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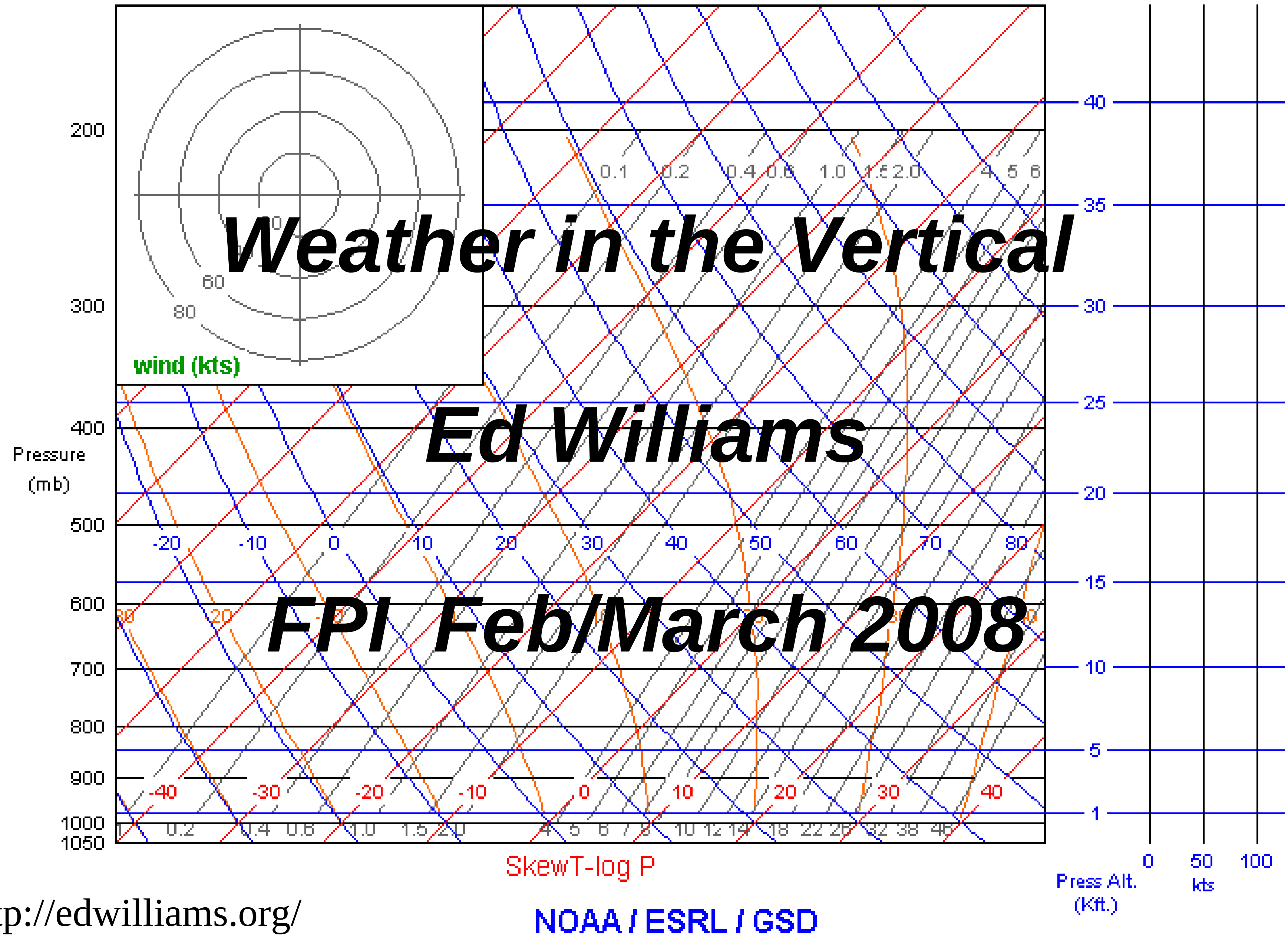
Weather in the Vertical

Ed Williams

FPI Feb/March 2008



http://edwilliams.org/

What's it all about?

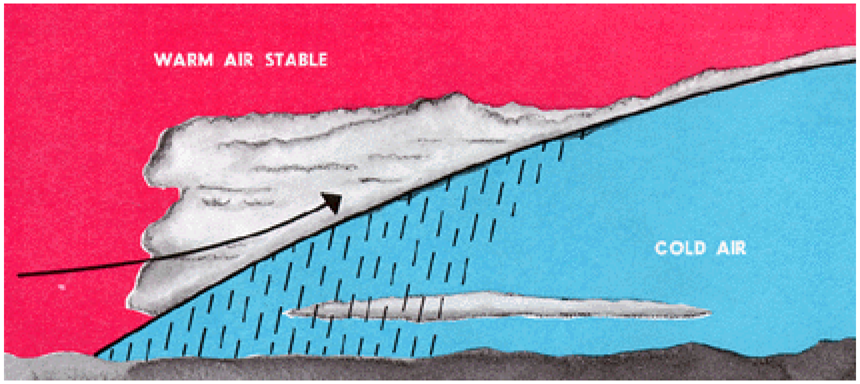
- Why is the vertical temperature and moisture profile so important?
  - Atmospheric stability
  - Characteristics of stable/unstable wx.
- How can we use vertical soundings ("Skew-T") plots to augment our wx briefings?
  - Cloud layers and tops
  - Thunderstorm potential
  - Icing potential
  - Fog, mountain waves…

A little weather "theory" is good for you!

- To understand *what* is happening, it helps to know *why*.
- The more we know, the less likely we are to be taken by surprise.
- We most likely don't have the skill and knowledge of a professional meteorologist. But we do have the advantage of being on the spot, in real time.

Parcel theory is a tool to assess vertical motion in the atmosphere

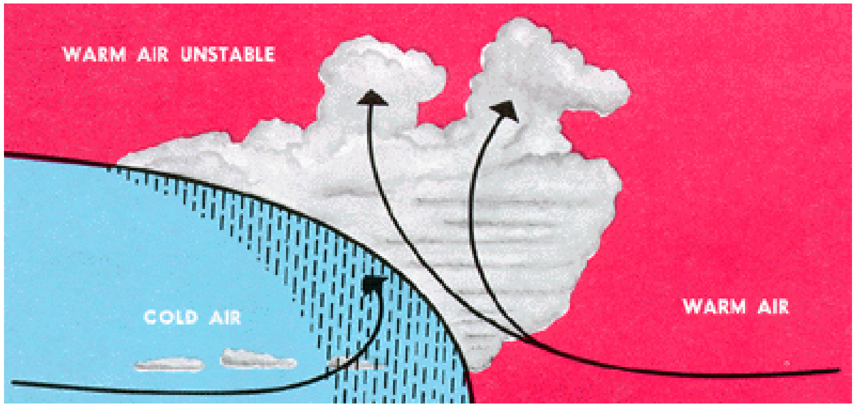
Vertical motion leads to:
- Clouds
- Precipitation
- Thunderstorms
- Icing
- Turbulence



Warm front

The air's response to lifting is determined by its *stability:*

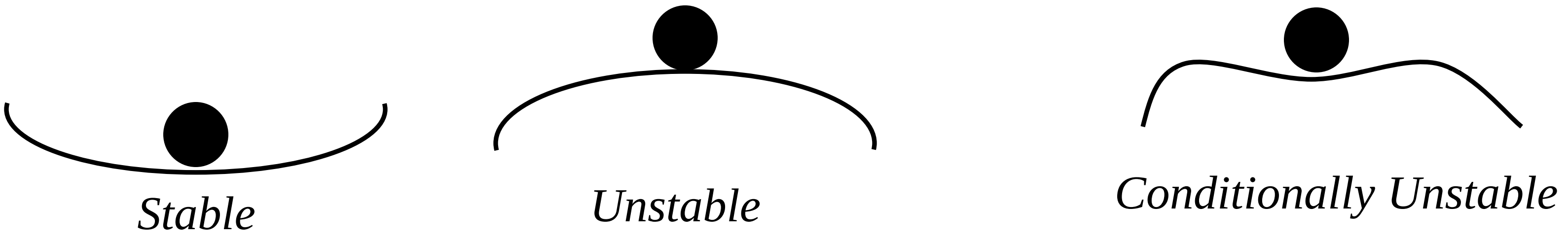
We assess this by hypothetically lifting *parcels* (imaginary bubbles) of air.



Cold Front

Actual lifting can come from a variety of causes:
- Fronts
- Orographic etc.

Stable systems return towards equilibrium when displaced



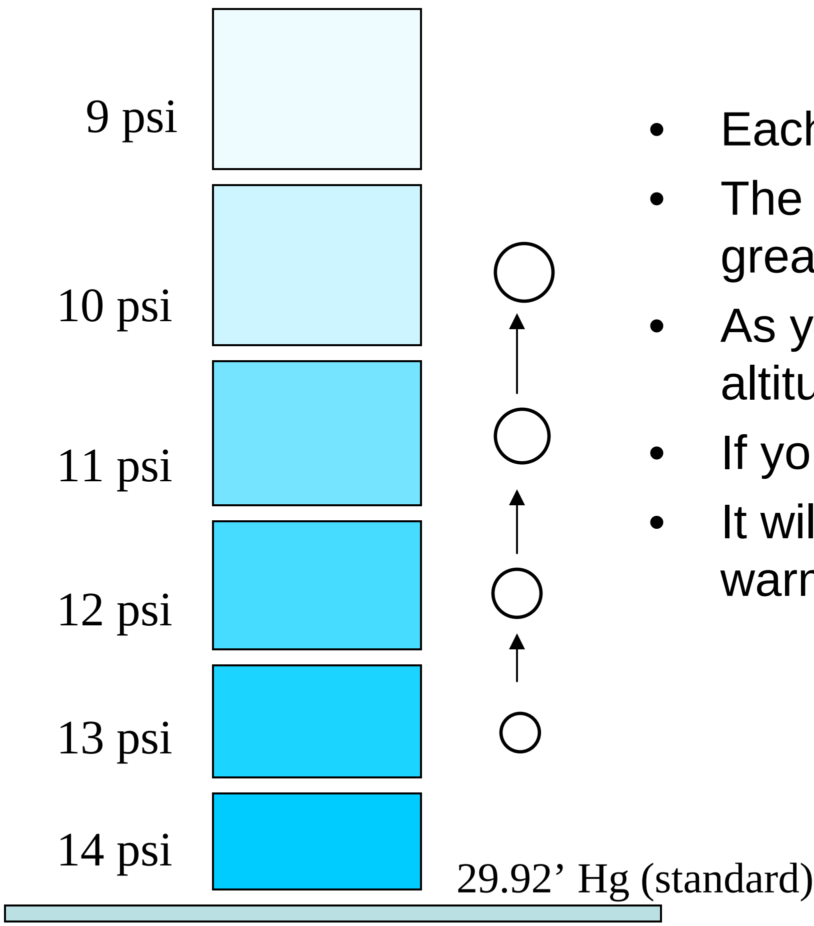
- A region of the atmosphere is stable if on lifting a parcel of air, its immediate tendency is to sink back when released.

- This requires the displaced air to be colder (and thus denser) than its surroundings.

Balloons (and air parcels) rise if they weigh less than the air they displace.

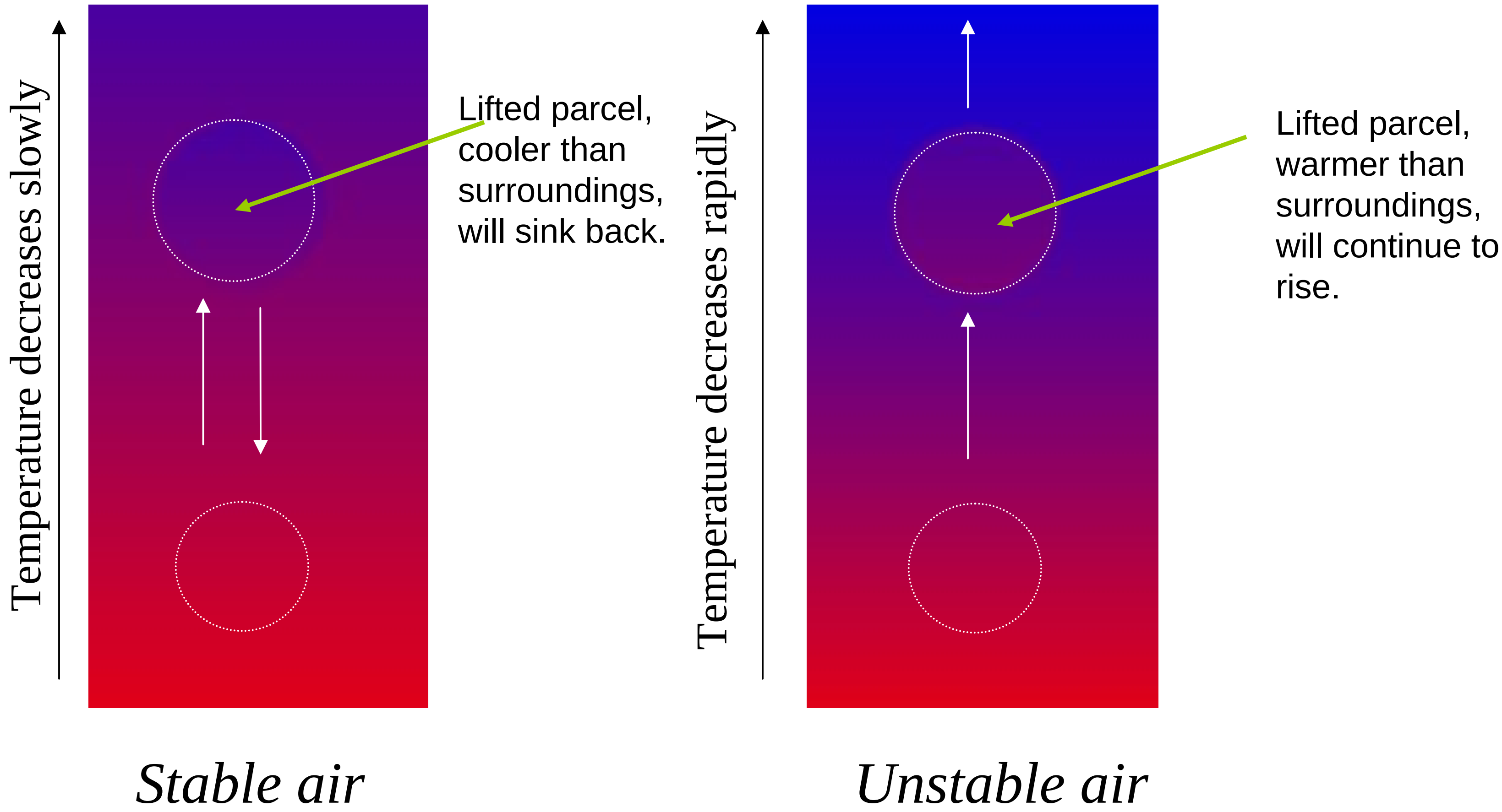
Pressure is the weight per unit area of the air above.

"Warm air rises" – but it's a little more complicated.



- Each layer supports all the layers above.
- The lower layers are compressed more by the greater pressure.
- As you climb, the pressure drops more slowly with altitude.
- If you lift a parcel of air it will expand and cool.
- It will continue to rise, if despite this cooling, it is warmer than its surroundings.

The atmosphere becomes unstable if its temperature drops sufficiently rapidly with altitude



Parcel theory is an idealization in which the lifted air is assumed to exchange no heat or matter with its surroundings – called an *adiabatic* process. This only imperfectly realized in nature.

Lifted parcels expand and cool at the *adiabatic* lapse rate

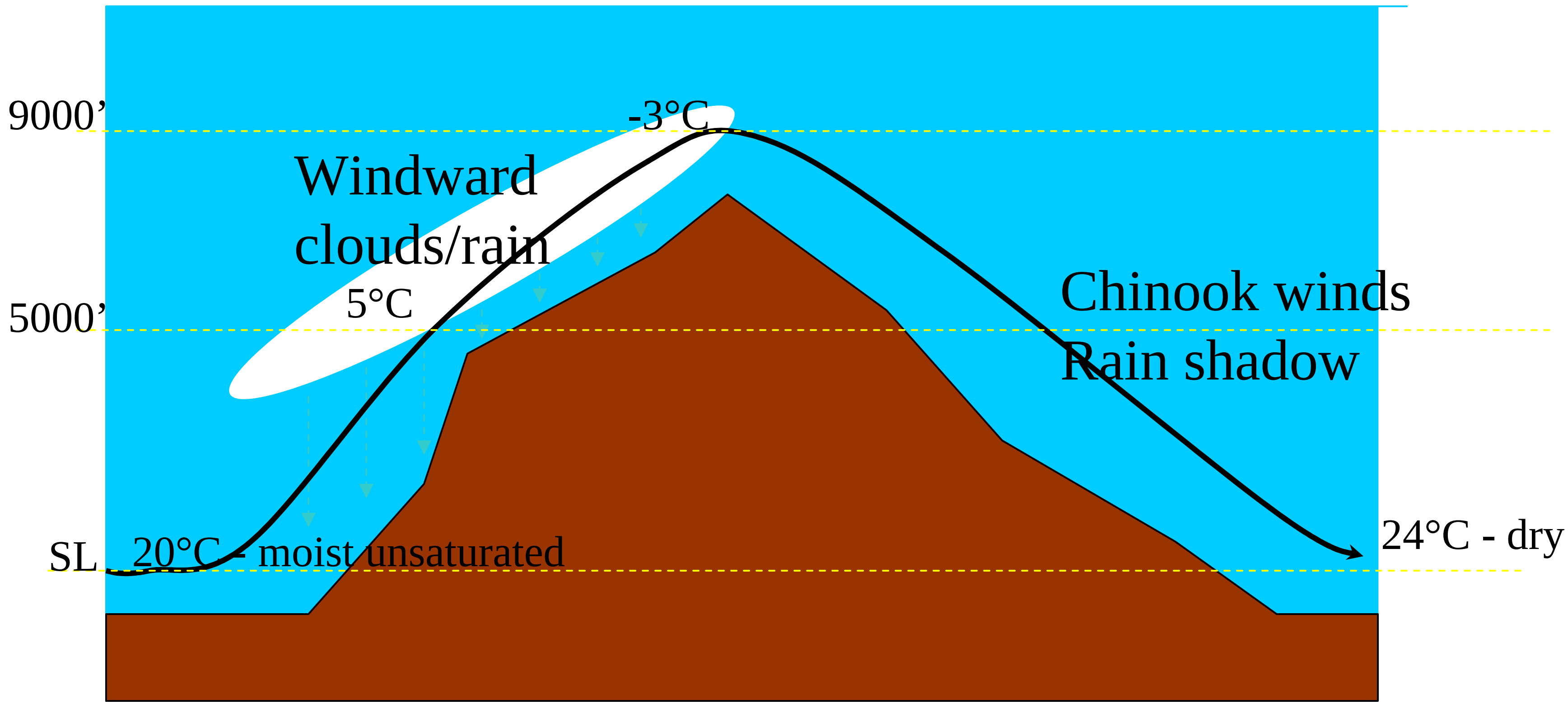
"Adiabatic" means no heat (or matter) is exchanged with the environment

Dry (=unsaturated) air cools at a constant 3C/1000ft on lifting.
This is reversible.

When saturated air (RH=100%) expands and cools, moisture condenses and latent heat is released - offsetting some of the cooling. The *moist (saturated) adiabatic lapse rate* varies with temperature/moisture content: 1C/1000ft at high temperatures to 3C/1000ft well below freezing.

This is typically *not* reversible because if the condensed moisture precipitates out, it is not available to be absorbed if the parcel descends and re-compresses. (called "*pseudo-adiabatic*")

Santa Ana/Chinook/Foehn conditions arise from this irreversibility



The saturated air on the windward side cools more slowly as it rises than the dried air warms on its leeward descent.

Other lapse rates...

- A *lapse rate* is the rate of decrease of some temperature with altitude.

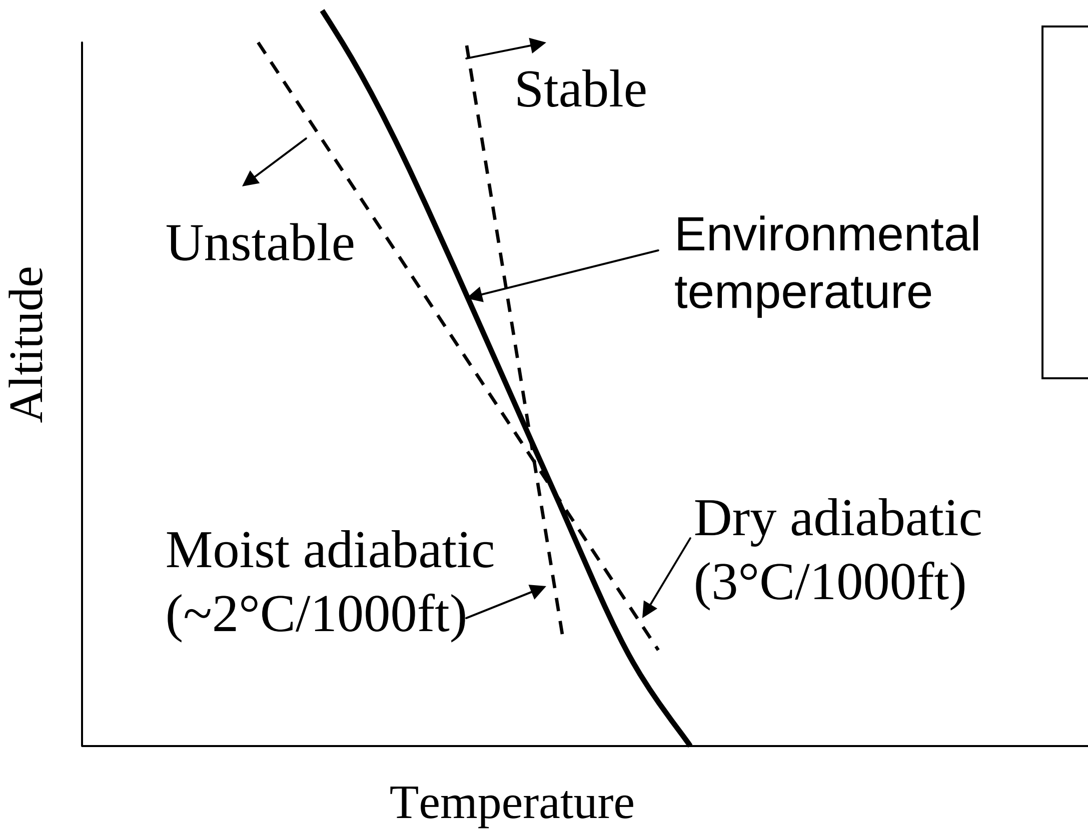
- The *standard* lapse rate of 2°C/1000ft: only for performance/reference – not relevant to weather.

- The *ambient* or *environmental* lapse rate refers to the actual temperature – e.g. as measured by a rawindsonde balloon – or forecast by a numerical model.

- *(pseudo)- adiabatic* lapse rates describe the rate at which air parcels cool on lifting

- Temperature soundings are made by balloon at 00Z and 18Z all around the world measuring, among other things, environmental lapse rates.

Instability results if the ambient lapse rate exceeds the adiabatic lapse rate

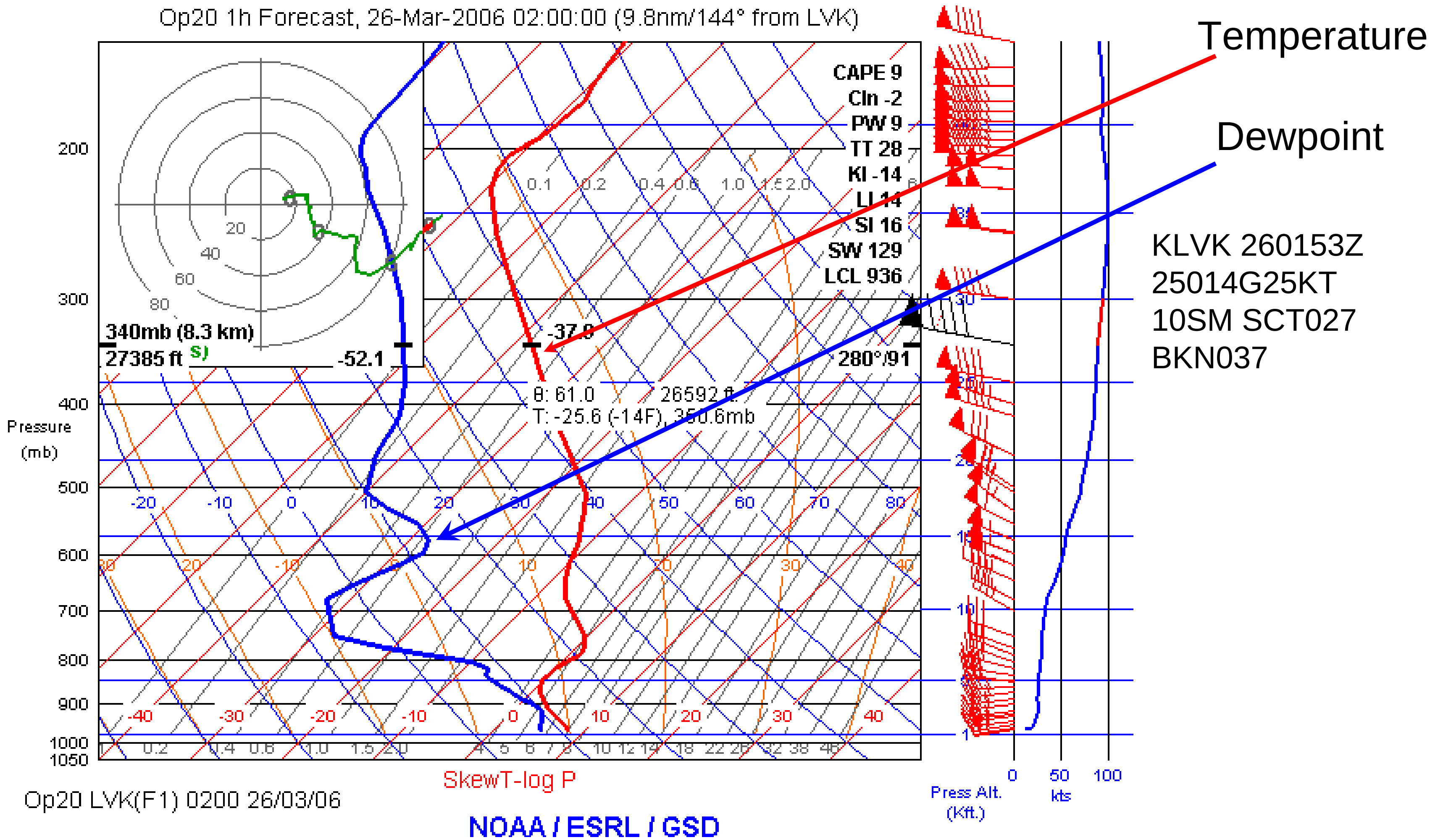


At a given altitude, the atmosphere is either stable, unstable or in between – conditionally unstable.

Conditional instability when the ambient lapse rate lies between the dry and moist rates. The air is then unstable if it is or becomes saturated.

Instability of dry air is unusual – near the surface in desert summers. Convection carries heat up from the surface until the lapse rate becomes dry adiabatic.

The Skew-T diagram is used to plot *soundings* – measured or forecast temperatures, dew-points and wind vs. altitude.

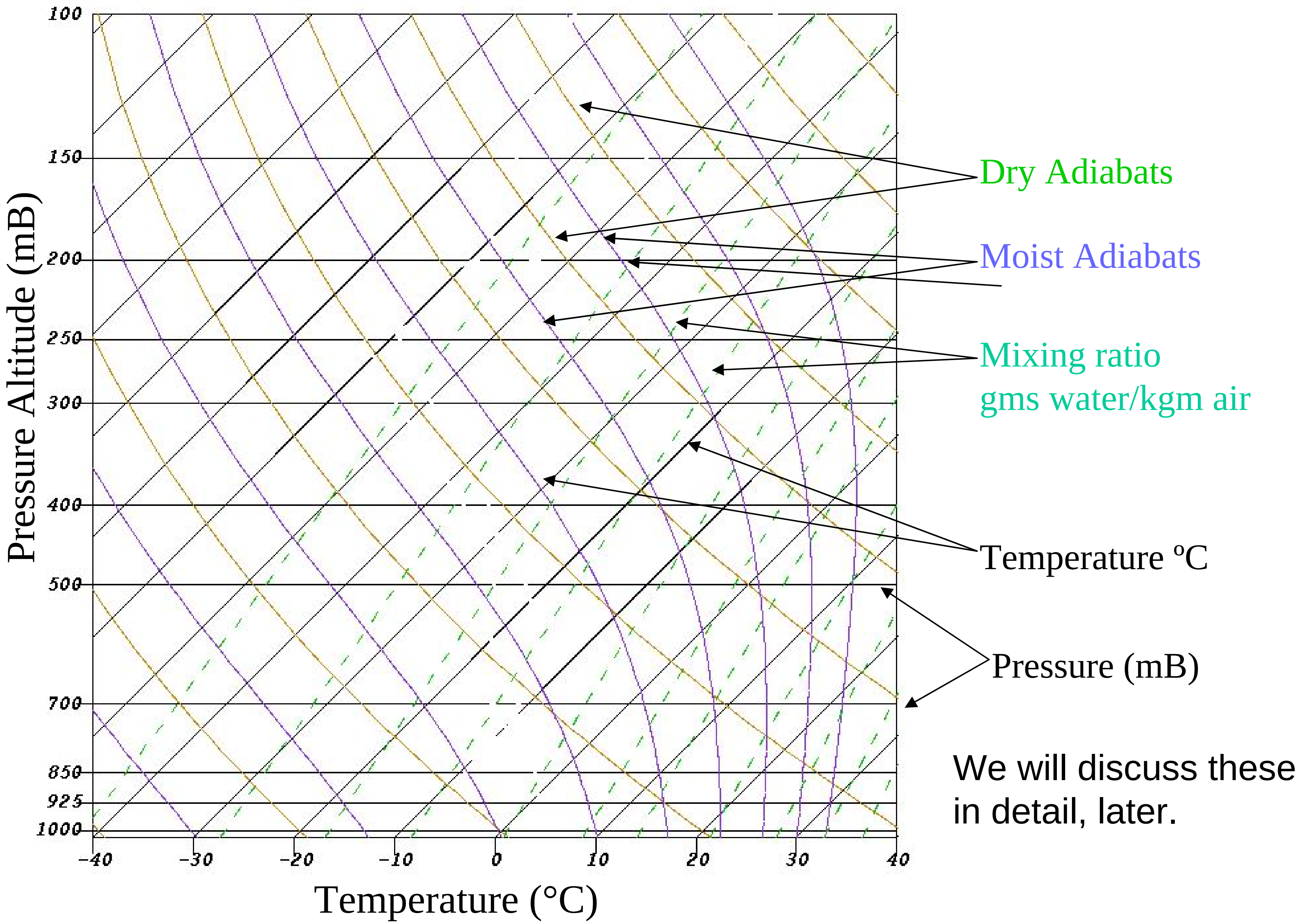


KLVK 260153Z
25014G25KT
10SM SCT027
BKN037

http://rucsoundings.noaa.gov/: **interactive plotter** from NOAA

sampleskew-t.html - click on LVK(F1)

Skew-T plots are an indispensable tool for meteorologists - but require training in their use...

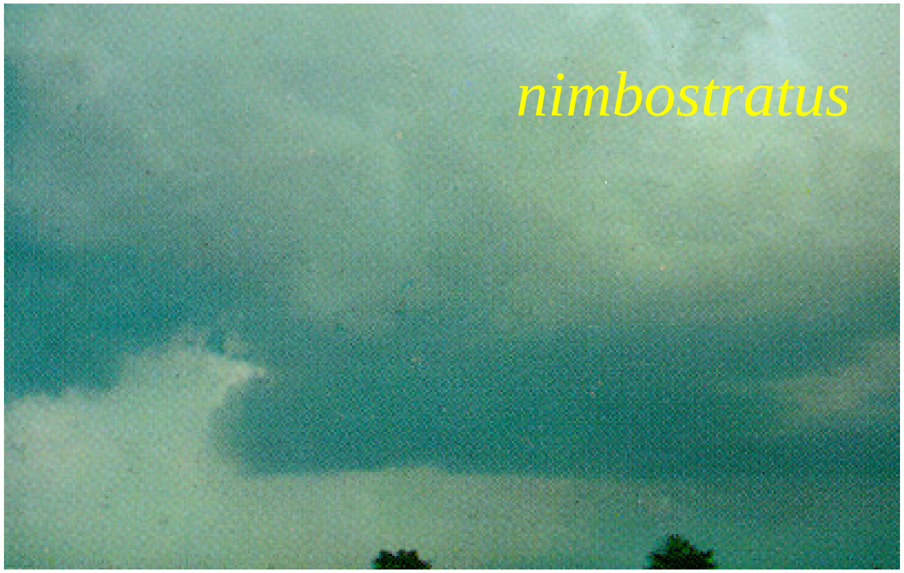


We will discuss these in detail, later.

Stable and unstable air are associated with distinct weather patterns

STABLE		UNSTABLE
Laminar air flow	↔	Up and down-drafts
Smooth flying	↔	Bumpy flying
Steady surface winds	↔	Gusty surface winds
Stratus type clouds	↔	Cumuliform clouds
Poor visibilities	↔	Good visibilities
Steady precipitation	↔	Showery precipitation
Continuous, typically light-moderate rime icing ICIP within ~4000’ of the freezing level	↔	Intermittent, possibly heavy clear icing extending to higher altitudes in the rising air.
Possible low ceilings and visibilities.	↔	Potential for thunderstorms.

Stratus type clouds form in stable air.



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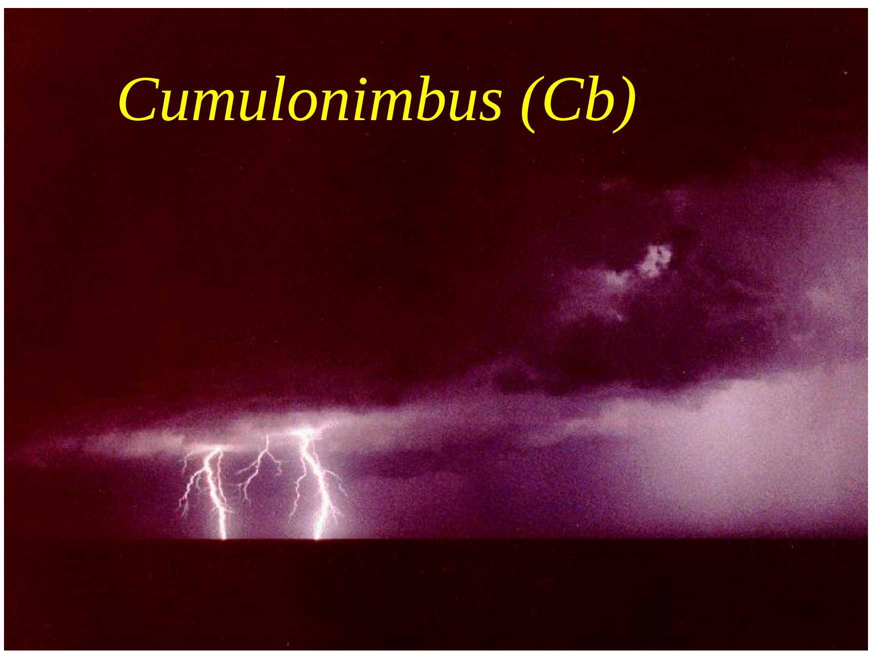
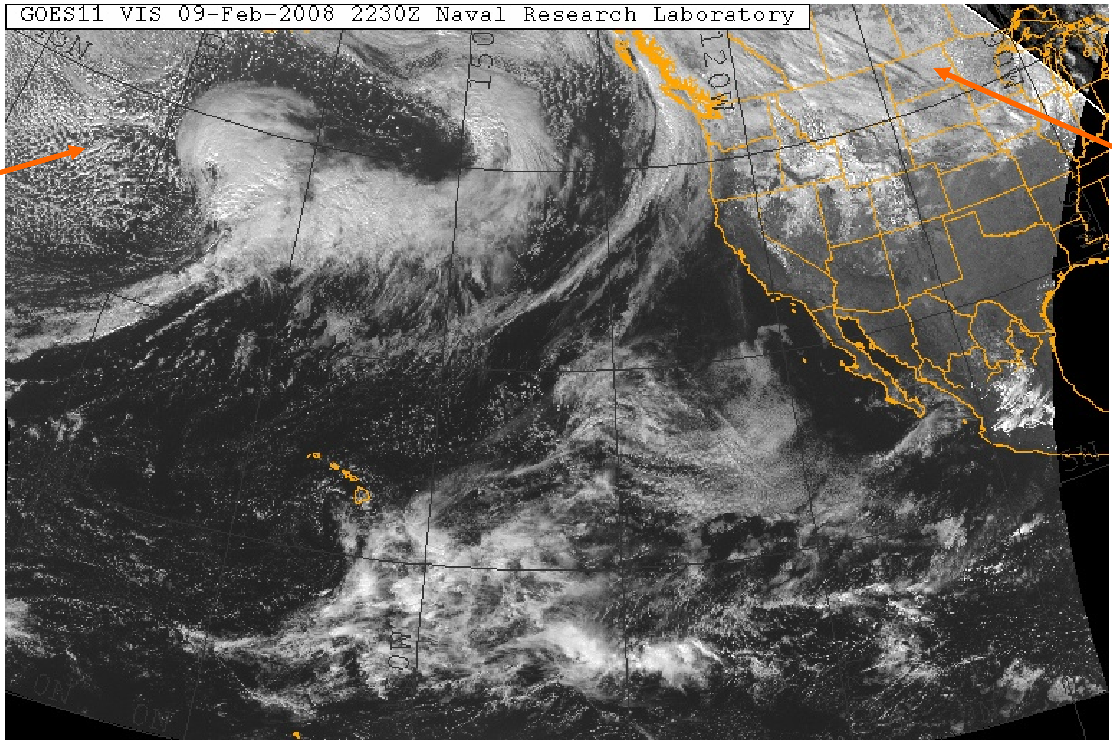
Cumulus type clouds form in unstable air



The cloud type may be visible in satellite images.

Cumulus clouds forming in the cold air overlaying the warmer ocean.



Stratus deck over the upper mid-western states.

Use time-loops to distinguish clouds from snow cover. Use IR satellite images to estimate cloud temperatures and therefore tops.

Stable air isn't guaranteed to be smooth.

Photo © 1999 Beverly Shannon

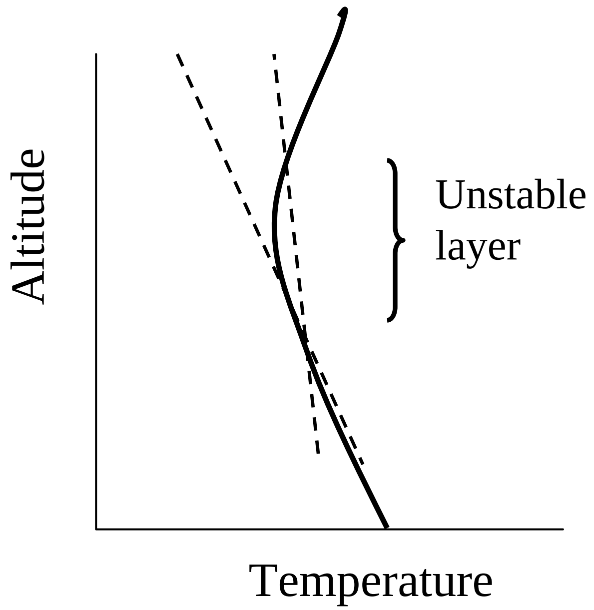
K-H clouds over Mt Shasta.

Here, wind-shear generated turbulence is made visible by moisture in the lower cooler layer.

Sharp vertical wind shears are only possible in stable air (e.g. at inversions). The stronger the inversion, the greater the shear required to generate vertical mixing.

Mountain waves require stable air – there may be turbulence if the waves break and below them if there are rotors.

Shallow layers of (conditionally) unstable air promote "fair weather cumulus"

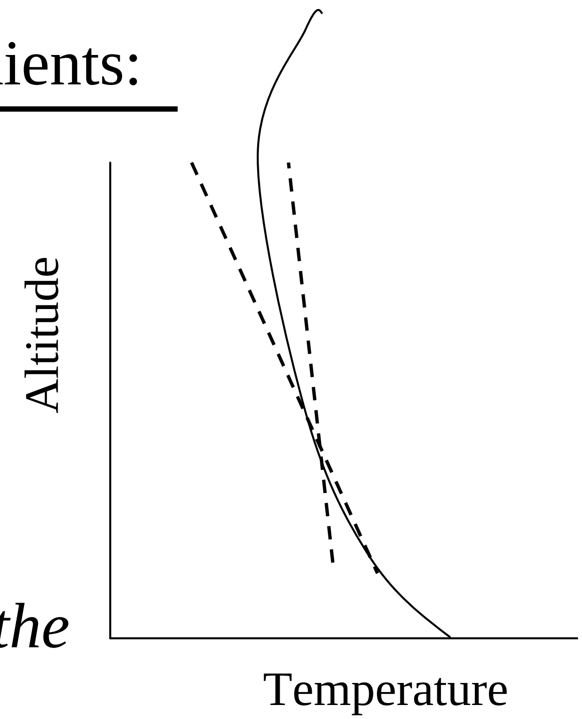


Instability triggered by surface heating or lifting.

Cloud bases at the "lifting condensation level" (surface temp - dewpoint °F)/4.4 in 1000's feet.

Deeper layers of unstable air have the potential for TRWs.

Thunderstorms development requires three ingredients:



- A deep layer of (conditionally) unstable air.
  Cu can build into Cb

- High moisture content
  The latent heat of condensation provides the energy to power the storm
- Lifting action:
  Airmass
  Frontal
  Squall line
  Orographic

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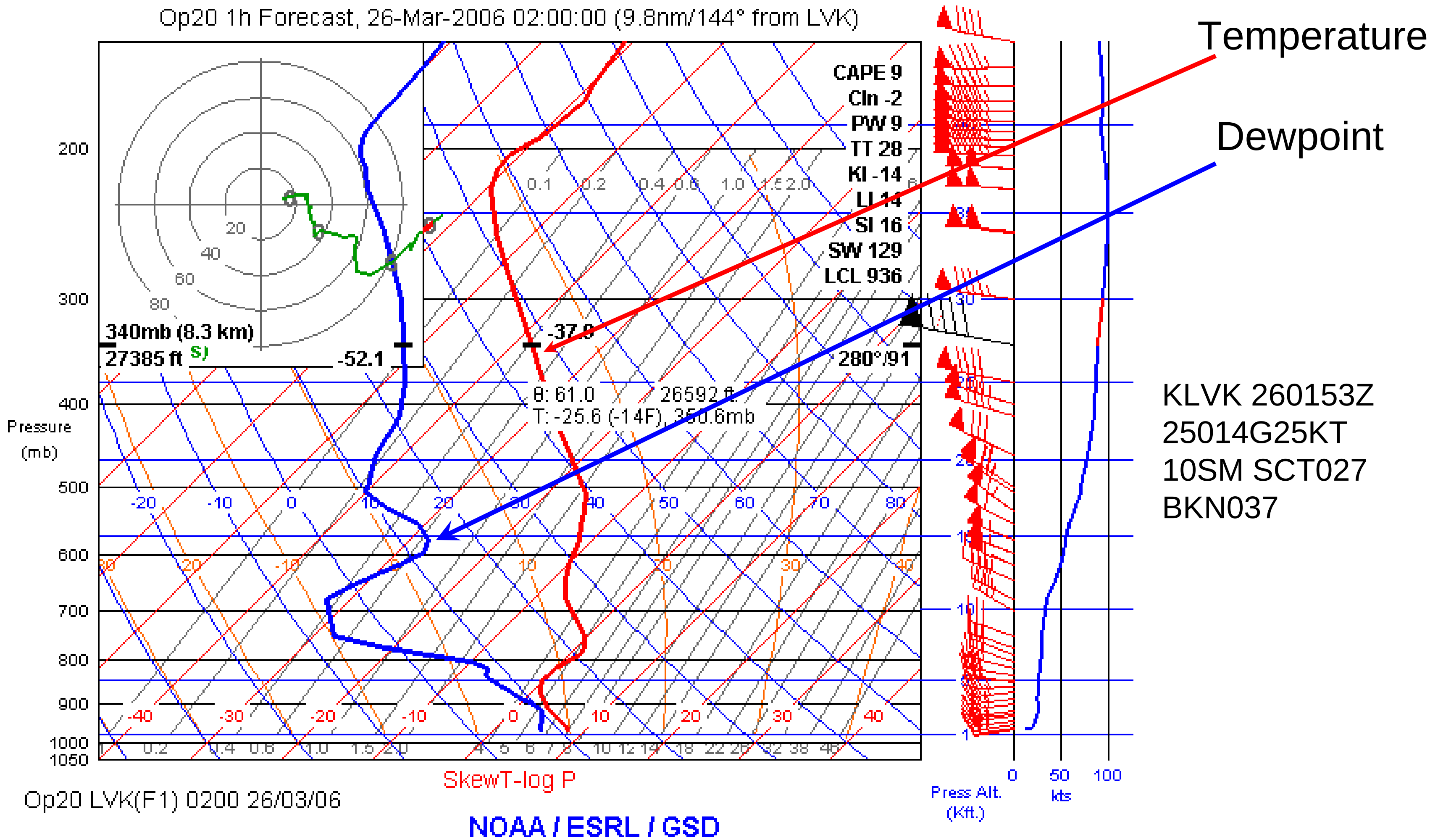
To summarize:

- Atmospheric stability is determined by comparing the ambient lapse rate to the appropriate adiabatic lapse rate.
- Stable – smooth air, steady winds, stratus clouds, steady precip, poor visibility, rime icing
- Unstable – bumpy air, gusty winds, cumulus clouds, showery precip, good visibility, clear icing
- Skew-T charts plot temperature/dewpoint soundings. Next month we'll learn to use these to extract usedful information:
  - Cloud layers and tops
  - Icing
  - Thunderstorms
  - Fog, turbulence, mountain waves etc.

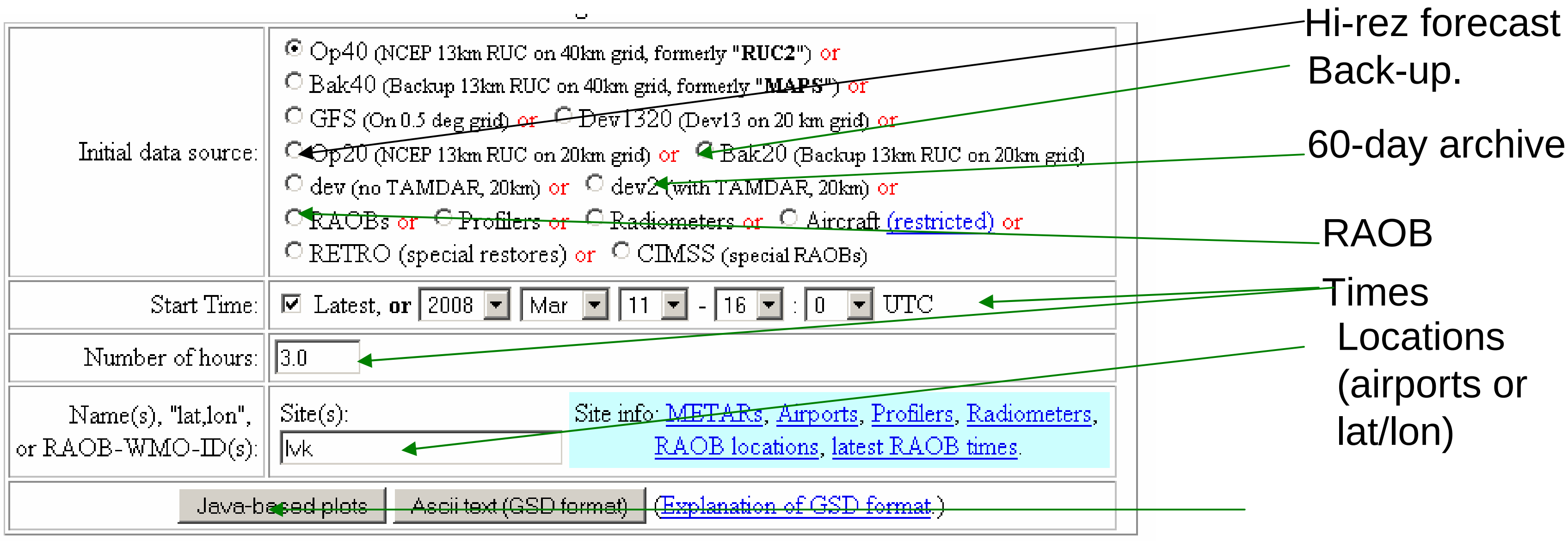
The Skew-T diagram is used to plot *soundings* – measured or forecast temperatures, dew-points and wind vs. altitude.



http://rucsoundings.noaa.gov **: interactive plotter** from NOAA

sampleskew-t.html - click on LVK(F1)

RAOBs are normally only taken twice per day (00Z&12Z). Forecasting numerical model runs (RUC) start hourly.



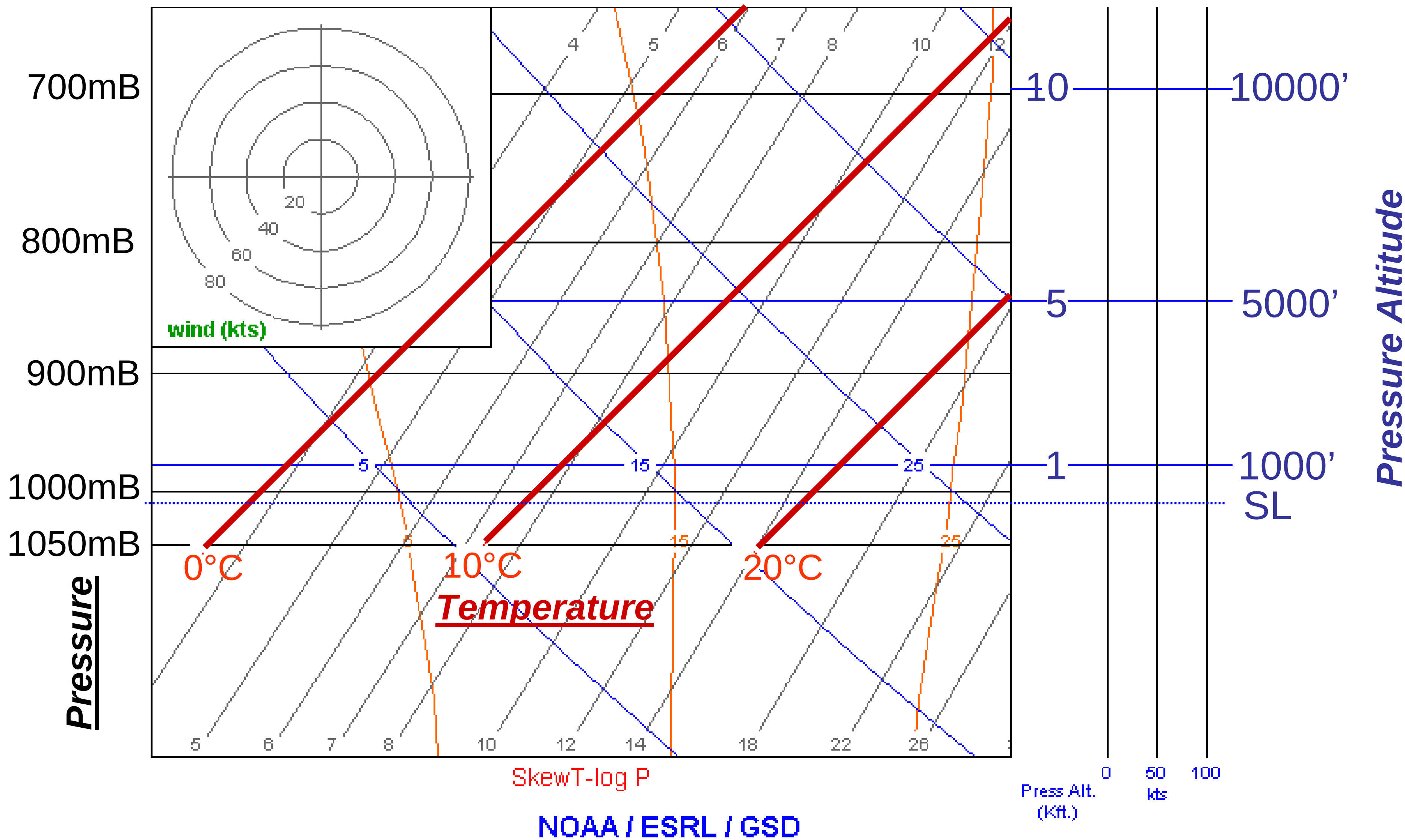
- The computer models incorporate atmospheric data from many sources, then project them forward into the near future. (RUC = Rapid Update Cycle)
- Hours not divisible by 3 (initial time = 1,2,4,5,7,8,10,11,13,14,16,17,19,20,22,23 UTC) - outputs at 00,01,02,03 h forecast projections only)
- Every 3rd hour (initial time = 00,03,06,09,12,15,18,21 UTC) - outputs at 00,01,02,03,06,09,12 h forecast projections
- Every 6th hour (initial time = 00,06,12,18 UTC) - additional outputs at 24, 36 h forecast projections
- Best source is http://rucsoundings.noaa.gov

Soundings give us a great deal of information about the local weather.

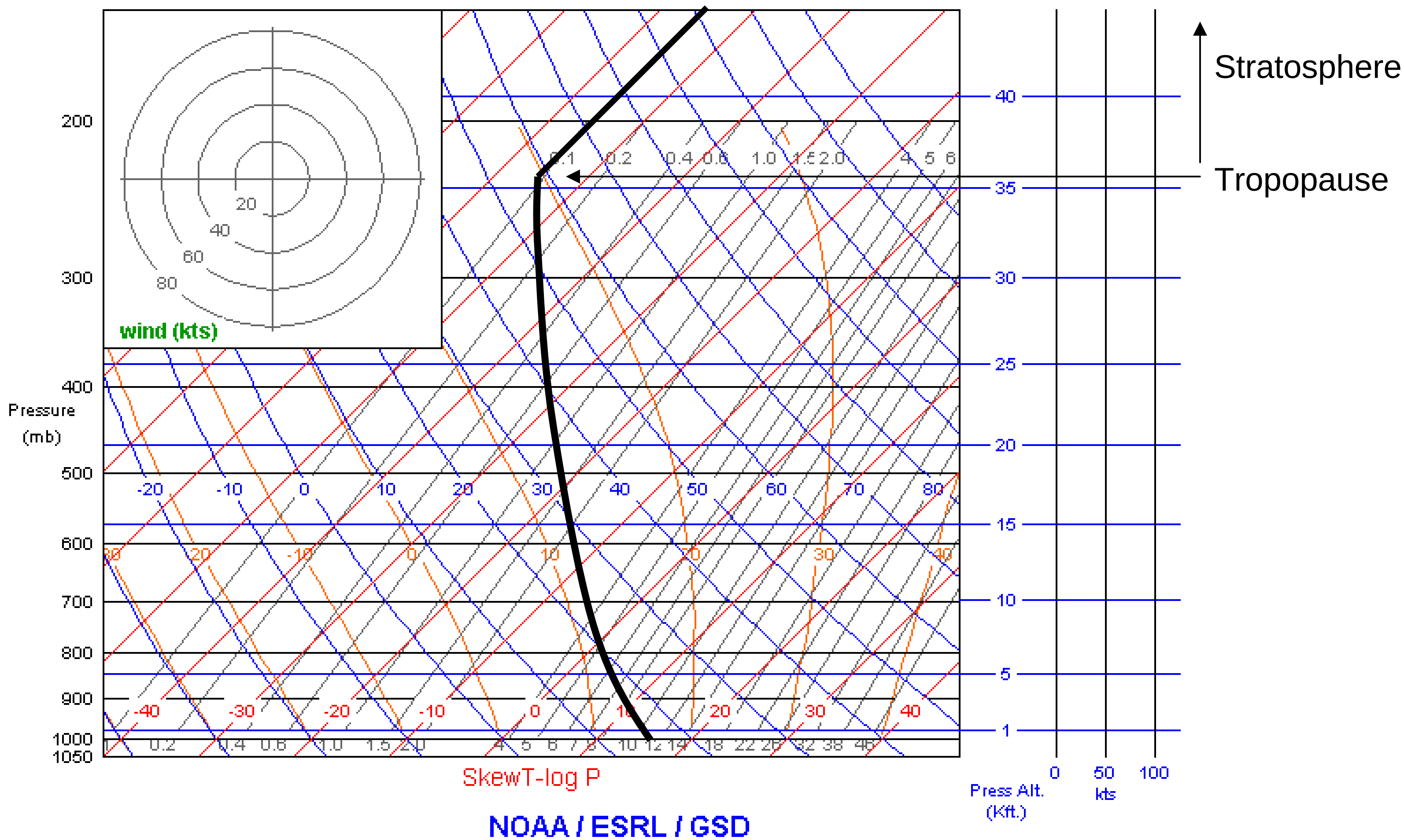
- Cloud layers: bases and tops
- Winds aloft
- Possible icing
- Possible turbulence
- Atmospheric stability
- Potential for fog, thunderstorms and other hazardous weather.

- Based on worldwide balloon (RAOB) observations at 00Z and 12Z daily.
- These are used as input to numerical weather prediction codes which produce hourly predictions.
- Many Internet sources:
  - http://rucsoundings.noaa.gov/plot_soundings.cgi? (java)
    http://rucsoundings.noaa.gov/gifs/ (bookmark-able gif)
  - http://weather.unisys.com/upper_air/skew/ (Raobs)

The temperature axis is skewed to the right (skew-T)
The vertical axis is pressure altitude (logP)

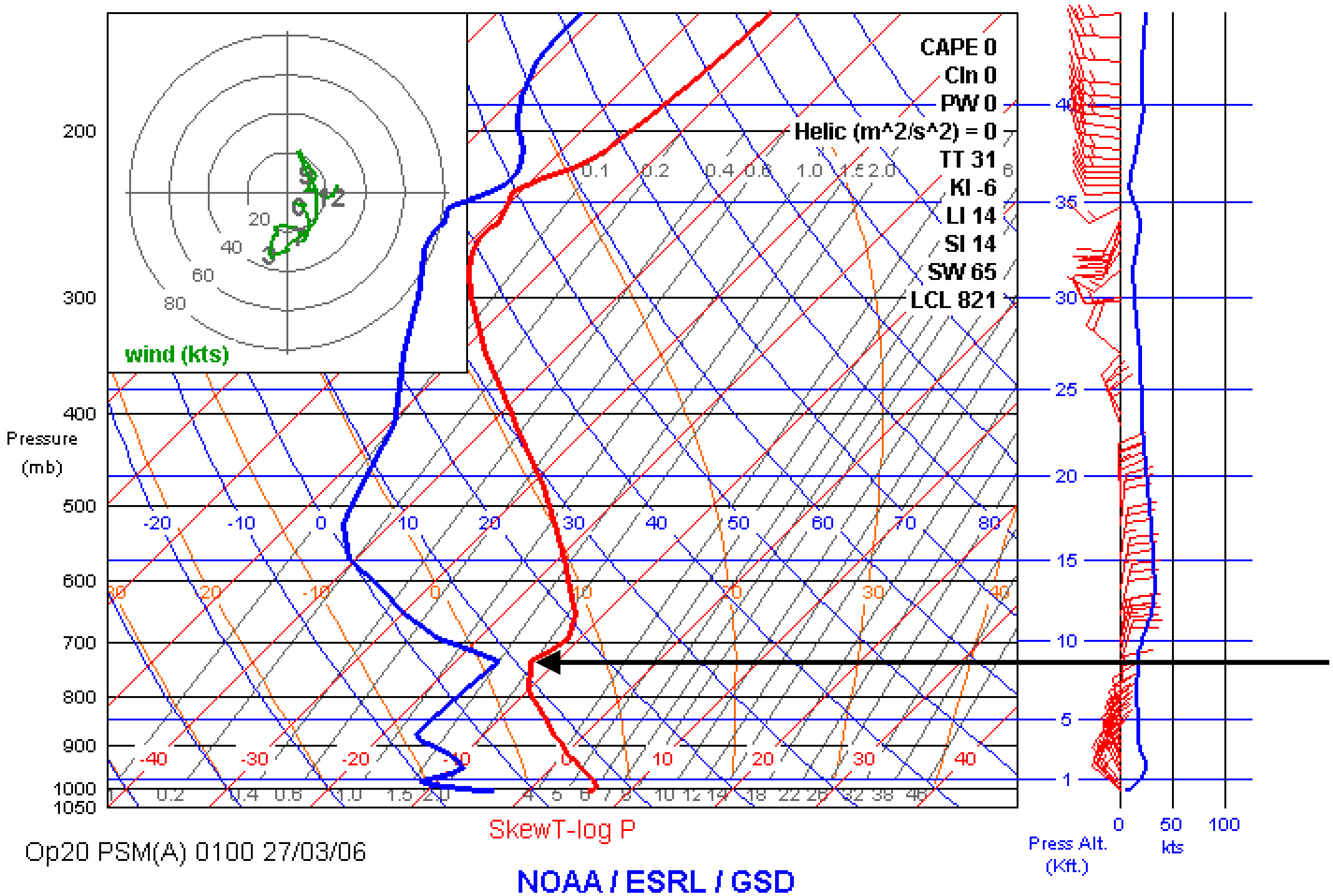


A “standard” atmosphere temperature sounding slopes slightly to the left in the troposphere.



ISA: 15°C at SL, decreasing 2°C/1000’ to the tropopause, then constant @ -56°C

Cloud layers are anticipated where the temperature and dewpoint are close.



KPSM 270055Z 33011KT 20SM OVC080 06/M03 A2990 RMK SLP128

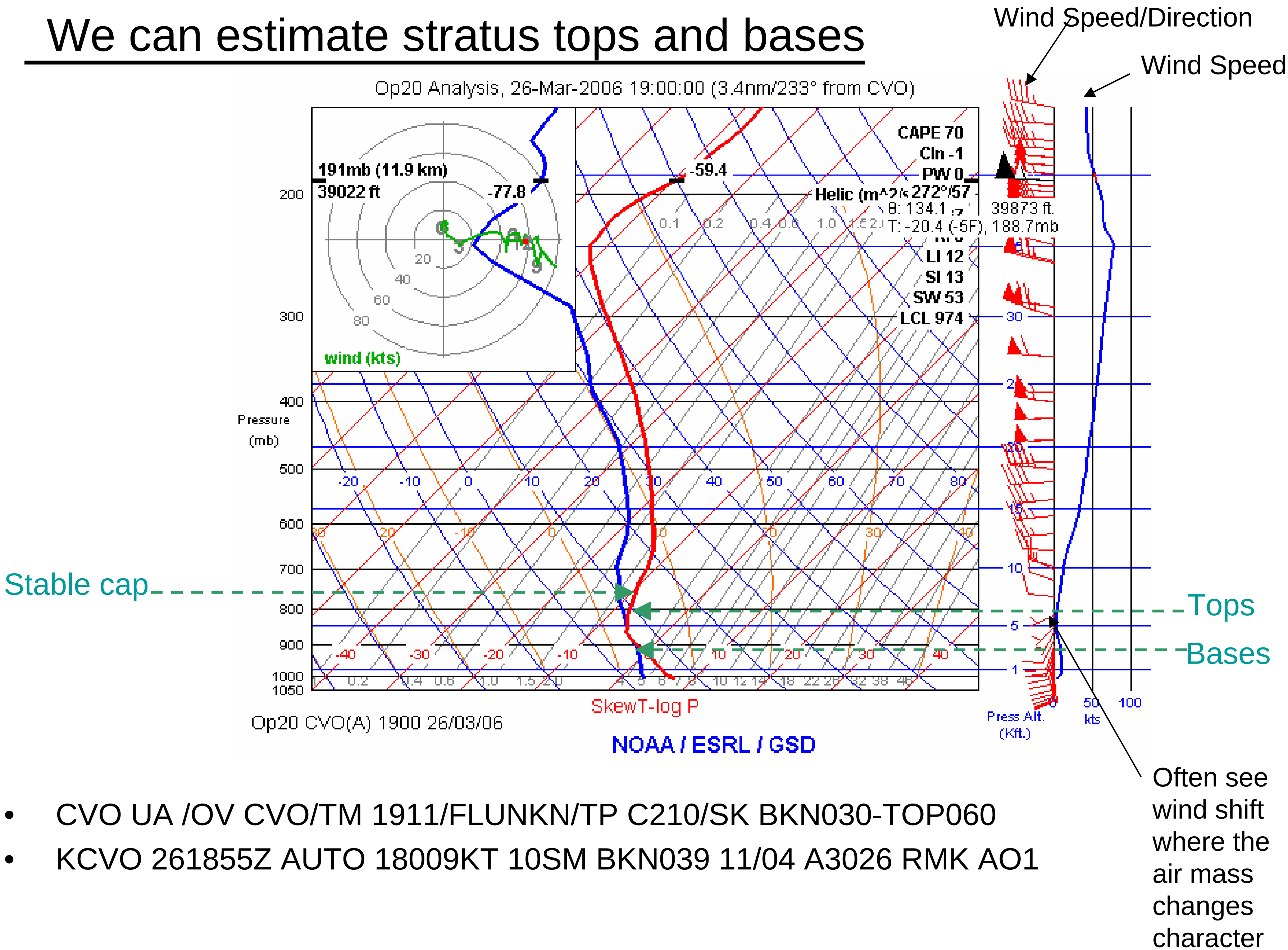
T_{dd} = Temperature – Dewpoint = 0 °C => Overcast cloud layer/fog.

- The forecast soundings represent an average over a 13km square, so layers that are less than overcast have dewpoint depressions >0°C.
- (Dew point depression, T_{dd} is Temperature – Dewpoint)
- OVC T_{dd} ~0°C
- BKN T_{dd} ~ 1° or 2°C
- SCT/FEW T_{dd} ~3°,4°,5° C
- However, the above depends somewhat on temperature. Below -25°C clouds may be associated with T_{dd}'s >6°C. OTOH, near the surface and in warm temperatures, smaller T_{dd}'s may be required…
- These considerations apply to *stratus* clouds in *stable* air – in *unstable* air clouds can build up into dryer air above - see later.
- In precipitation, the T_{dd}'s will be low even if there are gaps between the layers

More details on estimating tops and bases…

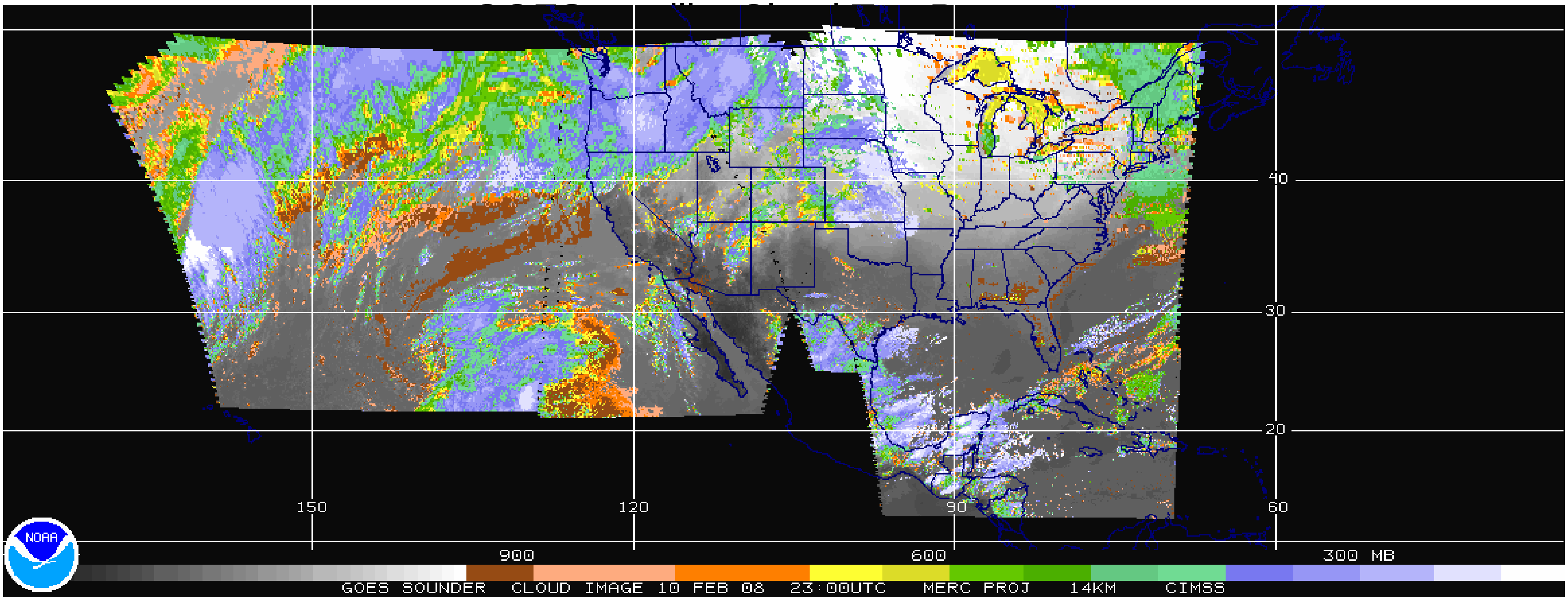
- ***Cloud layers* – The following rules are taken from the U.S. Air Force AWS/TR-79/006 manual**
- **A cloud base is almost always found in a layer (indicated by the sounding) where the dew-point depression decreases.**
- **The dew-point depression usually decreases to between 0°C and 6°C when a cloud is associated with the decrease. In other words, we should not always associate a cloud with a layer of dew-point decrease but only when the decrease leads to a minimum dew-point depression <6”C; at cold temperatures (below -25”C), however, dew-point depressions in cloud are reported as > 6°C.**
- **The dew-point depression in a cloud is, on the average, smaller for higher temperatures. Typical dew-point depressions are 1°C to 2°C at temperatures of 0°C and above, and 4°C between -10°C and -20°C.**
- **The base of a cloud should be located at the base of the layer of decreasing dewpoint depression, if the decrease is sharp.**
- **If a layer of decrease of dew-point depression is followed by a layer of stronger decrease, the cloud base should be identified with the base of the layer of strongest decrease.**
- **The top of a cloud layer is usually indicated by an increase in dew-point depression. Once a cloud base is determined, the cloud is assumed to extend up to a level where a significant increase in dew-point depression starts. The gradual increase of dew-point depression with height that occurs on the average in a cloud is not significant.**

We can estimate stratus tops and bases



- CVO UA /OV CVO/TM 1911/FLUNKN/TP C210/SK BKN030-TOP060
- KCVO 261855Z AUTO 18009KT 10SM BKN039 11/04 A3026 RMK AO1

There are dedicated products for cloud top heights



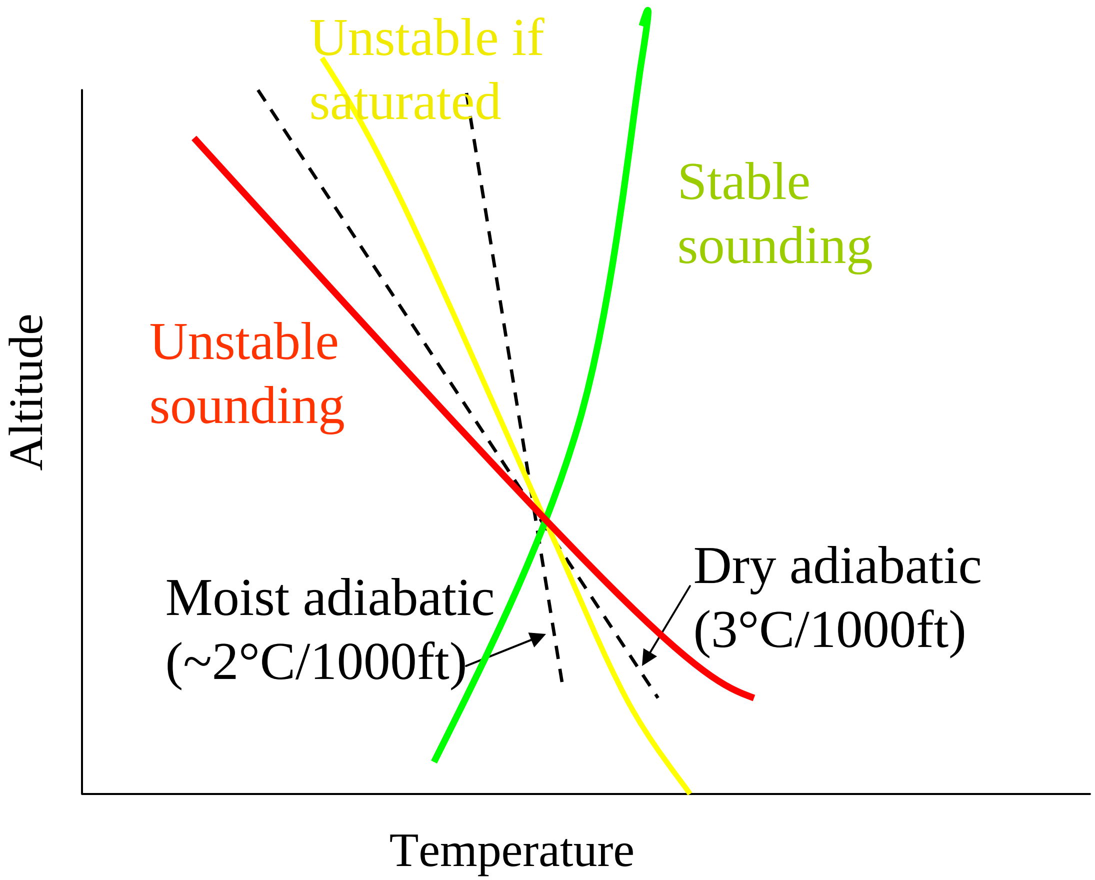
This product derives cloud top heights from IR spectral measurements from the GOES satellites.

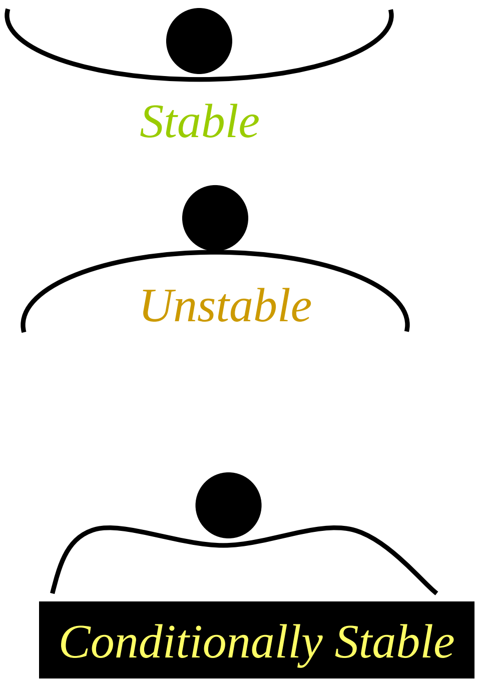
http://cimss.ssec.wisc.edu/goes/realtime/grtmain.html#ctop

The CIP tops incorporate RUC simulation data.

Plus satellite, pilot reports and other data.

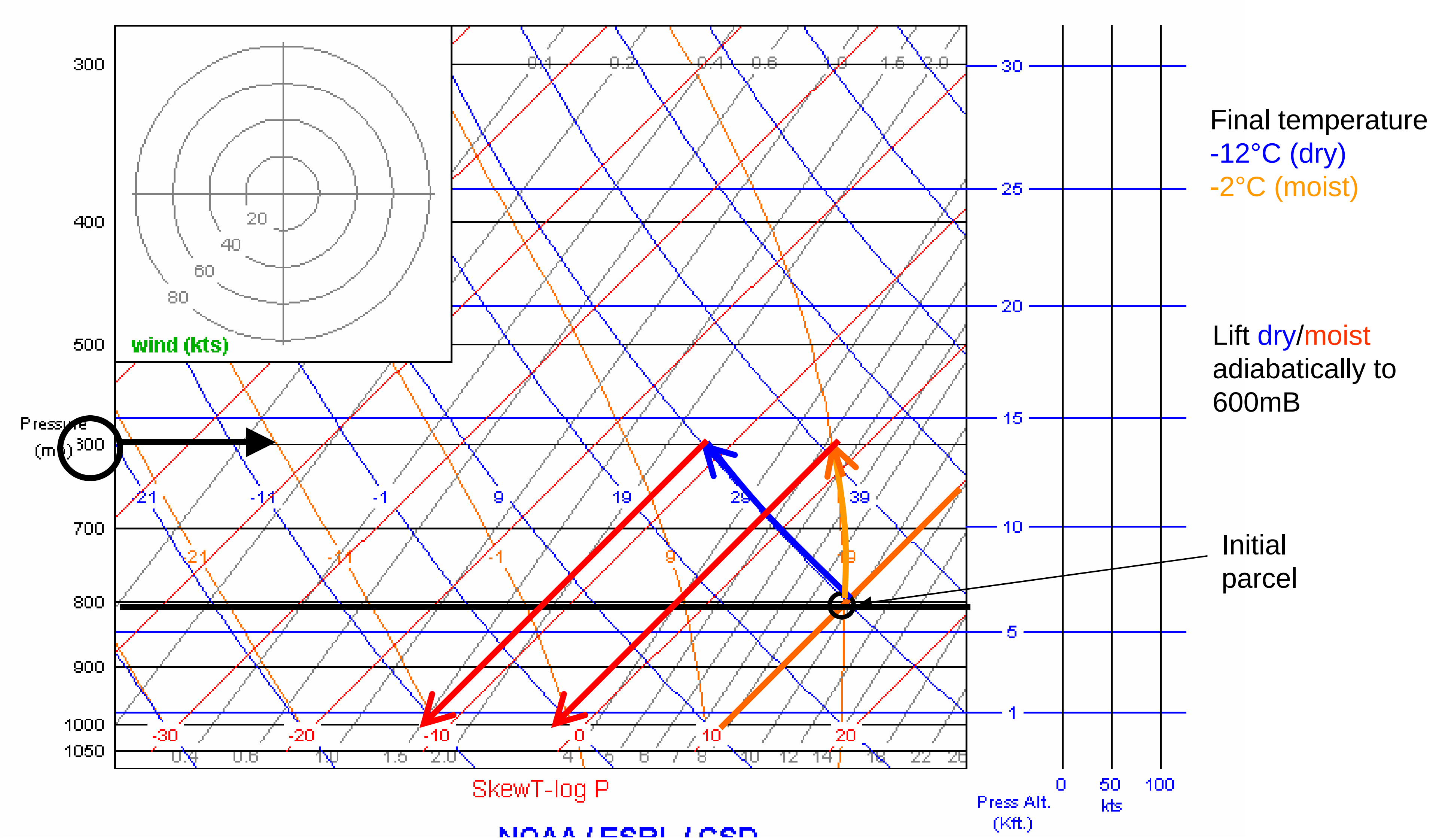
Instability results if the ambient lapse rate exceeds the adiabatic lapse rate



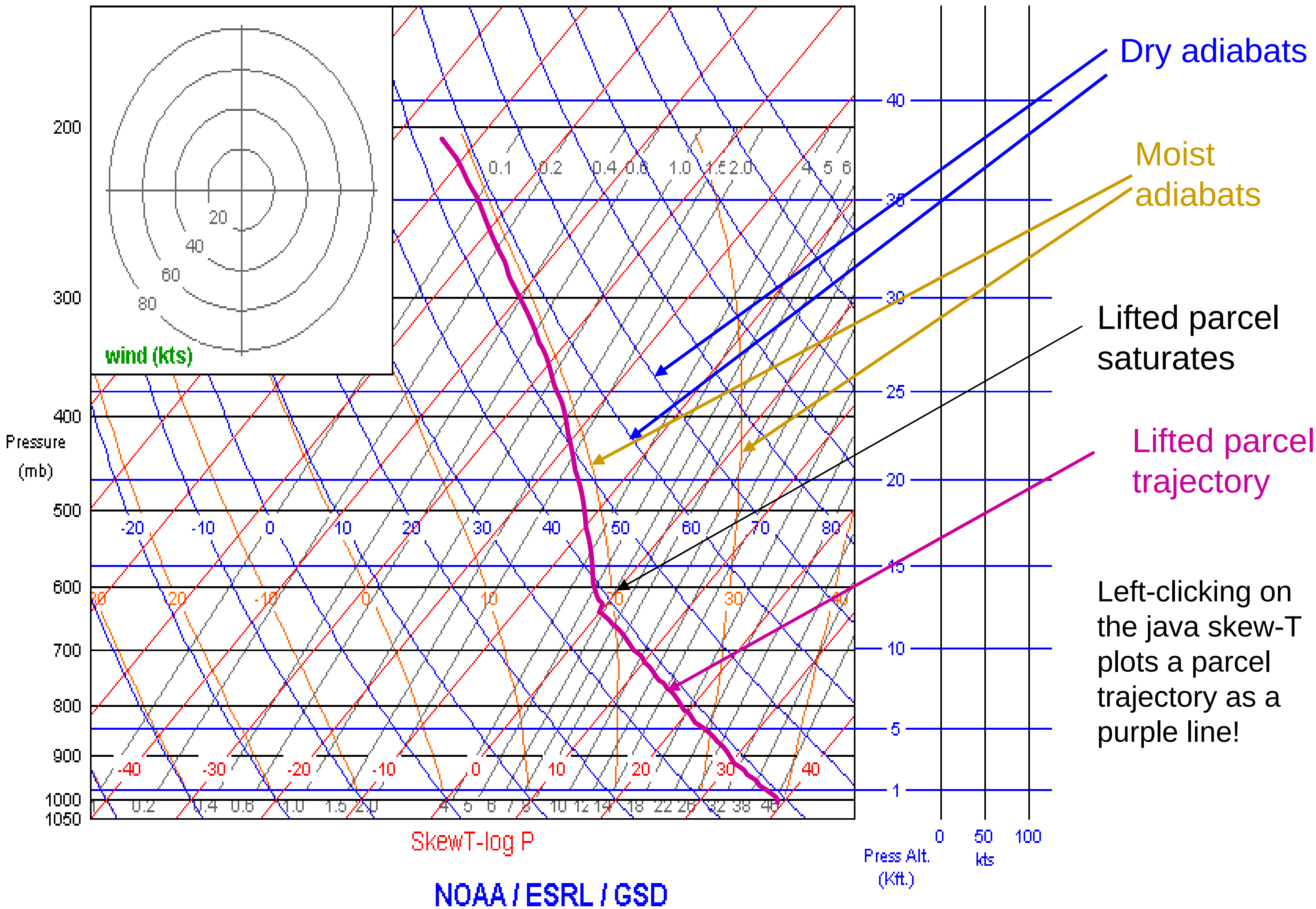


Conditional instability when the ambient lapse rate lies between the dry and moist rates. The air is then unstable if it is/becomes saturated.

?? A parcel at 10C is lifted from 800mB to 600mB (a) dry adiabatically (b) moist adiabatically, what will be its final temperature??

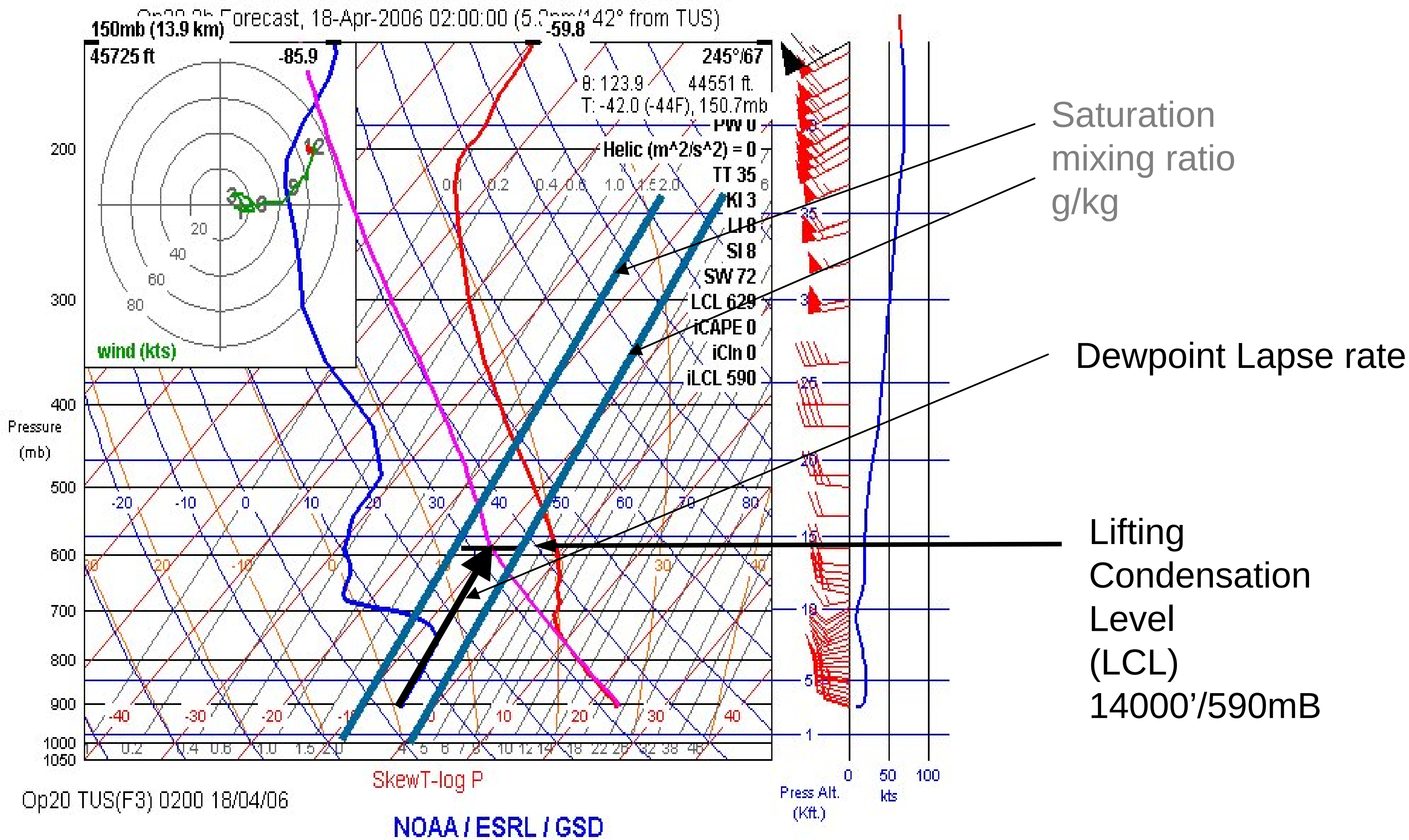


A lifted parcel will follow a dry adiabat until it saturates - then the moist one.



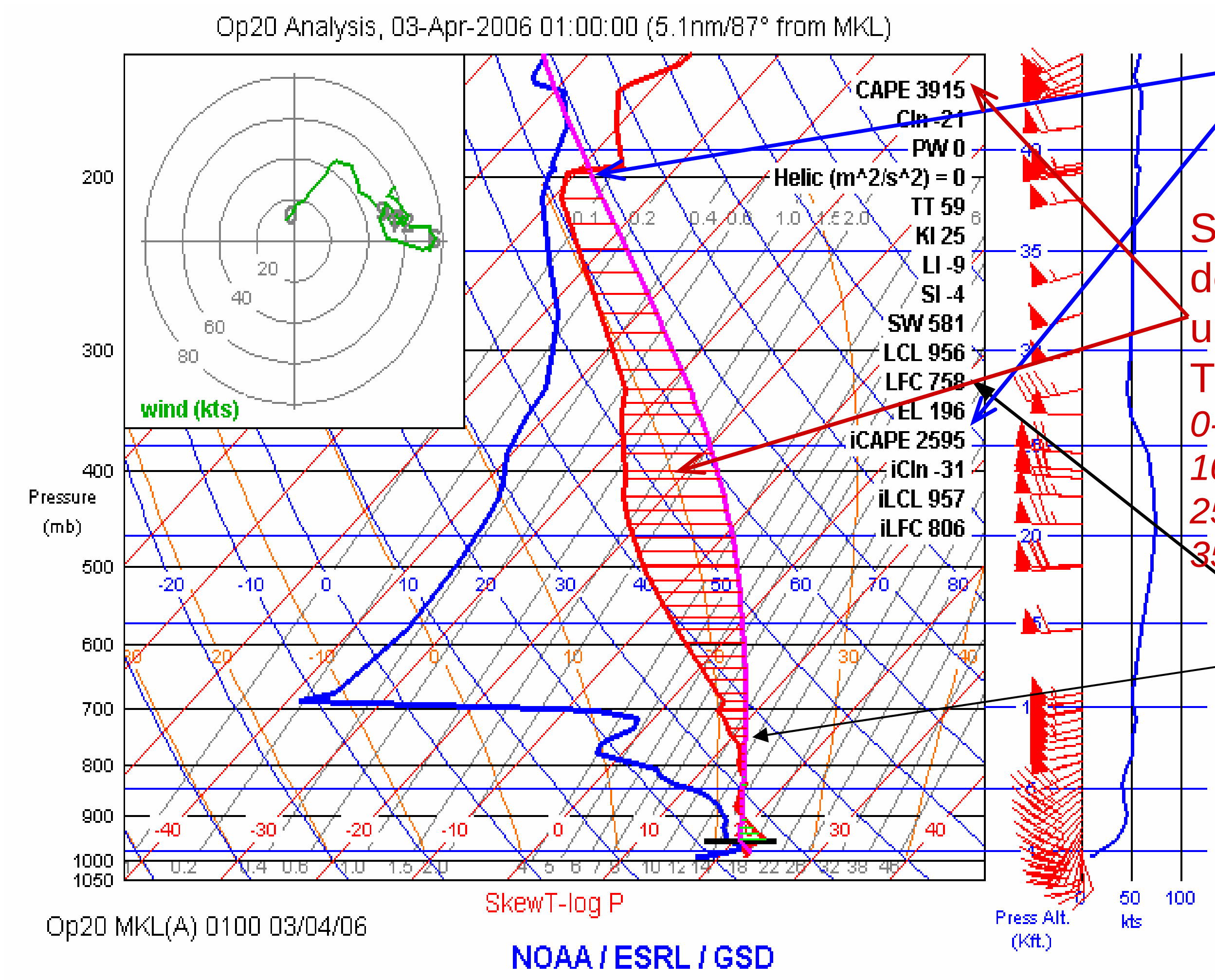
Left-clicking on the java skew-T plots a parcel trajectory as a purple line!

The grey lines slanting to the right tell us how the dew-point of the lifted parcel decreases with altitude.
It crosses the parcel's dry adiabat at the LCL.



Air is stable – purple line left of red => lifted parcel cooler than the environment

Jackson, Tennessee just before tornadoes struck…



Equilibrium level

Shaded area is CAPE: determines maximum updraft speed should TRWs develop.

0-1000 Marginally unstable

1000-2500 Moderately unstable

2500-3500 Very unstable

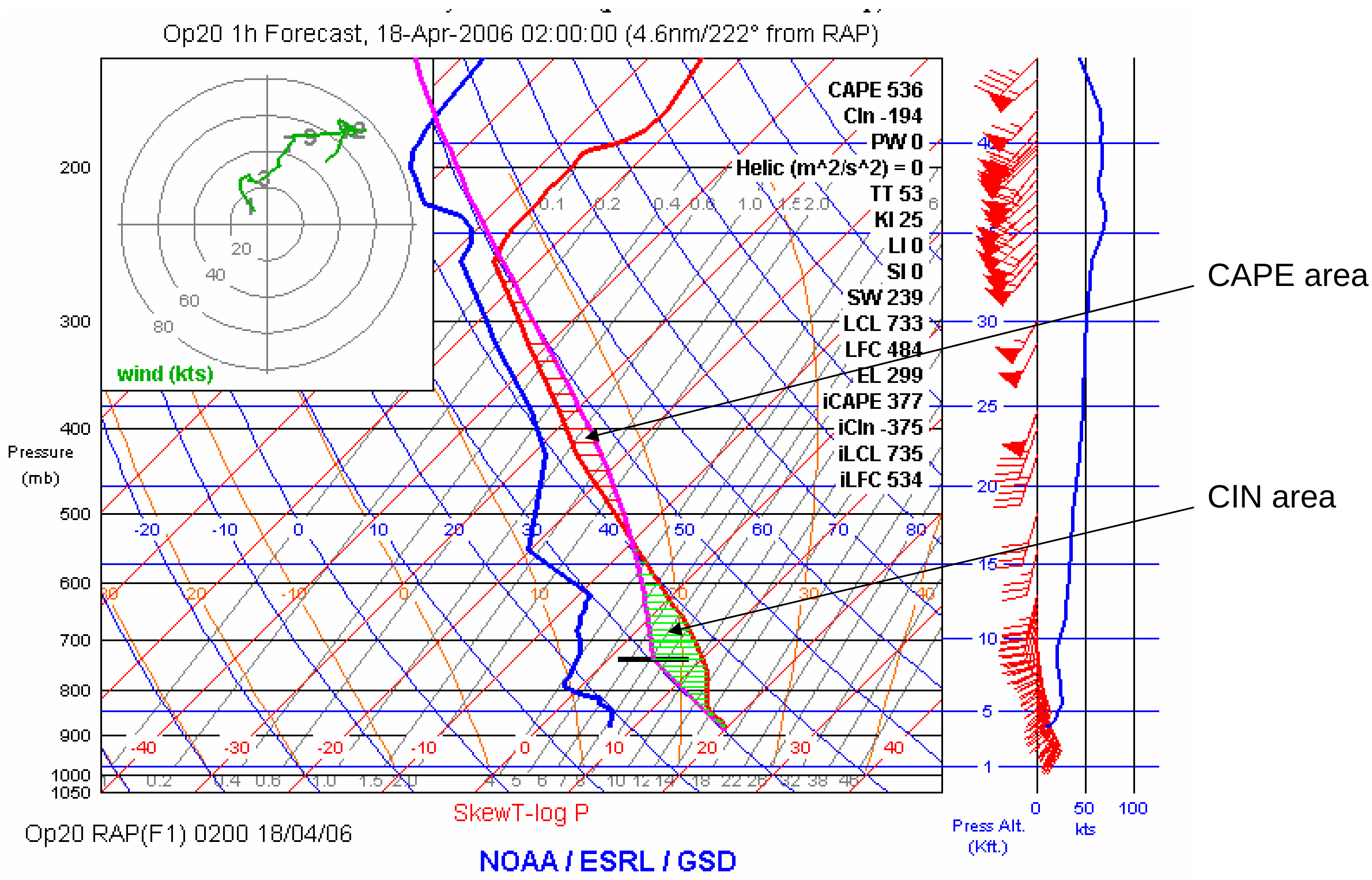
3500+ Extremely Unstable

Level of Free Convection (LFC)

Once the Cu tops punch through the LFC they'll build up through the Equilibrium Level. (EL)

Purple line right of red means lifted parcel warmer than environment – unstable!

The green shaded area is the Convective Inhibition (Cin). It's a measure of the strength of the lifting required to get parcels to the LFC.

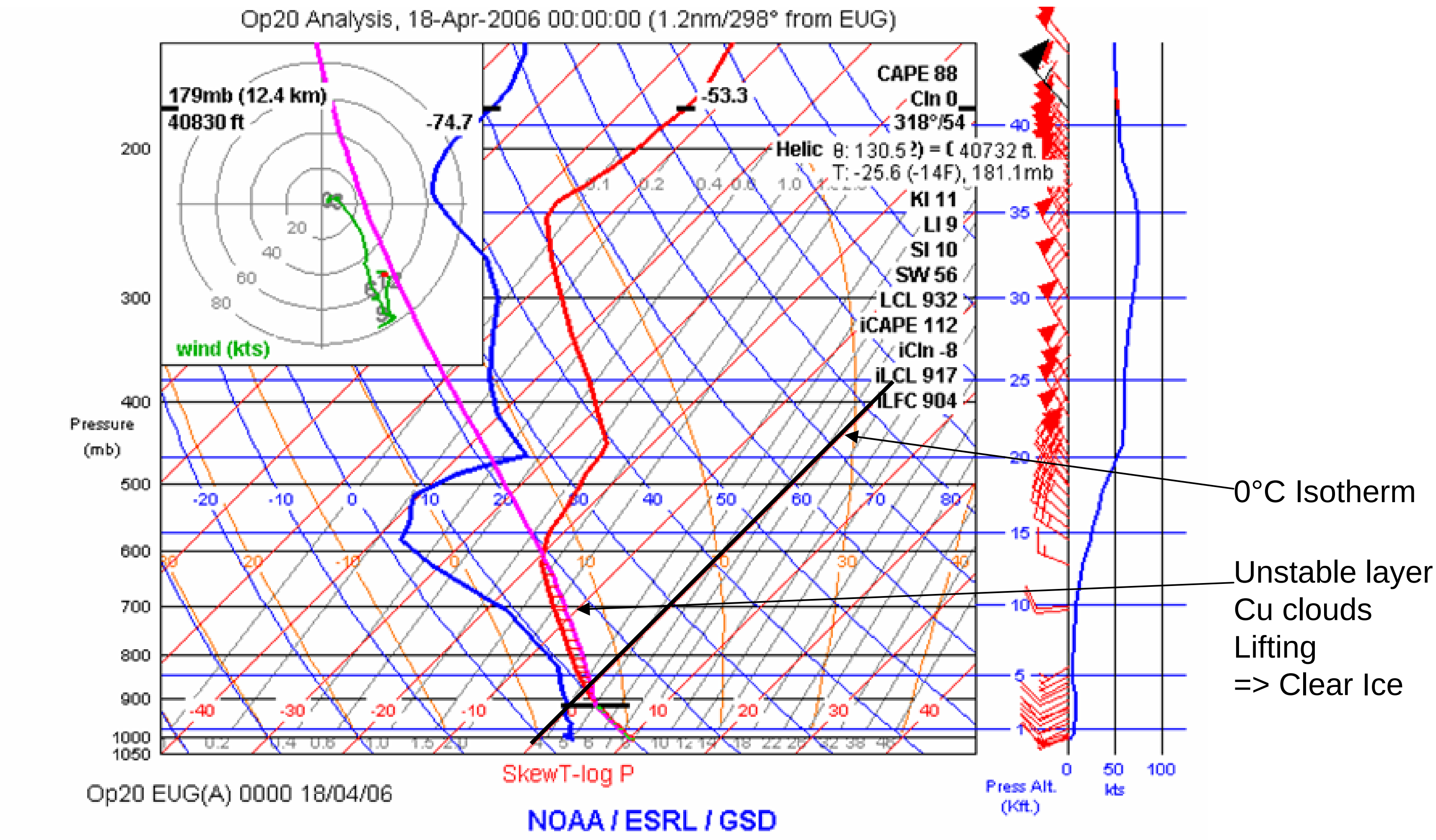


In fact, a few hours later a cold front triggered TRWs – despite the low CAPE.

The Skew-T/log-P is a great tool to check on potential icing conditions.

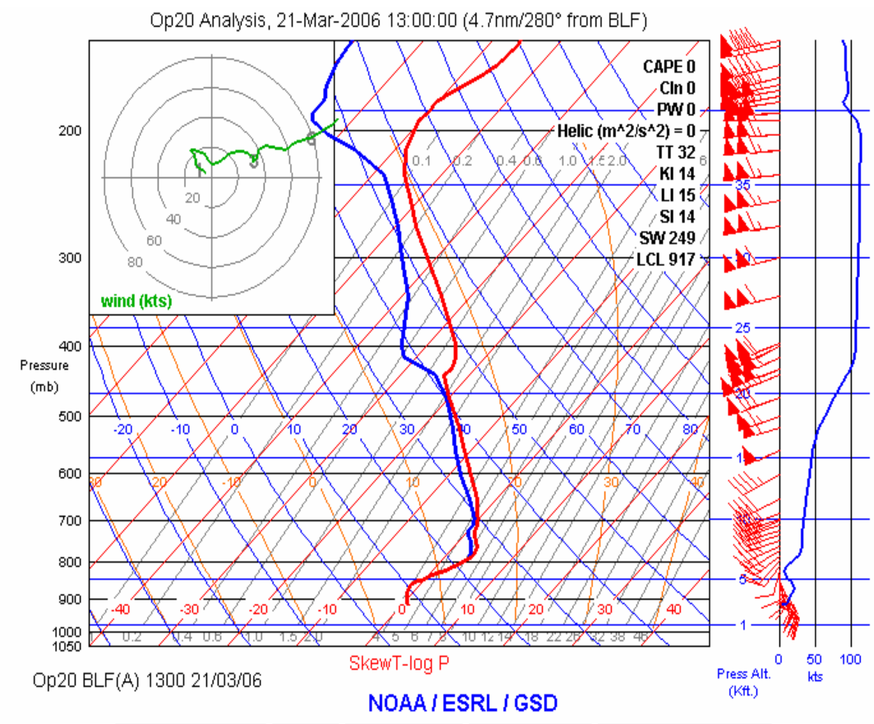
- Structural icing requires below freezing temperatures and visible moisture – clouds or precip.
- Freezing level(s) available on Skew-T (Note that freezing level graphics don't show if there are multiple freezing levels, which makes freezing rain a possibility.
- First, check the dedicated reports & forecasts e.g.
  - http://aviationweather.gov/exp/cip/ (current – including SLD)
  - http://aviationweather.gov/exp/fip/ (forecast out to 12 hours)
  - http://adds.aviationweather.gov/pireps/java/ (Pirep tool)

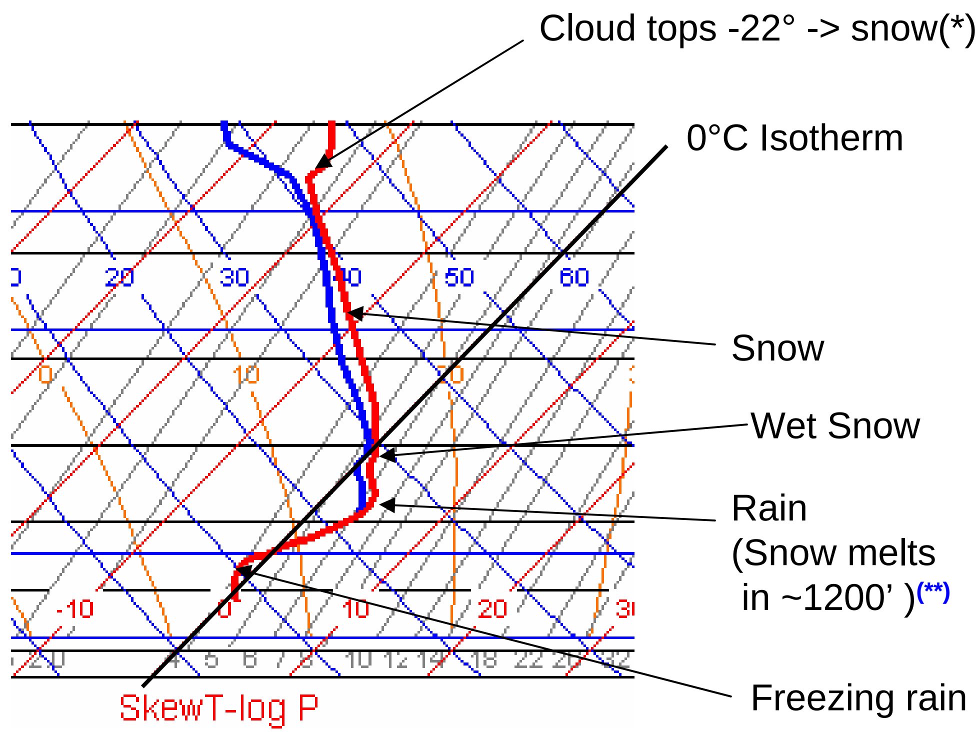
This BE99 pilot experienced moderate clear icing at 10000'



EUG UA /OV EUG160015/TM 0107/FL100/TP BE99/TA M07/IC MOD CLR/RM -ZSE

Here’s a sounding at BLF for freezing rain.





(*) When CTTs are <-10C snow ice crystal nuclei grow rapidly by the Bergeron process

(**) Snow melts more rapidly in warm air, if the air is moist or if the flakes are small and vice-versa.
http://www.theweatherprediction.com/habyhints/208/

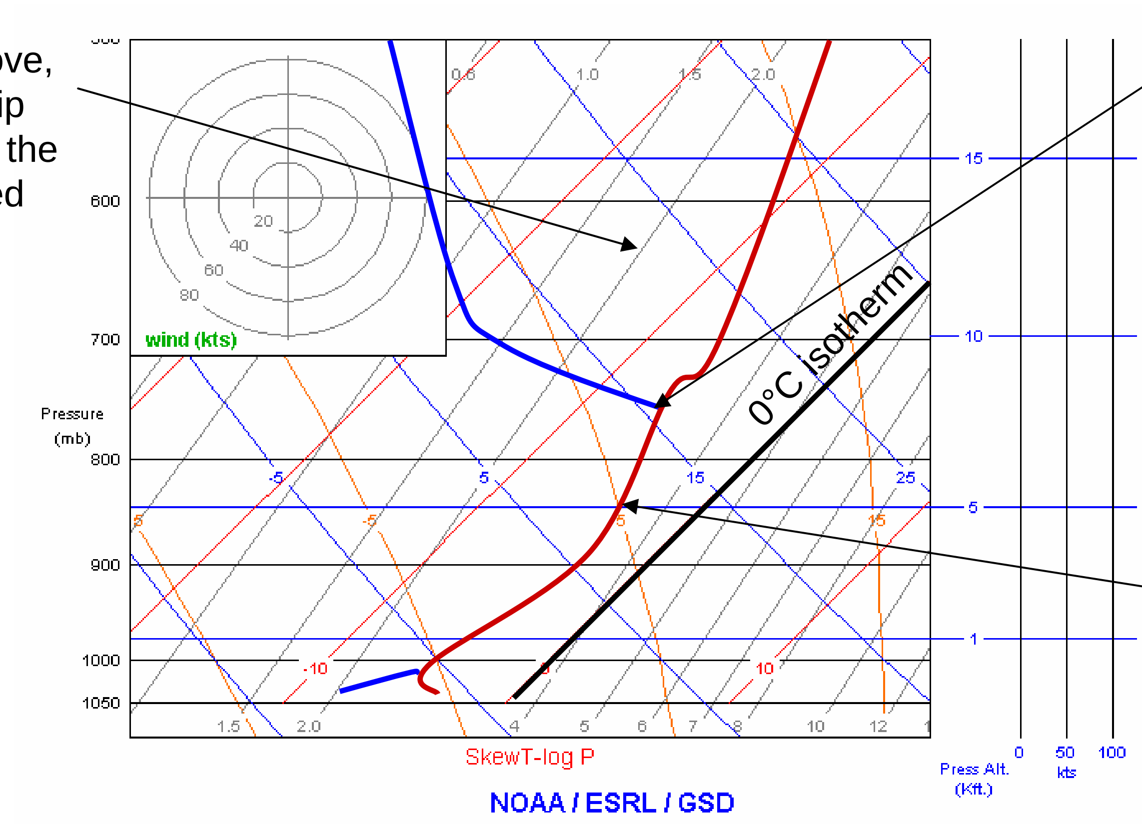
KBLF 211337Z AUTO 13009G18KT 8SM -FZRA BKN010 BKN019 OVC023 02/M01 A2973 RMK AO2 CIG 007V013 P0003

KBLF 211326Z AUTO 13011G20KT 100V170 3SM FZRA BKN010 BKN014 OVC021 02/M01 A2974 RMK AO2 CIG 007V011 P0002

KBLF 211252Z AUTO 12012G20KT 5SM -FZRA FEW006 BKN010 OVC026 02/M01 A2973 RMK AO2 RAE1157FZRAB1157 CIG 008V014 SLP078 P0009 T00171011

Freezing drizzle frequently (mostly!) occurs when the entire stratus cloud is below freezing!

Dry air above, so no precip to strip out the supercooled moisture below.



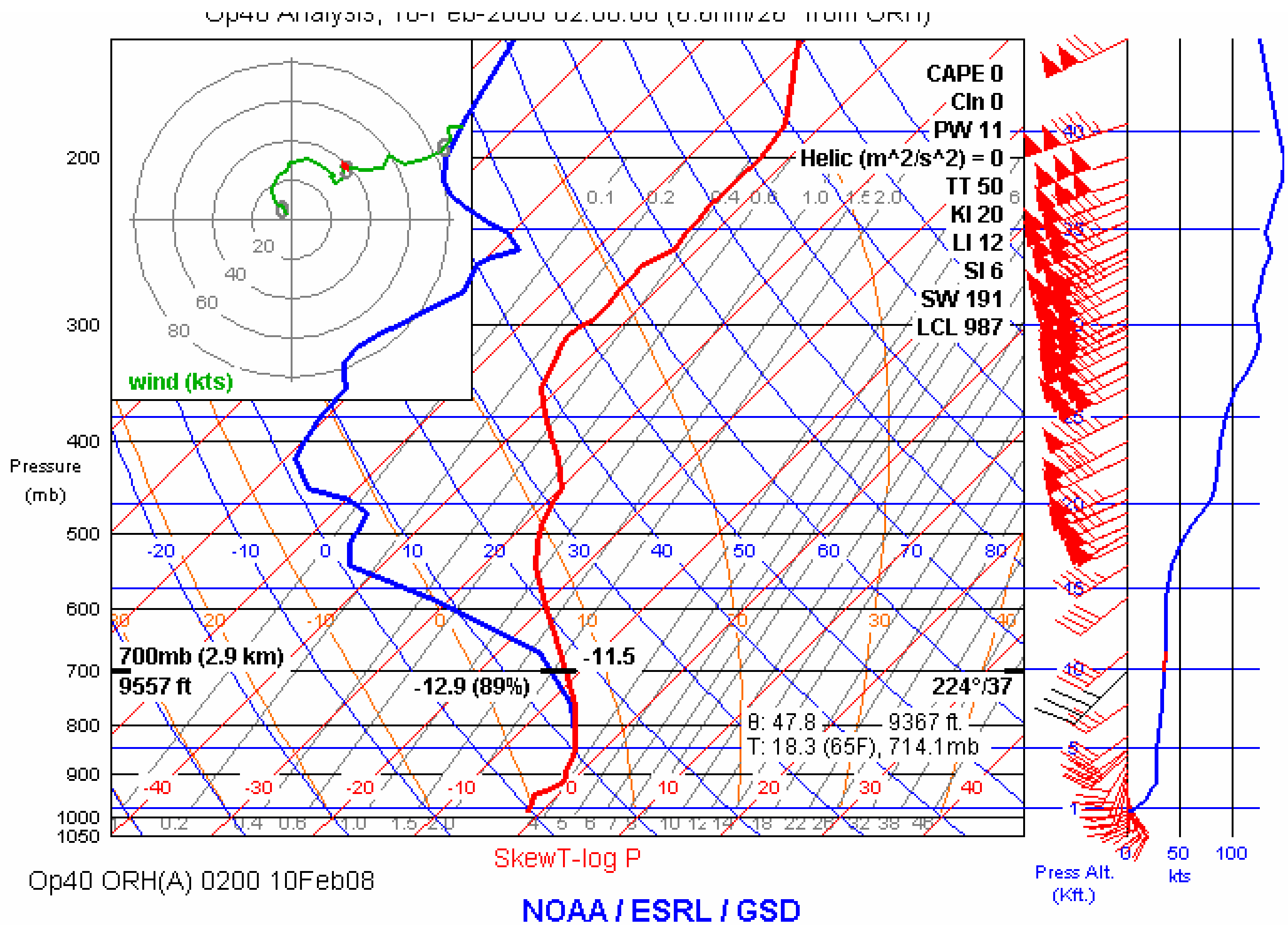
CTT -7°C (*)

(*) When cloud top temperatures >-10°C no ice crystals. Supercooled drops grow by the inefficient collision/coalescence mechanism. Don't get big enough to fall rapidly.

Stable saturated layer/
Inversion
Sub-freezing stratus.

- In this situation, climbing will not put you in above freezing temperatures to melt off the ice. You can try to get on top, though.
- Severe icing possible in the SCDD 500' – 8000'!

Fog at KORH



KORH 100254Z AUTO 14006KT 1/4SM R11/P6000FT -SN FZFG BKN001 OVC005 M01/M02

Tops ~12000 CTTs ~ -12C   - icy climb!

A classic mountain wave scenario

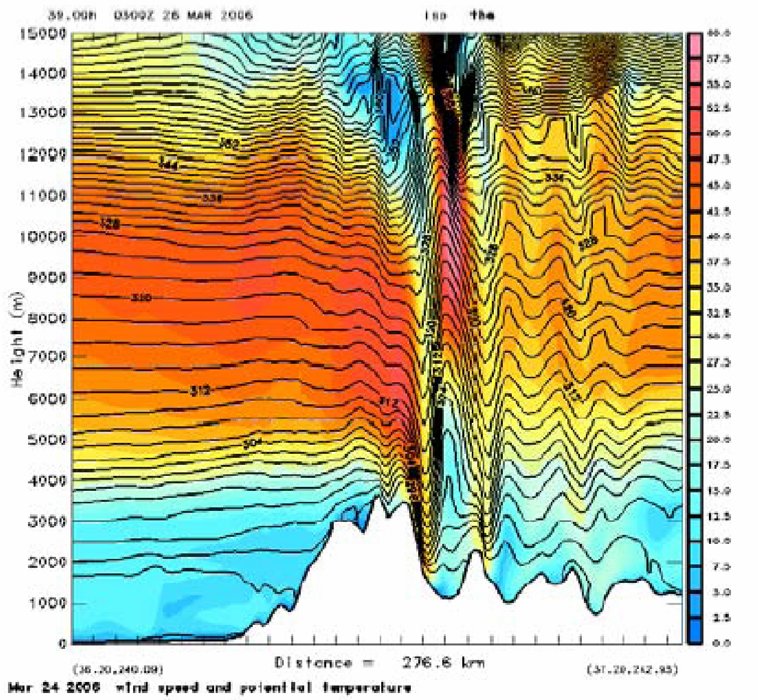


Figure 14. East-west vertical cross section from the 2-km NRL COAMPS centered over Independence, CA at 0300 UTC 26 March 2006. The color image depicts the wind speed (m s^{-1}). The black lines depict lines of potential temperature.

- Stable layer above ridge height sandwiched between two adiabatic layers.
- Wind direction not changing with height and perpendicular to the ridge line.

THE 22[ND] CONFERENCE ON WEATHER ANALYSIS AND FORECASTING
18[TH] CONFERENCE ON NUMERICAL WEATHER PREDICTION

FORECAST CHALLENGES AND IMPACTS OF SEVERE DOWNSLOPE WIND EVENTS

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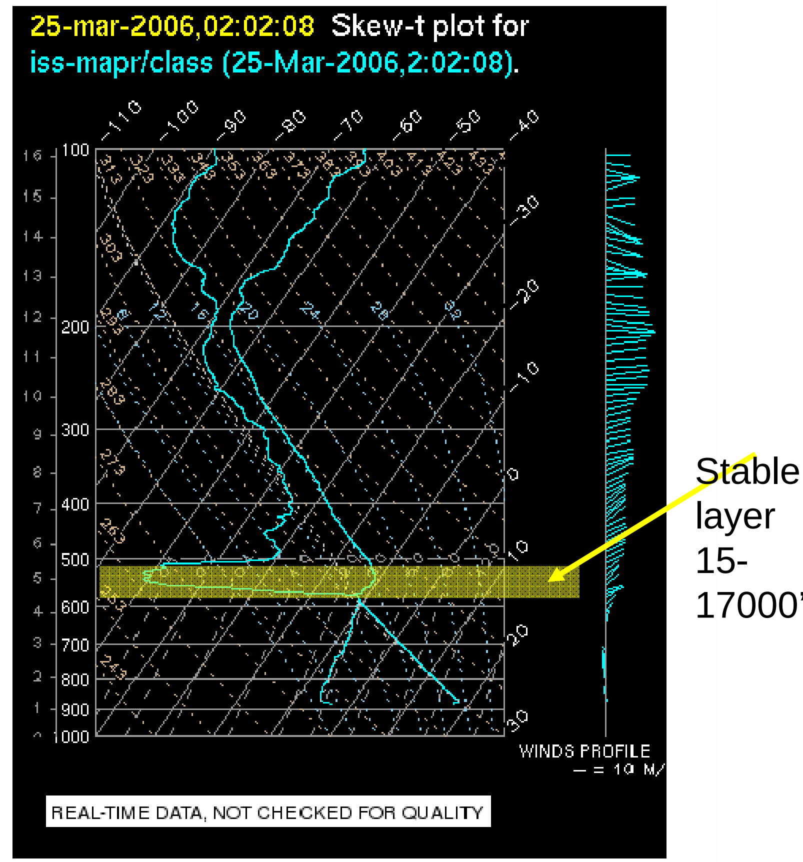

Figure 20. Skew-T Log P thermodynamic sounding from NCAR's MAPR in Independence at 0202 UTC 26 March 2006. The horizontal wind speed (m s^{-1}) and direction are shown to the right.

The Skew-T is a great tool but not the primary source of weather info!

- Go to the traditional sources – METARs, TAFs, PIREPs etc. first.
- The Skew-T can be useful to fill in some unknowns – eg tops and to assess why the forecasts are as they are.
- Caveat: the numerical models don't handle precip very well. They predict high humidities throughout, not resolving cloud layers within.

- http://williams.best.vwh.net/weather/weather.html My links to useful weather data sources
- http://www.theweatherprediction.com/thermo/ Jeff Haby on Skew-T's
- http://chesavtraining.com/ Scott Dennstaedt Meteorologist/CFII Offers weekend and net courses on weather.
- http://meted.ucar.edu/ Home of COMET meteorology education and training. Lots of interesting modules…
- http://vortex.weather.brockport.edu/~sweinbec/Skewt_ref/Tr79-006.pdf USAF manual on the use of Skew-T log-P charts.
- http://vortex.weather.brockport.edu/~sweinbec/Skewt_ref/NWS_skewt.pdf NWS training manual on Skew-T log-P charts.
- http://wahiduddin.net/calc/density_algorithms.htm The math…

Practice and validate before you use it to make decisions of consequence!