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Thermodynamics: Stability Indices and Thunderstorms

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Overview

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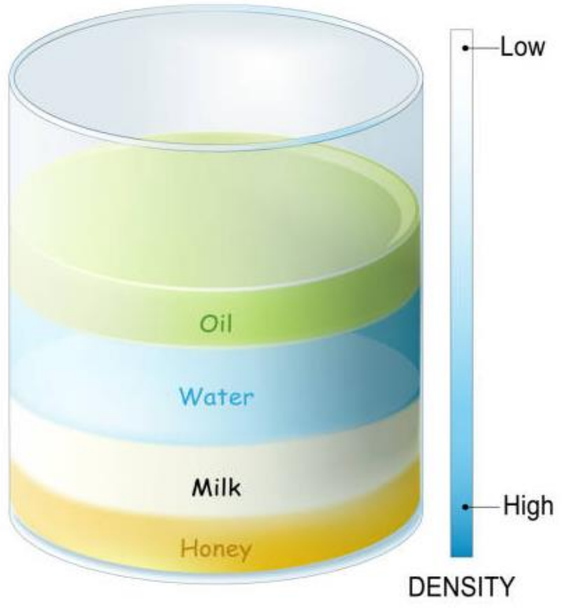
01

Static Stability and evaluation with soundings

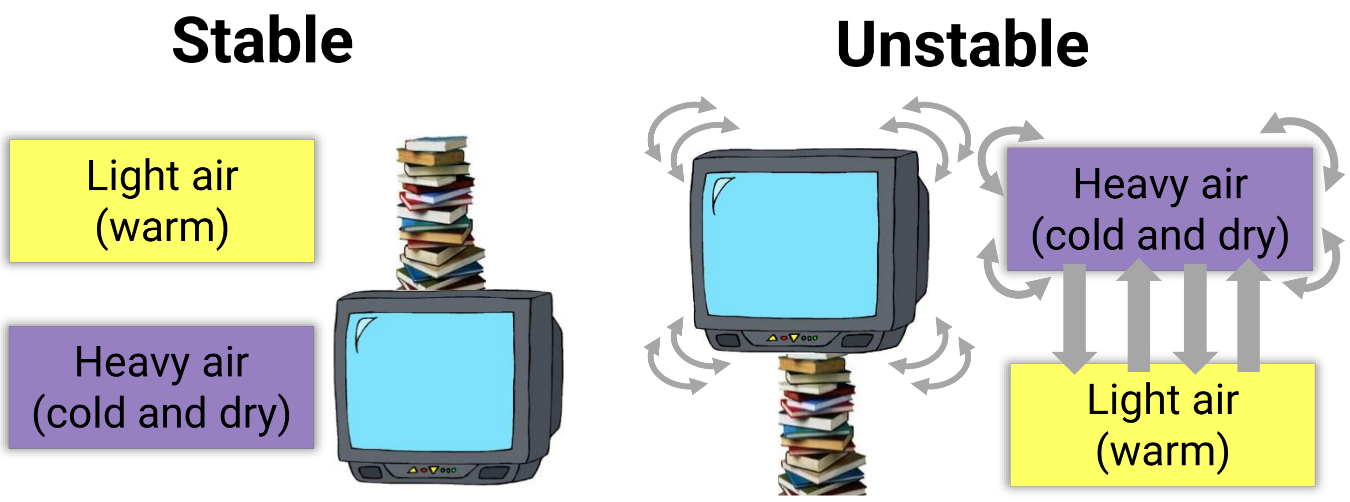
Static Stability

- It represents how unfavorable the atmosphere is for allowing the development of vertical motions.
- Think on the vertically stacking of fluids of different density. The denser (heavier) fluid will tend to sink to the bottom due to gravity.
- A fluid is stable if the denser portion is sitting at the bottom already.
- The atmosphere (a fluid) is stable when density decreases with height. This can be evaluated by analyzing vertical profiles of temperature and moisture.



Static Stability

- A stable situation is when light air sits over heavy air.
- If light air develops near the surface (e.g. solar radiation heats the air and turns it light), then an unstable situation will develop and vertical motions will form.



Importance for Aviation: Stability can be used to evaluate the potential for thunderstorms and also turbulence.

Static Stability in the Atmosphere

In the atmosphere, stable layers limit vertical motion and inhibit developing convection. Once a cloud reaches the stable layer, it spreads horizontally.

Stable

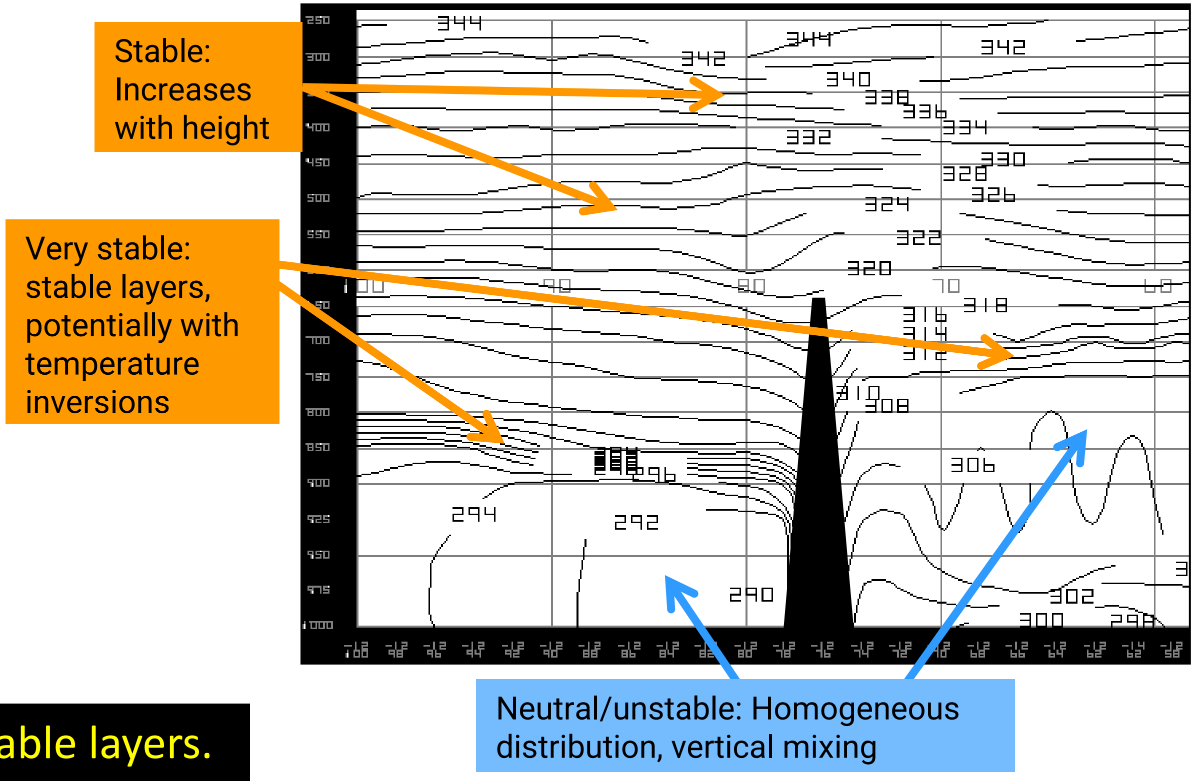
Stable Layer at the anvil top

Unstable

A stable layer can be seen as a region that separates a dense (cooler) air mass from an overlying light (warmer) one.

Evaluation of stability with cross sections of potential temperature, theta (Θ)

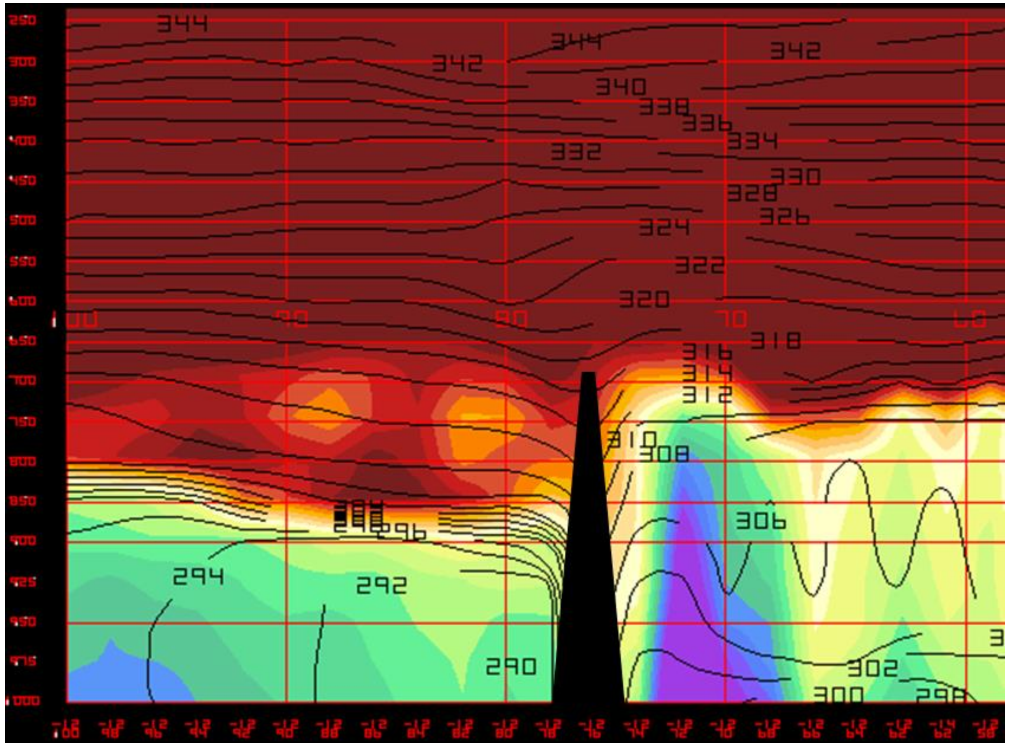
- Evaluation of stability ignoring the effects of moisture (consider theta-e for moisture).
- An increase with height implies stability.
- Theta increases with height naturally, meaning that the atmosphere is generally stable.
- **Stable Layers:** Sharp increases denote stable layers, which limit vertical mixing and vertical development of convection.



Aviation: It is generally safe to fly over stable layers.

Evaluation of stability with cross sections of equivalent potential temperature, theta-e (Θe)

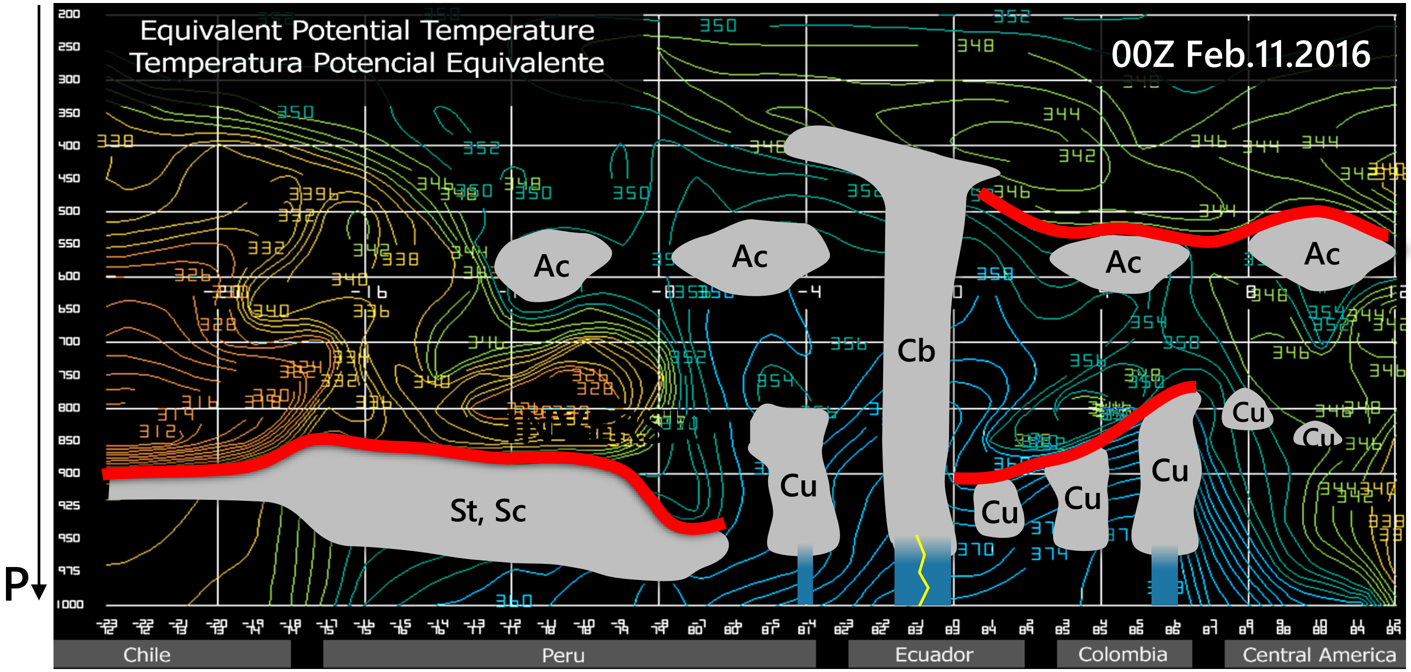
- **Theta-e definition:** Potential temperature a parcel would have if all its latent heat is released.
- **Interpretation:** Higher values mean more moisture present that could warm the parcel if condenses.
- **Applications:** Thus theta-e can be used to evaluate the effects of moisture.
- Dry air overlying inversions shows well in theta-e, which makes it a great tool to detect stable layers and especially subsidence inversions.



Quick assessment of Static Stability with Theta-e

- The equivalent potential temperature (theta-e) considers the effects of temperature and moisture on stability.
- In cross sections, captures fairly well the presence of stable layers and regions where dry air is present.
- The contribution ratio of heat vs moisture cannot be visually detected, thus it is recommended to look into temperature and moisture profiles in regions of interest.

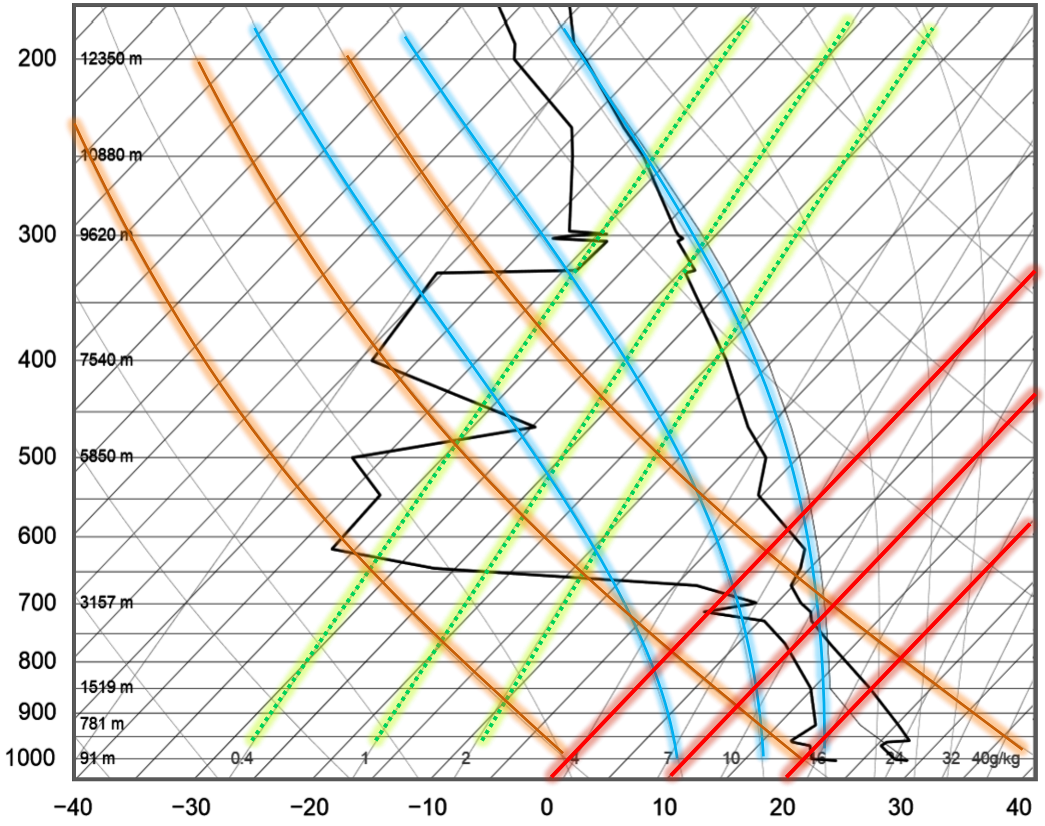
Meridional Theta-e Cross Section in the Eastern PAcific



Thermodynamic Diagrams

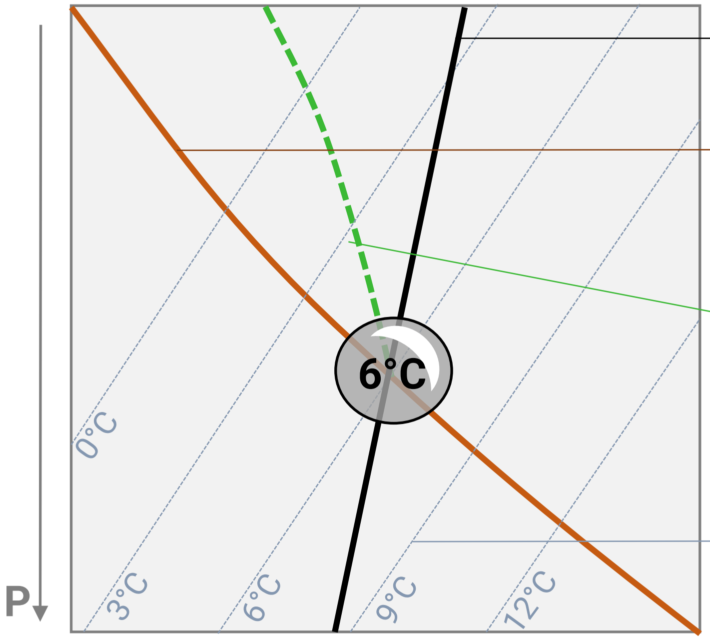
- Vertical profiles of temperature and moisture can be plotted and analyzed on a thermodynamic diagram.
- There are various types of diagrams, we are using the type called Skew-T.
- Skew-T uses pressure as a vertical coordinate. Temperature is skewed, and dry and moist adiabats curved. Mixing ratio lines are skewed as well.

Aviation interests: Evaluate the potential for the development of thunderstorms



Parcel Method for determining stability

On a thermodynamic diagram, we simulate the vertical displacement of a parcel assuming there is no mixing with the environment. After displacing it, the parcel temperature is compared to that of the environment (sounding). A warmer parcel implies instability and the development of ascent.



Environment temperature (sounding)

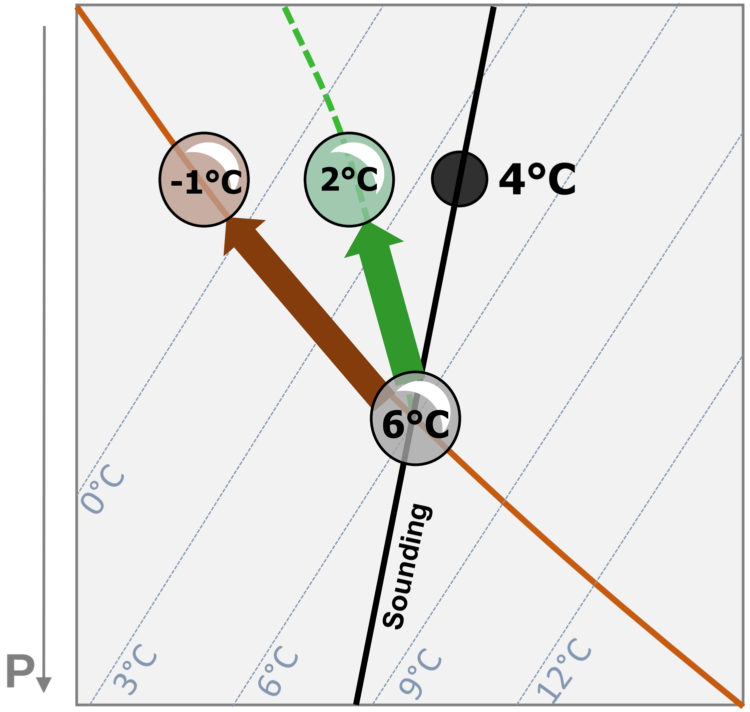
Dry Adiabat
Parcel ascends along it when not saturated.

Moist Adiabat
Parcel ascends along it when saturated. The slope is different to the dry adiabat due to the release of latent heat from condensation.

Isotherms

Stability

- Present when environmental temperatures decrease little (or even increase) with height.

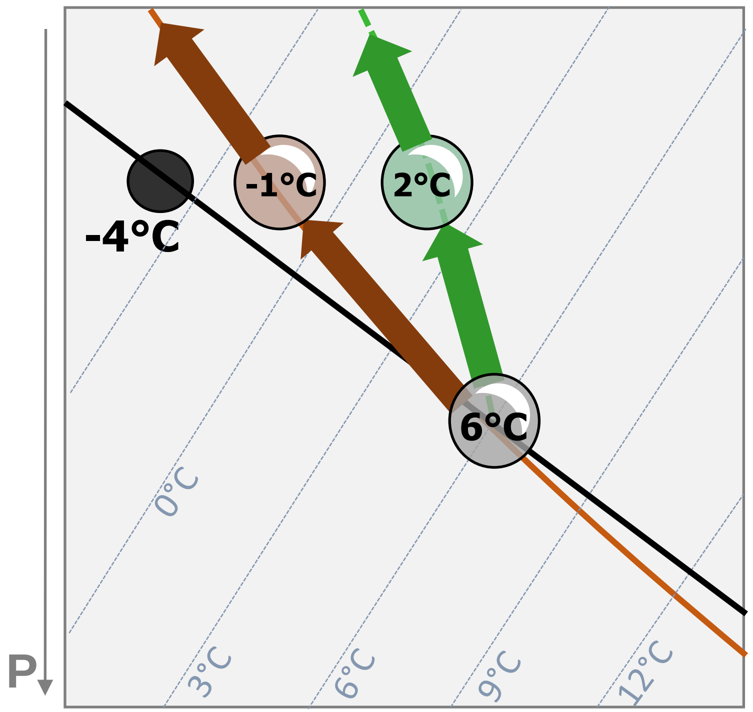


Stability Example

- Any upward displacement yields a parcel colder (denser) than the environment.
- Its reaction Will then be to sink until the level when temperatures become equal (the initial location).
- Key indicator: The sounding cools with height at a smaller rate tan the moist adiabat.

Instability

- When environmental temperatures decrease with height at a rate higher than the decrease in the dry adiabat.

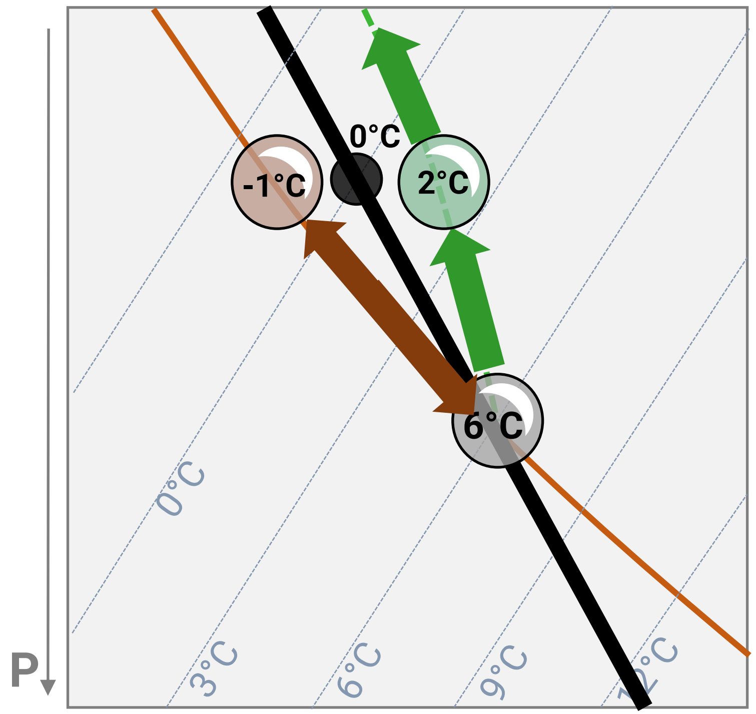


Instability Example

- Any upward displacement yields a parcel warmer (lighter) than the environment.
- Its reaction will then be to continue ascending until it finds a level where its temperature becomes similar to the enviromnental temperature. This results in continued parcel ascent, while environmental parcels descend, developing convection.
- Key indicator: The sounding temperature decreases rapidly with height, a a rate higher than that of the dry adiabat.

Conditional Stability

When it is determined by moisture content



ESTABILIDAD CONDICIONAL

If the sounding slope falls between that of the moist and dry adiabat, stability is dependent on whether the parcel is saturated or not.

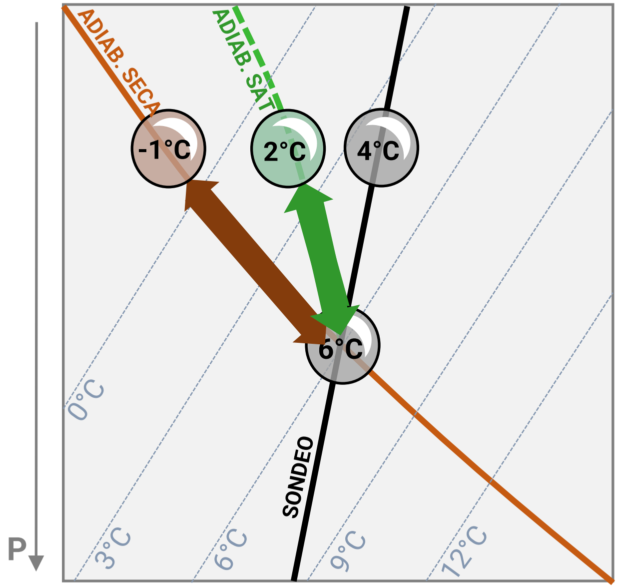
Saturated: Warmer parcel means that ascent will continue and convection will develop.

Unsaturated: The parcel becomes colder thus it Will return to its original position. This situation is stable and no convection is triggered.

Note: A moistening of the parcel (e.g. moisture advection, moisture flux convergence, etc.) could switch a stable environment to an unstable one.

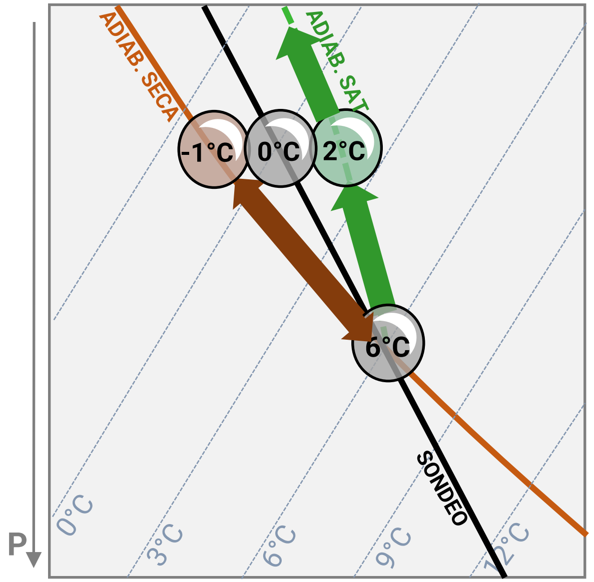
Intercomparison

Stability



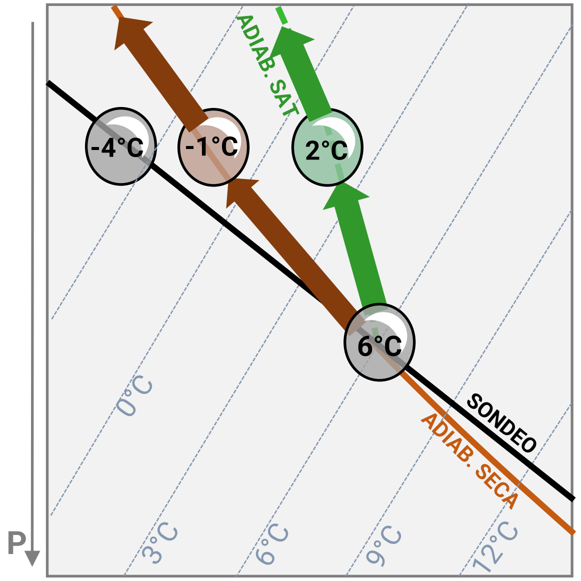
T_{sondeo} disminuye con la altura a una razón menor que la temperatura de la adiabática saturada

Conditional Stability



T_{sondeo} disminuye con la altura a una razón que cae entre la pendiente de la adiabática seca y la de la saturada

Instability

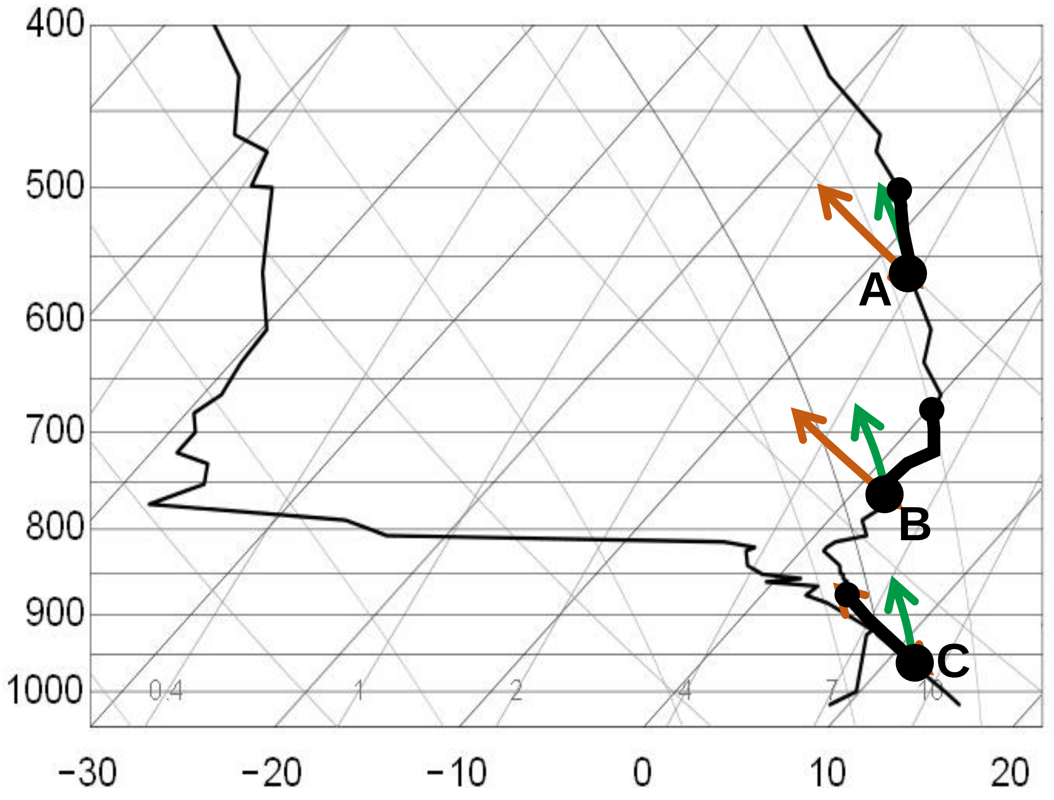


T_{sondeo} disminuye con la altura a una razón mayor que la temperatura de la adiabática seca

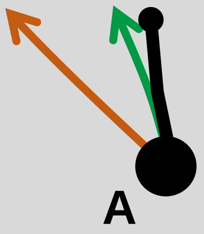
The parcel method focuses on a level, does not account for the entire sounding.

Parcel Method Example

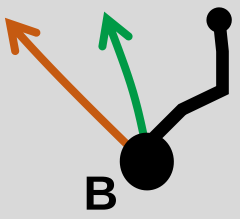
Ejemplo: Sondeo de convección llana (Key West, FL, 04-Mar-2013 00z)



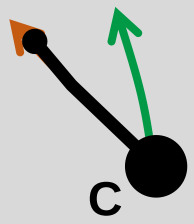
Notar que la parcela ascenderá por la adiabática seca por estar desaturada en A, B y C



ESTABLE
Al ascender la parcela siempre será más fría y densa que el ambiente.

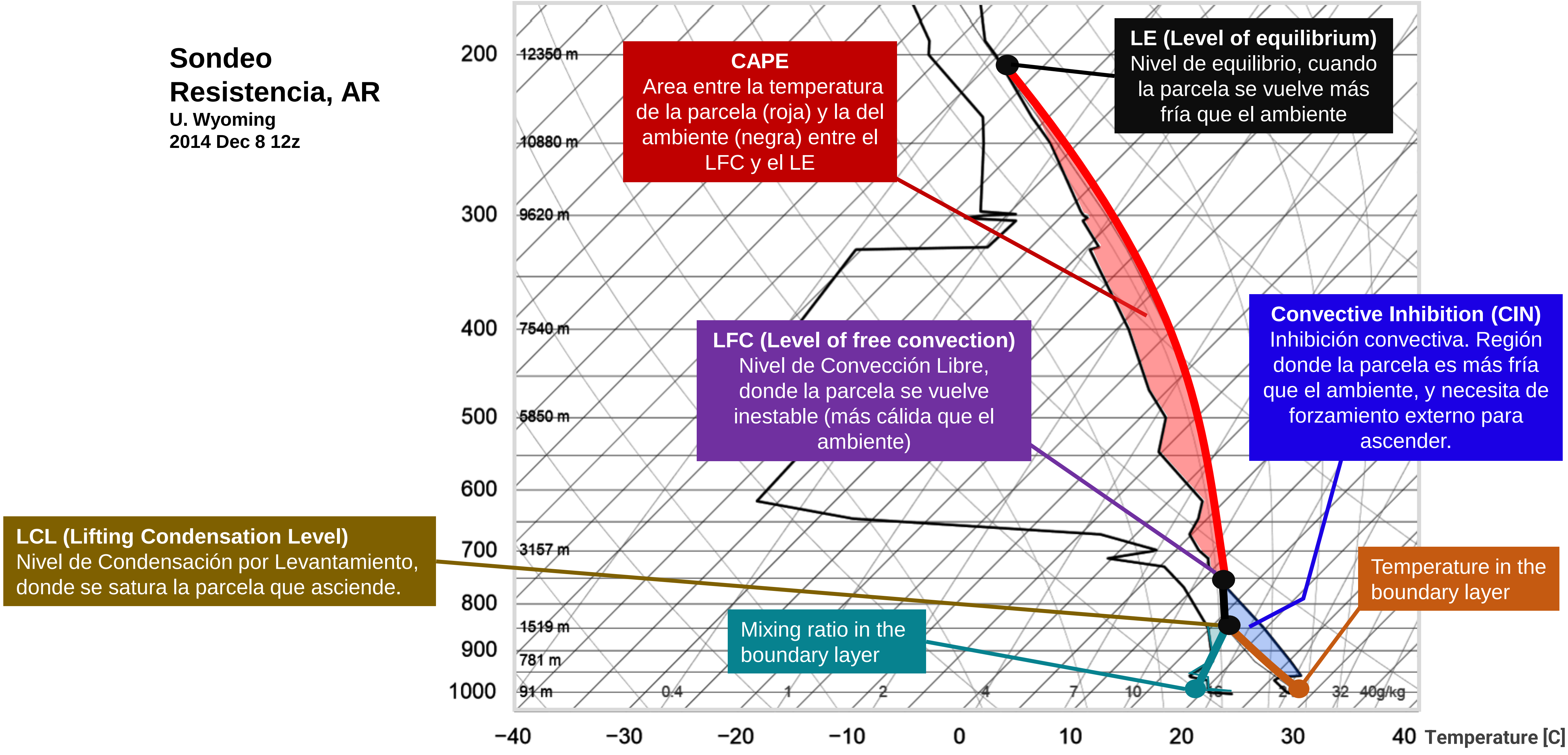


MUY ESTABLE
Al ascender la parcela siempre será más fría y densa que el ambiente.



INESTABLE/NEUTRO
Al ascender la parcela será más cálida o tendrá la misma temperatura que el medio ambiente.

Raising a Parcel using the entire sounding



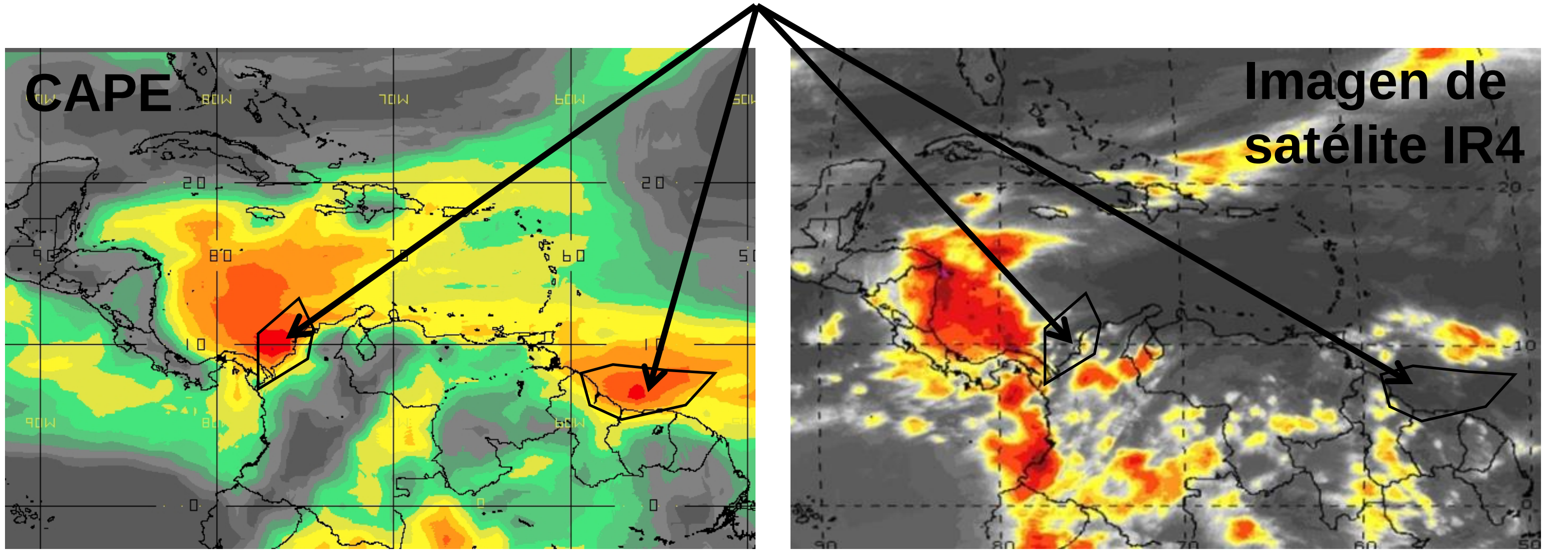
CAPE

- CAPE is “Convective Available Potential Energy” in a column.
- It is the maximum amount of energy that could be used by a parcel raised from the boundary layer.
- It can be calculated by the área between the región of the sounding located between the parcel ascent curve and the atmospheric temperature curve, when the parcel temeprature is higher tan that of the atmosphere.

Cape values in J/Kg	**Potential for Convection**
0	**Stable**
0-1000	**Marginally Unstable**
1000-2500	**Moderately Unstable**
2500-3500	**Very unstable**
3500+	**Extremely Unstable**

CAPE Limitations

- The convective inhibition needs to be taken into account, as it will limit convective development for Surface/boundary-layer parcels.
- There can be different types of CAPE, depending how the parcel is lifted (in which layer of the atmosphere it originates).
- CAPE does not work well in the Tropics. Values of CAPE can be very large and Little weather develops.



02

Stability Indices

What are stability indices?

They are quantities that estimate the potential for vertical motion and convection to develop based on the stability of the atmospheric column, and allow the analyst to assess the potential for thunderstorm formation over broad regions rapidly, versus having to look at independent thermodynamic profiles.

They ignore the effects of dynamical and mechanical forcing. This is why we use the term “static stability”

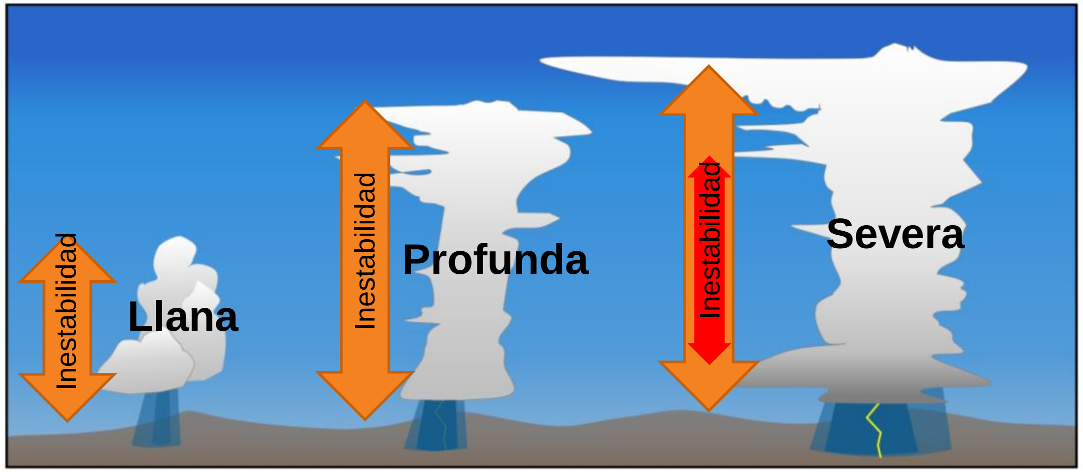
There are several that differ upon their methods of calculation.

Traditional Indices:

- Lifted Index (LI)
- Showalter Stability Index (SSI)
- Total Totals (TT)
- K Index (K)

Why are Stability Indices useful?

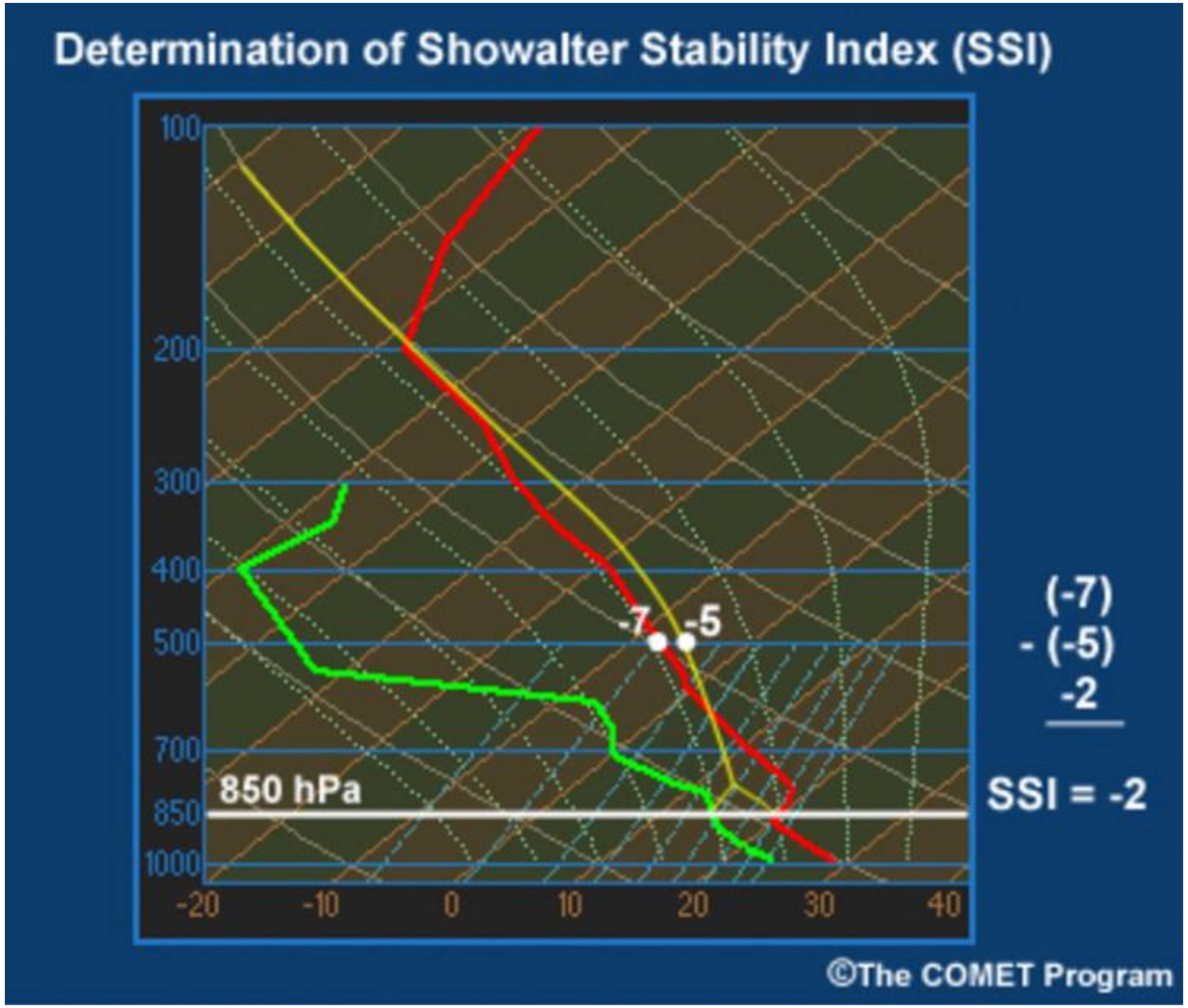
- They aid with determining the potential for the development of different types of convection quantitatively and rapidly.
- They allow evaluating the potential of shallow convection, deep convection or even severe convection without having to look at station profiles one by one.
- It is best to use them together with an analysis of the flow.



Aviation Impacts: Knowing where thunderstorms might form is useful for route planning and ground operations.

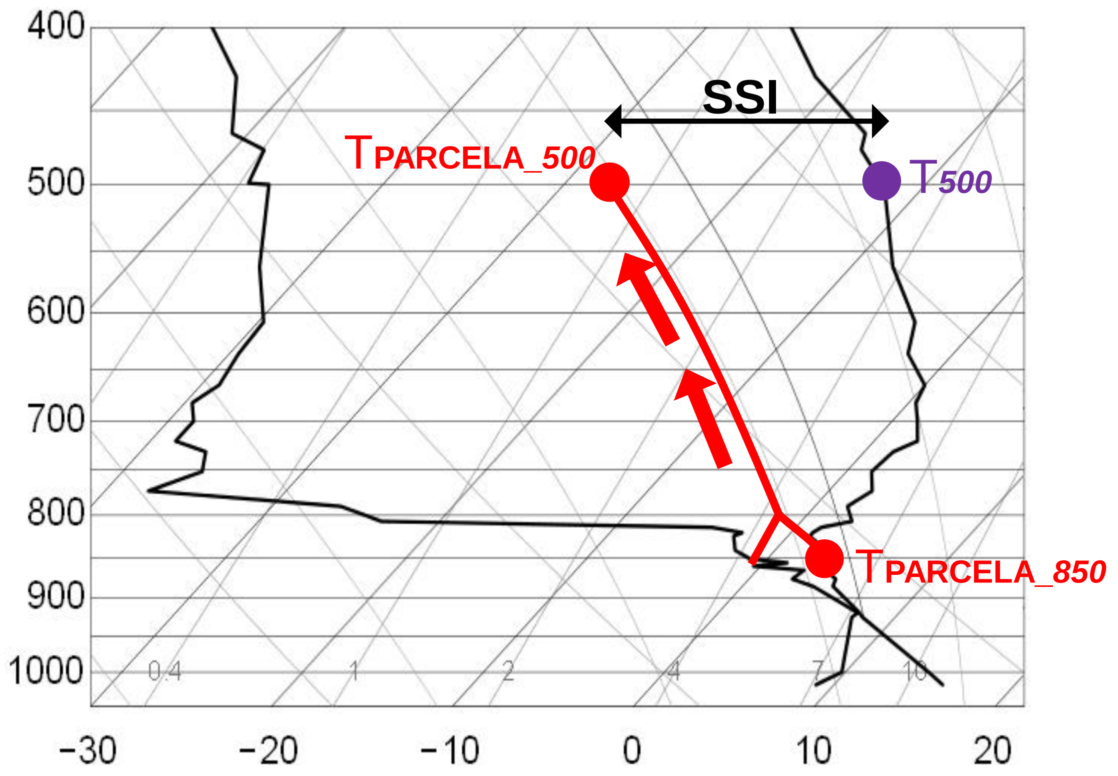
Showalter Index (SSI)

- One of the first to be developed.
- Is calculated by raising a parcel from 850 hPa to 500 hPa:
  - Uses T and Td in 850 hPA to find the LCL.
  - From the LCL, the parcel is raised moist adiabatically to 500 hPa.
  - Then compares the temperatures of the parcel and the environment's at 500 hPa.



Showalter Index (SSI)

SSI = Ambient T at 500 hPa − Parcel T at 500 hPA

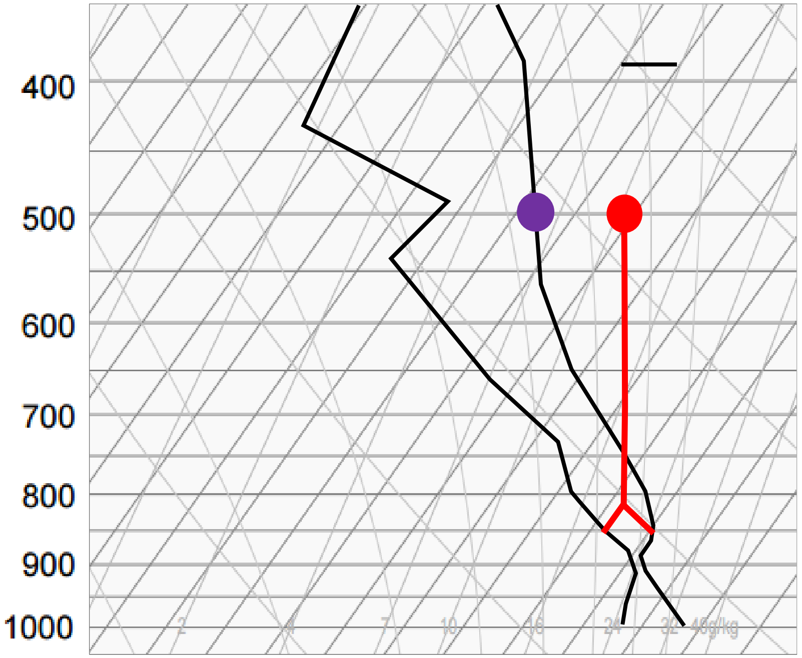


Showalter Index (SSI)

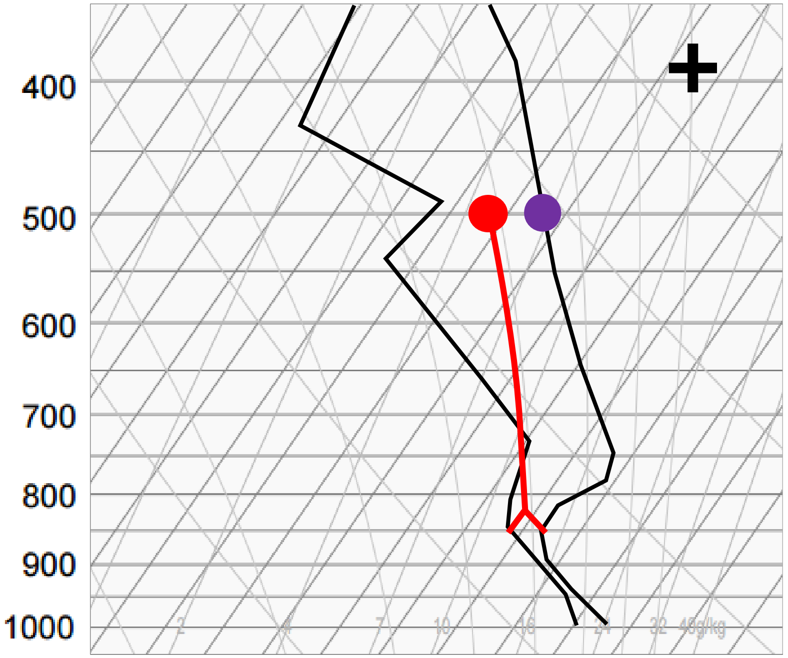
- The more negative, the more unstable, which means that the parcel is warmer than the environment.

$$SSI = T_{500} - T_{PARCELA\_500}$$

NEGATIVO: INESTABLE

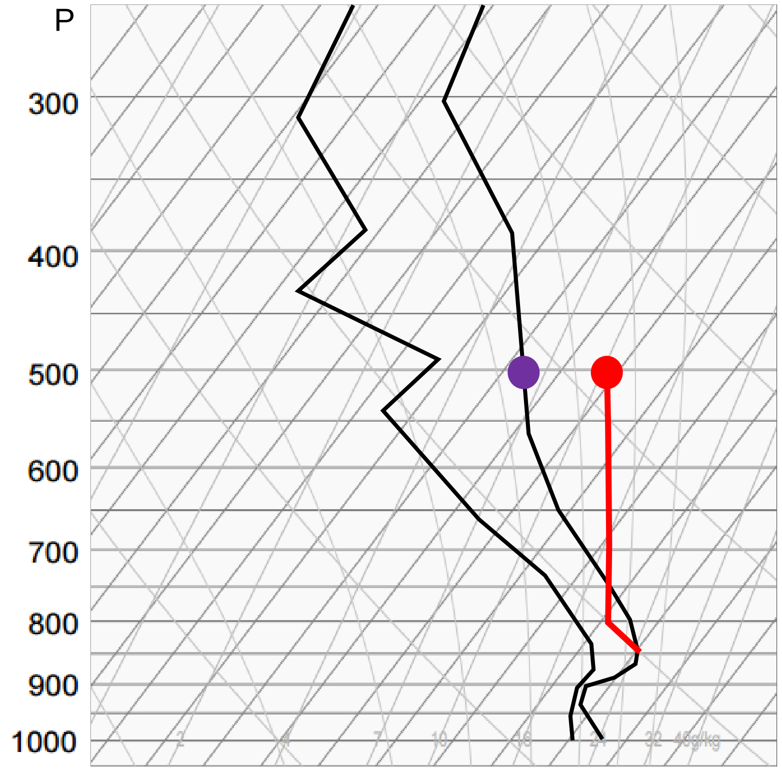


POSITIVO: ESTABLE



Showalter Index (SSI)

- Works for elevated convection, when there is a cold shallow layer underneath 850 hPa.
- Does not work when the cold layer surpasses 850 hPa.
- Does not consider diurnal heating.
- Does not work well if the station is located above 850 hPa.



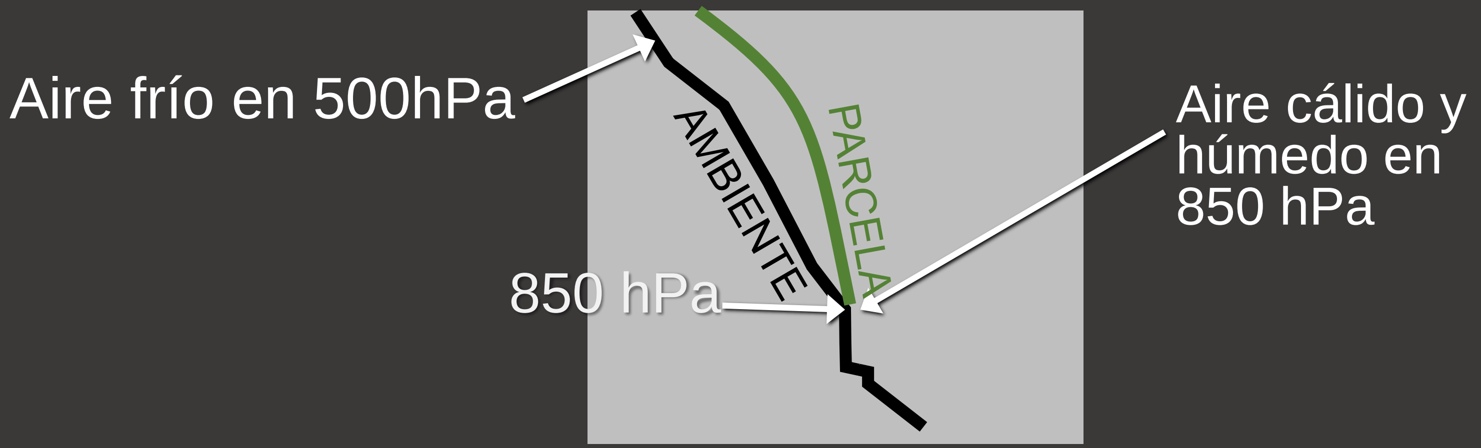
SSI = Positivo o Negativo?

Estable o inestable?

SSI values

- Positive: Estable
- 0 a -4: Marginally unstable
- -4 a -6: Very unstable
- <= -8: Extreme instability

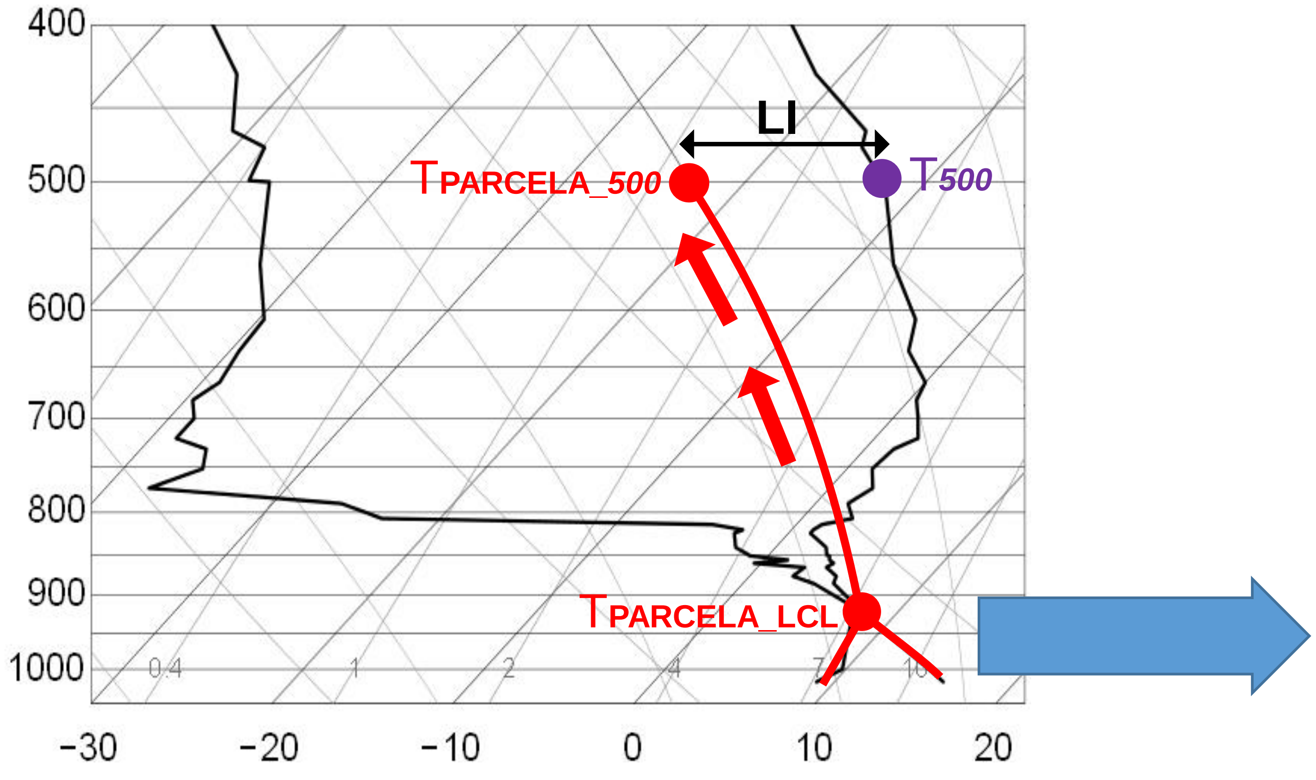
Para inestabilidad (negativo):



Lifted Index (LI)

Similar to SSI, but uses a parcel that is raised from the boundary layer

LI = Enviroment T at 500 hPa — Parcel temperature at 500 hPa



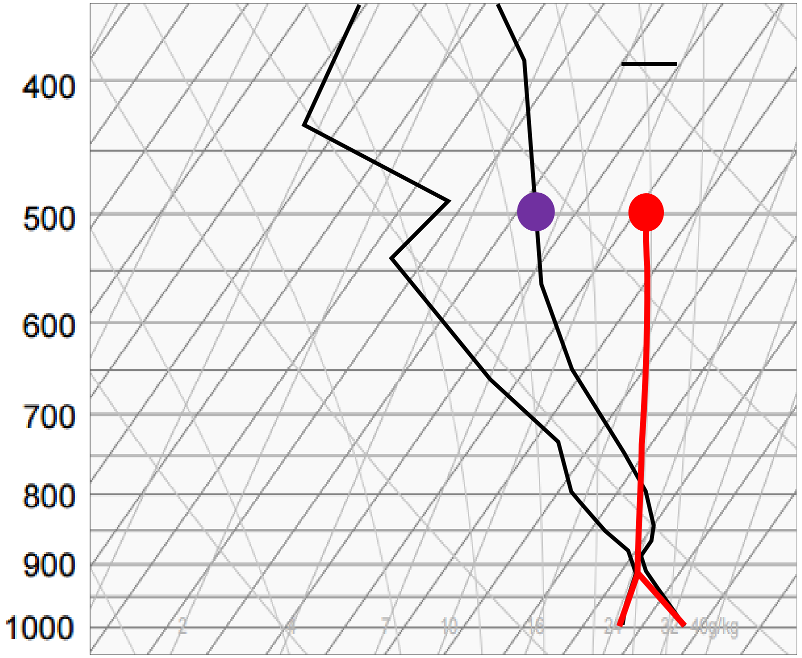
Temperature and moisture profiles in the boundary-layer matter.

Lifted Index (LI)

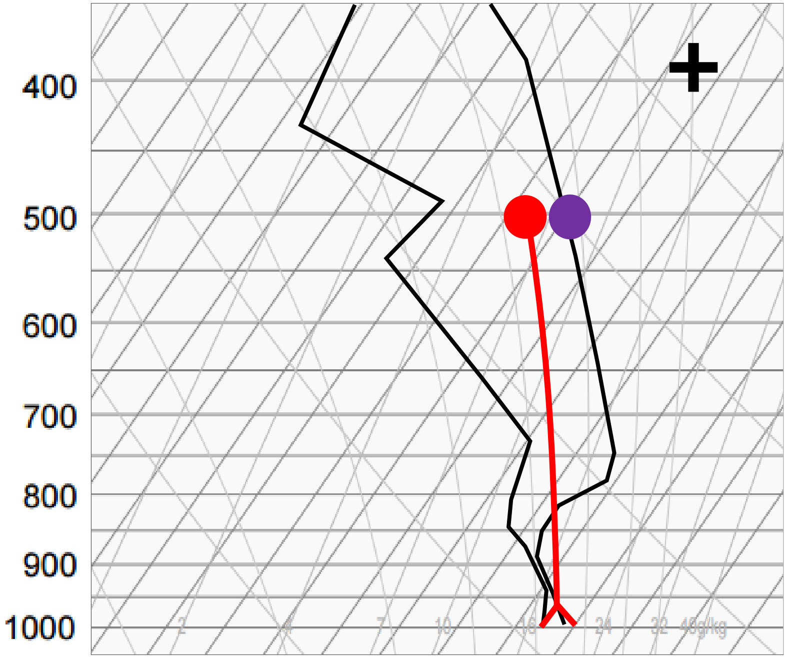
- The more negative, the more unstable.
- Limitations:
  - Considers only two levels.
  - Can be applied in the tropics, but close to upper troughs.

LI = $T_{500} - T_{PARCELA\_500}$

NEGATIVO: INESTABLE



POSITIVO: ESTABLE



Lifted Index (LI)

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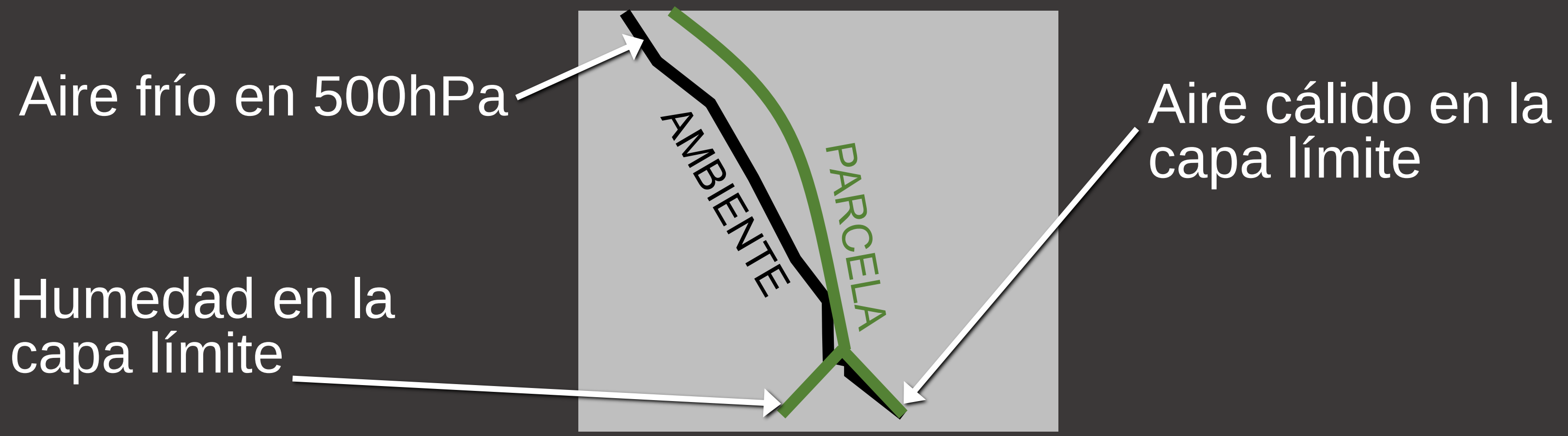
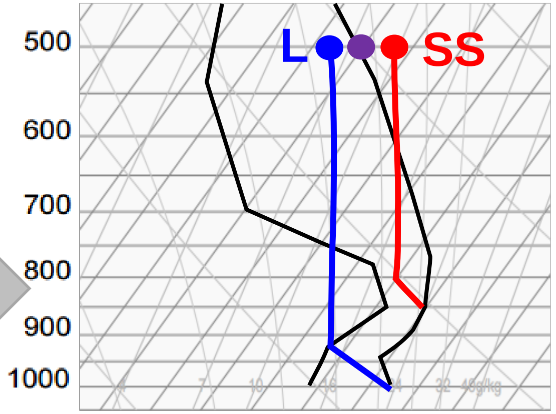
Para inestabilidad (negativo):



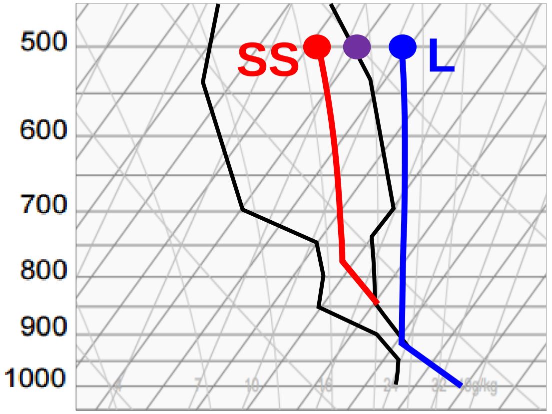
Comparison Lifted vs Showalter

A) **LI>0 & SSI>0** = Very stable.

B) **LI>0 & SSI<0** = Stable boundary layer, but atmosphere becomes les stable with height.



C) **LI<0 & SSI>0** = Boundary layer unstable, but posible inversión over 850 hPa.



D) **LI<0 & SSI<0** = Deep-layer instability.

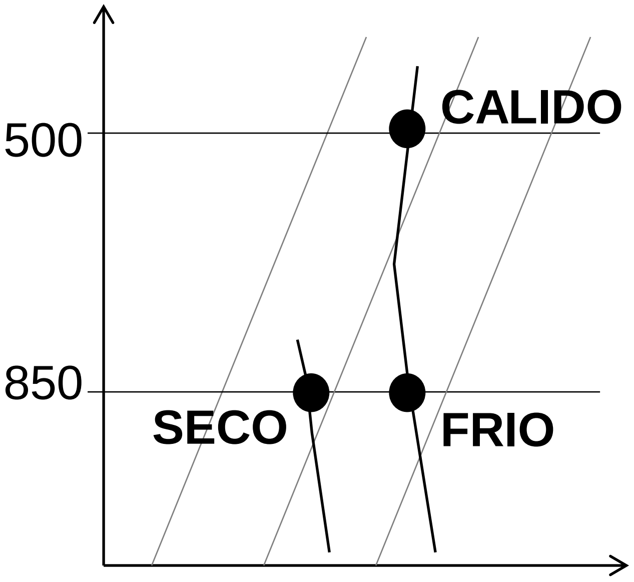
TOTAL-TOTALS Index (TT)

Uses 500 hPa temperature and both temperature and dewpoint temperature at 850 hPa.

$$TT = (T_{850} + T_{d}850) - (2 * T_{500})$$

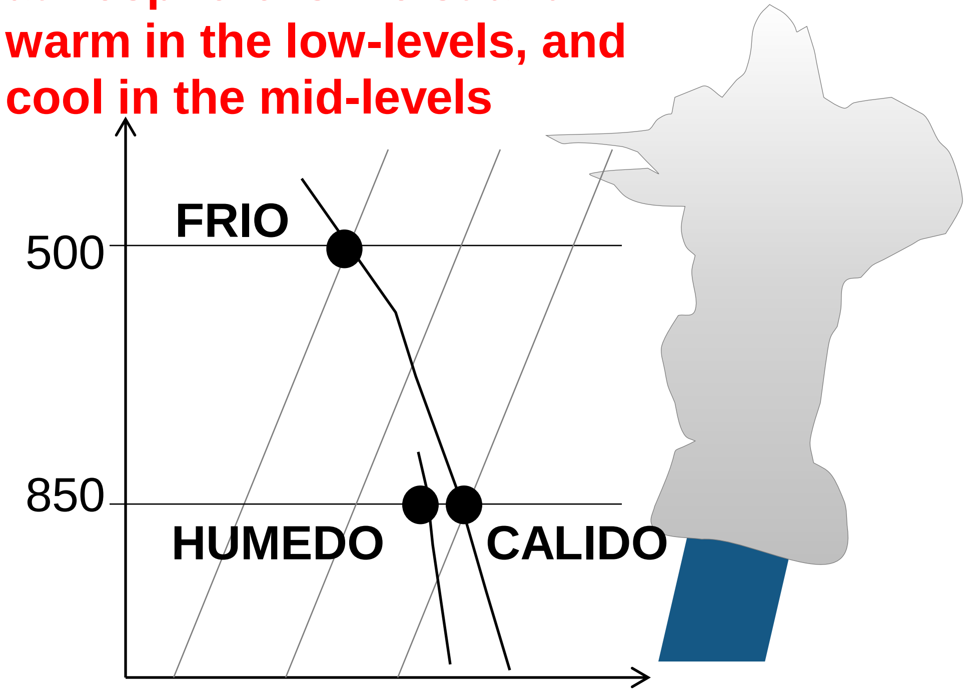
Stable (low values)

Lower values when the atmosphere is cool and dry in the low-levels.



Unstable (high values)

Higher values when atmosphere is moist and warm in the low-levels, and cool in the mid-levels



Índice TOTAL-TOTALS (TT)

PROS

- Easy to compute
- Works well in mid-latitudes and sometimes in the tropics.
- Intepretation is similar to SSI.

Limitations

- Uses only two levels.
- Does not work in elevated terrain (Psfc>850 hPa).
- Problems when inversions are present between these levels.
- Too high in post-frontal air masses.

Índice TOTAL-TOTALS (TT)

TT	*Event*
44	Tormentas
50	Tormentas Severas Posibles
55 or greater	Alto potencial de tormentas severas

Índice K

$$K = (T_{850} - T_{500}) + [\, Td_{850} - (T_{700} - Td_{700}) \,]$$

$(T_{850} - T_{500})$	$[\, Td_{850} - (T_{700} - Td_{700}) \,]$
Vertical temperature gradient (stability)	Moisture content

- The K Works better in the Tropics because it considers moisture content in 700 hPa.
- Better than the SSI, LI and TT for tropical maritime air masses and for air mass thunderstorms.

<u>CIMH (Barbados) found that Tstorms are favored when</u>

- Northern Caribbean K > 24
- Southern Caribbean, South America K > 30

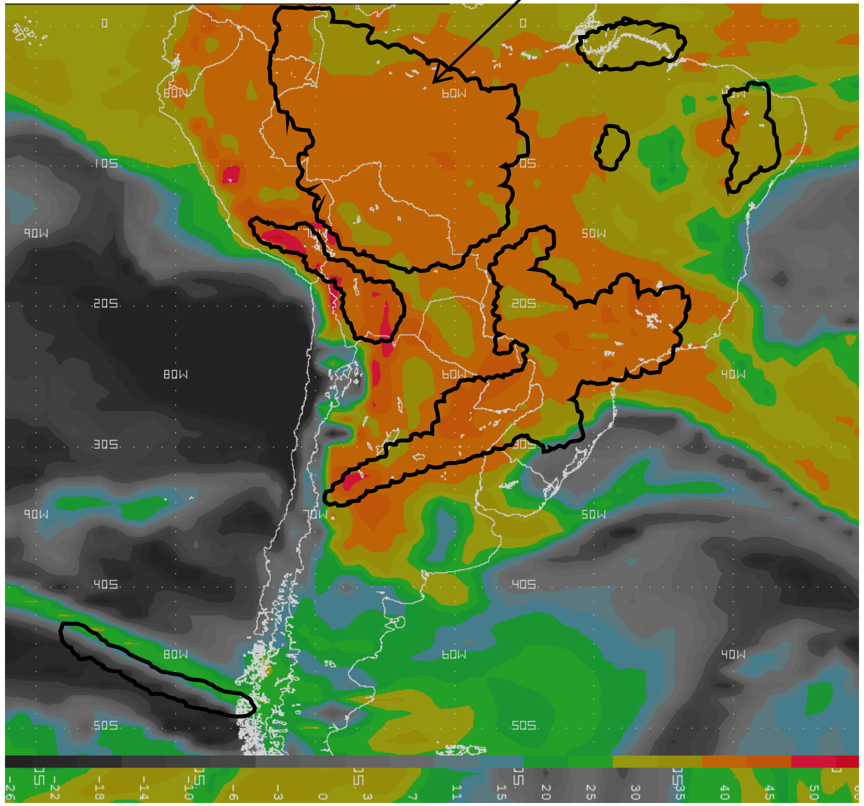
Índice K

Valores del K
(Latitudes Subtropicales y Medias)

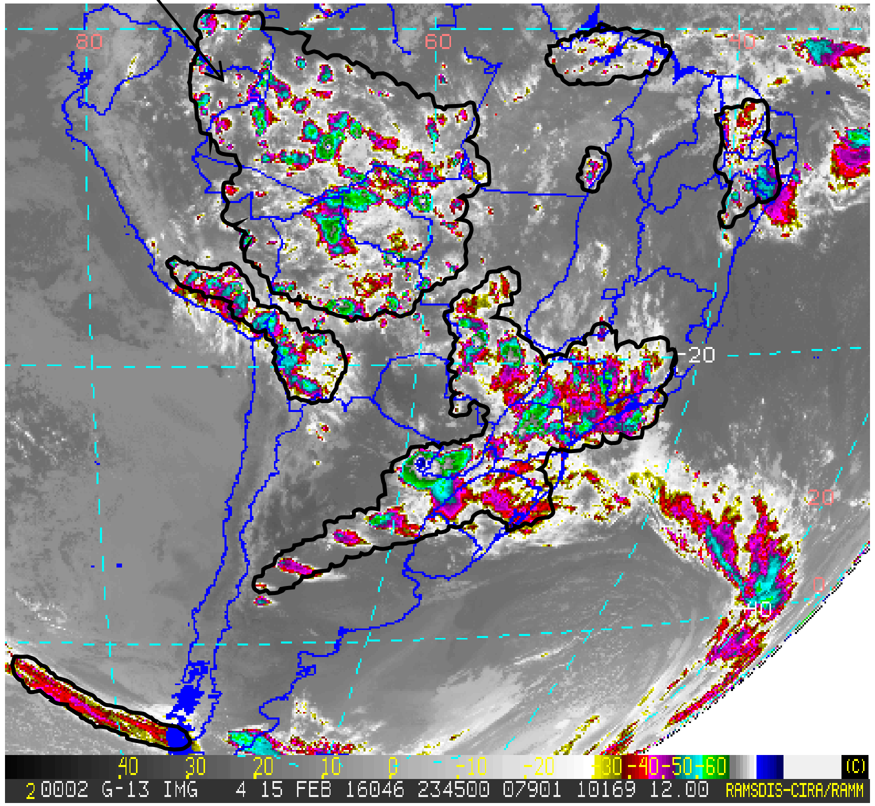
- 15 – 25 = Low convective potential
- 26 – 39 = Moderate convective potential
- +40 = High convective potential

K in South America (2016Feb1600Z)

AREAS CON CONVECCIÓN PROFUNDA:
El K tiende a sobreestimar la extensión de áreas de convección



$K_{GFS\_Analysis}$

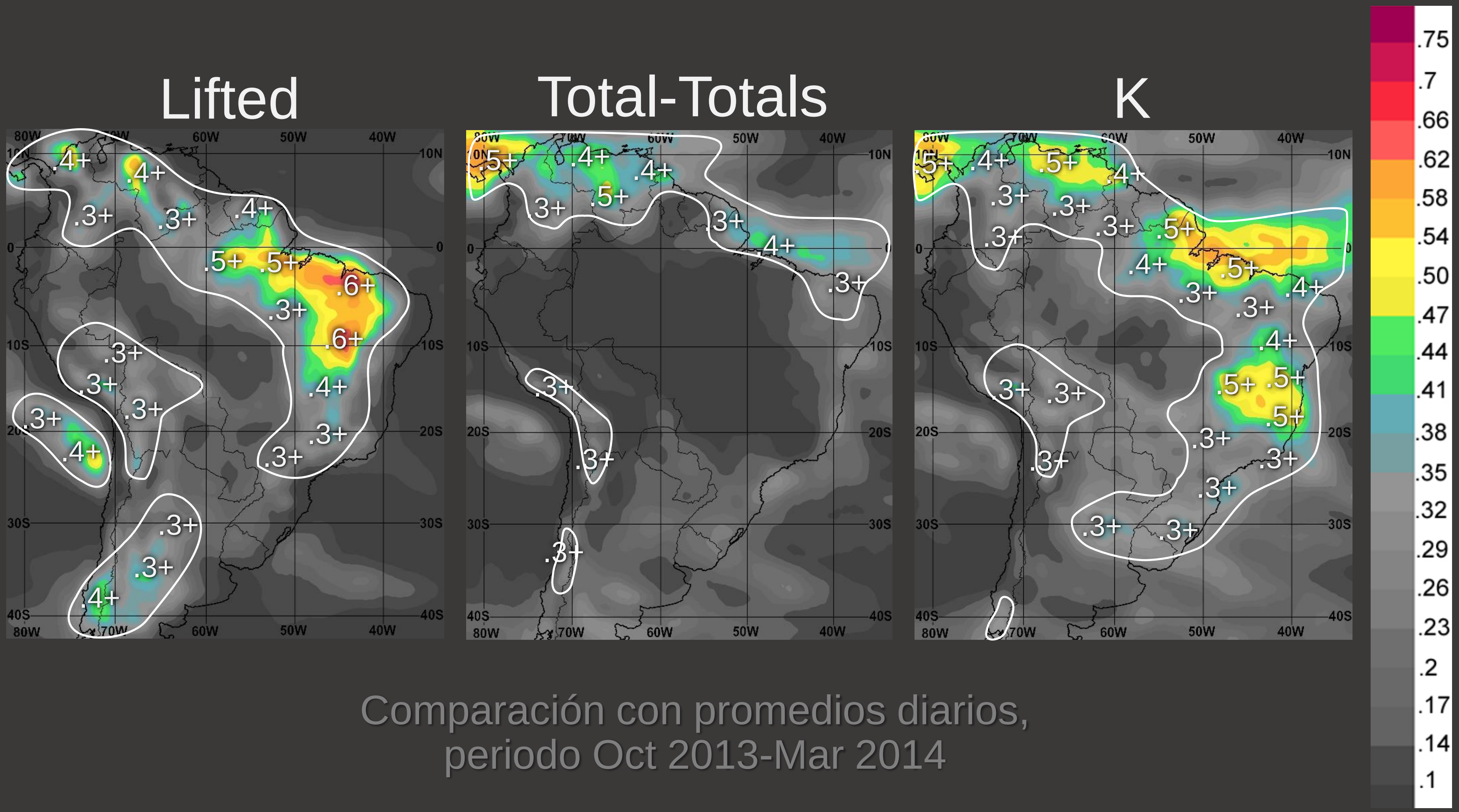


IR4 Image

K Skill in South america

$r^2_{\text{Indice-OLR}}$

Fracción de la variancia de OLR compartida con cada índice



Comparación con promedios diarios,
periodo Oct 2013-Mar 2014

03

The Galvez-Davison Index (GDI)

The Galvez-Davison Index (GDI)

What is the GDI?

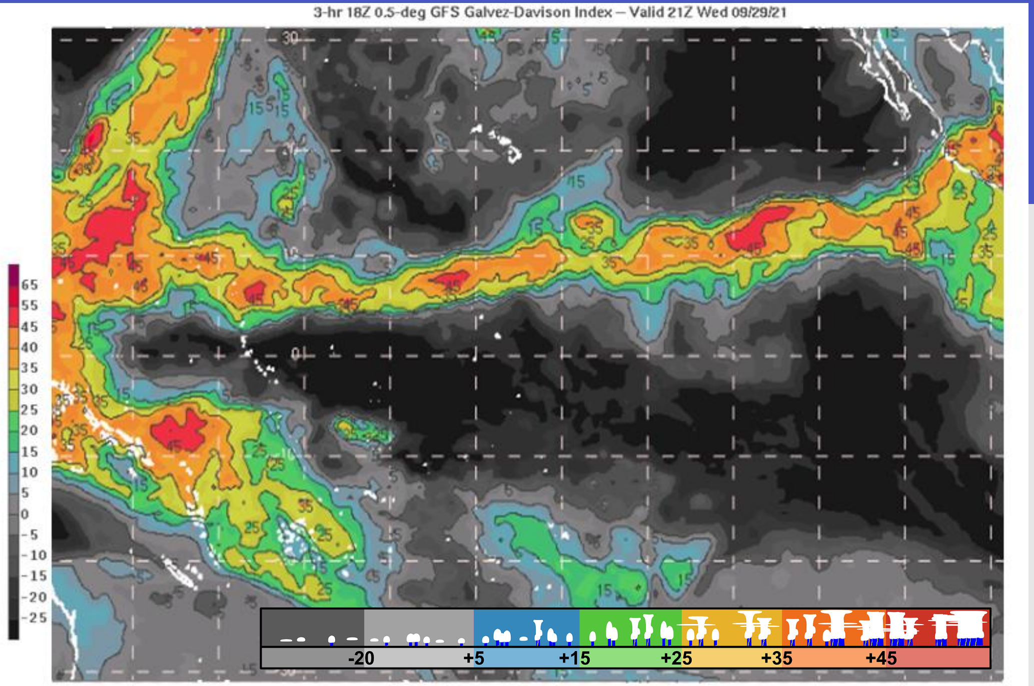
- Is a **thermodynamic index** developed by the WPC International Desks in 2014, to improve forecasts of trade wind regime convection.

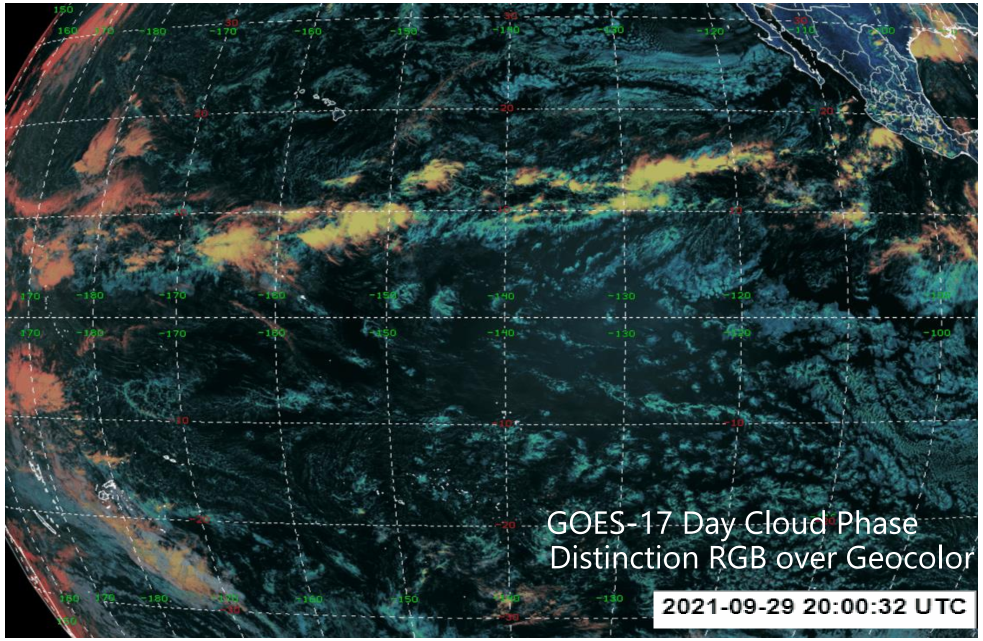
- It is a **diagnostic tool** that largely relies on equivalent potential temperature (theta-e). Emphasizes:

  (1) Availability of heat and moisture in the column

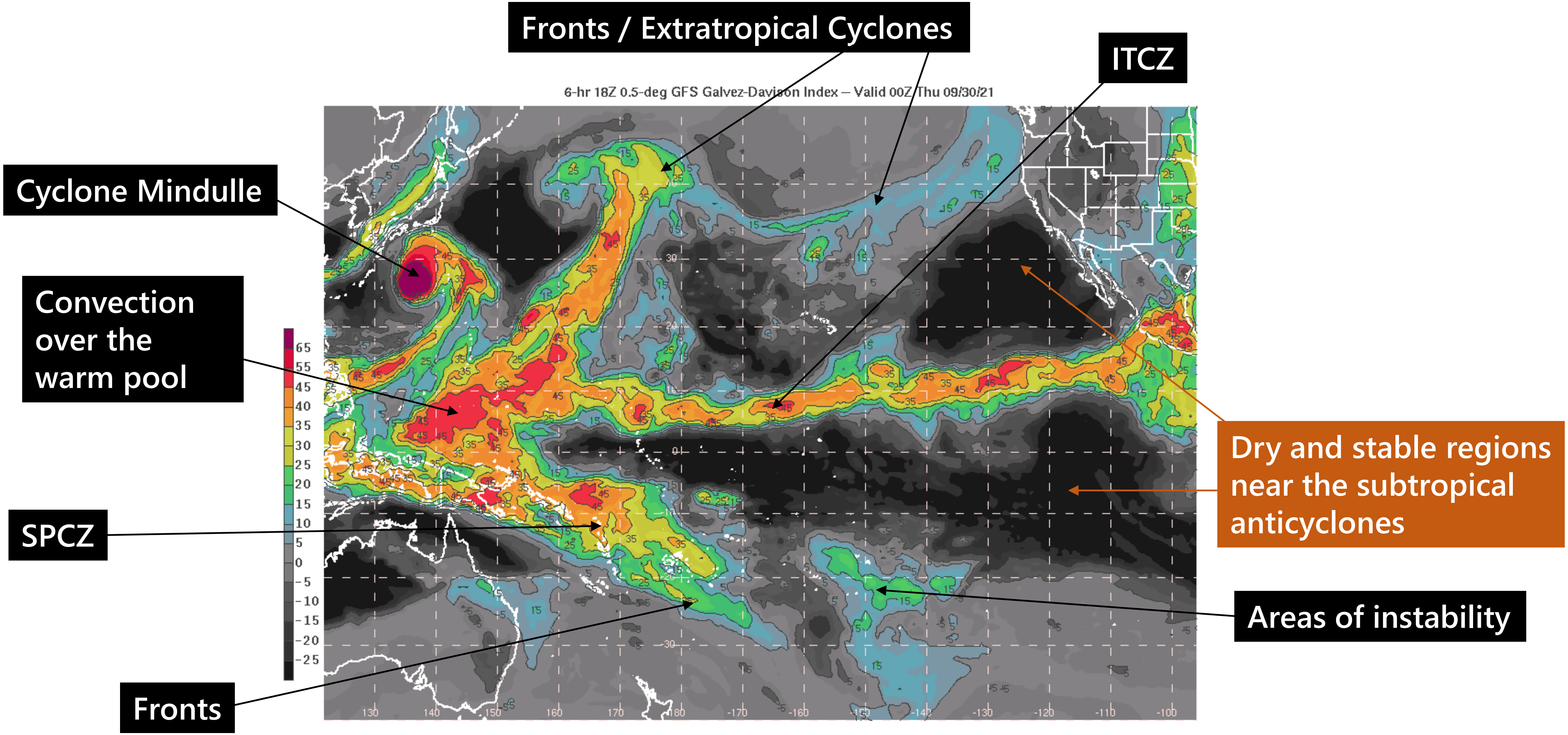
  (2) the stabilizing effects of mid-tropospheric ridges / destabilizing effects of troughs

  (3) the stabilizing and drying effects of trade wind inversions.





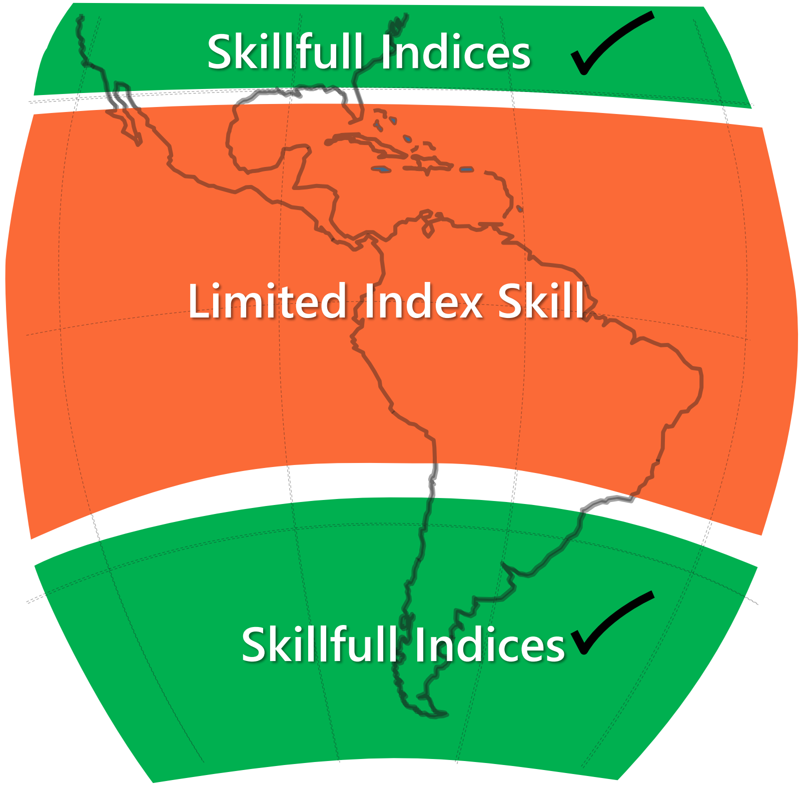
What can we see with the GDI?



Why was the GDI developed?

In 2013, there was no method to quickly assess tropical stability

- The WPC International Desks produces quantitative precipitation forecasts since the late 1980's.
- A great challenge identified early was the need to assess tropical stability rapidly.
- Using available traditional stability indices was not ideal, as these had been designed for mid-latitudes and had limited skill in the tropics.

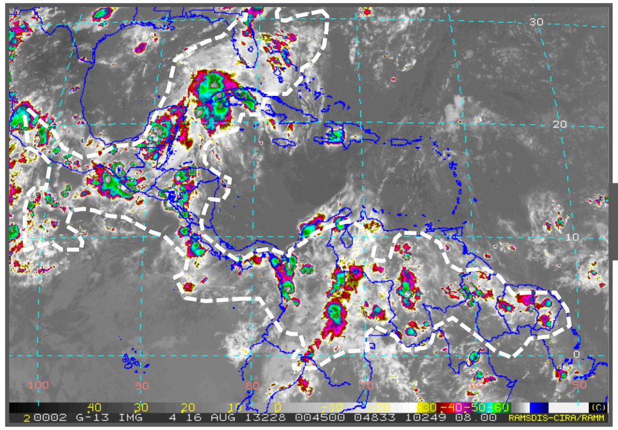


Traditional Stability Indices: Lifted, K, Total-Totals, CAPE/CIN, others

Example of Traditional Indices struggling in the Tropics

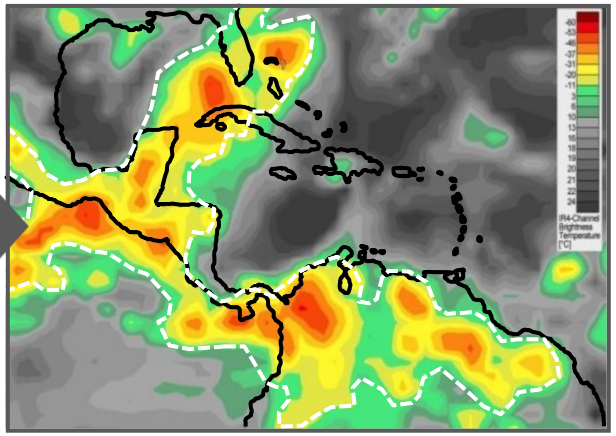
OBSERVED

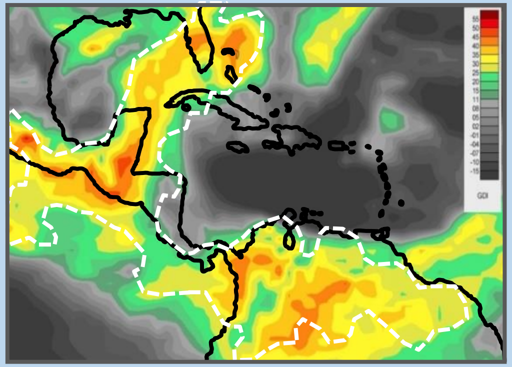
12-hr IR4 Brightness Temperature (BT) Loop



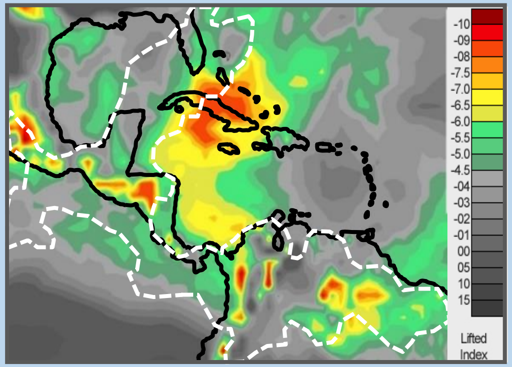
Average

12-hr Averaged BT

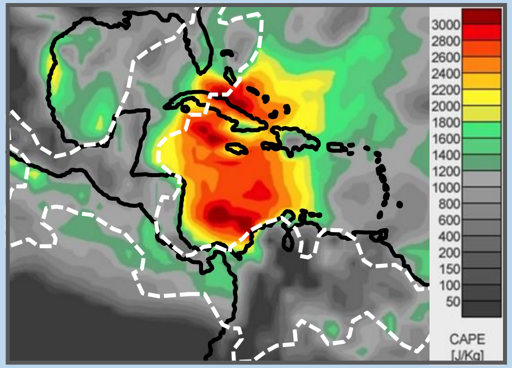




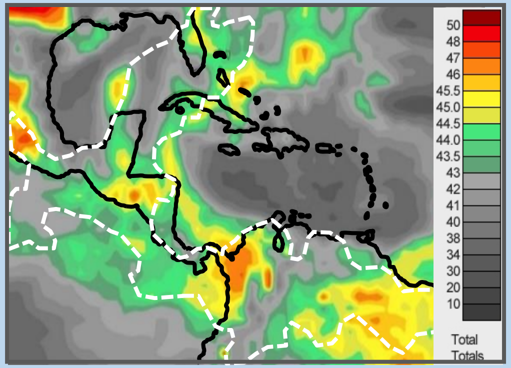
GDI
(Galvez and Davison, 2016)



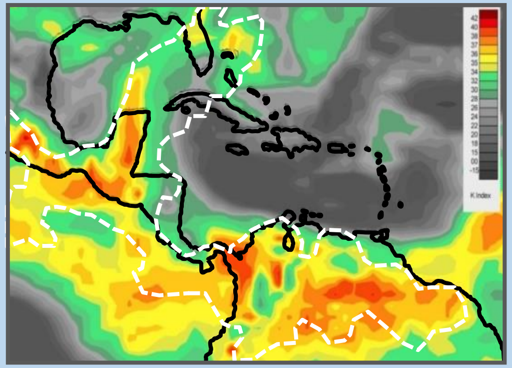
Lifted Index
(Galway, 1956)



CAPE



Total-Totals
(Miller, 1967)

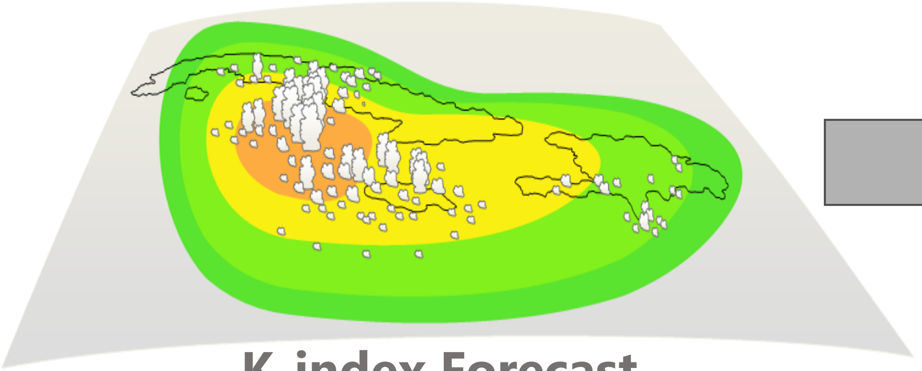


K-index
(George, 1960)

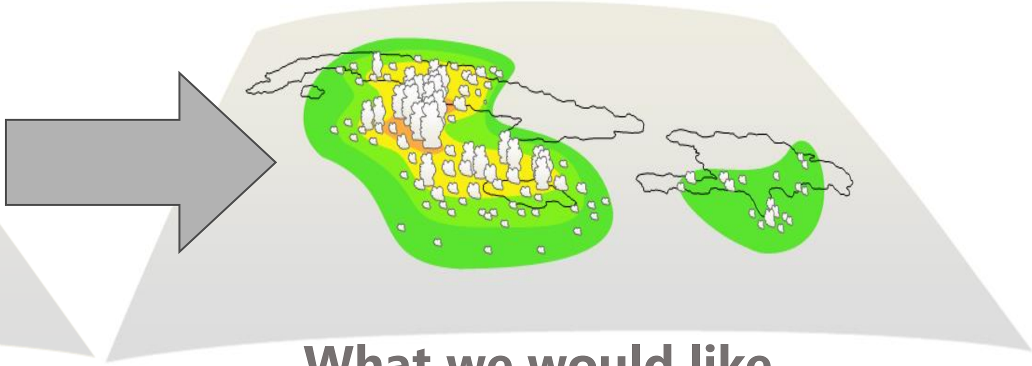
Desired benefits with the GDI

Desired Benefits

- Highlight processes that enhance trade wind convection
- Improve over the K-index (George, 1960)
  - → Main thermodynamic index for tropical convection from 1960 through 2014
  - → Too coarse for what is desired as a forecaster



K-index Forecast



What we would like

How to generate a better index?

(1) Identification of the key processes that modulate convection in the region.

What are the main processes that drive convection in the Caribbean? What is the K-index missing?

(2) Identification of how these processes reflect in atmospheric variables.

Which variables and levels matter?

(3) Algorithm Design: Combination of relevant variables to produce ONE number that summarizes the variable interactions.

How to combine the variables in an algorithm?

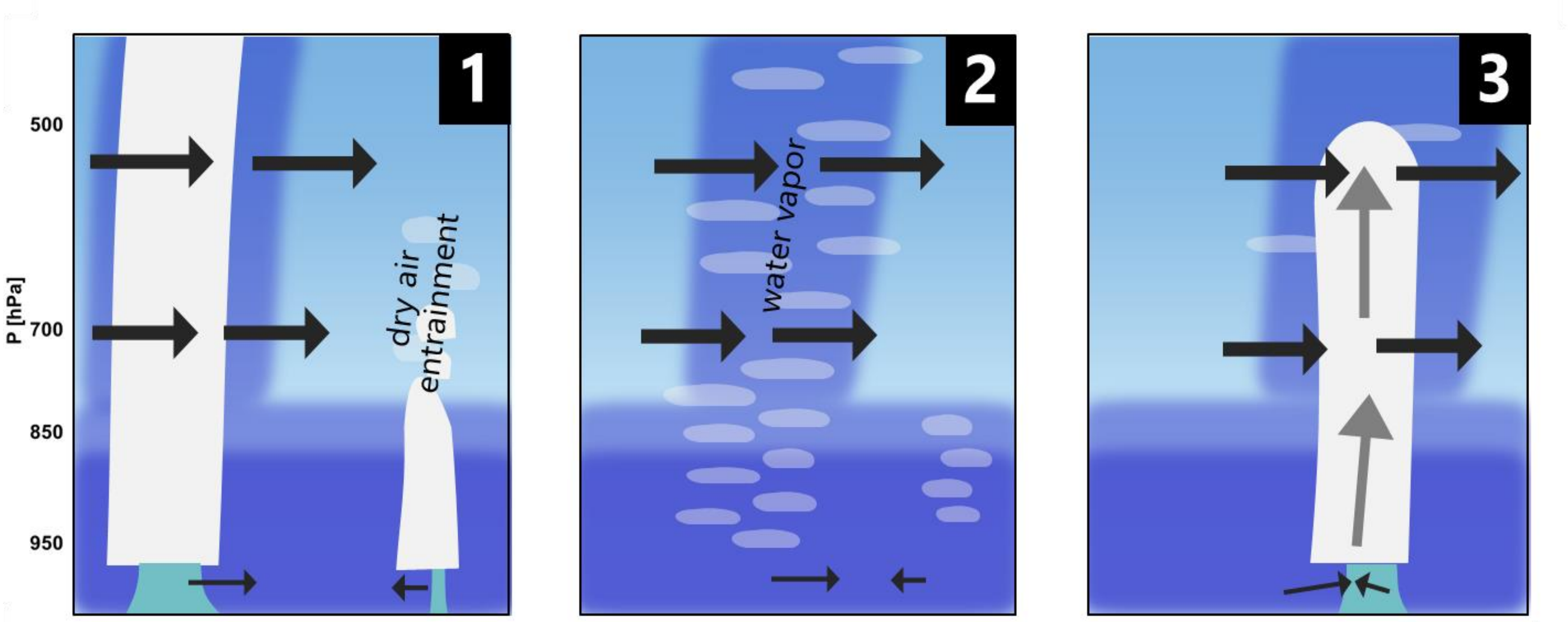
1) Identify key processes that drive trade wind convection

Moisture-Convection Feedback Mechanism

(Grabowski and Moncrieff, 2004)

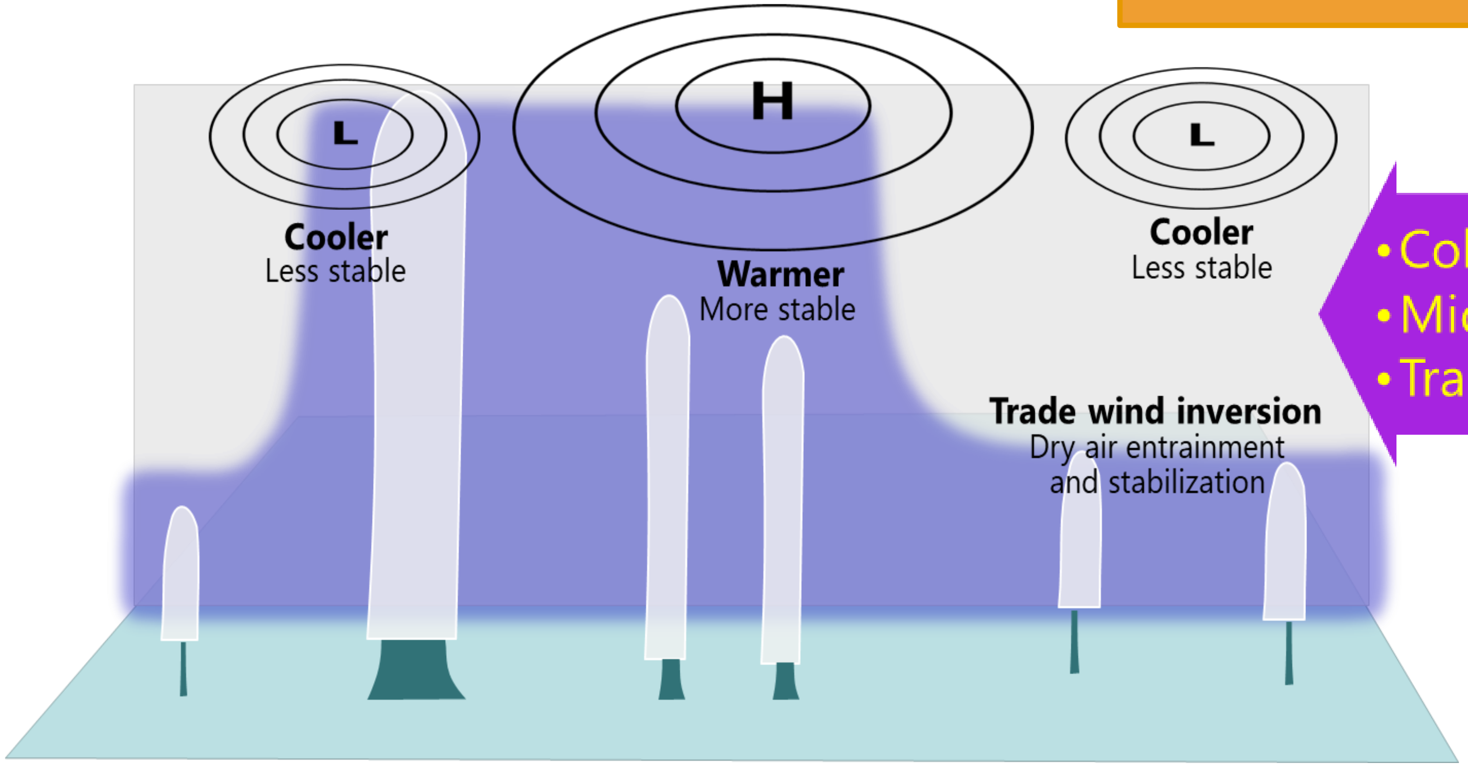
1) Tropical Convection is largely sensitive to moisture.

2) Moistening of the column by foregoing convection sets up an environment favorable for future convection, which would otherwise struggle.



Moisture REALLY matters in the tropics!

1) Identify key processes drive trade wind convection



What is the K-index missing?

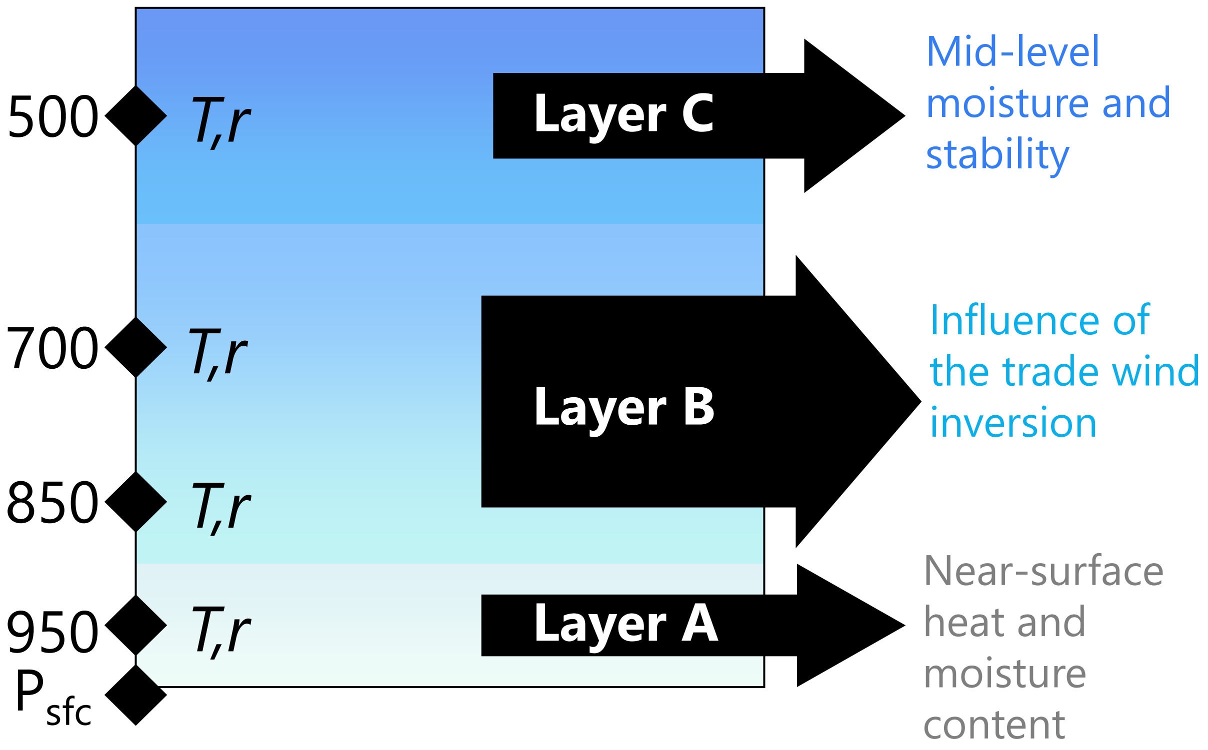
Not resolving the effects of the trade wind inversion with sufficient detail.

- Column moisture
- Mid-level temperatures
- Trade wind inversion

Processes Selected

2) Identify how these processes reflect in variables

Levels and variables that matter:



Temperatures and mixing ratios, are considered, as they allow to characterize the thermodynamic profile.

Levels:

- 500 hPa is used in most stability indices, as it can characterize the thermal properties of the mid-troposphere.
- 950 hPa characterizes the surface. 1000 hPa is not used due to noisier data in the models, from interactions with the surface.
- 700 and 850 hPa are layers that characterize trade wind cap and its features.

2) Identify how these processes reflect in variables

Tropical convection relates to structures visible in thermodynamic profiles between the surface and 500 hPa.

These examples show the profiles associated with different convective regimes.

Extracting temperature and mixing ratios at 950, 850, 700 and 500 hPa might be sufficient to characterize these convective regimes.

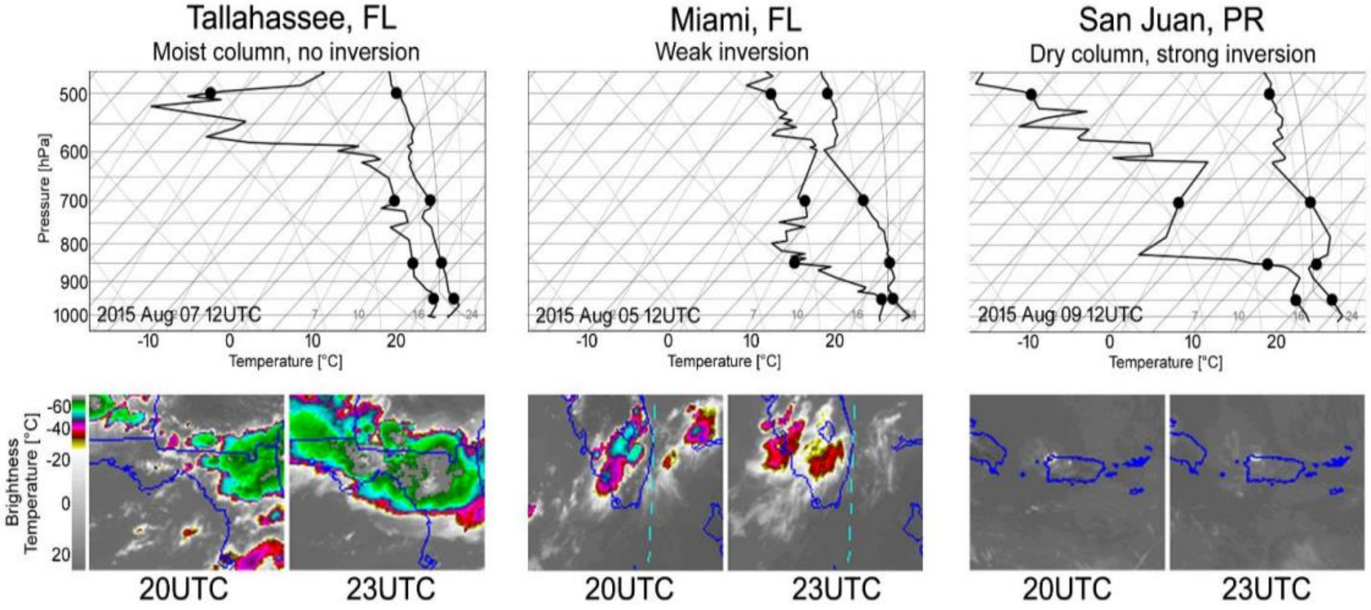
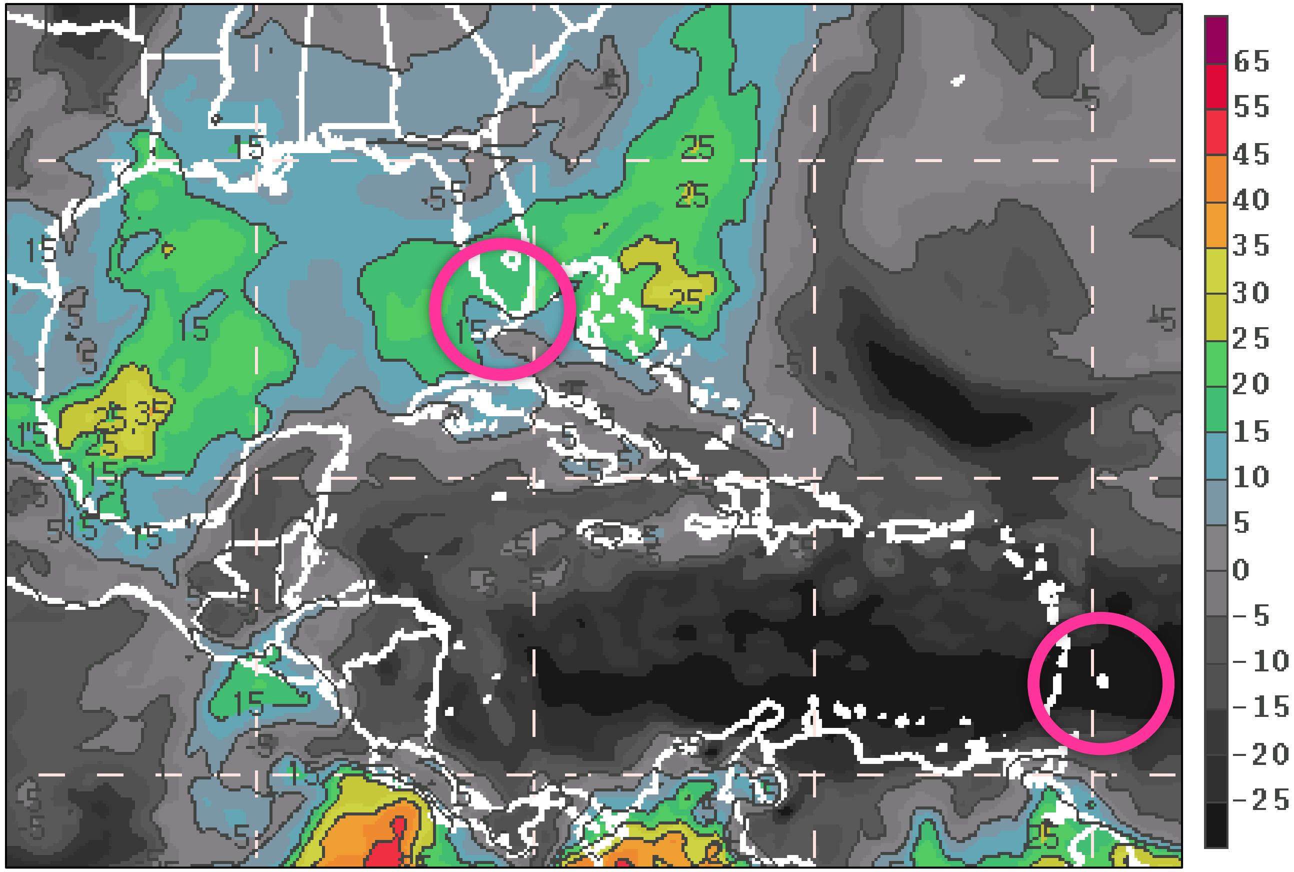


FIG. 2. 12UTC soundings (top) and corresponding GOES IR4-derived BT near 20 UTC and 23 UTC (bottom) for three locations: Tallahassee, FL (left); Miami, FL (center), and San Juan, Puerto Rico (right). The figure illustrates the evolution of afternoon convection near/downstream of each station in association with the morning sounding. The GDI calculation points are included in the soundings for later reference. Soundings are courtesy of the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html, 2015) and satellite images courtesy of CIRA (http://rammb.cira.colostate.edu/ramsdis/online/rmtc.asp, 2015).

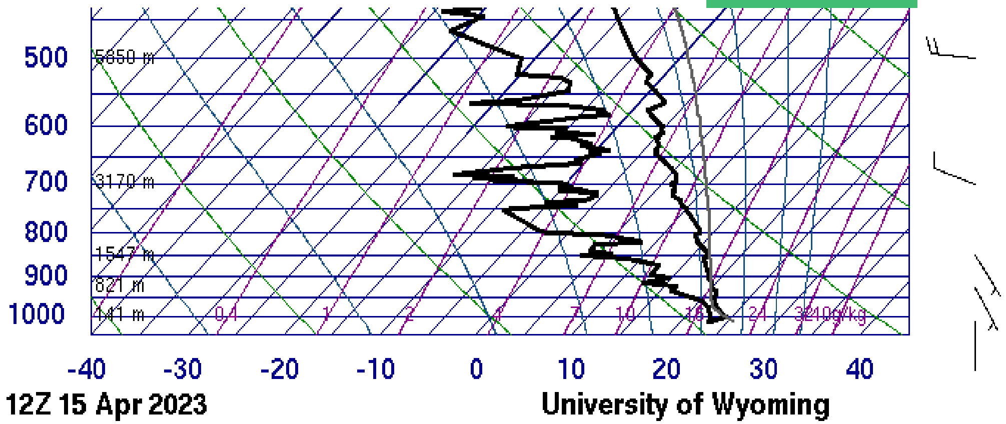
GDI and Soundings

12 UTC 15 April, 2023



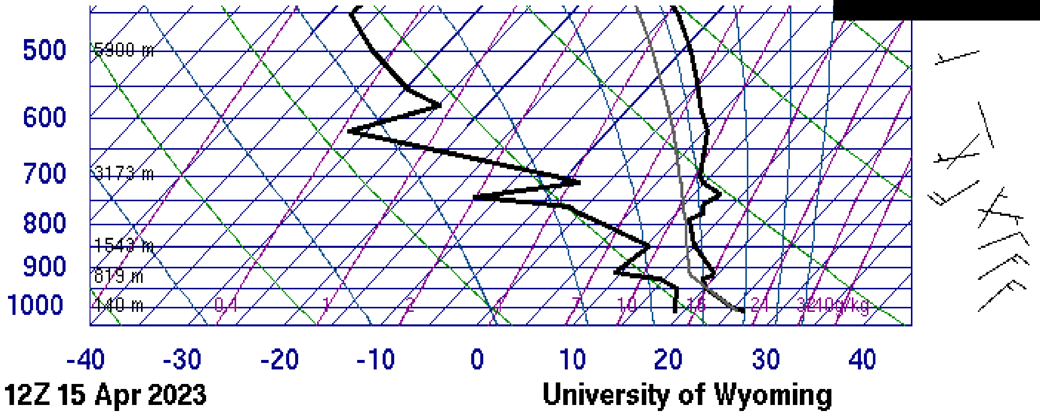
Miami, FL

GDI 20



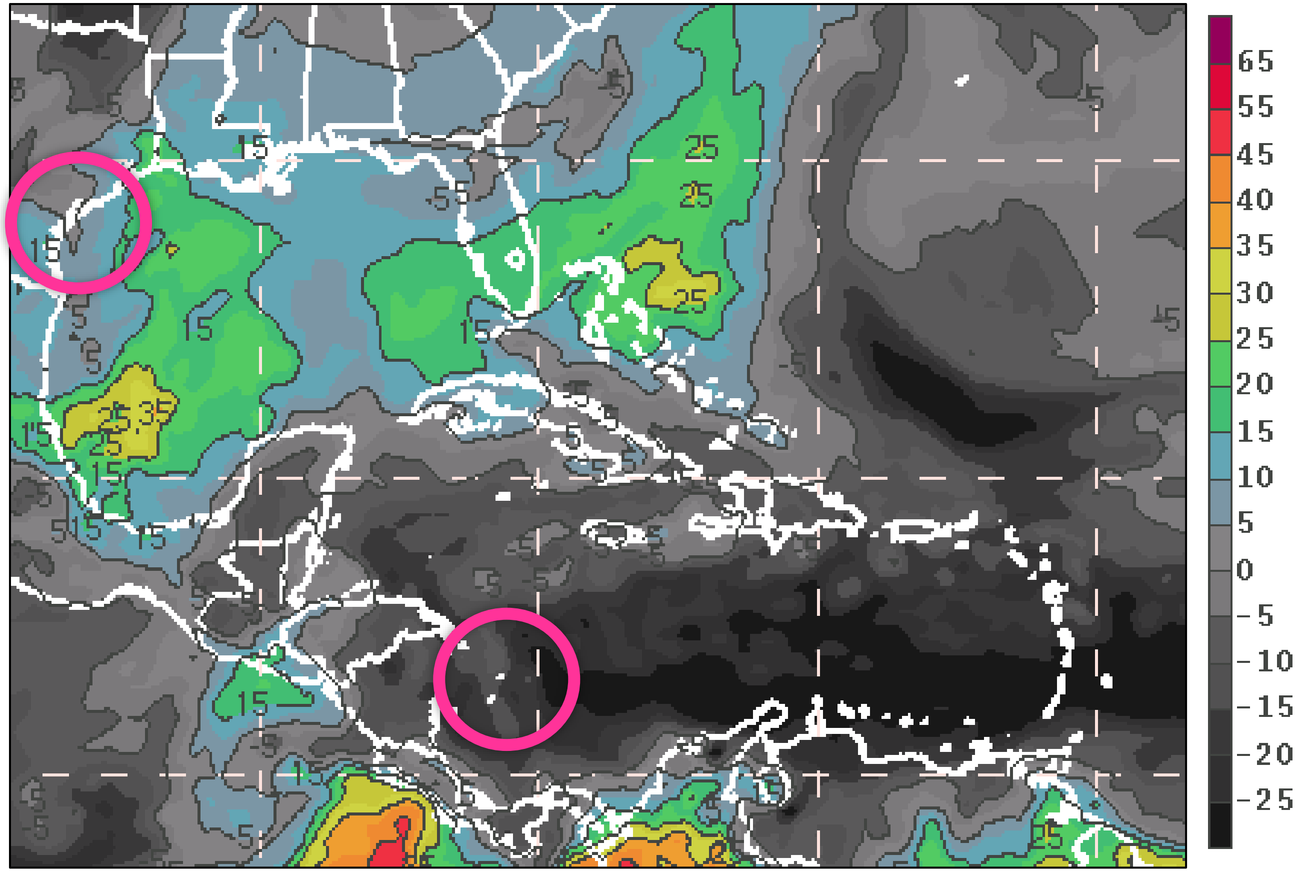
Grantley Adams, Barbados

GDI -25



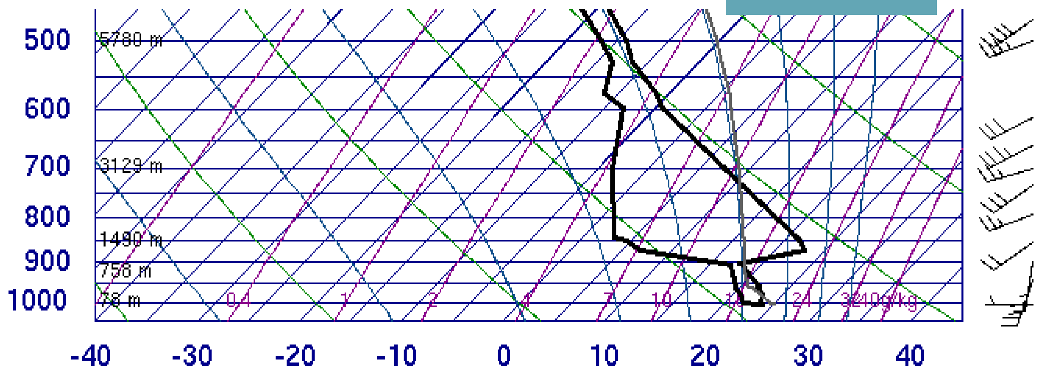
GDI and Soundings

12 UTC 15 April, 2023



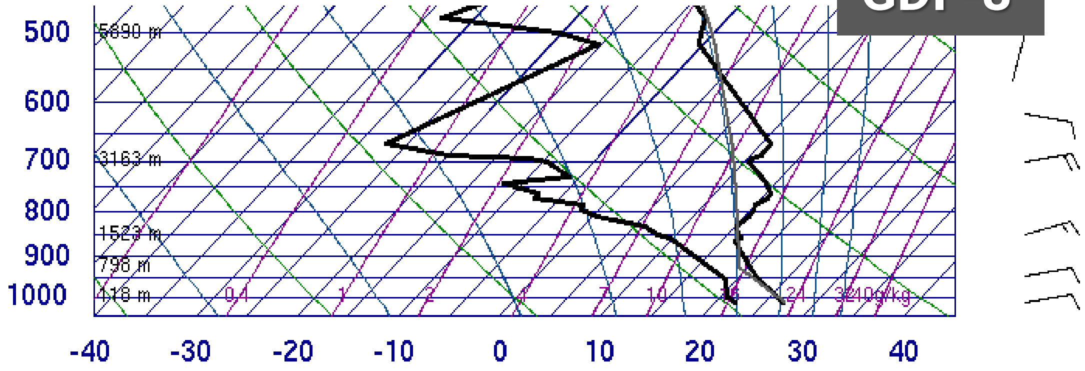
Corpus Christi, TX

GDI 11



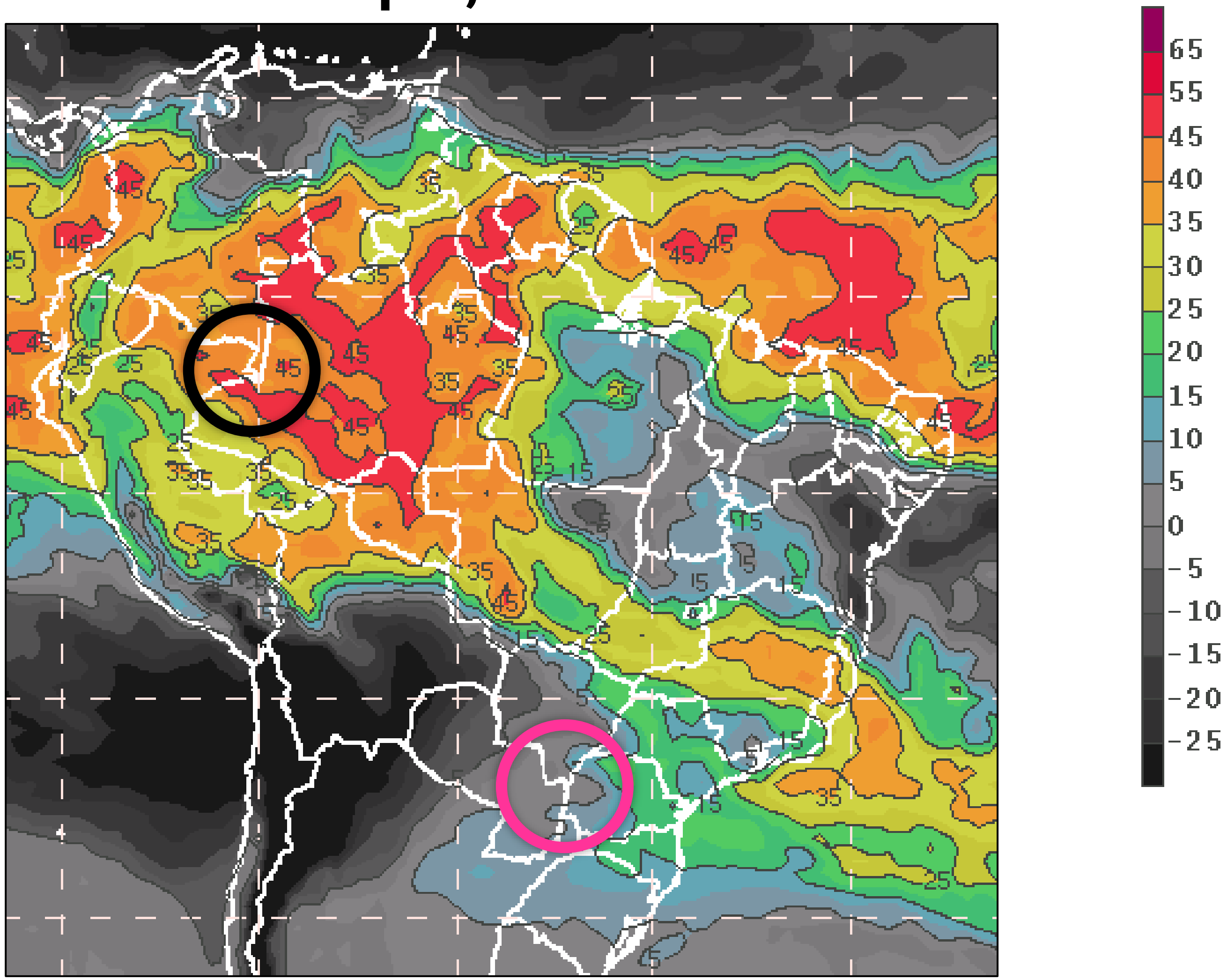
San Andrés, Colombia

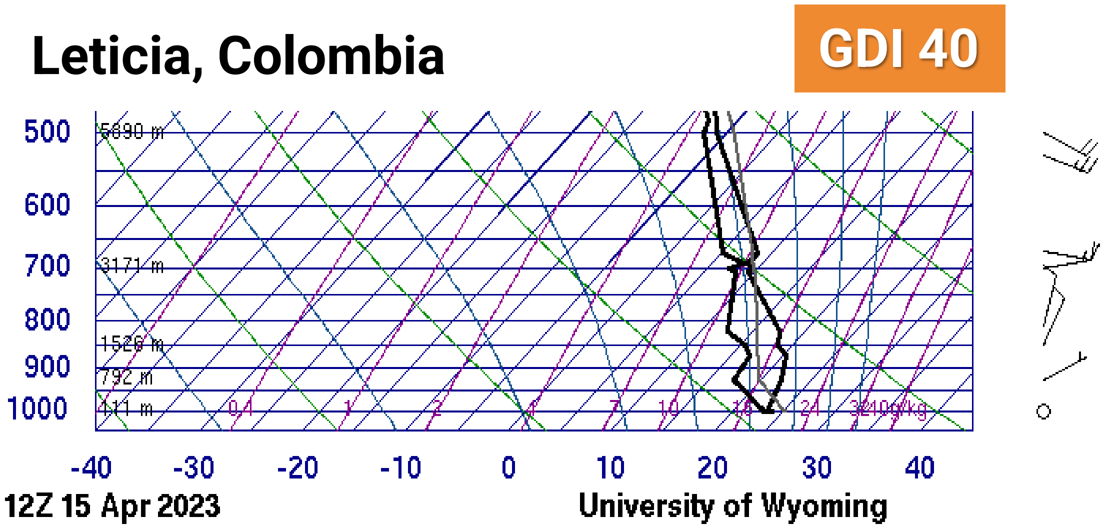
GDI -8

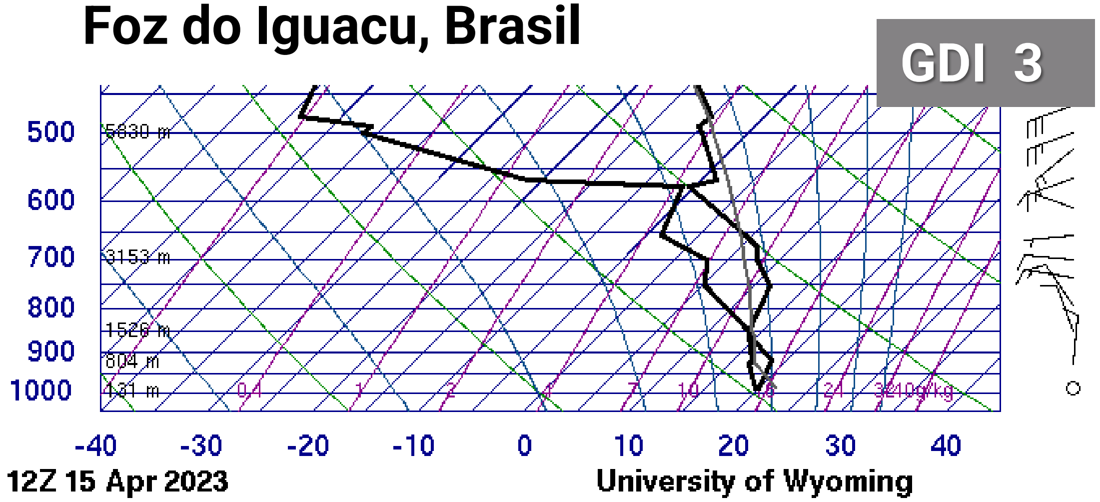


GDI and Soundings

12 UTC 15 April, 2023





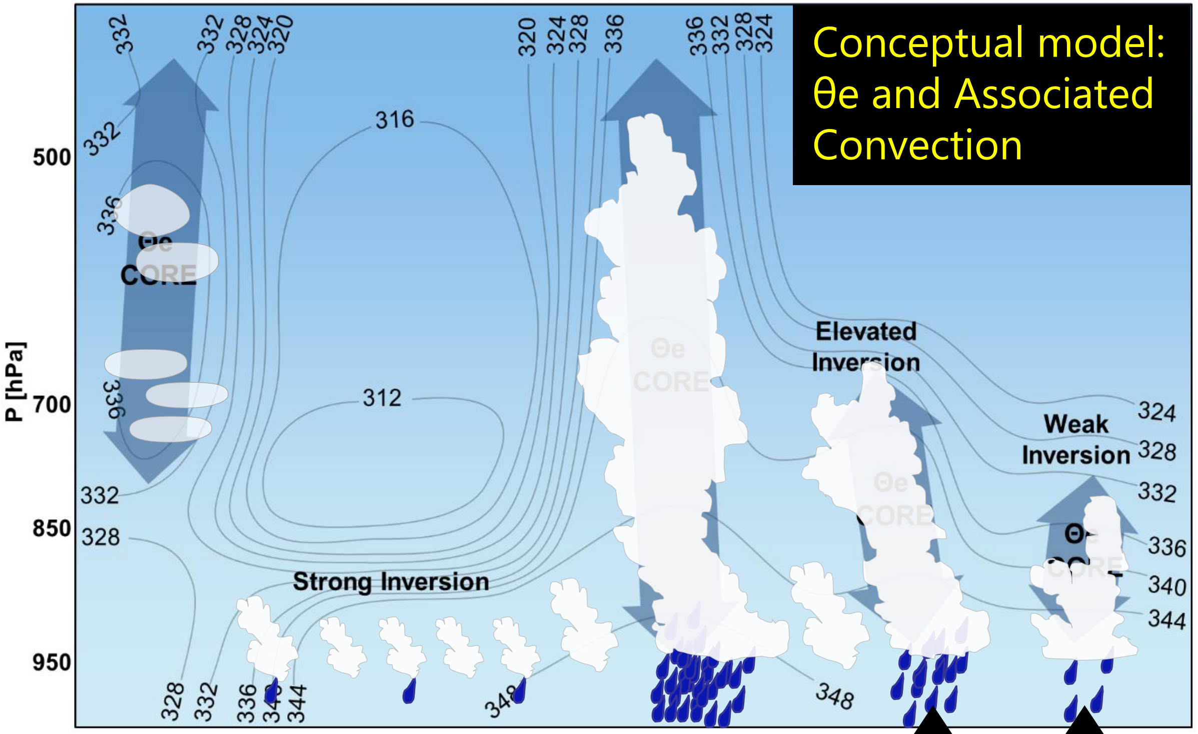


2) Identify how these processes reflect in variables

Key variable:

Θe (all 4 levels):

- Very useful.
- Relates closely to moisture in the tropics, which affects stability (moist air in the low-level destabilizes)
- Columns with large values indicate abundant heat and moisture in the entire column.
- But the dryness above a strong trade wind inversion also shows as very low Θe over higher values (sharp vertical gradient)



Small changes in tropical cloud depth can produce very large differences in rainfall

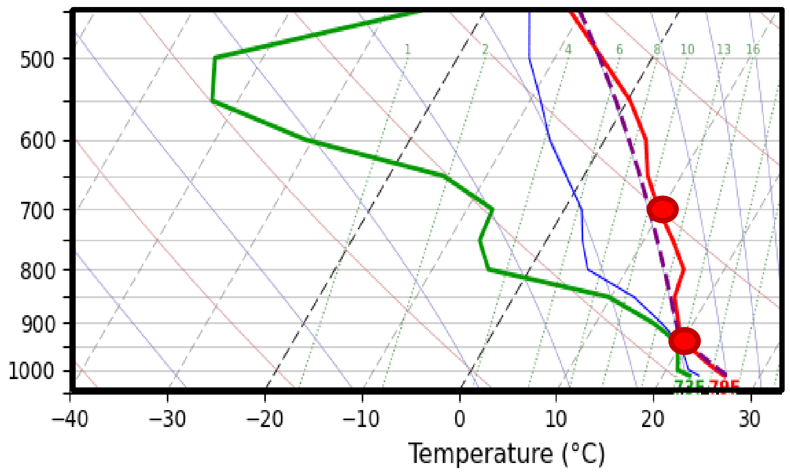
The K index often struggles with this

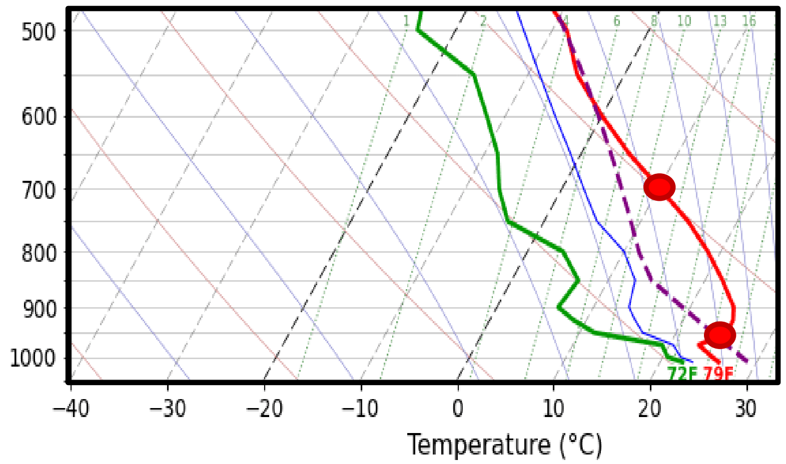
2) Identify how these processes reflect in variables

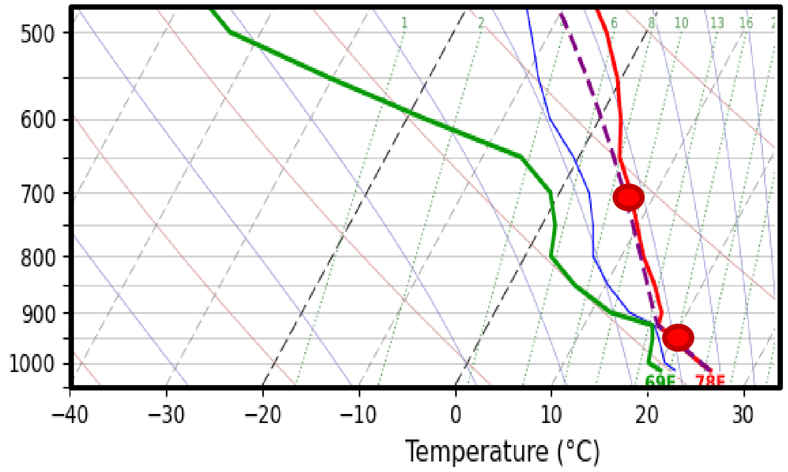
Variable:

T700 – T950 :

- The temperature difference between 700 and 950 hPa represents the lapse rate in the low troposphere.
- Stability and trade wind inversions, which largerly modulate convection, show as small negative values. Large negative values indicate instability.







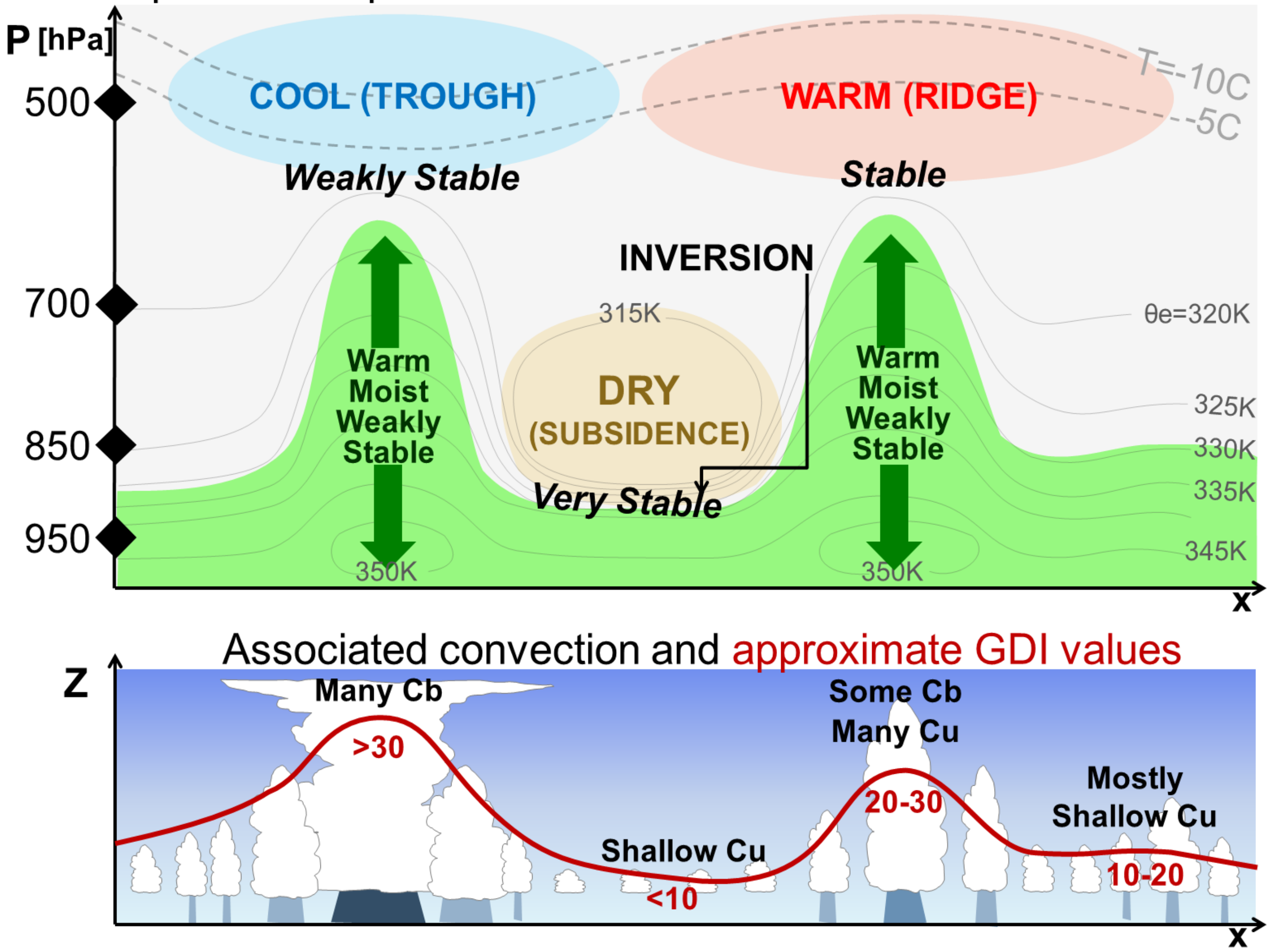
2) Identify how these processes reflect in variables

Variable:

T_{500}:

-Captures cool (unstable) pockets associated with TUTT or polar troughs.

Tropical Atmosphere Processes considered for GDI calculations



3) Algorithm Design

Manuscript for calculation:
https://www.wpc.ncep.noaa.gov/international/gdi/GDI_Manuscript_V20161021.pdf

Galvez-Davison Index (GDI)

=

Column Buoyancy Index (CBI)

Enhancement Factor. Heat and moisture available in the column. Increases non-linearly if warm/moist column is ground based.

+

Mid-level Warming Index (MWI)

Damping Factor. Mid-level stabilization by warm ridges.

+

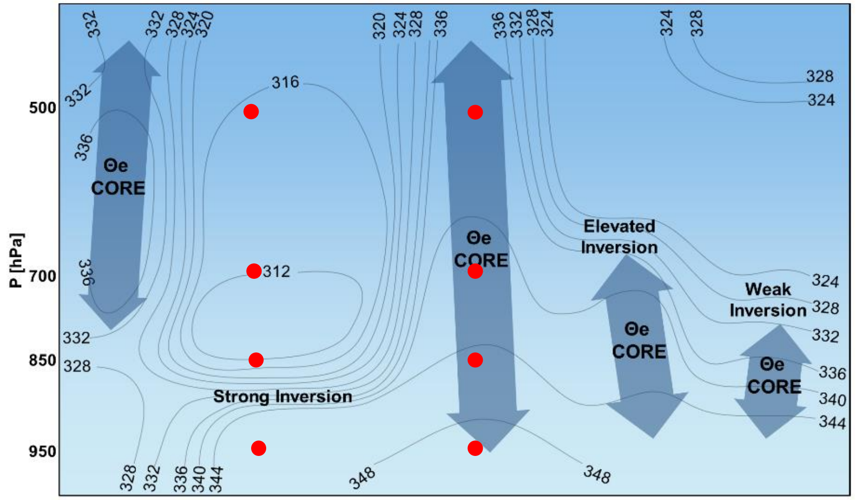
Inversion Index (II)

Damping Factor. Stabilizing effects of inversion together with dry air entrainment if convection penetrates the inversion.

+

Terrain Correction **(OC)**

Just to improve visualization for grids.



Stability damping factor **(S)**

The gentler the 950-700 hPa lapse rate, the more damping due to stability.

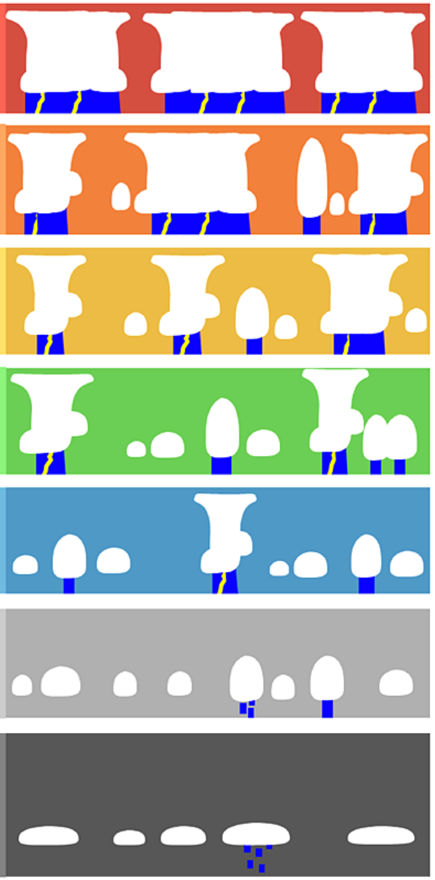
Drying damping factor **(D)**

The sharper the EPT decrease with height, more damping due to dry air entraiment.

GDI values and interpretation

General table

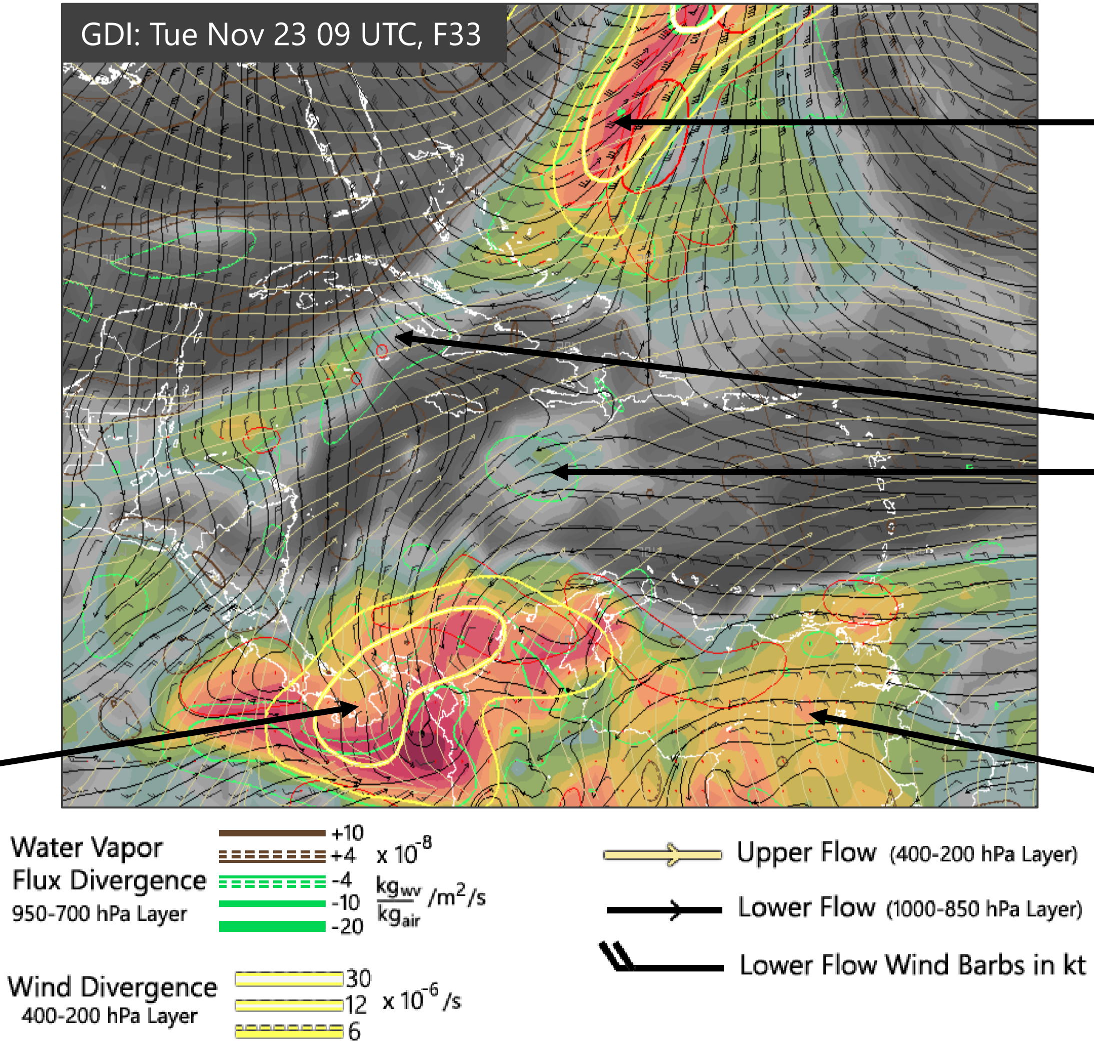
GDI > +45	Potential for scattered to widespread heavy rain producing thunderstorms.
+35 to +45	Potential for scattered thunderstorms some capable of producing heavy rainfall.
+25 to +35	Potential for scattered thunderstorms or scattered shallow convection with isolated thunderstorms.
+15 to +25	Potential for a few isolated thunderstorms, but mostly shallow convection.
+05 to +15	Potential for shallow convection. A very isolated and brief thunderstorm is possible.
-20 to +05	Potential for isolated to scattered shallow convection. Strong subsidence inversion likely.
-20 > GDI	Strong subsidence inversion. Any convection should be very shallow, isolated, and produce trace accumulations.

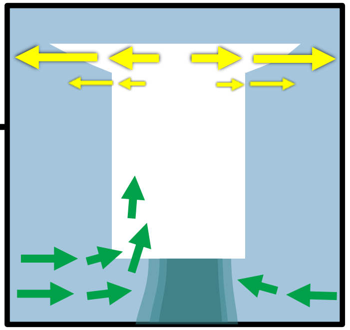


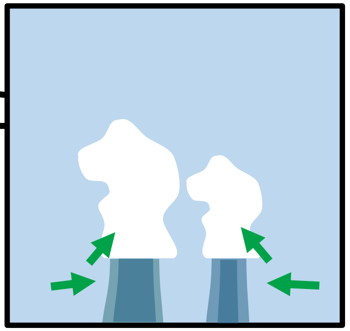
Skill and values do exhibit spatial and temporal variability: Validation is important

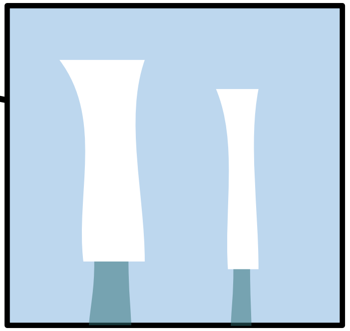
The GDI is not a stand-alone index

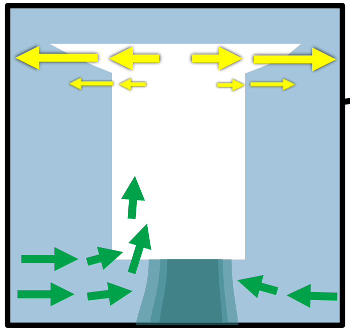
- Evaluates if the environment is suitable to host convection but does not look into convection triggers or enhancers.
- An analysis of the flow and dynamics needs to accompany the GDI.





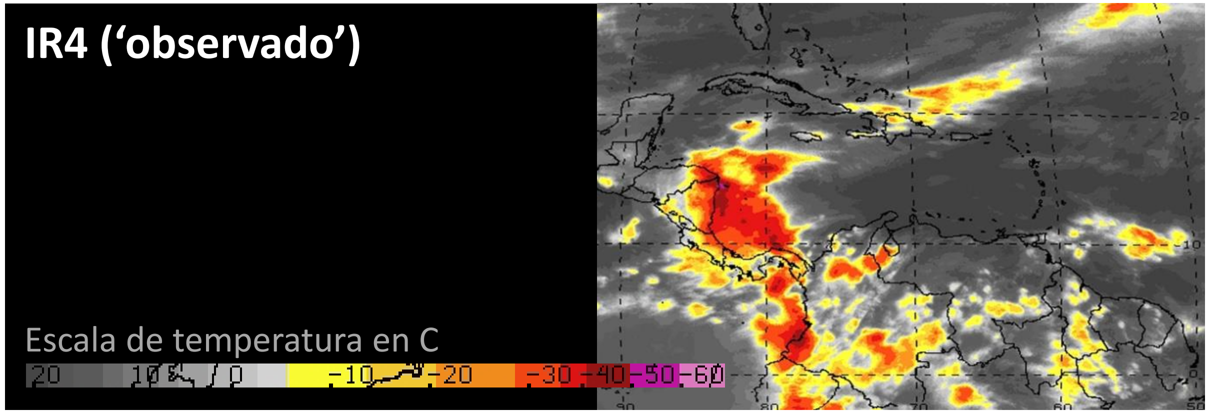


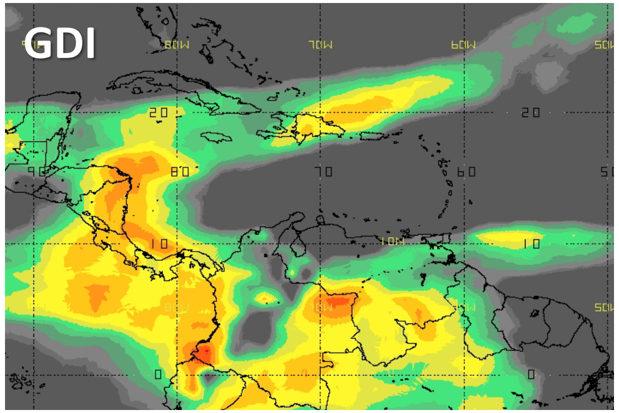




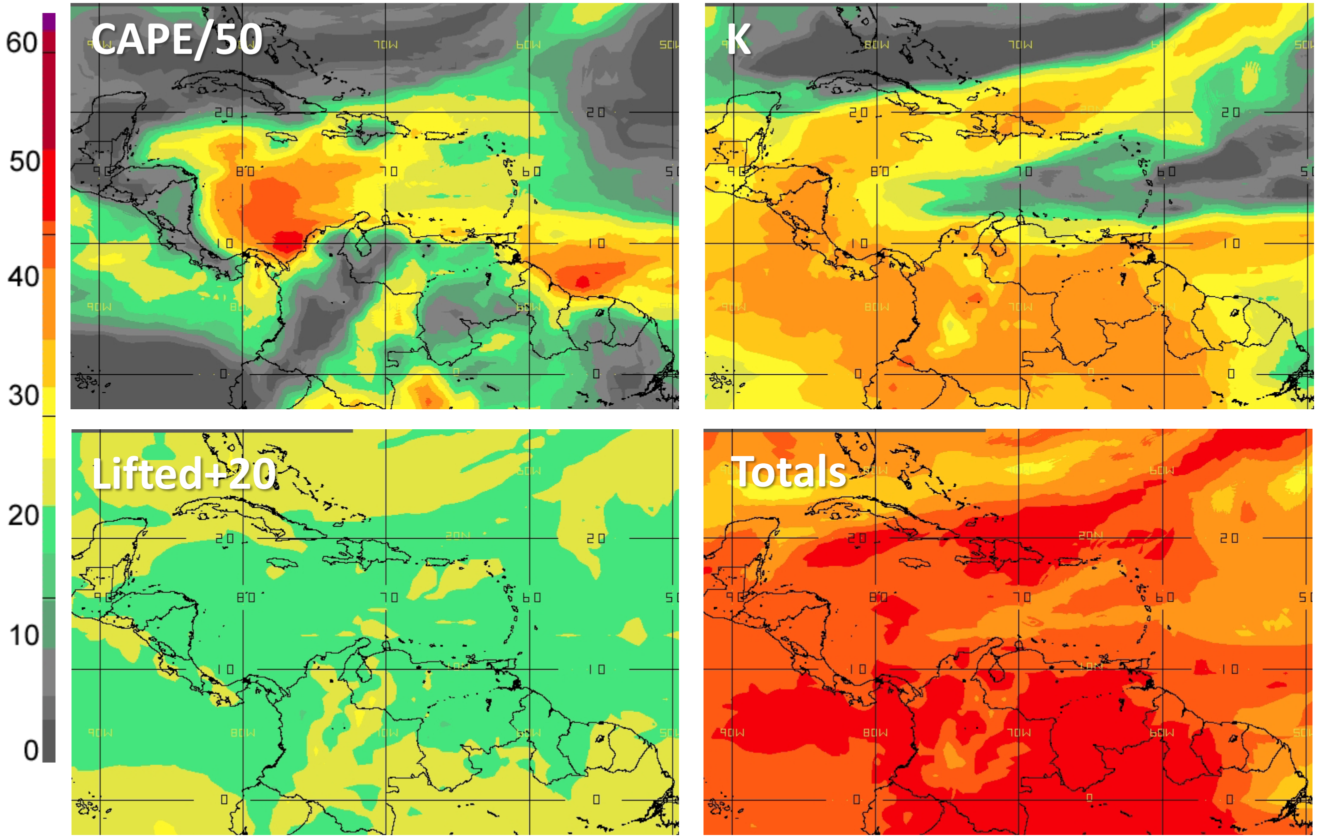
Otros ejemplos → GDI funciona bien!

Nov.4.2012





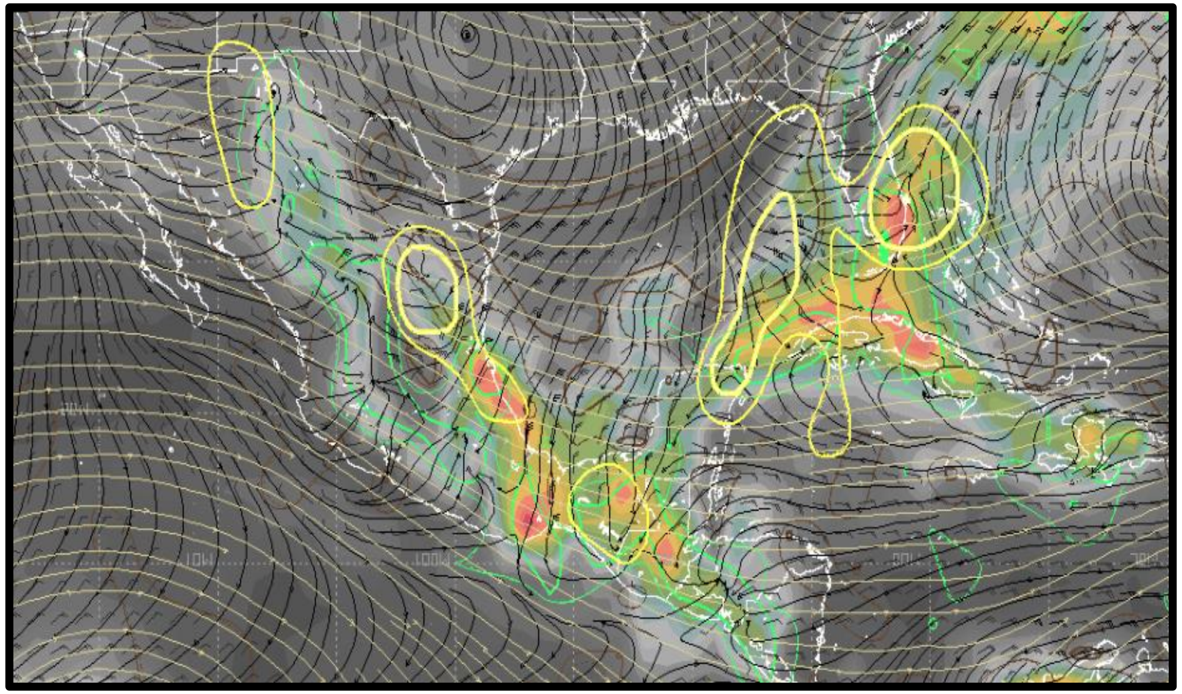
Intercomparación
Satellite-Index



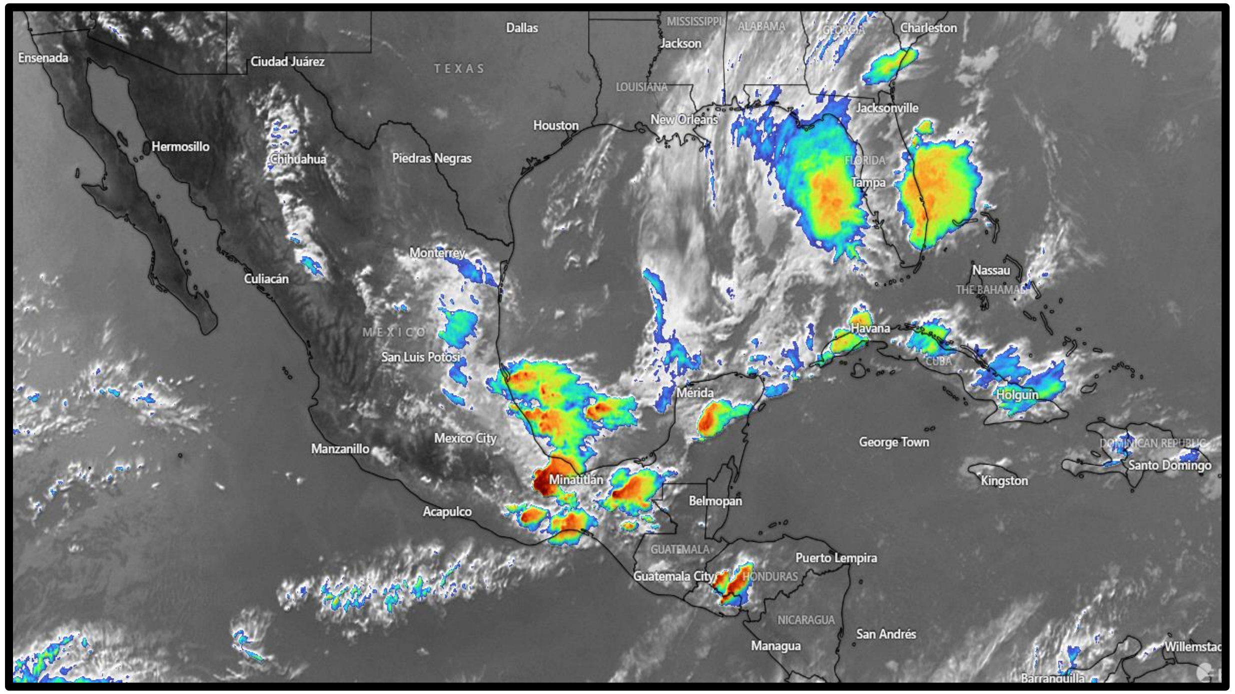
Validation in Mexico and the Northern Caribbean

April 17 2023, 00UTC

GDI and Flow



Long Wave IR



Water Vapor Flux Divergence 950-700 hPa Layer: +10, +4, -4, -10, -20 x 10^{-8} $\frac{kg_{wv}}{kg_{air}}$ $/m^2/s$

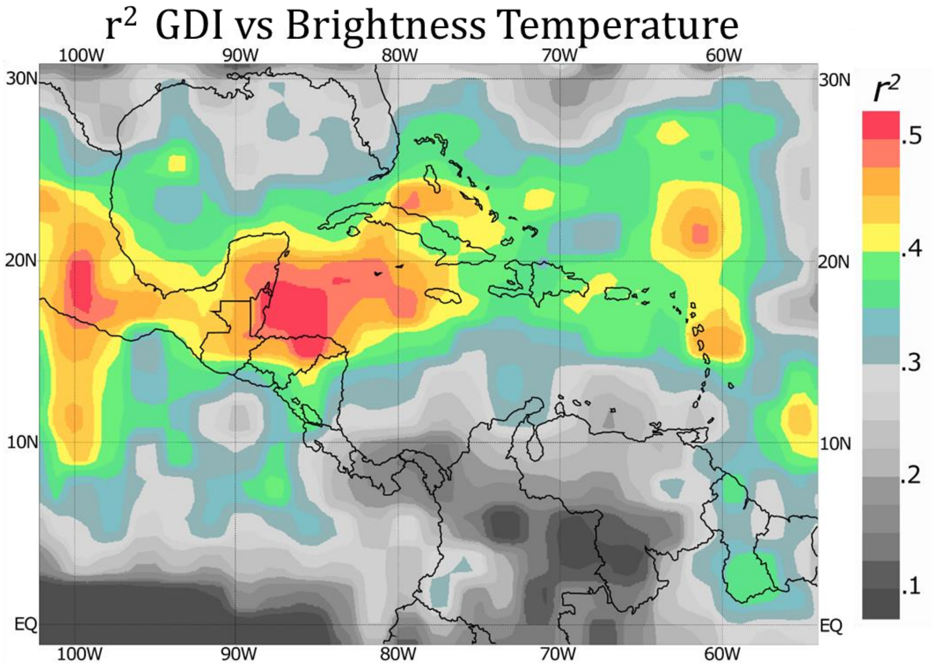
Wind Divergence 400-200 hPa Layer: 30, 12, 6 x 10^{-6} /s

Upper Flow (400-200 hPa Layer)

Lower Flow (1000-850 hPa Layer)

Lower Flow Wind Barbs in kt

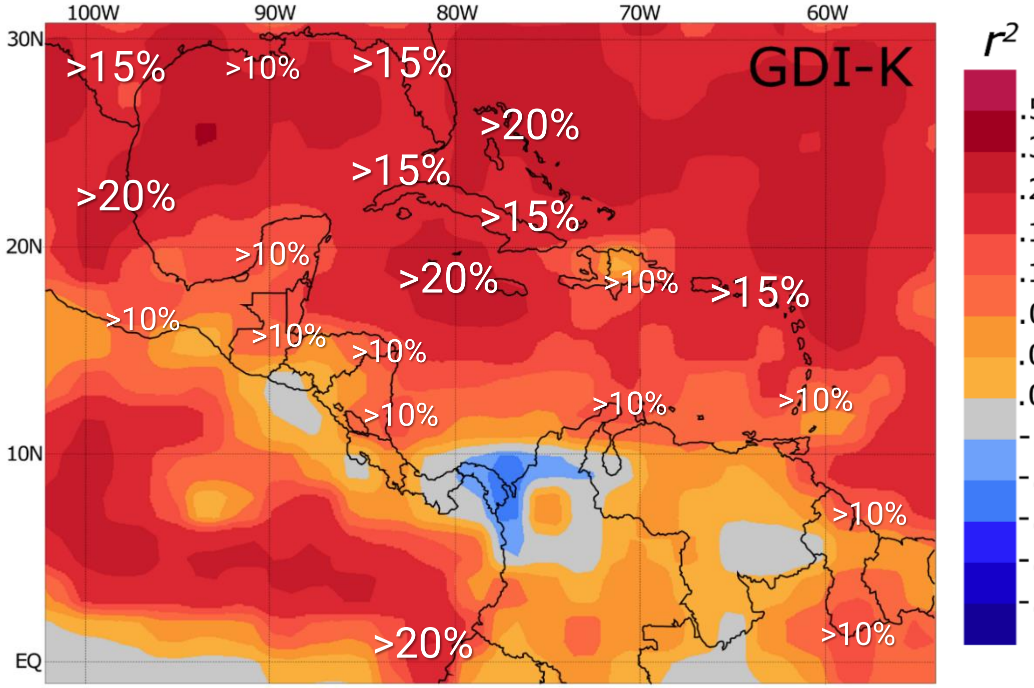
GDI Validation in the Caribbean and Central America



Meaning: in areas such as the Gulf of Honduras and Central Mexico the GDI alone might be able to detect ~50% of the brightness temperature variance.

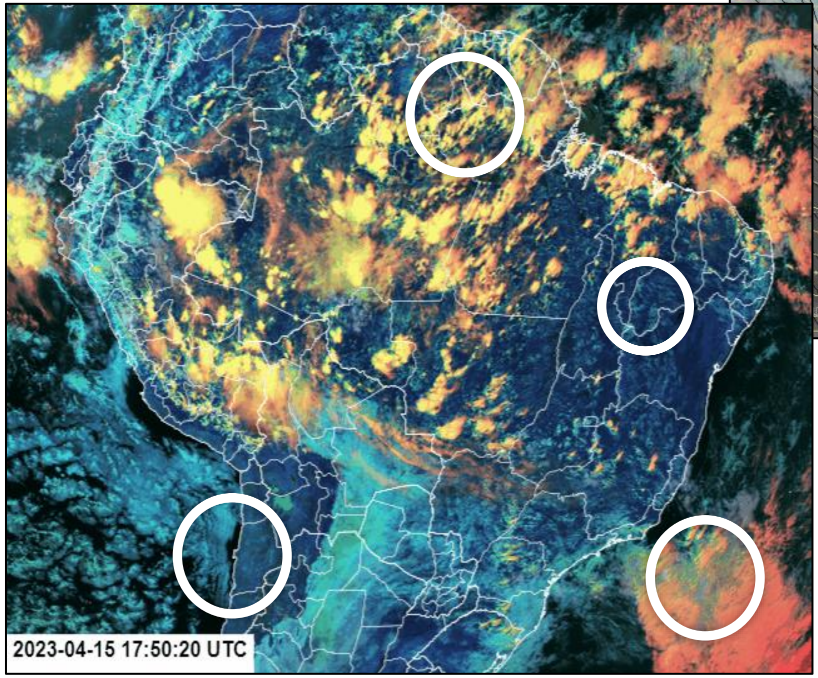
Improvement over the K

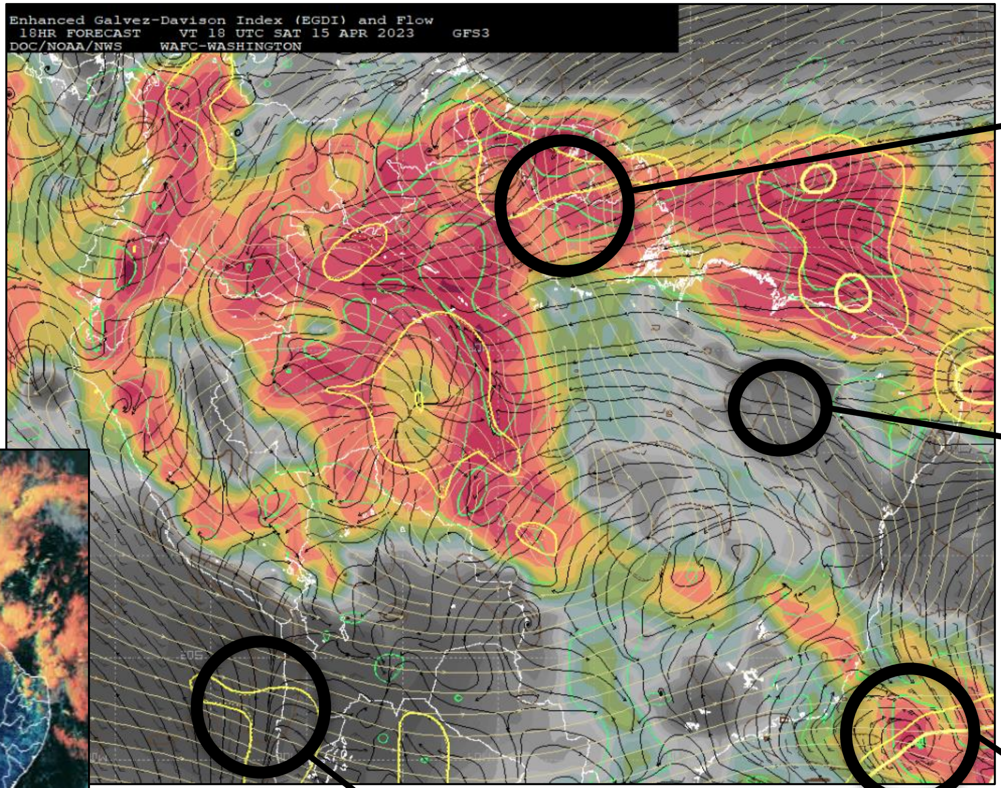
Additional brightness temperature variance detected

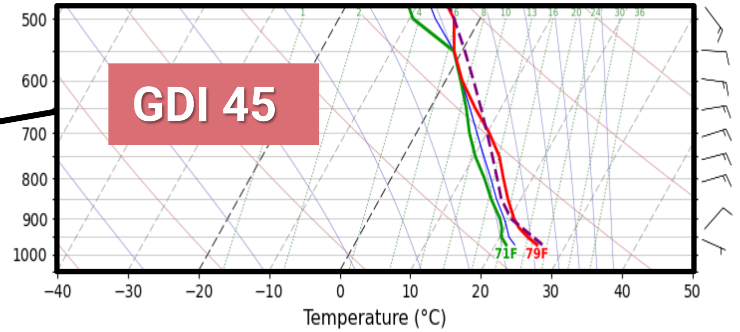


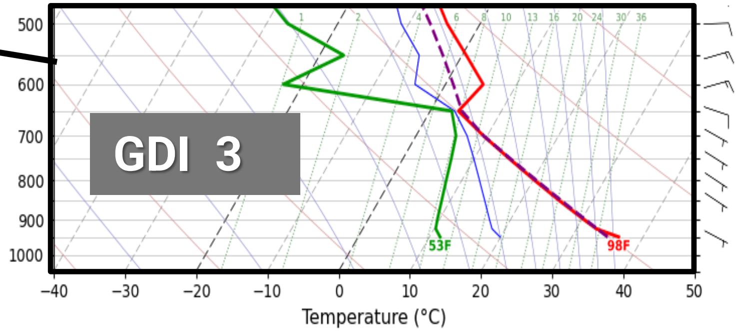
- GDI outperformed the K over most of the domain (>90%).
- Areas of most benefit, north Caribbean, Mexico, Bahamas, SE USA.
- GDI detected an additional 15-30% of OLR variance.
- Improvement over coastal/western Ecuador as well.
- Limitations along ITCZ/NET, where GDI driving processes don’t matter.

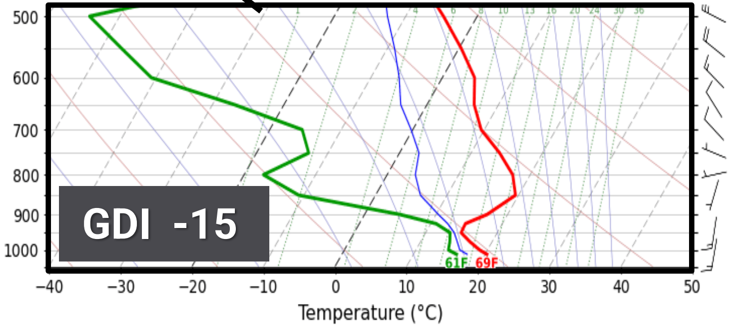
Validation in South America

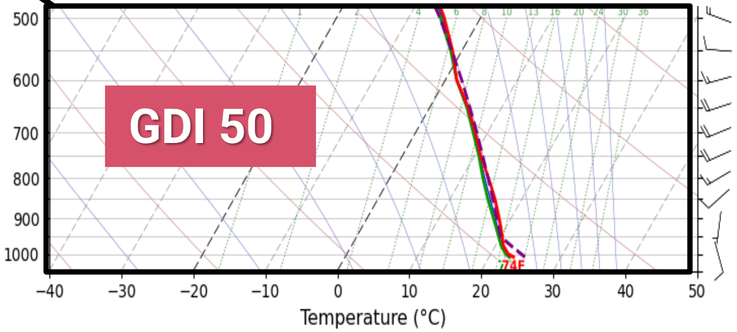










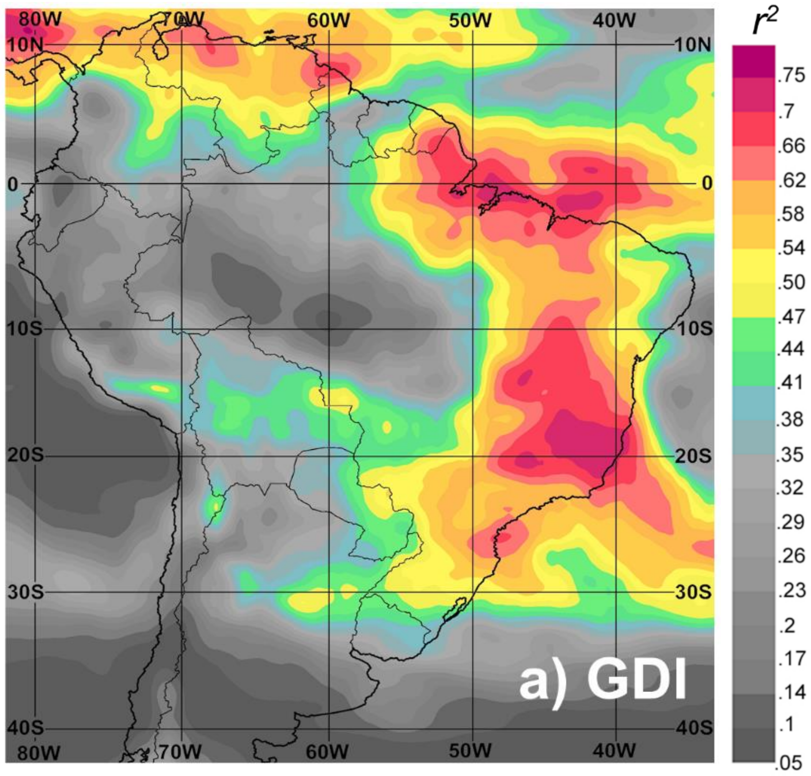


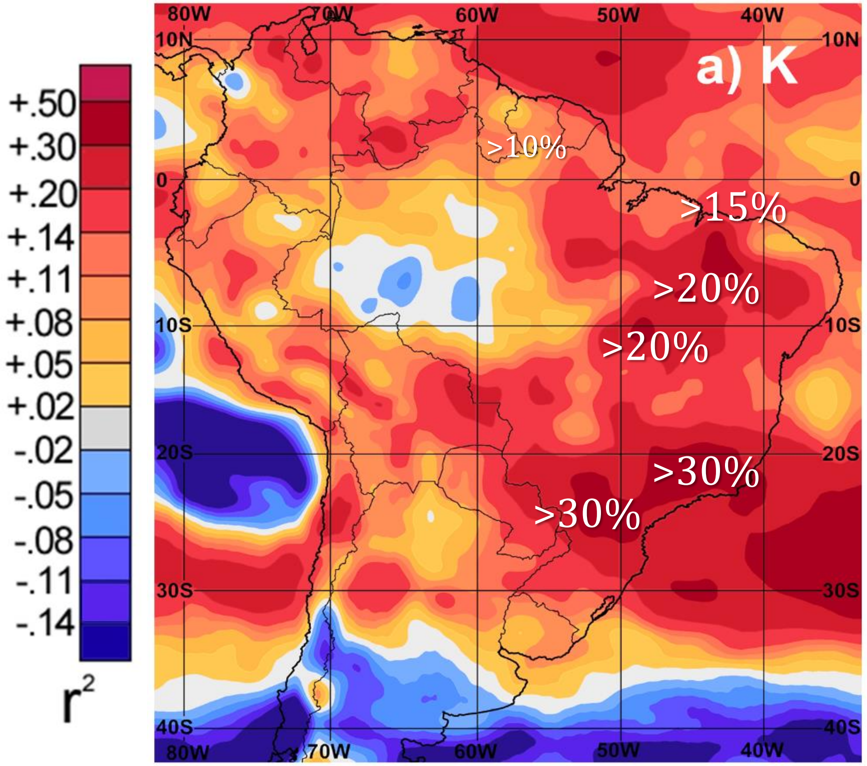
South America:

Improvement over the K

Additional brightness temperature variance detected

r^2 GDI vs Brightness Temperature





- GDI outperformed the K over most of the domain (>80%).
- Less skill in extra tropics where air masses are too cold and dry.
- Areas of most benefit, southeastern Tropical South America.
- GDI detected an additional 15-30% of OLR variance.
- More skill in Venezuela/Colombia than during rainy season due to enhanced incursion of Caribbean air masses during drier season.

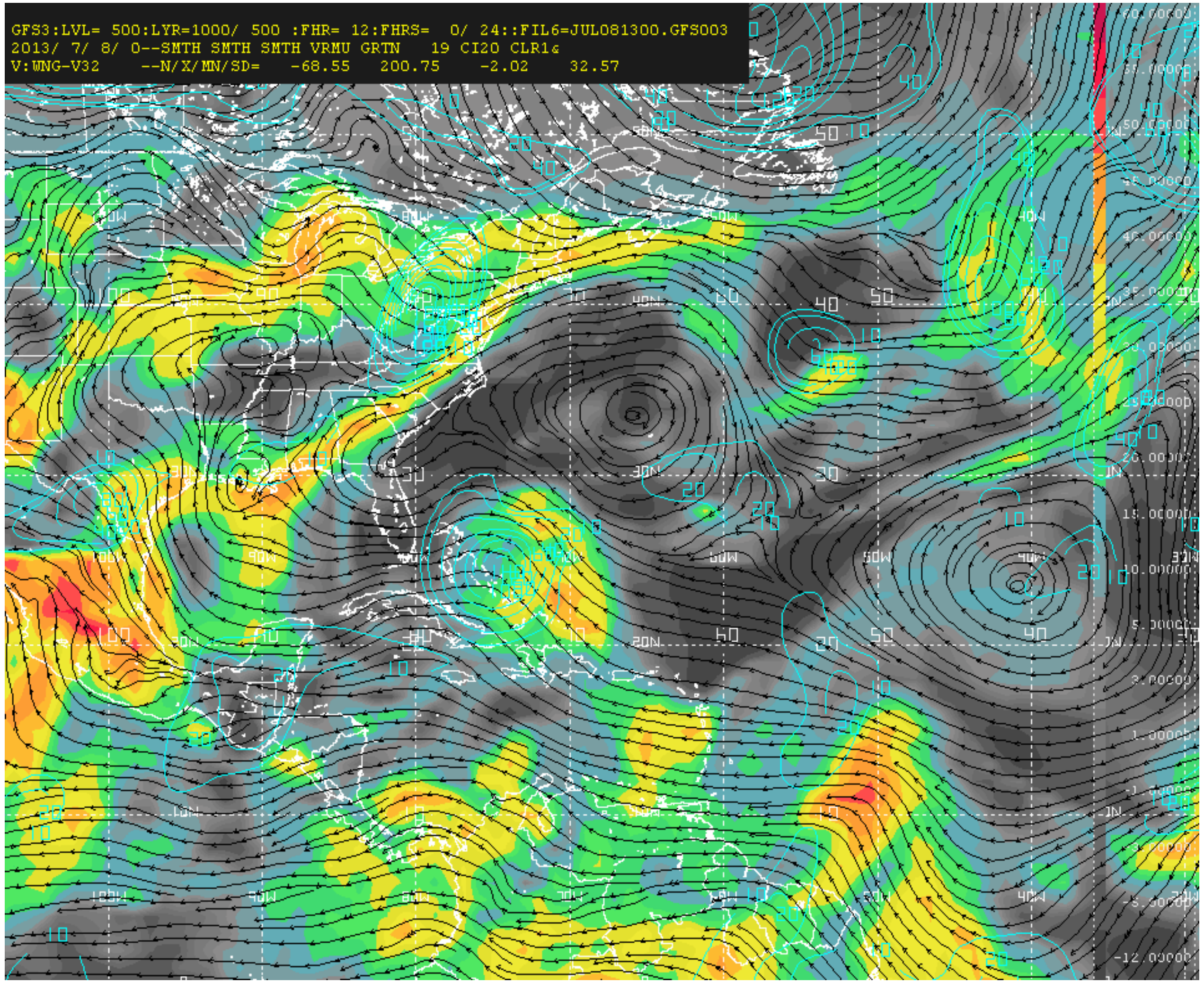
(1) GDI helps to track waves in the trades

Captures moisture and instability signatures associated with troughs in the trades.

Great to help to identify

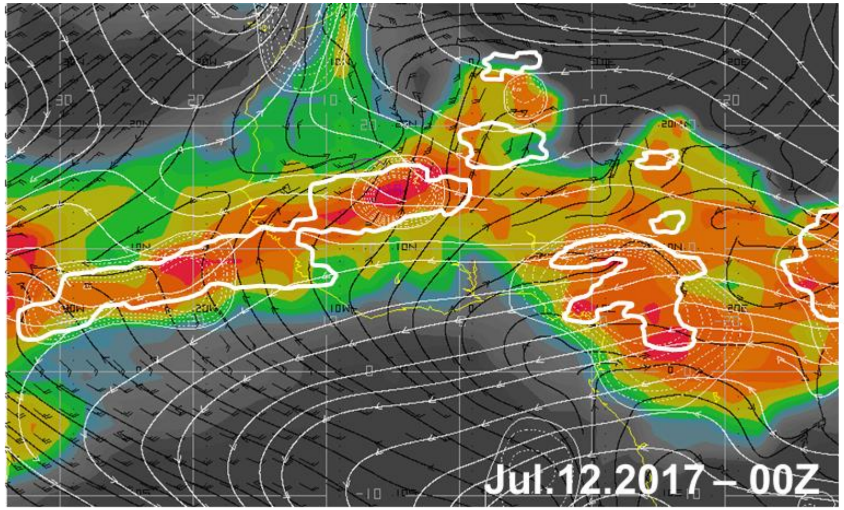
- Easterly Waves (EW)
- Perturbations induced by an upper trough

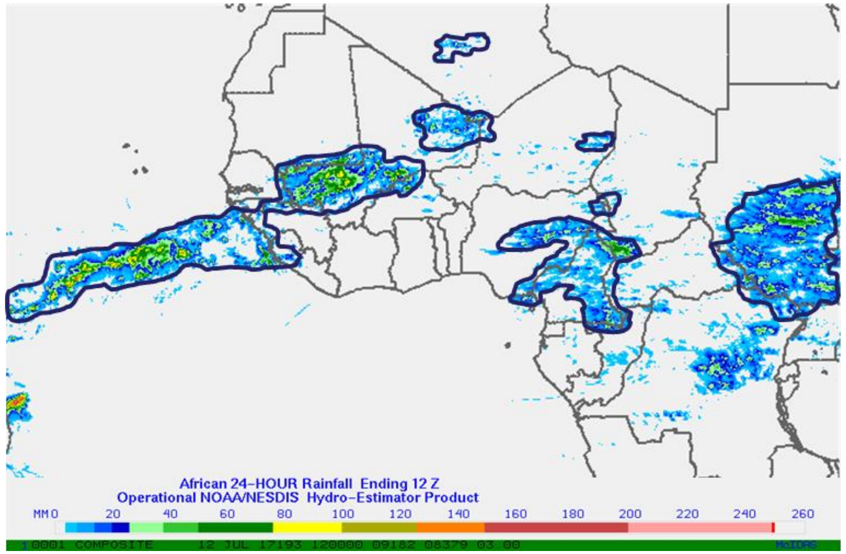
Thus, could be used as a tool to help identifying regions for tropical cyclogenesis and evolution.



(2) Improves the detection of the ITCZ/NET

- Also allows to detect the ITCZ/NET.
- Great for detecting active versus inactive ITCZ/NET convection
- Especially useful when models resolve ITCZ convection in different locations.
- Great for continental convection, especially ECMWF_{2019} GDI

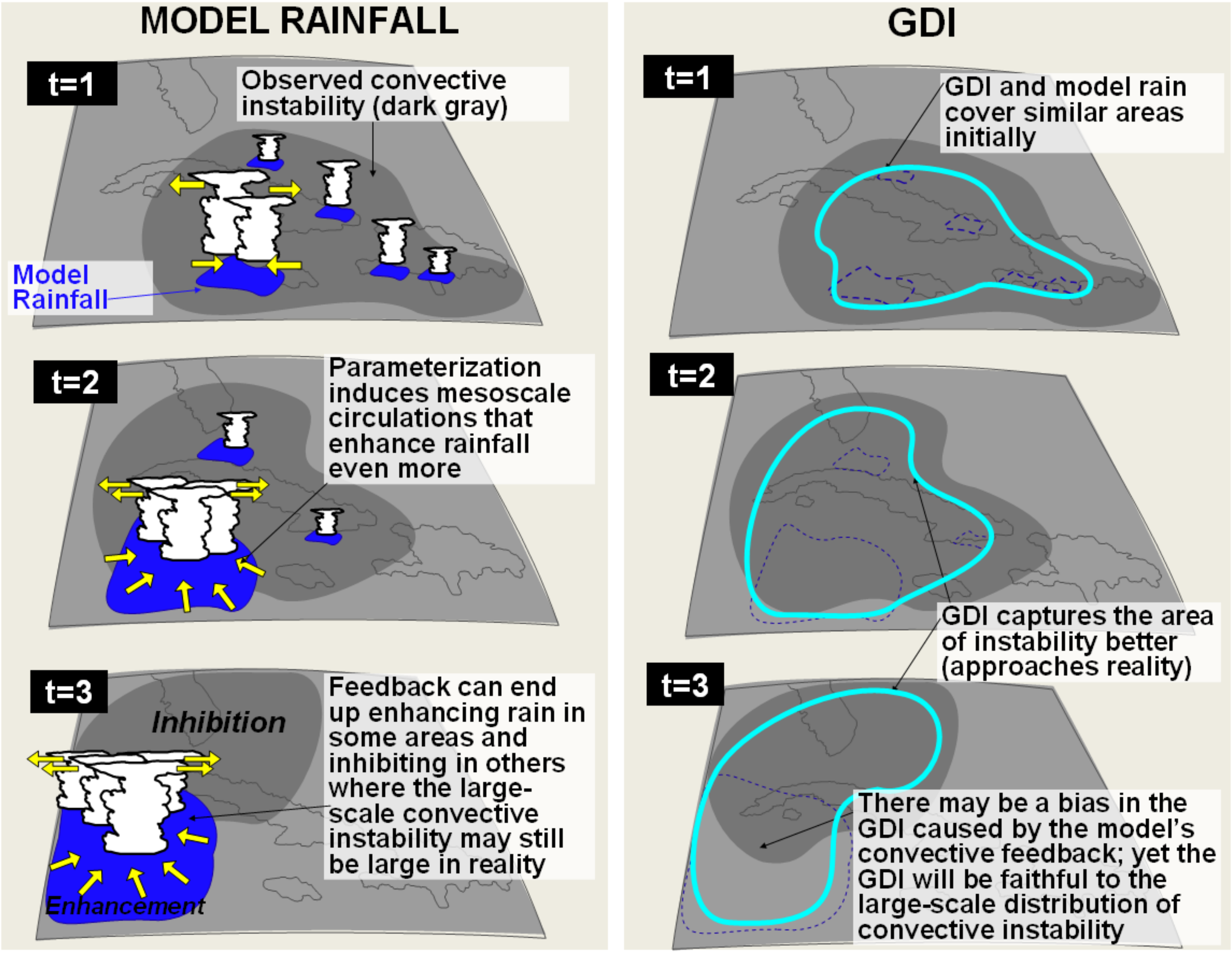




(3) Over time, the GDI is more reliable tan model rainfall

The GDI is more linked to moisture content and other variables that are better resolved by models than precipitation especially over time.

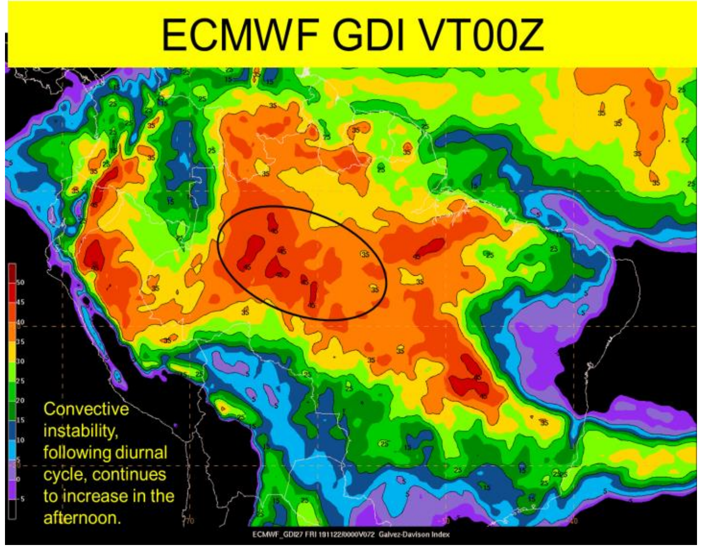
Models tend to generate rapidly growing errors when deep convection is resolved, because condensational heating processes are mesoscalar, hard to predict, and produce non-linear interactions.

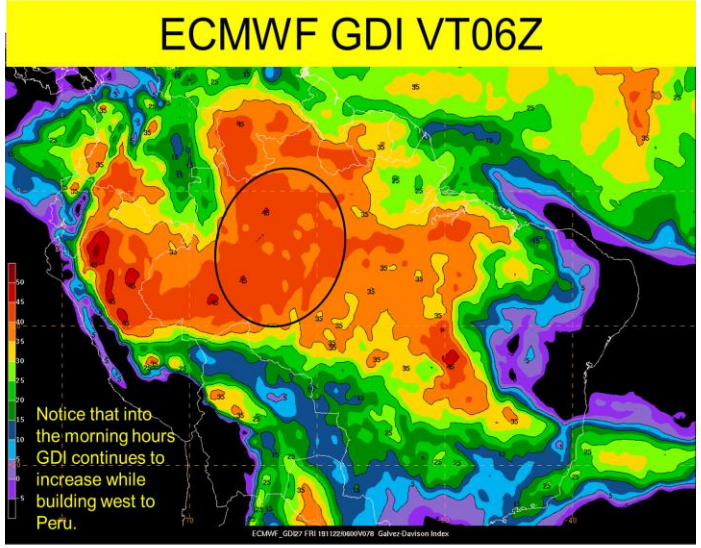


Convective feedback can alter model rainfall

(4) Helps to identify the potential for nocturnal MCS

- In a normal cycle, peak in convective instability should coincide with maximum heating.
  - Environment favorable for air mass thunderstorms
  - In the absence of meso-synoptic forcing, expect moderate/locally heavy rainfall amounts
- What happens if the GDI peaks during the nighttime?
  - Environment could be favorable for generation of Meso Scale Convective Systems (MCS)
  - Heavy Rainfall Amounts
    - Two peaks in convection, one in the afternoon and a second and much stronger peak during the nighttime/early morning hours.





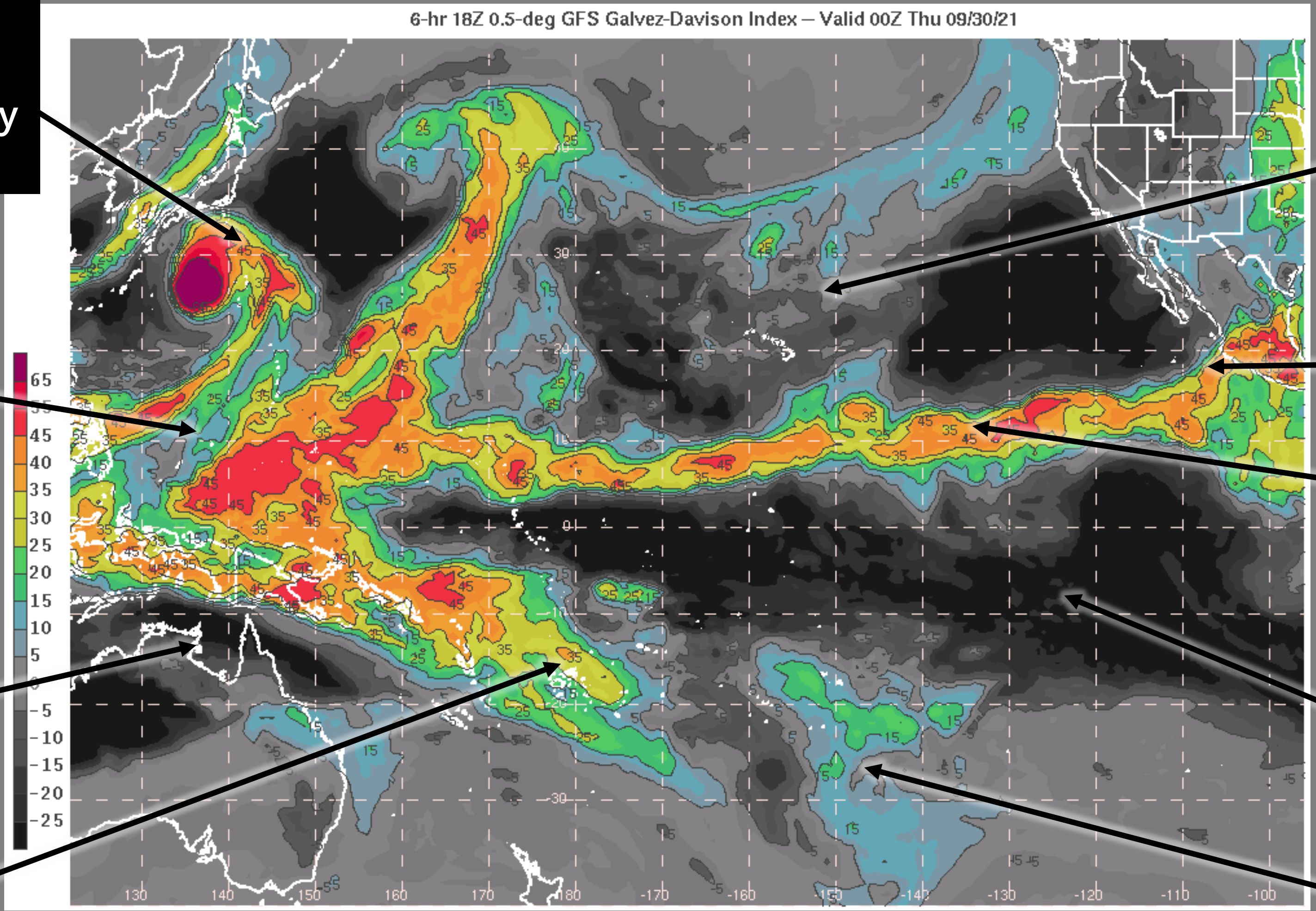
GDI Operational Application Examples

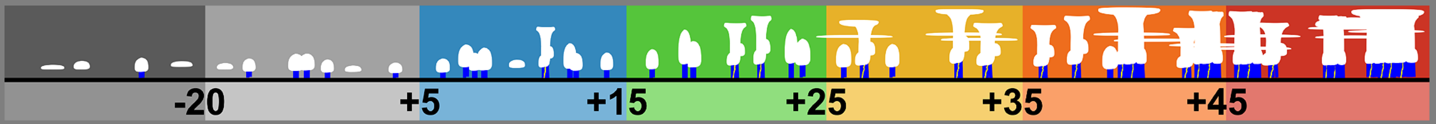
Cyclone Mindulle weakening as it is pulled to the ENE by an upper trough

Broad region of high GDI: Deep-Layer heavy rain producing convection. Tropical cyclones can originate from these areas.

Dry and stable in Northern Australia, trade wind inversion likely

SPCZ becoming more active near Fiji through October 3rd





Trade wind convection becoming deeper due to destabilization by a TUTT Low later in the Cycle

Easterly Wave

ITCZ Convection along 10-13N in the EPAC, and along 05-10N in the WPAC

Strong subsidence

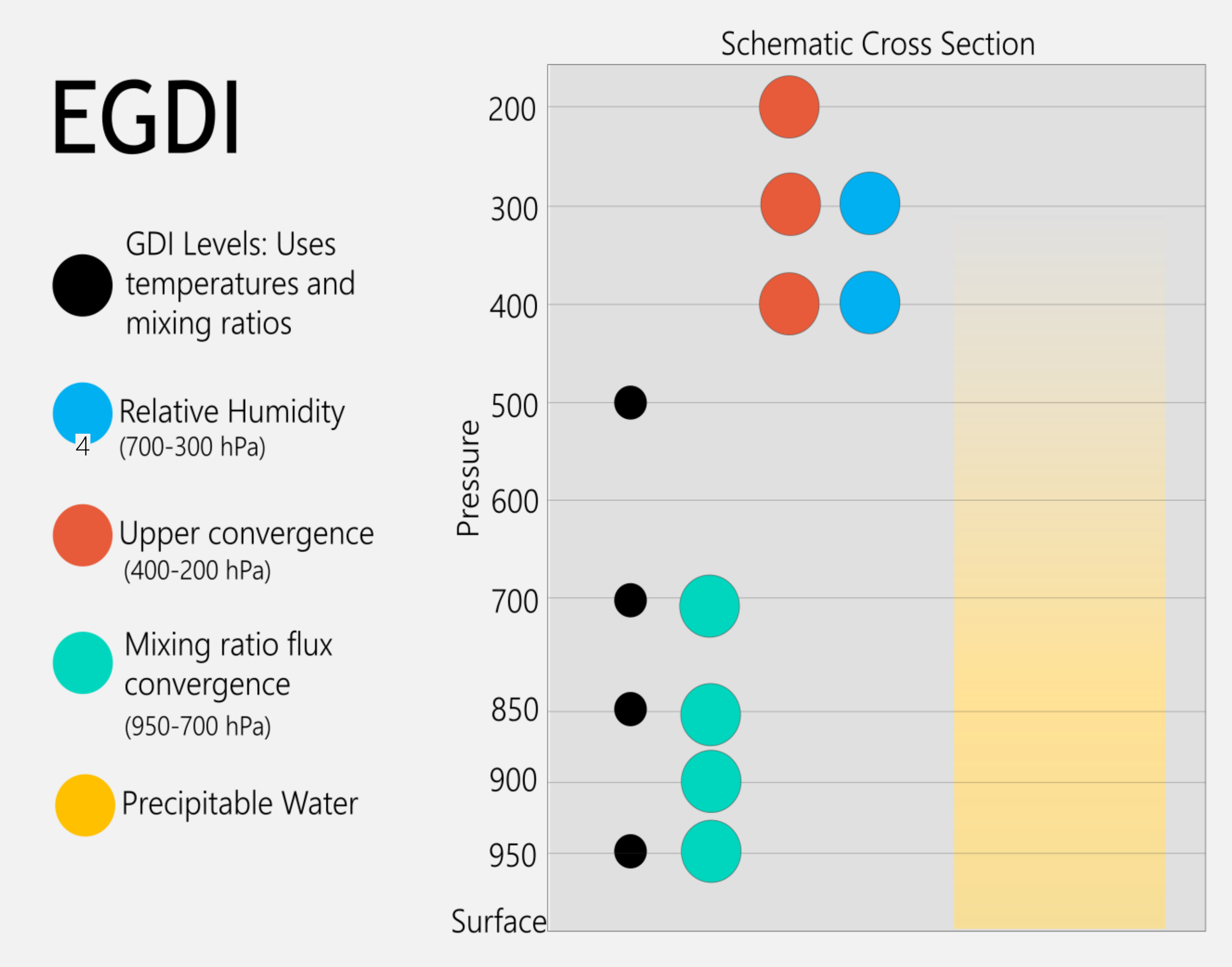
Atmospheric River organizing

Enhanced GDI (EGDI)

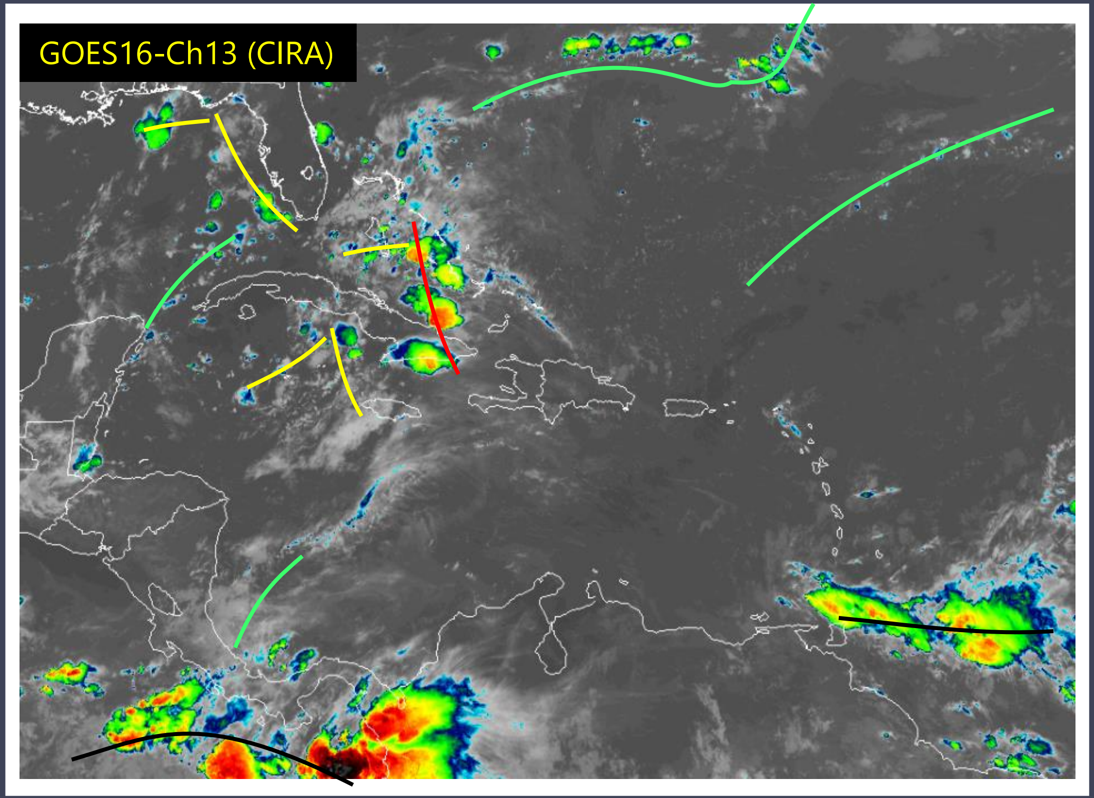
4 Additional Processes Added to the GDI:

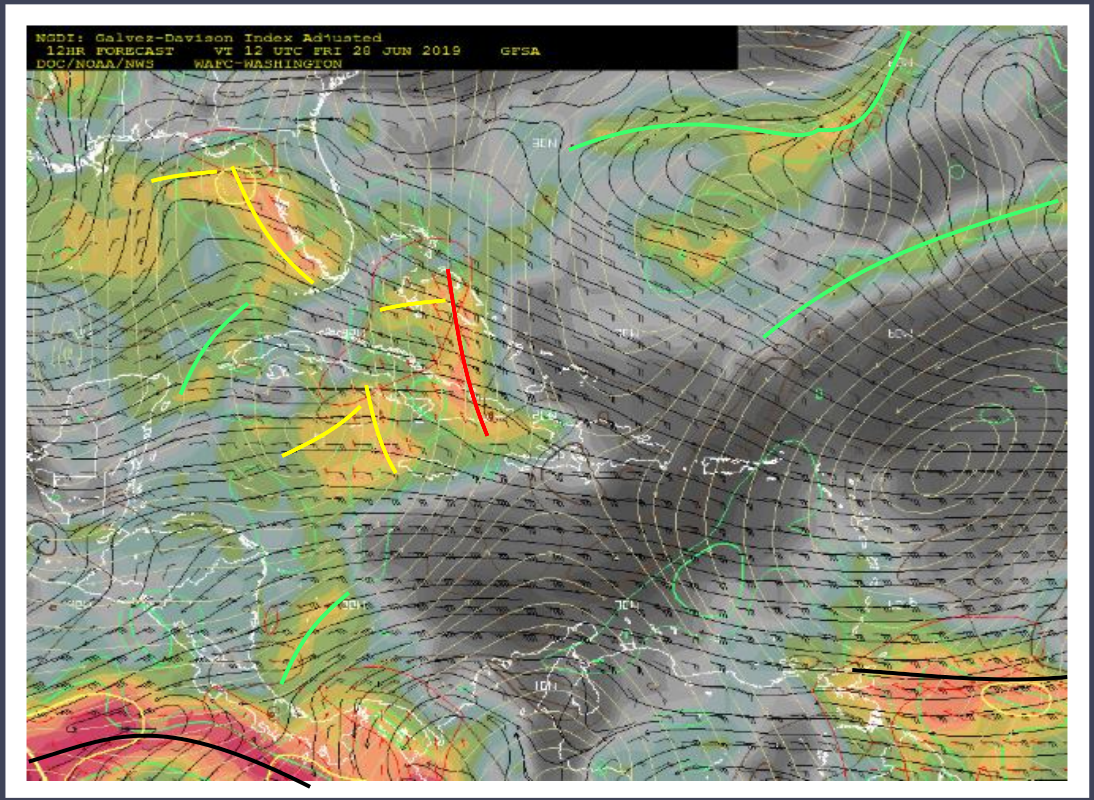
- Moisture Flux Convergence (950-700 hPa)
  Triggering of convection and adding moisture.
- Upper convergence (400-200 hPa)
  Stimulates descent and elevated inversions.
- Upper Relative Humidity (400-300 hPa)
  Associates with elevated inversions and dry entrainment processes that reduce rainfall rates in deep convection
- Precipitable Water
  TPW>30 enhances rainfall rates and convection.

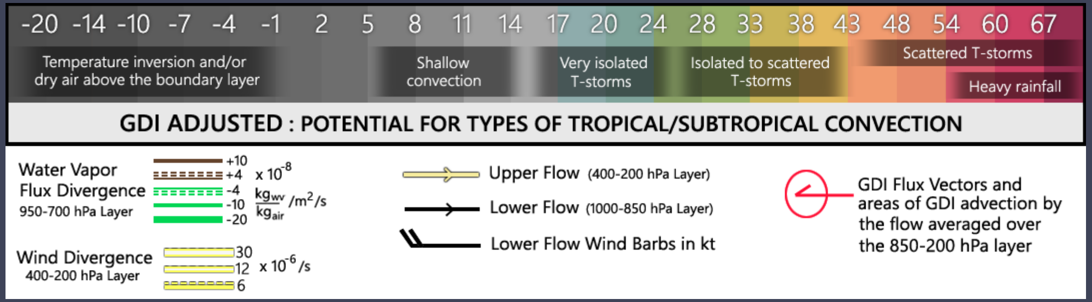
Including flow-derived properties (convergence quantities) makes the EGDI not a stability index anymore.



Enhanced Galvez-Davison Index (EGDI)





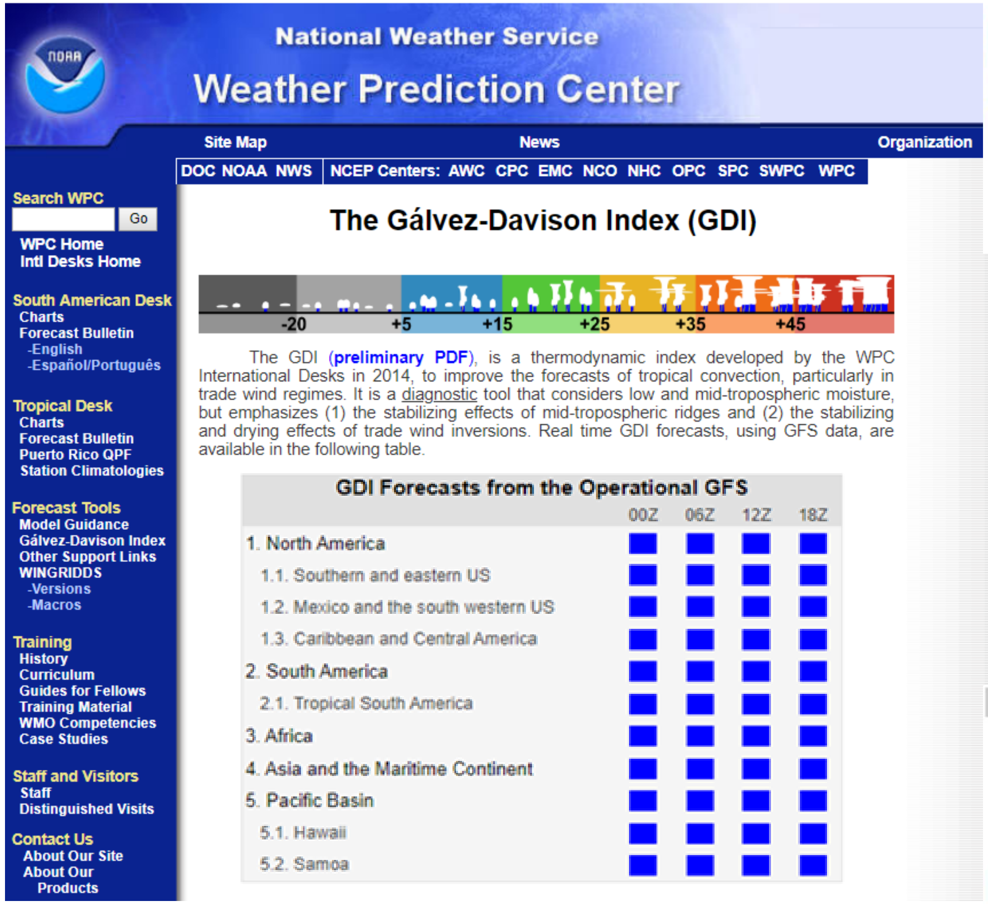


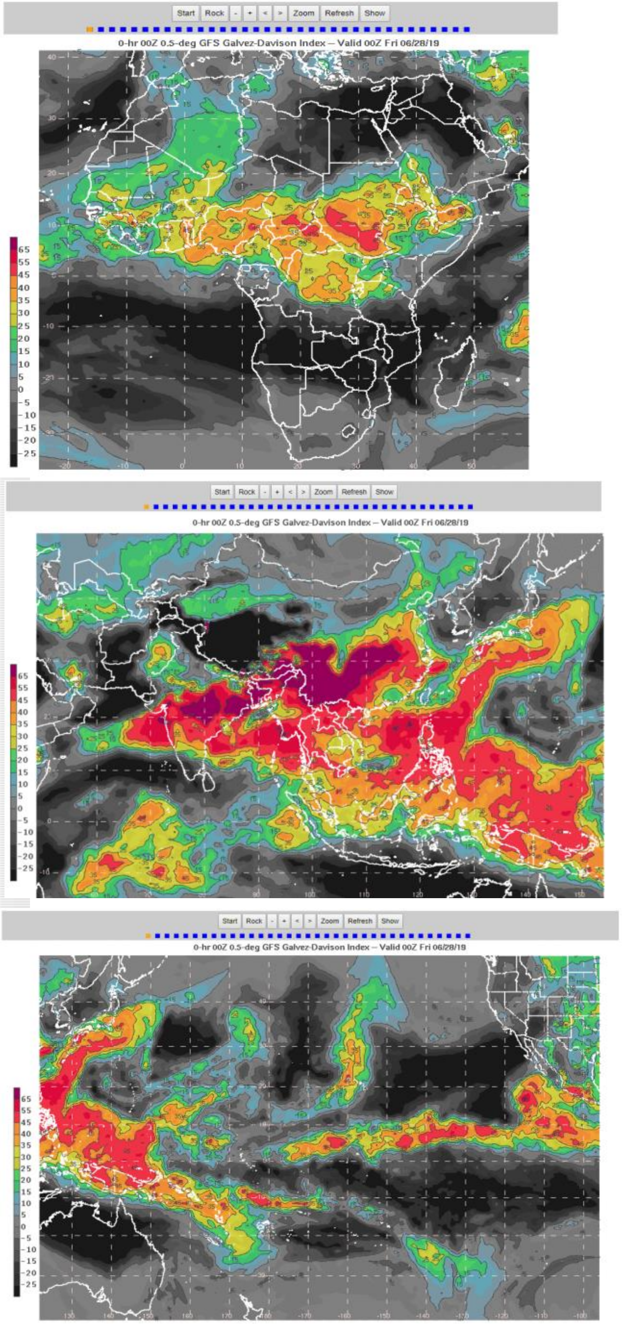
Convective features in the long wave IR (10.3um channel) align generally well with areas in the enhanced GDI product.

https://wpc.ncep.noaa.gov/international/wng/

Online Resources

- Link in International Desks Website (left menu)
- Access to:
  - Manuscript **(includes calculation algorithm)**
  - Current GFS GDI loops for different sectors of the world through 168 hrs (7 days)
  - Presentations
  - Related studies





https://www.wpc.ncep.noaa.gov/international/gdi/

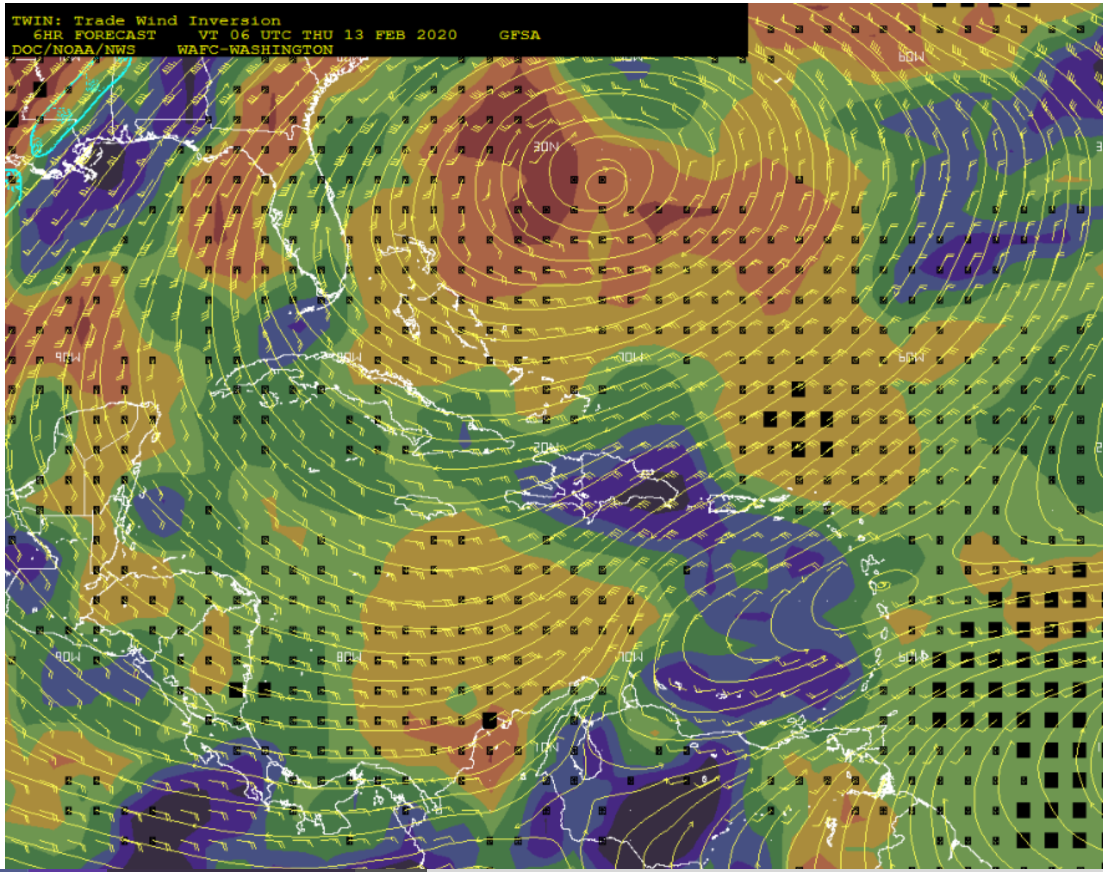
04

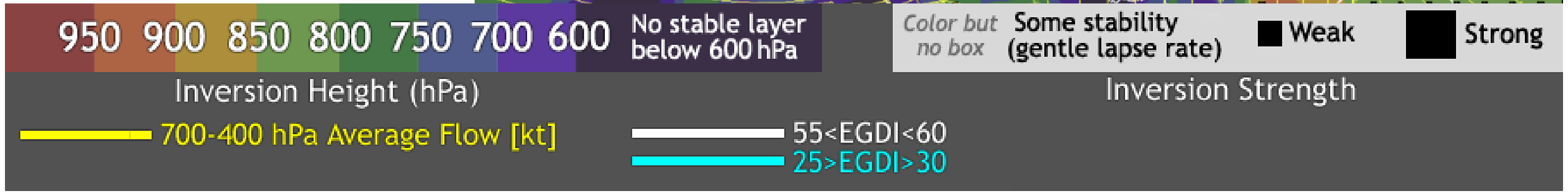
The Trade Wind Inversion Identification Tool (TWIN)

Trade Wind Inversion Identification Tool

What is it?

- Algorithms that detects the height and strength of the trade wind inversion (TWI).
- The height is plotted in shades, and intensity using squares.
- The mid-level flow is included to highlight mid-level troughs and ridges.
  - Mid-level ridges are generally linked to a stronger and longer-lasting TWI.
  - Troughs tend to relate with more convection and they can signal the effects of a TUTT or of easterly waves.

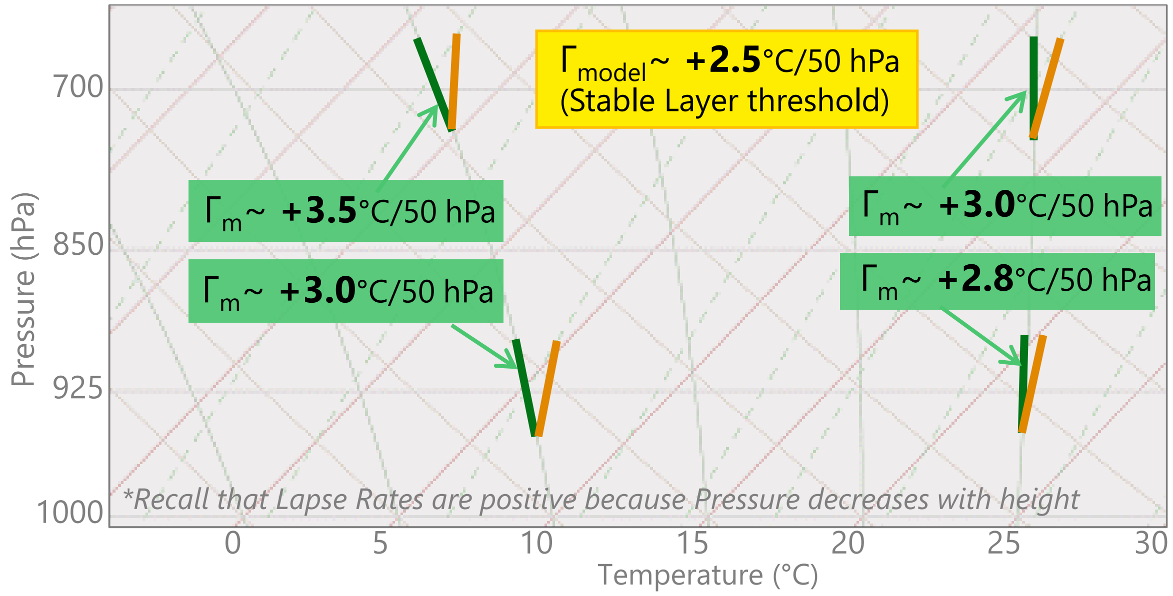




Trade Wind Inversion Identification Tool

How is the inversion detected?

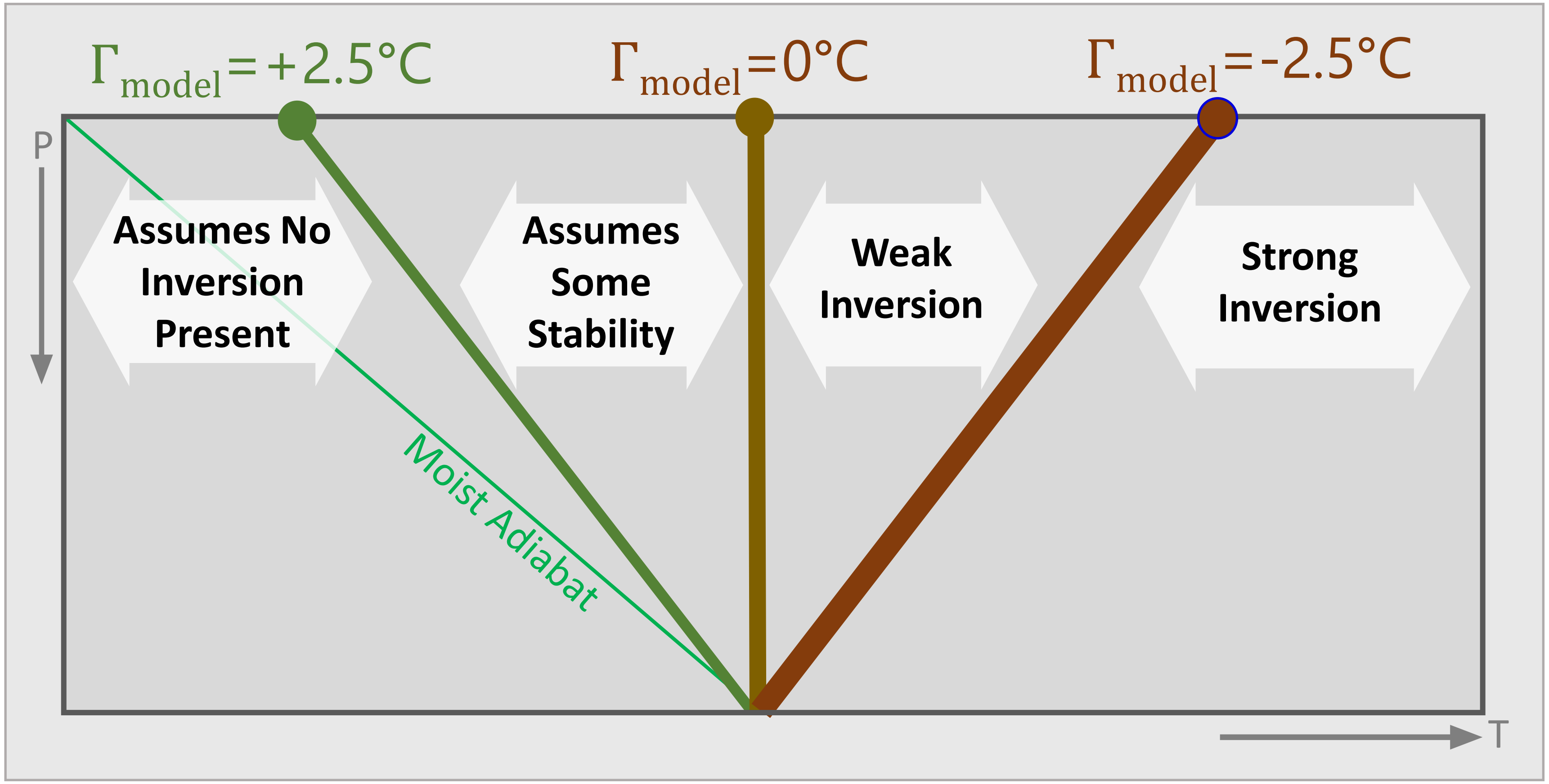
- By comparing the model lapse rate Γ_{model} with the moist adiabatic lapse rate Γ_m .
- Γ_m represents the rate of cooling of ascending saturated parcels.
- Typical values of Γ_m in the Caribbean mid-lower troposphere: +2.8 to +3.5°C /50hPa:
    - Stable Layer: If $\Gamma_{model} < \Gamma_m$
    - $\Gamma_{model} <$ +2.8°C/50hPa → some stability is present.



The presence of "some" stability is defined with a fixed threshold of Γ_{model} **< +2.5°C/50 hPa**. This can be improved, but this value is working for us so far.

Trade Wind Inversion Identification Tool

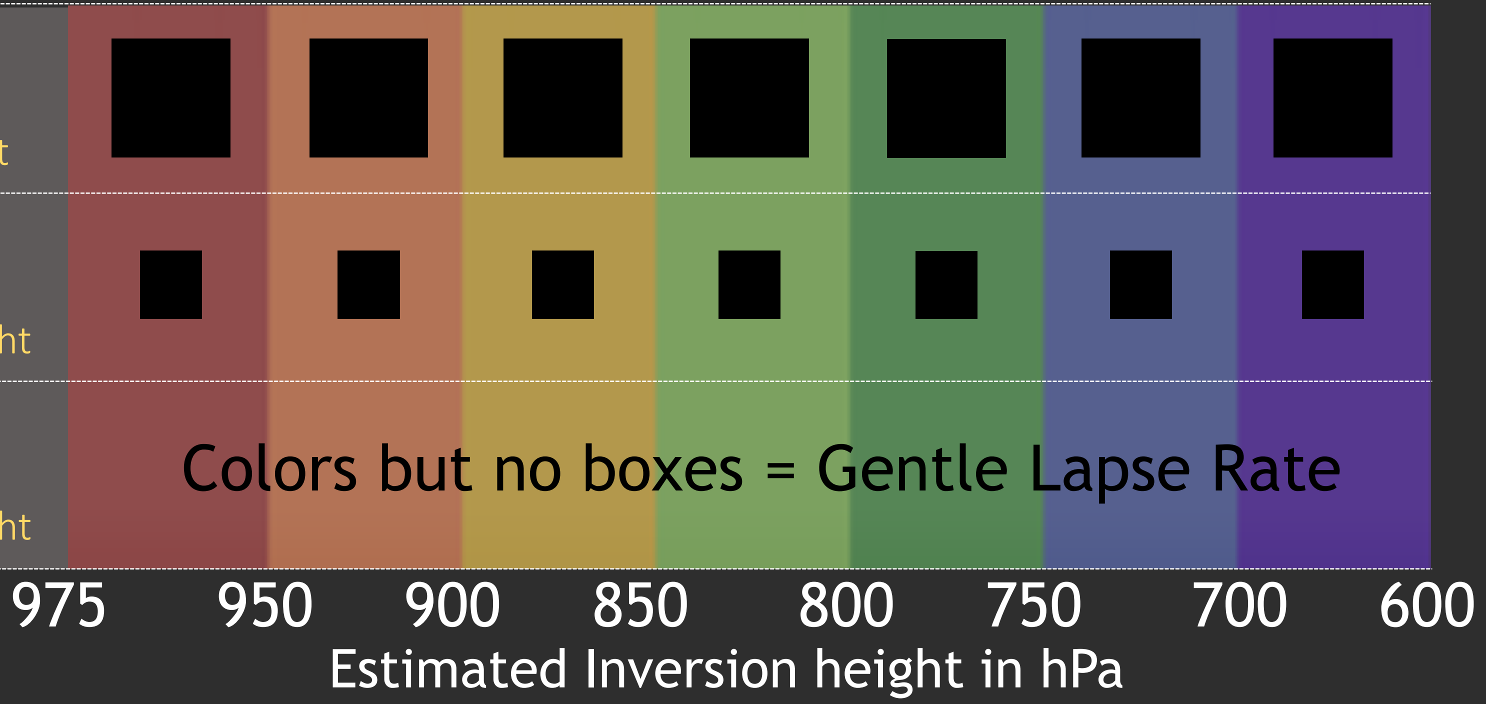
Thus, for a given 50 hPa layer:



Trade Wind Inversion Identification Tool

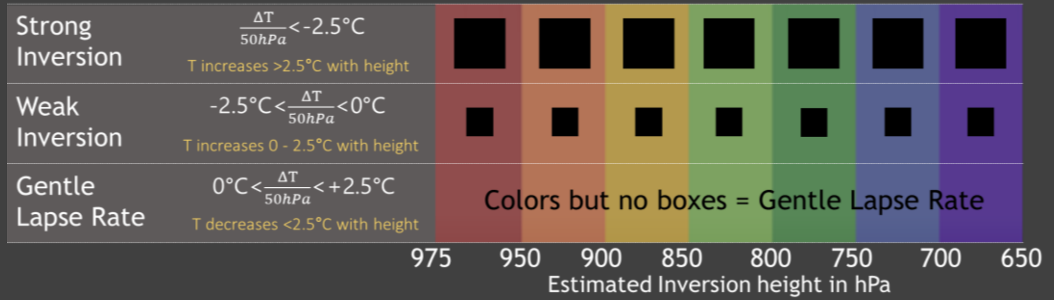
How is the inversion represented?

Strong Inversion	$\frac{\Delta T}{50hPa} < -2.5°C$ T increases >2.5°C with height	
Weak Inversion	$-2.5°C < \frac{\Delta T}{50hPa} < 0°C$ T increases 0 - 2.5°C with height	
Gentle Lapse Rate	$0°C < \frac{\Delta T}{50hPa} < +2.5°C$ T decreases <2.5°C with height	



Dark gray means that no stable layer was found under 600 hPa

Trade Wind Inversion Identification Tool

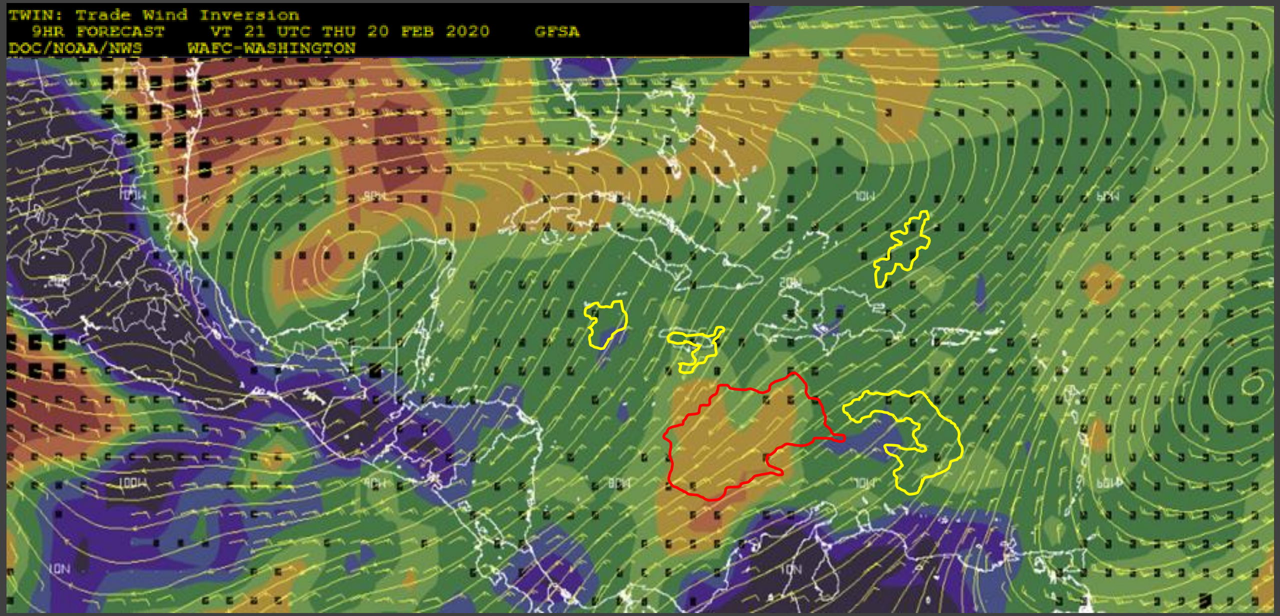


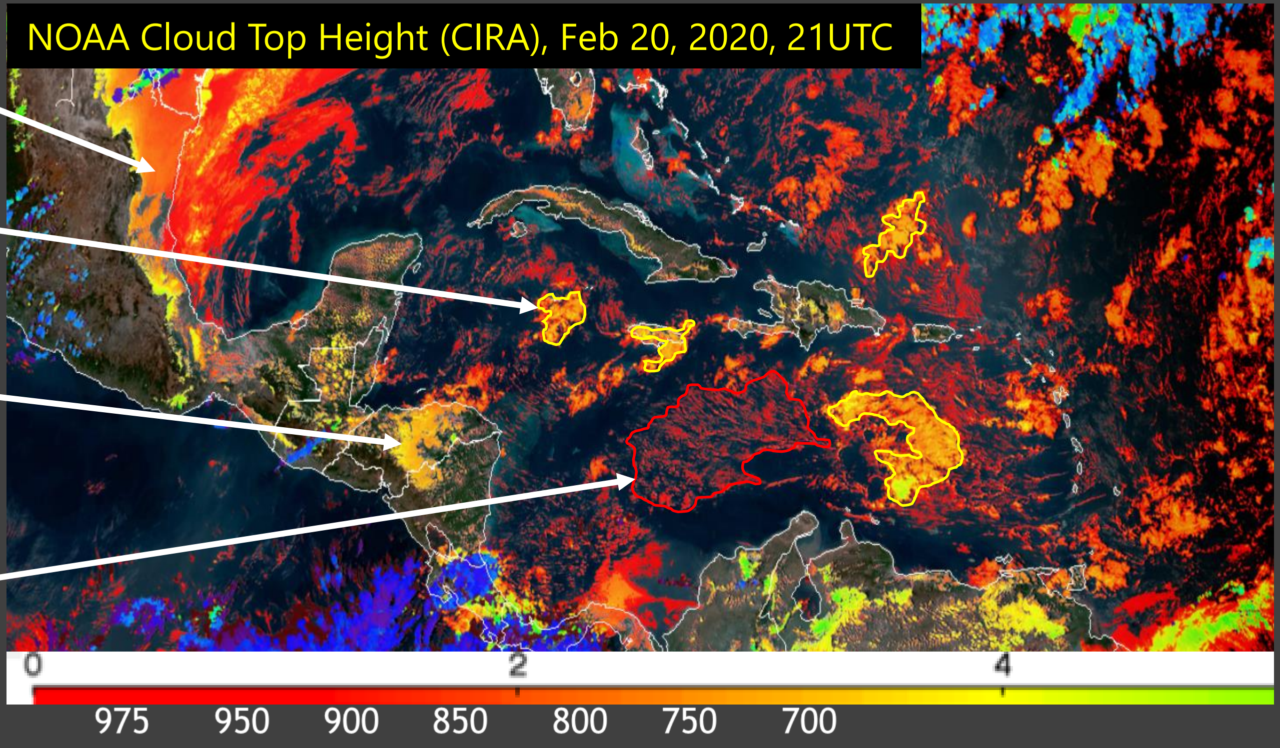
Sloping (color gradient) and strong (overcast) frontal inversion in NE Mexico, is consistent with the TWIN.

Cloud cluster south of the Cayman Islands reaches 750 hPa, consistent with the TWIN.

Convection in Honduras surpasses 700 hPa, suggested by the TWIN.

Low-lying gentle lapse rate in the TWIN is consistent with shallow convection and dry air entrainment, generating fair weather Cu fields in the Central Caribbean.





05

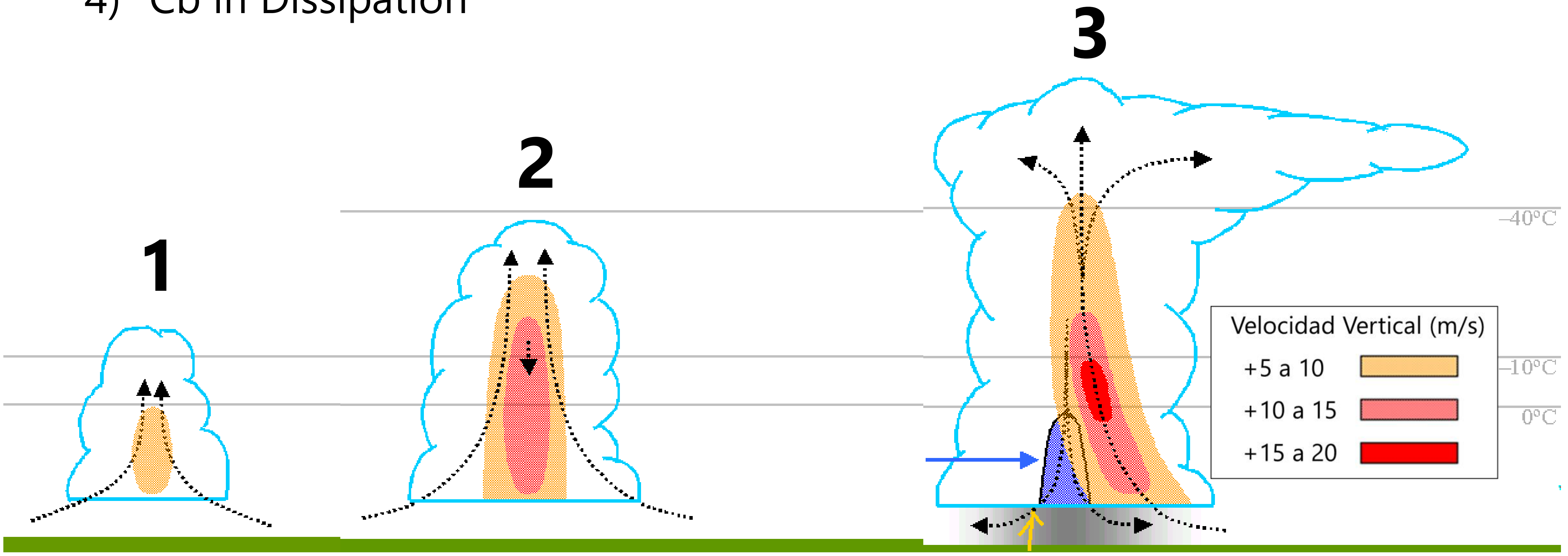
Thunderstorms and Severe Thunderstorms

Thunderstorms

- Deep convective cloud that develops electrification (lightning). The clouds are Cumulonimbus (Cb).
- Electrification of the cloud takes place when ice forms inside the cloud.
- Cloud tops of -20C, or lower, show high potential of ice forming.
- As a result, we can use vertical motion with respect to the -20C isotherm to determine when building Cumulus Congestus (TCu) evolve to Cumulonimbus (Cb).

Phases of Thunderstorms

1) Cumulus
2) Cumulus congestus or Tower Cumulus (Tcu)
3) Mature Cb
4) Cb in Dissipation



Severe Thunderstorm Classification (US NWS Standards)

- Storms with winds > 50 Kt
- Hail > 20mm (.75”)
- Tornados
- Pay particular attention to storms with tops near/overshooting the tropopause
- When storm top within 1.5 Km of the tropopause
- Determine temperature/height of the tropopause from model guidance and/or RAOBS..
- Compare cold cloud tops on satellite imagery vs analyzed temperature of the tropopause

Severe Parameters for Uruguay/Argentina (INUMET)

Helicidad relativa a la tormenta (HRT o SRH) 0-1km
< -150 $m^2\ s^{-2}$: rotación próximo a la superfície (tornados)

Helicidad relativa a la tormenta (HRT o SRH) 0-3k
< -300 $m^2\ s^{-2}$: rotación em bajos níveles (superceldas - SC)

Cizalladura 0-3km (Shear 0-3)
Unicelular: hasta 10 m·s-1.
Multiceldas: 10 a 20 m·s-1.
Supercelulas: pueden alcanzar hasta los 50 m·s-1.

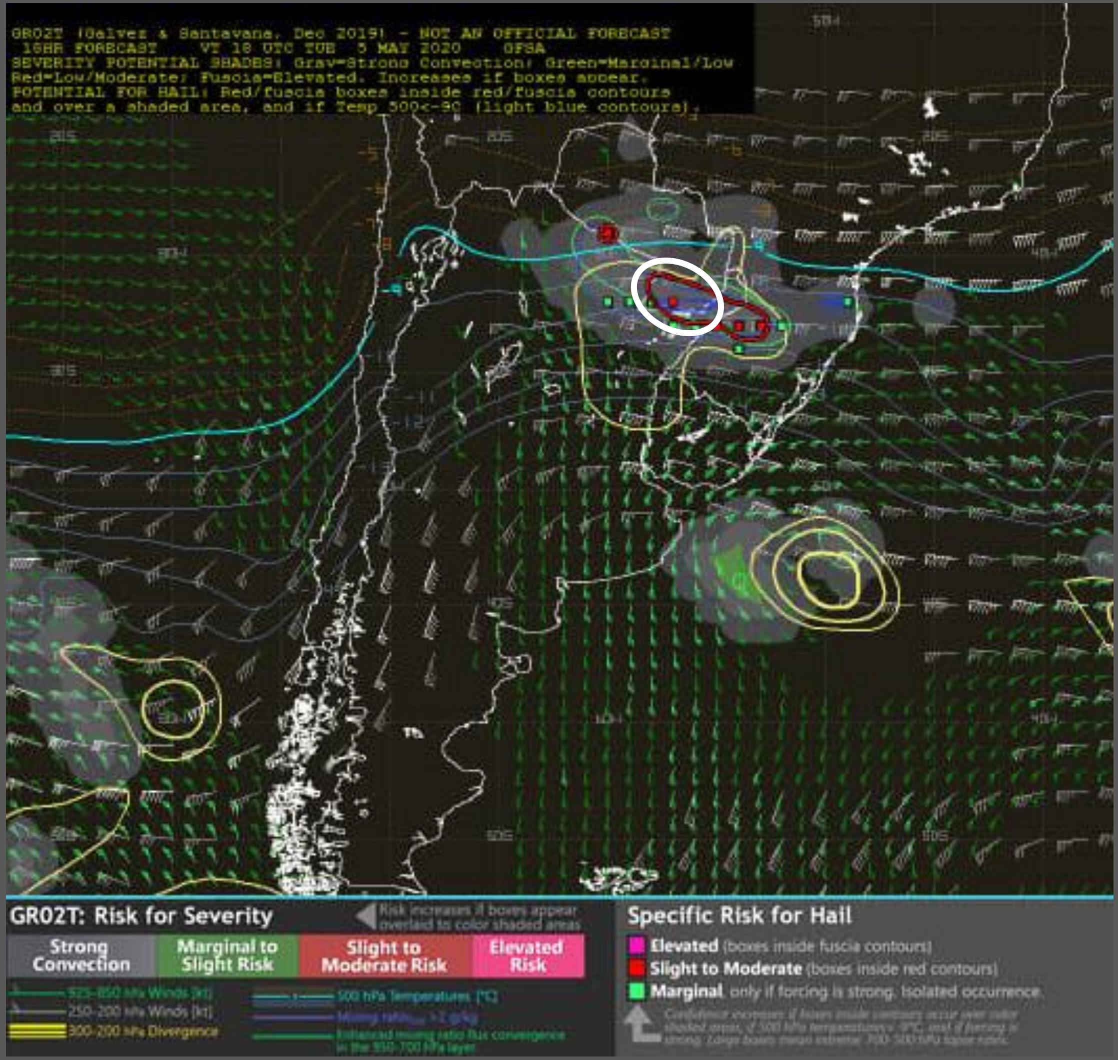
Cizalladura 0-6km (Shear 0-6)
< 10 $m\ s^{-1}$ → Tormentas poco organizadas
Entre 10 / 15 $m\ s^{-1}$ → Tormentas organizadas
Entre 15 / 25 $m\ s^{-1}$ → Tormentas muy organizadas (SC)
25 $m\ s^{-1}$ → Tormentas com intensa rotación

Energía potencial disponible para convección (*Convective Available Potential Energy - CAPE*)
< 500 $J\ kg^{-1}$ → baja inestabilidad
Entre 500 / 1500 → inestabilidad moderada
Entre 1500 / 3000 → alta inestabilidad
> 3000 → inestabilidad extrema

Índice de levantamiento (*Lifted Index* - LI)
LI > 0 → sin inst. termodinâmica
- 2 < LI < 0 → inestabilidad baja
- 4 < LI < - 2 → inestabilidad moderada
- 6 < LI < - 4 → inestabilidad alta
LI < - 6 → inestabilidad extrema

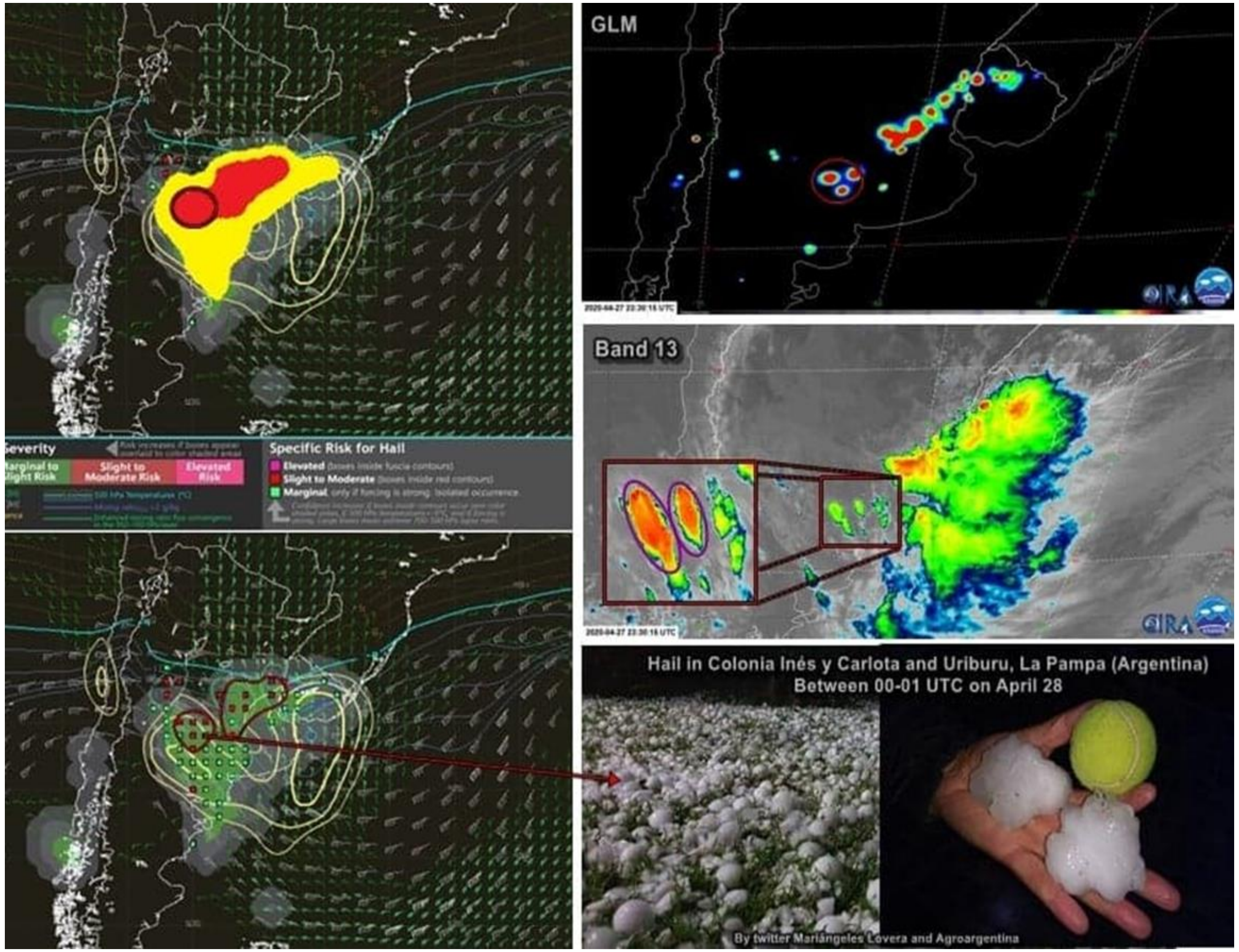
Severe Convection
and the GR02T Algorithm
for the Detection of Severe Weather and Hail

Hail event in South America



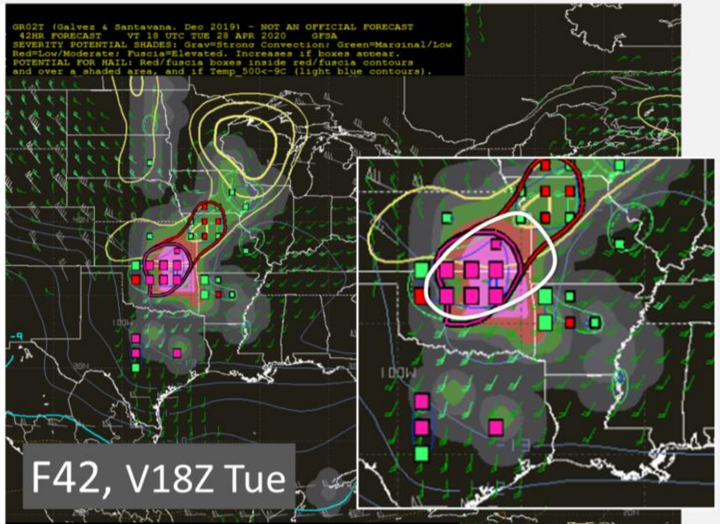
GR02T: Algorithm to forecast severe weather and hail

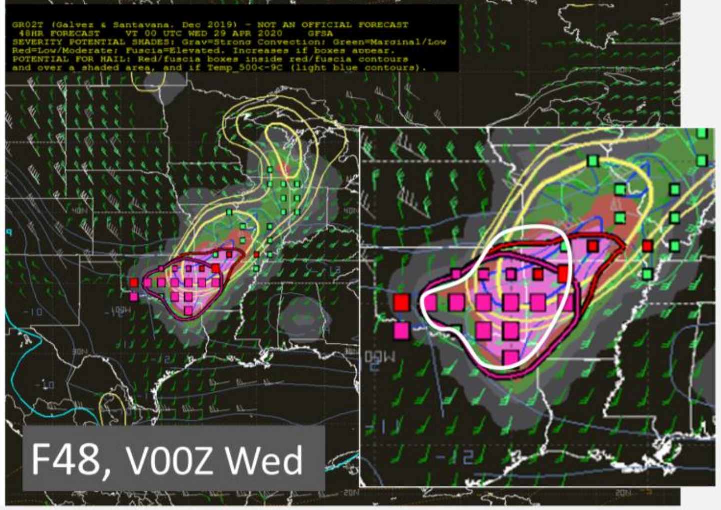
- Based on hail forecasting algorithms developed for South America GR01 and GR02 (Galvez and Santayana, 2015 and 2019), developed for Uruguay/northern Argentina.
- Adapted for a wider range of severe weather.
- If mid-level (500 hPa) temperatures are too cold (<-8°C) and/or the terrain is elevated, the risk for hail increases.
- Hail is also more likely over broader terrain. Not as much in small islands due to limited diurnal heating.



GR02T Interpretation

Monday 00Z Initialization



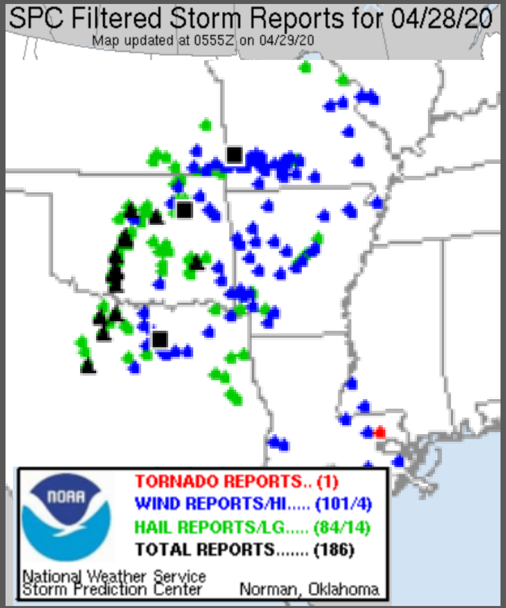


GR02T: Risk for Severity

Risk increases if boxes appear overlaid to color shaded areas

Strong Convection	Marginal to Slight Risk	Slight to Moderate Risk	Elevated Risk

- 925-850 hPa Winds [kt]
- 250-200 hPa Winds [kt]
- 300-200 hPa Divergence
- 500 hPa Temperatures [°C]
- Mixing ratio$_{500}$ >2 g/kg
- Enhanced mixing ratio flux convergence in the 950-700 hPa layer.

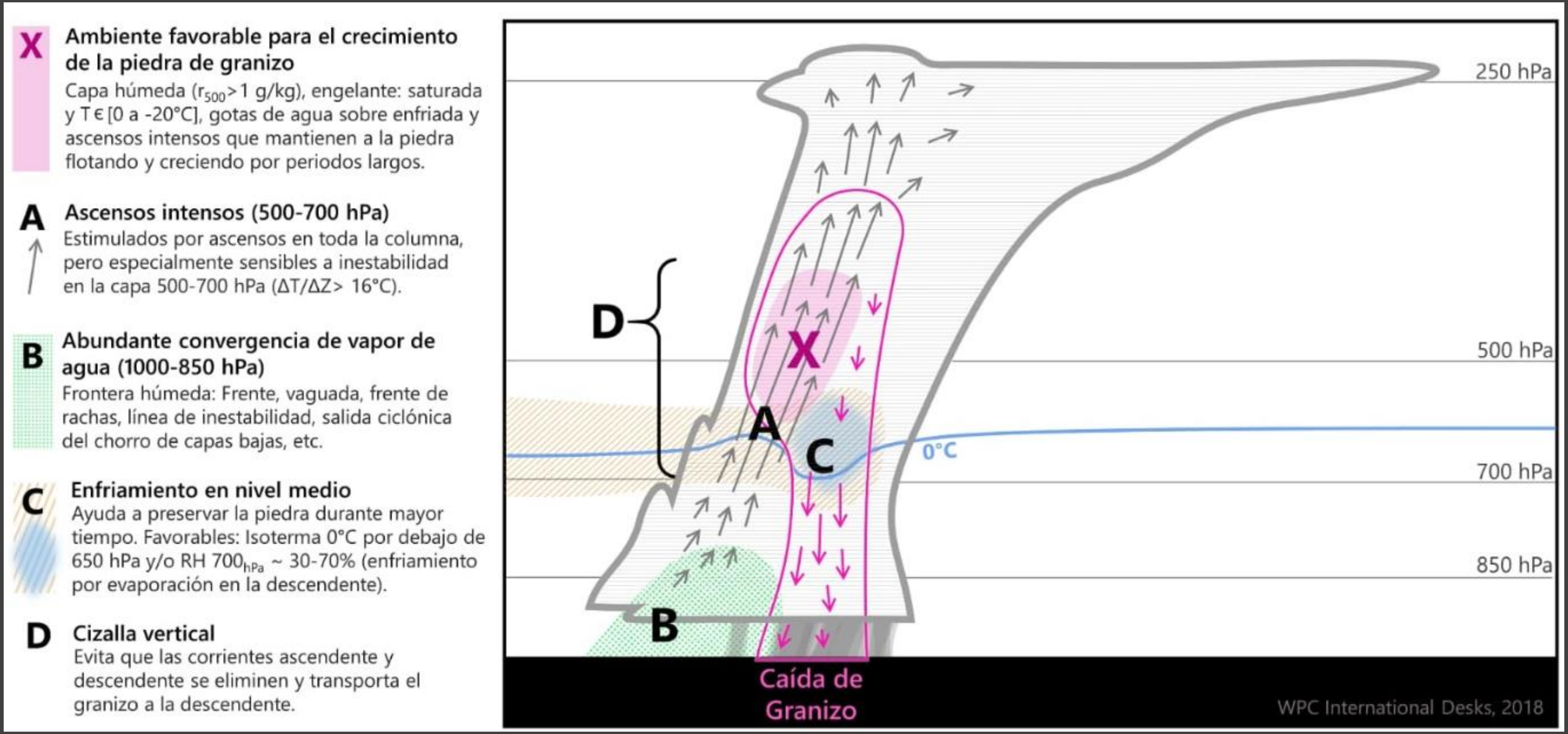


Specific Risk for Hail

- **Elevated** (boxes inside fuscia contours)
- **Slight to Moderate** (boxes inside red contours)
- **Marginal**, only if forcing is strong. Isolated occurrence.

Confidence increases if boxes inside contours occur over color shaded areas, if 500 hPa temperatures<-9°C, and if forcing is strong. Large boxes mean extreme 700-500 hPa lapse rates.

Processes that stimulate Hail



GR02T: Generation of Shaded Areas
"Potential for Severity"

(1) Detection of areas with the potential for strong deep moist convection

a) Binary masks are created:

-They contain 1 where a favorable variable is identified, zeros otherwise.

-Masks are created for

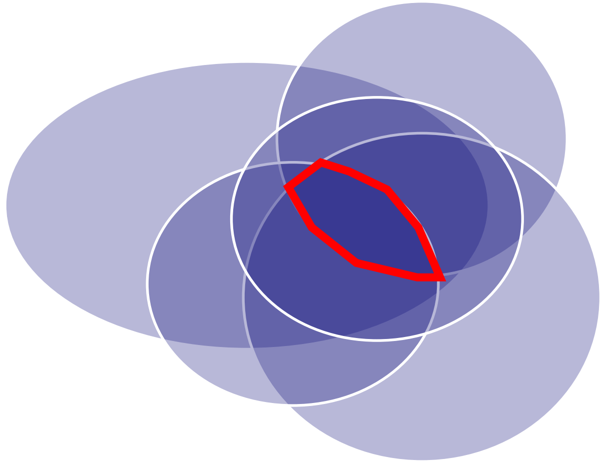
-PWAT > 20mm – *Deep-layer moisture*

-LI<0°C – *Deep-layer instability*

-T_{600} < +2°C – *Mid-level instability or cold air*

-$RH_{700\text{-}500}$ > 80% – *Saturation in hail-formation layer*

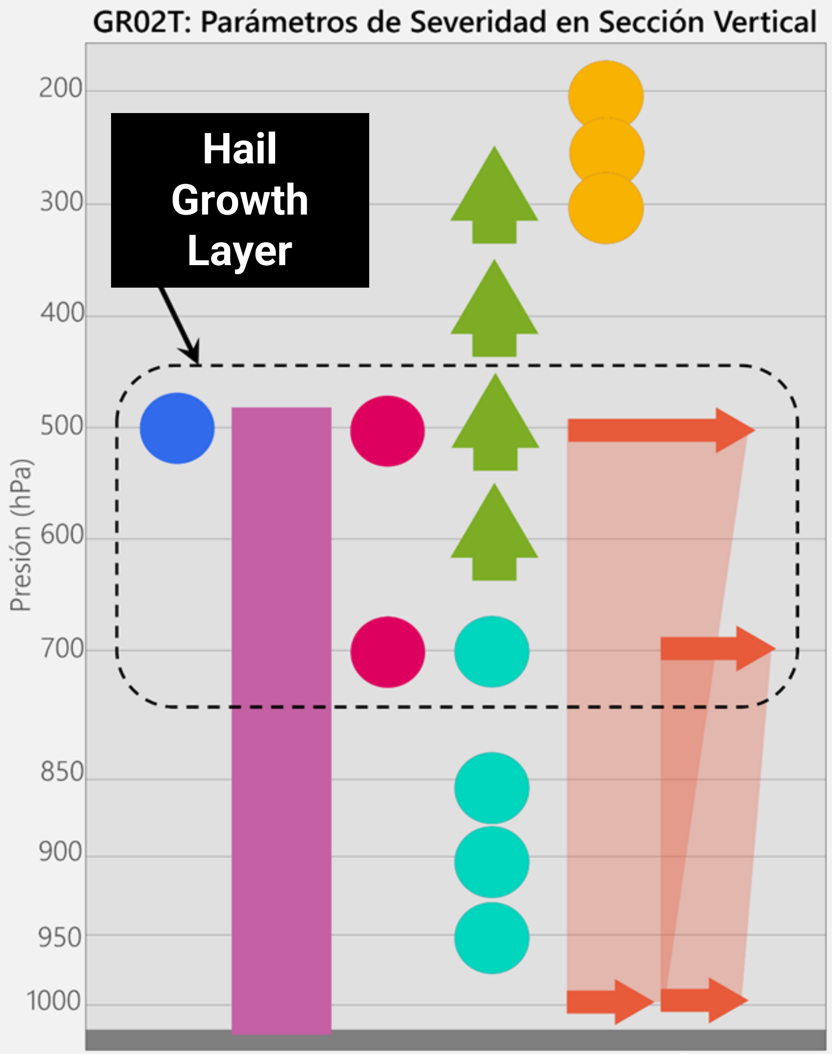
-$OMEGA_{600\text{-}300} < -10^{-4}$ Pa s^{-1} – *Dynamically-induced ascent*



b) They are multiplied:

-Thus '1' will be present ONLY when these 5 factors multiply.

GR02T: Filling the “Strong Deep Moist Convection” Masks with values



Fuente: WPC International Desks, 2020

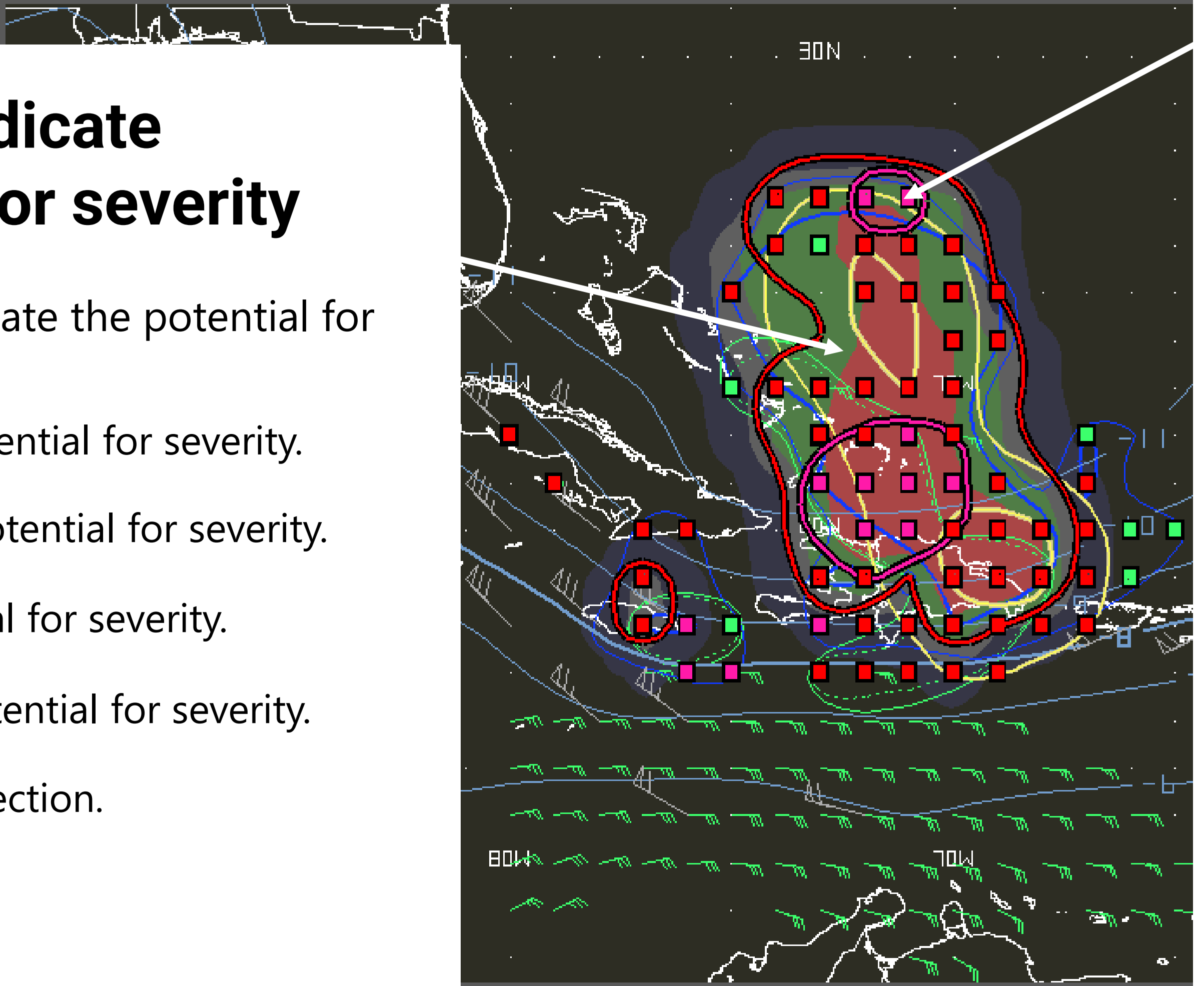
1. T_{500} < -8°C cold air in the mid-levels
2. Lifted Index < -0°C deep-layer instability
3. Lapse rate 700-500 >16°C Mid-layer instability (key for hail growth)
4. $Omegas_{600\text{-}300}$ < 0 pa s^{-1} Vertical motion (ascent)
5. $DFR_{950\text{-}700}$ < -0.5×10^{-8} kg kg^{-1} m^{-2} Covergence of the flux of mixing ratio (moisture convergence)
6. Shear $\overline{\text{0-3km 0-6km}}$ > 20m/s Vertical wind shear under 500 hpa, stimulates updraft strength
7. $Div_{300\text{-}200}$ > 1.3 10^{-6} s^{-1} Upper divergence strengthens ascent and reflects role of upper jets.

Interpretation of GR02T

Shades indicate potential for severity

Color shades indicate the potential for severity:

- Elevated potential for severity.
- Moderate potential for severity.
- Low potential for severity.
- Marginal potential for severity.
- Strong convection.



Boxes and contours are for hail forecasting

Boxes are drawn when the following intercept: steep 700-500 hPa lapse rates (>16°C) and unstable Lifted Index; and dynamically-induced ascent or negative omegas in the 600-300 hPa layer.

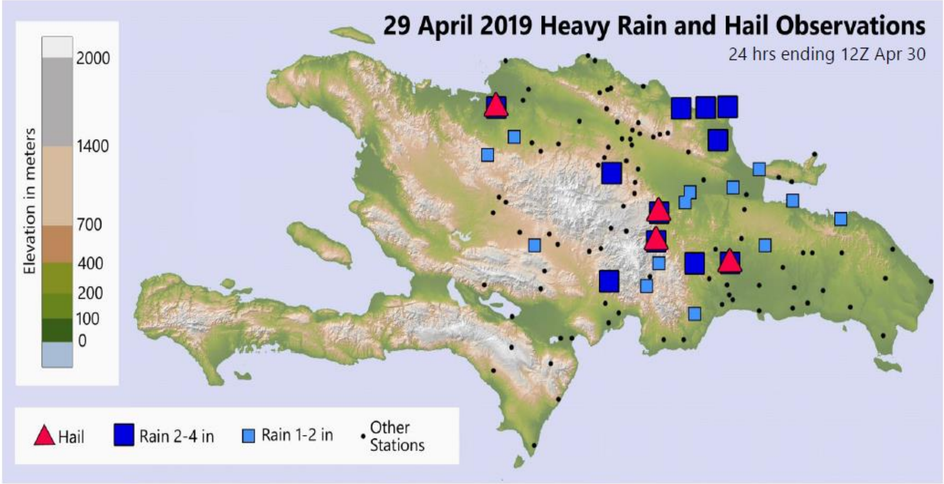
Green, red and fuscia indicate different thresholds of these variables:

- LI<-6°C OMGA<$-2x10^{-2}$ Pa s^{-1}
- LI<-3°C OMGA<$-2x10^{-2}$ Pa s^{-1}
- LI<-1°C

The risk for severity increases if red- and fuscia-colored contours with boxes inside, intercept color shaded areas and 500hPa temperatures < -8°C.

GR02T detects hail events in Hispaniola

Example : Apr 29, 2019 event

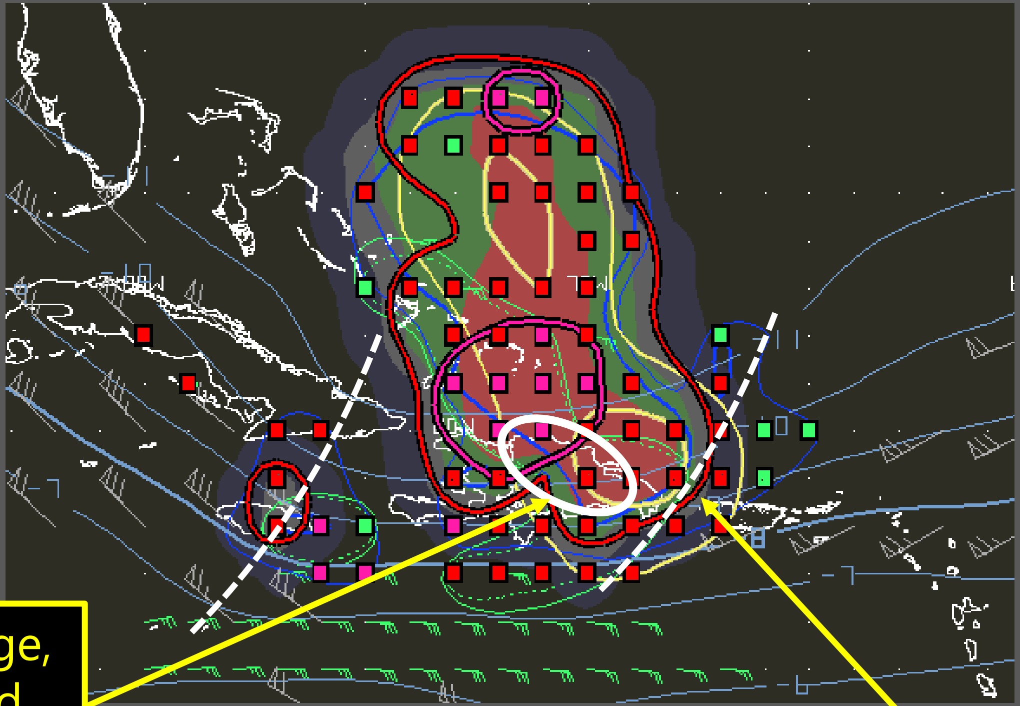


HAIL
5% of stations

Heavy rain (>2in)
11% of stations

Heavy rain (1-2in)
13% of stations

Note: Hail reported in lower elevations

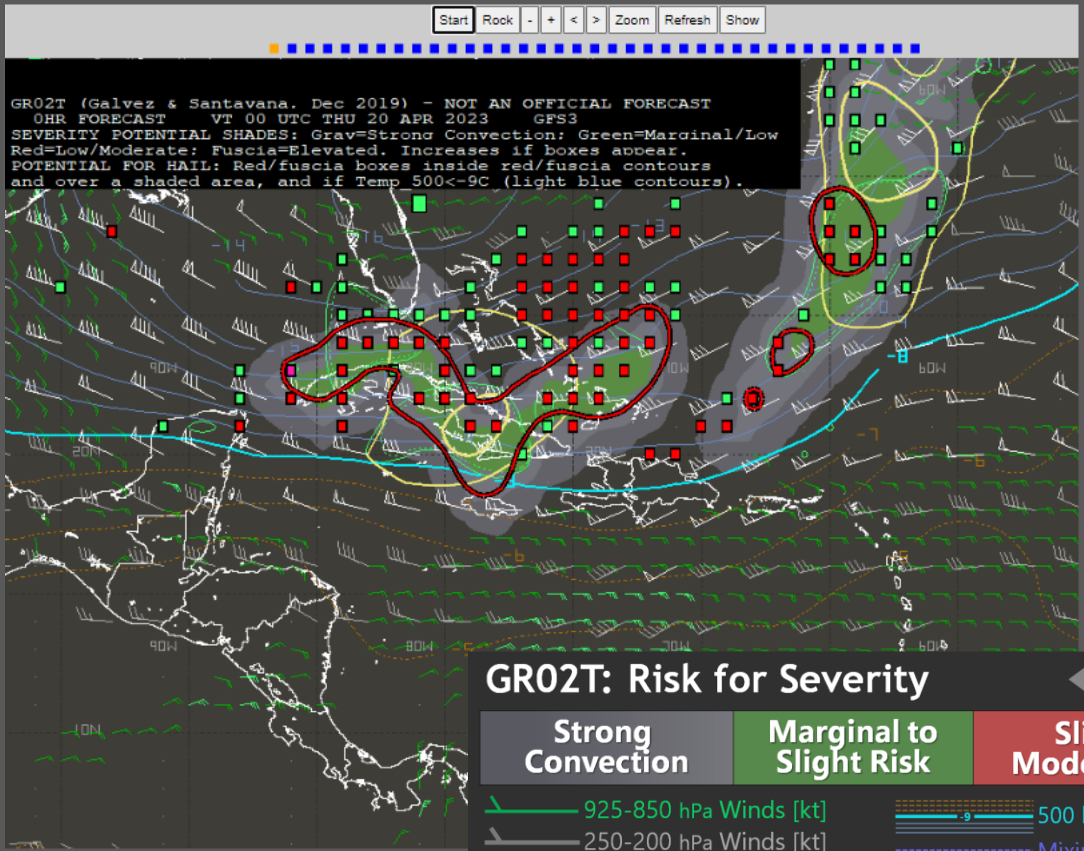


Although the environment for hail and squally weather was large, hail only occurred at higher elevations and foothills (colder and stronger topographical forcing

Hail occurred where the following intercepted: (1) Boxes inside contours, (2) red shaded area, (3) orographic effects, (4) mid-level perturbations, (5) enhanced upper divergence.

Passing mid-level short wave troughs, evident in the 500 hPa temperature field, played a role.

Hail in Cuba yesterday (April 19, 2023)



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Southern African
(ESAF) Office
Nairobi
South American
(SAM) Office
Lima

Thank You!