Different Convective Indices

- - -

How appropriate they are/will be using future satellite data sources?

Ralph A. Petersen[1]

[1] *Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin – Madison, Madison, Wisconsin, USA*

*Will additional input from **Steve Weiss**, NOAA/NWS/Storm Prediction Center*

✓ Increasing the Utility / Value of real-time Satellite Sounder Products to fill gaps in their short-range forecasting processes

Creating Temperature/Moisture Soundings from Infra-Red (IR) Satellite Observations

A Conceptual Tutorial

All level of the atmosphere is continually emit radiation toward space.

Satellites observe the net amount reaching space.

- Conceptually, we can think about the atmosphere being made up of many thin layers

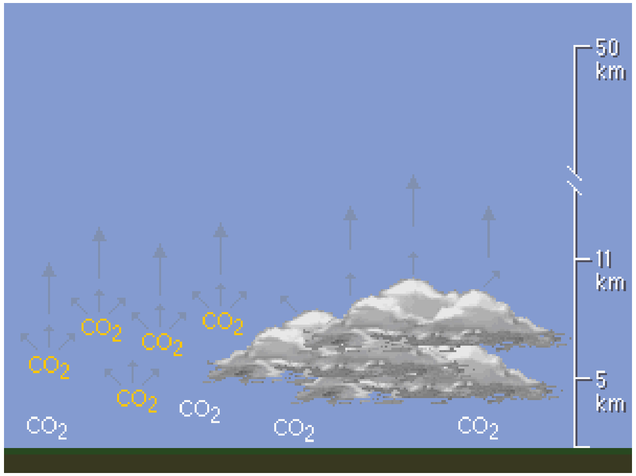
  Start from the bottom and work up.

  1 – The greatest amount of radiation is emitted from the earth's surface

  - *Remember, Stefan's Law: Emission* $\sim \sigma T_{Sfc}^4$

  2 – Molecules of various gases in the lowest layer of the atmosphere absorb some of the radiation and then reemit it upward to space and back downward to the earth's surface

  - Major absorbers are CO_2 and H_2O
  - *Emission again* $\sim \sigma T^4$*, but* $T_{Atmosphere} < T_{Sfc}$
    - *Amount of radiation decreases with altitude*



The COMET Program

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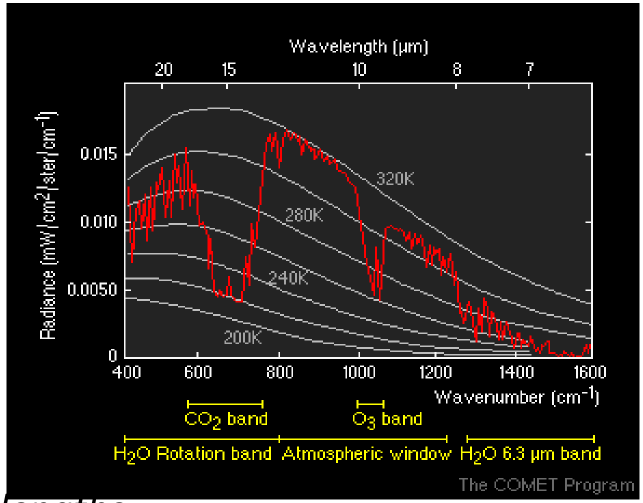
  - *Emission again ~* σT^4, *but* $T_{Atmosphere} < T_{Sfc}$

    - *Amount of radiation decreases with altitude*

  - *Wavelength of radiation related to 1/T*

    - *Colder temperatures layers emit at longer wavelengths*



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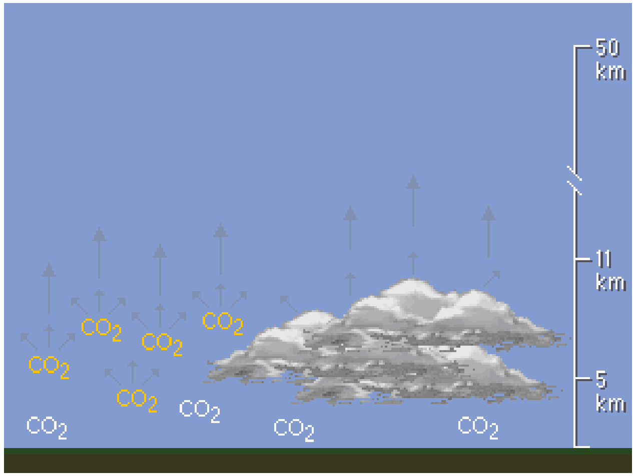
  - *Emission again ~* σT^4*, but* $T_{Atmosphere} < T_{Sfc}$

  3 – Process repeats to the top of the atmosphere

  - *Absorbing Gas concentrations change with elevation*
    - *CO_2 fairly constant, H_2O decreases with height*



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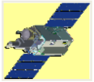
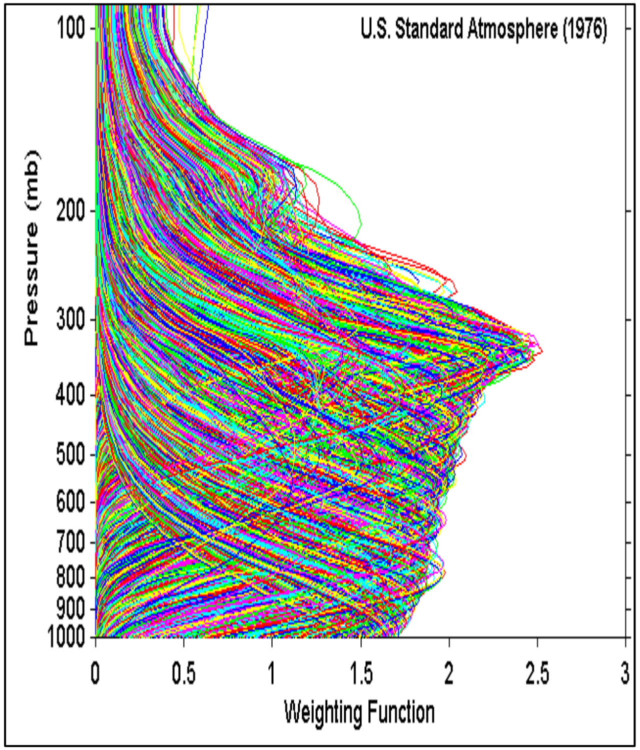


Satellites observe radiation emitted by deeper layers of the earth's atmosphere

- Depends on IR wavelength and 'observing width' of sensors used on each satellite

- Ideally, we would like thousands of 'narrow' observations at different wavelengths



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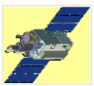

Satellites observe radiation emitted by deeper layers of the earth's atmosphere

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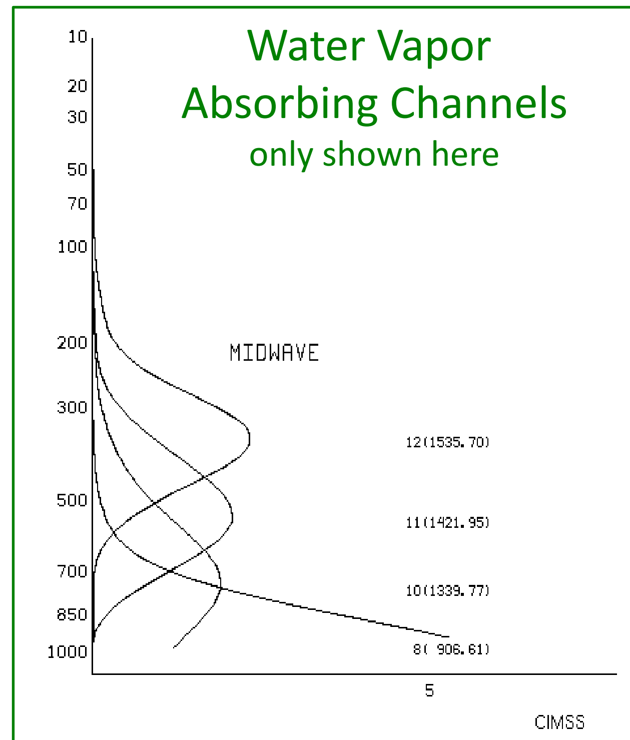
- These are called weighting functions ➔

- Historically, satellite used radiometers that observed many fewer (and wider) spectral regions (*e.g., SEVIRI*)



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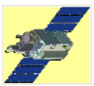

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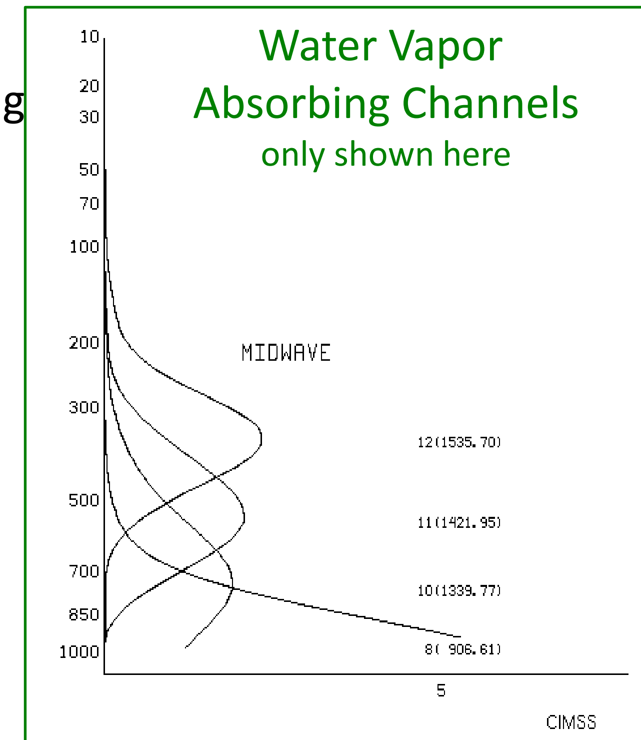
- Soundings are obtained like 'peeling an onion' , starting from the top of the atmosphere an working down



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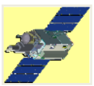

Satellites observe radiation emitted by deeper layers of the earth's atmosphere

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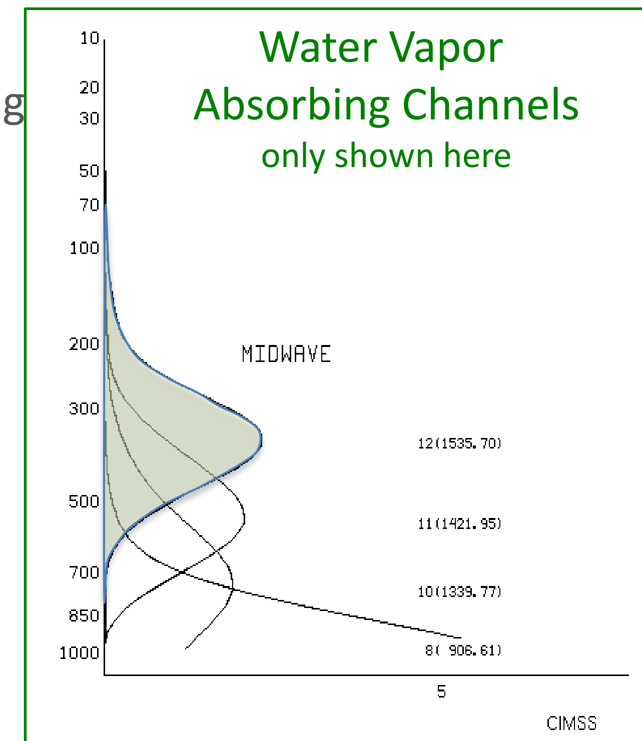
- For moisture, the upper-most channel detects the temperature of the radiation being emitted by upper-most water vapor in the atmosphere

  - The drier the atmosphere is, the farther down in the atmosphere the channel can 'see'



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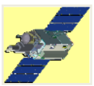

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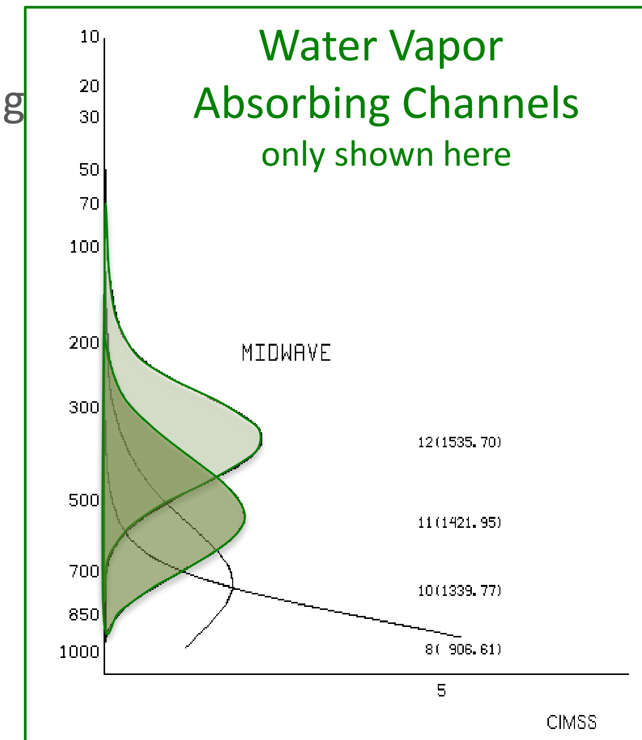
- The next channel measures the temperature of the radiation being emitted by water vapor in the middle troposphere



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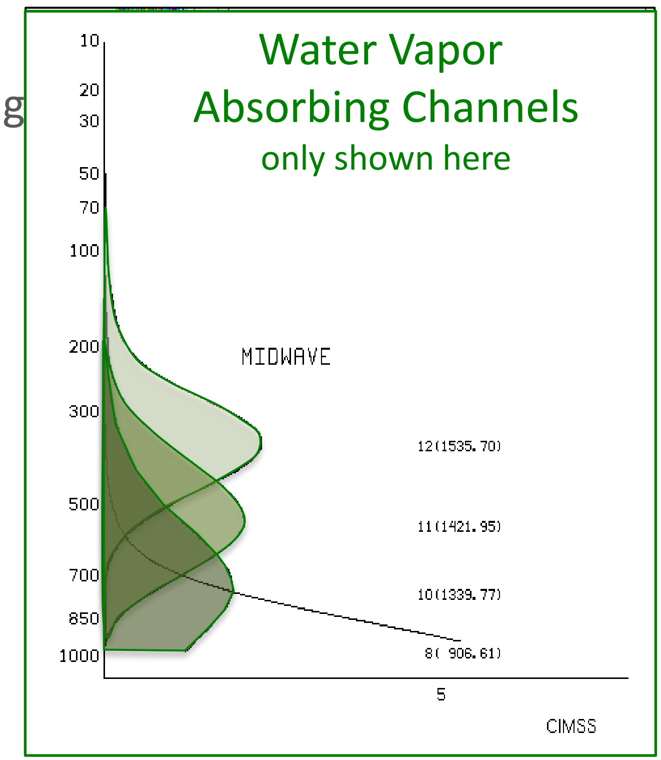
- Soundings are obtained like 'peeling an onion' , starting from the top of the atmosphere an working down

- The bottom channel measures a combination of the temperature of the radiation being emitted by water vapor in the bottom of the troposphere and the temperature of the earth's surface

✔ Problem: Because of the overlap between channels, it is very difficult to obtain one single solution



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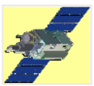
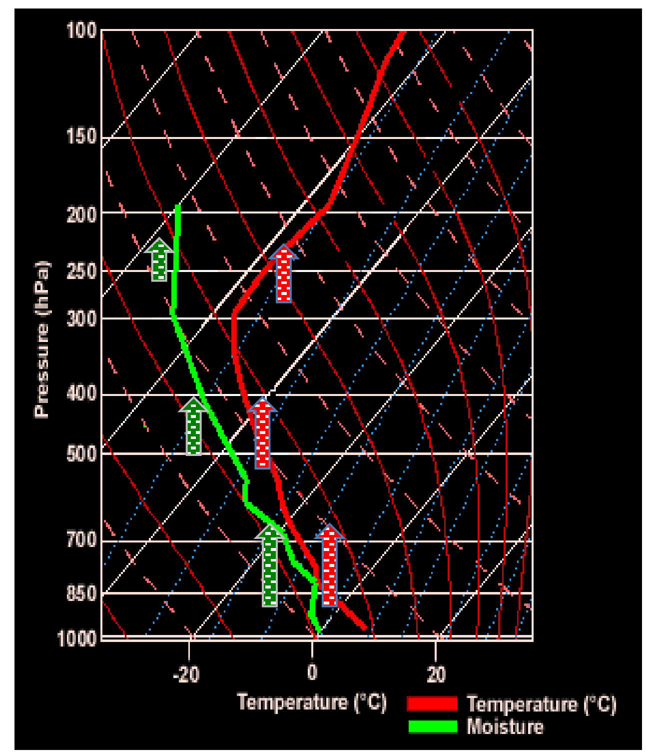


An Alternative Sounding Approach

- Start with a 'first-guess' sounding

  - Climatology or NWP output

- Calculate what the 'outgoing radiation' should be for this 'first guess' sounding, based on the temperature and moisture in layers corresponding to the 'weighting functions' of the satellite sensors



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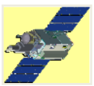
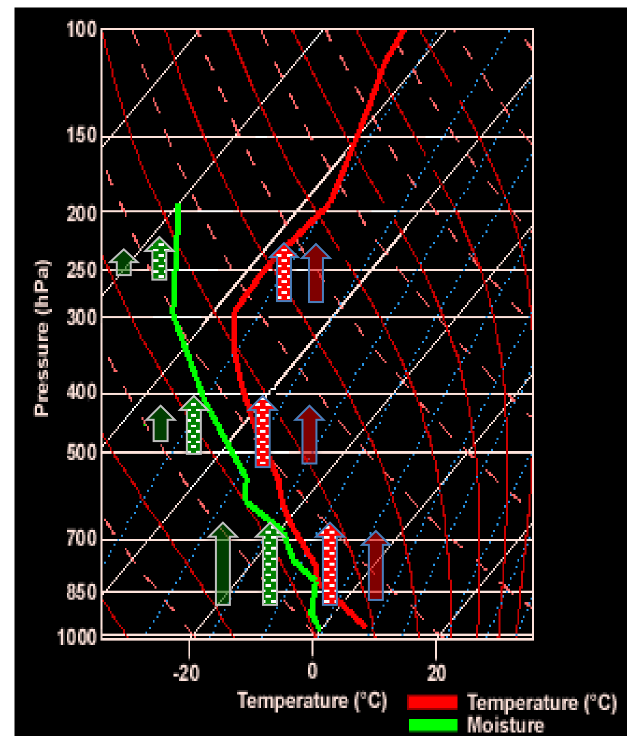


An Alternative Sounding Approach

- The ‘first-guess’ radiances are then compared to the observed radiances in each channel



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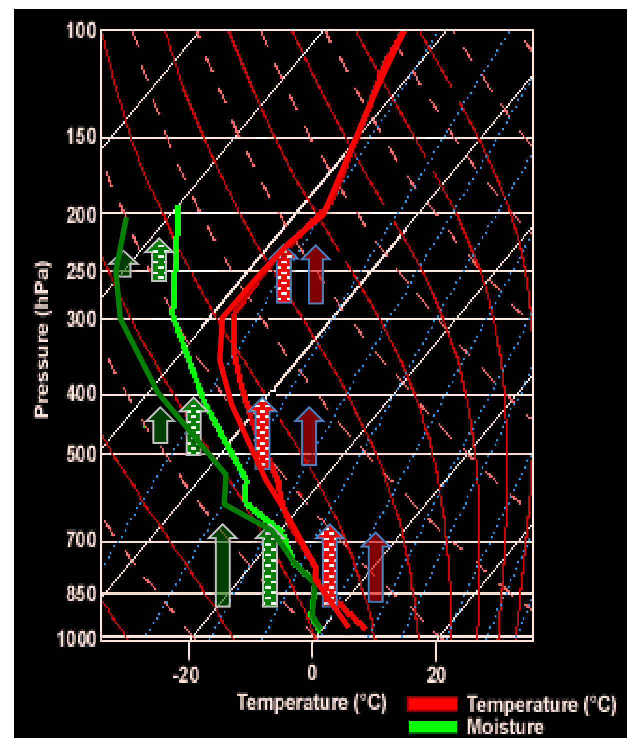
- The 'first-guess' radiances are then compared to the observed radiances in each channel

  - Adjustments are made to increase or decrease the temperature and/or moisture <u>in deep layers</u> depending on whether the the radiance observations are warmer or colder than those calculated from first guess



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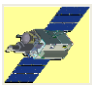 An Alternative Sounding Approach

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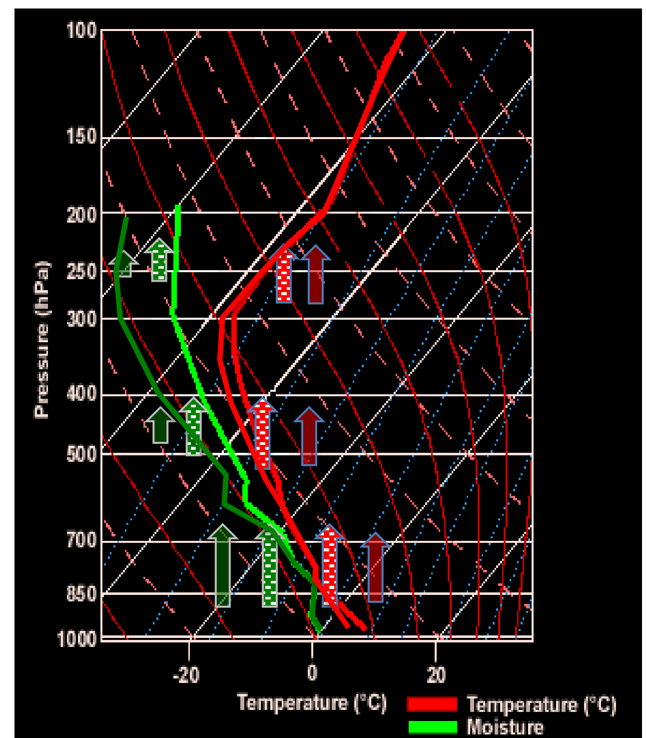
    - Adjustments are made to increase or decrease the temperature and/or moisture <u>in deep layers</u> depending on whether the the radiance observations are warmer or colder than those calculated from first guess
- This process is complicated when using channels that contain information about the vertical structure of both temperature and humidity



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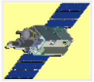

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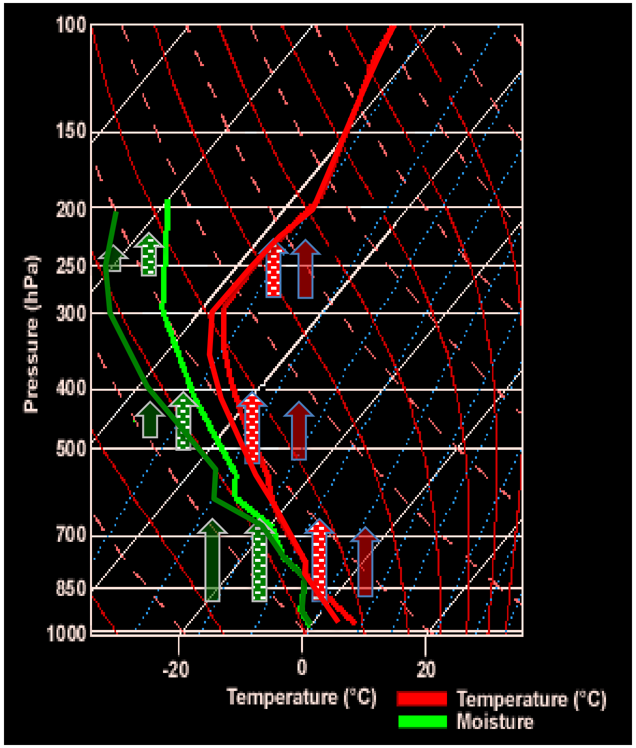
- Because satellites provide information in deep layers defined by instrument weighting functions, all derived products should be consistent with these layers also



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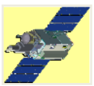

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- Depends on IR wavelength and 'width' of sensors used on each satellite

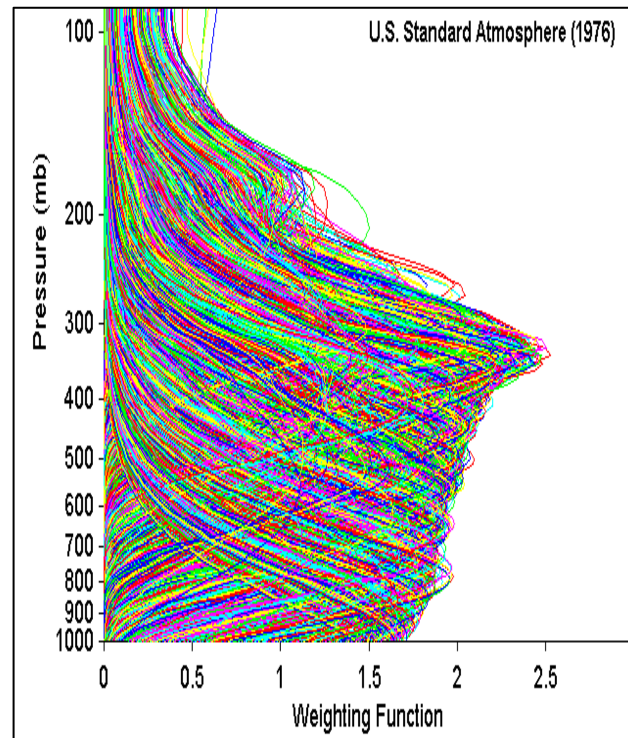
- Ideally, we would like thousands of 'narrow' observations at different wavelengths

  - *Already on Polar-Orbiting Satellites (POES)*

-The MTG Infra-Red Sounder (MTG-S) will do just that

Increased 'spectral resolution' will provide:

- Thinner Layers with Less Overlap (~1 km)
- More frequent observation updates than POES
- Additional information about vertical gradients



Meteosat Third Generation: Mission overview

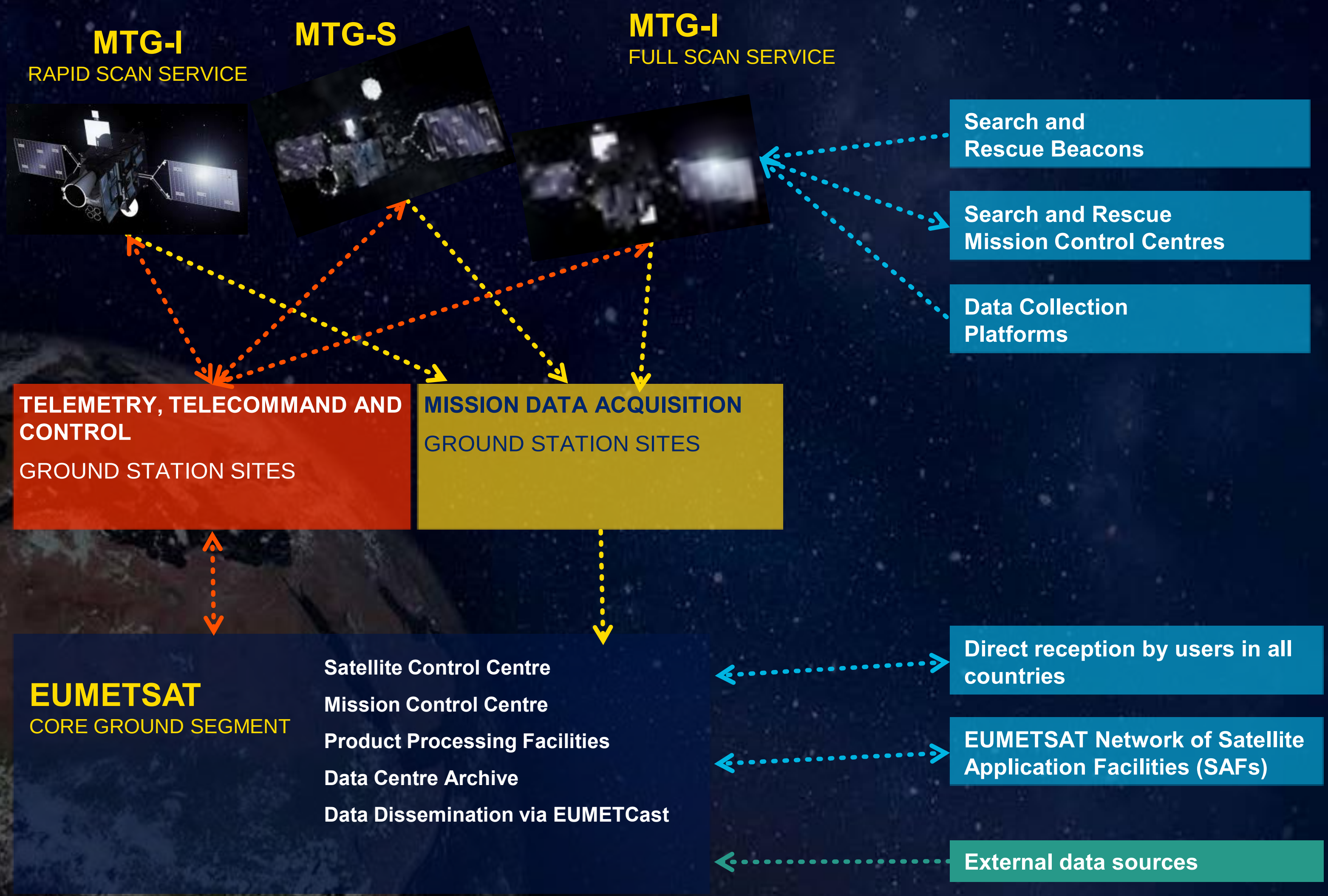
- Imagery mission implemented by a two-satellite MTG-I system:
    1. Full disk imagery every 10 minutes in 16 spectral bands
    2. Fast imaging of European weather every 2.5 minutes
    3. Lightning Imager (LI)

- Hyperspectral Infrared (IRS) Sounding mission:
    4. 3D mapping of water vapour, temperature,
    5. Air quality monitoring and atmospheric chemistry in synergy with Sentinel-4 Ultraviolet Visible

- start of operations in 2019 and 2021
- operational exploitation: 2019–2040

Courtesy EUMETSAT

MTG Programme – Overall system configuration



InfraRed Sounder (IRS) on MTG-S

Fourier Transform Interferometer, working in step-and-stare scanning mode

Earth covered by a sequence over four local areas of 15 min - each area scanned in a pattern that repeates every 6 hours such that Europe is covered every 30 minutes, and the earth view in 60 min.

Output (level-1b): Earth spectral radiance, in two bands: LWIR (680-1210 cm^{-1}) and MWIR (1600-2250 cm^{-1}), both with resolution 0.625 cm^{-1}

Data calibrated through cold space and Black Body views

Spatial Sampling Distance at sub-satellite point:
4 km in both north-south and east-west directions

NEDT: 0.2-0.5K

Accuracy better than 0.5K

Medium term stability better than 0.1K

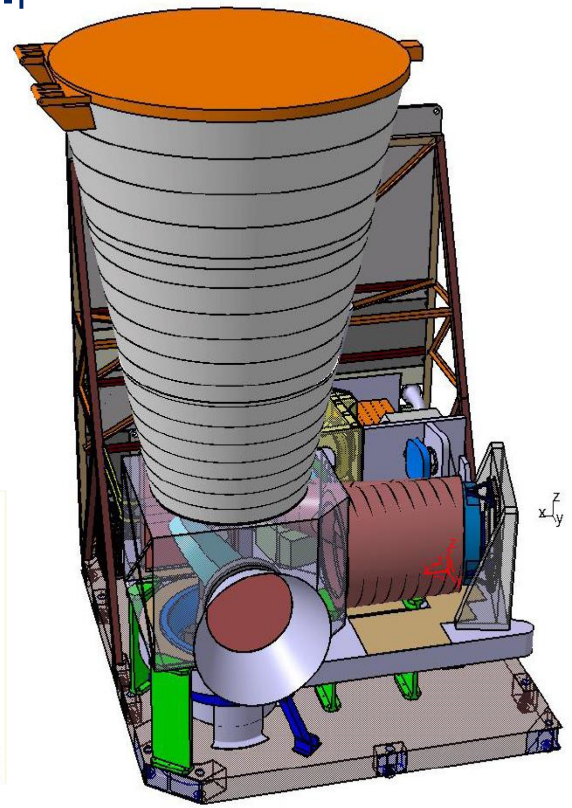
Mass: 459.5 kg

Power: 747 W (average)

Volume: 1400*1600*2200 m

Data rate: 193 Mbps

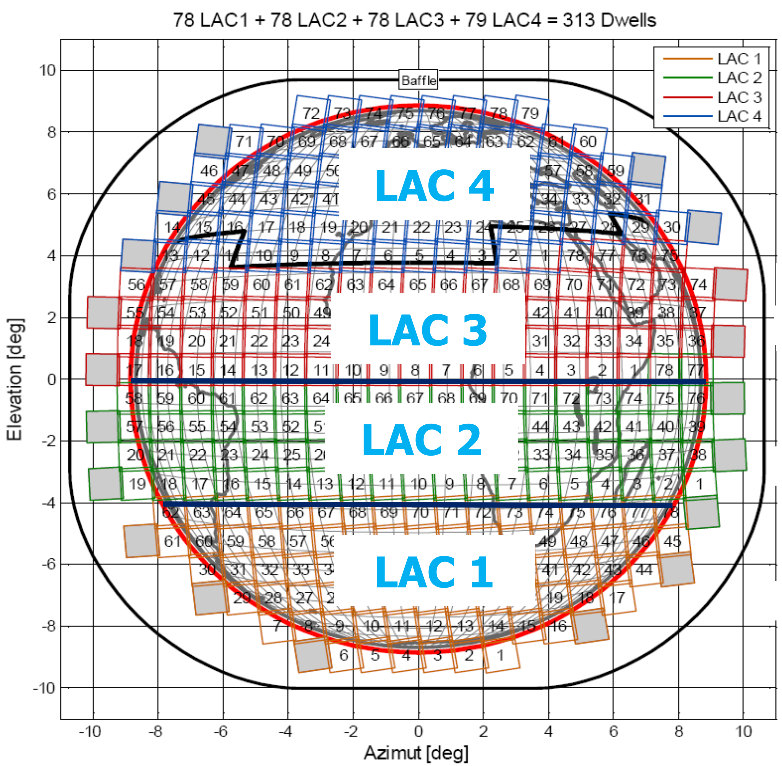
Source: IRS PM10 (Mar 2014)

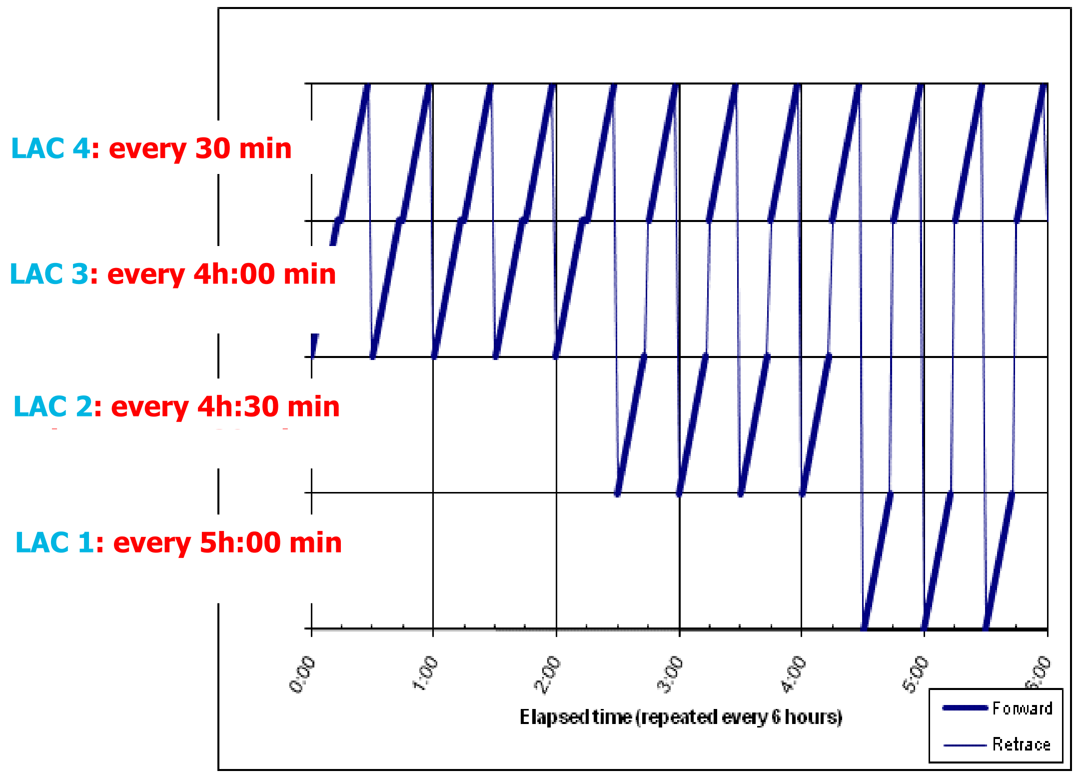


MTG Mission: InfraRed Sounder (IRS)

MTG-IRS will deliver unprecedented information on horizontal and vertical gradients of moisture, wind and temperature from the geostationary orbit:

- **hyperspectral soundings at 0.625 cm^{-1} spectral sampling in two bands:**
  - ✓ **Long-Wave-IR (LWIR: 700 – 1210 cm^{-1} ~820 spectral samples)**
  - ✓ **Mid-Wave-IR (MWIR: 1600 – 2175 cm^{-1} ~920 spectral samples)**
- **4 Local Area Coverage (LAC) zones, South to North, with LAC4 covering Europe;**
- **LAC-4 every 30 minutes;**
- **spatial resolution of 4 km.**

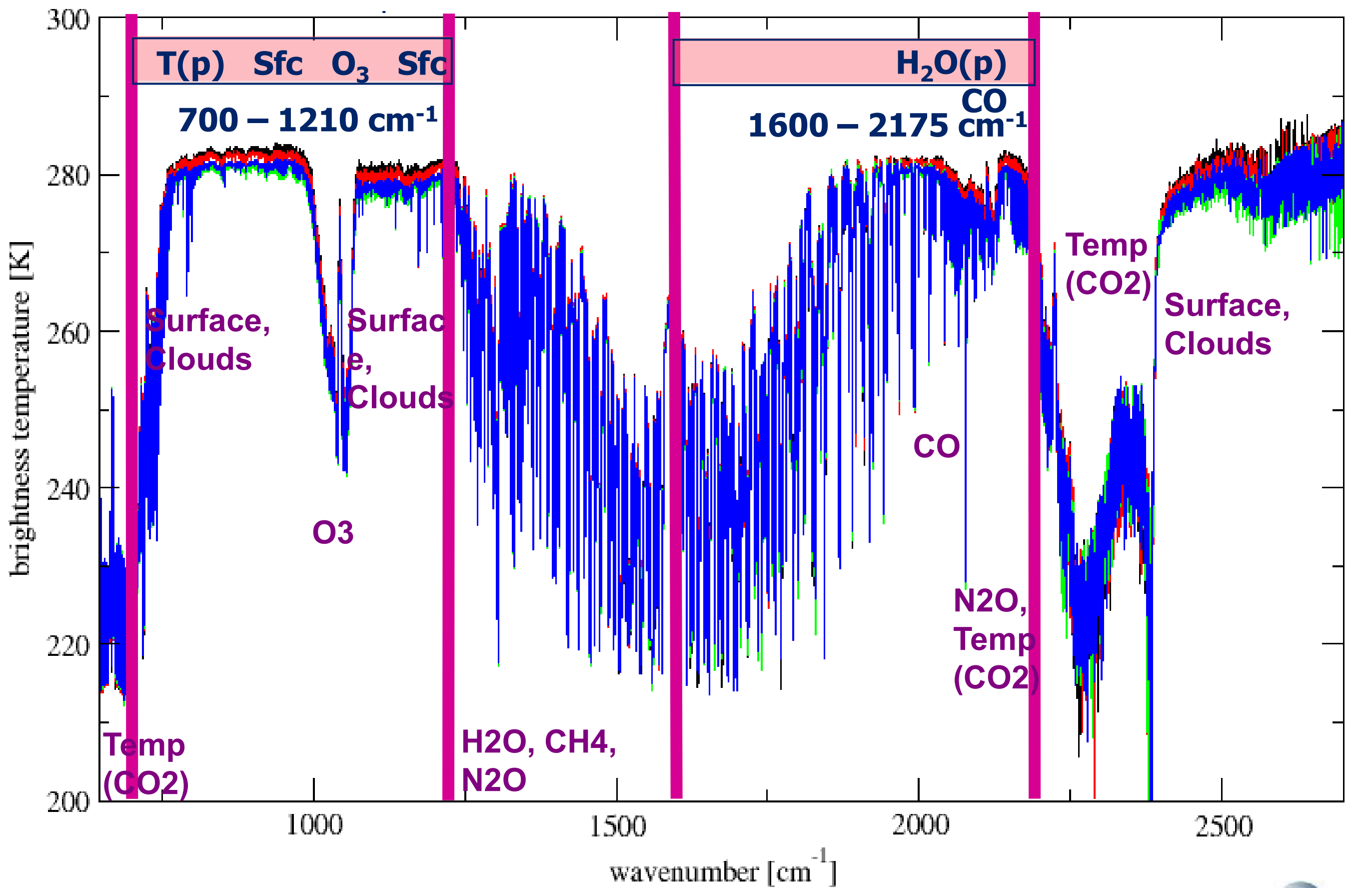




EUMETSAT

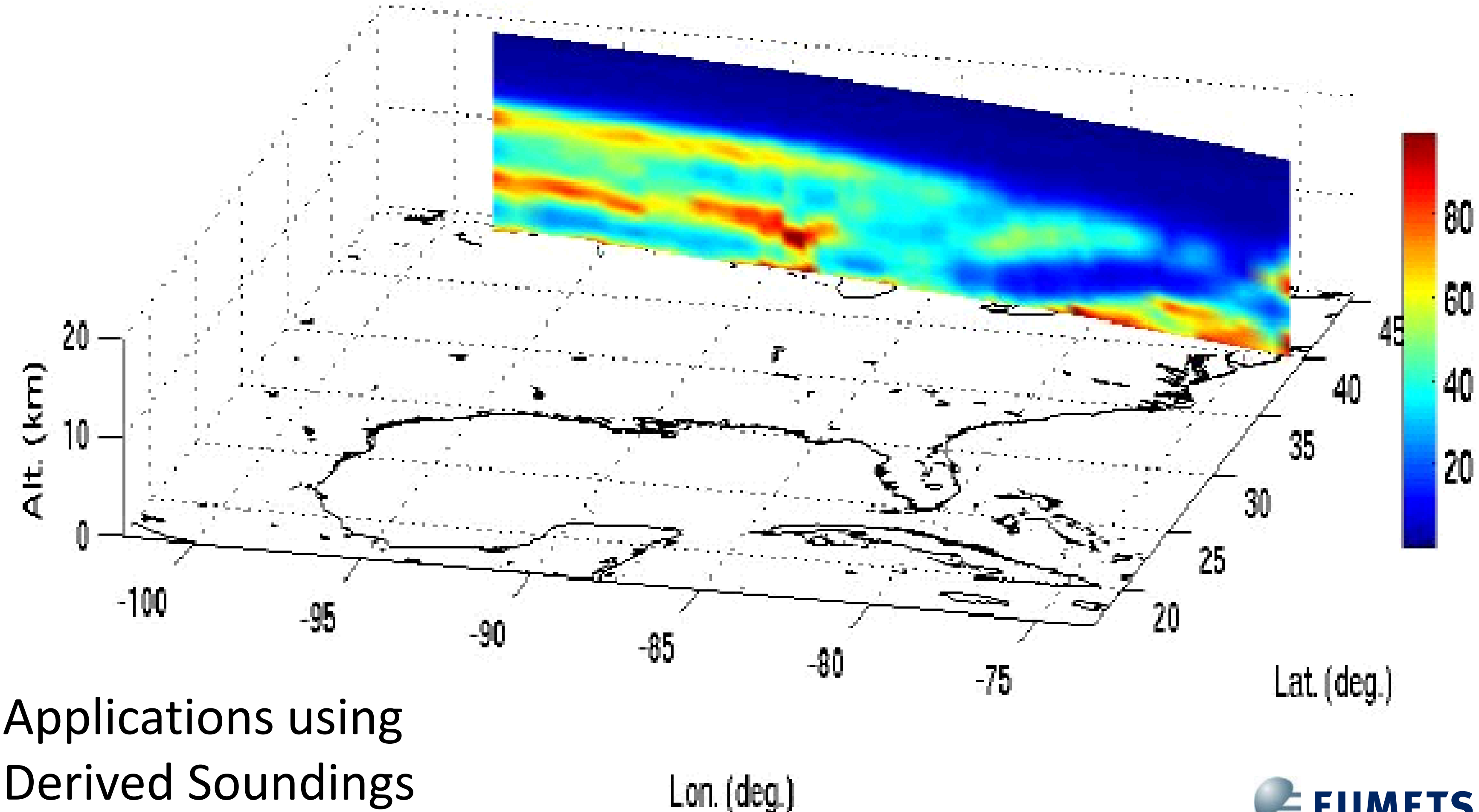
MTG-IRS to Detect ‘River Like Moisture Flows’

MTG-IRS: information on horizontal and vertical gradients of temperature and moisture



MTG-IRS to Detect 'River Like Moisture Flows'

Low level flow of moisture rivers.



Applications using Derived Soundings

EUMETSAT

MTG Missions IRS – Benefits Summary

- The IRS (30 min repeat cycle over Europe) will fill large spatial and temporal voids in the 12-hour standard radiosonde observations and will provide time and space interpolation of moisture/temperature observations taken from the polar orbiting satellites.
- The IRS derived information on tropospheric moisture structures and their variation in time is expected to lead to a better depiction of the hydrological cycle in models, potentially providing better precipitation forecast.
- The IRS will provide information on vertically resolved atmospheric motion vectors with improved height assignment, which in particular is beneficial for the tropical areas having only a weak coupling between the dynamic and thermodynamic atmospheric fields.
- The IRS will provide information to identify pre-convective situations supporting NWC applications to forecast convective initiation. ← NWC = Nowcasting
- IRS will support forecasting pollution and monitoring of atmospheric minor constituents through its capability to provide estimates of diurnal variations of tropospheric contributions of atmospheric trace gases as O_3 and CO.

MTG Mission: InfraRed Sounder (IRS)

Main challenges of the IRS Products are linked with:

- **Size of product;**
- **Needed computation resources;**
- **Detector number: IASI 2x2 detectors → IRS matrix 160x160**
  - ✓ **Shall be tackled at L1 product.**

New applications need to be developed to support:

- Rapidly Refreshed NWP models
  - Updated every 1-2 hours or less

N

- Nowcasting Tools for Forecasters
  - Use improved information about horizontal <u>and vertical </u>moisture structures
    - Now and in the near future hours.

Severe Weather Indices

Variables used to ‘summarize’ the potential for Severe Weather formation

Evolved over past 60 years

Based on long history of severe weather “proximity” soundings

All intended for use in interpreting radiosonde soundings

Most based on “Parcel Method”

Good forecasting tools

<u>IF</u>

forecasters understand why values are approaching critical levels

Review here will be in historical sequence

Start at the beginning - Showalter Index

Thermodynamic only
Developed to forecast tornadoes in Oklahoma
using “mandatory level” radiosonde data only

Before the era of automated radiosonde observations in the US,
data were transmitted in several parts *at 300 characters per minute*:

First – Mandatory level data from surface to 100 hPa
Second – Other “significant” levels form surface to 100 hPa
Third – Mandatory level data from surface to 100 hPa
Last – Other “significant” levels form surface to 100 hPa

First transmission of mandatory level data was ALWAYS required and
made 30-60 minutes earlier that other transmission

It remains important to use earliest data available.

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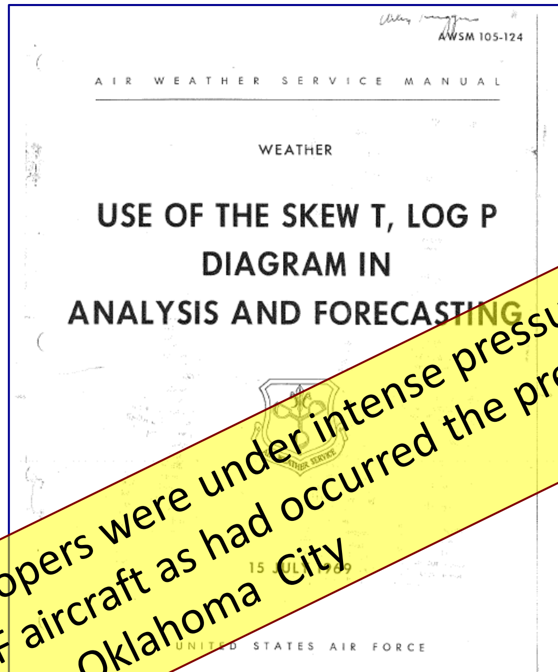

AWSM 105-124

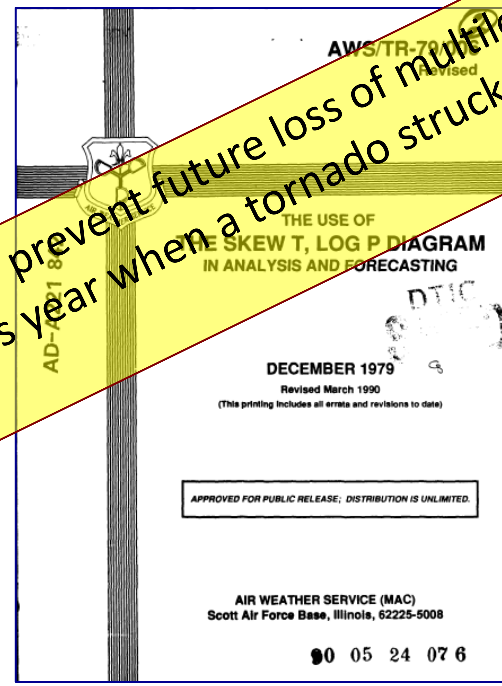
AIR WEATHER SERVICE MANUAL

WEATHER

USE OF THE SKEW T, LOG P DIAGRAM IN ANALYSIS AND FORECASTING

15 JULY 1969

UNITED STATES AIR FORCE


Revised

THE USE OF THE SKEW T, LOG P DIAGRAM IN ANALYSIS AND FORECASTING

DECEMBER 1979
Revised March 1990
(This printing includes all errata and revisions to date)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

AIR WEATHER SERVICE (MAC)
Scott Air Force Base, Illinois, 62225-5008

90 05 24 076

Developers were under intense pressure to prevent future loss of multile USAF aircraft as had occurred the previous year when a tornado struck a base in Oklahoma City

It remains important to use earliest data available.

Additional Point: Many US Air Force weather forecasters did <u>not</u> have college degrees – Indices were a means to have them produce forecasts without a full understanding of the underlying physics.

Showalter Index

Thermodynamic only
Developed to forecast tornadoes in Oklahoma
using "mandatory level" radiosonde data only

SI = Difference of Temperature of parcel lifted from 850 hPa and the 500 hPa temp.

$$\mathbf{SI = T_{500} - T_{Pcl500}}$$

Measures the buoyancy of a **parcel** lifted from the lower to the mid-troposphere

Does not account for buoyancy (vertical accelerations) above or below 500 hPa

Does account for 850 hPa moisture implicitly when lifted parcel reaches saturation, but not above or below 850 hPa – does not include mid-level dryness

Intended for stations near sea level, but also found to be good for elevated convection

Critical values:

- *0 or greater= stable*
- *-1 to -4= marginal instability*
- *-5 to -7= large instability*
- *-8 to -10= extreme instability*
- *-11 or less = ridiculous instability*

Showalter Index

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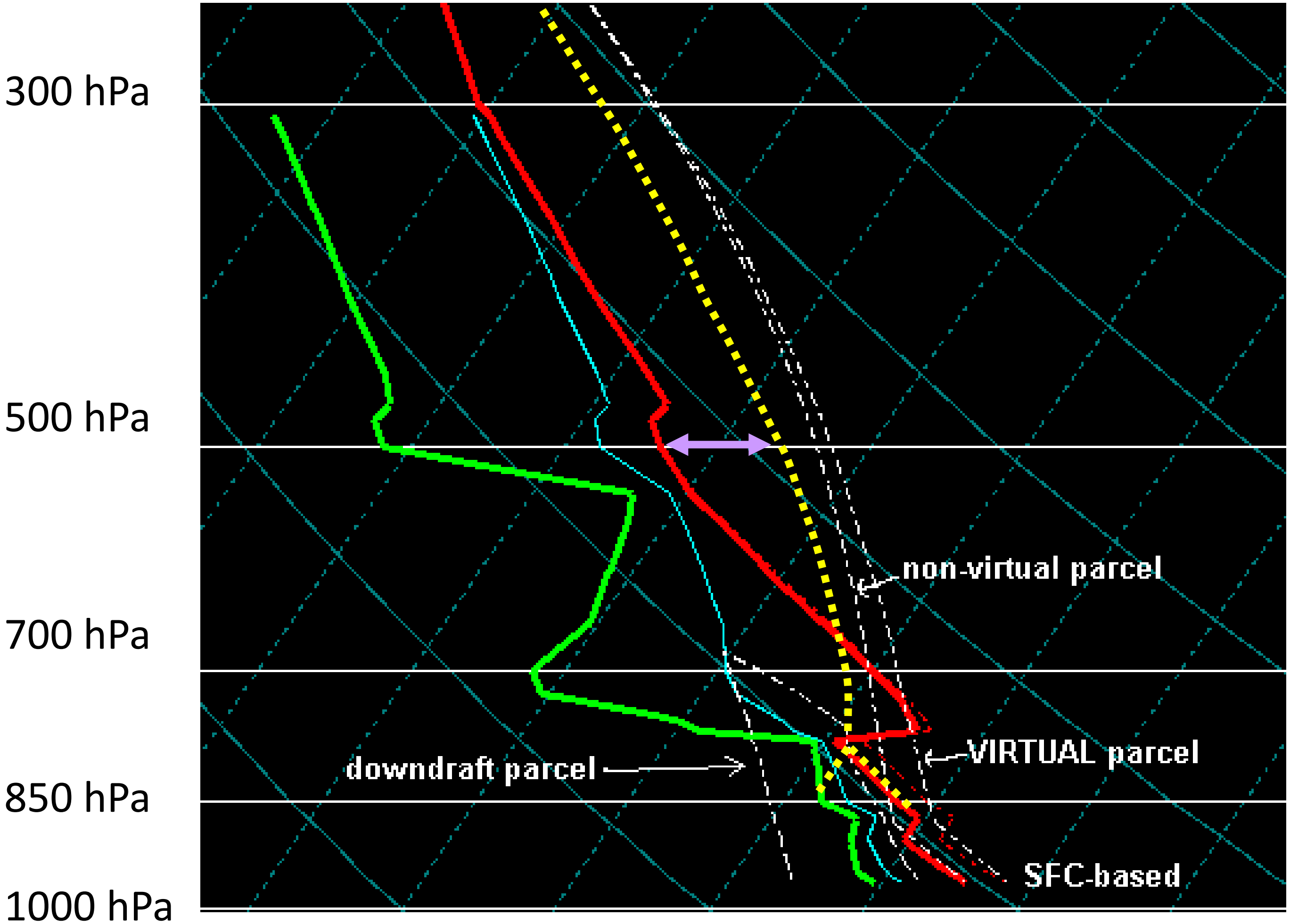


Total Totals Index

Simplified - Thermodynamic only
Developed to forecast tornadoes in Oklahoma
using "mandatory level" radiosonde data only

Totals Totals = Vertical Totals + Cross Totals Indices

Vertical Totals = $(T_{850} - T_{500})$ Cross Totals = $(T_{d850} - T_{500})$

TT = $(T_{850} - T_{500}) + (T_{d850} - T_{500})$

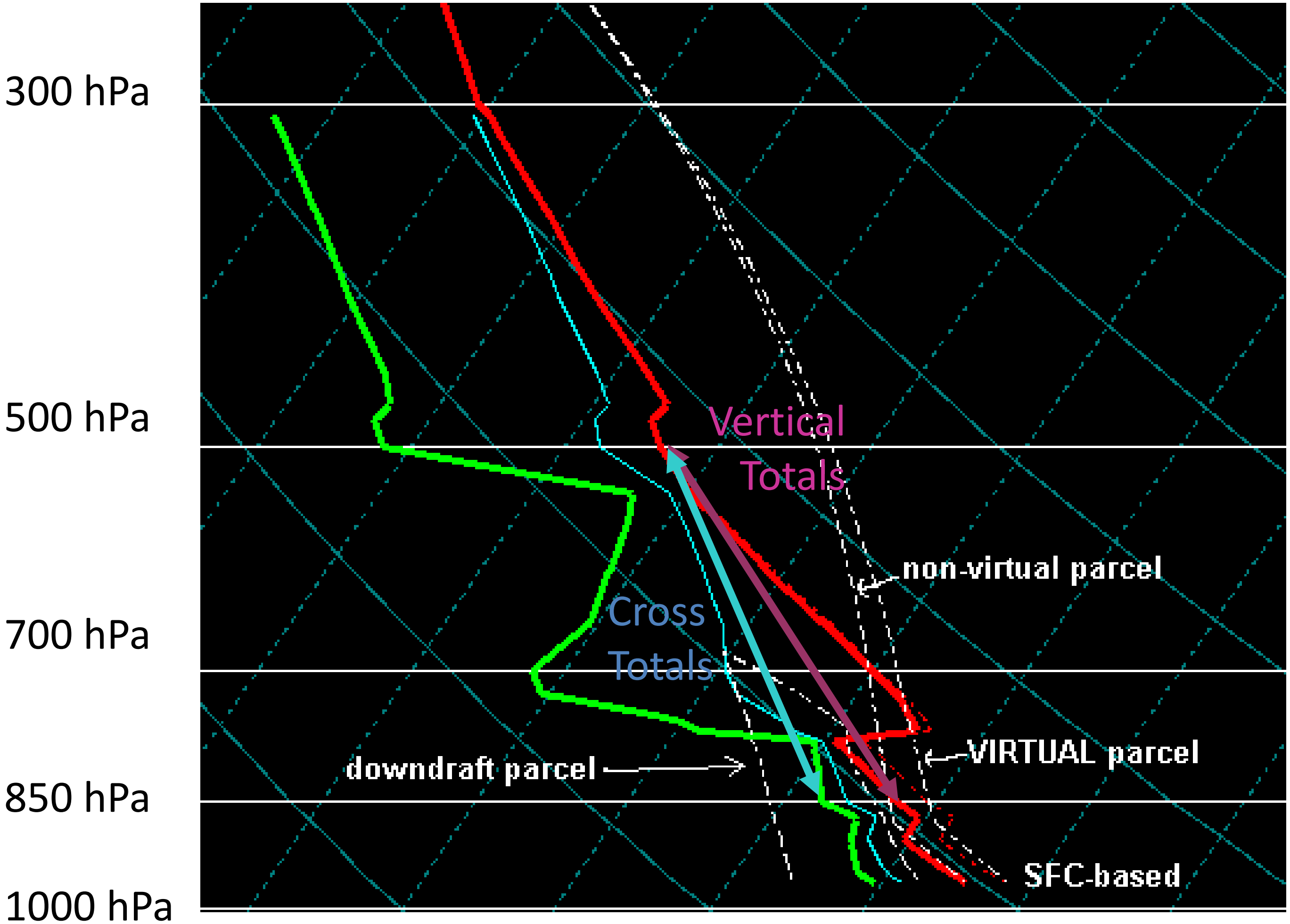
Combines lower tropospheric lapse rate (doubled?) + amount of moisture at low levels
Does not account for low level moisture above or below 850 hPa

Intended for stations near sea level

Critical values:
<44 Convection not likely
44-50 Likely thunderstorms
51-52 Isolated severe storms
53-56 Widely scattered severe
>56 Scattered severe storms

Total Totals Index

Simplified - Thermodynamic only
Developed to forecast tornadoes in Oklahoma
using “mandatory level” radiosonde data only



K Index

Modification of Total Totals Index for tropical convection

Simplified - Thermodynamic only

Developed to forecast convection in southeastern US using "mandatory level" radiosonde data only

K Index = Vertical Totals + lower tropospheric moisture characteristics

Vertical Totals = (T_{850} - T_{500})   Moisture = (T_{d850} – T_{dd700}),
where T_{d850} is 850 hPa dewpoint value
and T_{dd700} is 700 hPa dewpoint depression

K = (T_{850} - T_{500}) + (T_{d850} – T_{dd700})

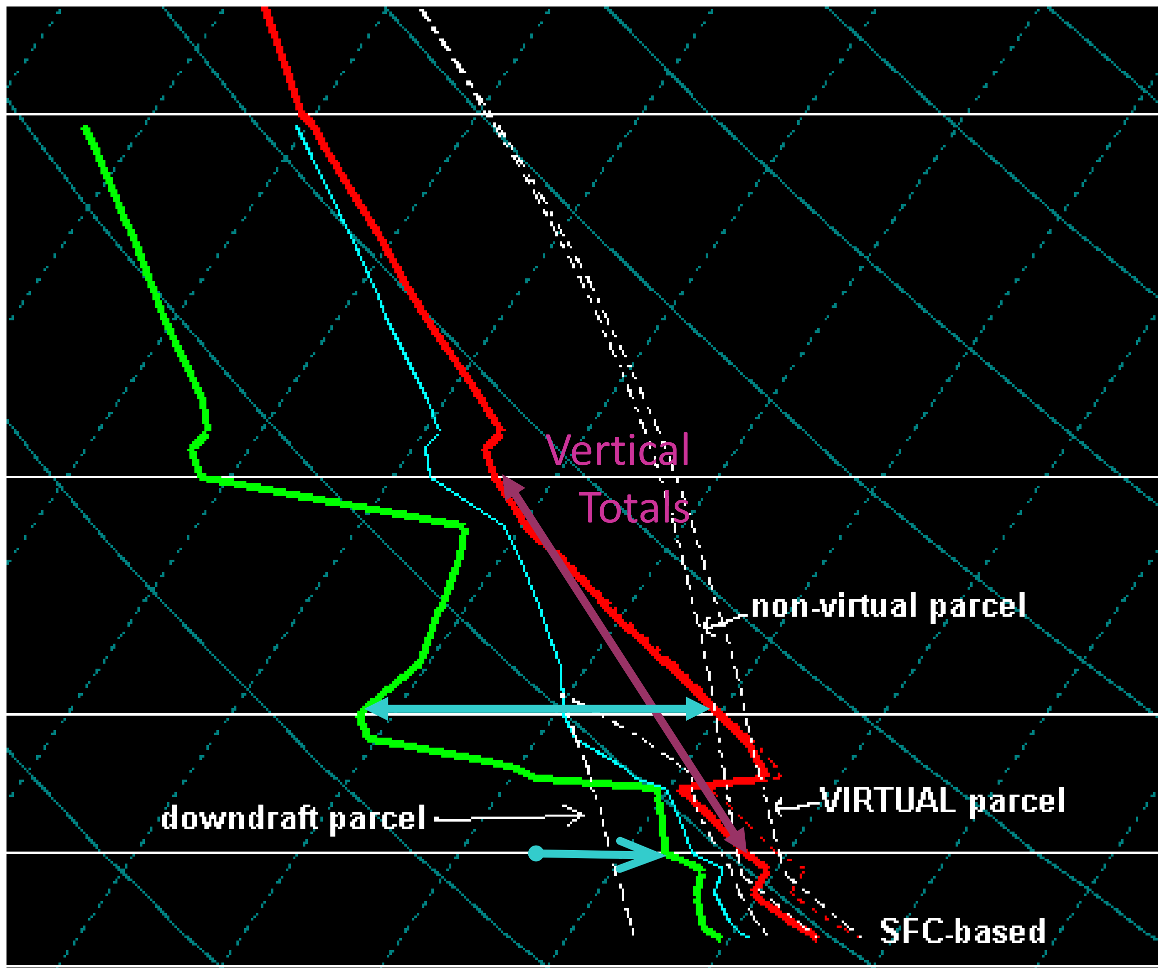
Combines lower tropospheric lapse rate + amount of moisture in 850-700 hPa layer, but does not account for presence of mid-level dryness

Does not account for low level moisture aside from 850 and 700 hPa
Intended for stations near sea level

Critical values:
15-25 Small convective potential
26-39 Moderate convective potential
40+   High convective potential

Total Totals Index

Simplified - Thermodynamic only
Developed to forecast tornadoes in Oklahoma
using “mandatory level” radiosonde data only



SWEAT (*Severe Weather Threat*) Index

Expansion of Total Totals Index

Thermodynamic and wind based

Developed to forecast tornadoes and thunderstorms using "mandatory level" radiosonde data

SWEAT= 12(T_{d850}) + 20(TT - 49) + 2(V_{850}) + (V_{500}) + 125(sin((dd_{500} - dd_{850})) + 0.2)

T_{d850} = 850 mb dewpoint

TT = Total Totals Index

V_{850} = 850 mb wind speed

V_{500} = 500 mb wind speed , - (dd_{500} - dd_{850}) = Directional backing of wind with height (warm advection)

Many 'emperial' factors, but <u>includes importance of wind structure and warm advection</u>

Does not account for low level moisture above or below 850 hPa, parcel buoyancy or mid-level dryness

Intended for stations near sea level

-If TT less than 49, then that term of the equation is set to zero
-If any term is negative then that term is set to zero
-Winds must be veering with height or that term is set to zero

Critical values:

150-300 Slight severe

300-400 Severe possible

400+ Tornado possible

EJSSM E-Journal of Severe Storms Meteorology, Vol 1, No 3 (2006)

As noted by Doswell:

"Many of these indices, including the SWEAT index, CT, EHI, SCP, and STP, have combined variables in ways that have no physical rationale. In other words, the process of forming sums, products, and ratios has not been done in accordance with a formula originating in the mathematics describing a physical process. Rather, the mathematical expression for the index is more or less arbitrary."

"As we have mentioned for the case of simple diagnostic variables calculated from observations combining two or more variables in a way that has a physical basis affects the interpretation and use of the resulting variable. If a variable is conserved during certain physical processes, for example, that is quite relevant to its application in diagnosis or forecasting."

"At issue is whether or not the variable can be related to physical principles. Examples of diagnostic variables based on physical principles might be something like the static stability time tendency, potential vorticity, or energy dissipation rate. Combining two or more variables in an arbitrary way leaves open many questions and makes it difficult to relate the variable to any physical understanding of the process. The individual diagnostic variables used to form an index may have physical relevance to the problem at hand, but when a specific formula combining them is unphysical, this can be problematic."

Going Back to more Basic Principles - Equivalent Potential Temperature (θ_E)

Thermodynamic only

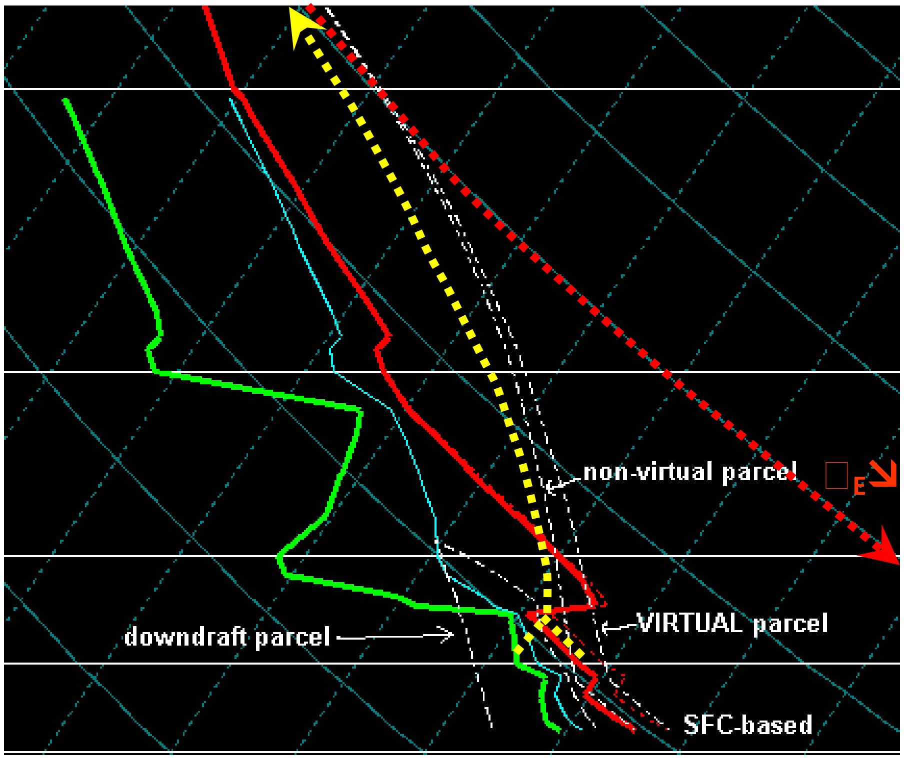
Developed to assist forecasting of tornadoes and severe thunderstorms using any "mandatory level" *and "significant level"* radiosonde data

Equivalent Potential Temperature (θ_E) is a measure of the total thermal energy of a parcel of air, including both its sensible temperature and any latent heating potential present from its moisture content.

Calculated by lifting a parcel of air dry/moist adiabatically from any level up to 100 hPa and then returning it dry adiabatically back down to 1000 hPa.

Can be applied to parcels from any level, including surface, boundary layer, predicted maximum temperature, etc.

MUST use Virtual Temperature to calculate θ_E, - otherwise warm/moist parcelswill appear too dense and cold dry environment not dense enough



Critical values:

Higher values show greater potential for latent heat release and therefore buoyancy

Going Back to more Basic Principles - Lifted Index
Expansion of the Showalter Index
Thermodynamic only
Developed to forecast tornadoes across the US
using "mandatory level" *and "significant level"* radiosonde data

Mixed Layer (ML) LI = Difference of Temperature of **parcel** lifted from a layers representing the lowest portion of the atmosphere and the 500 hPa temp.

$$\mathbf{LI = T_{500} - T_{Pcl@500}}$$

Measures the buoyancy of a parcel lifted from the lower to the mid-troposphere

Does not account for buoyancy (vertical accelerations) above or below 500 hPa

Accounts for low level moisture implicitly when lifted parcel reaches saturation

Intended for stations at most elevations

Critical values:
- *0 or greater= stable*
- *-1 to -4= marginal instability*
- *-5 to -7= large instability*
- *-8 to -10= extreme instability*
- *-11 or less = ridiculous instability*

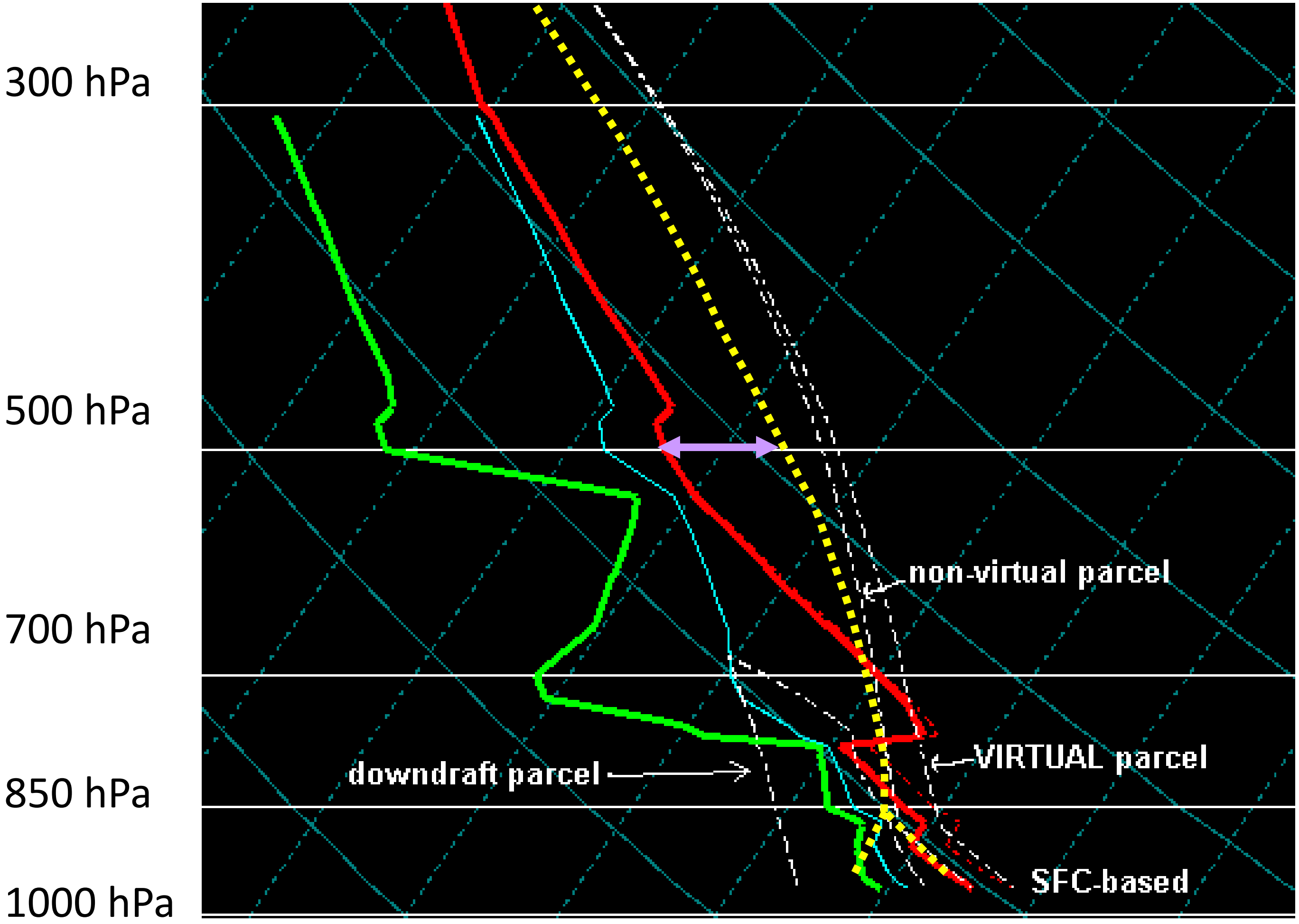
Lifted Index

Expansion of the Showalter Index

Thermodynamic only

Developed to forecast tornadoes across the US

using "mandatory level" <u>*and*</u> *"significant level"* radiosonde data



Variations on the theme of the Lifted Index

Further expansion of the Showalter Index

Thermodynamic only

Developed to forecast tornadoes in Oklahoma

using "mandatory level" *and "significant level"* radiosonde data

LI = Difference of Temperature (buoyancy) of parcel lifted from lowest 50-100 hPa of the atmosphere and the 500 hPa temp. $LI = T_{500} - T_{Pcl500}$

Surface Based (SB) LI – Uses parcels starting from the surface (can be used to combine Hourly METAR data with model 500 forecasts)

Best (Most Unstable) LI – Takes parcels from all reporting levels in the lowest 150 hPa and determines the least stable calculation – Good for elevated and nocturnal convection

Forecast (Virtual) LI - Uses parcels starting from the surface using forecast max temperature

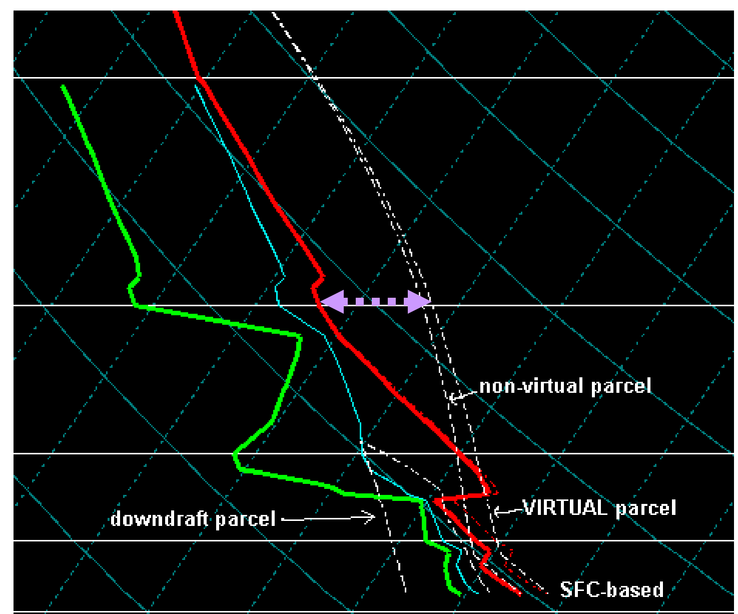
Critical values:

- *0 or greater= stable*
- *-1 to -4= marginal instability*
- *-5 to -7= large instability*
- *-8 to -10= extreme instability*
- *-11 or less = ridiculous instability*

LI calculated using model forecast profiles are NOT necessarily comparable.

NCEP MU LI (and CAPE) use 7 30 hPa deep layers starting at local surface elevation.

Others will use Surface (of 2 m) forecasts or data at every σ-layer of the model.



Convective Available Potential Energy (CAPE)

Expansion of the variations of the Lifted Index

Thermodynamic only

Developed to forecast tornadoes and severe thunderstorms using "mandatory level" *and "significant level"* radiosonde data

CAPE = the positive area on a sounding (the area between the parcel and environmental temperature throughout the entire sounding)

Includes no wind information nor information about the strength of the "LID" inhibiting convection

Can be used to forecast storm intensity, including heavy precip, hail, wind gusts

Use in conjunction with Convective Inhibition (CIN) and Precipitable Water (PW)

Max vertical motion ≈ $(2 \times \text{CAPE})^{1/2}$, without including water loading, entrainment

Intended for all stations.

Critical values:

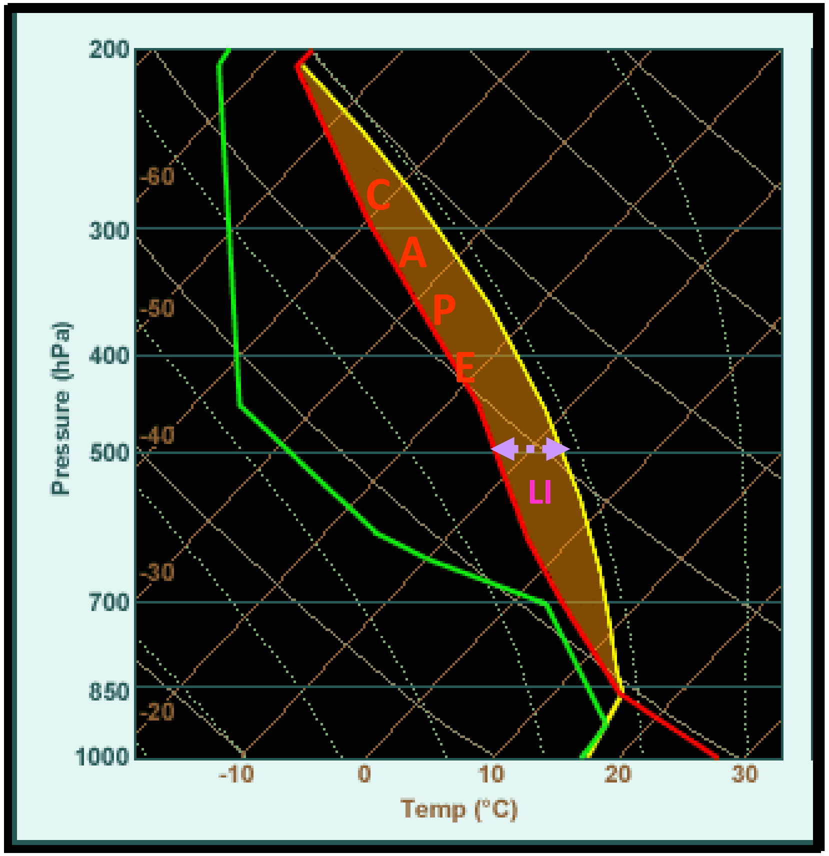
- *1 to 1,500 Positive CAPE*
- *1,500 to 2,500 Large CAPE*
- *2,500 + Extreme CAPE*

Convective Available Potential Energy (CAPE)

Expansion of the variations of the Lifted Index

Thermodynamic only

Developed to forecast tornadoes and severe thunderstorms using "mandatory level" *and "significant level"* radiosonde data



High CAPE means storms will build vertically very quickly. The updraft speed depends on the CAPE environment.

Hail: As CAPE increases (especially above 2,500 J/kg) the hail potential increases. Large hail requires very large CAPE values.

Downdraft: An intense updraft often produces an intense downdraft since an intense updraft will condense out a large amount of moisture. Expect isolated regions of very heavy rain when storms form in a large or extreme CAPE environment.

Lightning: Large and extreme CAPE will produce storms with abundant lightning.

Variations of Convective Available Potential Energy (CAPE)

Expansion of the variations of the Lifted Index

Thermodynamic only

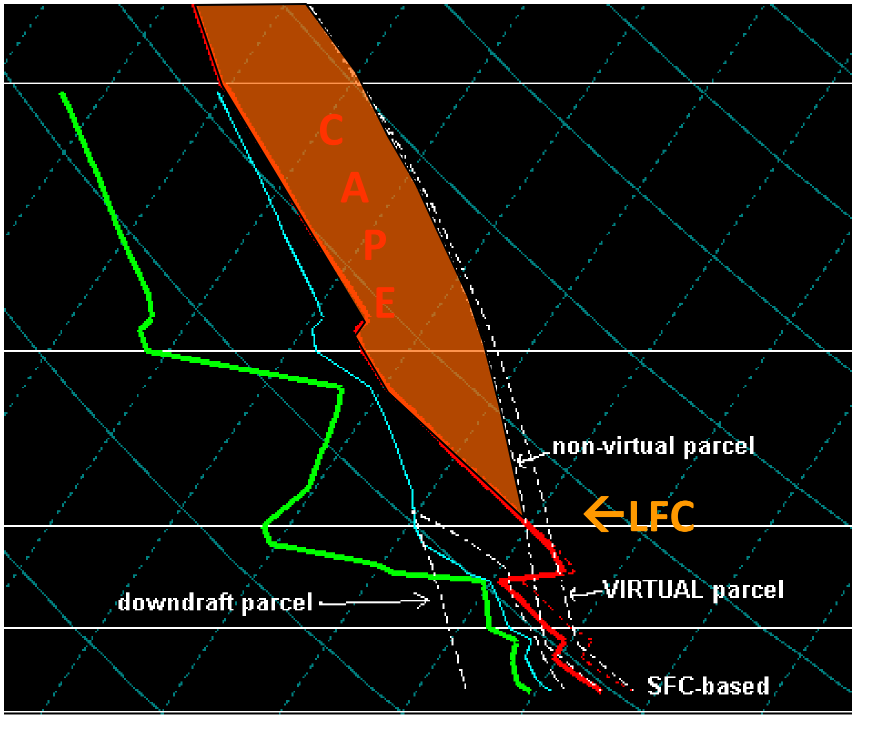
Developed to forecast tornadoes and severe thunderstorms using "mandatory level" *and "significant level"* radiosonde data

CAPE = the positive area on a sounding (the area between the parcel and environmental temperature throughout the entire sounding)

Mixed Layer CAPE – Uses parcels starting from 50-100 hPa deep boundary layer

Surface based CAPE – Uses parcels starting from the surface (can be used to combine Hourly METAR data with model 500 forecasts) - strong diurnal variability – PM storms

Most Unstable CAPE – Takes parcels from all many levels in the lowest 150-200 hPa and determines the least stable calculation – Good for elevated and nocturnal convection



Forecast (Virtual) CAPE - Uses parcels starting from the surface using ***forecast maximum temperature***

Critical values:

- *1 to 1,500 Positive CAPE*
- *1,500 to 2,500 Large CAPE*
- *2,500 + Extreme CAPE*

Convective Inhibition (CINH)

Expansion of the variations of the Lifted Index

Thermodynamic only

Developed to forecast *non-occurrence* of tornadoes and severe thunderstorms using "mandatory level" *and "significant level"* radiosonde data

CINH is the area of the sounding between parcel's starting level and to the level at which CAPE begins to be positive. In this region, the parcel will be cooler than the surrounding environment - thus this is a stable layer.

CINH will be reduced by: 1) daytime heating, 2) synoptic upward forcing, 3) low level convergence, 4) low level warm air advection (especially if accompanied by higher dewpoints).

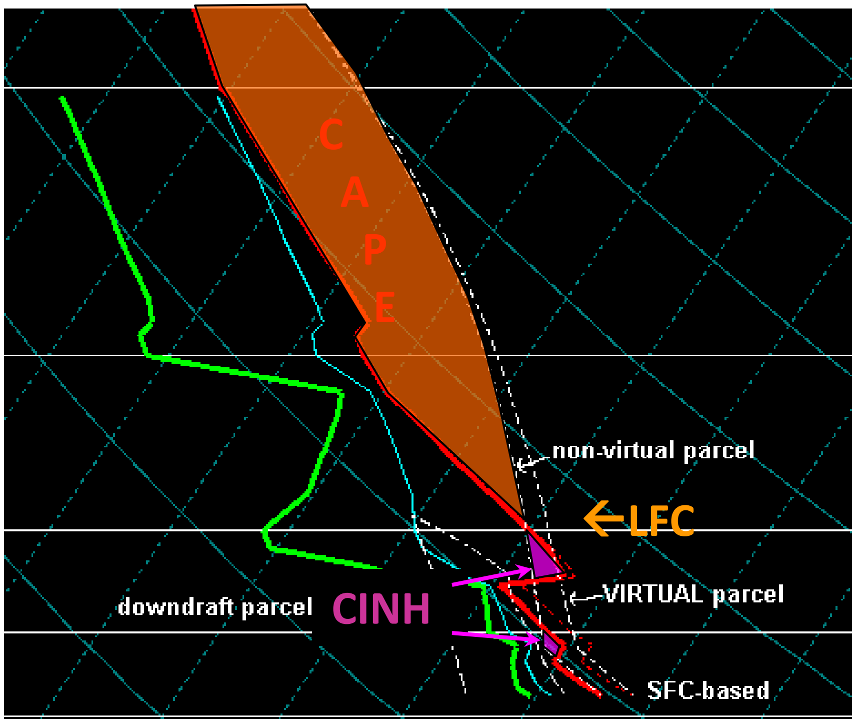
CINH is most likely to be small in the late afternoon since daytime heating plays a crucial role in reducing CINH.

Critical values:

0 – 50 Weak Cap

51 – 199 Moderate Cap

200+ Strong Cap



Additional Parameters related to Convective Available Potential Energy

Expansion of the variations of the Lifted Index

Thermodynamic only

Developed to forecast tornadoes and severe thunderstorms using "mandatory level" *and "significant level"* radiosonde data

Equilibrium Pressure (EP) = Pressure at top of *positive* CAPE *area* at which the air parcel temperature again equals environmental temperature.

Cloud Top Pressure (CTP) = Pressure at which the *negative area* above EL equals the positive CAPE area.

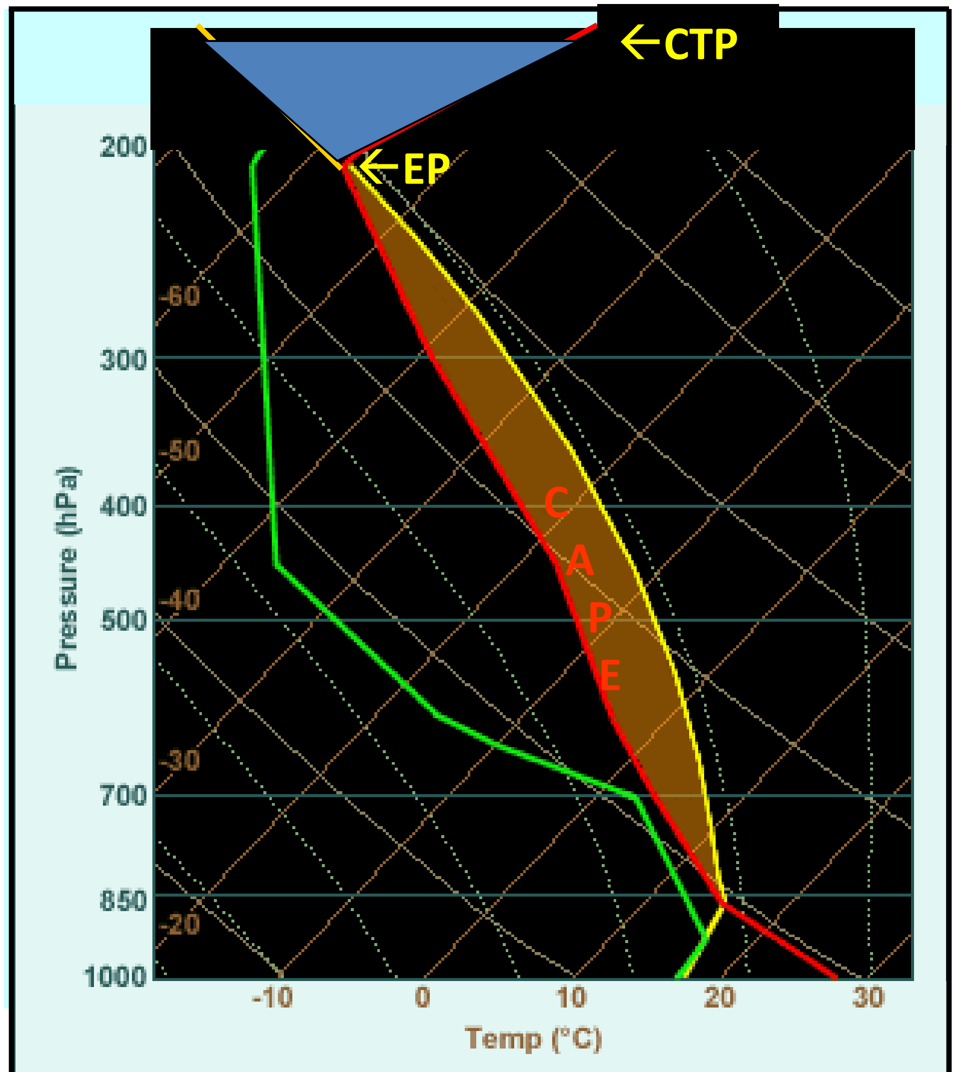
Precipitable Water (PW) – Total amount of rain that would fall from a cloud if all moisture removed from atmosphere

Cloud Base – From LCL – SBCAPE has biases

Critical values:

EP and CTP - Larger values give deeper Clouds and more opportunity for growth

PW – Water loading reduces CAPE impact
PW < 2.5 cm = small, > 5 = larger effects



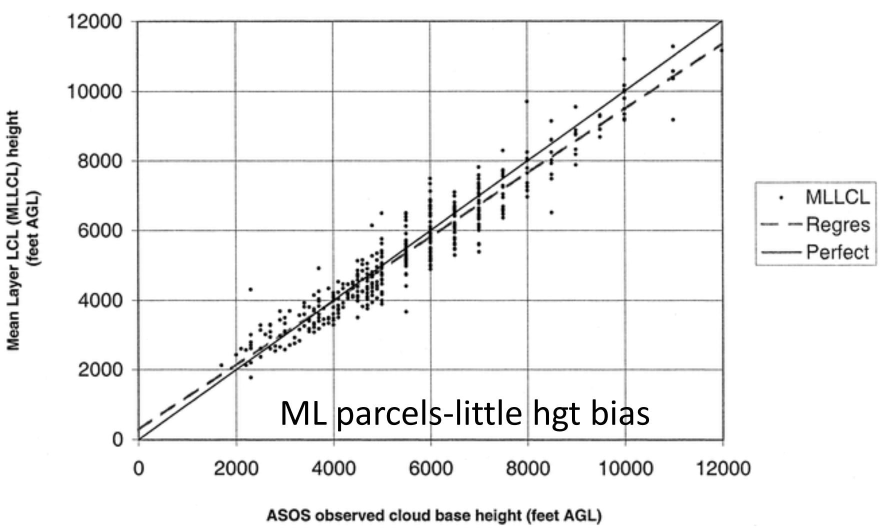
Diagnosis of Instability

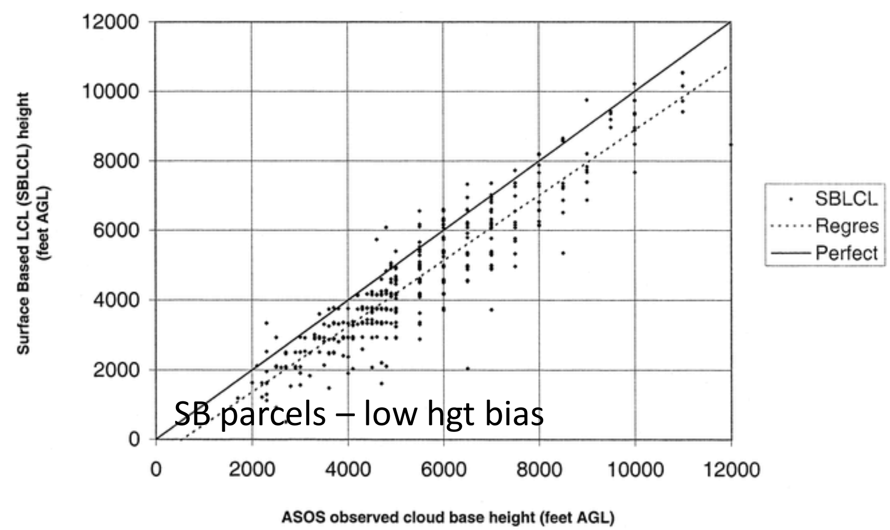
- Measures of instability such as CAPE or LI can vary depending on choice of lifted parcel
  - **Surface-Based (SB)**
    - *Allows use of high resolution hourly METAR obs*
    - *Assumes surface conditions representative of well-mixed PBL*
    - *Can overestimate instability*
  - **Mean (or Mixed) Layer (ML)**
    - *More representative of actual convective cloud processes*
    - *Requires accurate information about PBL profile*
    - *Default PBL depth is 100 mb in NSHARP*
  - **Most Unstable (MU)**
    - *Uses level of maximum theta-e as lifted parcel level*
    - *Most useful in identifying elevated instability above PBL*
    - *May be identical to SB parcel (when max theta-e is at surface)*
    - *Overestimates instability if theta-e "spike" exists at one level*

From Steve Weiss, SPC

Diagnosis of Instability – ML vs SB

- Craven, Brooks, and Jewell (2002) examined more than 400 warm season 00z soundings
- They estimated convective cloud base height using 100 mb ML and SB parcels and compared with observed ASOS cloud base heights





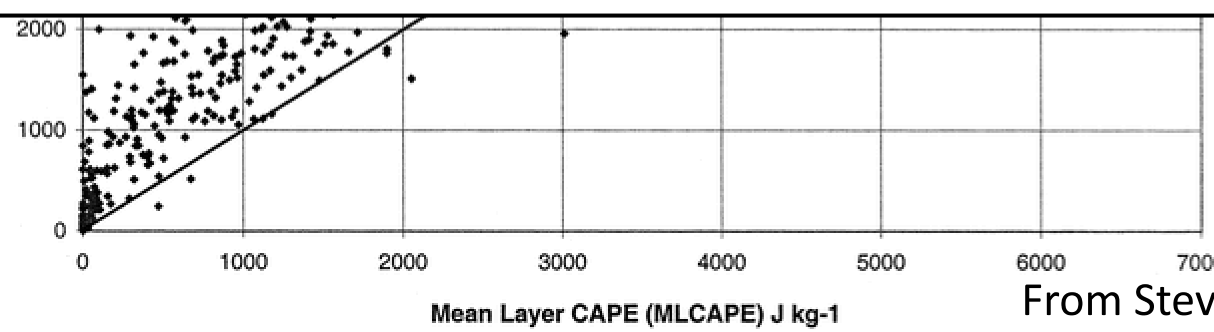
SB parcels tended to underestimate convective cloud bases (SB parcel too warm/moist), whereas ML parcels better represented convective processes

From Steve Weiss, SPC

Craven et al. Findings (cont'd)

- SBCAPE almost always larger than MLCAPE
  - *Suggests surface conditions do not typically represent late afternoon PBL structure*
  - *Implies MLCAPE more representative of convective processes and potential (SBCAPE less useful)*

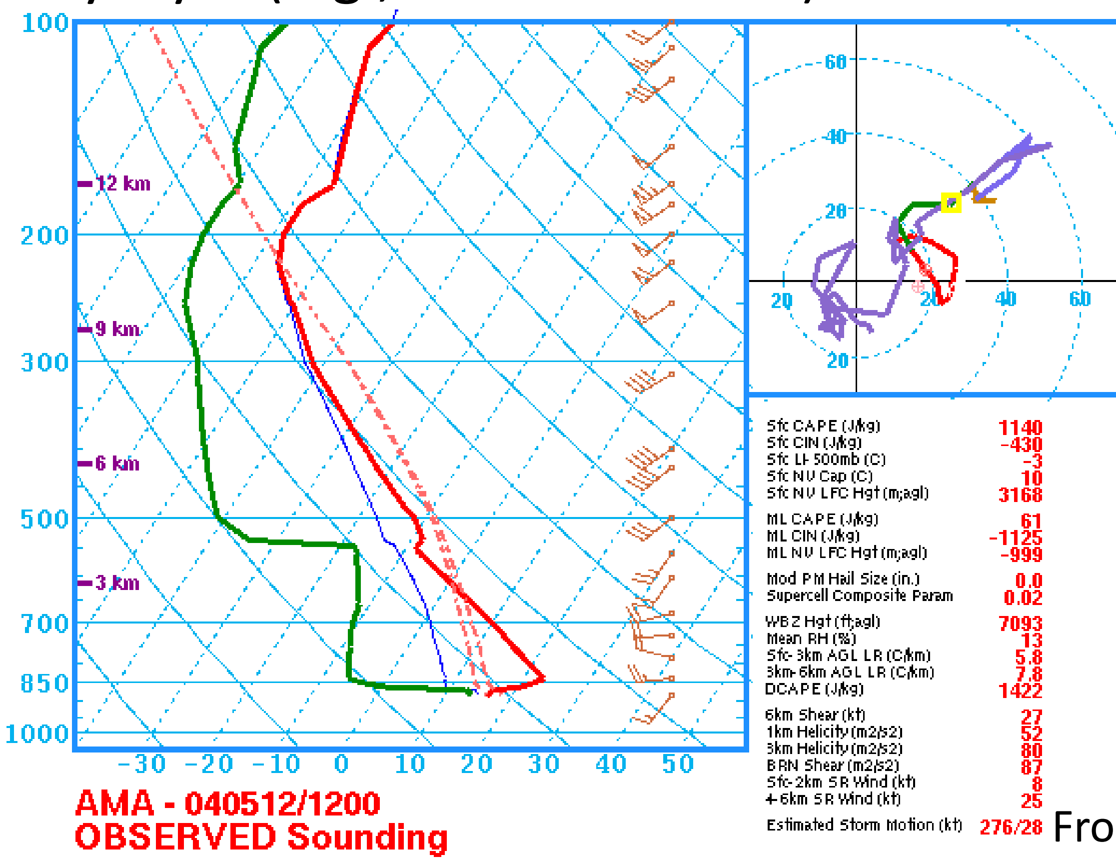
- Dilemma – Surface METAR data has high resolution in time and space but… - Hourly lifted surface parcels may provide misleading information - ("Best Case" instability IF well-mixed PBL exists)



From Steve Weiss, SPC

Sounding Interpretation in Cases of "Skin" Moisture

- For **observed** soundings with "skin" moisture, surface-based parcels are not representative of true convective boundary layer (e.g., well-mixed PBL)



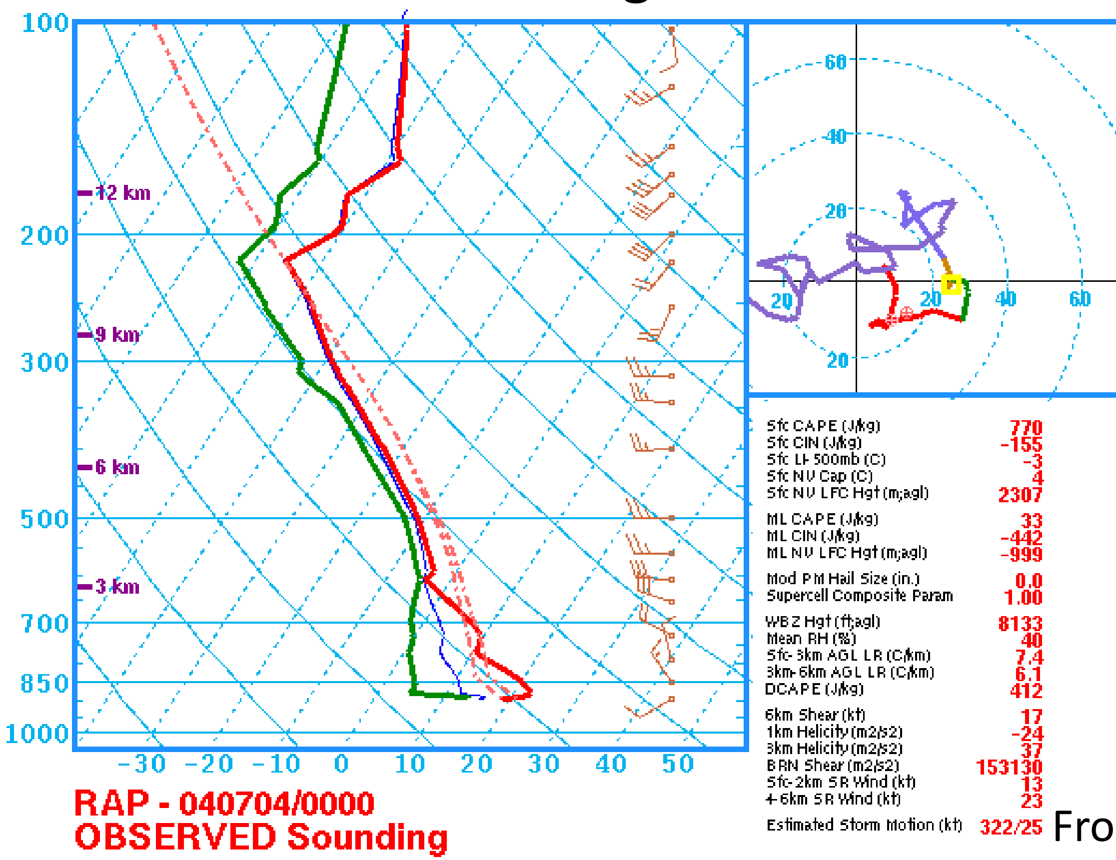
SBCAPE=1140

MLCAPE=61

From Steve Weiss, SPC

Sounding Interpretation in Cases of “Skin” Moisture

- Although these types of soundings occur more frequently at 12z, they also are found at 00z
- We favor the MLCAPE as being more correct



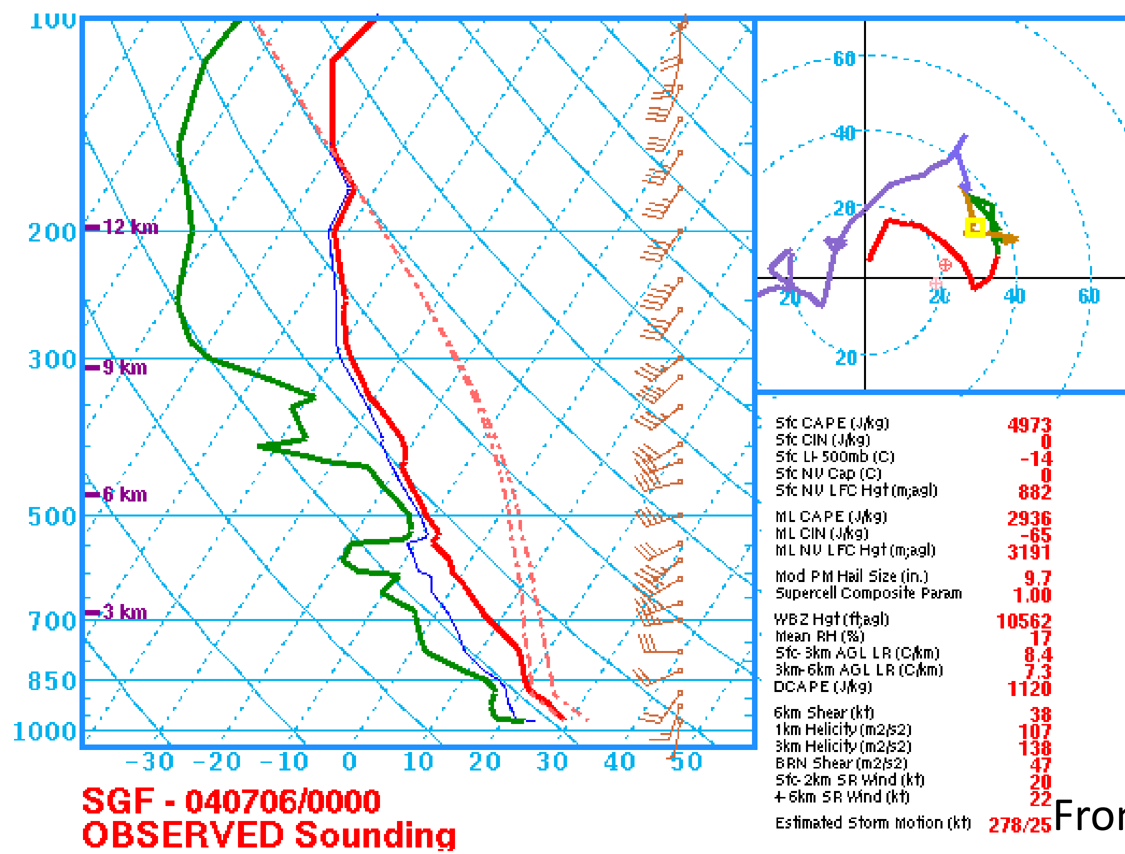
SBCAPE=770

MLCAPE=33

From Steve Weiss, SPC

Skin Moisture with Large CAPE

- Even with ample moisture/instability, we assume the SBCAPE is an overestimate and favor MLCAPE values (supported by Craven, Brooks, Jewell results)



SBCAPE=4973

MLCAPE=2936

From Steve Weiss, SPC

Observed vs. Model Soundings

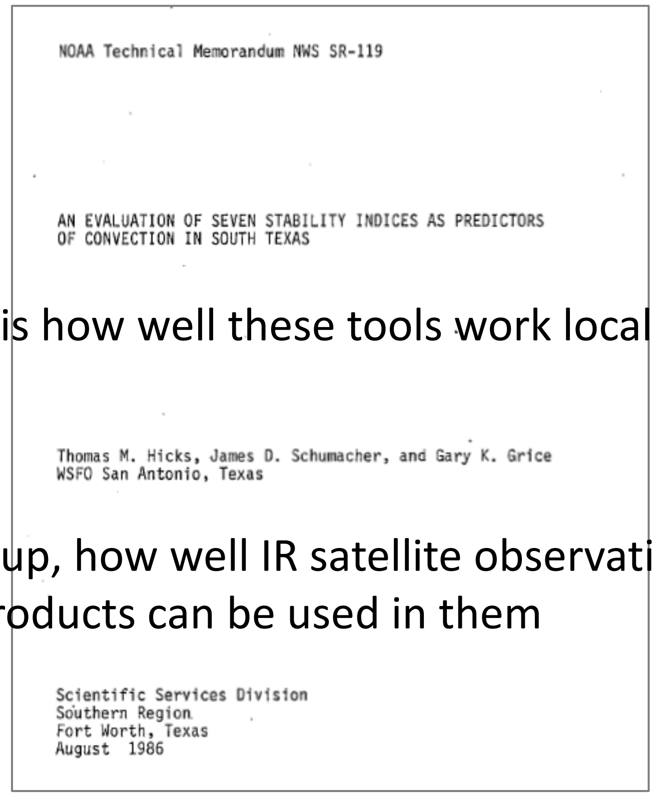
- Be cautious when interpreting model soundings as if they were observed soundings
  - *We know that model physics errors can have negative impacts on sounding structure (e.g., Eta soundings with BMJ scheme)*
- However, blending observed surface data with RUC model soundings may occasionally result in appearances of "skin" moisture
  - *For observed soundings, we discount the SB parcel in favor of ML parcel-based parameters*
  - *But for RUC/surface observation blends, the SB parcel <u>may</u> be more appropriate when the model PBL background structure is too dry*

From Steve Weiss, SPC

Summary of critical value of Traditional Severe Storm Indices

Lifted index

-1 to -4	Marginal instability
-4 to -7	Large instability
-8 or less	Extreme instability


NOAA Technical Memorandum NWS SR-119

AN EVALUATION OF SEVEN STABILITY INDICES AS PREDICTORS
OF CONVECTION IN SOUTH TEXAS

Thomas M. Hicks, James D. Schumacher, and Gary K. Grice
WSFO San Antonio, Texas

Scientific Services Division
Southern Region
Fort Worth, Texas
August 1986

What matters is how well these tools work locally!

And for this group, how well IR satellite observations and products can be used in them

CAPE

<1,500	Positive
1,500 - 2,500	Large
>2,500	Extreme

Good web reference:
www.theweatherprediction.com/severe/indices

Simulating MTG-S versus SEVIRI Equivalent Potential Temperatures

Truth>

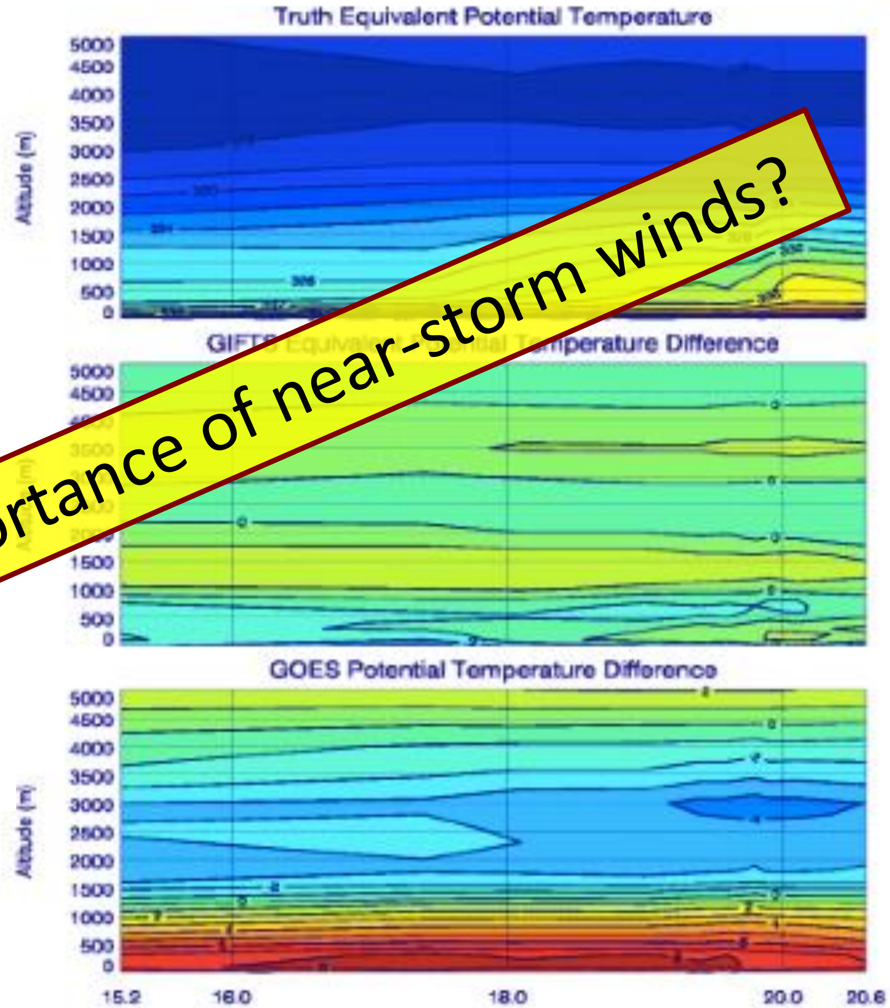
Note – Increase of Convective Instability between 1-2000 m after 18Z

Simulated MTG-S - like Errors >

Note: Because SEVIRI overestimates θ_E near the surface and underestimates it near 700 hPa, vertical gradients are in error by almost 50%

overestimated by nearly 50%

Simulated SEVIRI-like Errors >



What about the importance of near-storm winds?

Hyperspectral Sounder Simulations show vertical error structures consistent with predicted vertical resolving power of ~ 1 km

– This should be the driver for selection of derived indices/tendency monitoring -

Severe Weather Forecasting at SPC

(More from Steve Weiss)

Severe Weather Forecasting at SPC

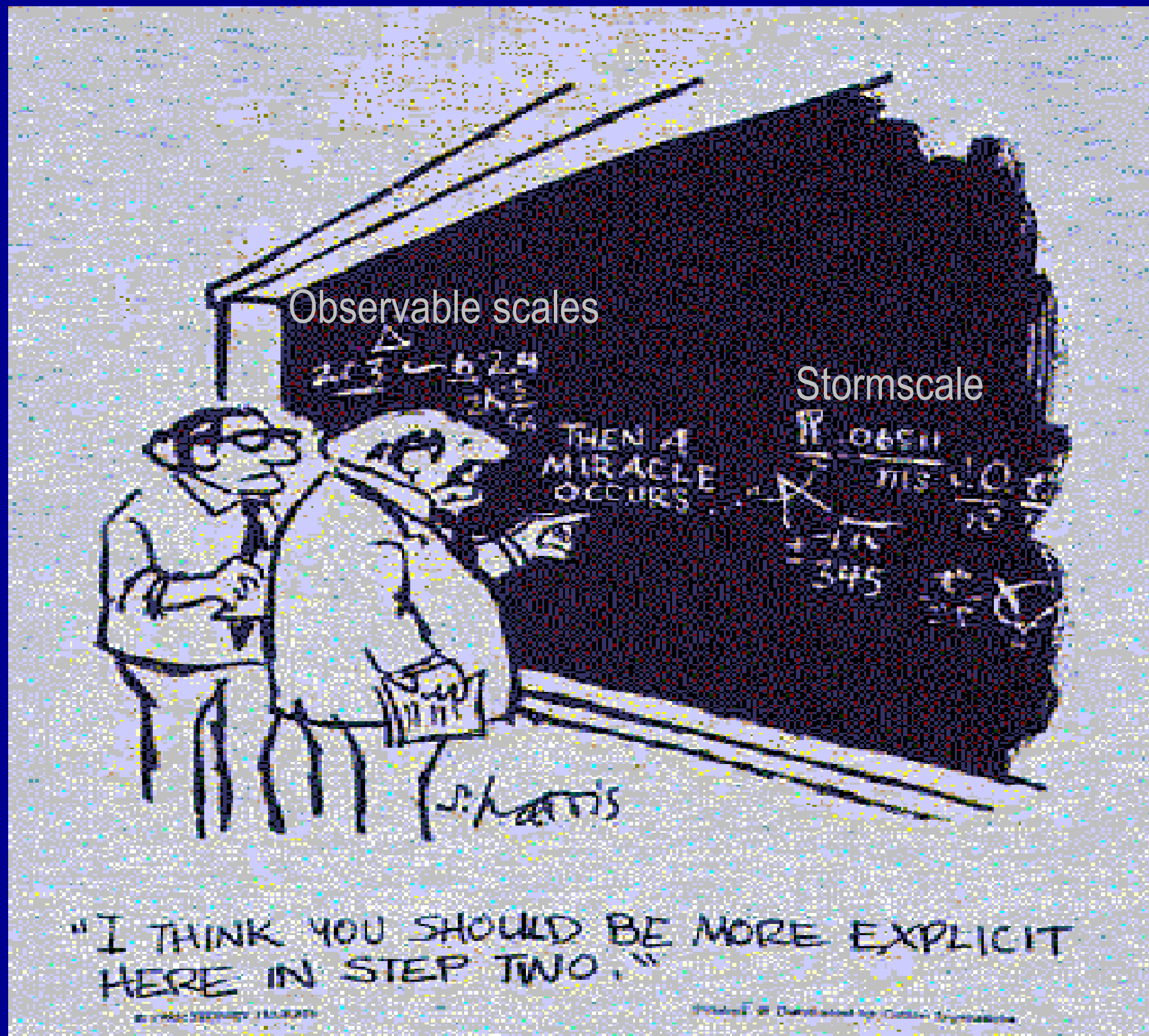
• The weather phenomena of interest (severe thunderstorms and tornadoes) typically occur on scales below those of the standard observational network and operational NWP

• We are most interested in forecasting the development of these phenomena ahead of time

  • *difference between "detection" of existing phenomena and "prediction" of their future occurrence*

  • *we must use our (incomplete) knowledge of the environment and convective processes to determine the spectrum of storms that are possible and how they may evolve over time*

The Link Between Observable Scales and Stormscale is not Necessarily Clear



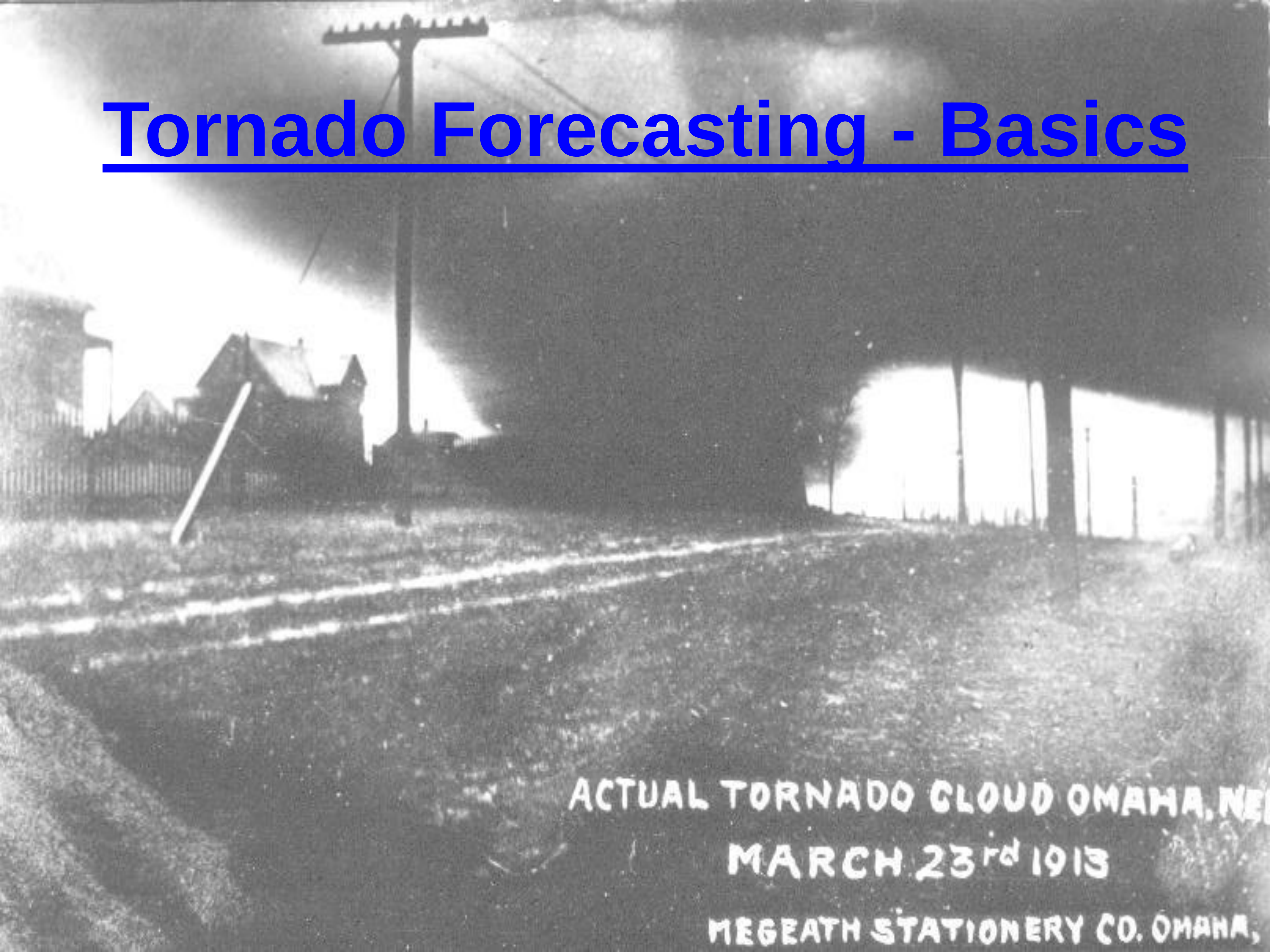
Severe Weather Forecasting at SPC

- In its most basic sense, we ask the following questions:
  - Can thunderstorms develop?
    - *Moisture, instability, lift*
  - If yes, can the storms become severe?
    - *Instability, vertical shear, etc.*
  - If yes, what types of threat are possible?
    - *Tornadoes, damaging winds, large hail*
  - When and where are these events possible?
  - What is the likelihood of occurrence (quantify uncertainty)

Severe Weather Forecasting at SPC

- The most significant severe storms are usually associated with organized storms or convective systems
    - *Mesoscale Convective Systems (MCS)*
    - *Supercell and Bow Echo Thunderstorms*
- Significant tornadoes, very large hail, and extreme wind events most often associated with **supercells**
- Widespread damaging wind events (derechos) most often associated with **quasi linear MCSs** (embedded bow echoes)
- These types of events usually occur within environments characterized by stronger vertical shear
    - *But, reports of severe storms are becoming more frequent in weakly sheared environments (pulse severe)*

Tornado Forecasting - Basics



Tornadic Supercell Forecasting - Basics

- **Determine likelihood of thunderstorms**
  - *Sufficient moisture, lapse rates, and lift*
- **Is deep layer vertical shear sufficient for supercells?**
  - *15-20 m/s in lowest 4-6 km*
- **Does low-level shear favor right-movers?**
  - *Clockwise turning hodograph / 0-1 km SRH ~ 100 m2/s2*
- **What characteristics will downdrafts have?**
  - *Potential for evaporational cooling (low and mid levels)*
  - *Moist PBL appears more supportive for tornadoes (LCL ~doesn't exceed 1500 m)*

Tornado Forecasting - Basics

- **Unfortunately, it's not as simple as "CAPE + shear = tornadoes"!**

- **Convective Mode:** **Tornadic storms in major outbreaks almost always develop as discrete, surface-based cells**

- **Timing:** **How long will storms be in the "favorable" environment, and will that be long enough for multiple tornadoes?**

    - *Is there a large warm sector that doesn't need local CAPE/SRH augmentation near boundaries?*

    - *If a boundary is "necessary", will supercell move along boundary or normal to it?*

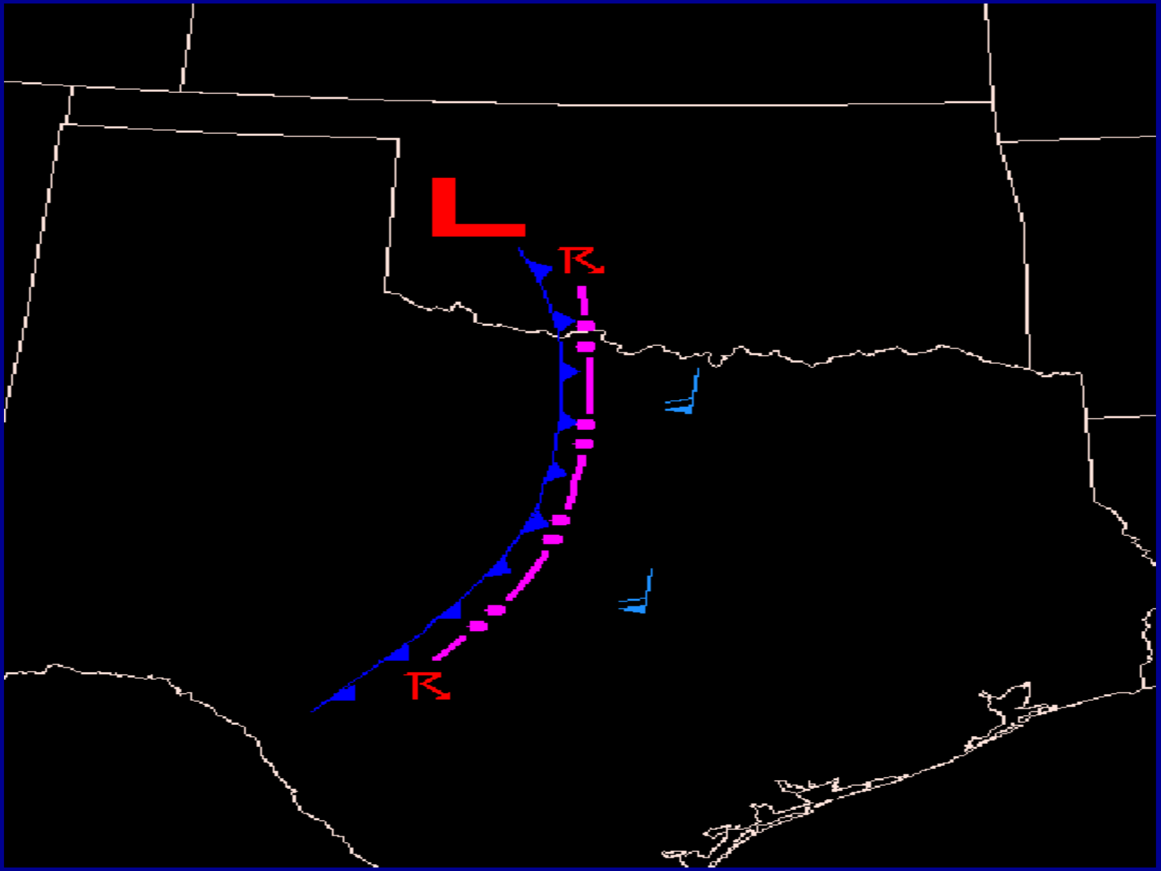
What Influences Convective Mode?

- Deep Shear vector orientation relative to boundaries:
  - Parallel (lines dominate, with end supercells)
  - 45° (discrete supercells, little storm interaction)
  - 90° (colliding storm splits, but depends on storm spacing and hodograph shape)
- "Forcing" compared to CIN and LFC height
  - Large CIN or high LFC – need strong mesoscale ascent ; only a few storms may form (discrete cells)
  - Small CIN/low LFC – many storms initiated by subtle features (lines/multicell clusters)
  - CIN depends on parcel choice!

- Ongoing work by UW-CIMSS and UAH using CI data bases is quantifying these relationships for developing and non-developing storms – including importance of Convective Temperature Depression.

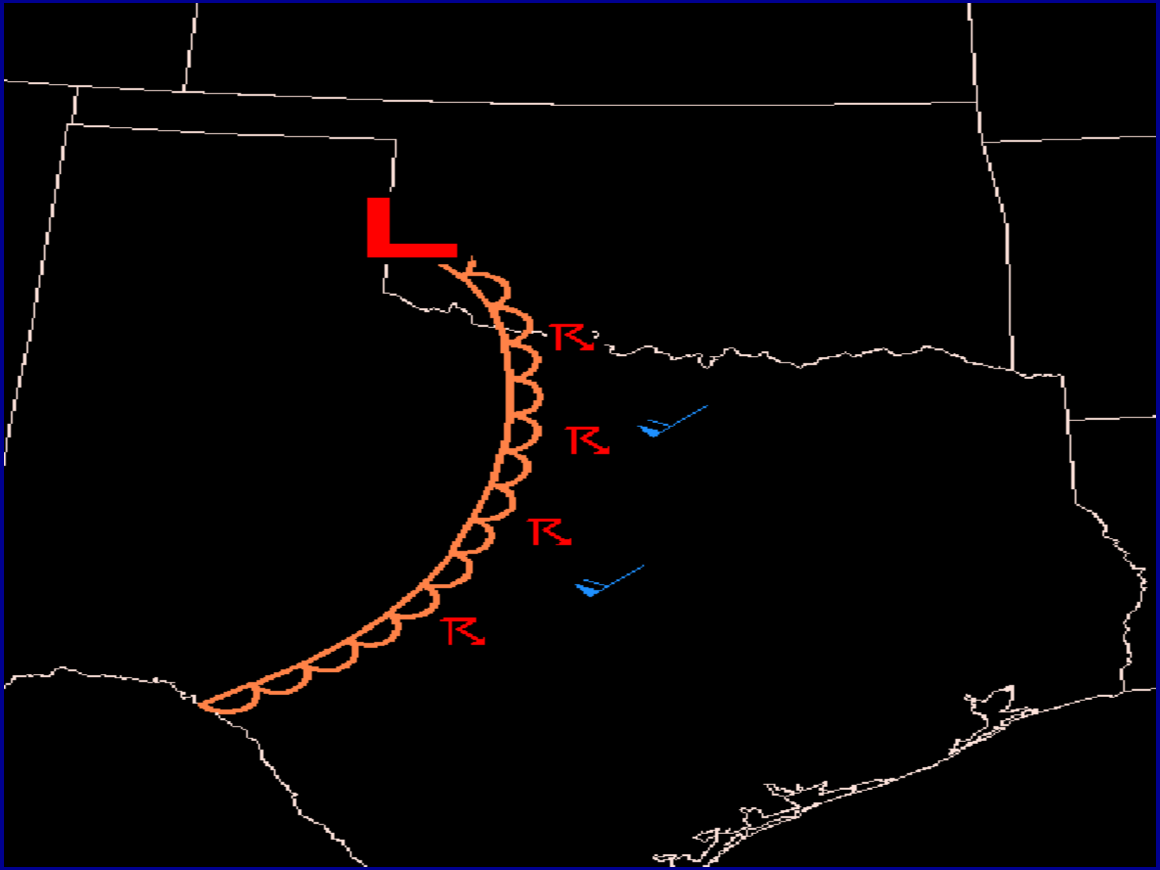
What Influences Convective Mode?

Shear vector parallel to initiating boundary: storm interactions favors line formation, with end supercells possible.



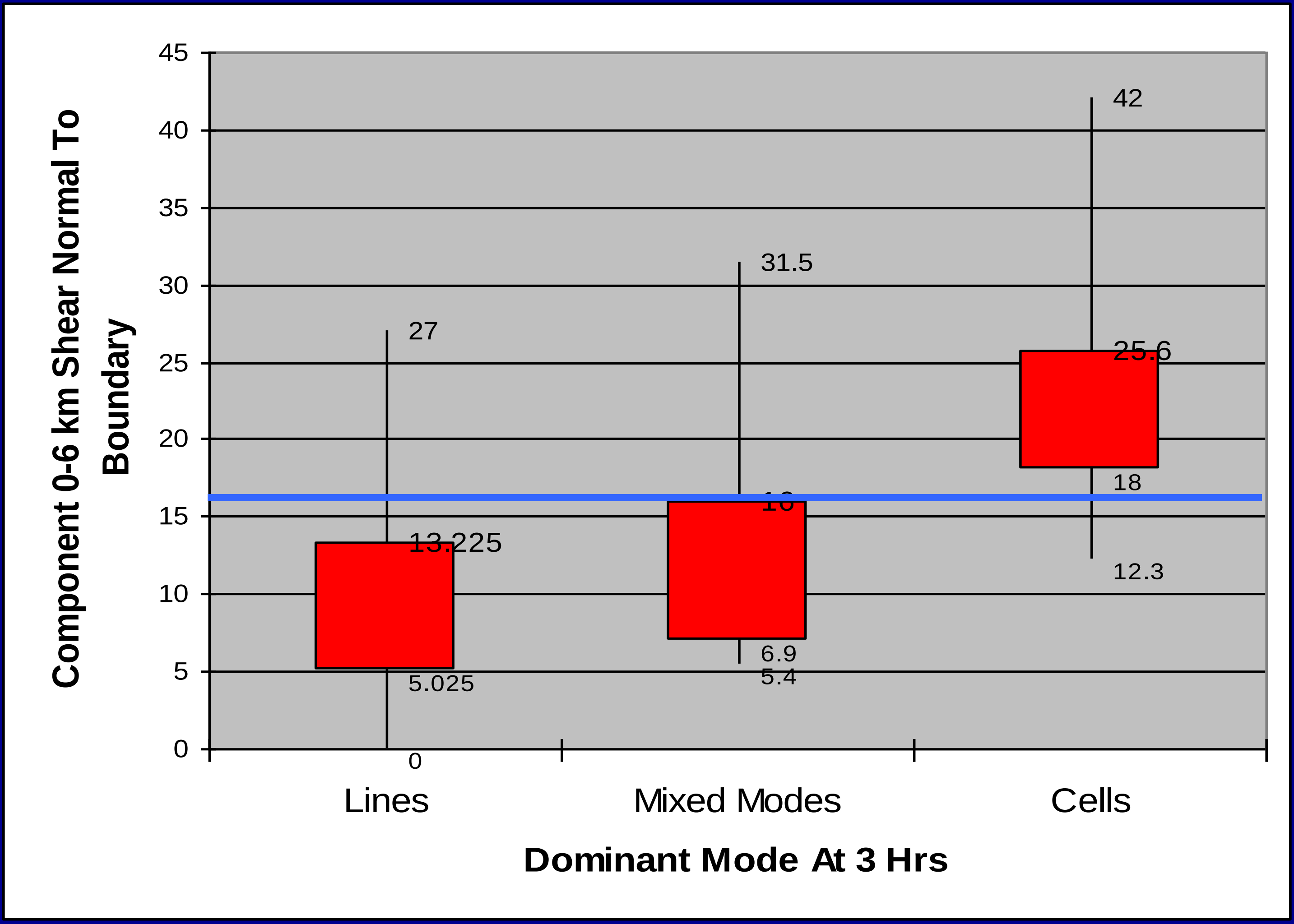
What Influences Convective Mode?

Shear vector ~ 45° across initiating boundary:
discrete cells without split interactions



Normal Component of 0-6 km Shear (m/s) and Mode

(From Dial and Racy 2004)



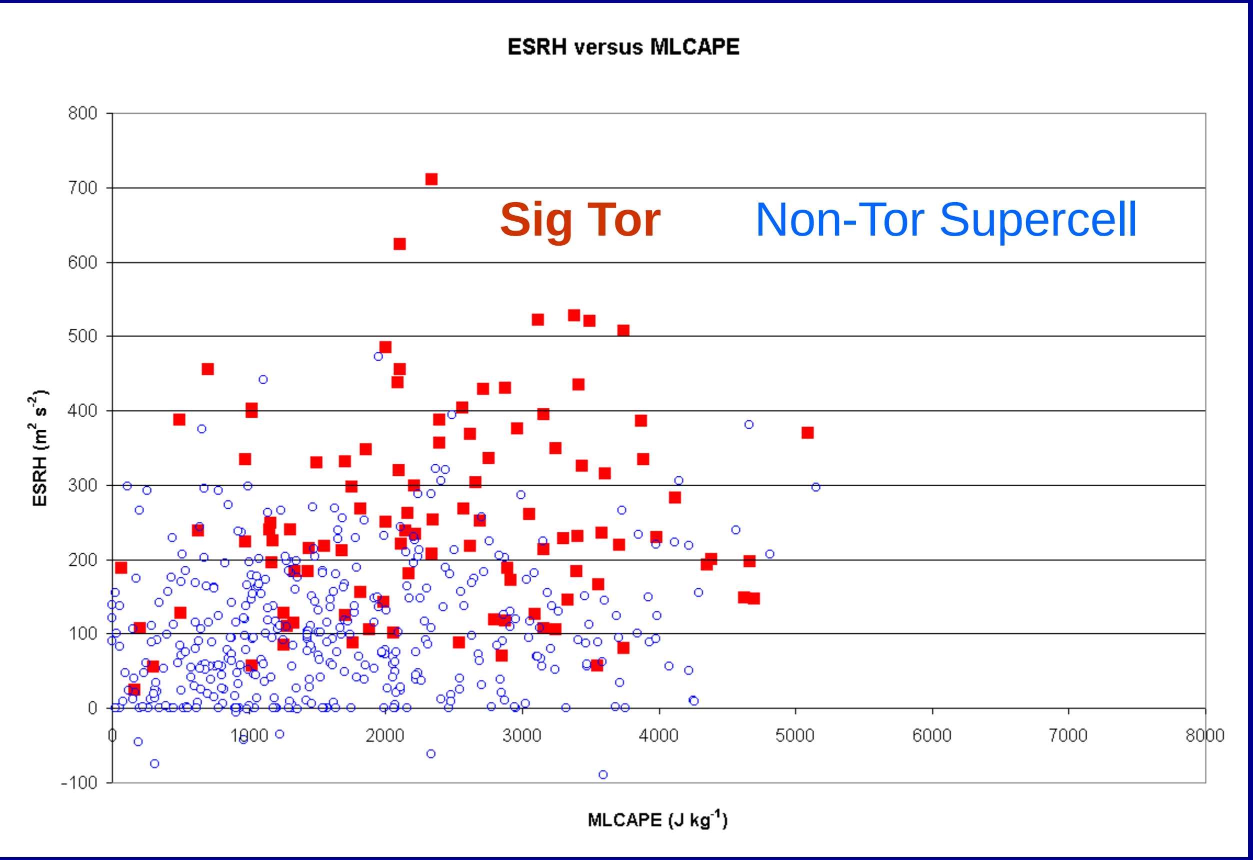
How Sensitive is Convection to Environmental Conditions?

Most Sig Tor Events Occur with MLCAPE > 1000 J/kg and ESRH > 100 m2s2

But many non-tornadic supercells also occur in that parameter space

Similar environments produce different storm types

Different environments produce similar storm types



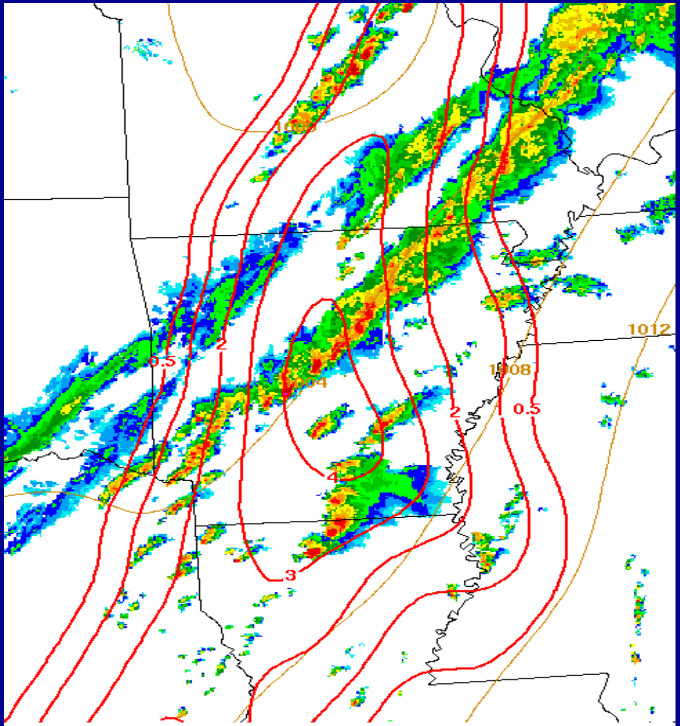
MLCAPE/Effective SRH Scatterplot

Results from Updated Thompson et al. RUC Analysis Sample

How Sensitive is Convection to Environmental Conditions?

- Operational experience and proximity sounding studies suggest relationship of storm character to environment is highly variable

Example - Numerous severe storms in Arkansas but only one produced a significant tornado



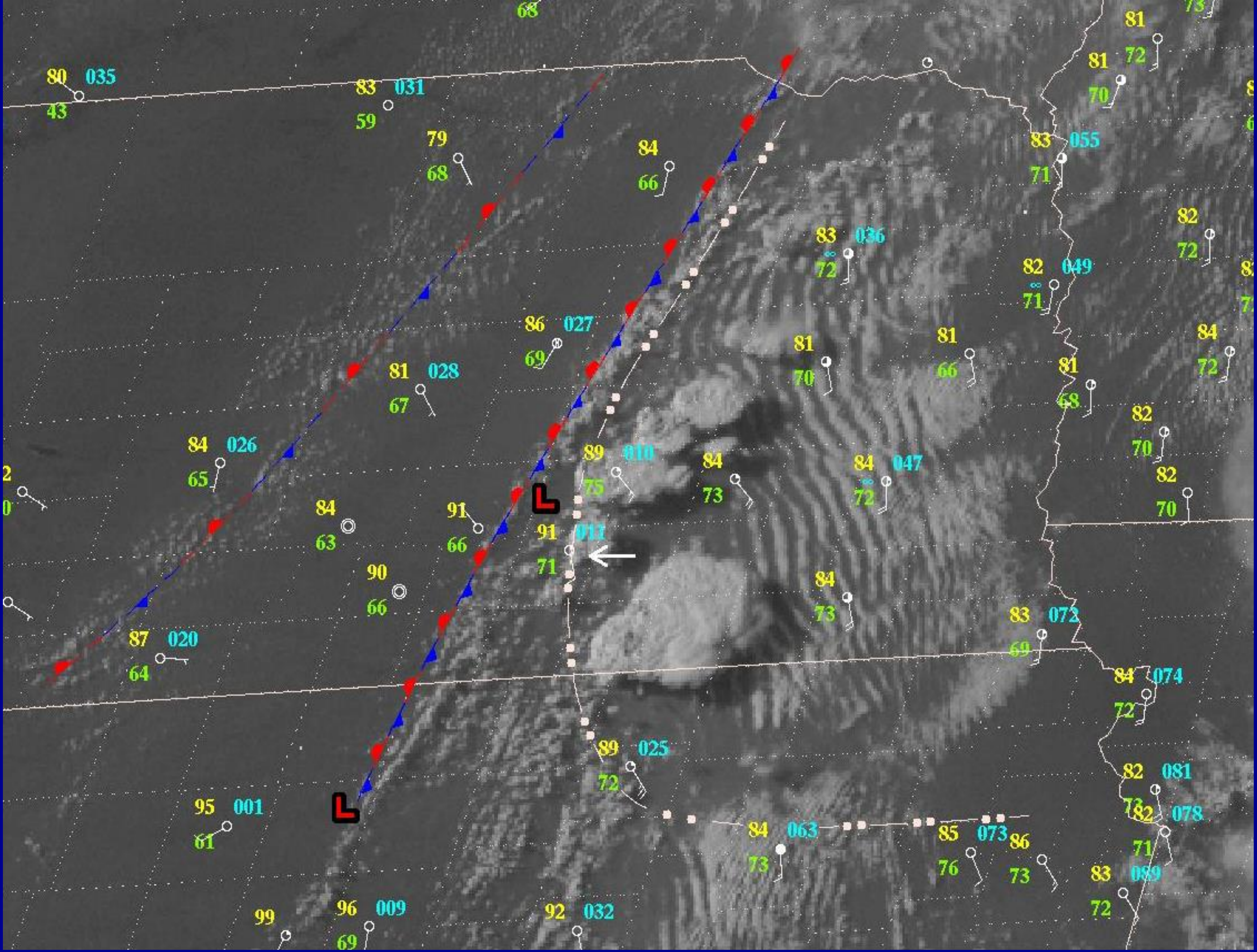
021218/2200 Significant Tornado Parameter

Importance of Convective Mode

- Basic law of severe weather forecasting:
  - Correct prediction of convective mode is of paramount importance
  - If you don't get the mode right, the predominant type of severe weather that occurs may be different than you expected

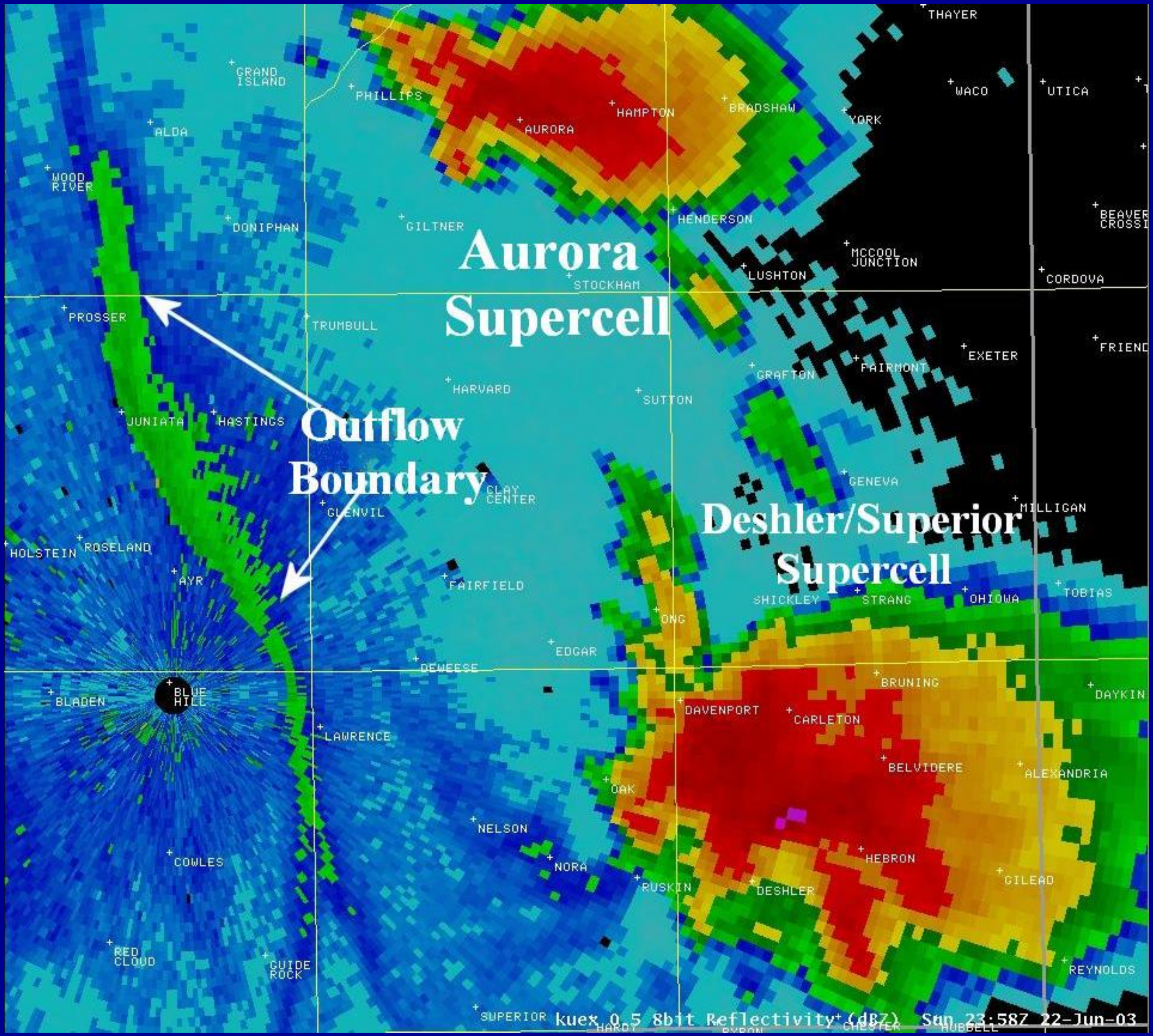
Importance of Convective Mode

- Corollary - even when the mode is the same, different events may occur in close proximity to each other
    - 22 June 2003 severe storms in Nebraska



2245 UTC Satellite and Analysis *(from Guyer and Ewald)*

0.5 deg Reflectivity 2358 UTC



Aurora Supercell Produced Record 7" Hailstone

Deshler Supercell Produced F2 Killer Tornado

(from Guyer and Ewald)

Summary – Improving Thunderstorm Forecasting

- There are many issues that suggest accurate prediction of convective details will be a slow, incremental process
  - We don’t understand small scale phenomena and processes as well as synoptic scale processes
    - *As we go down in scale the science is less and less mature*
  - We don’t sample the atmosphere in enough detail
    - *Small differences in structure may impact storm evolution*
  - It is hard enough to accurately predict a single storm and its evolution
    - *Complexity increases (by orders of magnitude?) once multiple storms develop and they begin to interact*
  - Large uncertainty is inherent in convective prediction and we can’t ignore it --> *probabilistic approaches*

Summary – Improving Thunderstorm Forecasting

- As forecasters, we must remember that the real atmosphere is more important than a model atmosphere
  - *Model atmosphere may not replicate real atmosphere*
- We must develop skills to synthesize observational datasets
  - *Construct a coherent picture of important synoptic scale and mesoscale features that may impact convection*
- Understand strengths/limitations of observing network and objective analysis support systems
  - *Consider mesoscale/stormscale limits of predictability in decision-making process*
- Play active role in the forecast process
  - *Recognize your unique contributions to the human/computer mix*

Back to question – What Indices should be used for MTG-S?

- MTG-S systems should focus on producing soundings, not indices!
  - Indices can be produced from soundings but not visa versa
  - Different users will have different needs for difference events and seasons
  - 1 km vertical resolution should be sufficient to address biases produced using 'surface parcels'

- How will sounding products be used?
  - In stand-alone forecasting or as checks/enhancements to NWP products?
    - If NWP, then consider using NWP background in retrieval system to incorporate other asynoptic data sets, e.g., aircraft tropopause data
  - What will be more important, indices or their tendencies?
    - If tendencies, need to be able to determine "Why are they changing?"
  - Will wind information need to be appended to the soundings?
    - Needed for 'storm type/intensity' forecasting.

- How will all of this new information be integrated into your own forecasting processes and warning systems?

Thank You