850} - T_{500} + T_{d\ (850)} - (T_{700} - T_{d(700)})$

Although the K-index values correlate to the probability of thunderstorm development, the values will vary by season, location, and overall weather patterns.

K-Index	% Probability of Thunderstorms
≤ 14	Zero
15 - 20	20%
21 - 25	20-40%
26 - 30	40-60%

31 - 35	60-80%
36 - 40	80-90%
≥ 41	near 100%

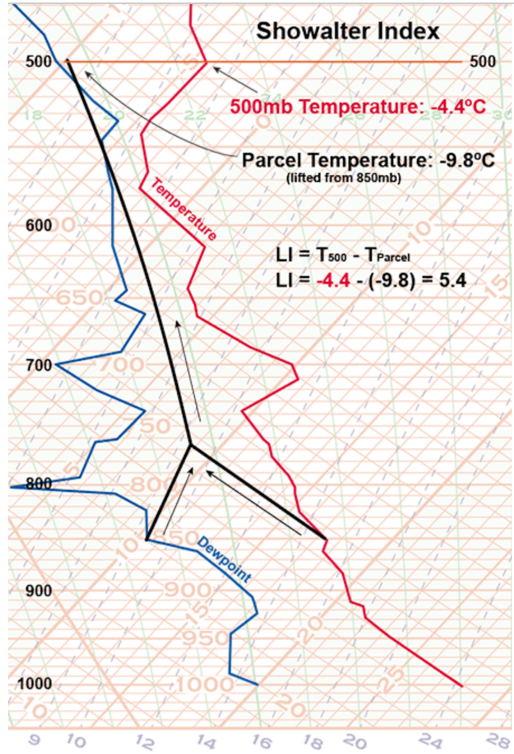
SWEAT Index

Developed by the U.S Air Force, the **S**evere **Wea**ther **T**hreat **Index** is used to estimate the potential for severe weather (not ordinary thunderstorms). The SWEAT Index looks at the amount of moisture at the 850 mb level, the Total-Totals Instability, the wind speed at both 850 mb and 500 mb, as well as how the wind direction changes between these two levels.

Its primary use is to help distinguish severe thunderstorms from non-severe thunderstorms. The main difference is the addition of the change in wind direction with height to the equation. If there is little change in the wind direction with height, then any precipitation that develops will fall back into the updraft, thereby leading to a short life span of the storm and making it less likely to be severe.

With veering winds (wind direction that changes with height in a clockwise motion), precipitation will fall away from the updraft, allowing the storm to continue to develop and possibly become severe.

SWEAT values >300 means severe thunderstorms are possible. SWEAT values >400 means thunderstorms with tornadoes are possible.



SI LI VT CT K CAPE

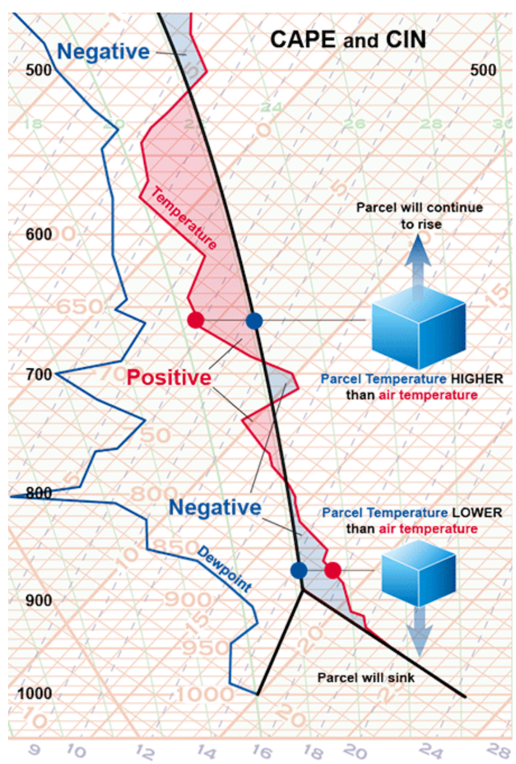
CAPE

The difference between the air temperature trace from the radiosonde observation and the moist adiabat trace of a rising parcel is an indicator of the buoyancy of the atmosphere.

If the parcel temperature is greater than the air temperature at any particular level, it is said to have positive buoyancy and will continue to rise. The warmer an air parcel is compared to the air around it, the faster it will continue to rise on its own.

Conversely, if the parcel temperatures become lower than the surrounding atmosphere, then the parcel's upward motion will be inhibited. If the parcel remains in a region where it is colder than the surrounding environment, then its upward motion will cease altogether. When mapped on a Skew-T plot, the positive areas are often shaded red and the negative areas are shaded blue.

The term for these positive areas is **CAPE**, which stands for **C**onvective **A**vailable **P**otential **E**nergy. CAPE represents the potential energy per kilogram a lofted air parcel contains. Another way of looking at it is the energy that would be expended if the parcel were raised above the LFC. Unlike the above indices, which are unit-less numbers, CAPE has units of measurement in joules per kilogram of air (J/kg).



Positive (red) and negative (blue) areas respectively represent CAPE and CIN on an atmospheric sounding.
Download Image

Convective **In**hibition (**CIN**) refers to the negative (blue) areas on a sounding. Also called 'negative CAPE', CIN is the amount of energy needed to overcome the negatively buoyant energy in the atmosphere. As CIN increases, more energy is needed to overcome the negative area(s) in the atmosphere and, therefore, inhibits the growth of cumulonimbus clouds that produce thunderstorms.

This is primarily where the term conditional instability comes into play. The atmosphere may be very unstable in the middle elevations (10,000 to 25,000 feet; 3,000 to 7,600 meters), as indicated by a large CAPE value. However, in the lower atmosphere below about 5,000 feet (1,500 meters), a strong inversion (called a “cap”) may be present, indicated by a large CIN value.

The atmosphere's instability is based on the potential for an air parcel to be successfully lofted through the cap, allowing the parcel to rise on its own thereafter. When this occurs, it is referred to as "breaking the cap".

CAPE Value	Convective Potential
< 1000	Weak Instability
1,000-2,499	Moderate Instability
2,500-3,999	Strong Instability
≥ 4,000	Extreme Instability

In other words, if enough energy is added to the lower layer of the atmosphere to overcome the negative buoyant energy, then a parcel will be able to rise into the unstable portion of the atmosphere. The two most common ways this happens is (1) from the Sun heating the Earth’s surface and the lower levels of the atmosphere, which in turn, adds energy to the air near the surface or (2) along a boundary such as a front where air is forced up into the unstable portion of the atmosphere.

These two values, CAPE and CIN, are typically the most referred to variables concerning how great a threat of thunderstorms exist and their severity.

Last updated June 2, 2023