Skew-T Plots for Soaring Pilots

How I use Skew-T plots

Sit up front. Numbers on graphs are hard to see

To be technically correct...

"**Skew-T / Log-P** plot"

T is for temperature

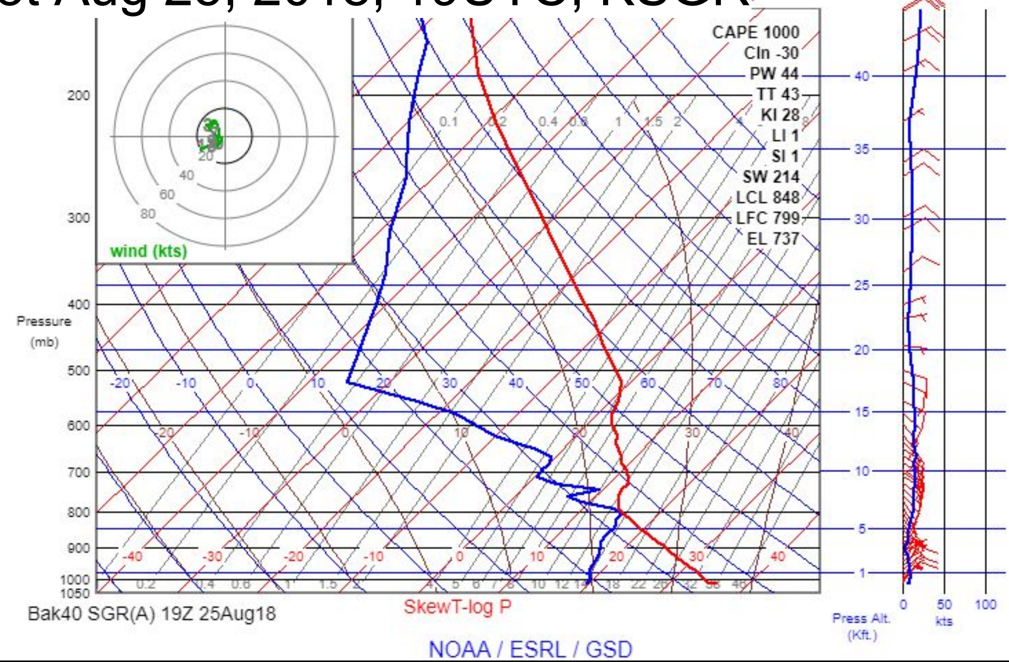
P is for pressure (height)

Get out a tablet if you have one.

Go to rucsoundings.noaa.gov

Skew-T plot Aug 25, 2018, 19UTC, KSGR

Go to rucsoundings.noaa.gov



What a mess!
What do all the lines mean? Don’t worry, you’ll be an expert in no time today.

Motivation

Being able to read skew-t charts will help tell you:

- If there will be thermals
- The height and strength of the thermals
- If there will be marker clouds
- If it will be blue
- If there will be cirrus clouds that shut down or retard thermal formation
- If there will be a stratus deck of clouds and at what height
- Wind direction and strength in each level of the atmosphere
- If there will be streeting

Physics of air parcels with different temperature

Sun + dark ground => warmer air

Warmer air is less dense than surrounding cooler air

Cooler air pushes warmer air upwards

(The warmer air becomes “buoyant”)

Ideal gas law:

$PV = nRT$

P=Pressure, V = Volume, n = # of moles, R = gas constant, T = Temperature in Kelvin

Pressure, volume, and temperature are related. As pressure decreases, volume increases and/or temperature falls

This doesn’t explain the entirety of why we get thermals. Need to know about lapse rates and stable and unstable air.

Warm air rising -> thermals??

Some days, the sun shines, but no thermals. How can that be?

When does the rising air stop rising? Why?

Warm air rises

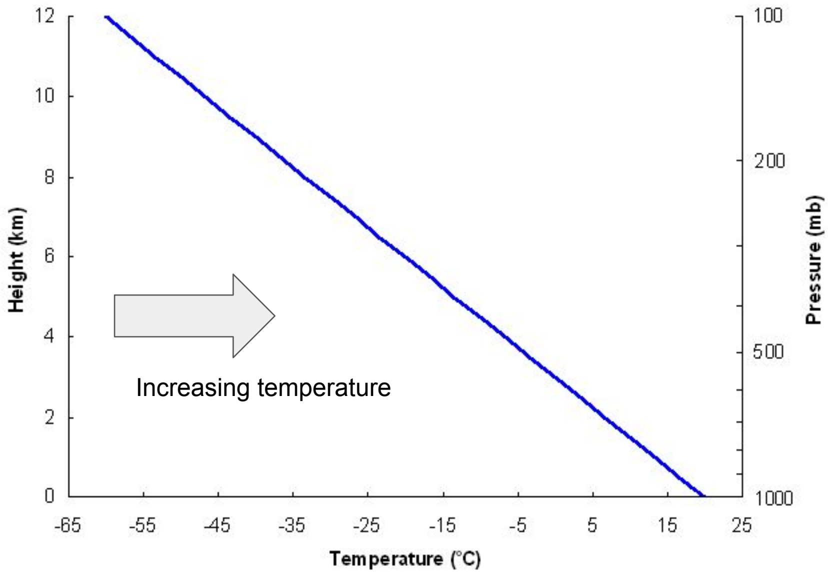
As it rises, it expands

Expanding air cools

Air farther up is cooler...

We still don't have all the knowledge we need to untangle the story of thermals. By the way -- what is heat? (Motion of atoms. More motion, more heat. More heat/motion in a gas -- less dense.)

Air temperature decreases with height (pressure)



Lines of equal temperature on this graph are vertical.

Lines of equal height are horizontal.

Standard atmosphere: the temperature decreases with height (blue line).

Not to a skew-t plot just yet!
Explain vertical and horizontal axis

What is a sounding?

A sounding tells us:

- Temperature at each level of the atmosphere
- Dew-point at each level of the atmosphere (humidity)
- Strength and direction of winds at each level of the atmosphere

A sounding can be from:

- Actual real-life data (weather balloon)
- A forecast sounding (column of air in a computer forecasting model)

We are mostly interested in forecast soundings

Sounding -> graph it!

A sounding can be displayed on a

(1) Simple temperature and pressure graph like we just saw, or...
(2) A skew-T/log-P plot/graph
    (a) Same basic thing, but a bit different in one key way
    (b) More lines to help interpretation

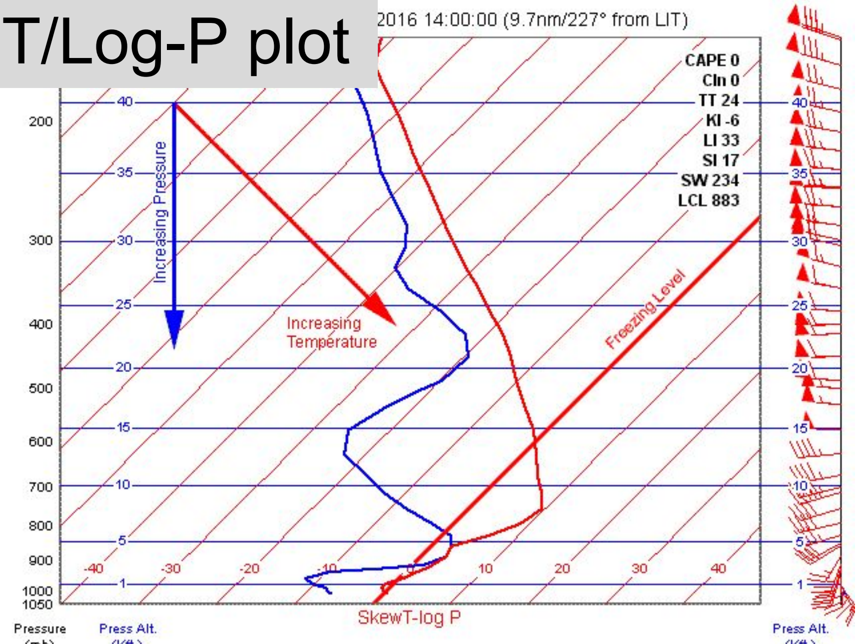
Skew-T/Log-P plot

Isobars (lines of equal pressure) BLUE horizontal

Log-P Logarithmic pressure scale (not linear) on vertical axis

Isotherms (lines of equal temperature) RED slanted

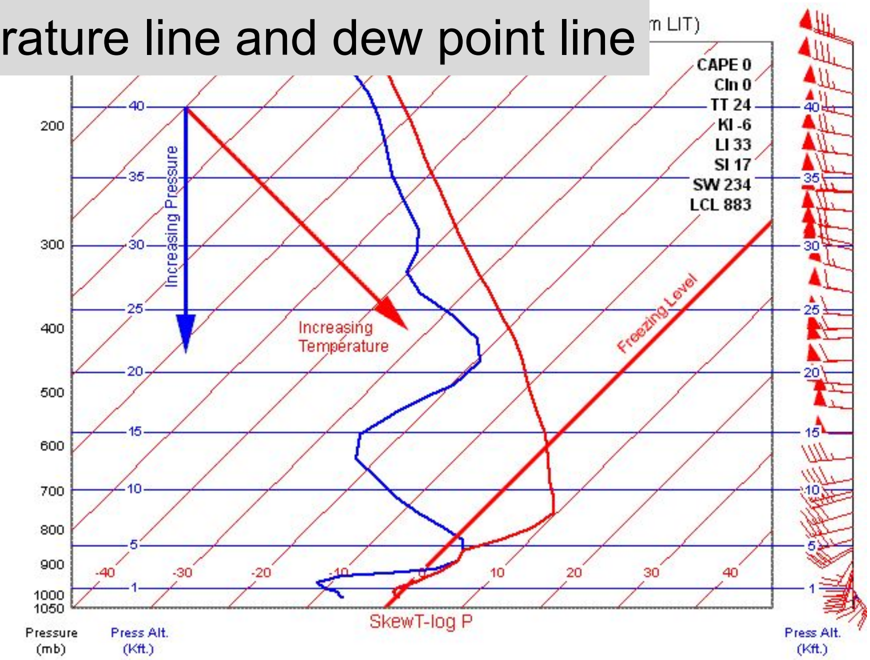
Wind barbs on right



Isotherm (lines of equal temperature) RED slanted

Ignore blue and red thick lines for now.
Lines of equal temperature on a skew-t plot are slanted. Why? To fit more of the sounding lines on a smaller graph as a standard lapse rate causes temperatures higher in the atmosphere to be much colder than temperatures lower in the atmosphere
Show Isobars
Show Isotherms
Which way is higher pressure (lower height)? [down]
Which way is higher temperature? [downward and to the right]

Temperature line and dew point line



Thick red line is temperature
Thick blue line is dew point
What is the definition of dew point? Temperature at which air becomes saturated with water vapor and condensation occurs (clouds, dew, fog)
What is the temperature of the air at the ground? 0 C
What is the dew point of the air at the ground? -8 C

What do you think happens at 4k feet on this day? [Clouds form -- blue line touches red line, indicating air will be 100% saturated]
Where would a cup of water freeze in this atmosphere? [at/near ground, above 14k feet]

Geek’s note - Why Skew-T/Log-P plot

The Skew-T, Log-P diagram is preferred because:

- (a) most of the important isopleths are straight rather than curved,
- (b) the angle between the adiabats and isotherms is large enough to facilitate estimates of the stability,
- (c) the ratio of area on the chart to thermodynamic energy is the same over the whole diagram,
- (d) the vertical in the atmosphere approximates the vertical coordinate of the diagram (i.e. the isobars are plotted to a logarithmic scale and pressure in the atmosphere decreases nearly logarithmically with height), and
- (e) an entire sounding to levels in the stratosphere can be plotted on one chart.

Lynn McMurdie

Isopleth => a line on a map connecting points having equal incidence of a specified meteorological feature.

Thermals, part II

Sun heating a dark patch of ground, causing air above to warm...

Warm air rising…

Rising air expands and cools (how fast does it cool? Next slide)

But what is temperature of surrounding air once the thermal rises 100 feet, 500 feet, 1000 feet, 2000 feet, …. ?

When does that rising air stop rising?

When does that rising air stop rising? Being able to answer this question helps us answer if there will be thermals and if the day will be soarable.

Lapse rate

Adiabatic Lapse Rate: **How fast a parcel of air cools** as it is lifted to a higher position in the atmosphere

- No mixing of air with surrounding air → no heat mixing → “adiabatic”

Dry adiabatic lapse rate: How fast unsaturated air cools as it is lifted

Moist (Saturated) adiabatic lapse rate: How fast saturated air cools as it is lifted

Varies with pressure (height). Dry lapse rate is much faster than moist lapse rate in lower 10k or 15k feet of atmosphere (**Dry: 3 °C per 1000’ / 5.38 °F per 1,000’ Saturated: 1.5 °C per 1000’ / 2.7 °F per 1,000’**)

To understand when the air will stop rising, we need to understand the concept of lapse rates

Geek’s note

“The moist adiabatic lapse rate is less than the dry adiabatic lapse rate because as vapor condenses into water (or water freezes into ice) for a saturated parcel, latent heat is released into the parcel, mitigating the adiabatic cooling.”

http://apollo.lsc.vsc.edu/classes/met130/notes/chapter6/dry_moist.html

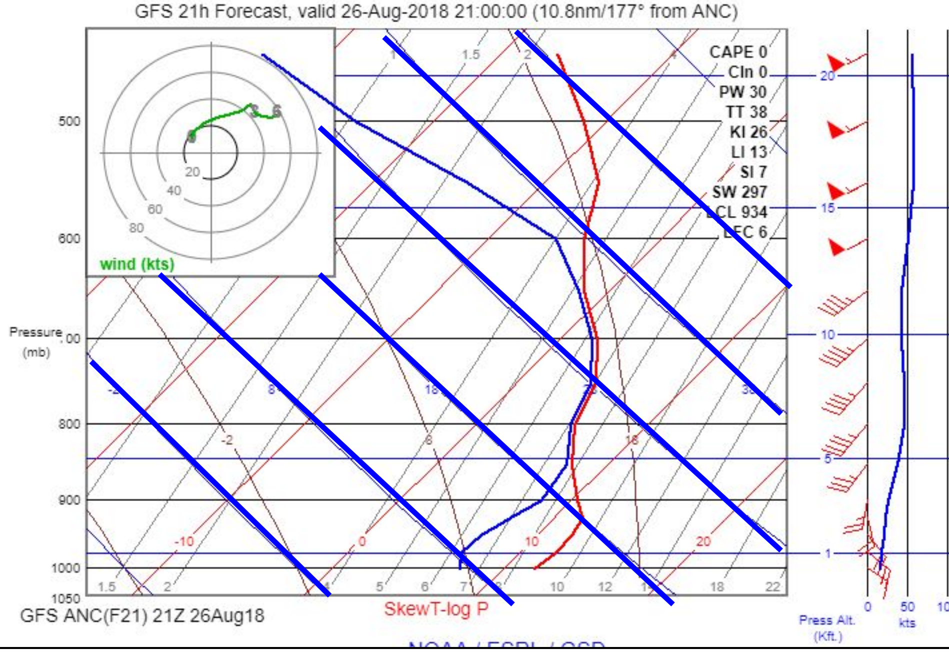
Extra credit: Why is latent heat released into the parcel?

“Parcel” -> parcel of air

Dry lapse rate lines on skew-T plot

Blue lines slanting downward right

(upward left)



If parcel of air is lifted, what rate it cools off at as it is lifted? Dry Adiabatic Lapse Rate

What lifts air again? Surrounding air that is more dense (cooler) pushing it up.

Anchorage airport. Say we're at the ground and a parcel of air is heated and starts rising. When does it stop?
Heated air (moving right at bottom of graph from end of red line). Rising up parallel to blue dry adiabat.
Ans: it stops really soon because surrounding air is as warm as rising air.

Warm air rising -> thermals??

Air rises if it is lifted.

Warmer air is displaced (pushed up) by cooler air. 100 degree air vs 90 degree air.

Warmer air is said to be “buoyant”

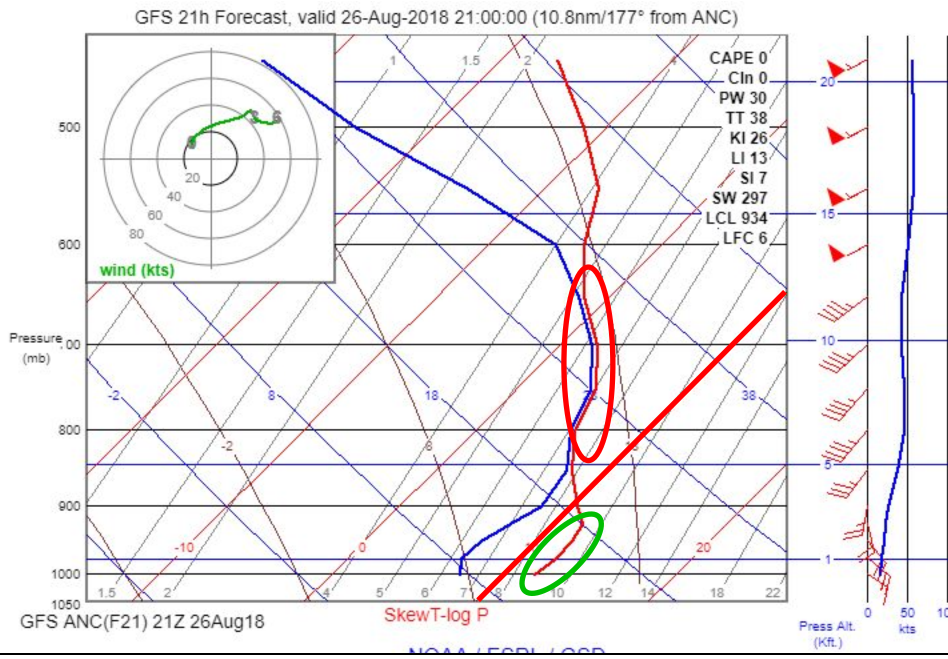
When does the rising air stop rising?

When does rising air lose its buoyancy?

Air does not have buoyancy when it reaches air that is at the same temperature. Rising air may have enough speed (thus momentum) and keep going for a while after same temperature is reached.

Stable air

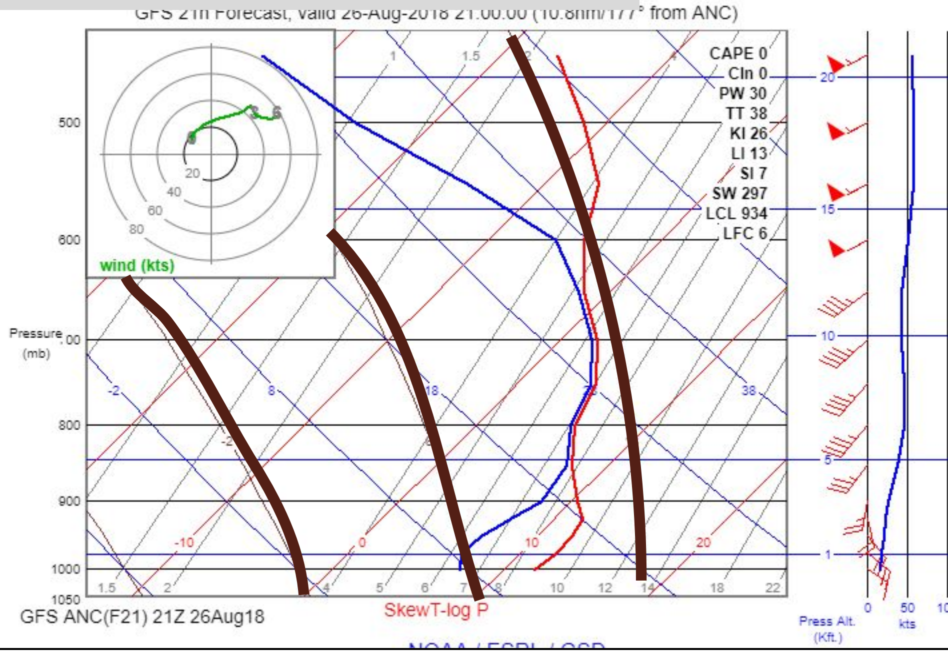
What happens if the sun shine gets to the ground on this forecasted day (will it? -- why?) and that heats a parcel of air? Thermals?



Why no sun? Cloud layer probable at 5k-12k due to dewpoint close to temperature of air.
Why no thermals? Stable air in lower part of atmosphere.
Air will rise at dry adiabatic lapse rate (parallel to dry adiabat lines) and lose buoyancy immediately.
Isothermic air in lower 2.5k of atmosphere. Temperature stays the same (roughly) for first ~2.5k feet.

Saturated lapse rate lines on skew-T plot

Brown lines starting at bottom and curving upward and to the left



We'll see how and when these saturated lapse rate lines work in a couple of slides. But first we need to know about mixing lines -- they tell us when an unsaturated parcel of air becomes saturated as it is lifted

Mixing lines

How do we know when a rising parcel of air becomes saturated?

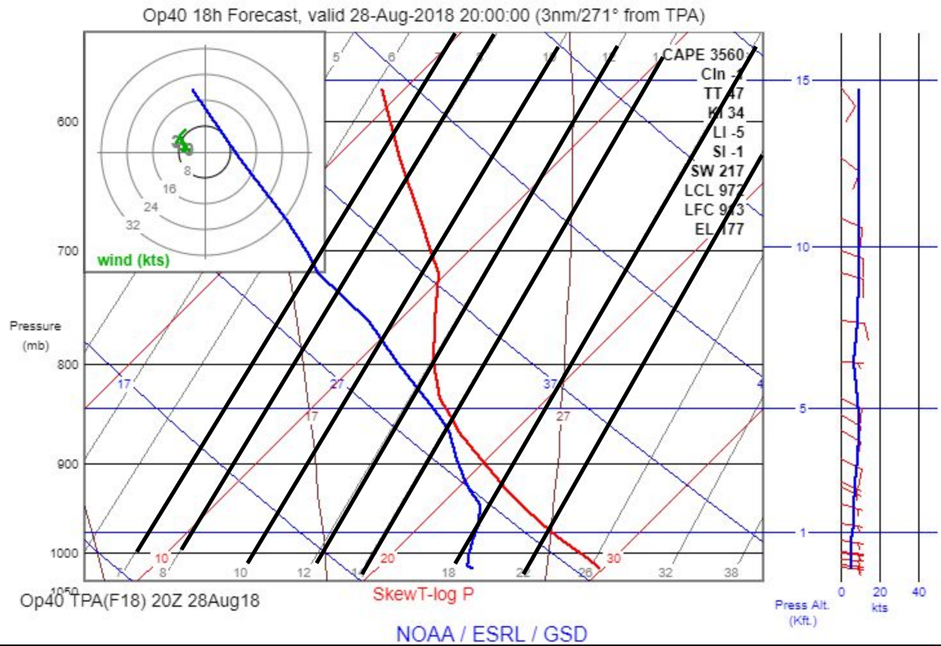
Use the “mixing lines”

Black lines lower left to upper right.

Start from the surface dewpoint temperature.

When line parallel to mixing line intersects rising parcel of air, air becomes saturated and clouds form.

Then, air rises at moist lapse rate!!!



A parcel of air that is heated at the ground and starts rising will keep going to at least 3k feet

Next slide demonstrates the use of the mixing line.

Unstable air

Tampa, FL

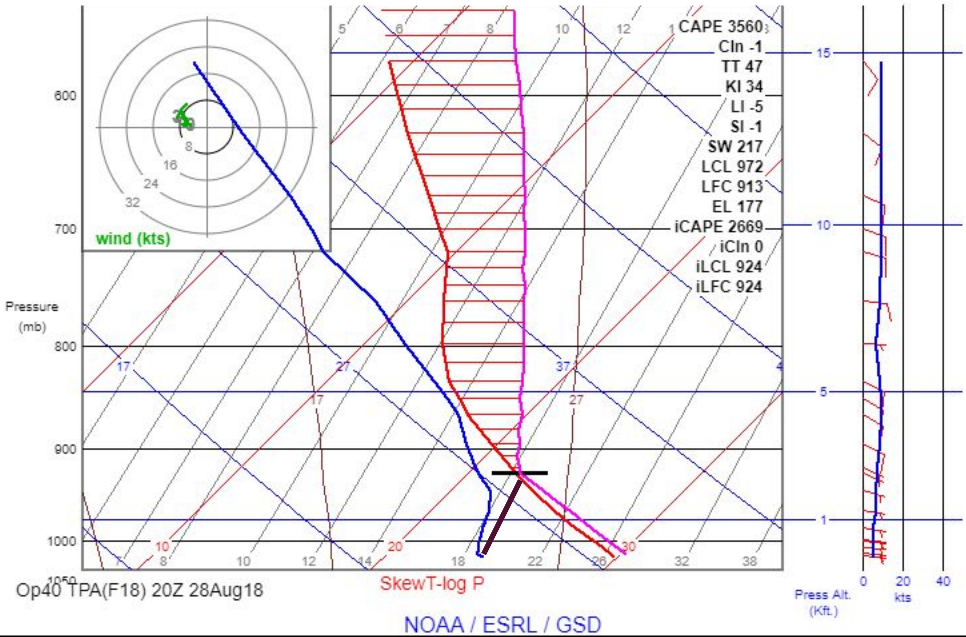
Mixing line

Dry -> Moist

Then what happens?

Good soaring?

Thunderstorms!



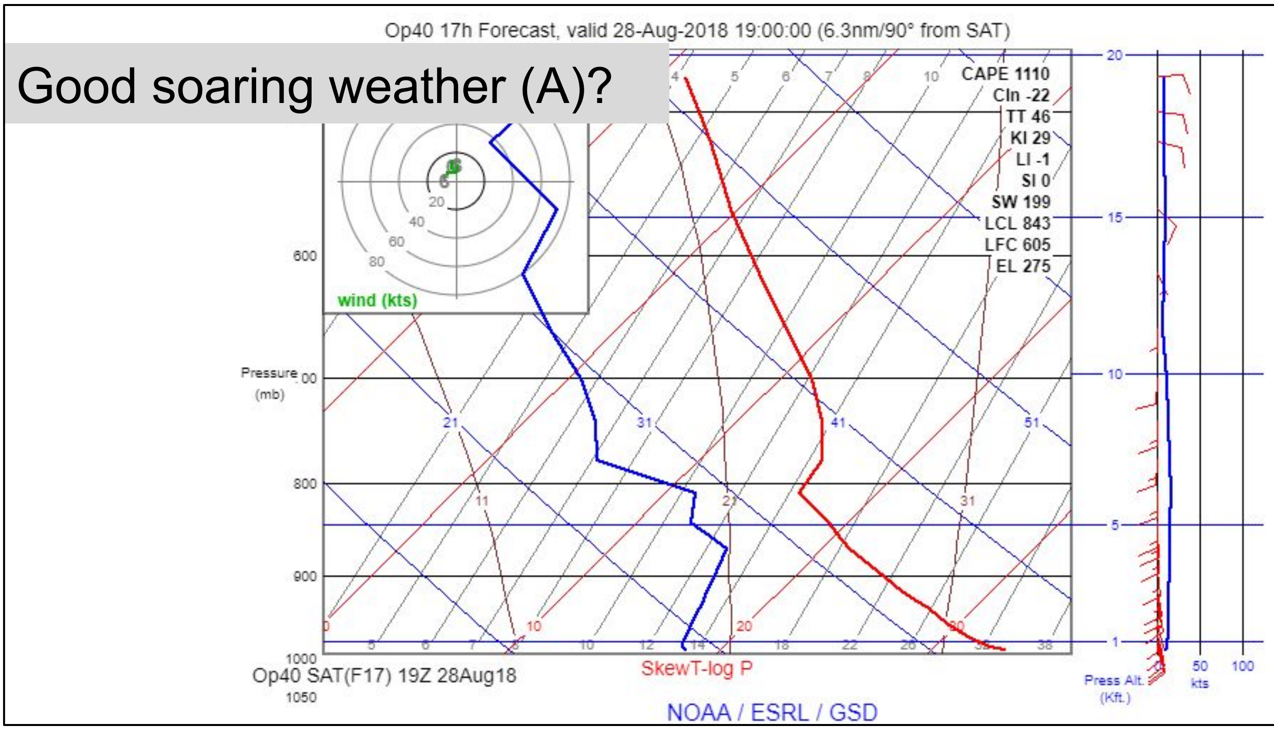
The website rucsoundings.noaa.gov has interactive chart so you can see what a lifted parcel of air will do. This is a pink line. Click with the mouse

- When it becomes saturated
- Is that place where it becomes saturated on the temperature line or to the right?
    - Yes? Clouds will form
    - No? The parcel of air won't get to that height and therefore clouds will likely not form from (at the top of) thermals

Is it going to be good soaring weather today? -- Don't answer quite yet! -- [thunderstorms very likely this day]

Area under curve (between - left of pink and right of red line) after saturation indicates the strength of thunderstorms (CAPE - convective available potential energy)

Good soaring weather (A)?



A parcel of air that is heated at the ground and starts rising will go to 6k feet

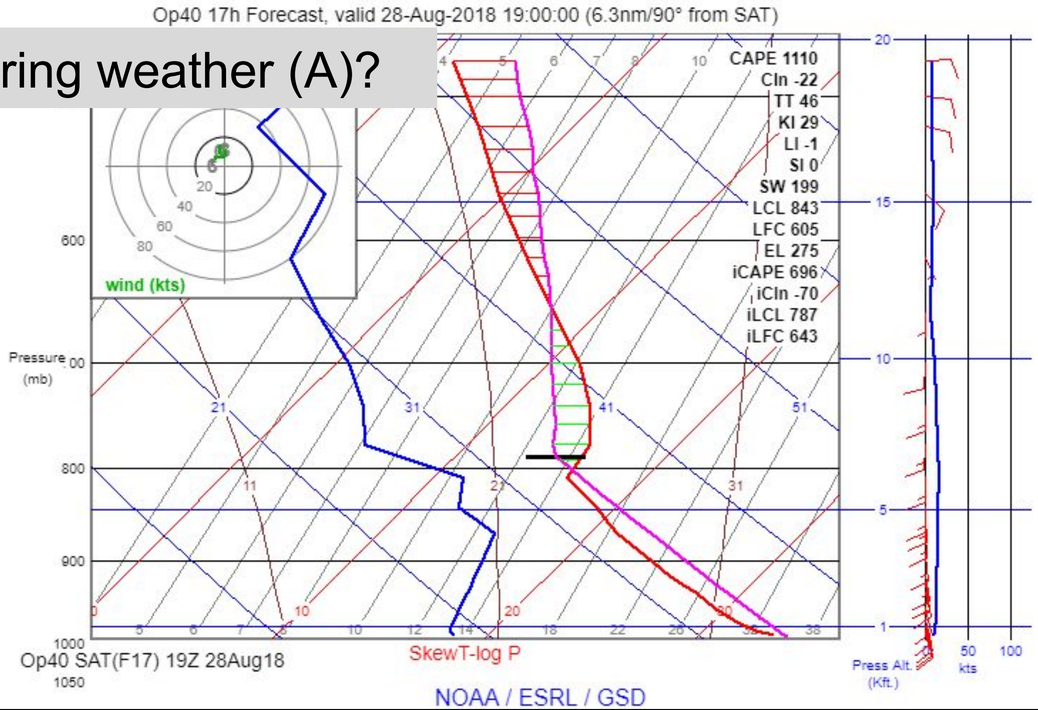
Air rises to 6k feet and then stops because of isothermic layer (layer of air doesn't follow std dry lapse rate).

Capping inversion / temperature inversion. Why is a capping inversion important? This will prevent thunderstorm activity. Capping inversion should be above the height you'd like to soar at. Capping inversion will stop thermals from rising higher.

Parallel dry lapse rate lines until air arrives at height where surrounding air is same temperature. Air does not become saturated or just barely saturated.
Marker clouds? Maybe wisps or thin cumulus because of momentum of thermal air overshooting equal temp level.

Definitely good thermals if ground is not wet and no high clouds.
Would have to see upper part of skew-t at 20-40k feet (these are cropped to see lower part of atmosphere)

Good soaring weather (A)?



Same graph, but with pink line showing lapse rate of rising thermal. Note that thermal would stop as soon (or soon after) it touches the red (temperature) line at approx 800mb.

A parcel of air that is heated at the ground and starts rising will go to 6k feet

Air rises to 6k feet and then stops because of isothermic layer (layer of air doesn't follow std dry lapse rate).

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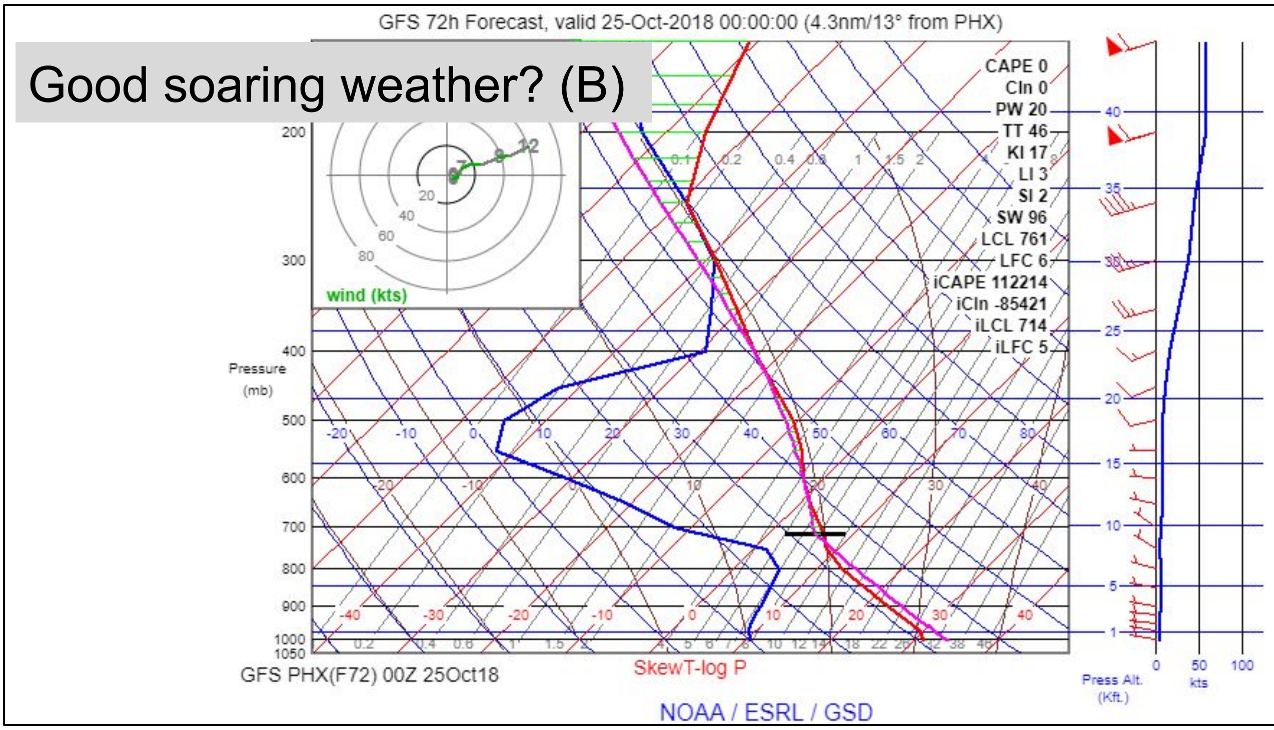
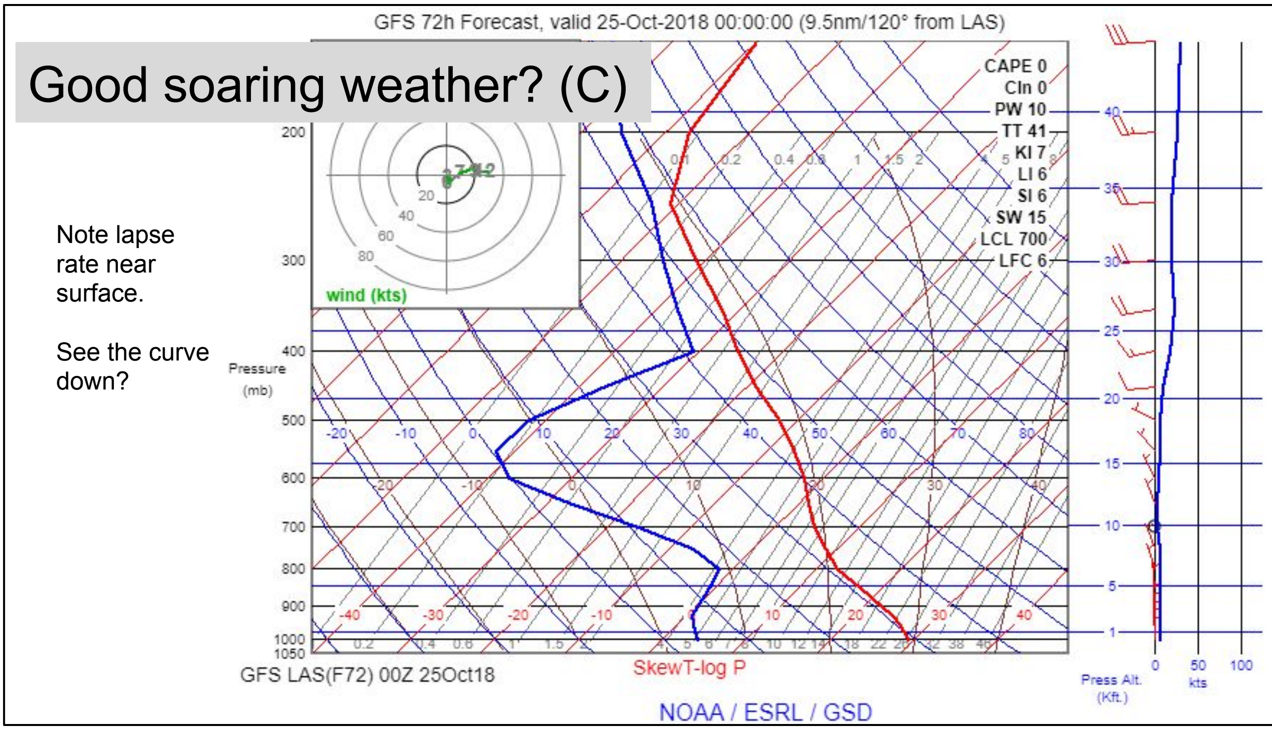
Parallel dry lapse rate lines until air arrives at height where surrounding air is same temperature. Air does not become saturated or just barely saturated.
Marker clouds? Maybe wisps or thin cumulus because of momentum of thermal air overshooting equal temp level.

Good soaring weather? (B)



Good soaring weather?
Lapse rate through lower 8k feet looks good!

Probably no thunderstorms -- area under curve after saturation is minimal
But...
No - High clouds will likely weaken or entirely prevent thermals



Moving north west on the same day… Up from Phoenix to Vegas Good soaring weather? Vegas

What's different about this skew-t plot?

Maybe - lapse rate not very strong at surface. Need very strong heating of ground to get high thermals.

Note wide dewpoint/temperature. If lapse rate was good enough, would be blue. Follow mixing line.

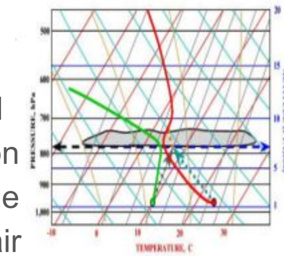
In absence of other data, it would still probably be worth it to go out the the airfield. Remember, model data has imperfect view of atmosphere.

Compare thunderstorm slide to good thermal day slide. What do you notice about how close the dewpoint and temperature are on the ground?

A higher dewpoint at the surface results in lower cloud bases. E.g. The closer the surface dewpoint is to the surface temperature, the lower the cloud bases will be. Follow the mixing line from the dewpoint at the surface and the dry adiabat from the surface temperature until they intersect. As long as the lifted dry parcel doesn’t cross to the left of the temperature line (blue conditions), the intersection of the mixing line and the dry adiabat will indicate the height/pressure of the cloudbase.

Look at skew-T plots over the span of several forecasted hours

Over-development



“Many good soaring days are ruined by overdevelopment, or as I prefer to call it, spreadout. The cause of spreadout is predicted on inspection of this Skew-T example: In the vicinity of cloudbase the dewpoint and temperature of the general airmass (i.e. all of the air NOT in thermals) are rather close to one another. Humidity is thus high, and dispersal of clouds through evaporation is slow. If a temperature difference of less than 3°C at, or in the vicinity of cloudbase, there is a good possibility of spreadout. The smaller the difference, the greater the chance. It may seem historically, that the dewpoint so frequently approaches the temperature at the inversion, but this is no accident: The moisture is transported there by convection, and prevented from rising by the inversion.”

-Jim Martin, Finger Lakes Soaring Club

Using rucsoundings.noaa.gov

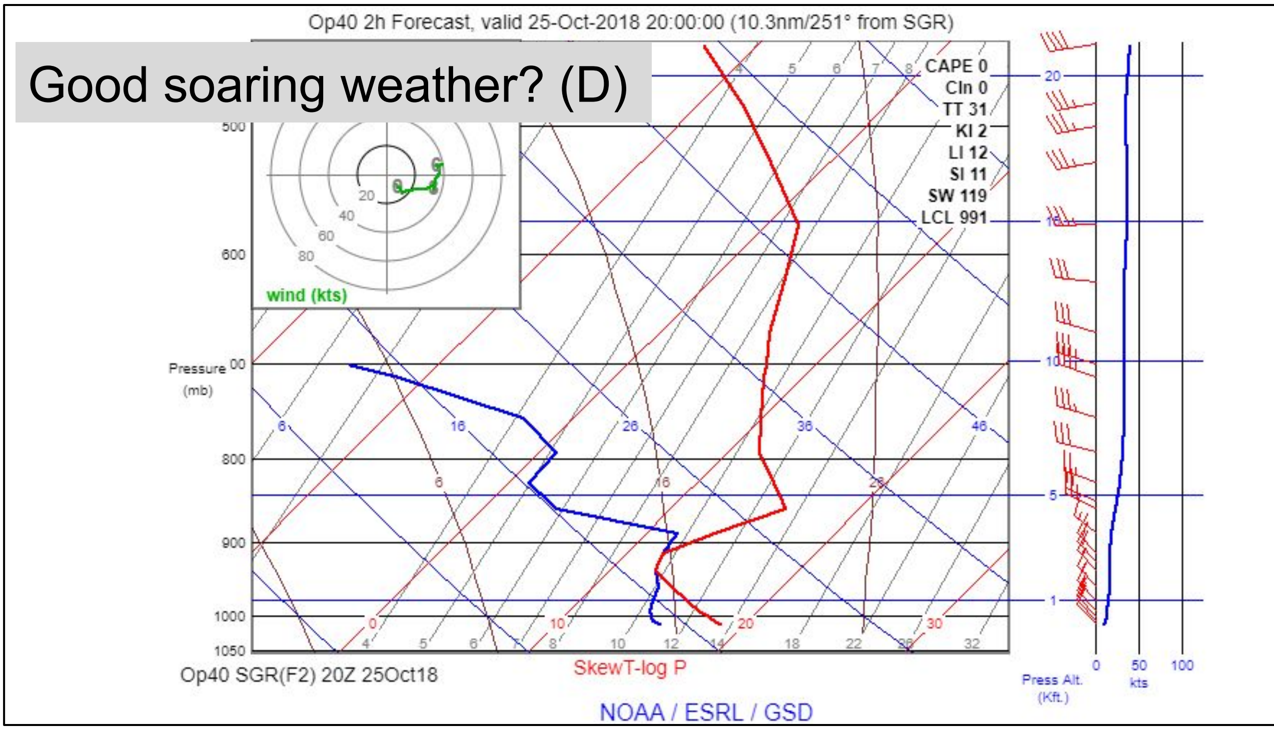
OP40 vs GFS

Plot rising air

Determine thermal level

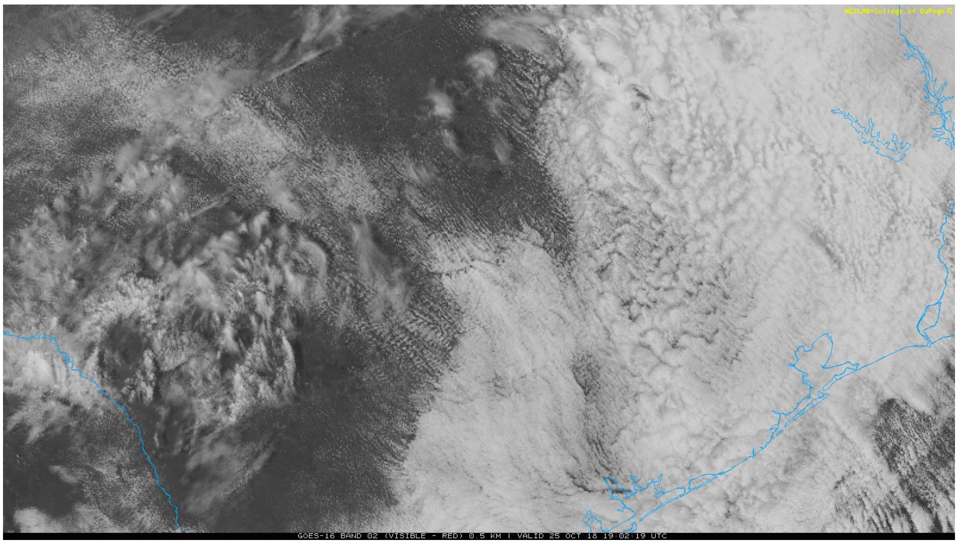
Zoom

Good soaring weather? (D)



Good soaring?
No -- layer of stratus at 2000’

And even if there wasn’t a layer of stratus at 2000’, the inversion is low -- thermals would only go to 2000’ or so.



GOES E (GOES 16) satellite imagery at approx same time as forecast Skew-T on previous slide (Good soaring weather? D)

Typical “good soaring” sounding profile in SE Texas

What am I looking for -- ideal soaring conditions?

1. Strong lapse rate for first 2-4k feet (temp line leaned over to left - at or more slanted than dry adiabat)
2. Temp - Dewpoint spread to allow higher cloudbase, but not too high of a spread to be blue
3. Temperature inversion 1-3k feet above cloudbase (mixing line meeting temp line) so layer stops rising air -> shuts down thunderstorm/cumulonimbus development
4. No strong wind (although strong lapse rate + moderate winds can lead to streeting)
5. No height at which temp = dewpoint. This would mean clouds not formed by thermals or risk of overdevelopment (Also see overdevelopment slide)

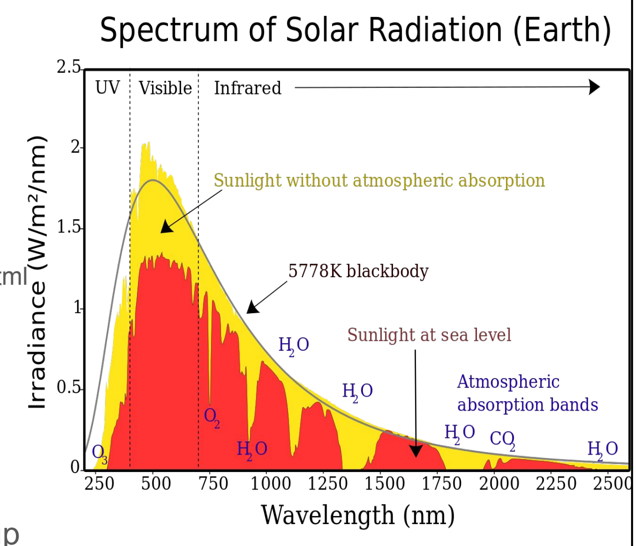
<u>See slide “Good Soaring Weather? (A)”</u> (Maybe a bit more humidity to ensure marker clouds)

Ideal profile would have higher heights in West Texas / Utah / NM / etc

What else am I looking for?

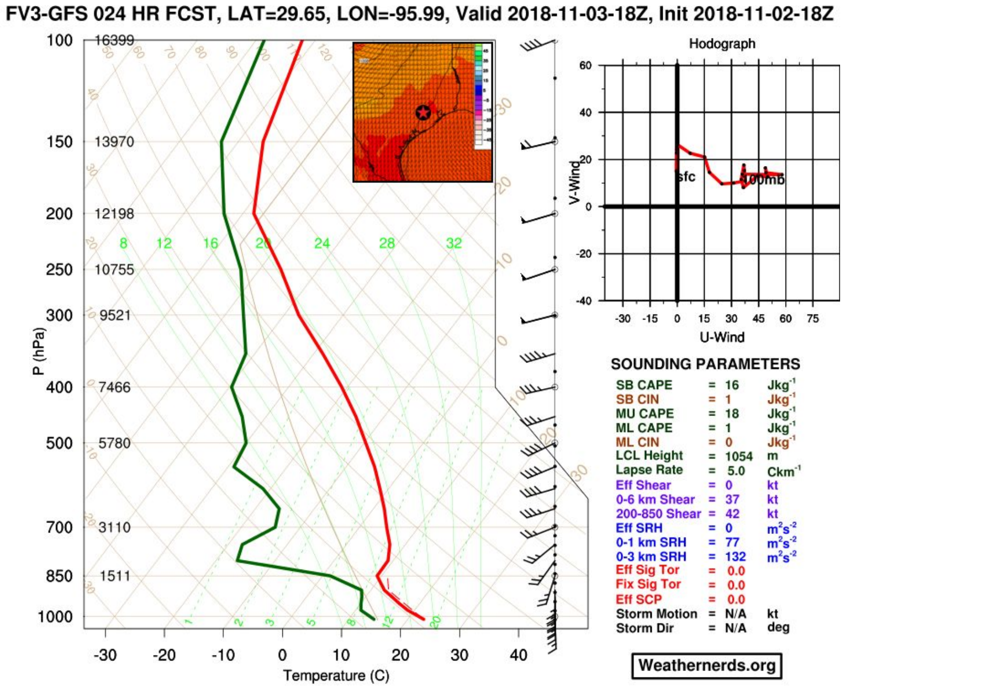
Anything that affects strength of thermals

- Time of year: “Near” solstice = better surface sun => Watt/m^2
  - Dr Jack can tell you estimated surface sun
    - http://www.drjack.info/BLIP/univiewer.html
  - Looking for greater than about **800 Watt/m^2**
- Dry ground - wet ground can (but not always) slow/prevent thermal formation
- Wind conditions -- affects strength and consistency of thermals -- how broken up and tilted they are



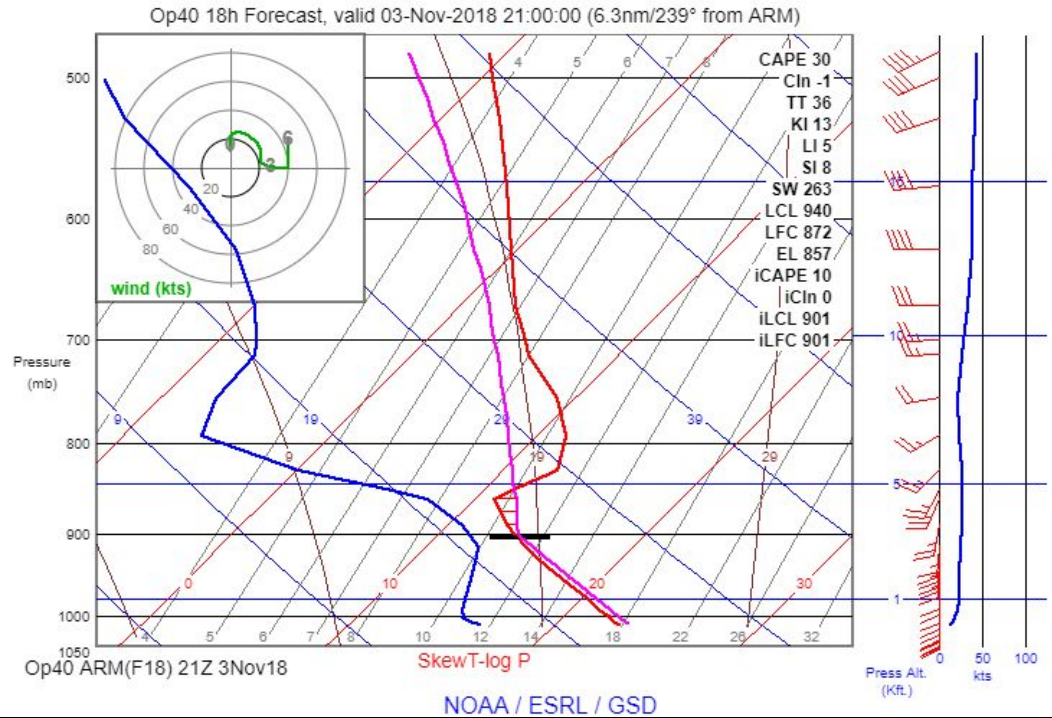
Wet ground -- lots of thermal mass in water that must heat up before air above it will heat up
Wet ground and fields are bad news. Look for (metal) rooftops, blacktop -- will be relatively dry vs wet soil

Nov 3, 18z WeatherNerds



Good soaring?
No clouds.
Good lapse rate.
Inversion preventing thunderstorms.
Thermals to possibly 4000-4500 ft (The thermals appear to stop at the inversion around 850-875 mb)

Nov 3, 2018 Op40 18Z



Skew-T looks great.
No clouds
Good lapse rate in lower part of atmosphere.
Inversion preventing thunderstorms.
But, November sun may not be enough for cross-country.

Are forecast soundings the perfect tool?

No!

Doesn't tell you with certainty how strong the thermals will be.

Skew-T forecast plots are only as good as the computer forecast model and the data input into that model

Use Skew-T plots to check Skysight, XC Skies, Dr Jack BLIPMAP to supplement and cross-check.

Viewing Skew-T plots

Websites (work well on tablets, but not on phones):

- https://www.weathernerds.org
- https://rucsoundings.noaa.gov

Android App:

- Skew-T (free)

IOS App:

- SkewTLogPro ($)

References

http://www.atmos.millersville.edu/~lead/SkewT_Parameters.html

http://funnel.sfsu.edu/courses/metr200/handouts/skewt.html

https://wildcardweather.com/2015/02/21/learn-to-read-a-skew-t-diagram-like-a-meteorologist-in-pictures/

http://flsc.org/portals/12/PDF/Read_Skew_T.pdf

http://newlangsyne.com/articles/skewt/index.htm

http://funnel.sfsu.edu/courses/metr200/problems/prob.1.WarmAirRises.html

https://atmos.washington.edu/~mcmurdie/classes/370/skew-t/Skew-T.pdf

Additional websites:

www.windy.com

http://www.drjack.info/BLIP/univiewer.html

http://skysight.io

Q&A

Backup slides follow

Mixing ratio -- Theory

The dash-dotted curves that slope upward and to the right on the thermodynamic diagram are saturation mixing ratio lines, or isohumes. They describe the saturation mixing ratio of air and are labeled in grams per kilogram (g/kg) along the bottom of the diagram. For any particular pressure and temperature—that is, for any particular location on the diagram—the isohume passing through that location tells you the maximum amount (mass) of water vapor that could be present in each kilogram of dry air at that temperature and pressure.

http://funnel.sfsu.edu/courses/metr200/handouts/skewt.html

Causes of Temperature Inversions

Radiation Inversion - clear night - ground emits IR into space and cools air above it

Advection Inversion - cool seabreeze

Subsidence Inversion - High pressure - sinking air compresses layer of air

https://www.encyclopedia.com/earth-and-environment/atmosphere-and-weather/weather-and-climate-terms-and-concepts/temperature-inversion

https://www.youtube.com/watch?v=T_U3TXHBt-0

https://www.thoughtco.com/temperature-inversion-layers-1434435

https://www.ag.ndsu.edu/publications/crops/air-temperature-inversions-causes-characteristics-and-potential-effects-on-pesticide-spray-drift

I'm guessing summertime inversions at 4-6k feet around Houston are the result of a combination of two or three of these, but I have no proof or source for this guess.

Surface type and heat capacity

Except for a vacuum, motionless air is the poorest heat conductor known, and it also has low heat capacity. Because loose materials such as mulch, compost, crop residue or insulating materials have many air-filled pore spaces, they have very low thermal conductivity and heat capacity. For example, insulating material such as blankets or sweaters feel warm to the touch even when they are cold because of low thermal conductivity.

Denser, low-porosity materials such as soil, stone or concrete have higher thermal conductivity and heat capacity. When they are touched, heat is conducted away from your skin rapidly, so they feel cold even if the material is only a little colder than your skin. In addition, their high heat capacity causes their temperature to change very slowly.

When the sun heats a bare, uncultivated soil surface in the morning, much of that heat energy is conducted deeper into the soil than it would be through a less-dense, cultivated soil or a soil with a surface mulch. As a result, more energy is stored below the surface of the denser, uncultivated soil, and the soil's surface remains cooler, compared with the cultivated soil, the mulched soil or other porous surfaces.

The more porous mulched surfaces will be hotter throughout the day because only a shallow surface layer of the mulch is heated. As a result, the overlying air also will be hotter.

In addition, large amounts of energy will be lost by **terrestrial radiation** because of the greater surface temperature. In mid to late afternoon as the sun sinks lower, these surfaces begin cooling. The mulched surface temperature decreases rapidly because of its low heat capacity, but the uncultivated soil surface cools far more slowly because some of the extra energy stored deeper in the soil during the day is conducted back to the cooler surface.

Because little energy was stored under the mulched surface, its surface will be much colder than the denser soil surface. As a result, inversions form more rapidly over mulched or porous surfaces and also will be more intense.

https://www.ag.ndsu.edu/publications/crops/air-temperature-inversions-causes-characteristics-and-potential-effects-on-pesticide-spray-drift