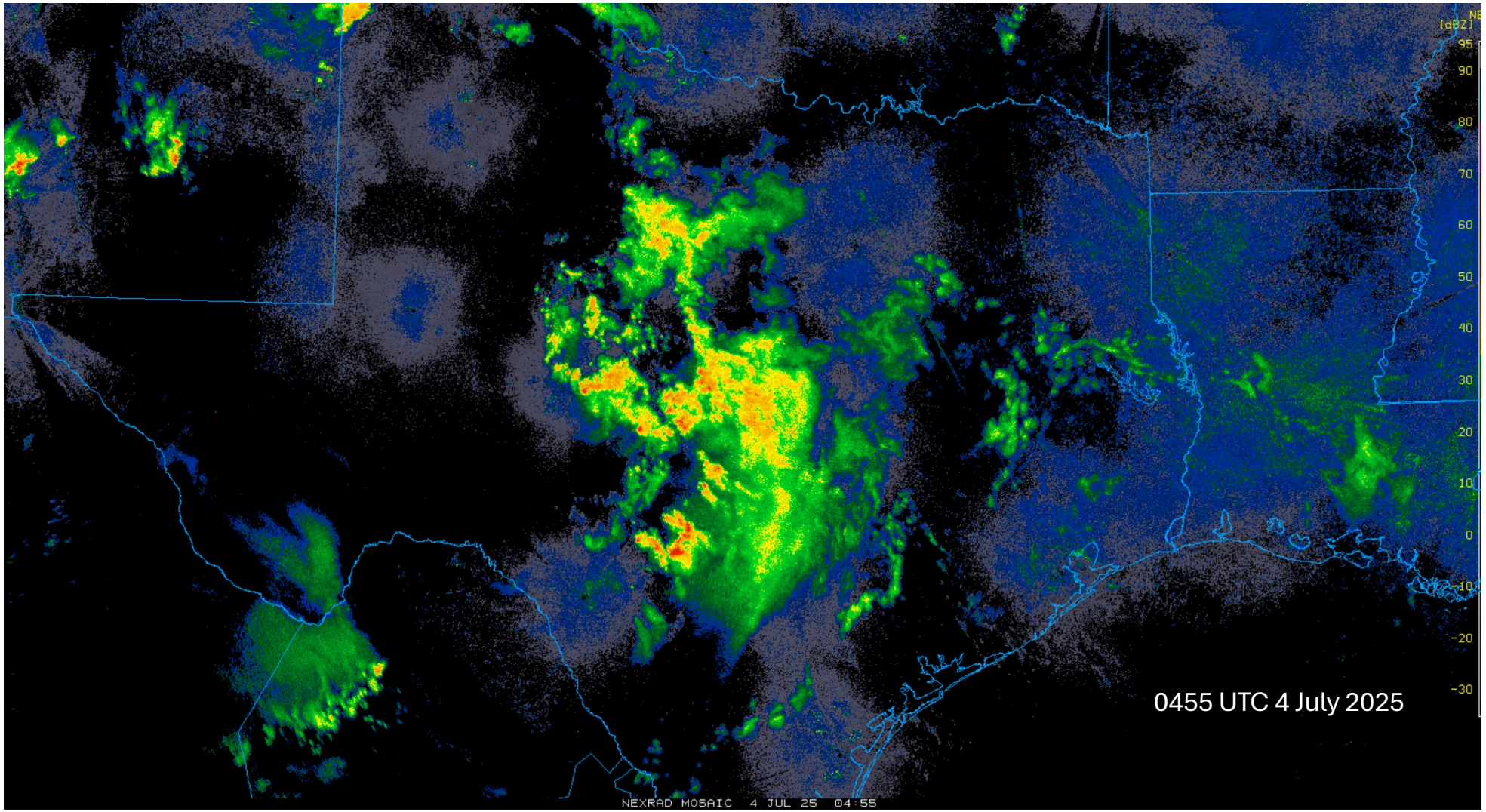
Extreme Rainfall from Warm Season Thunderstorms in ~~Mountainous~~ *Complex* Terrain: Lessons Learned from the Texas Hill Country Flooding of July 2025

John Nielsen-Gammon

Texas A&M University

Texas State Climatologist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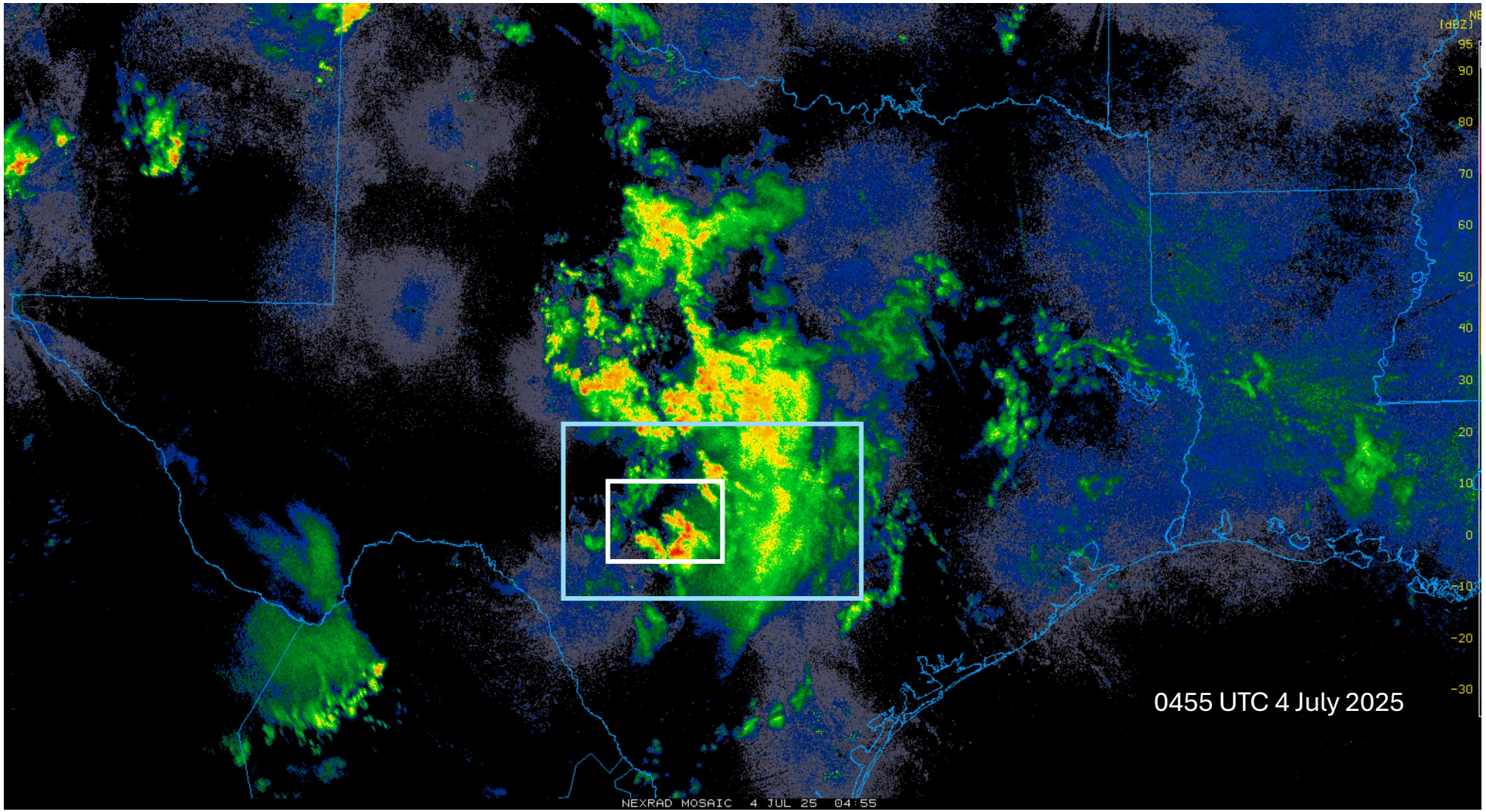
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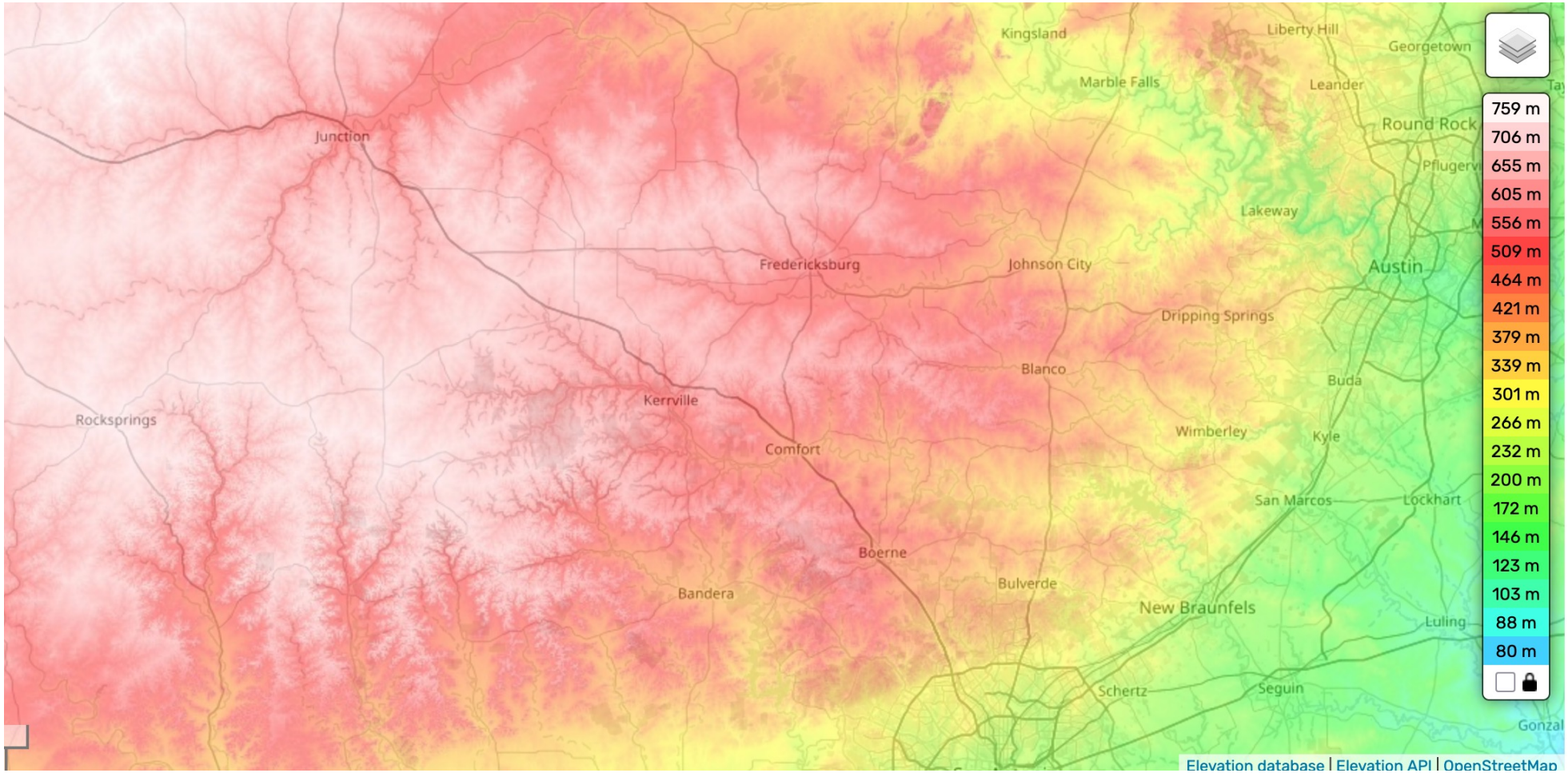
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Leander
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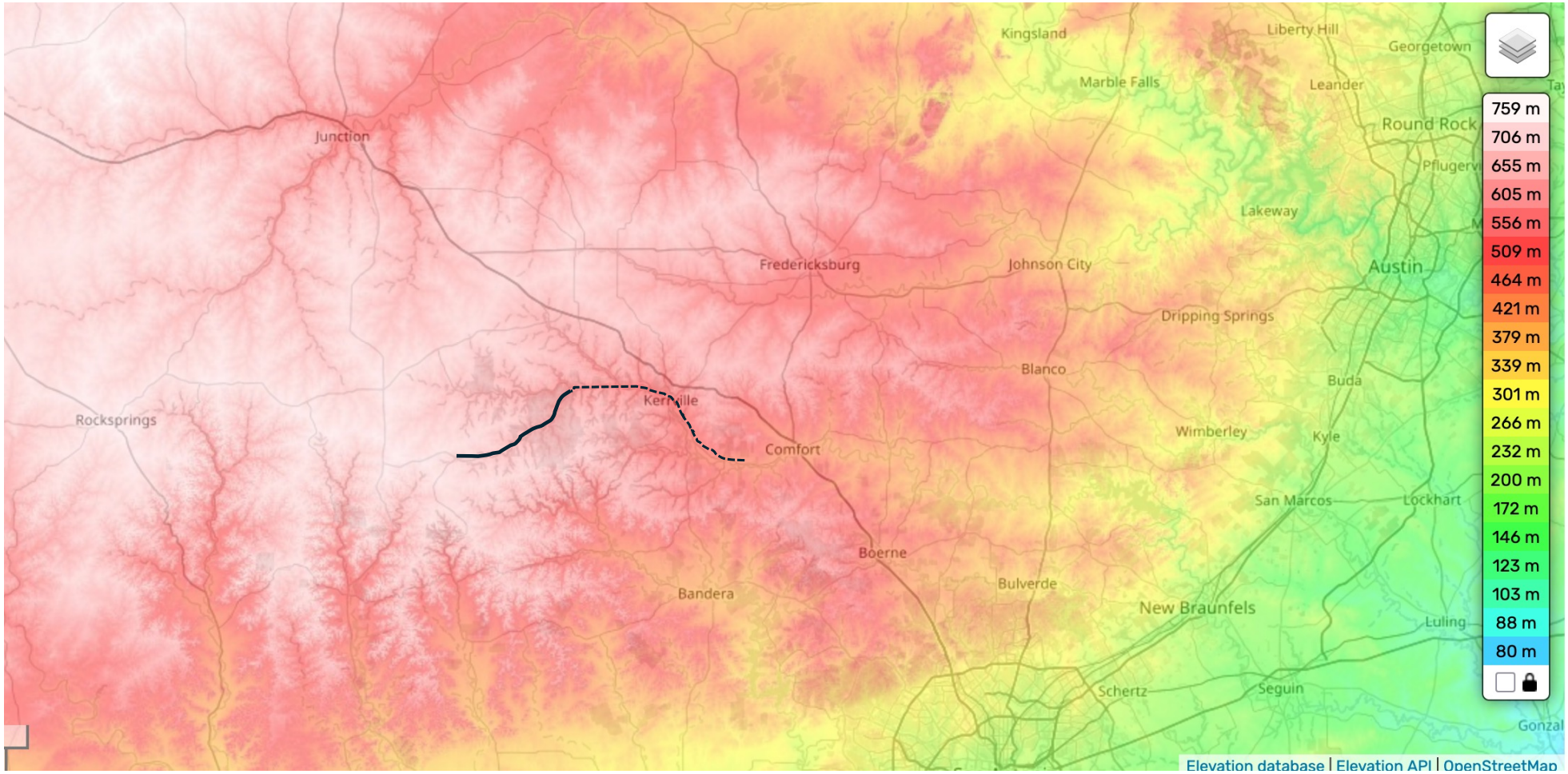
Elevation database | Elevation API | OpenStreetMap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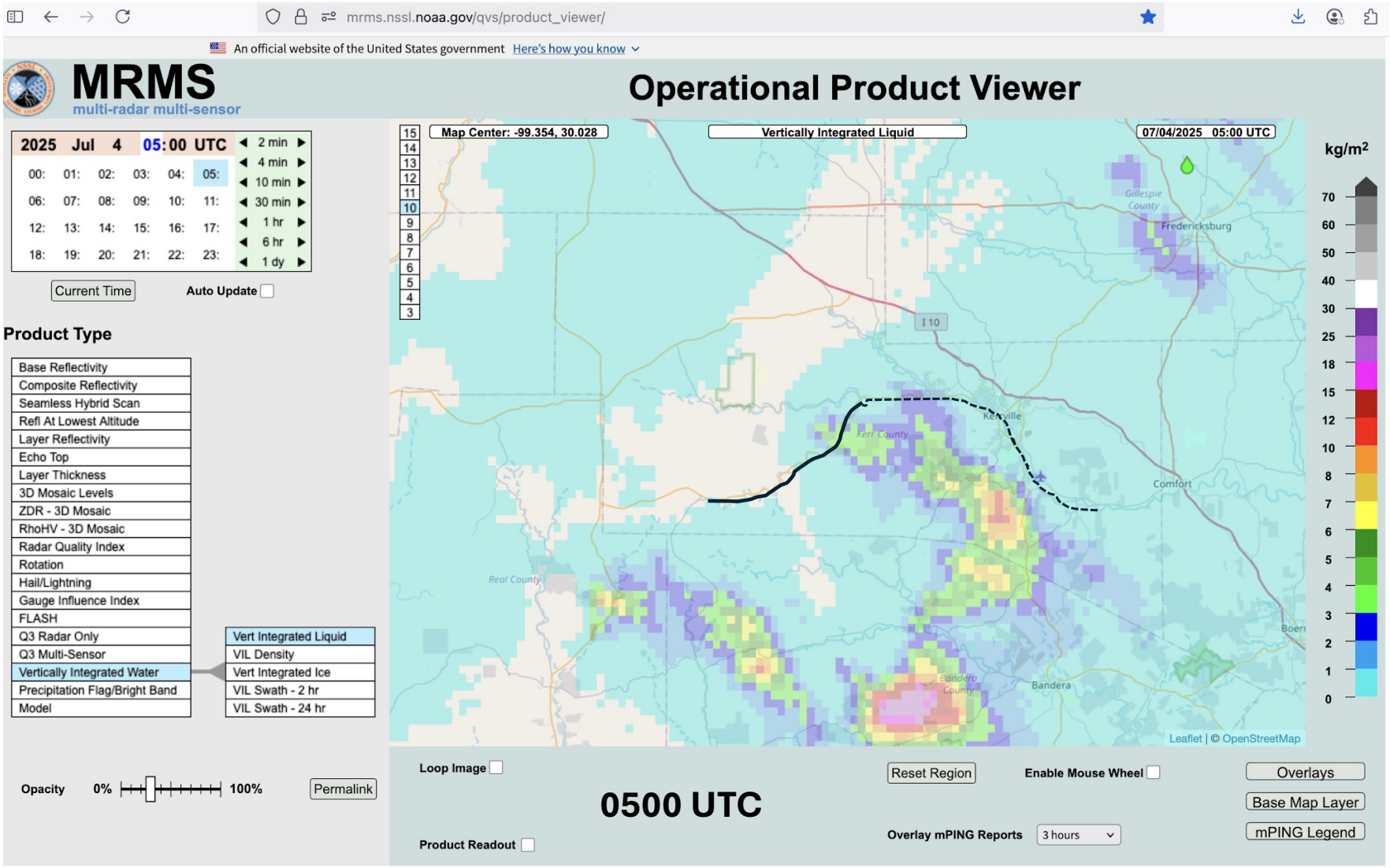
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VIL Density
Vert Integrated Ice
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VIL Swath - 24 hr
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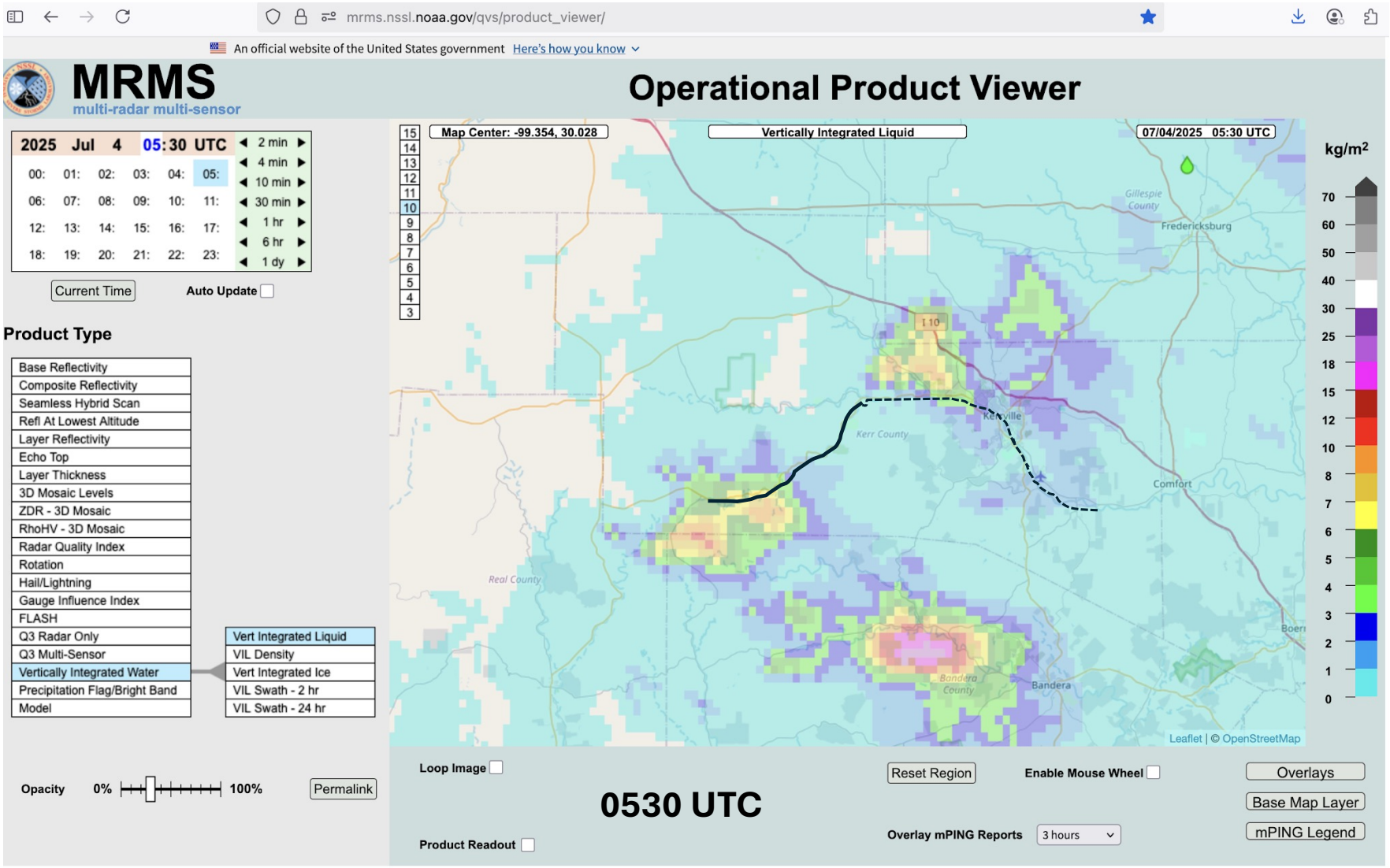
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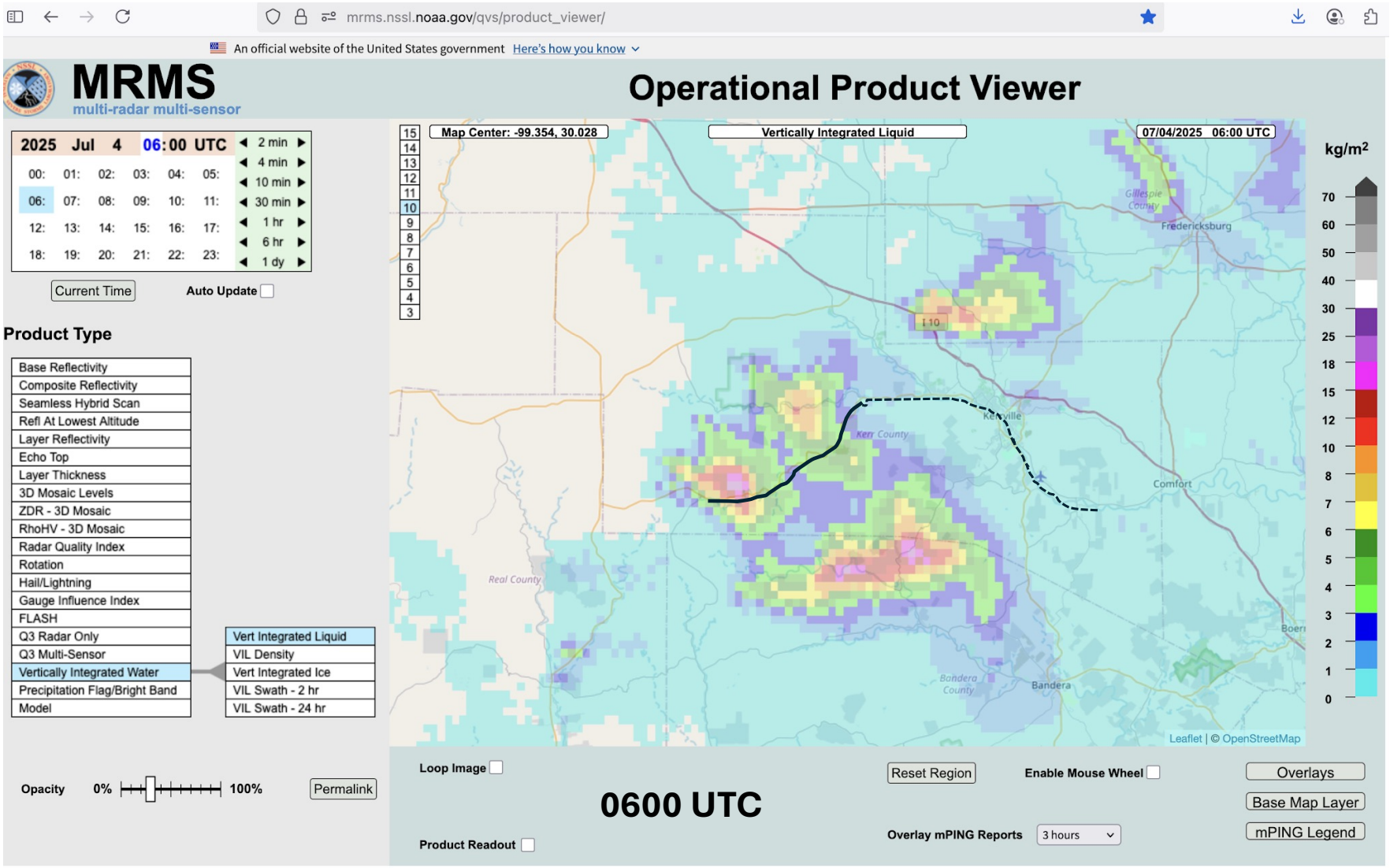
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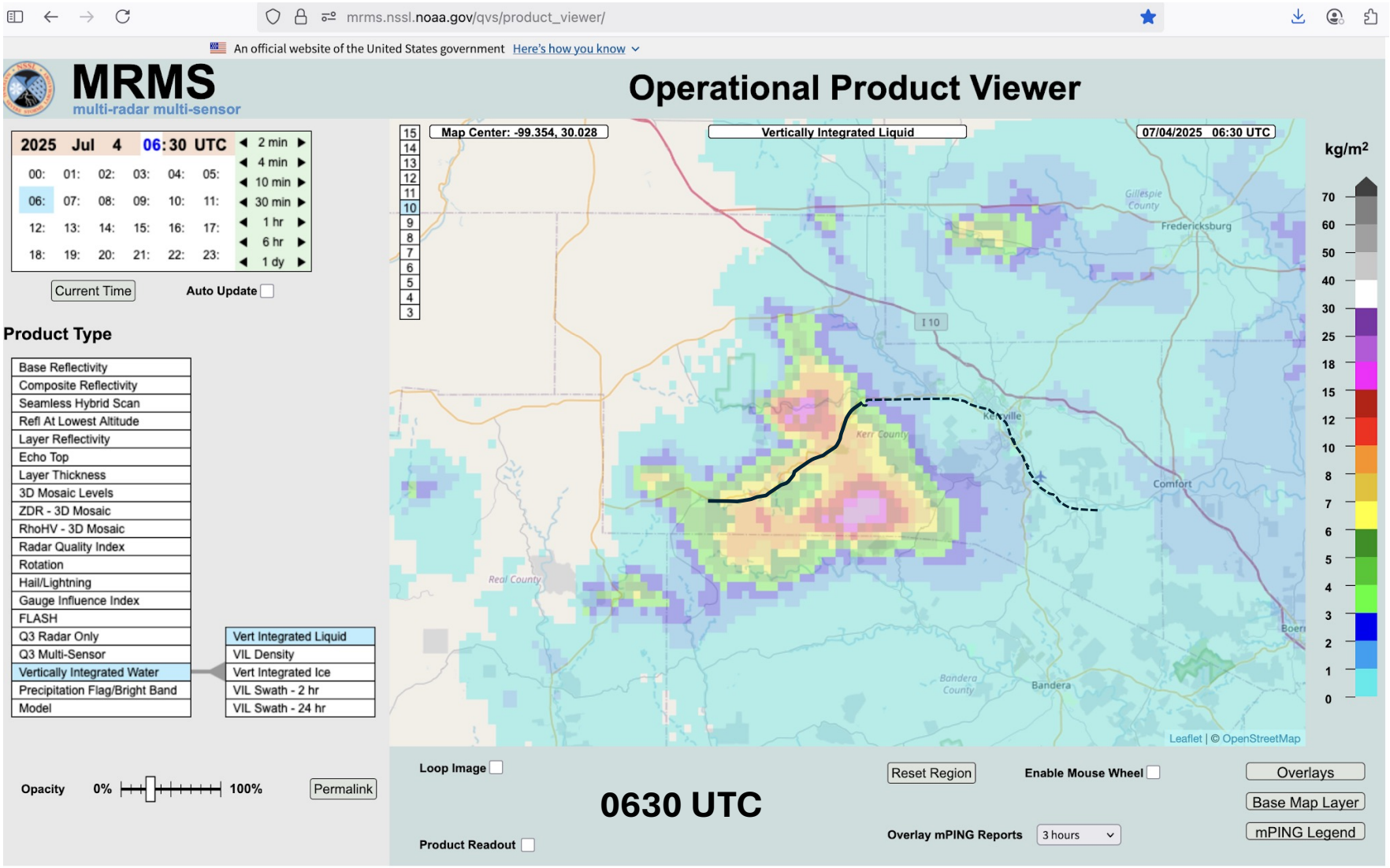
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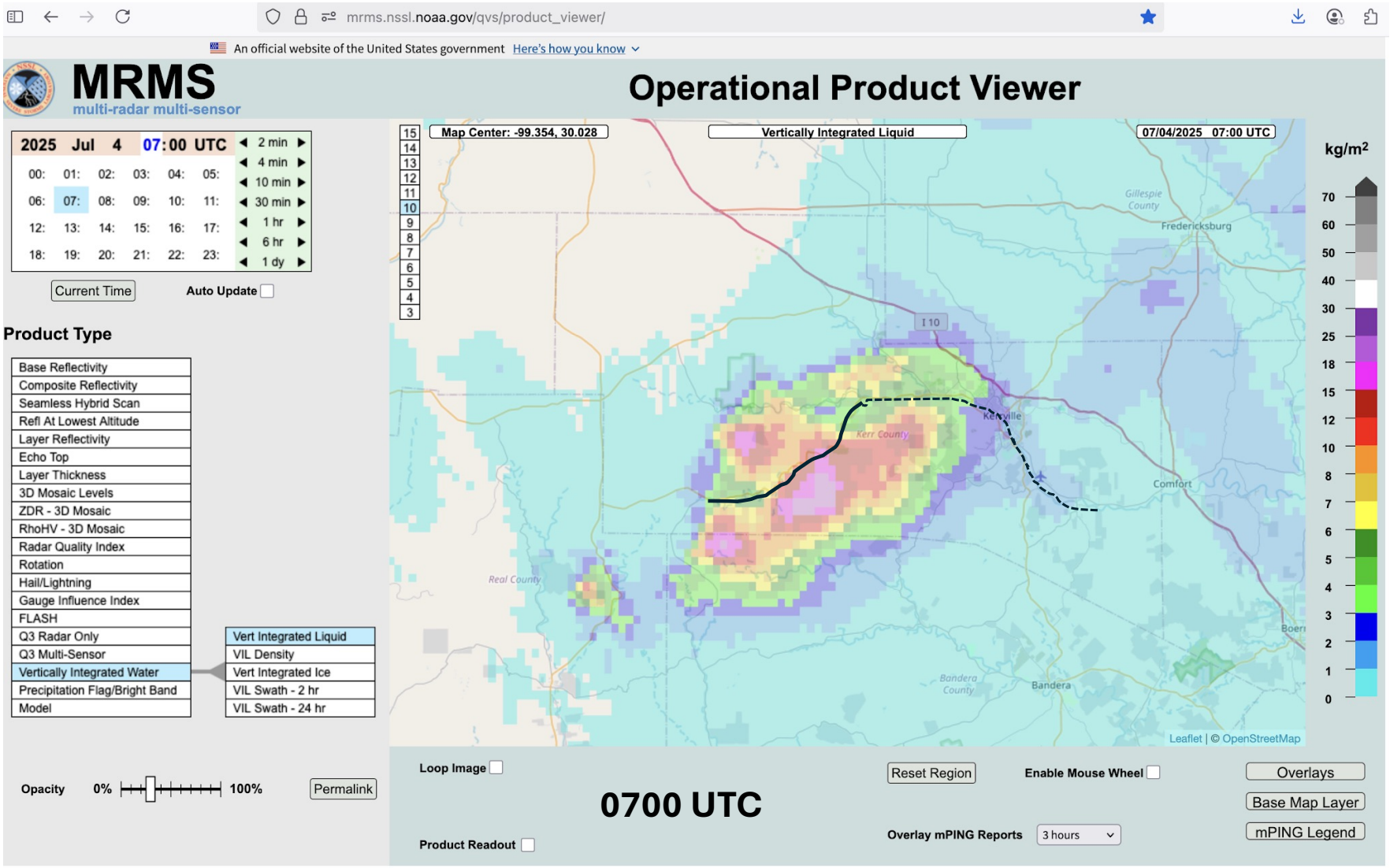
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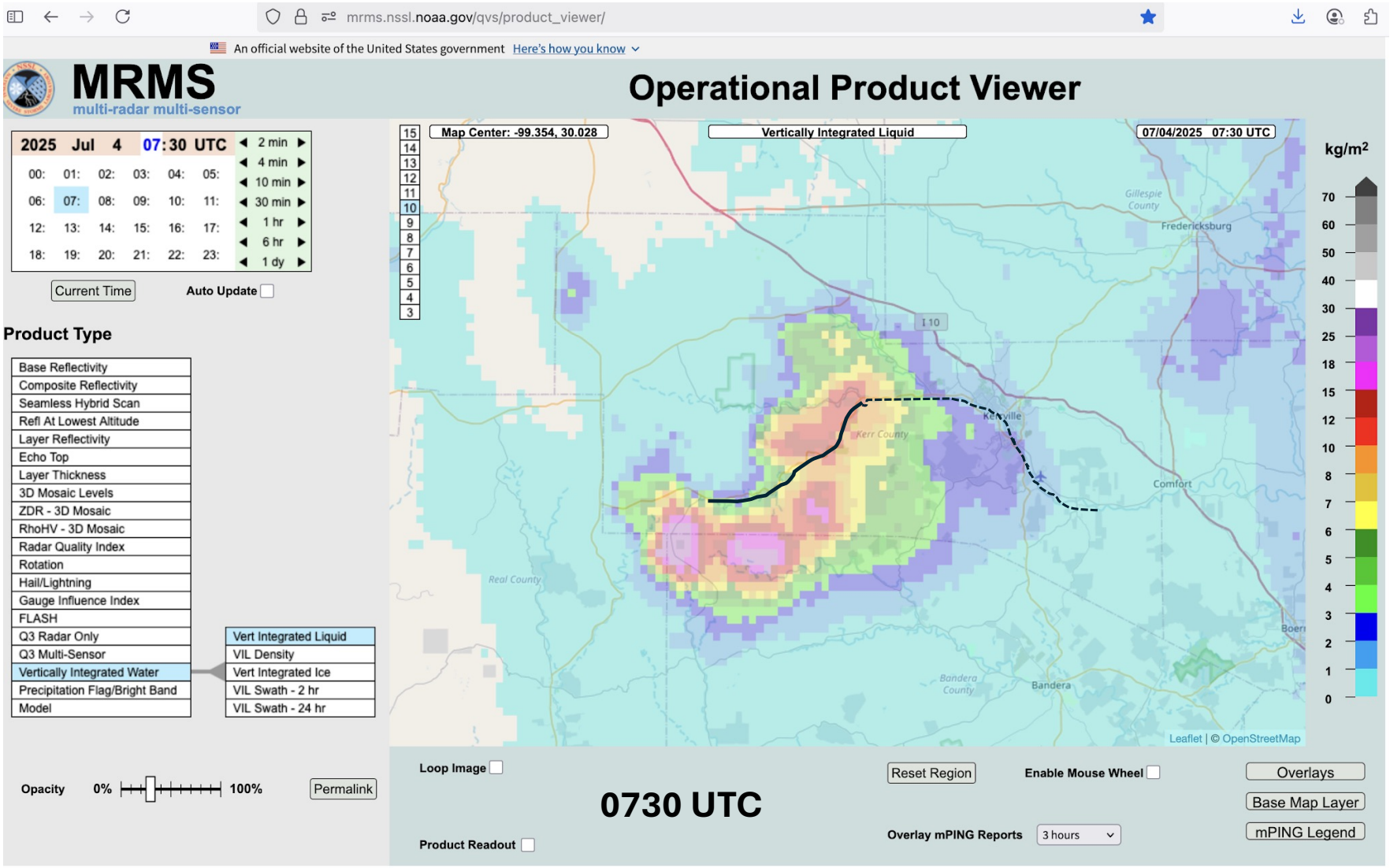
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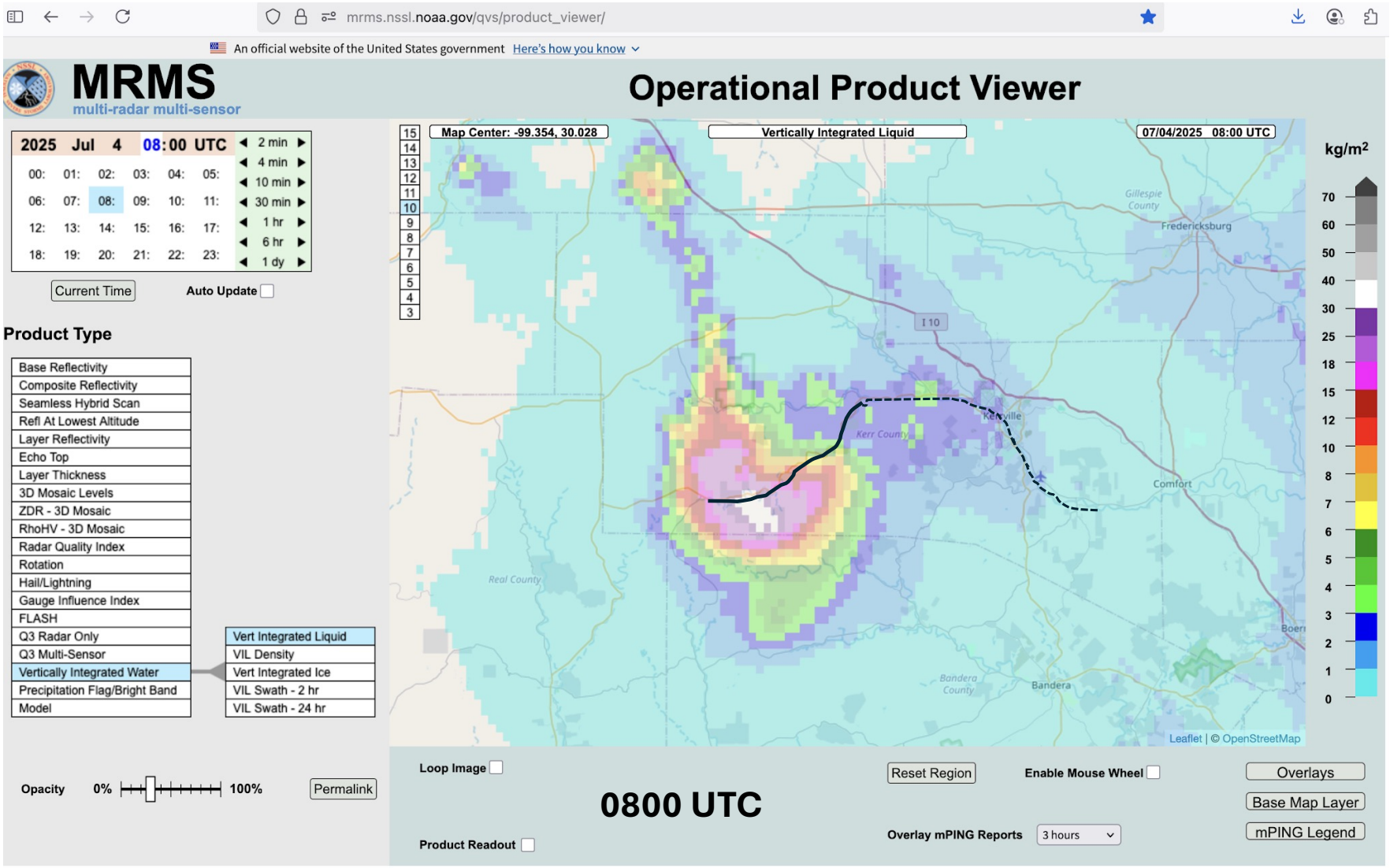
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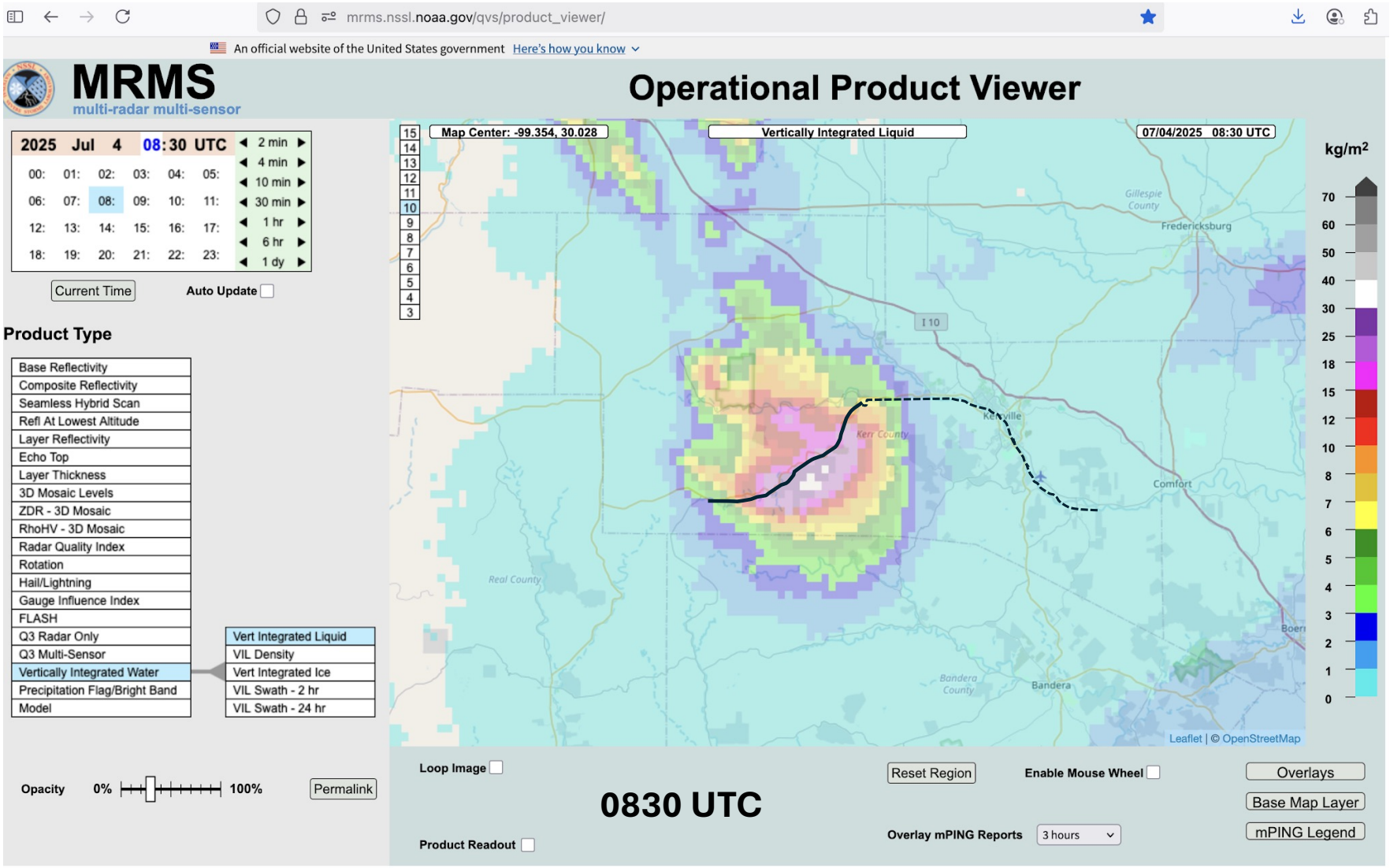
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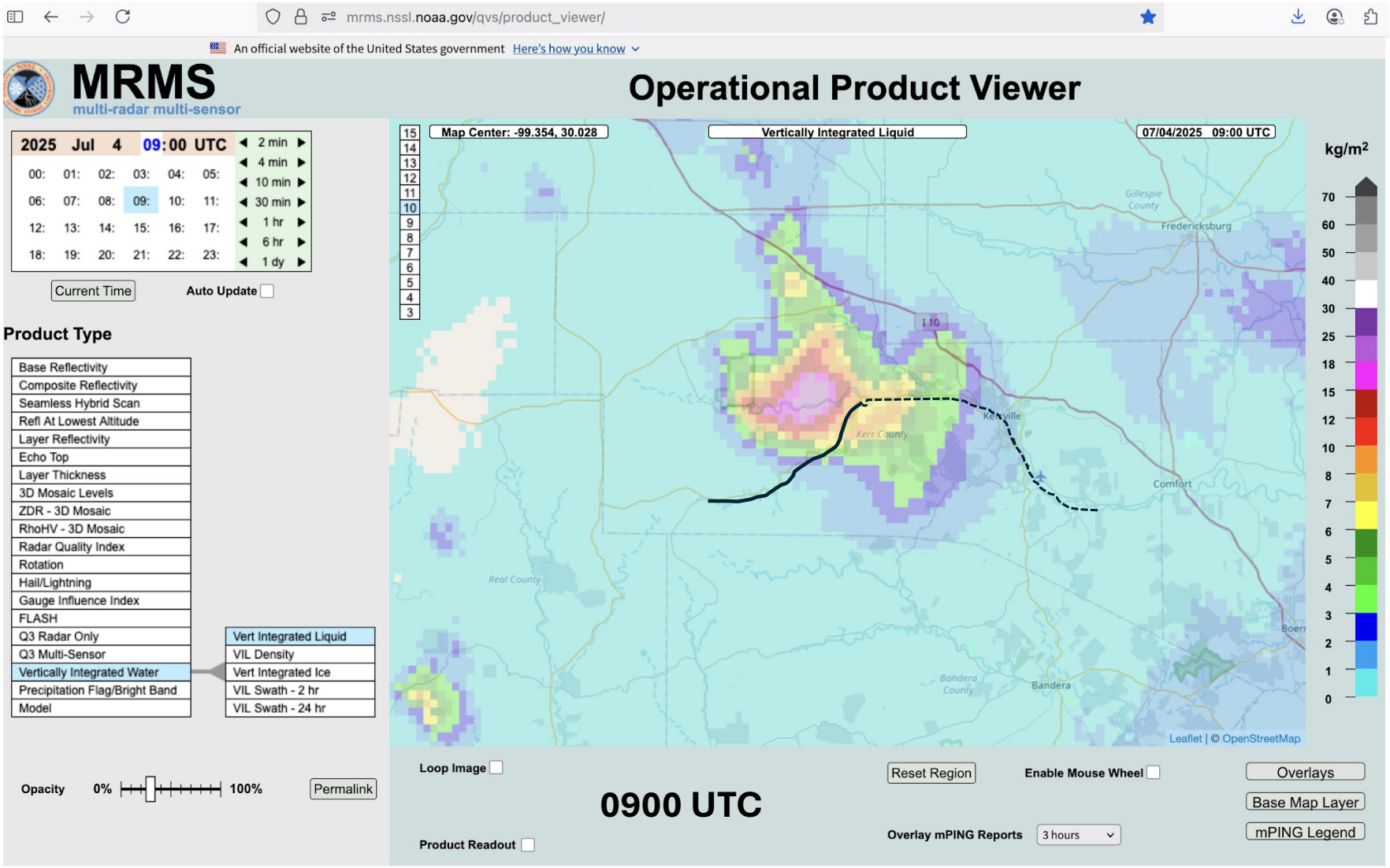
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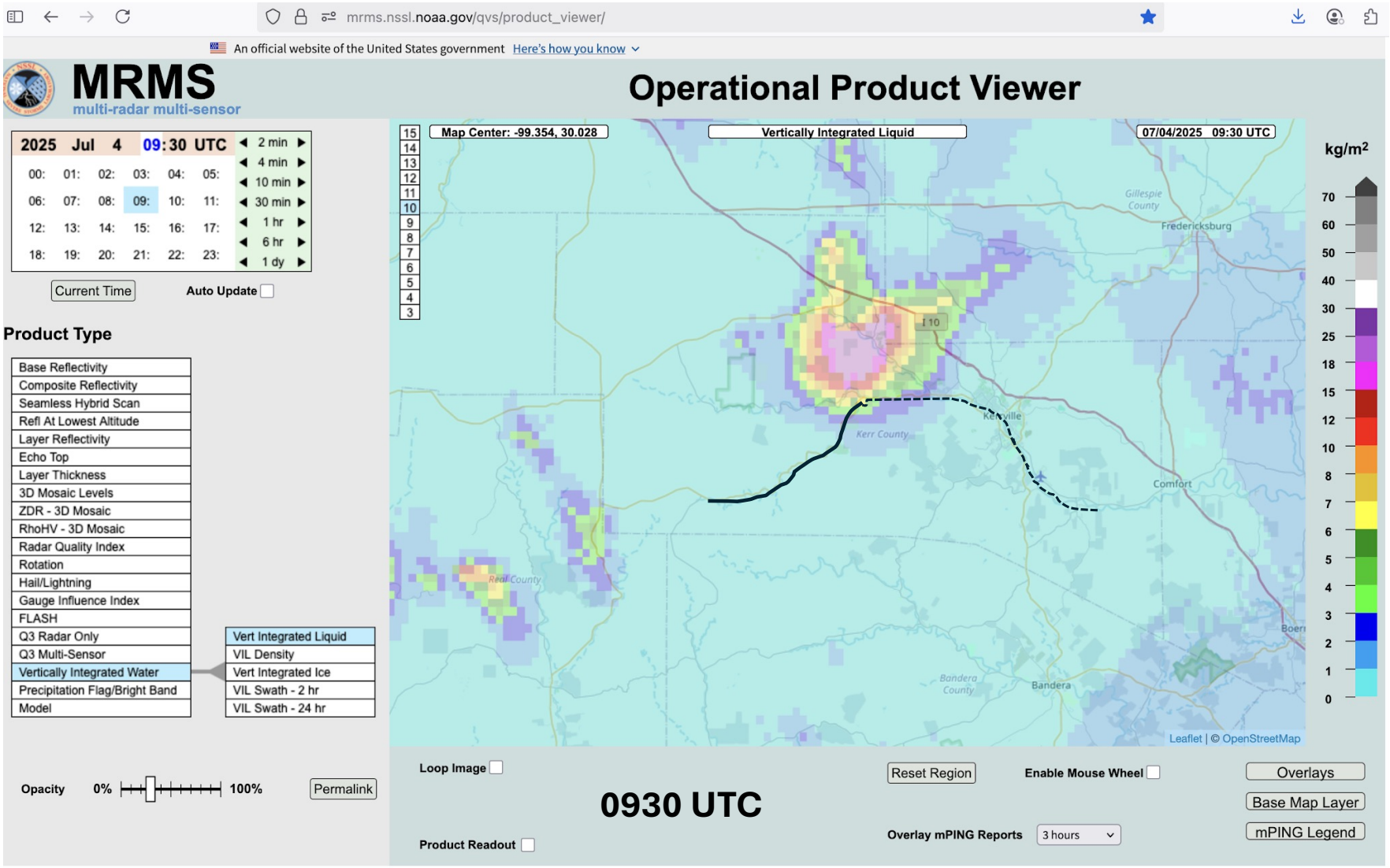
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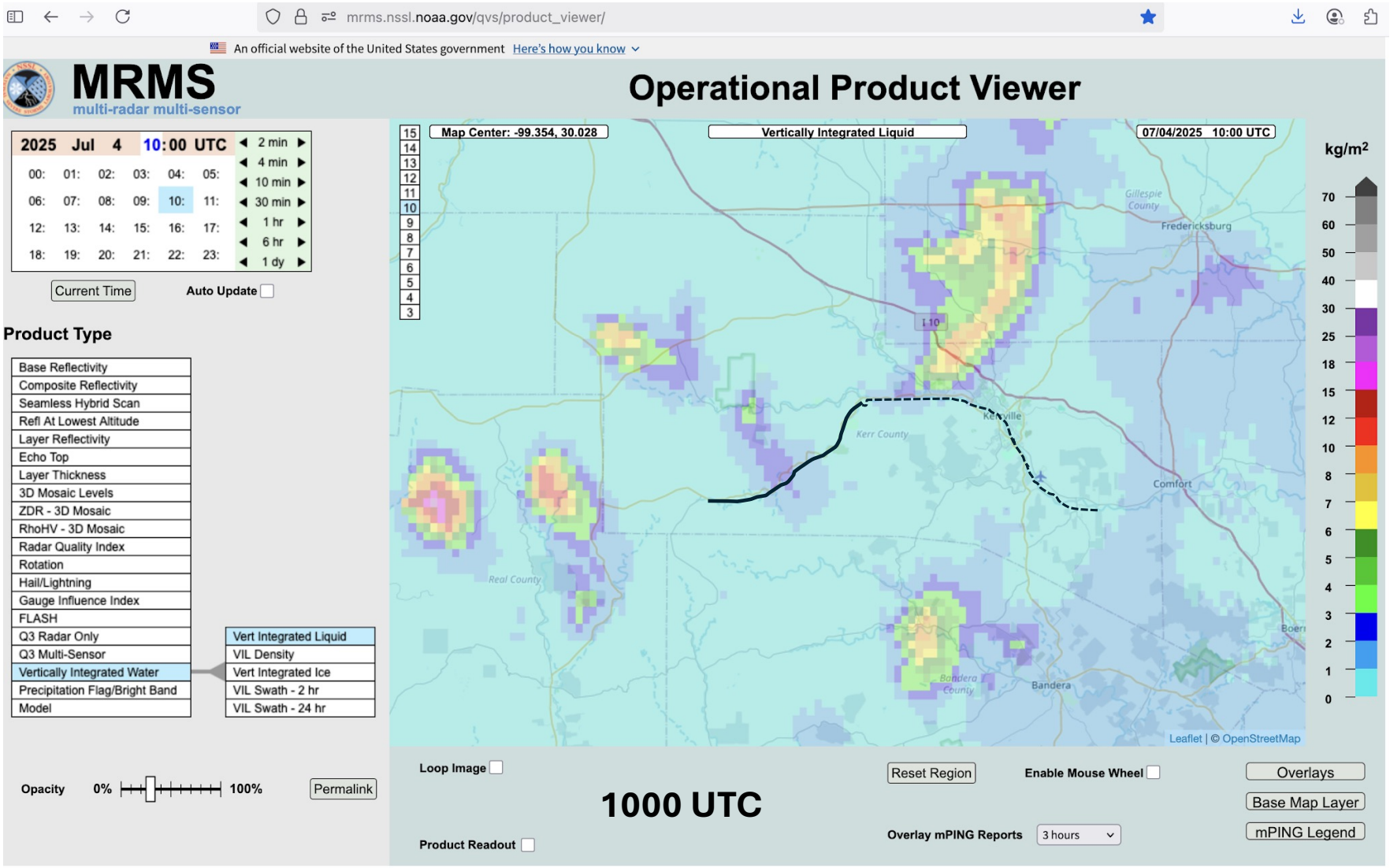
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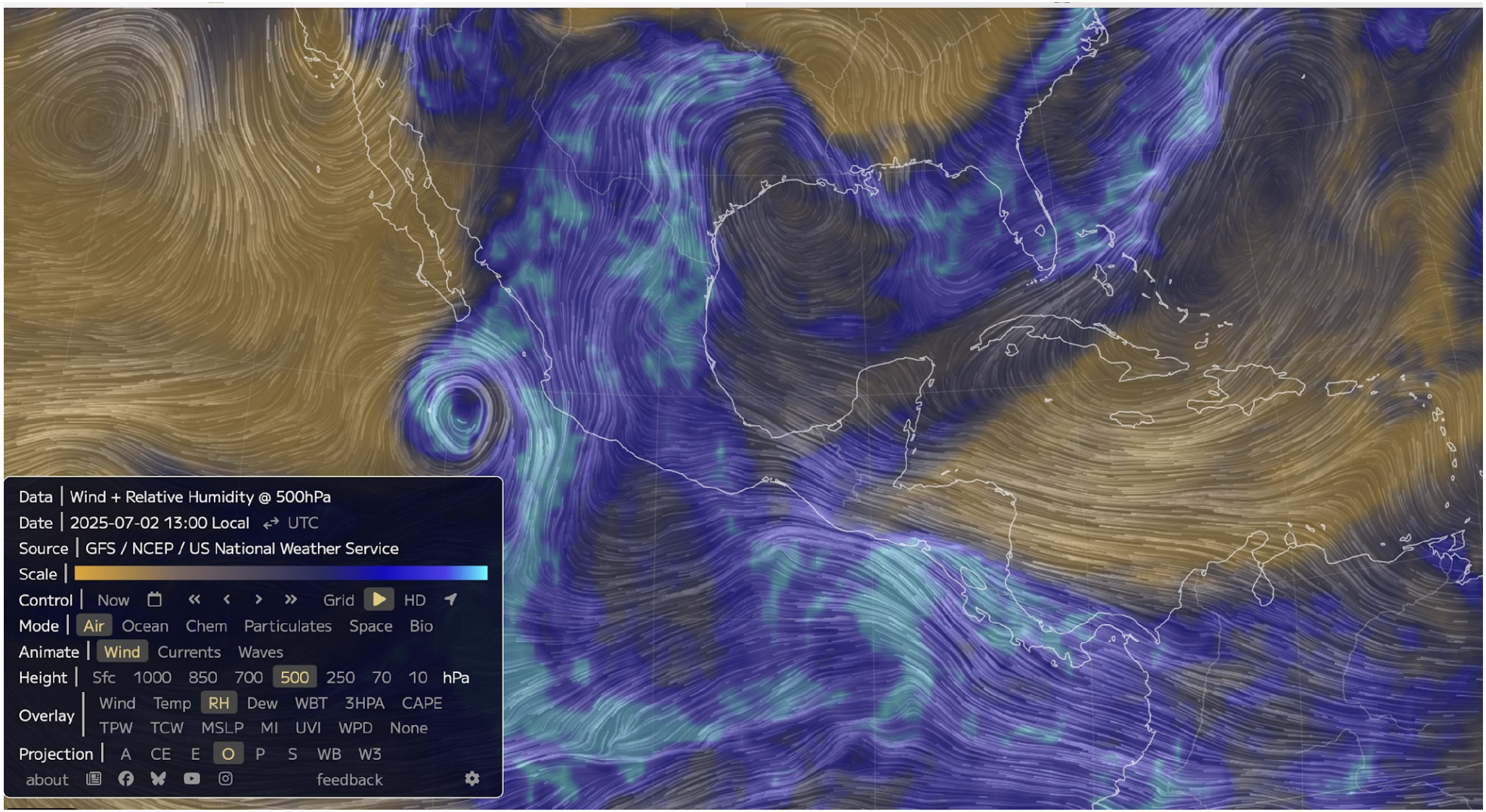
Fredericksburg
I 10
Kerrville
Kerr County
Comfort
Real County
Bandera County
Bandera
Leaflet | © OpenStreetMap
Loop Image
1000 UTC
Product Readout
Reset Region
Enable Mouse Wheel
Overlay mPING Reports
3 hours
Overlays
Base Map Layer
mPING Legend


Data | Wind + Relative Humidity @ 500hPa
Date | 2025-07-02 13:00 Local UTC
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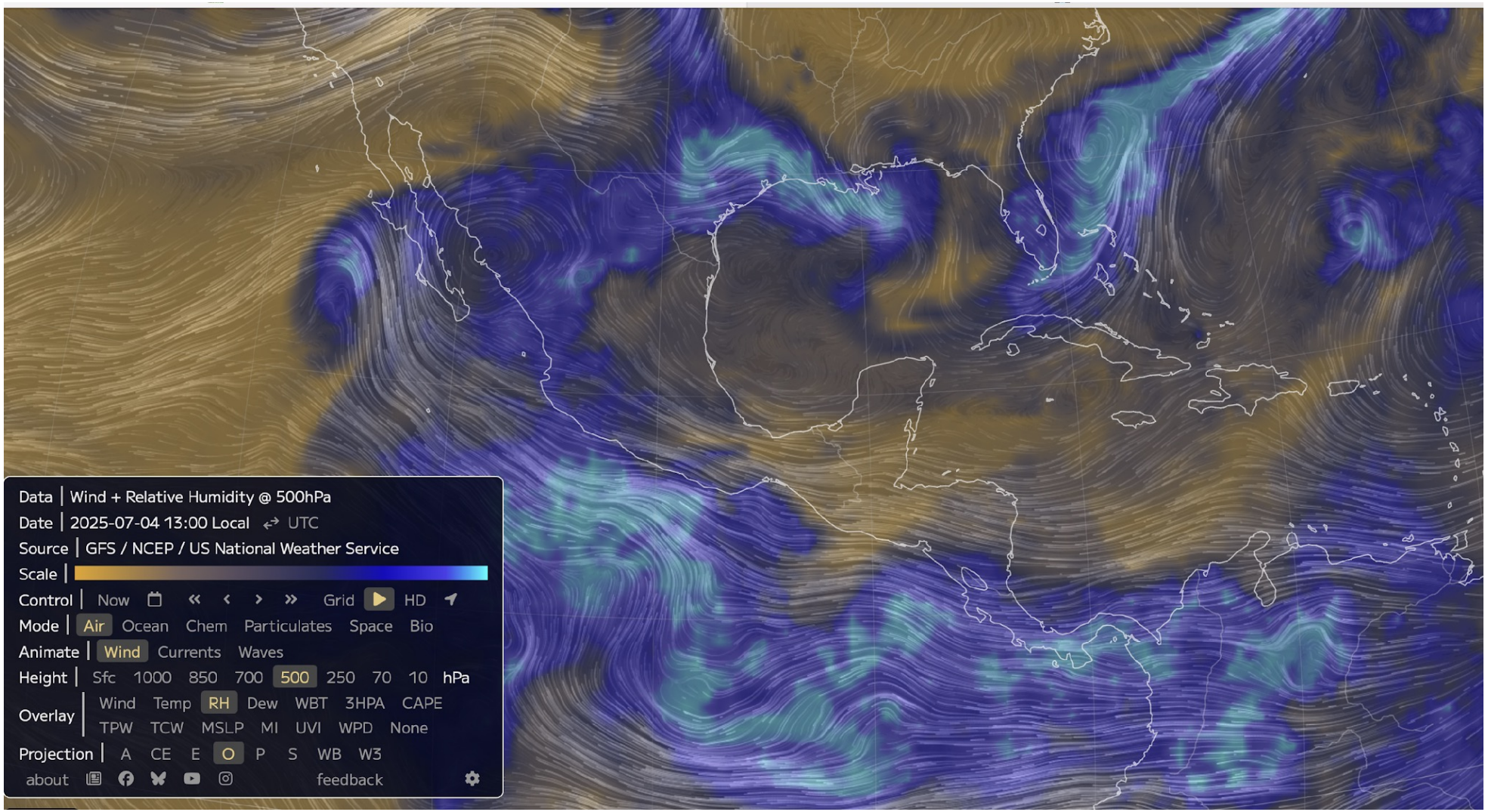
Mode | Air Ocean Chem Particulates Space Bio
Animate | Wind Currents Waves
Height | Sfc 1000 850 700 500 250 70 10 hPa
Overlay | Wind Temp RH Dew WBT 3HPA CAPE
TPW TCW MSLP MI UVI WPD None
Projection | A CE E O P S WB W3
about feedback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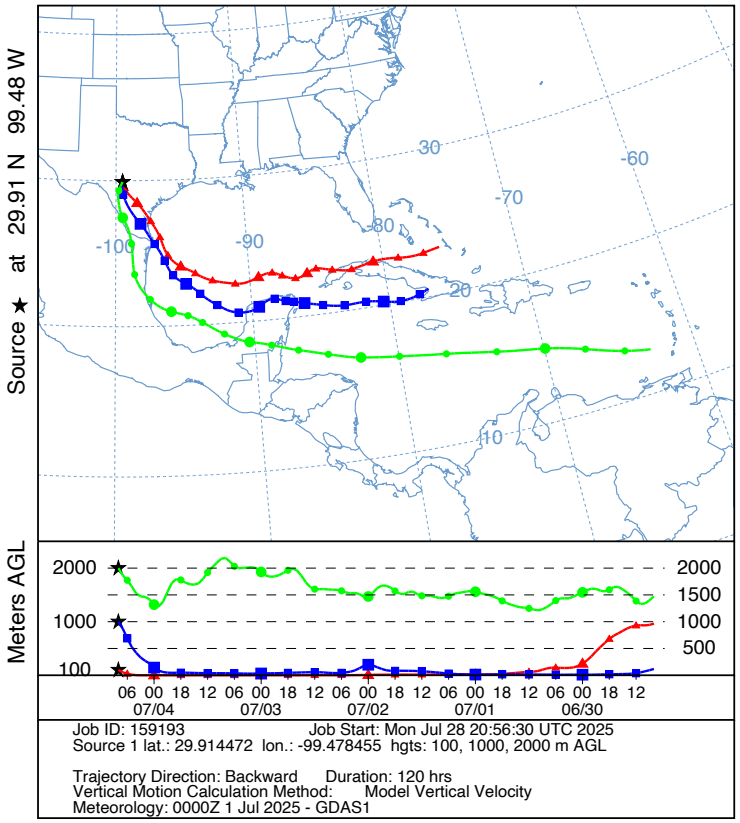
Mode | Air Ocean Chem Particulates Space Bio
Animate | Wind Currents Waves
Height | Sfc 1000 850 700 500 250 70 10 hPa
Overlay | Wind Temp RH Dew WBT 3HPA CAPE
TPW TCW MSLP MI UVI WPD None
Projection | A CE E O P S WB W3
about feedback

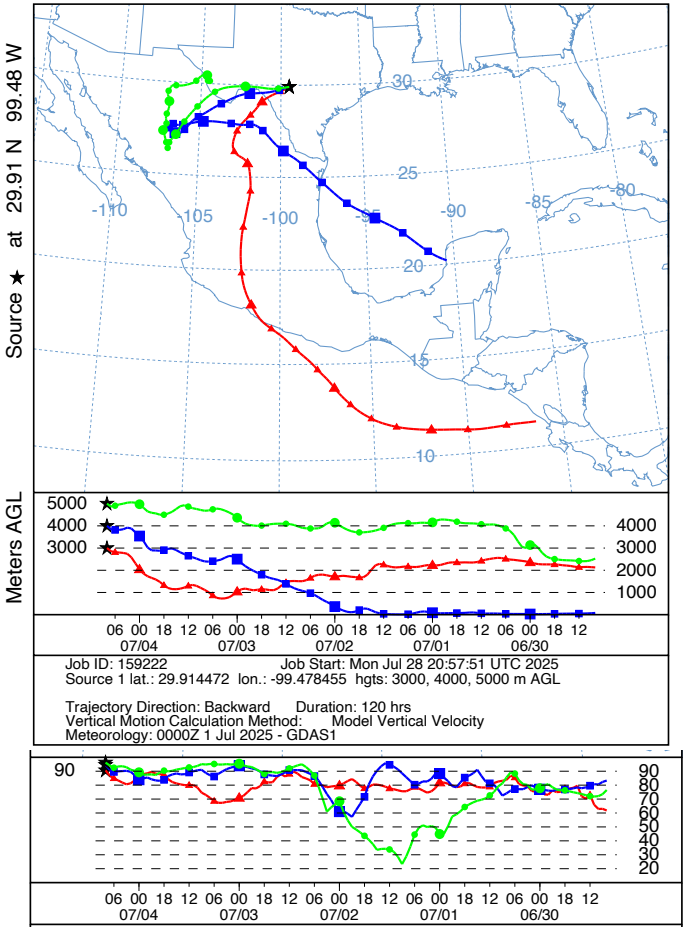
NOAA HYSPLIT MODEL
Backward trajectories ending at 0800 UTC 04 Jul 25
GDAS Meteorological Data



Job ID: 159193 Job Start: Mon Jul 28 20:56:30 UTC 2025
Source 1 lat.: 29.914472 lon.: -99.478455 hgts: 100, 1000, 2000 m AGL

Trajectory Direction: Backward Duration: 120 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2025 - GDAS1

NOAA HYSPLIT MODEL
Backward trajectories ending at 0800 UTC 04 Jul 25
GDAS Meteorological Data



Job ID: 159222 Job Start: Mon Jul 28 20:57:51 UTC 2025
Source 1 lat.: 29.914472 lon.: -99.478455 hgts: 3000, 4000, 5000 m AGL

Trajectory Direction: Backward Duration: 120 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2025 - GDAS1

Del Rio one day before flood

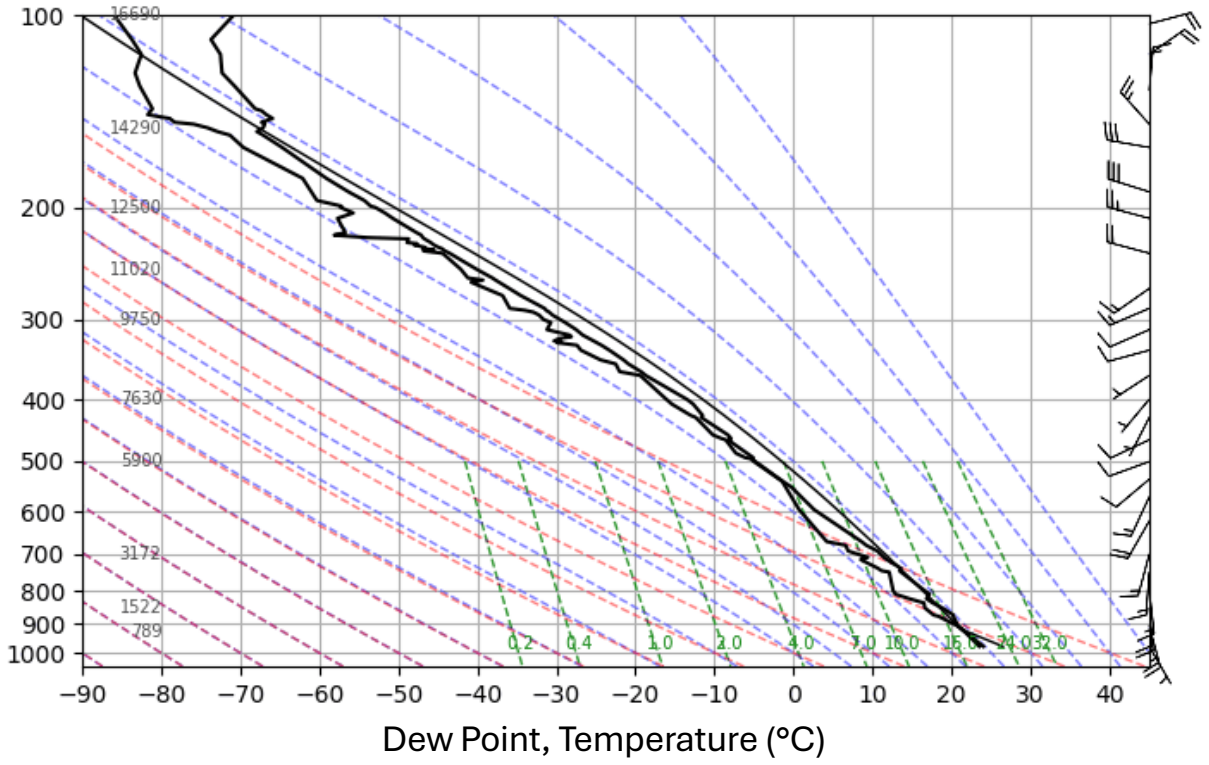
15,000 m: dry

12,000 m: humid

9,000 m: humid

6,000 m: humid

3,000 m: humid



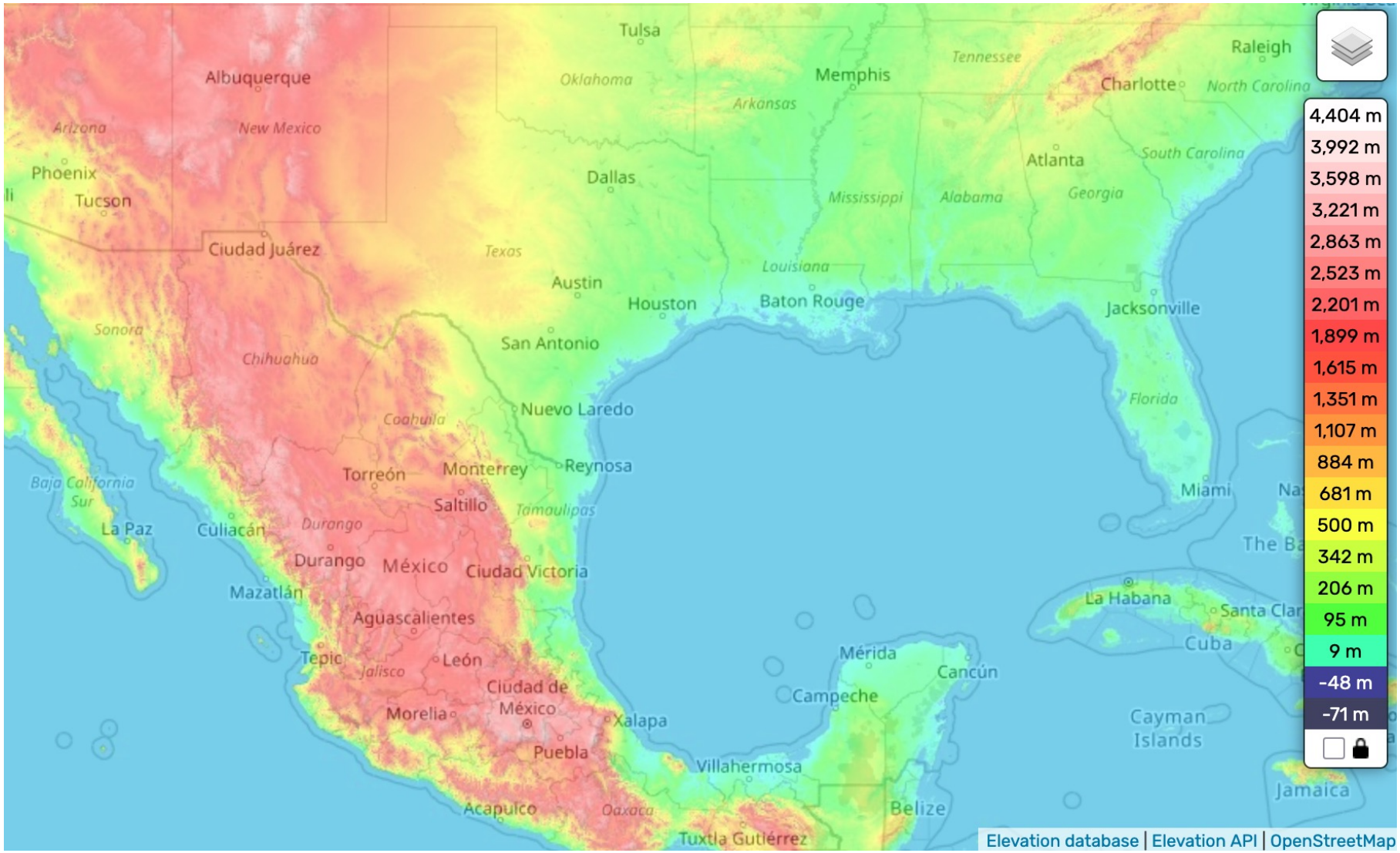
15,000 m: stable

12,000 m: unstable

9,000 m: unstable

6,000 m: unstable

3,000 m: neutral


Tulsa
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Jacksonville
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San Antonio
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Saltillo
Tamaulipas
Miami
La Paz
Culiacán
Durango
Durango
México
Ciudad Victoria
Mazatlán
La Habana
Aguascalientes
Cuba
Tepic
León
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Cancún
Ciudad de México
Campeche
Morelia
Xalapa
Cayman Islands
Puebla
Villahermosa
Jamaica
Acapulco
Oaxaca
Belize
Tuxtla Gutiérrez
4,404 m
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3,598 m
3,221 m
2,863 m
2,523 m
2,201 m
1,899 m
1,615 m
1,351 m
1,107 m
884 m
681 m
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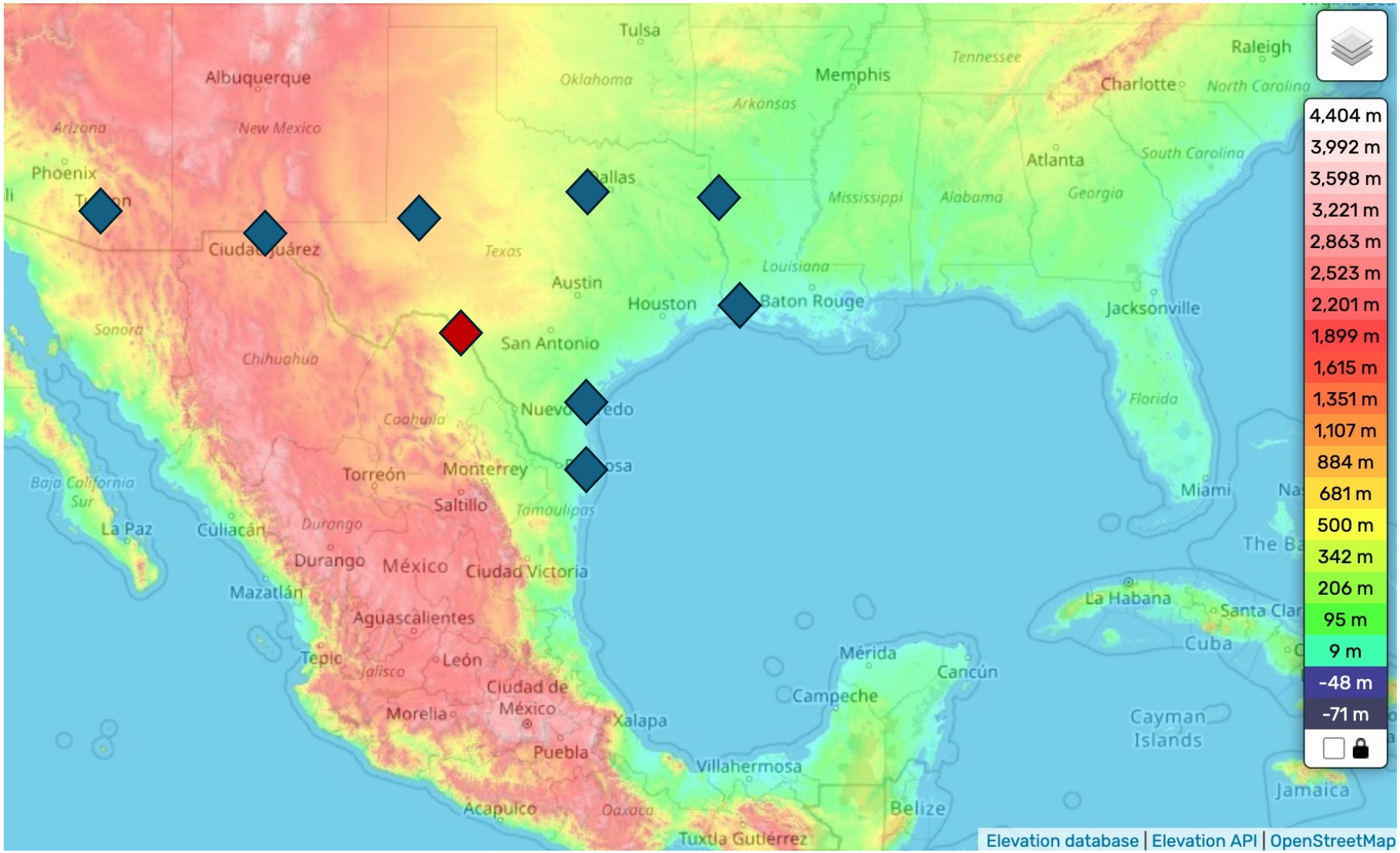
-71 m
Elevation database | Elevation API | OpenStreetMap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Elevation database | Elevation API | OpenStreetMap


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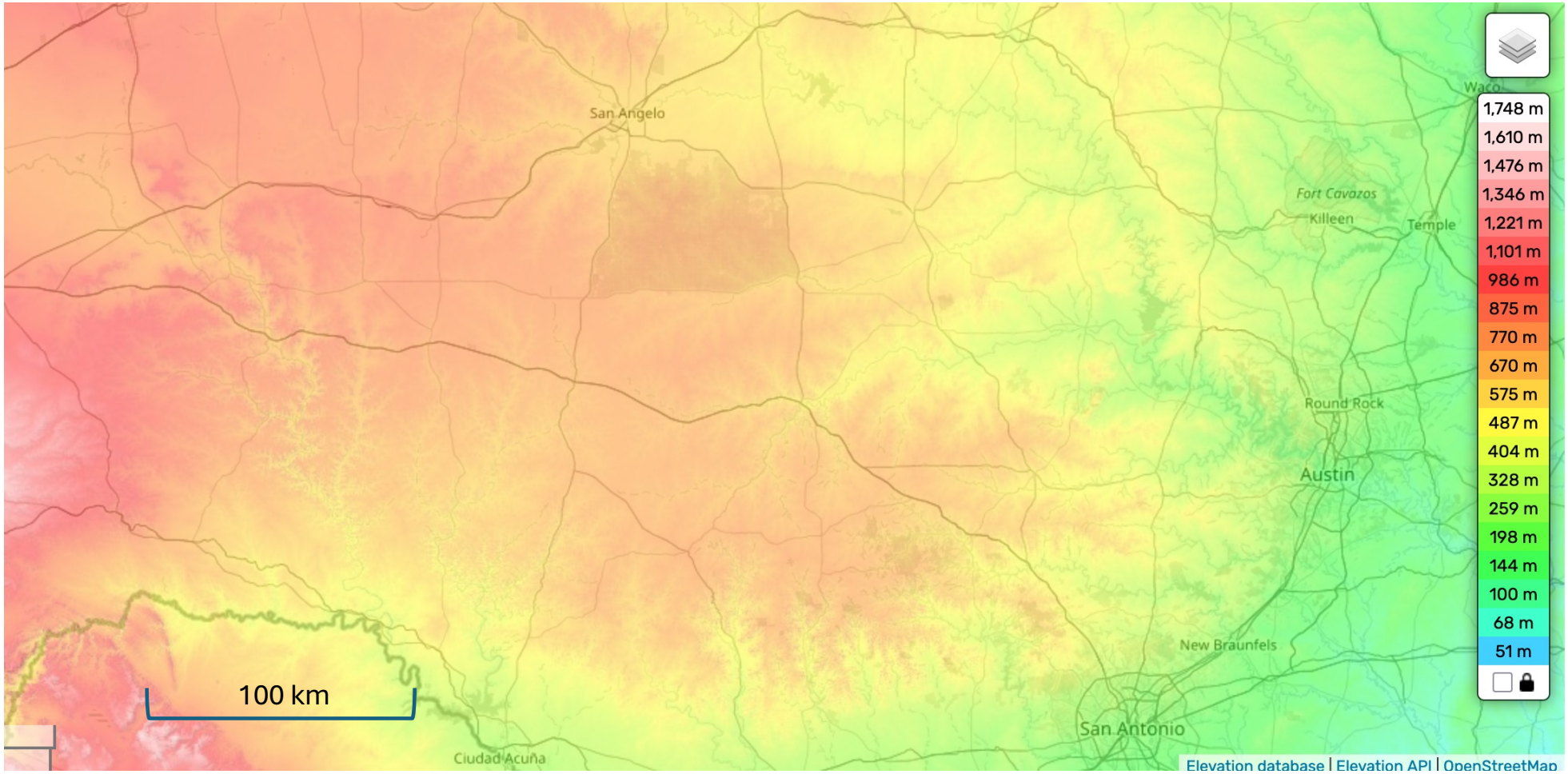
San Angelo
Waco
Fort Cavazos
Killeen
Temple
Round Rock
Austin
New Braunfels
San Antonio
Ciudad Acuña
100 km
1,748 m
1,610 m
1,476 m
1,346 m
1,221 m
1,101 m
986 m
875 m
770 m
670 m
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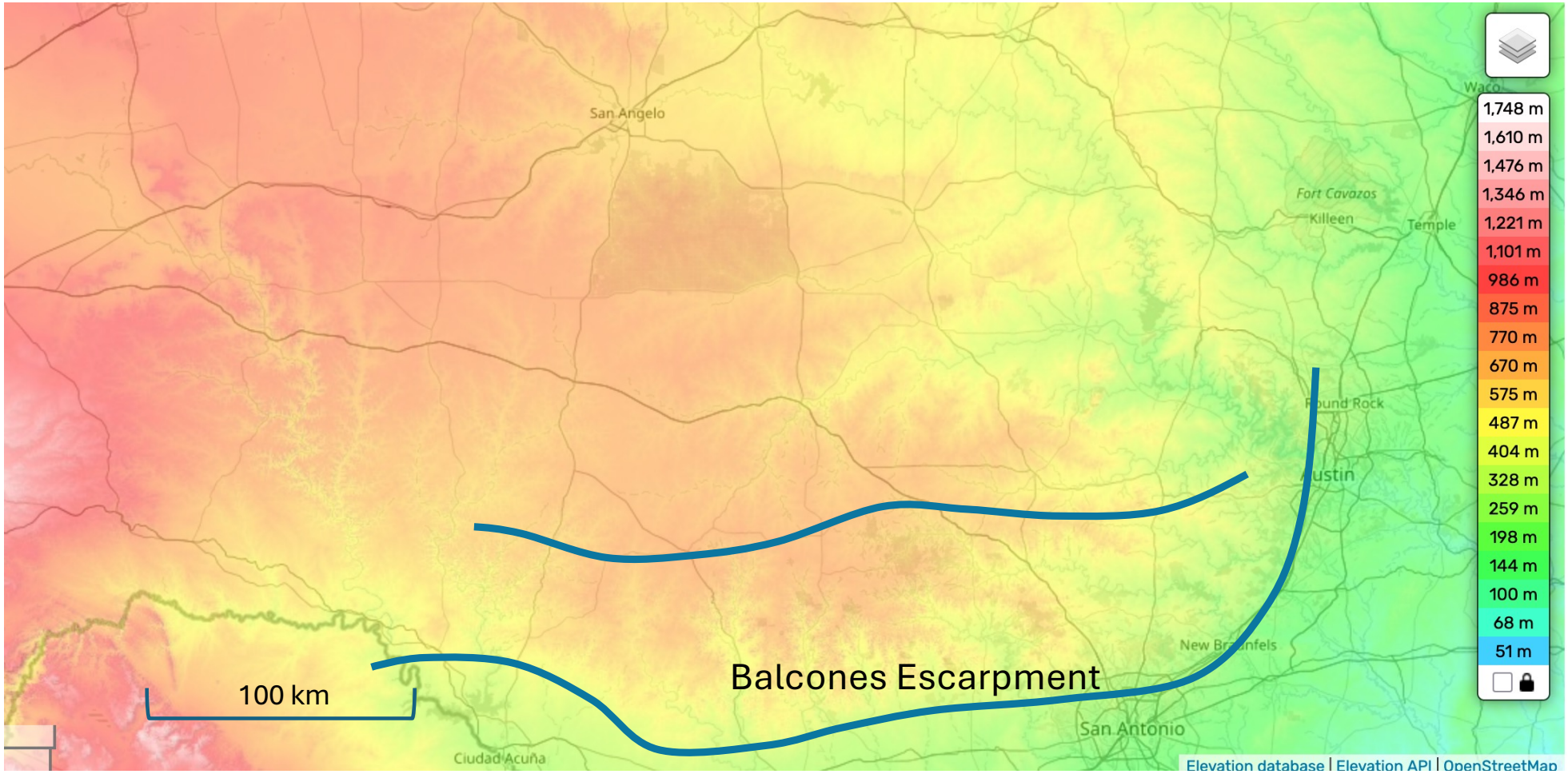
404 m
328 m
259 m
198 m
144 m
100 m
68 m
51 m
Elevation database | Elevation API | OpenStreetMap


San Angelo
Fort Cavazos
Killeen
Temple
Waco
Round Rock
Austin
New Braunfels
San Antonio
Ciudad Acuña
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986 m
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487 m
404 m
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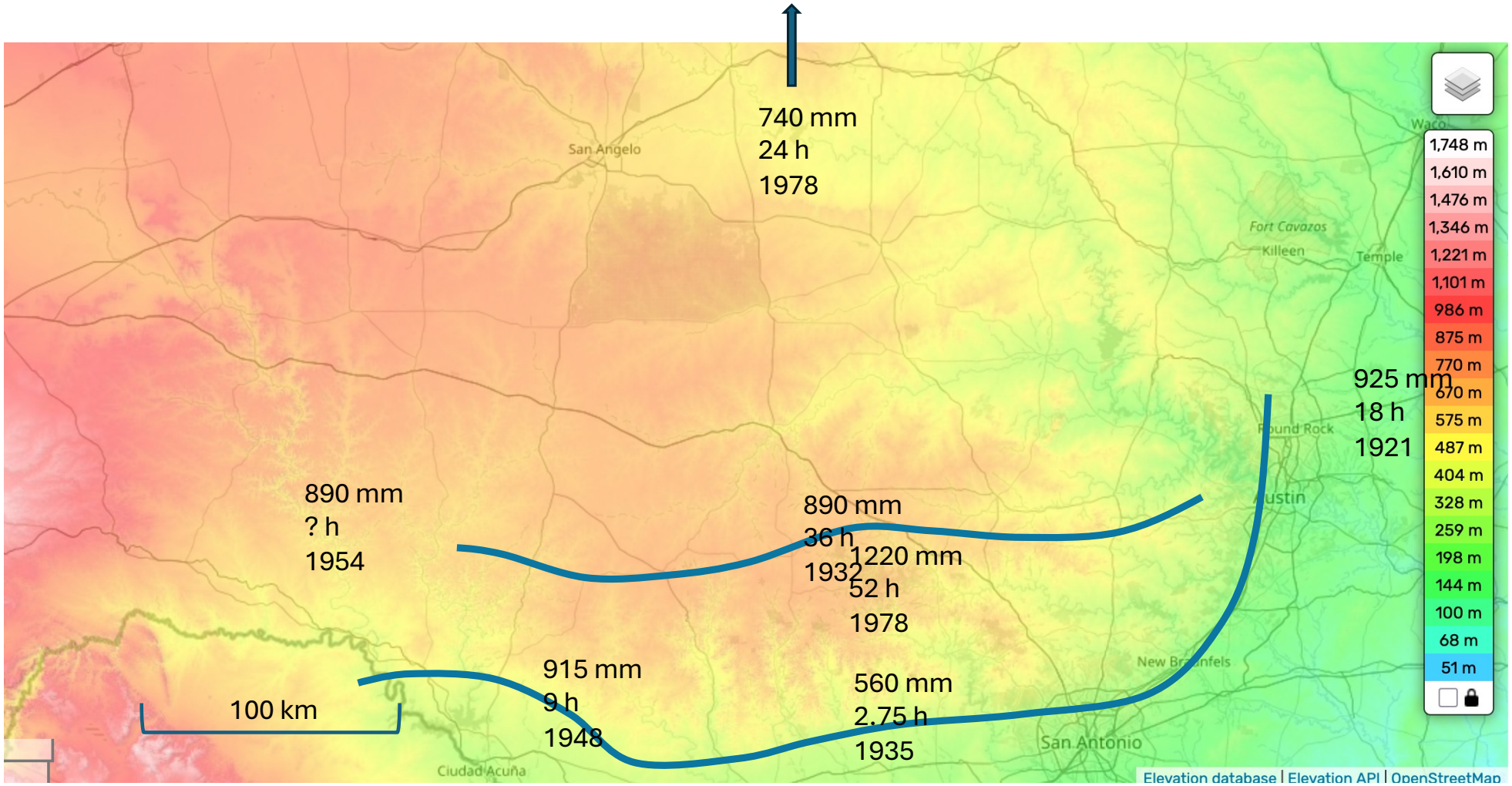
259 m
198 m
144 m
100 m
68 m
51 m
100 km
Balcones Escarpment
Elevation database | Elevation API | OpenStreetMap


740 mm
24 h
1978
925 mm
18 h
1921
890 mm
? h
1954
890 mm
36 h
1932
1220 mm
52 h
1978
915 mm
9 h
1948
560 mm
2.75 h
1935
100 km
San Angelo
Fort Cavazos
Killeen
Temple
Round Rock
Austin
New Braunfels
San Antonio
Ciudad Acuña
1,748 m
1,610 m
1,476 m
1,346 m
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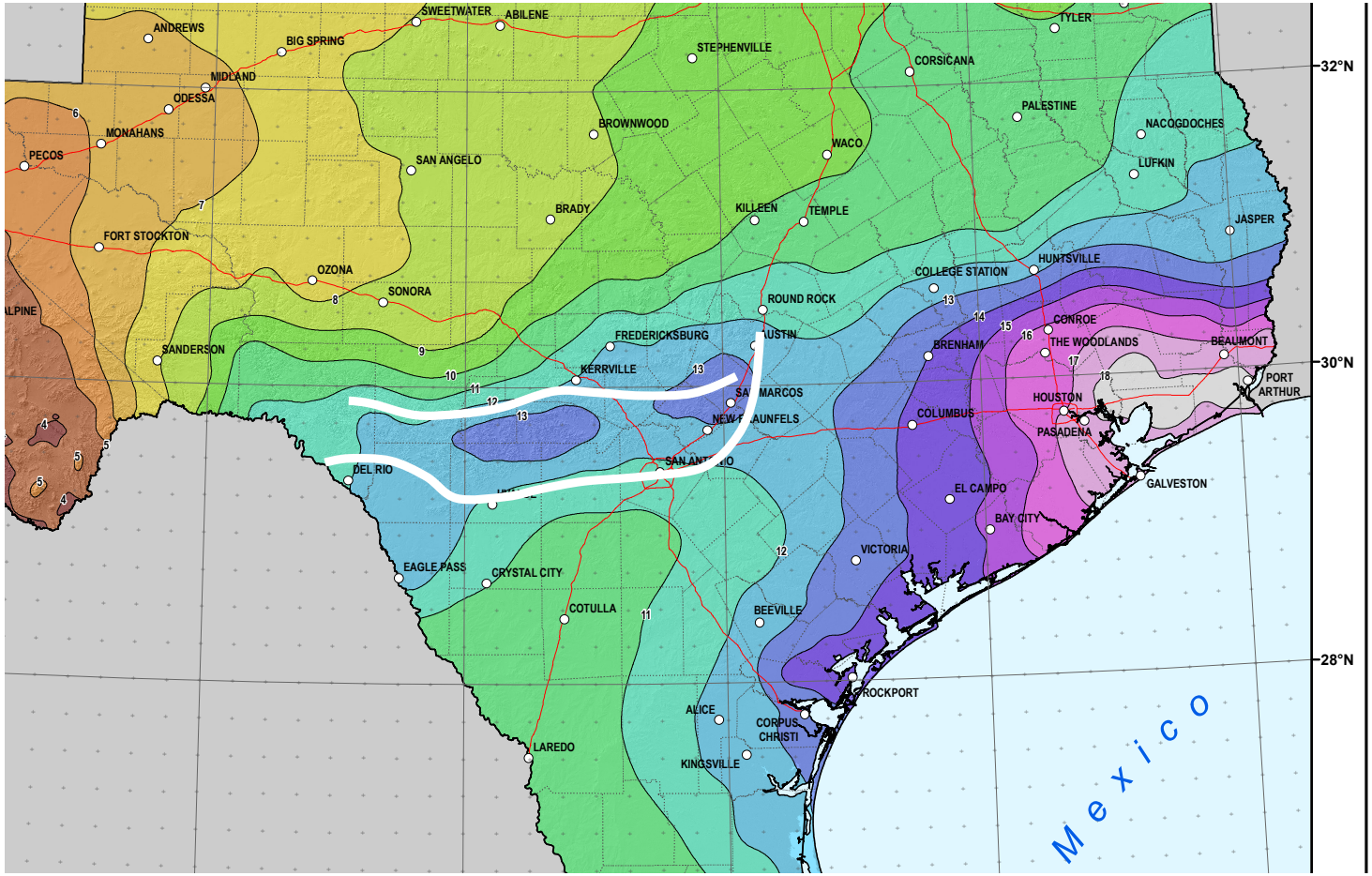
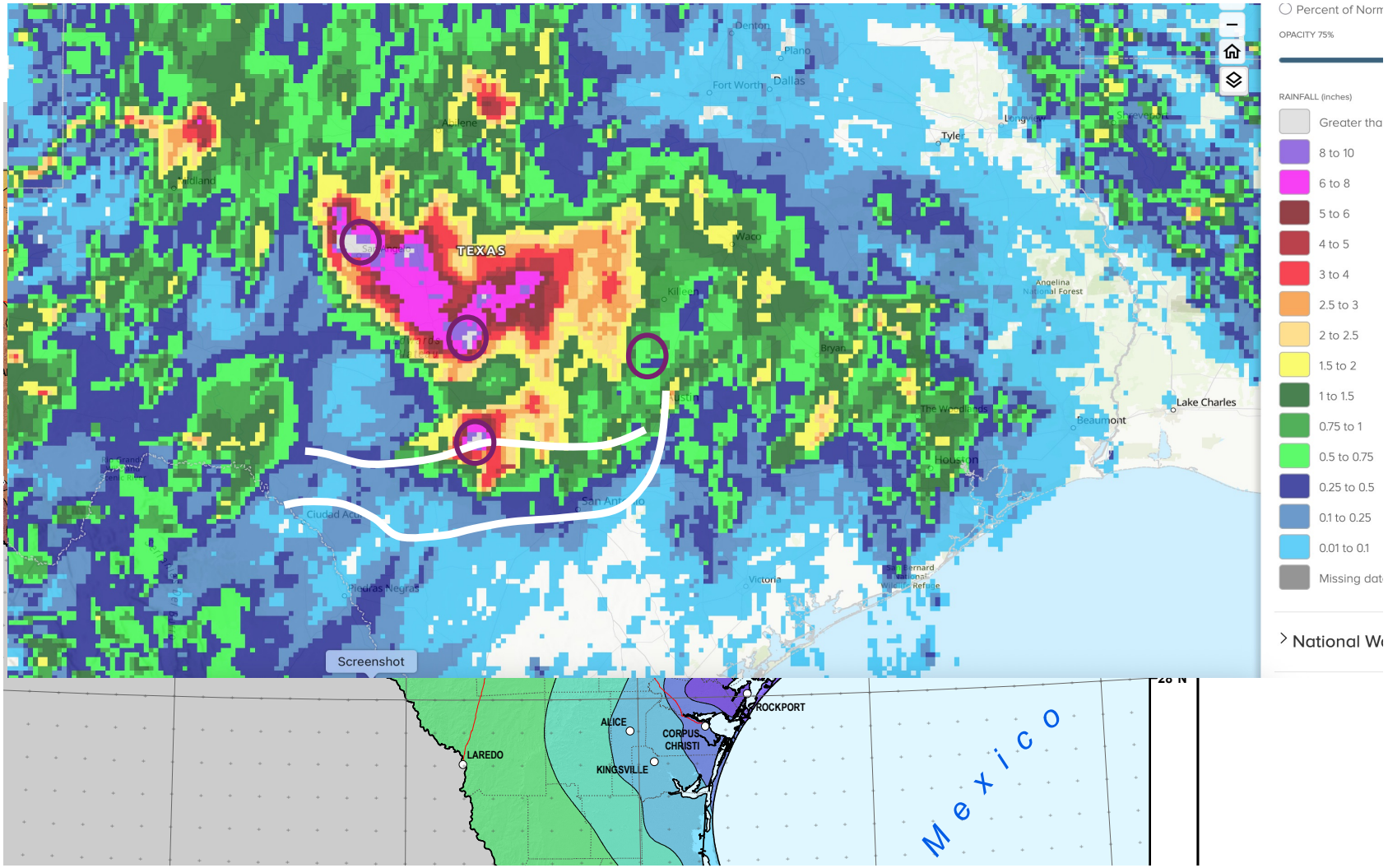
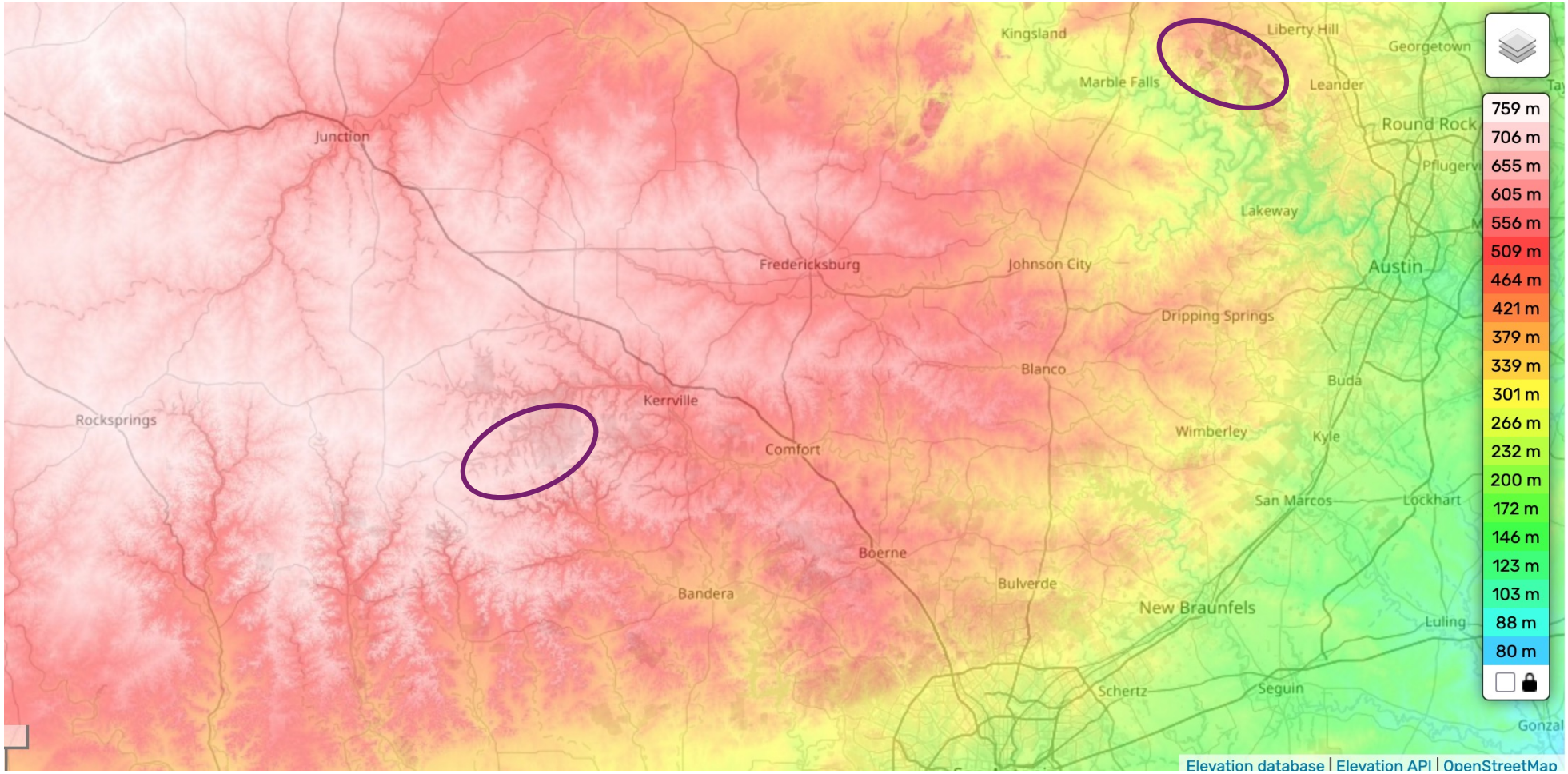
Elevation database | Elevation API | OpenStreetMap


SWEETWATER
ABILENE
ANDREWS
BIG SPRING
STEPHENVILLE
TYLER
CORSICANA
MIDLAND
ODESSA
PALESTINE
NACOGDOCHES
MONAHANS
BROWNWOOD
WACO
PECOS
SAN ANGELO
LUFKIN
BRADY
KILLEEN
TEMPLE
JASPER
FORT STOCKTON
HUNTSVILLE
COLLEGE STATION
OZONA
SONORA
ROUND ROCK
CONROE
FREDERICKSBURG
AUSTIN
BRENHAM
THE WOODLANDS
BEAUMONT
SANDERSON
KERRVILLE
PORT ARTHUR
SAN MARCOS
HOUSTON
COLUMBUS
PASADENA
DEL RIO
EL CAMPO
GALVESTON
BAY CITY
VICTORIA
EAGLE PASS
CRYSTAL CITY
COTULLA
BEEVILLE
ROCKPORT
ALICE
CORPUS CHRISTI
LAREDO
KINGSVILLE
Mexico
32°N
30°N
28°N


Percent of Norm
OPACITY 75%
RAINFALL (inches)
Greater tha
8 to 10
6 to 8
5 to 6
4 to 5
3 to 4
2.5 to 3
2 to 2.5
1.5 to 2
1 to 1.5
0.75 to 1
0.5 to 0.75
0.25 to 0.5
0.1 to 0.25
0.01 to 0.1
Missing dat
National W
TEXAS
Denton
Plano
Fort Worth
Dallas
Abilene
Midland
Tyler
Waco
Killeen
Angelina National Forest
Bryan
Lake Charles
Beaumont
Houston
San Antonio
Ciudad Acuña
Piedras Negras
Victoria
Screenshot
ROCKPORT
ALICE
CORPUS CHRISTI
LAREDO
KINGSVILLE
Mexico


Kingsland
Liberty Hill
Georgetown
Marble Falls
Leander
Round Rock
Junction
Lakeway
Fredericksburg
Johnson City
Austin
Dripping Springs
Blanco
Buda
Kerrville
Rocksprings
Wimberley
Kyle
Comfort
San Marcos
Lockhart
Boerne
Bulverde
Bandera
New Braunfels
Luling
Schertz
Seguin
759 m
706 m
655 m
605 m
556 m
509 m
464 m
421 m
379 m
339 m
301 m
266 m
232 m
200 m
172 m
146 m
123 m
103 m
88 m
80 m
Elevation database | Elevation API | OpenStreetMap

Why the loss of life?

- Forecasts
  - Nonspecific locations
  - Peak rainfall amounts larger than expected
- Warnings
  - Maximum amount “possible” less than what occurred
  - Limited distribution
    - Poor cell phone coverage
    - Early morning hours
  - Poor situational awareness
    - Early morning hours
    - Non-natives
    - Last huge flood was 90 years ago
  - No distinction between “It’s a flash flood, seek shelter” and “It’s a flash flood, evacuate”

Quote from Texas camp owner (not on Guadalupe River), October 2025

[Their] camp sits on the floodplain. “We’re unique. We’re within the city limits. We’re on a river that has not flooded in our 86-year history. We believe it’s important to evaluate each camp based on its site-specific characteristics. Not all floodplains are the same.”

Quote from Texas camp owner (not on Guadalupe River), October 2025

[Their] camp sits on the floodplain. “We’re unique. We’re within the city limits. We’re on a river that has not flooded in our 86-year history. We believe it’s important to evaluate each camp based on its site-specific characteristics. Not all floodplains are the same.”

- Note: the man-made lake in the center of the camp occupies a flood channel.

Take-Home Messages

- Hill Country rainfall is orographically enhanced, mechanism is unknown
  - Convective triggering?
  - Convective enhancement?
  - Orographic anchoring?
  - Orographic efficiency?
  - Depends on storm?
  - PMP transposition?
- Lack of upstream tropospheric data
  - Subtle temperature variations matter
- Risk is highly location-specific
  - Need personal warnings (GPS-based warnings / hyperlocal observations)