Forecasting Tool to detect Environments favorable for Hail

GR02T

By José Manuel Gálvez

13 October 2025

Motivation

Hail poses a significant threat across the mid-latitudes of South America, particularly within the Paraná and Río de la Plata Basins.

Large Hail in Argentina, March 12, 2024. Source: weatherandradar.com

Large Hail in Paraguay, 21 September 2025. Source: Paraguay Weather Service.

The challenges of forecasting hail in these regions led to the development of a specialized forecasting tool designed to identify environments favorable for hail and severe convection: “Granizo Version 2 – Trial” (GR02T).

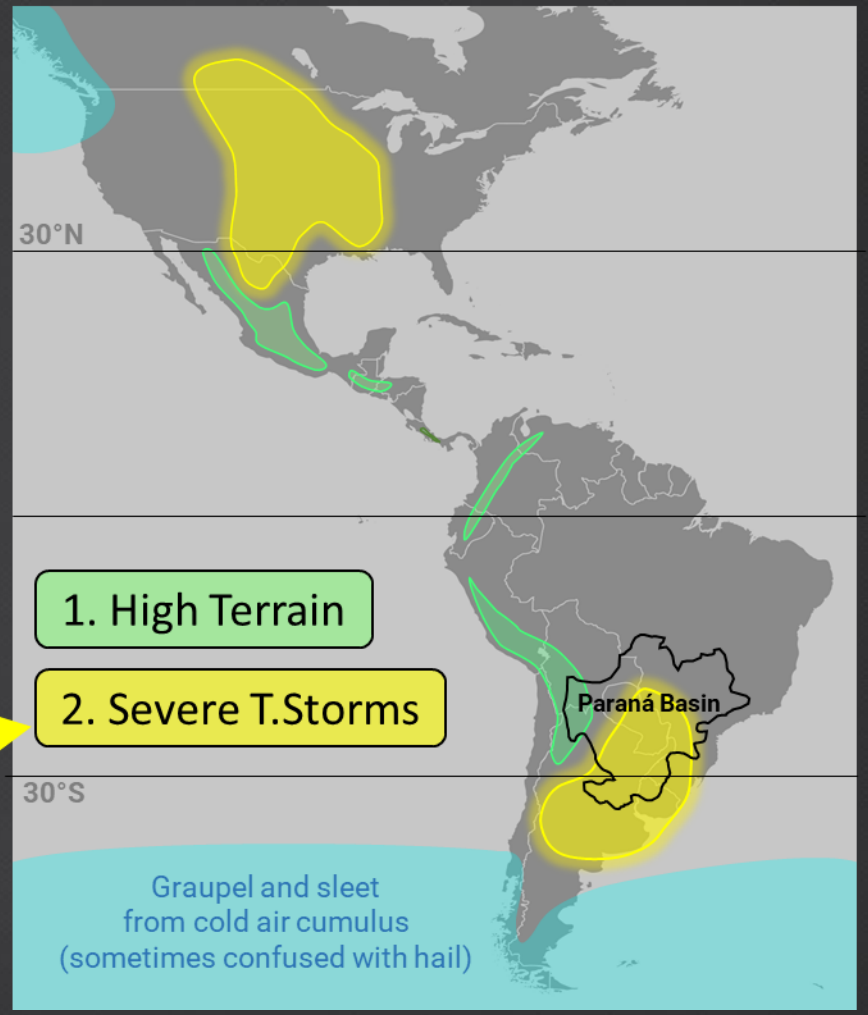
Where does hail occur in the Americas?

There seem to be two types of hail events in the Americas:

(1) **Small hail in high terrain**, including the tropical Andes. This often occurs when strong thunderstorms with high moisture content develop over mountains, where the hail formation layer is already close to the surface.

(2) **Hail associated with severe thunderstorms.** Occurs in mid-latitudes and the subtropics, east of large mountain ranges. Here, warm, moist and very unstable airmasses of tropical origins interact with cold upper troughs and strong mid-latitude dynamics. This forms severe thunderstorms with very strong updrafts. Hail can become large.

GR02T is designed for this type of hail



Where does hail occur in South America?

1. Climatology in Argentina based on surface stations[1].
2. Climatology based on overshooting tops filtered by environments prone for the occurrence of hail using ERA5[2].

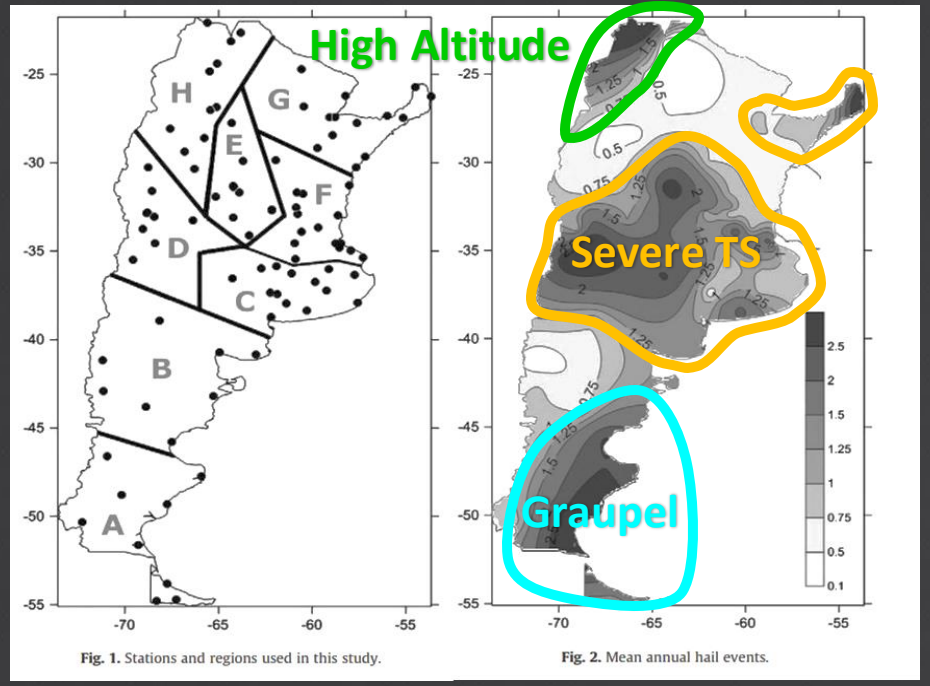


Fig. 1: Hail Climatology in Argentina from surface stations (48 years) and a simple Kriging Method for interpolation. Source: Mezher et al. (2012)

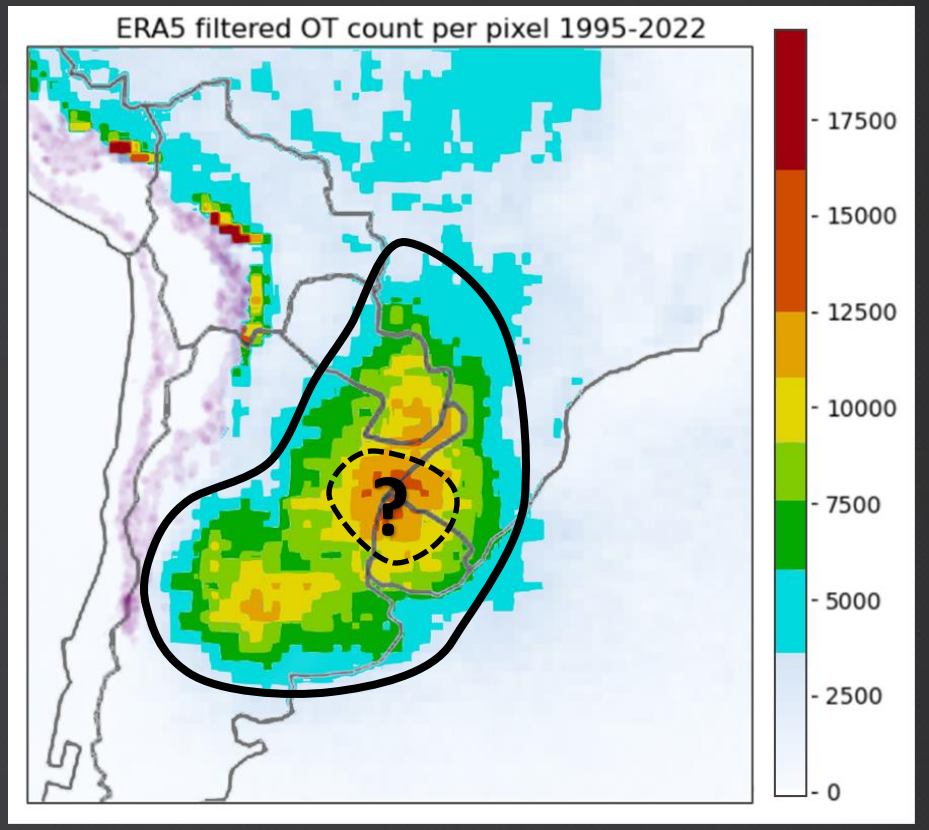


Fig. 2: Count of OT detections per 50x50 km over the whole dataset (28 years), filtered to environments favorable for hail. Country boundaries and the outline of the high mountain ranges are indicated as black and violet lines, respectively. Source: CEDIM.

Sources: (1) Mezher, R. N., Doyle, M., and Barros, V. (2012). Climatology of hail in Argentina. Atmos. Res. 11, 70–82. doi: 10.1016/j.atmosres.2012.05.020
(2) CEDIM, Karlsruhe Institute of Technology

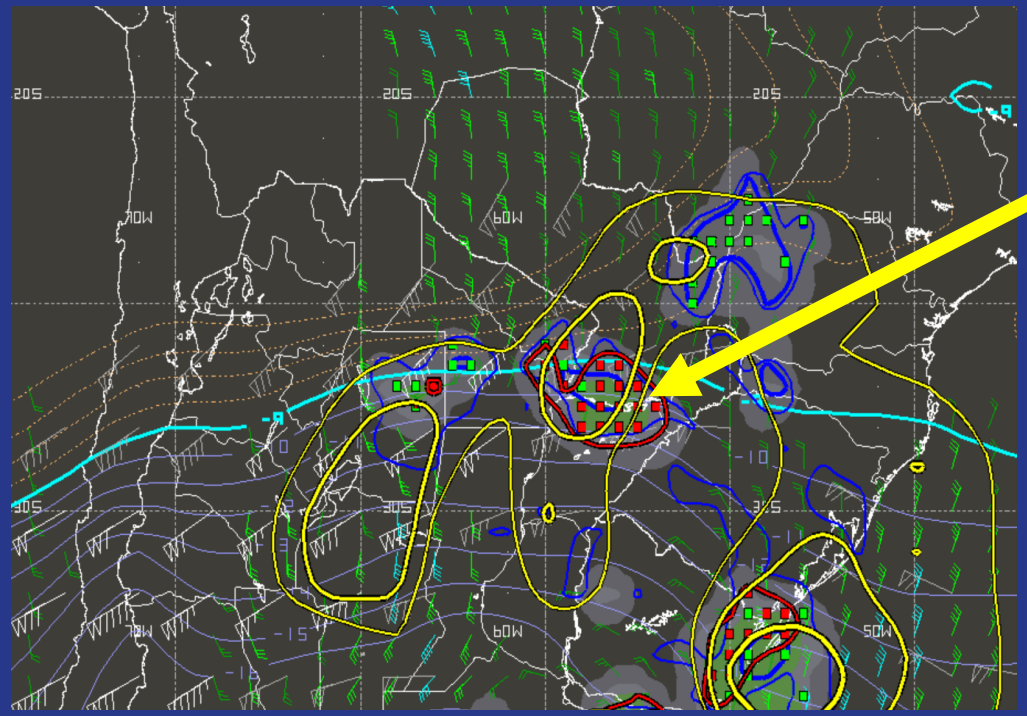
Development of GR02T

- GR02T stands for “Granizo Version 02-Trial” or “Hail Version 02-Trial”.
- It was developed in 2015 by Néstor Santayana (INUMET)* and José Manuel Gálvez (NOAA), to support the forecasting of hail in the Rio de la Platra and Paraná River Basins.
- An initial version of the algorithm, GR01, was released experimentally in 2015. This version was very simple, and based on thresholds of a few variables present during hail events in Uruguay.
- The algorithm evolved into a more complex version in 2019, GR02T.

*INUMET: Uruguay Weather Service

Tool GR02T: Hail and Severe Convection Environments

We will explore the interpretation of GR02T using the severe weather event that happened in southeast Paraguay last Saturday night into early Sunday.

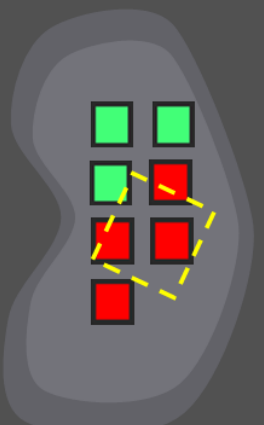


Courtesy of Angel Arguello, Paraguay.

How to interpret GR02T

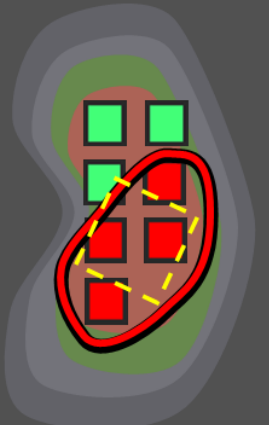
Risk for Hail

- Boxes over shaded areas.
- Risk increases when boxes become red or magenta, and appear inside red or magenta contours.

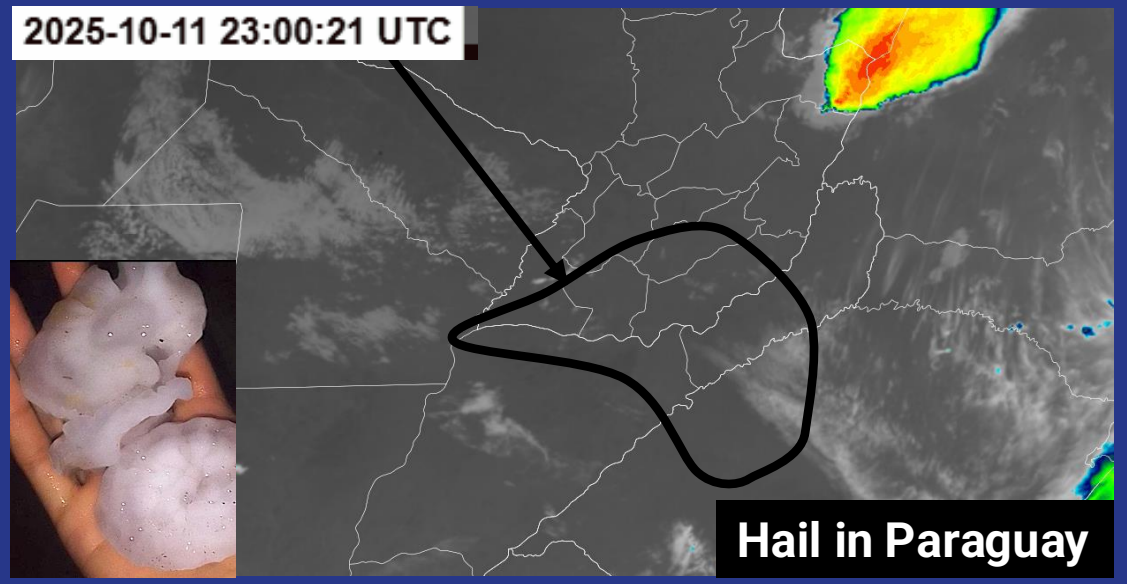


Case A: Very isolated hail if a cell forms, but chances are very low

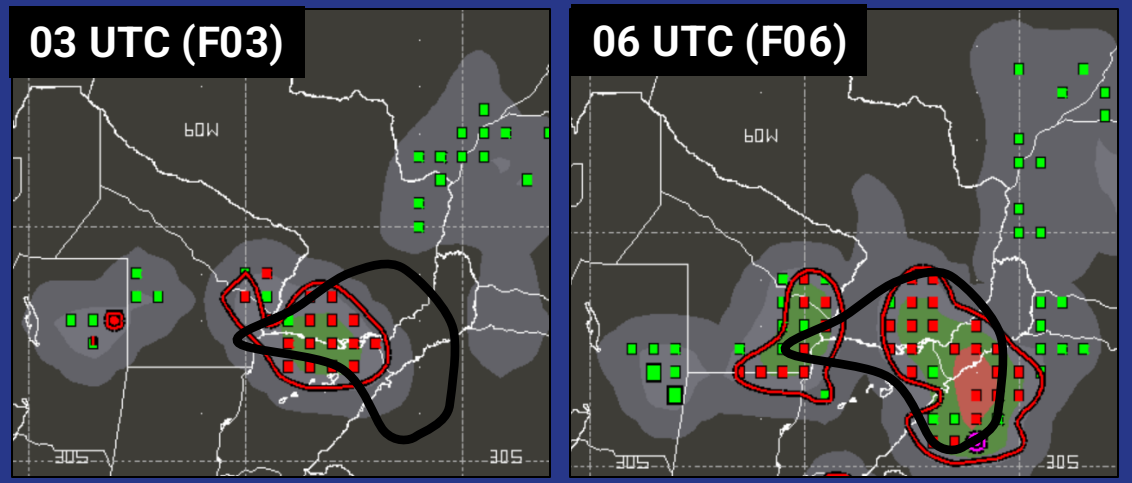
Case B: Isolated hail in cells that form. Chances are low, but higher than in case A.



Case C: Moderate chance for hail, as red contours, red boxes and red shading overlap.



10.3um Channel GOES-19 (CIRA)

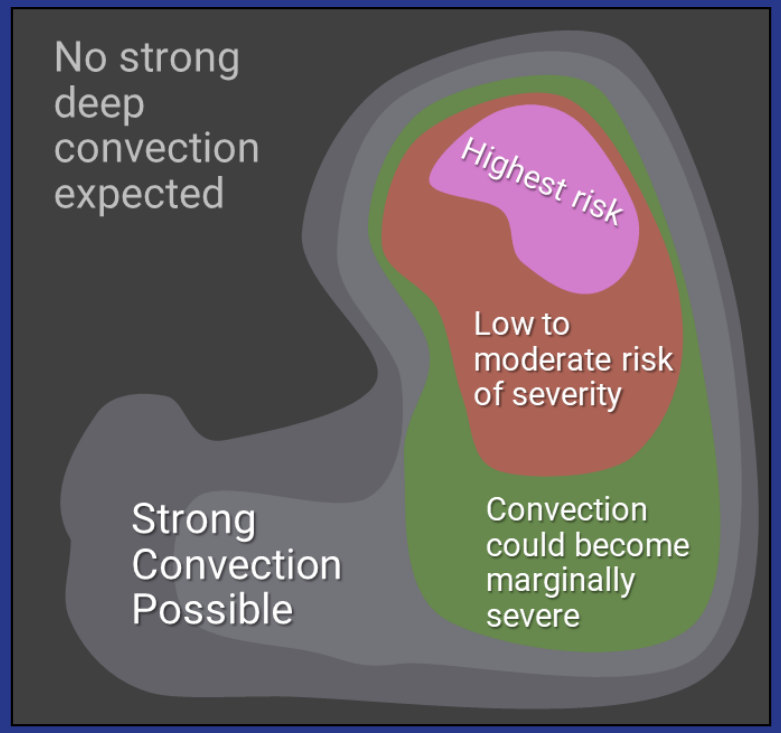


GFS 0.5-degree 00Z Run, 12-Oct-2025 (NOAA)

But what are the shaded areas?

They represent a general risk of severity.

- They are calculated using 7 parameters associated with severity.
- Their goal is to provide a general background of how favorable the environment is to host severe convection.
- They do not speak about a specific risk, but rather a general risk that combines the influence of the seven factors. More information on this later!



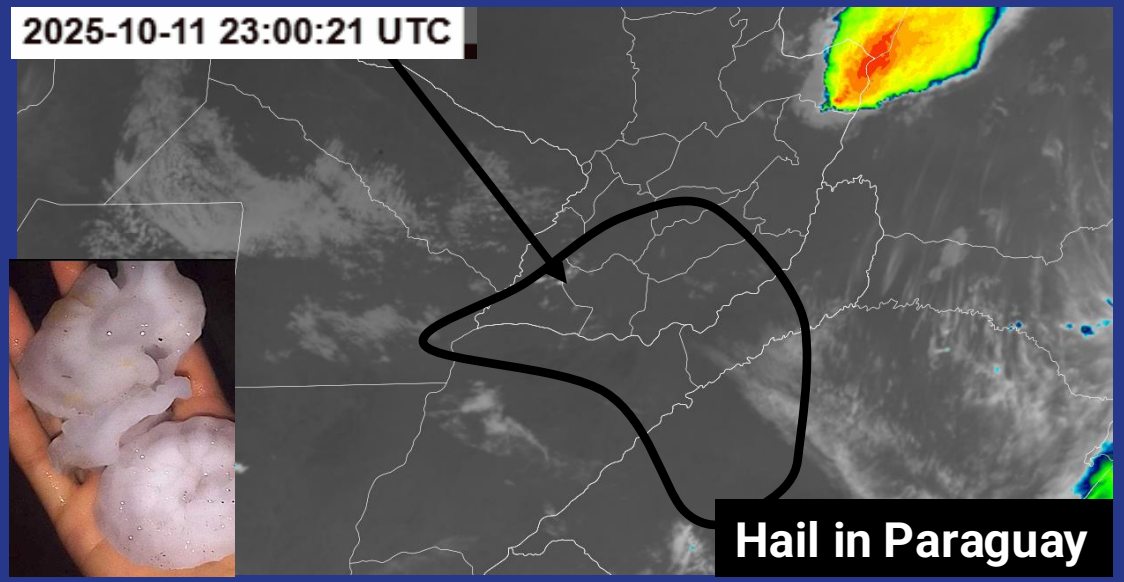
Categories for a General Risk for Severity

Strong Convection	Marginal to Low Risk	Low to Moderate Risk	Moderate to Elevated Risk

Therefore, overlapping the risk of hail over the general risk for severity builds forecast confidence!

Red boxes inside a red contour indicate a chance for hail. Since they appear over a region with a marginal risk for severity (green), the chance for hail increases.

Since the risk for severity is higher here, the confidence on a hail forecast increases, and it could arrive accompanied by other severity threats.



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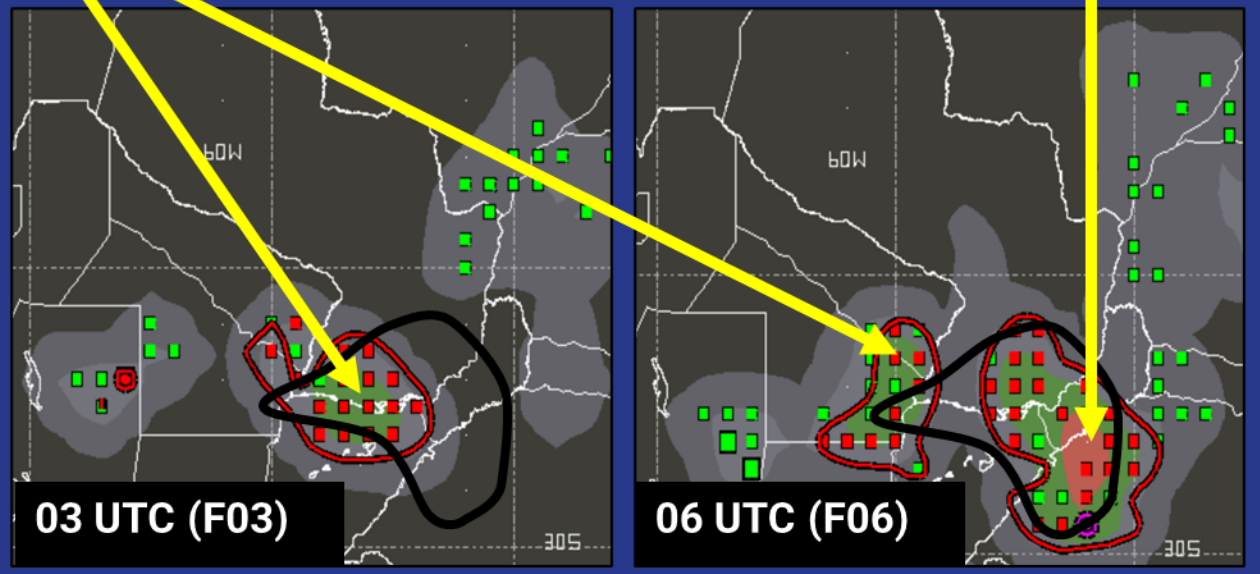


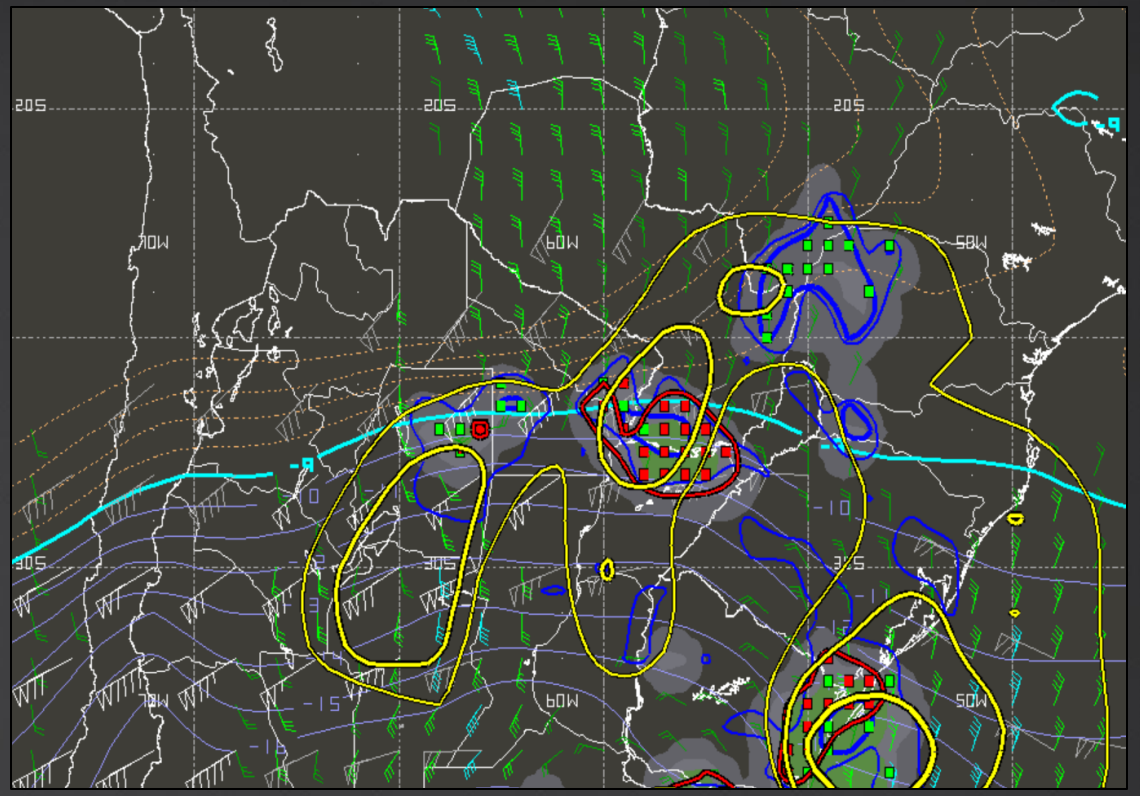
GFS 0.5-degree 00Z Run, 12-Oct-2025 (NOAA)

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

What are the other fields included in GR02T?



Strong Convection	Marginal Risk for Severity	Low to Moderate Risk for Severity	Moderate to Elevated Risk for Severity

925-850 hPa Winds [kt]

250-200 hPa Winds [kt]

300-200 hPa Divergence

500 hPa Temperatures [°C]

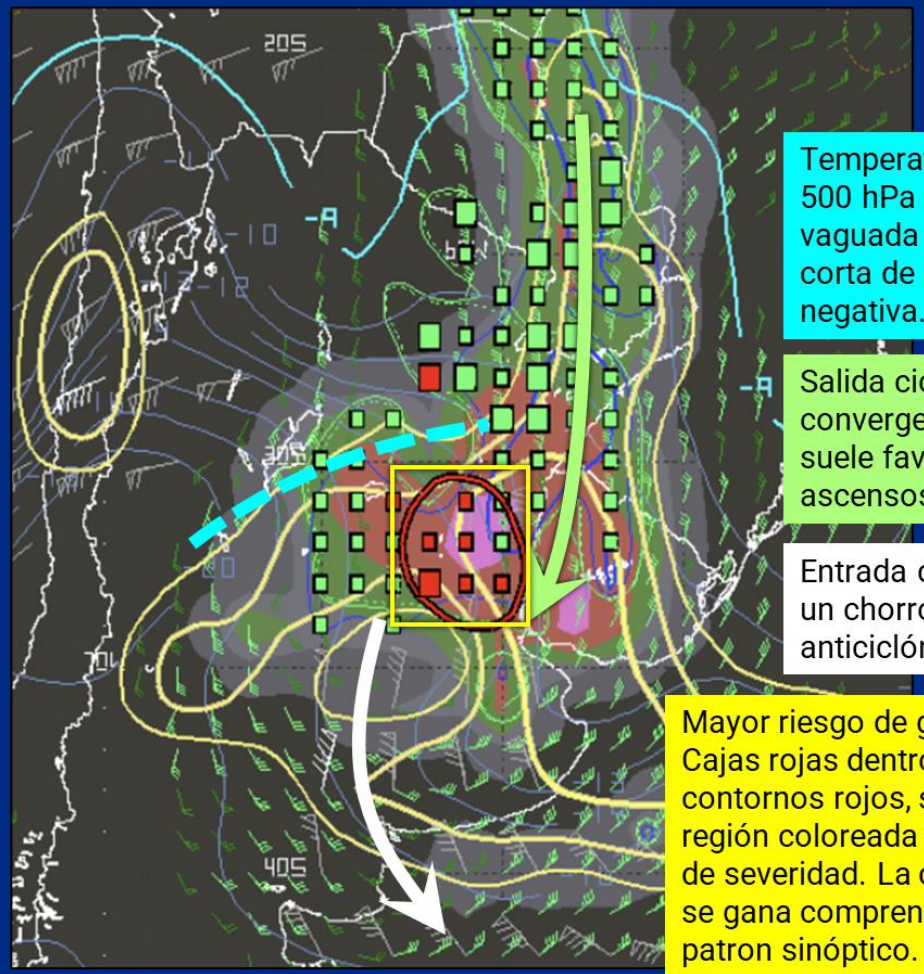
Mixing ratio$_{500}$ >2 g/kg

Enhanced mixing ratio flux convergence in the 950-700 hPa layer.

Hail Risk

- Elevated (LI<-6, Very Strong Ascent, dT$_{700\text{-}500}$>16C)
- Moderate (LI<-3, Strong Ascent, dT$_{700\text{-}500}$>16C)
- Marginal (LI<0, Moderate Ascent, dT$_{700\text{-}500}$>16C)

Interpretation of GR02T



Temperaturas de 500 hPa sugieren vaguada de onda corta de inclinación negativa.

Salida ciclónica y convergente del LLJ suele favorecer ascensos.

Entrada cálida de un chorro con giro anticiclónico.

Mayor riesgo de granizo: Cajas rojas dentro de contornos rojos, sobre una región coloreada con riesgo de severidad. La confianza se gana comprendiendo el patron sinóptico.

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Understanding the synoptic pattern is essential to improve the confidence in a hail forecast produced by GR02T.

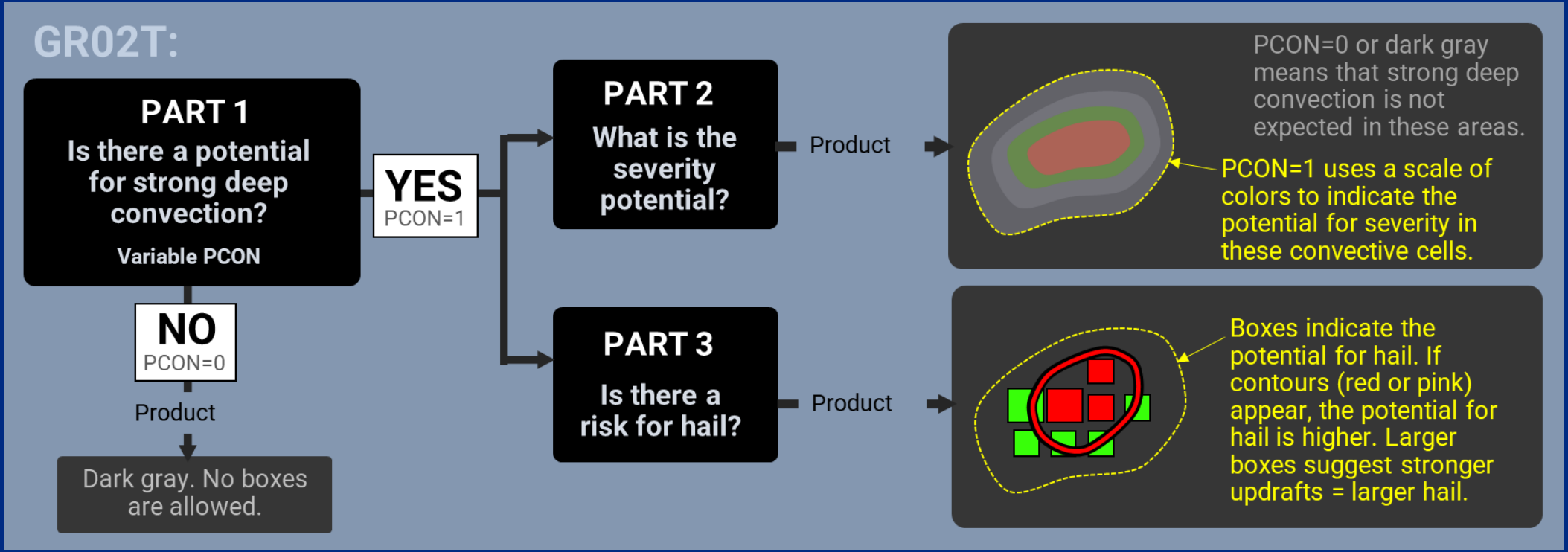
This is why key fields are included in the graphical output: Low-level winds, to understand the influence of low-level jets; upper winds for upper jets; 500 hPa temperatures for systems in the mid-levels; high mixing ratio values in the mid-troposphere, etc.

How does GR02T compute its fields?

GR02T: Calculations

The algorithm has three steps:

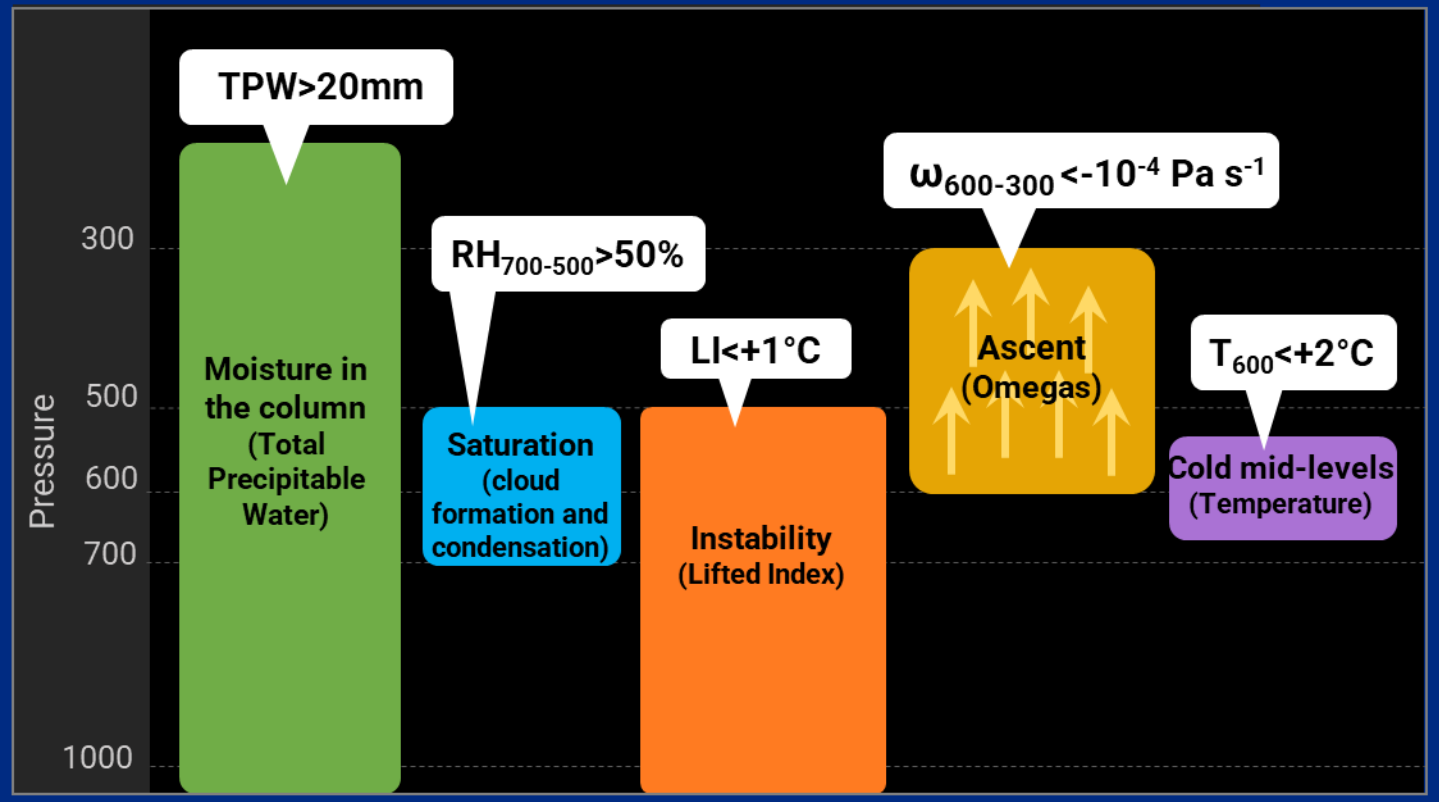
- Part 1: Definition of where strong deep convection might develop
- Part 2: Definition of the severity potential of that deep convection
- Part 3.: Definition of the potential for hail



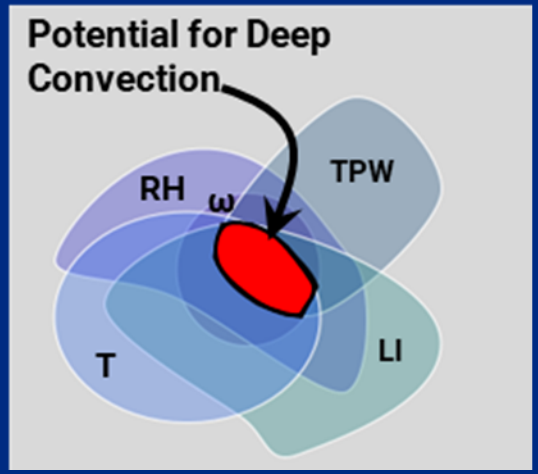
GR02T PART 1

Assessing if there is a potential for strong deep convection

1) Five parameters are evaluated:

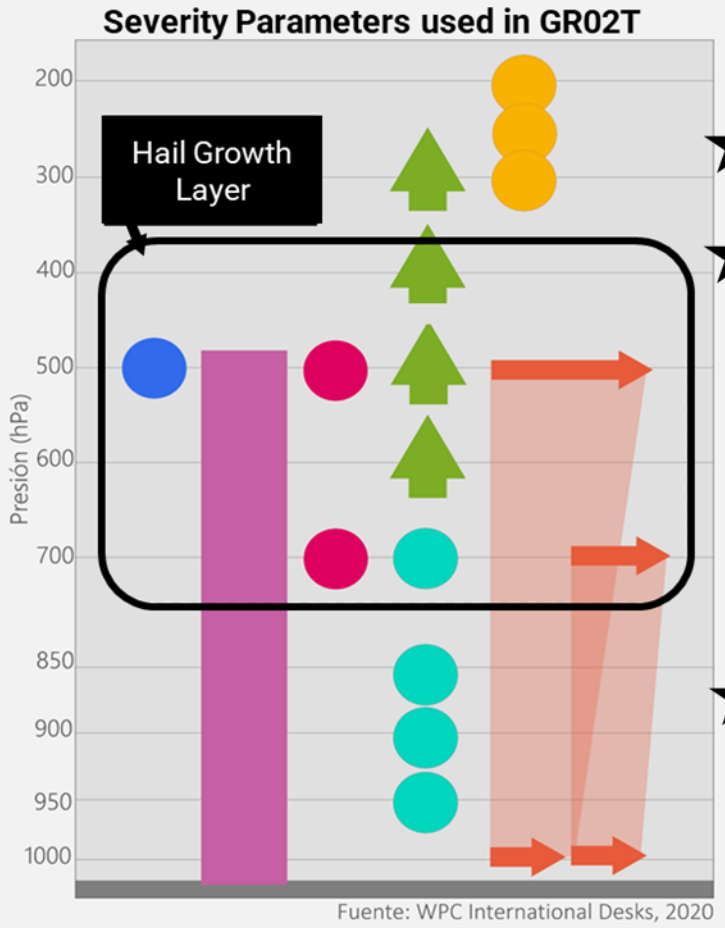


2) If all the 5 parameters exceed the established thresholds inside a gridpoint, it is marked as a point where strong deep convection is possible.



GR02T PART 2

Assessing the potential for severity in areas of strong deep convection



1. T_{500}<-7°C — Cold air in the mid-troposphere
2. ★ LI < +1°C — Instability between the surface and 500 hPa
3. ★ $dT_{700-500}$ > 15°C — Extreme instability in the mid-troposphere, associated with quasi-adiabatic thermodynamic profiles)
4. $\omega_{600-300} < 0$ Pa s^{-1} — Dynamic ascent (vertical velocity in pascals)
5. $CFMX_{950-700} > 3\ 10^{-8}$ kg m^{-2} s^{-1} — Convergence of the flux of mixing ratio (moisture convergence)
6. ★ Bulk Shear $\overline{\text{0-3km 0-6km}}$ > 25 m s^{-1} — Averaged bulk shear in the 0-3km and 0-6km layer
7. $Div_{300-200} > 0\ s^{-1}$ — Upper divergence, which stimulates ascent.

GR02T PART 3

Assessing the potential for hail in areas of strong deep convection

3 Parameters are Evaluated

- Lifted Index (LI)
- 600-300 hPa Omegas
- 500-700 hPa lapse rates

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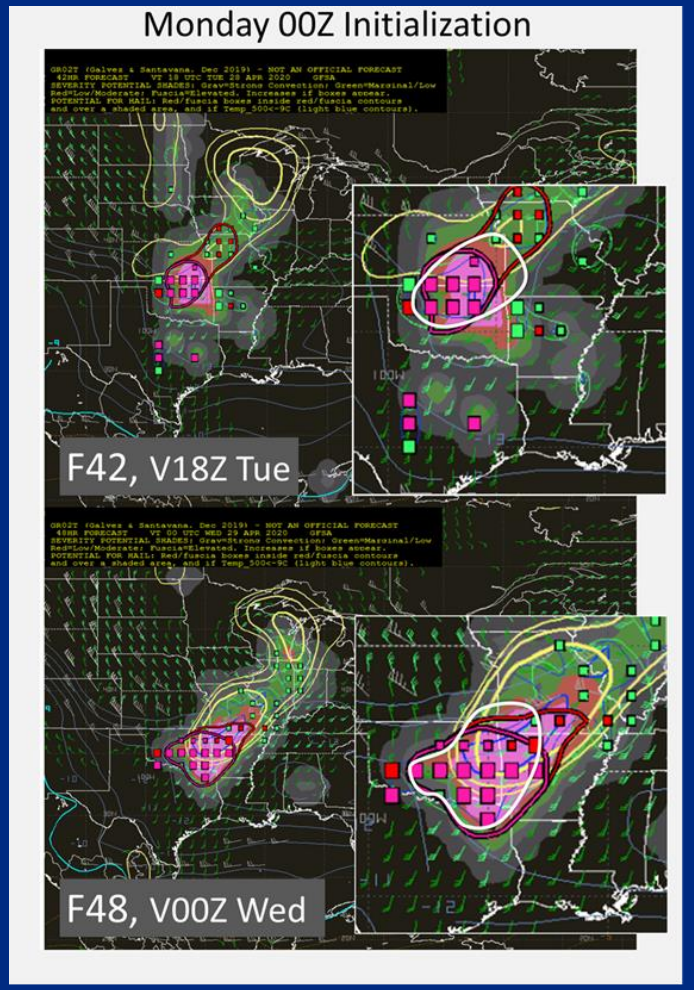
Applications and Verification

GR02T aligns with official Severe Wx Forecasts in the US



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

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300-200 hPa Divergence

-9 500 hPa Temperatures [°C]

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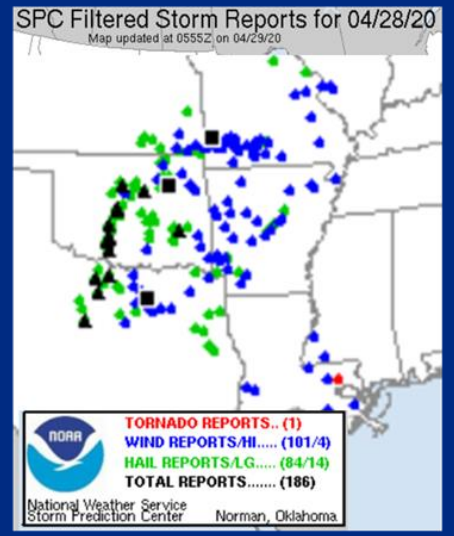


Specific Risk for Hail

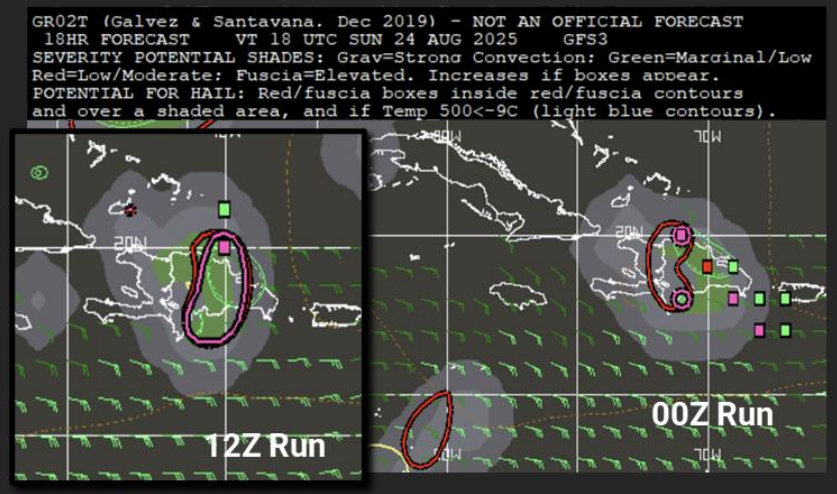
- **Elevated** (boxes inside fuscia contours)
- **Slight to Moderate** (boxes inside red contours)
- **Marginal**, only if forcing is strong. Isolated occurrence.

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.

It aligns well with reports as well!

GR02T works in the northern Caribbean, northern Central America and Mexico

(1) GR02T Output

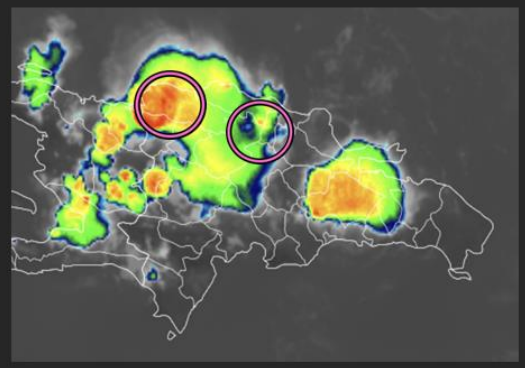


(2) Official Forecast

- Shows a potential in the Dominican Republic.
- Forecasters know that wide terrain and mountains in the island, located at a latitude of nearly 20 degrees, favor the occurrence of hail when this type of signal is present in GR02T.

(3) Verification

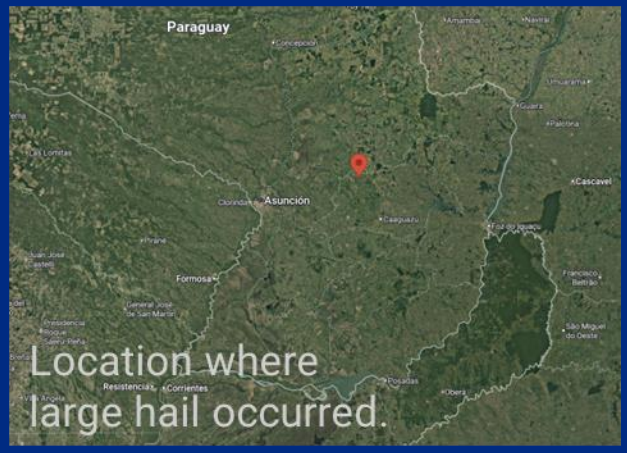
- Reports of hail and damaging winds.

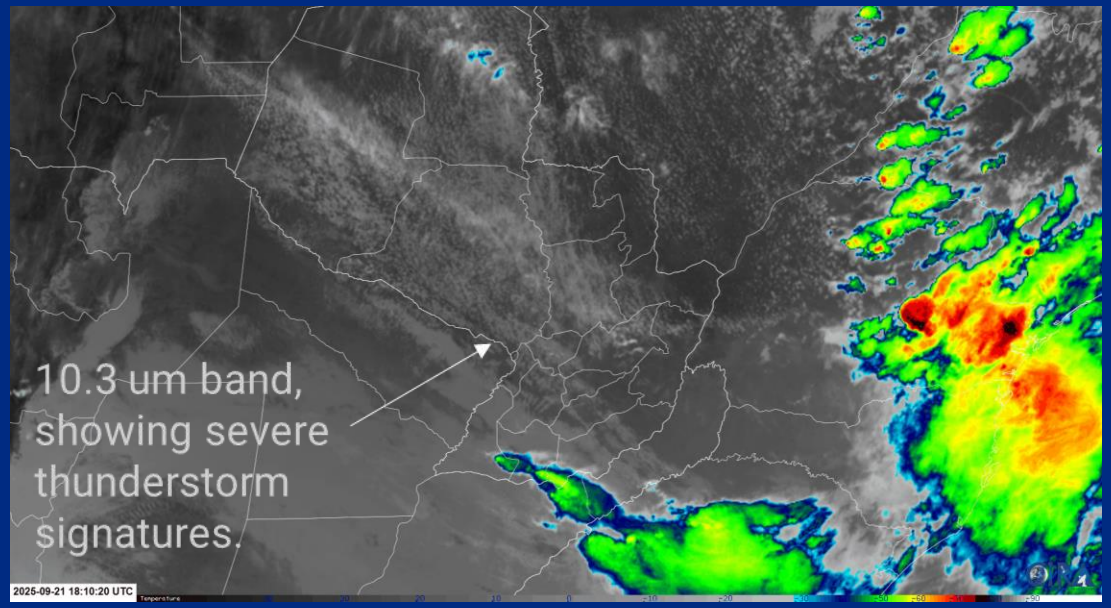


Case of Large Hail in Paraguay: 21 September 2025

- Large hail occurred in Central Paraguay between 19 and 20 UTC.
- Satellite imagery shows V-shapes, typical from severe convection.

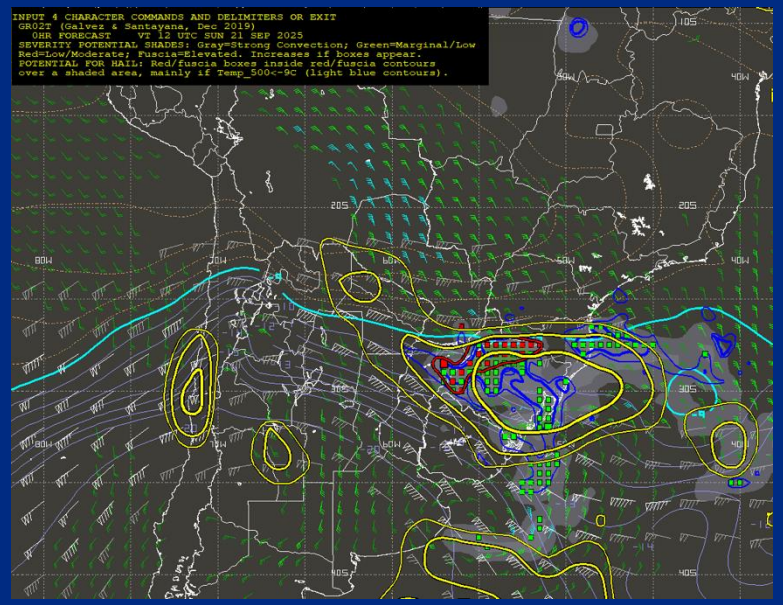
Photos of large hail

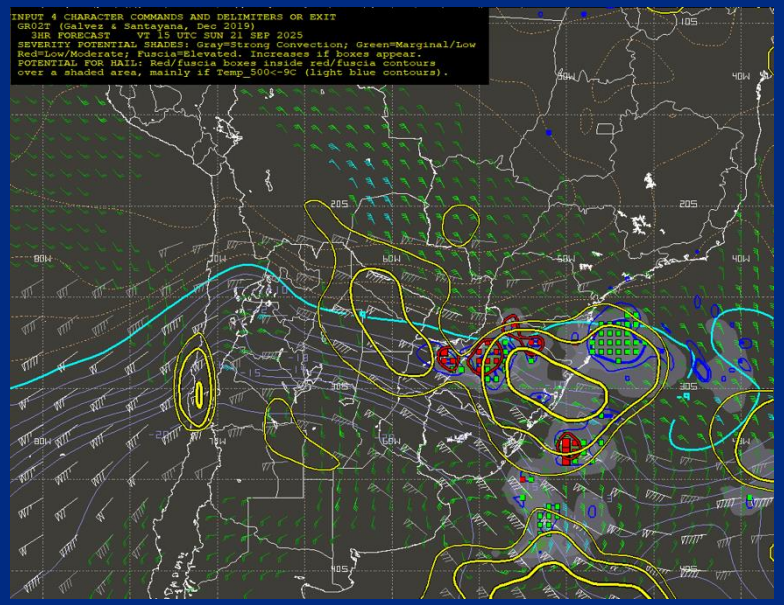


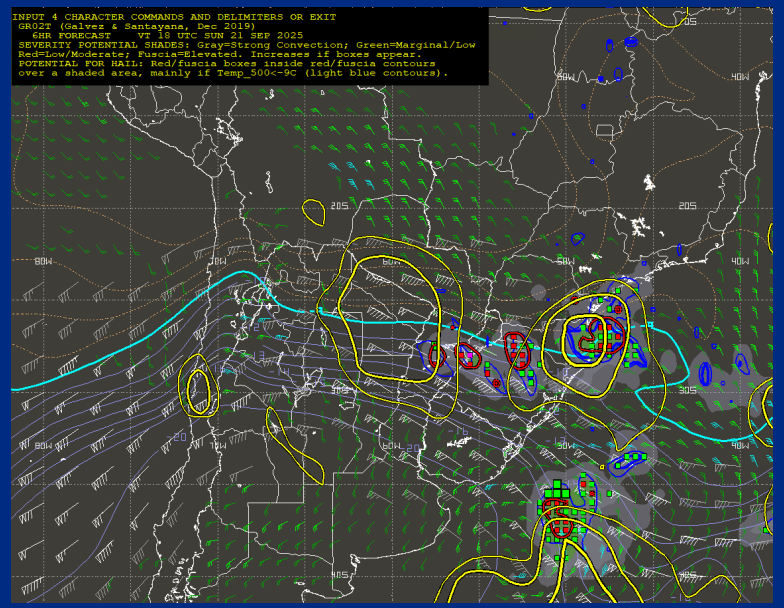


Video showing descending winds in strong thunderstorms in Asunción

GR02T







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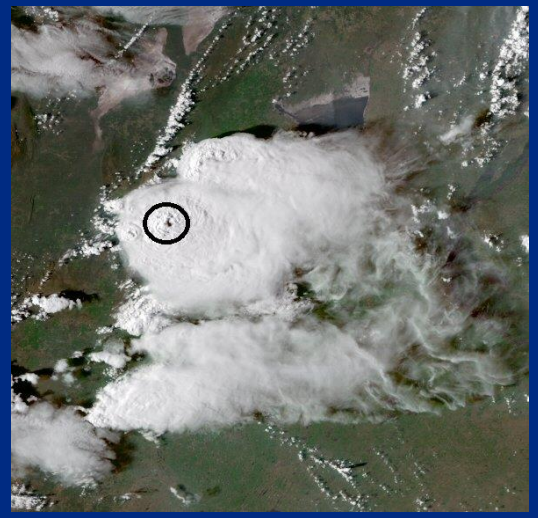
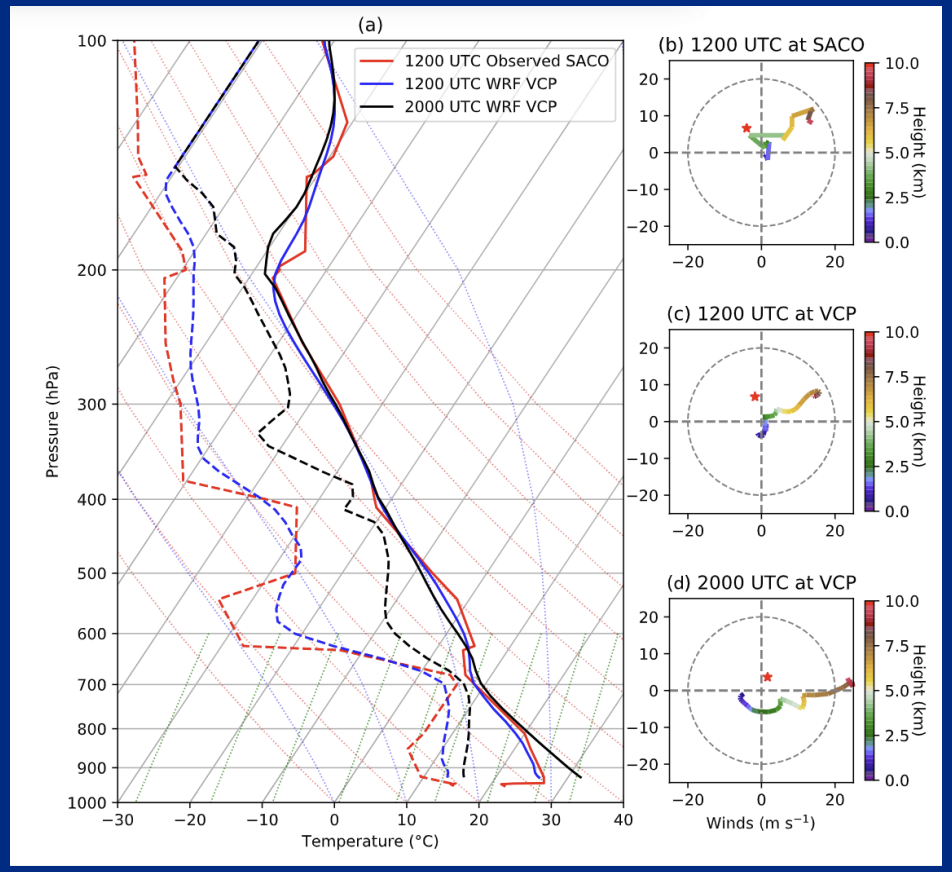
There is always room for improvement !

Villa Carlos Paz Event

- Gargantuan Hail
- Enormous hail occurred in Córdoba, Argentina in 2018. But GR02T was not able to detect the potential.

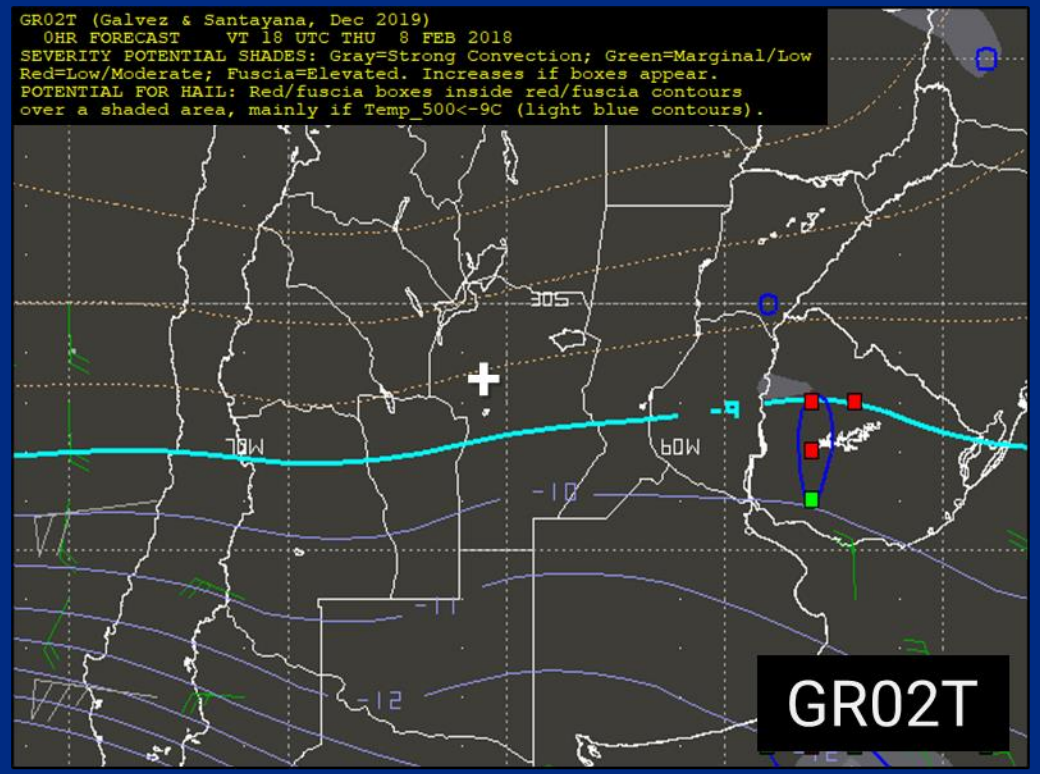


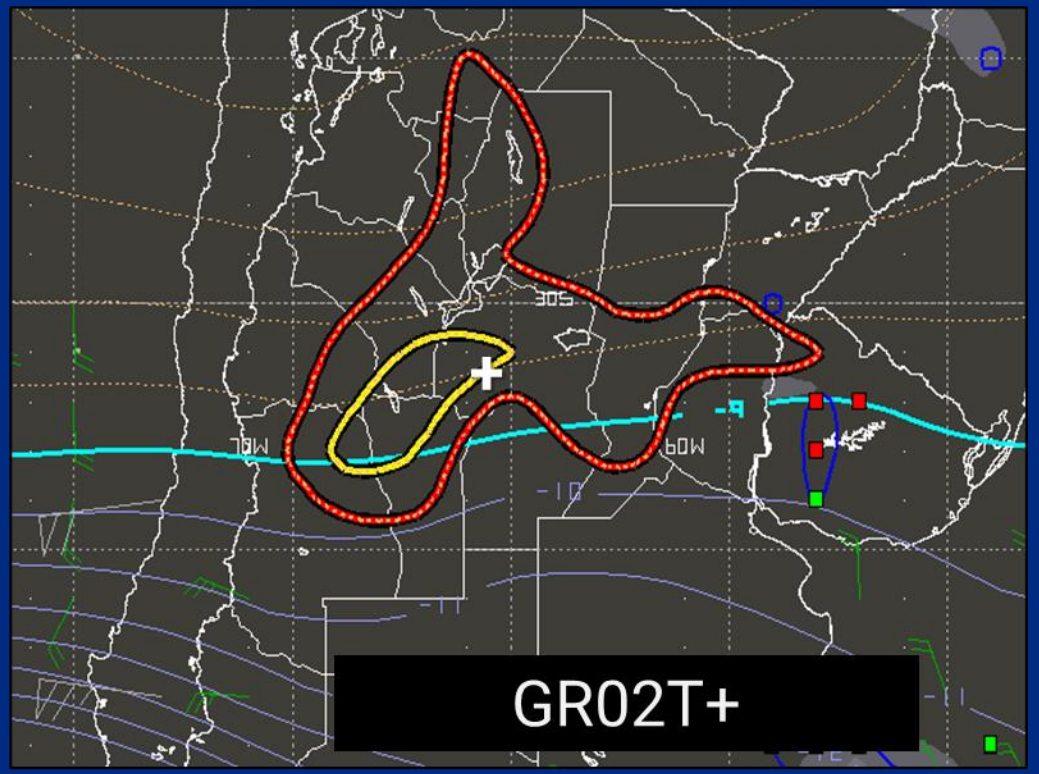


Sources: Kumjian et al. (2020): Gargantuan hail in Argentina

Villa Carlos Paz Event

- GR02T was not able to grasp a signal for hail.
- However, considering other variables, especially wind shear in the 700-500 hPa layer, allowed the detection of a potential for hail.





Thank you!

Questions?