



Eastern Kentucky Flash Flood Risk and Vulnerability



City of Prestonsburg, KY
(Picture courtesy of WYMT news)

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Building a Weather-Ready Nation



Feb-March 2021 Major River Flooding

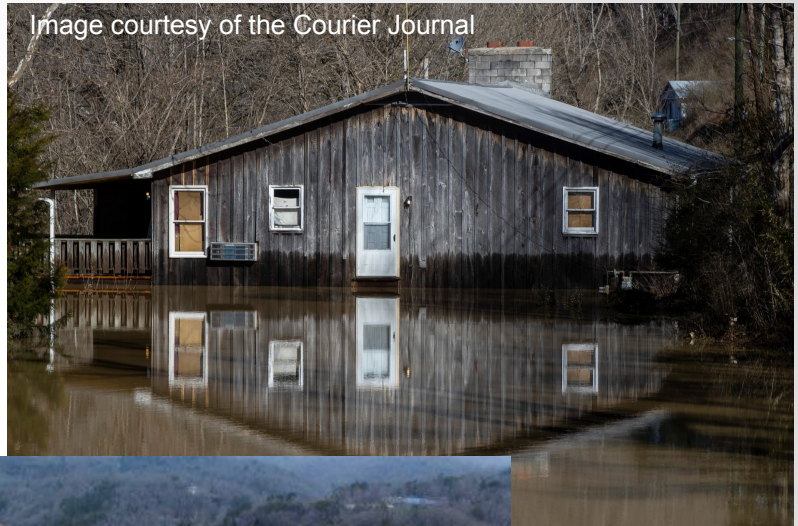


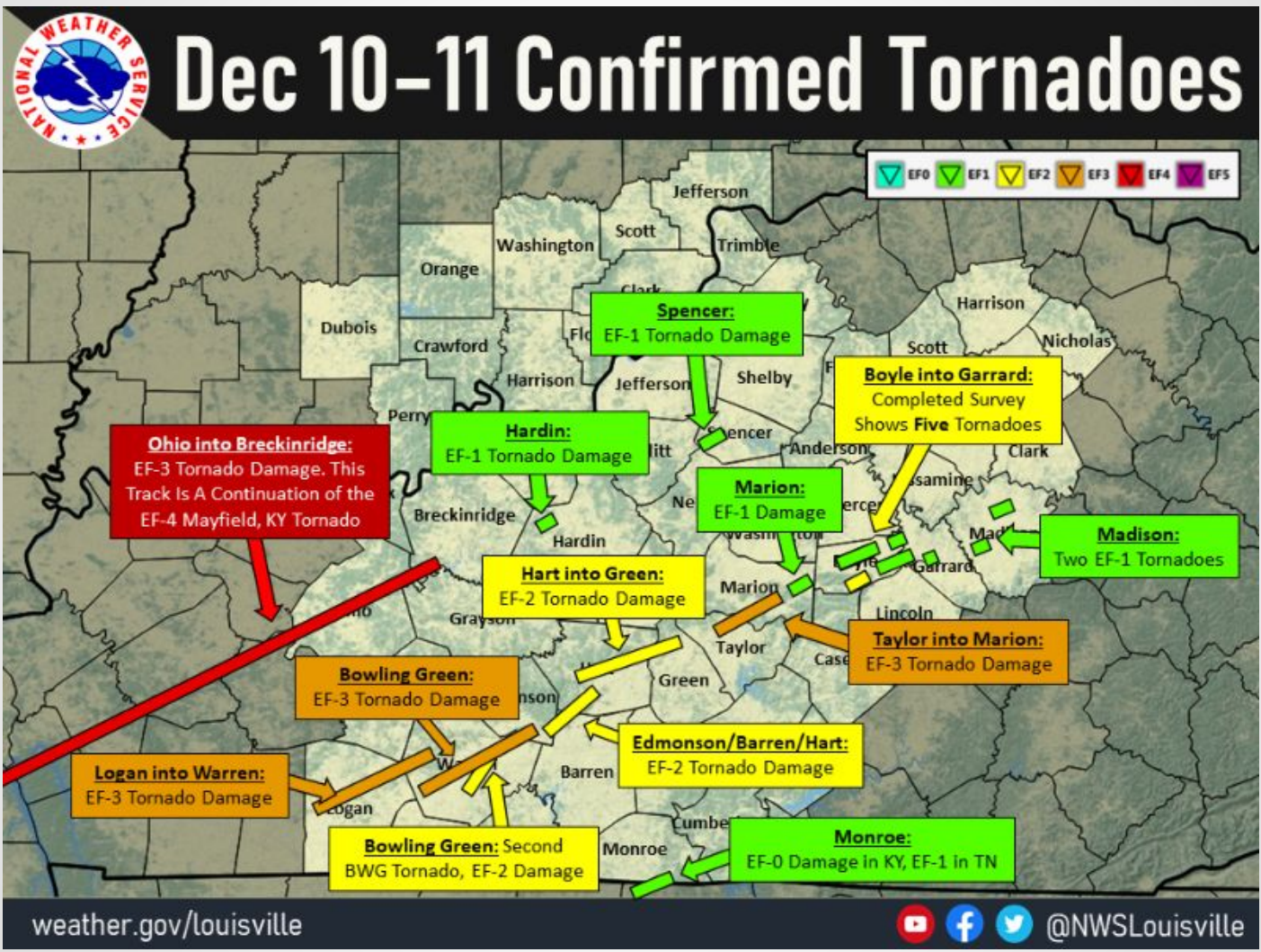
Photo by Donnie Benton





December 10-11

Tornadoes in West and Central KY





July 2022

Devastating Flash Flooding



northern portions of Perry County



Building a Weather-Ready Nation



July 2022

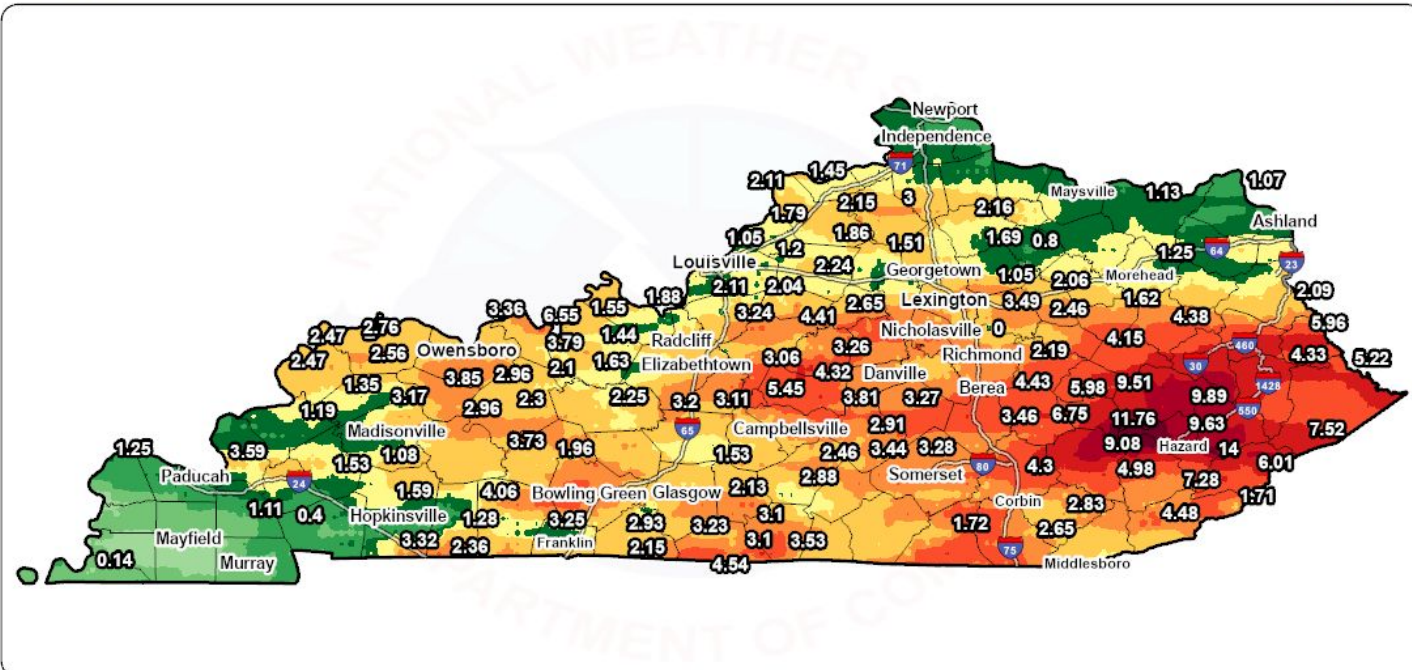
Devastating Flash Flooding



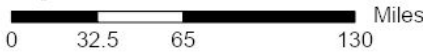
National Weather Service State of Kentucky

Rainfall Analysis 07/25/2022 08:00AM to 07/29/2022 08:00AM EDT

Analysis Data Source: NCEP Stage IV and Regional Observations



Created: 07/31/2022 01:11PM



This is an experimental product of the NWS GAZPACHO software package. Care should be taken in using the data. Unofficial observations may be plotted. Values at interpolated locations may not represent actual reports at that location.

Precipitation (in)	Color
0.00"	White
0.01" - 0.09"	Lightest Green
0.10" - 0.24"	Light Green
0.25" - 0.49"	Medium Green
0.50" - 0.99"	Dark Green
1.00" - 1.49"	Light Yellow
1.50" - 1.99"	Yellow
2.00" - 2.99"	Orange
3.00" - 3.99"	Light Orange
4.00" - 5.99"	Red-Orange
6.00" - 7.99"	Red
8.00" - 9.99"	Dark Red
10.00" - 14.99"	Maroon
15.00" - 19.99"	Dark Purple
20.00" - 29.99"	Light Purple
30.00" - 50.00+"	Very Light Purple



Building a Weather-Ready Nation



July 2022

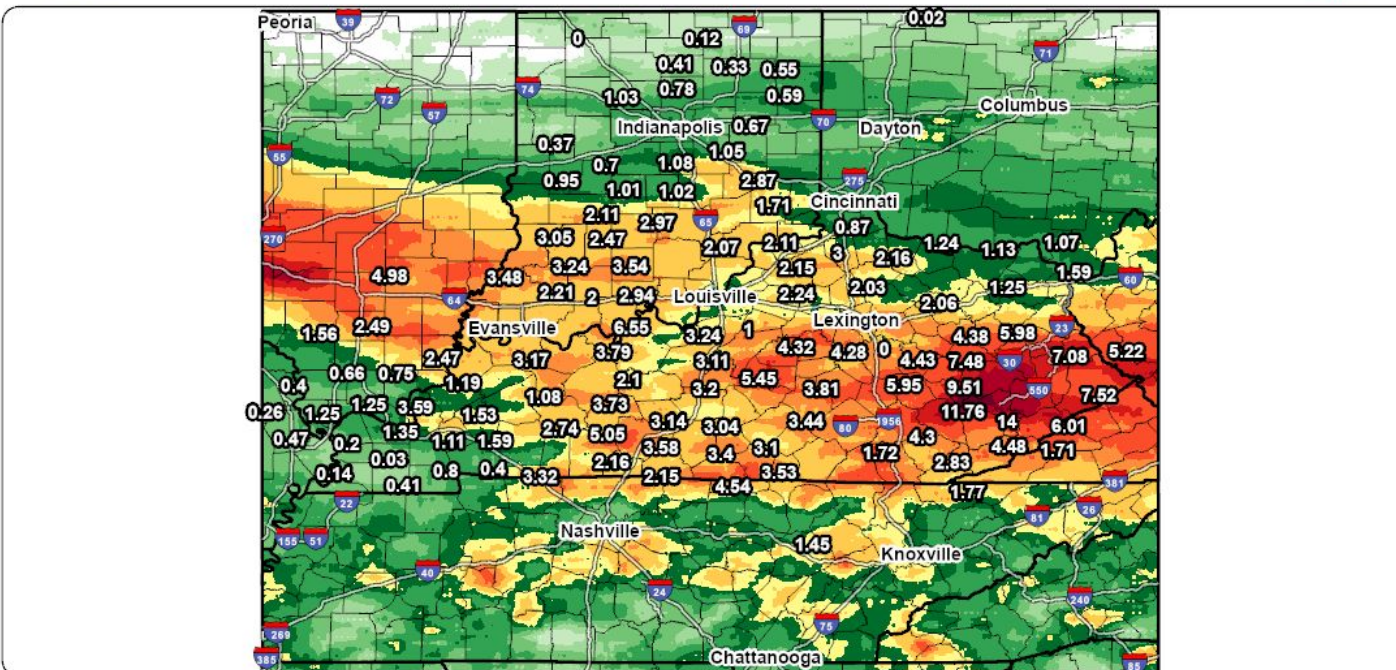
Devastating Flash Flooding



National Weather Service

Rainfall Analysis 07/25/2022 08:00AM to 07/29/2022 08:00AM EDT

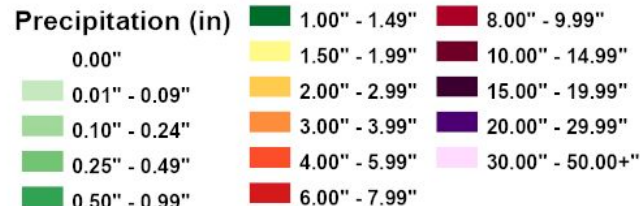
Analysis Data Source: NCEP Stage IV and Regional Observations



Created:
07/31/2022 01:52PM



This is an experimental product of the NWS GAZPACHO software package. Care should be taken in using the data. Unofficial observations may be plotted. Values at interpolated locations may not represent actual reports at that location.



Building a Weather-Ready Nation



July 2022

Leading up to the event

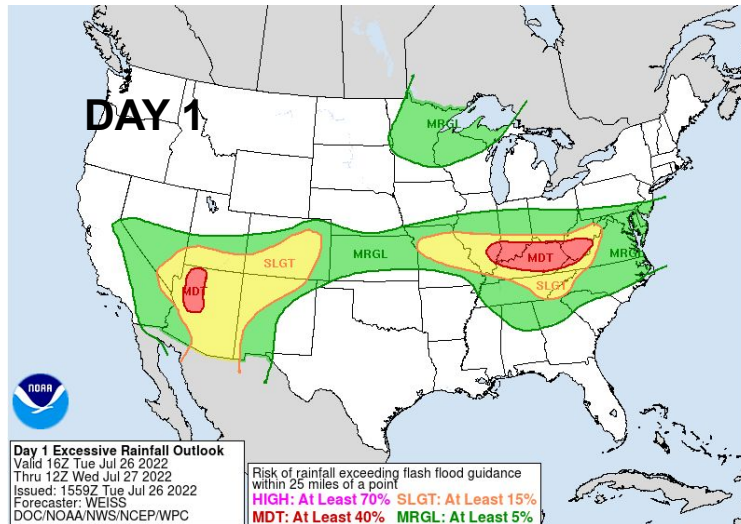
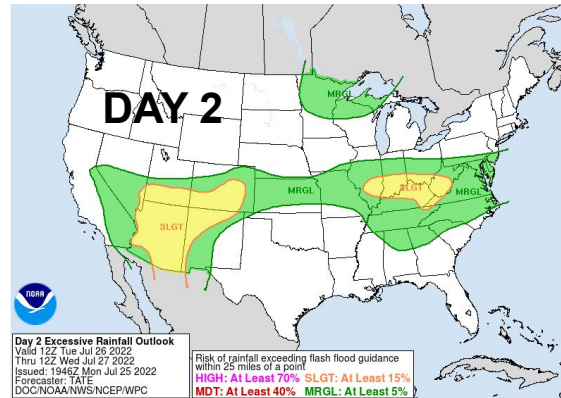
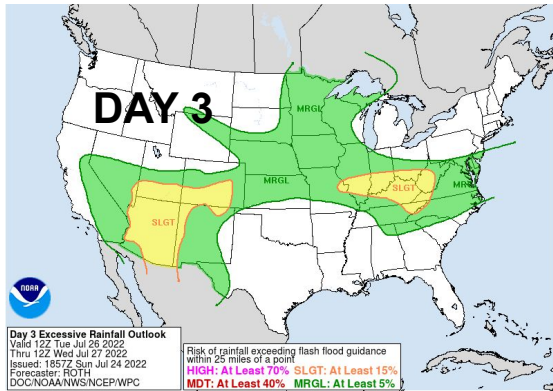


- **Model Evaluation Group summary of the lead up to the event**
 - **Models**
 - **WPC**

(Marcel Caron, Logan Dawson, and Geoff Manikin)

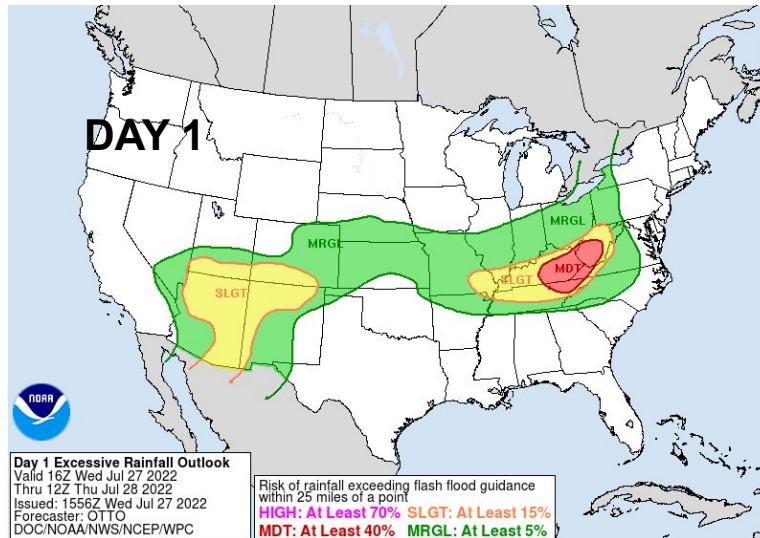
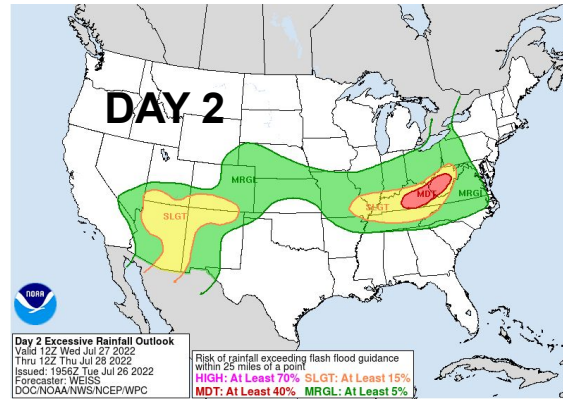
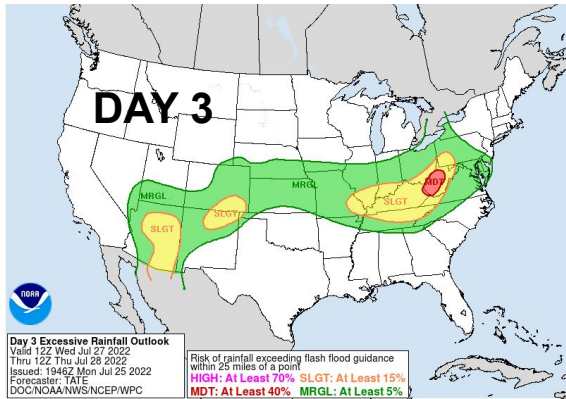


WPC Days 1-3 Excessive Rainfall Outlooks July 26-27



- This was for the day before the extreme KY event
- This shows that there was already significant concern about flooding in this area the previous day
- The soils in the area of interest were already close to saturation when the “main event” occurred on the night of 7/27 into 7/28

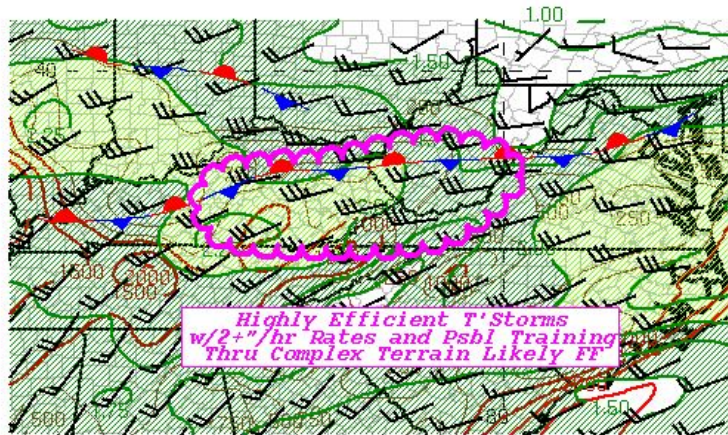
WPC Days 1-3 Excessive Rainfall Outlooks July 27-28



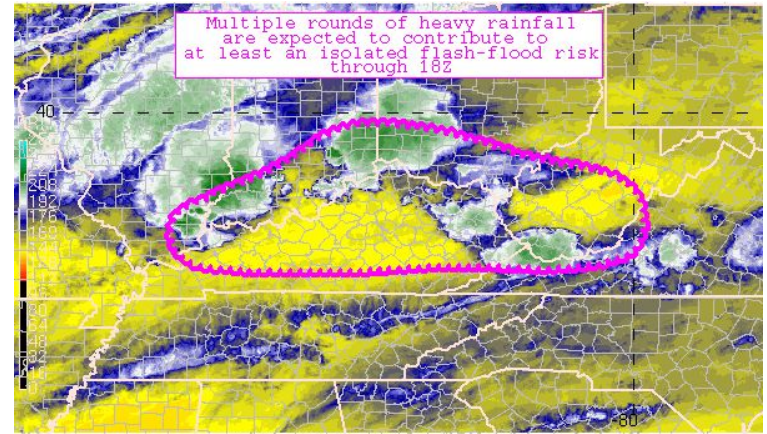
- The potential for a significant event somewhere in the Appalachian region on the day being examined was noted by WPC at Day 3
- The higher-end threat over eastern KY was clear by Day 2, although this appeared to be as much due to antecedent soil conditions and terrain impacts as due to concern about an extreme rainfall event (FFG was extremely low)



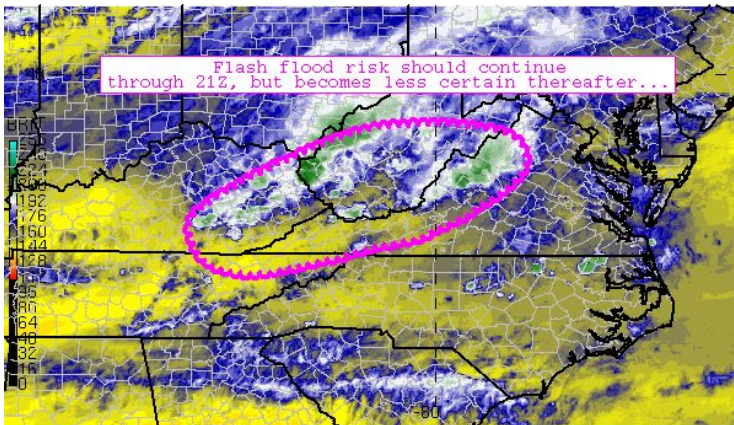
WPC Mesoscale Precip Discussions July 26-27



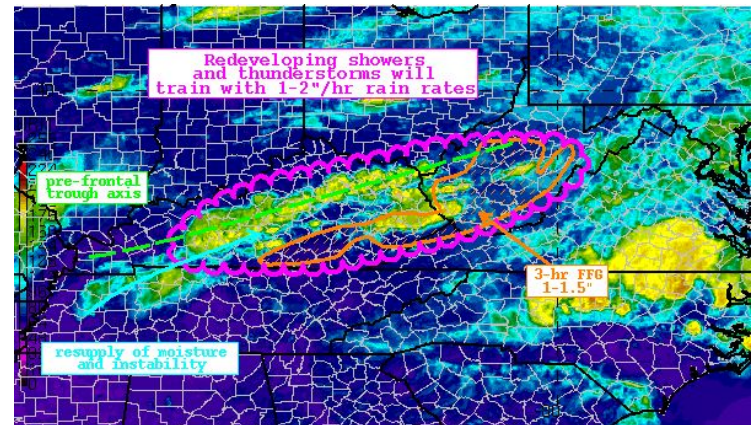
RAP32 SB CAPE 220727/0600f002
RAP32 PRECIP WATER 220727/0600f002
RAP32 850 MB WINDS 220727/0600f000
WPC MPD #0601



220727/1141 GOES16 CH10 WV_7.3
WPC MPD #0602



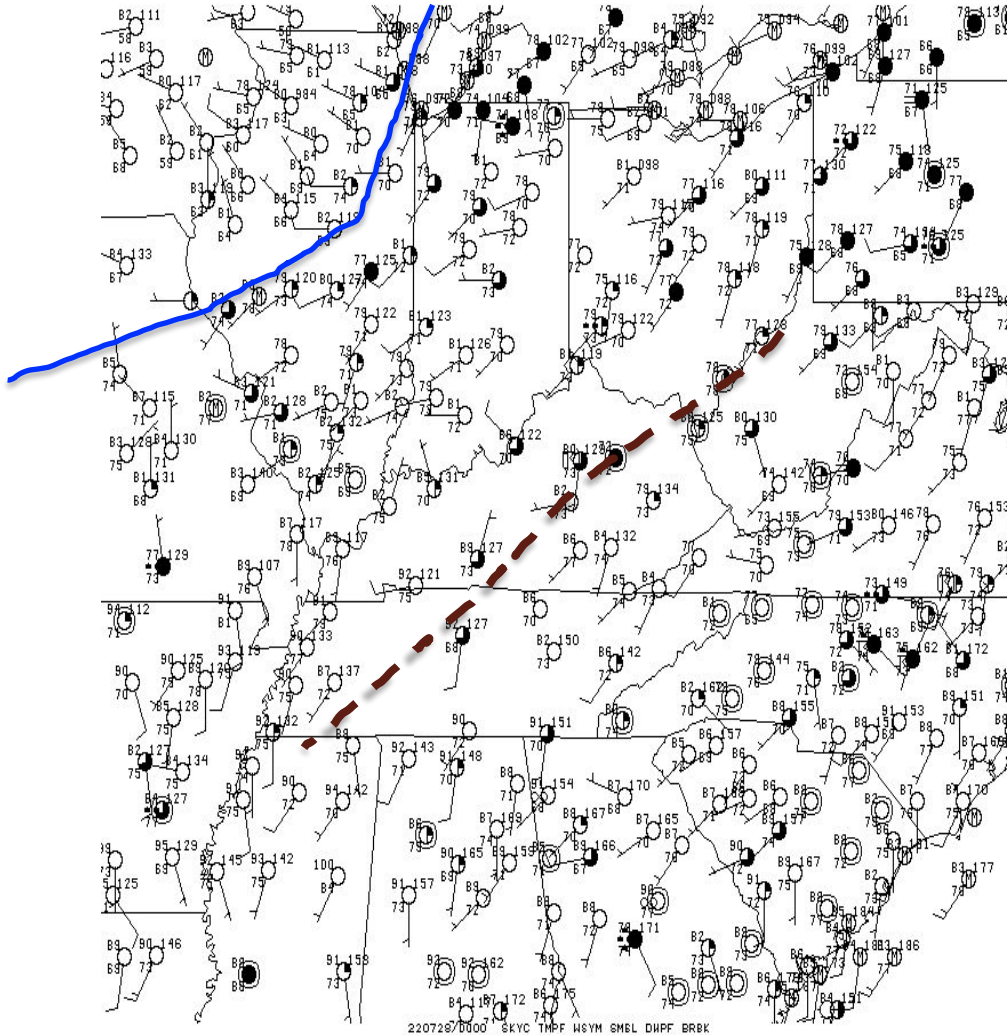
220727/1756 GOES16 CH10 WV_7.3
WPC MPD #0604



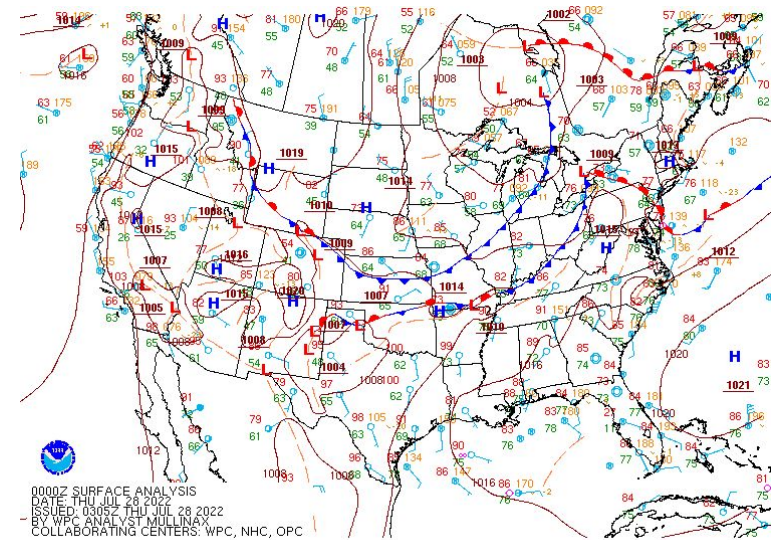
220727/2356 GOES16 CH07 SWIR_3.9
WPC MPD #0606



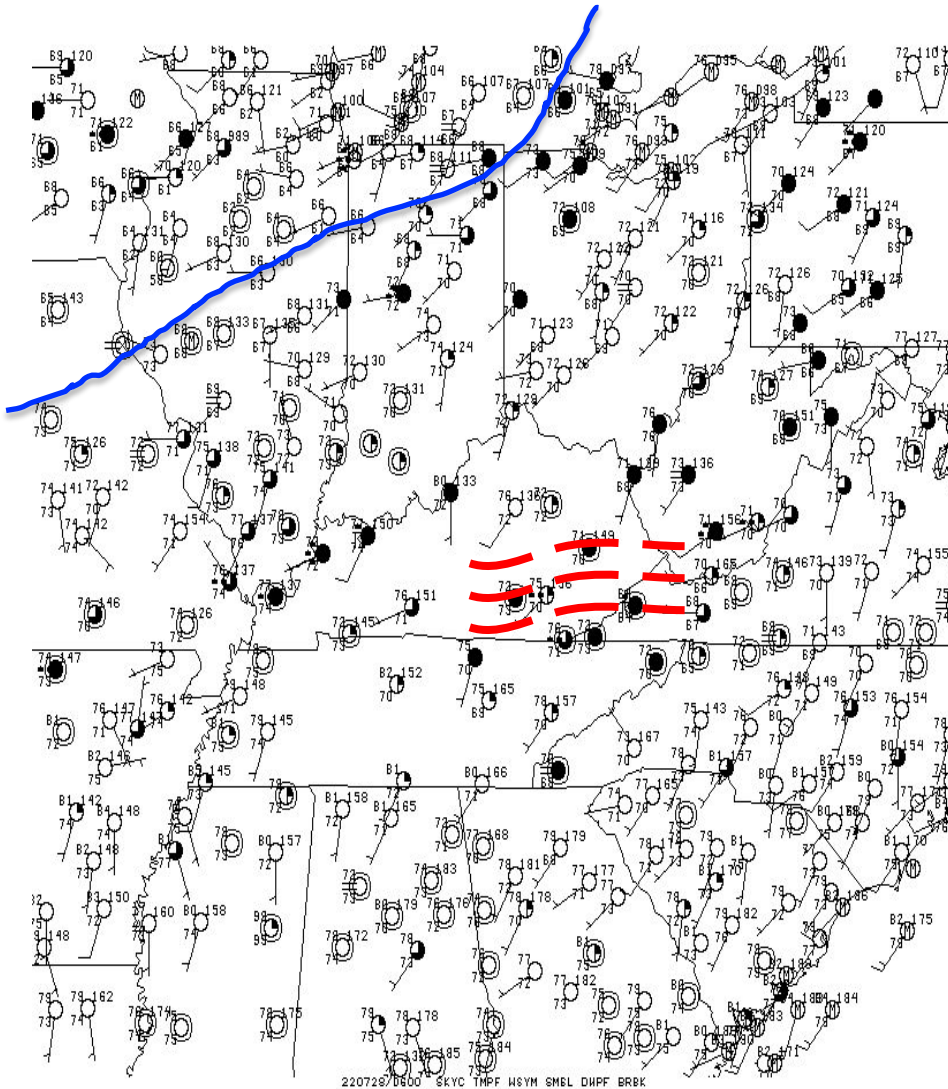
00Z 7/28/22 Surface Analysis



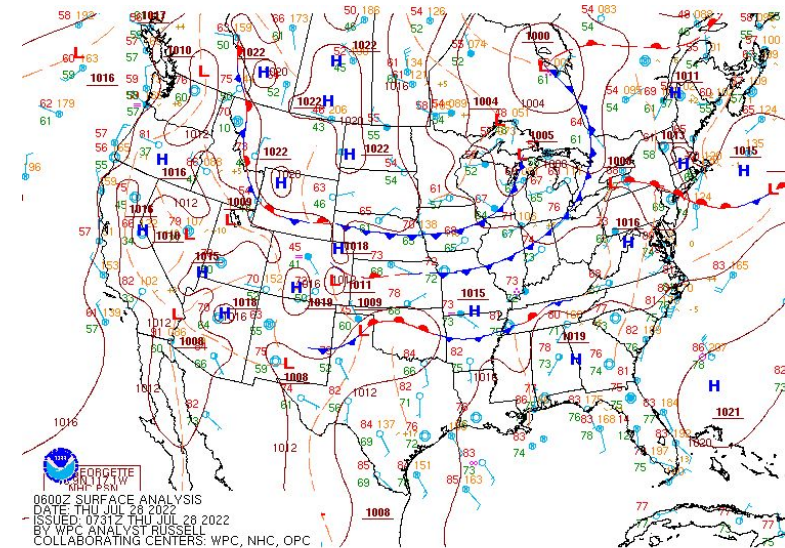
- A surface trough was situated SW-NE across central KY



06Z 7/28/22 Surface Analysis

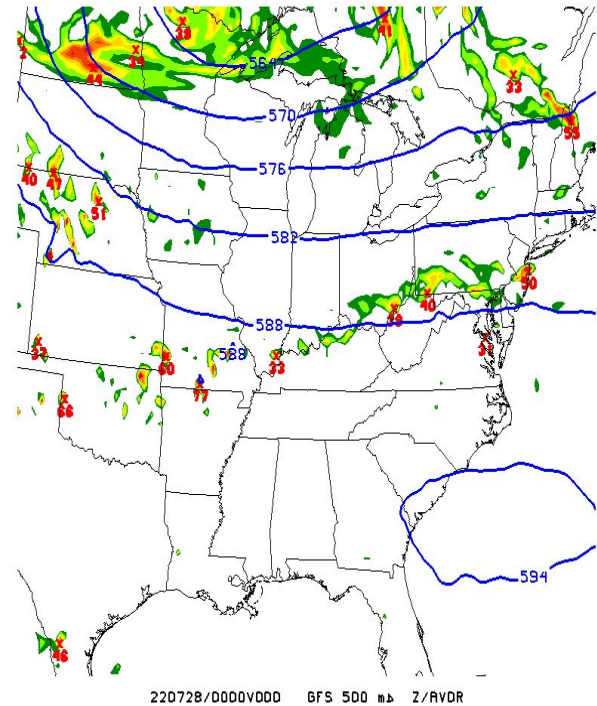


- Very difficult to identify any surface features across eastern KY at 06Z
- The remnant sfc trough feature might have still been in place over eastern KY, but it's tough to identify

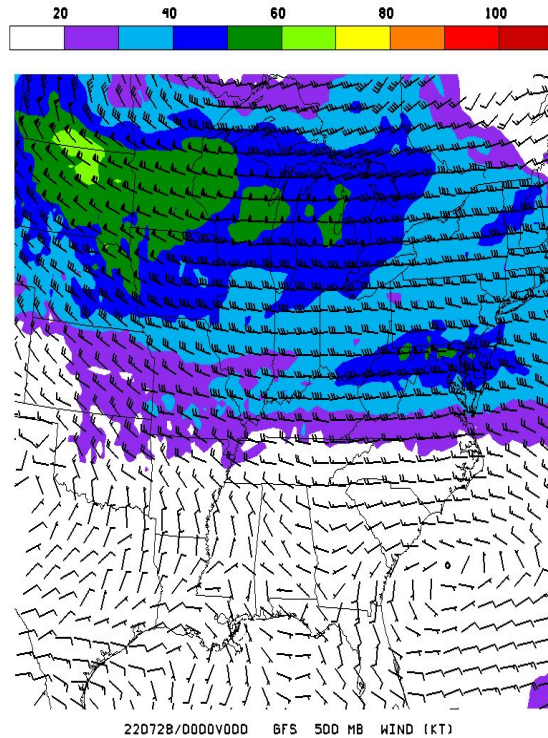


500-hPa and CAPE Analyses

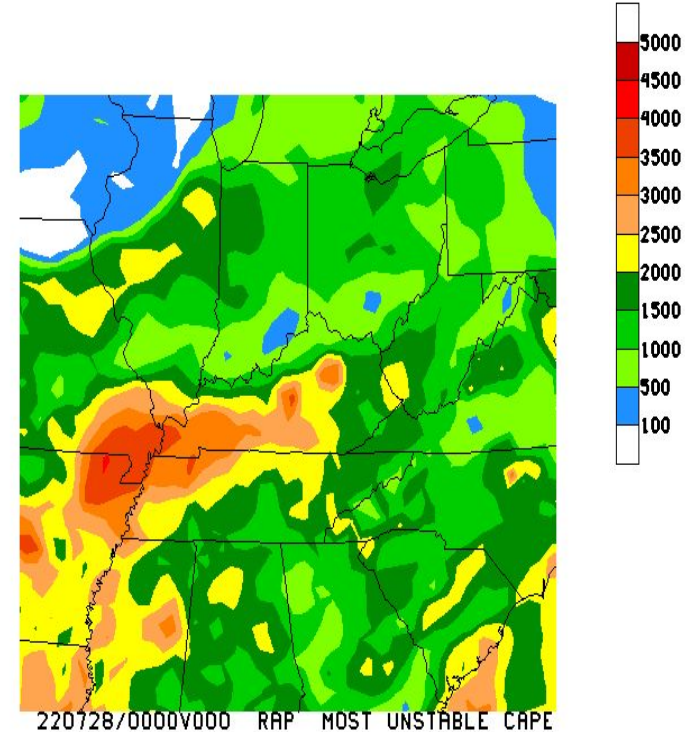
500Z 00Z 7/28



500W 00Z 7/28



MUCAPE 00Z 7/28

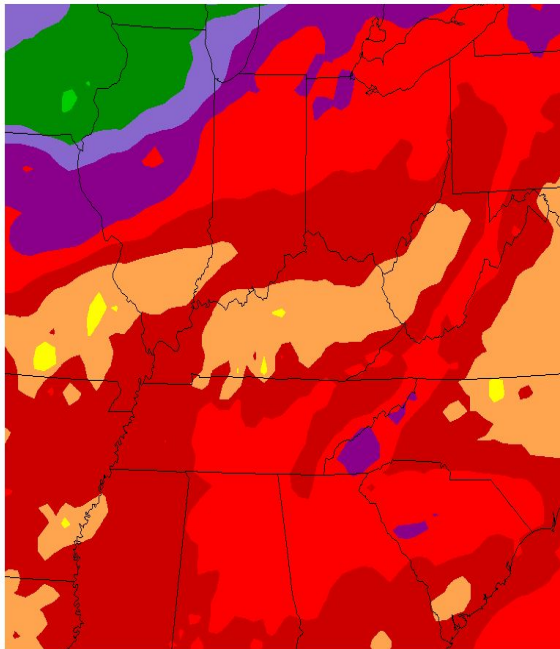
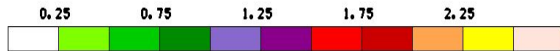


- Flow was slightly diffluent ahead of the Upper Midwest trough with moderate westerly mid-level flow
- Significant instability was available to the west / southwest of the zone of interest



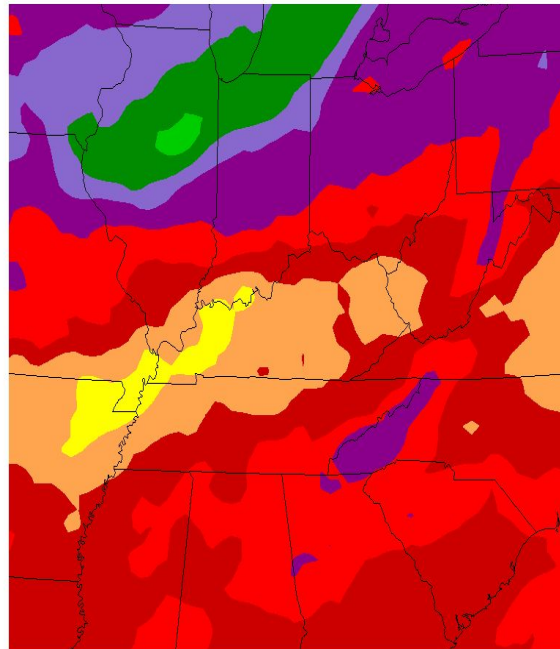
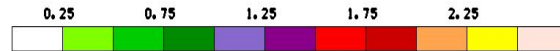
GFS PW Analyses

00Z 7/28



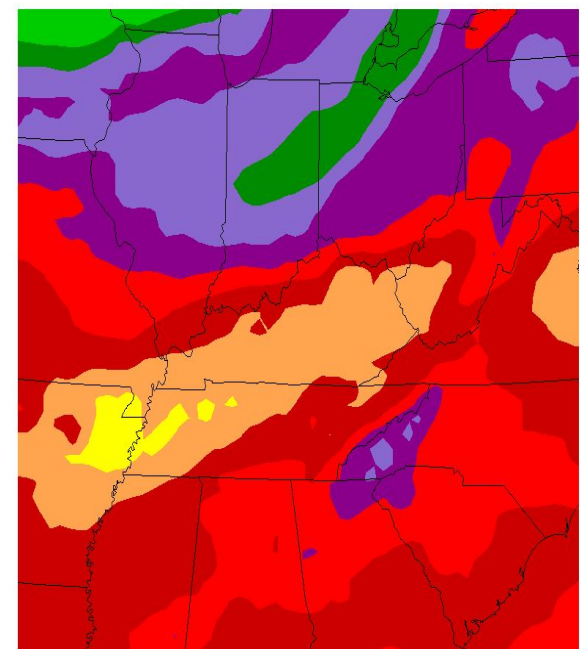
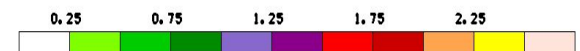
220728/0000V000 GFS PCP WATER

06Z 7/28



220728/0600V000 GFS PCP WATER

12Z 7/28



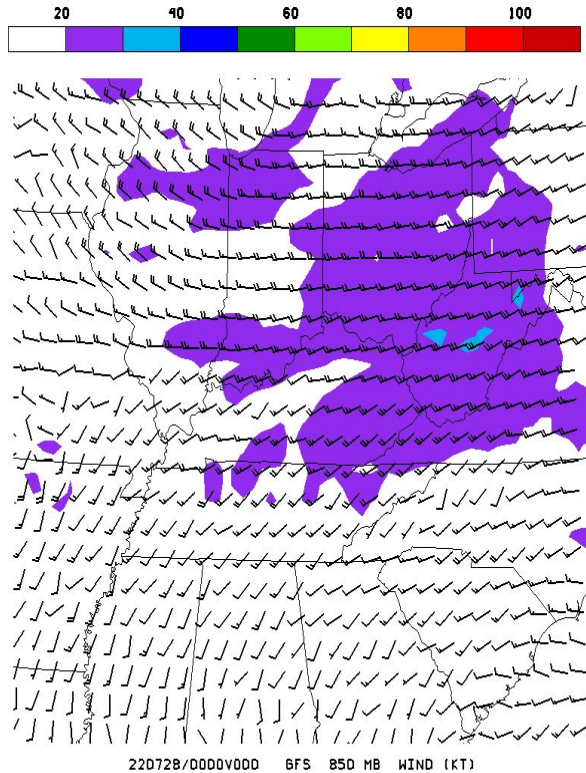
220728/1200V000 GFS PCP WATER

- There was a constant source of high PW air in that SW-NE axis across KY ahead of the surface trough

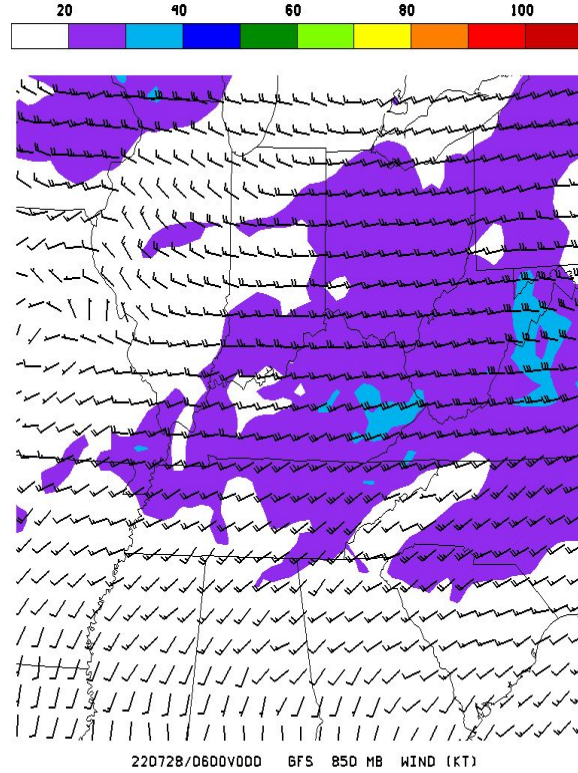


GFS 850-hPa Wind Analyses

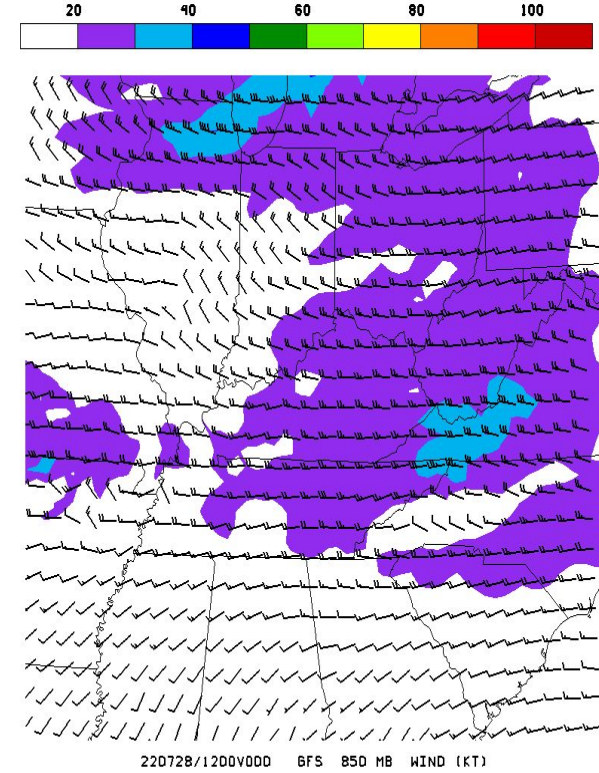
00Z 7/28



06Z 7/28



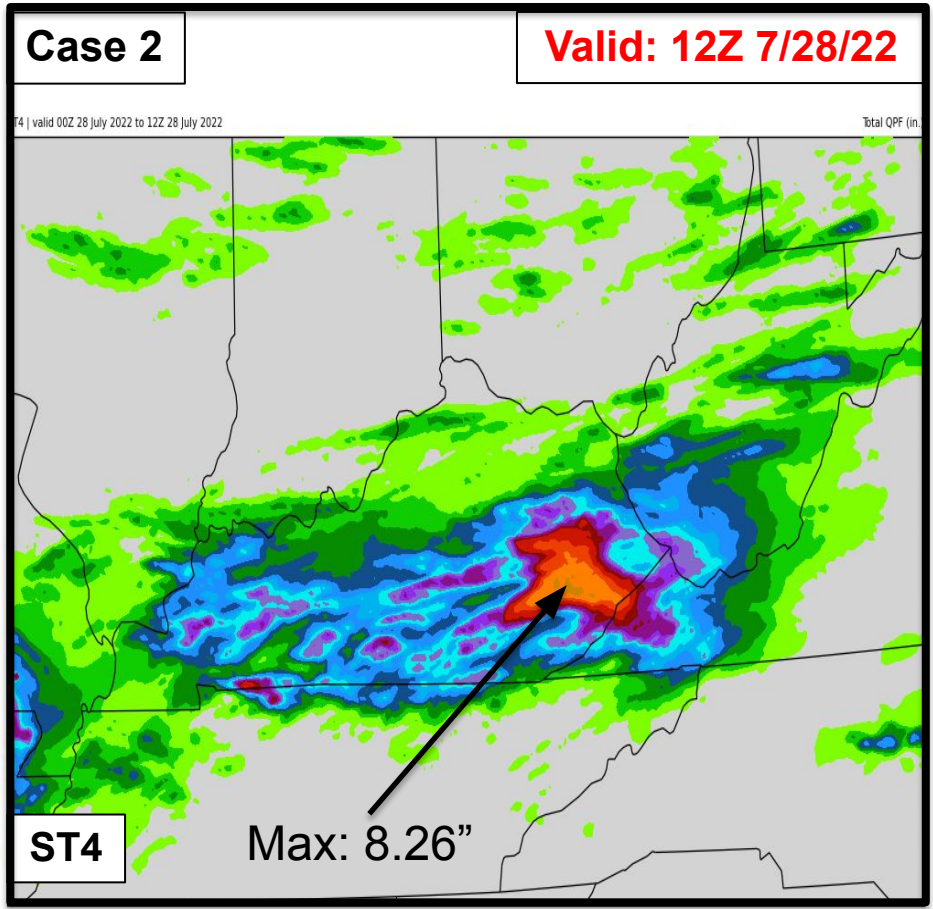
12Z 7/28



- Low-level jet (LLJ) increased after 00Z and was parallel to the low-level boundary, suggesting potential training; there was also likely interaction with terrain
- LLJ veered during the night, but some modest speed and directional convergence was implied over eastern KY at 00 and 06Z

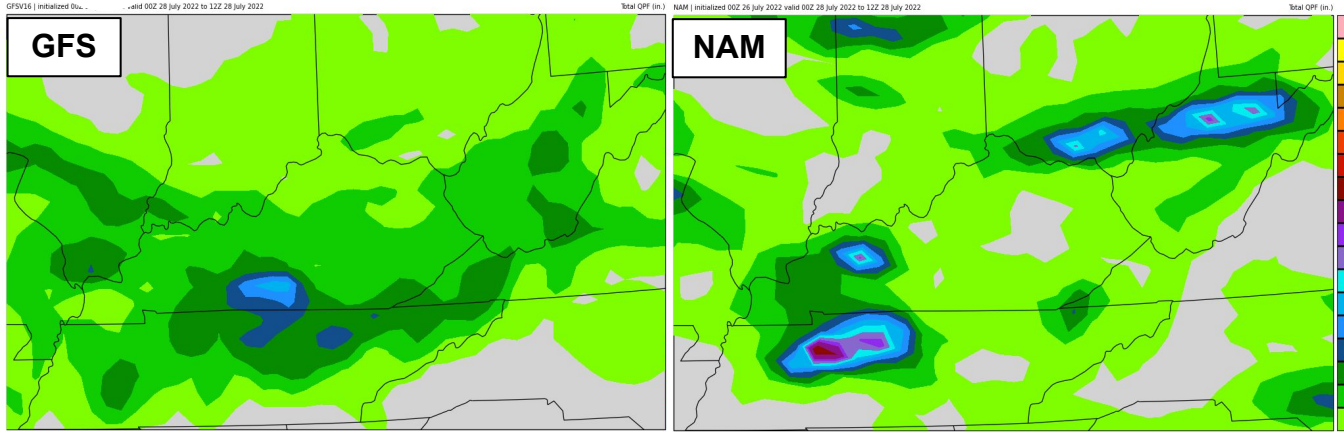


12-h Accumulated Precipitation



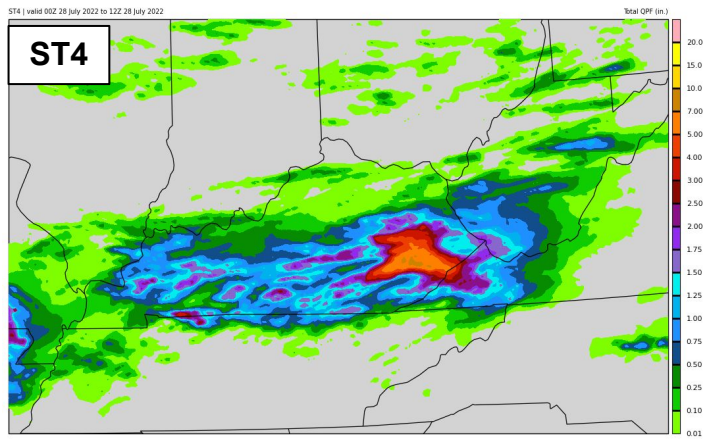


12-h QPFs



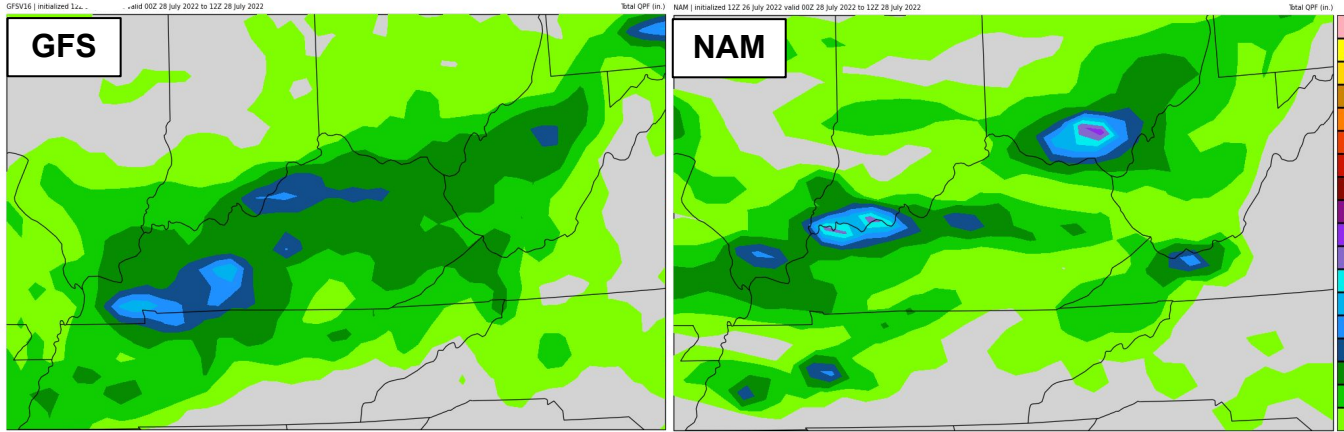
Initialized: 00Z 7/26/22
Valid: 12Z 7/28/22 (F060)

- GFS and NAM forecasted some moderate and somewhat localized precipitation in portions of the Appalachians into western KY
- Neither captured the large magnitude and extent of the analysis precipitation
- Neither focused the heaviest precipitation in eastern KY



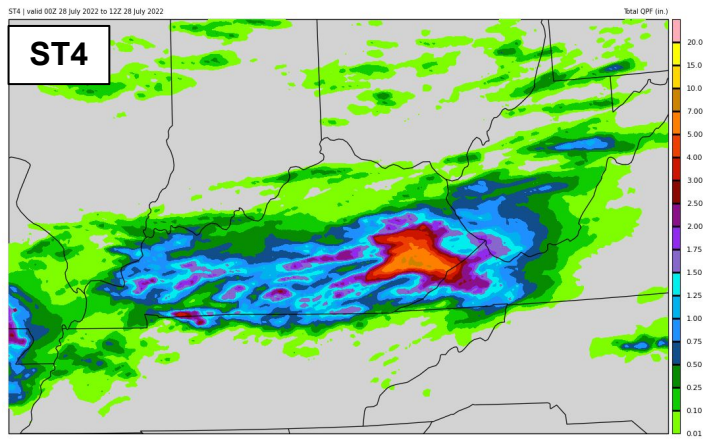


12-h QPFs



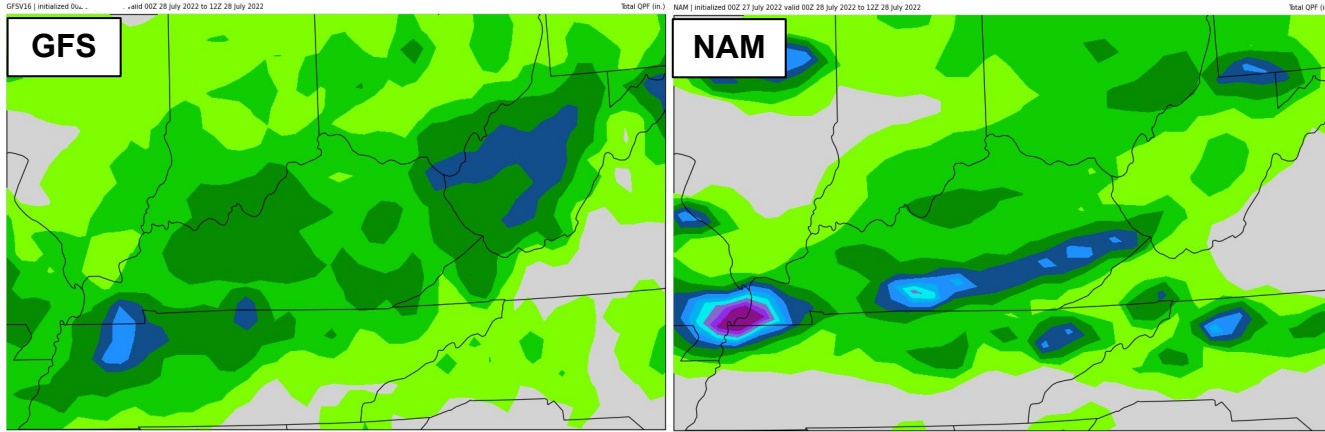
Initialized: 12Z 7/26/22
Valid: 12Z 7/28/22 (F048)

- Both models increased the precipitation extent and focused the heaviest precipitation closer to the Ohio Valley
- The GFS had the largest swath of >.25 inch precipitation (dark green contour)



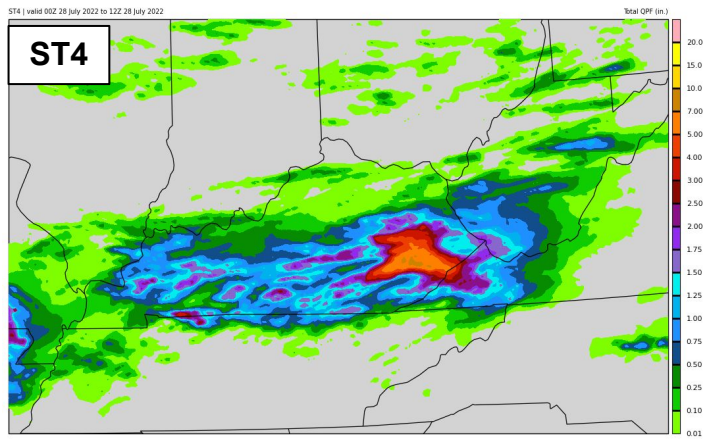


12-h QPFs



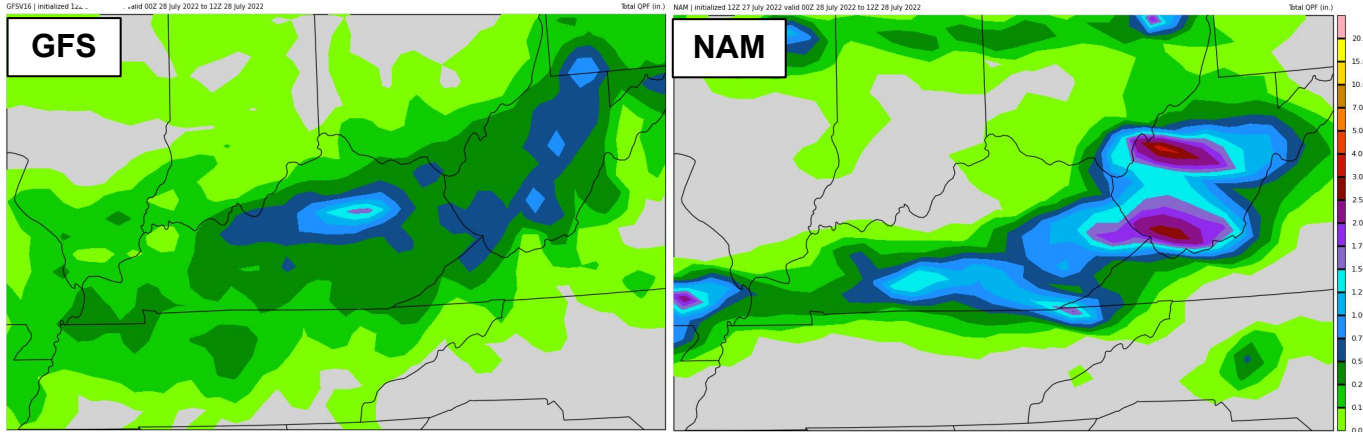
Initialized: 00Z 7/27/22
Valid: 12Z 7/28/22 (F036)

- Both models increased the magnitude of localized precipitation, shifting the heaviest precipitation farther south
- NAM indicated >2 inches of precipitation in far western KY and a large swath of >.5 inches of precipitation in south and southeastern KY



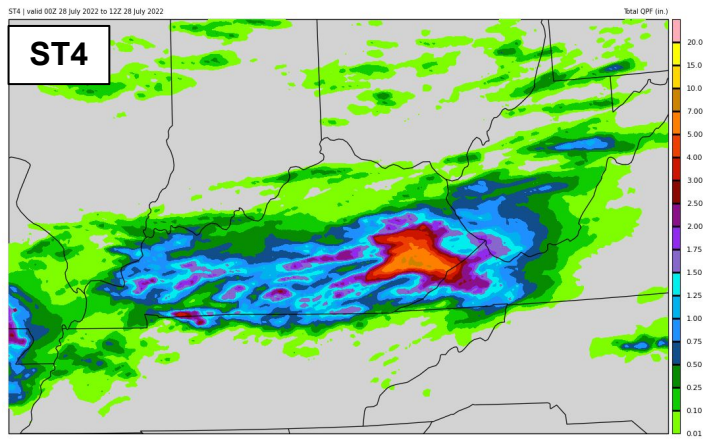


12-h QPFs



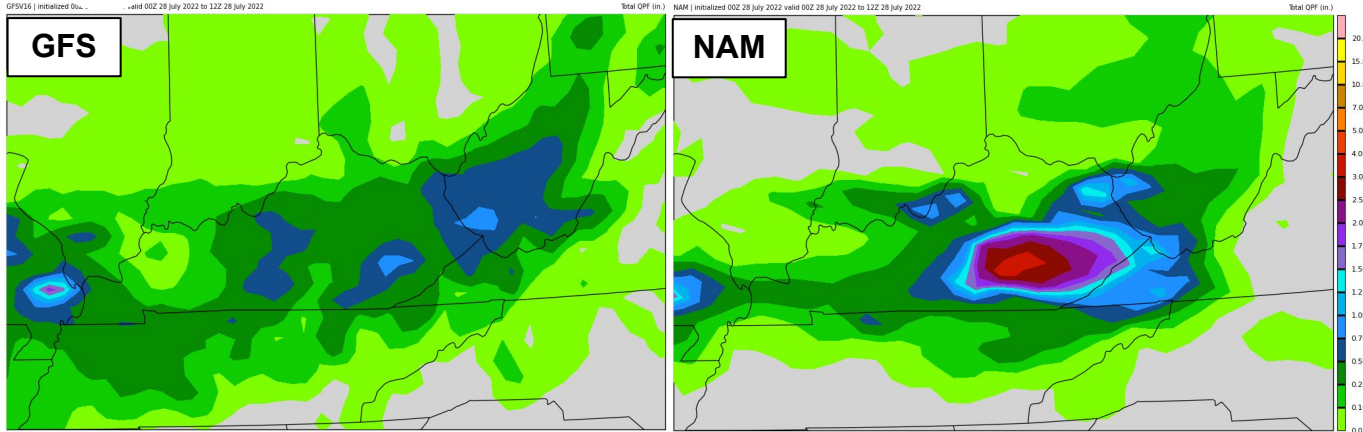
Initialized: 12Z 7/27/22
Valid: 12Z 7/28/22 (F024)

- Both models focused the heaviest precipitation in the east, toward the higher elevations, with some relative precipitation maxima in eastern KY
- Both models forecasted $>.25$ inches of precipitation over the majority of KY, but heavy precipitation was the most widespread in WV



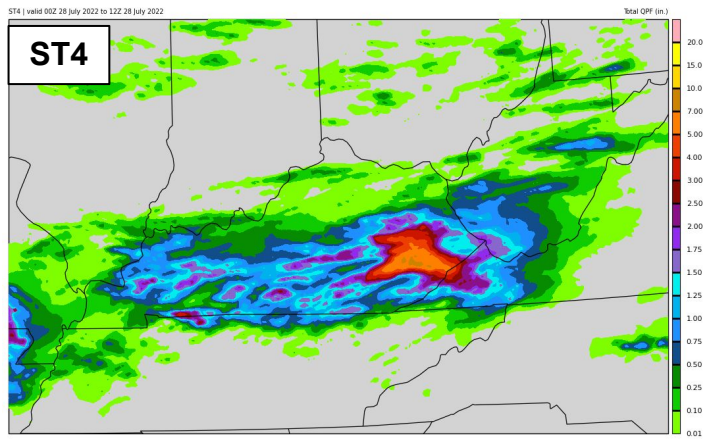


12-h QPFs



Initialized: 00Z 7/28/22
Valid: 12Z 7/28/22 (F012)

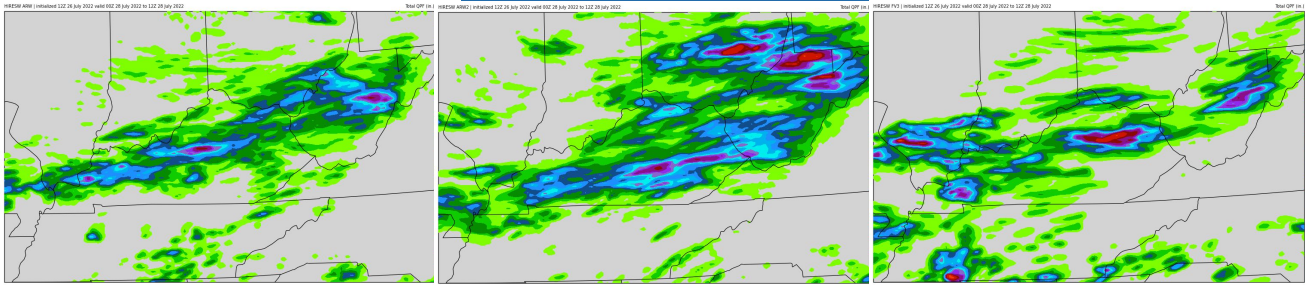
- NAM substantially increased precipitation over eastern KY, forecasting a 3.76 inch maximum
- GFS moved the heaviest precipitation southward, but did not correctly forecast the magnitude of either the widespread or localized heavy precipitation in southern KY





12-h QPFs

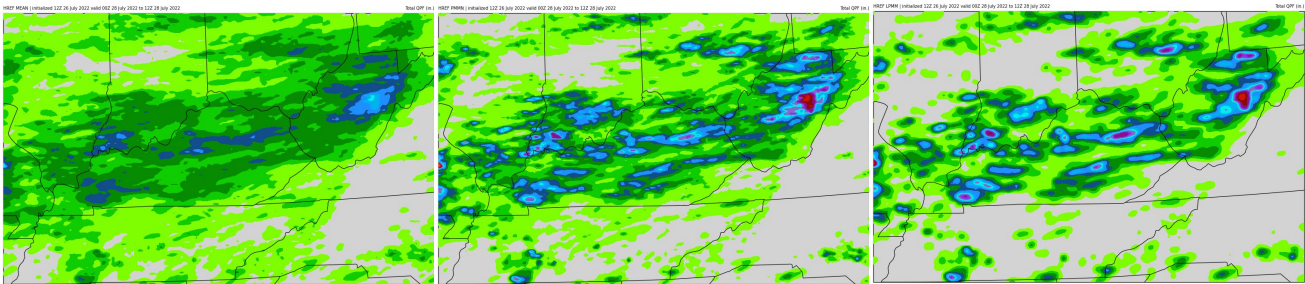
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HRW-ARW

HRW-ARW2

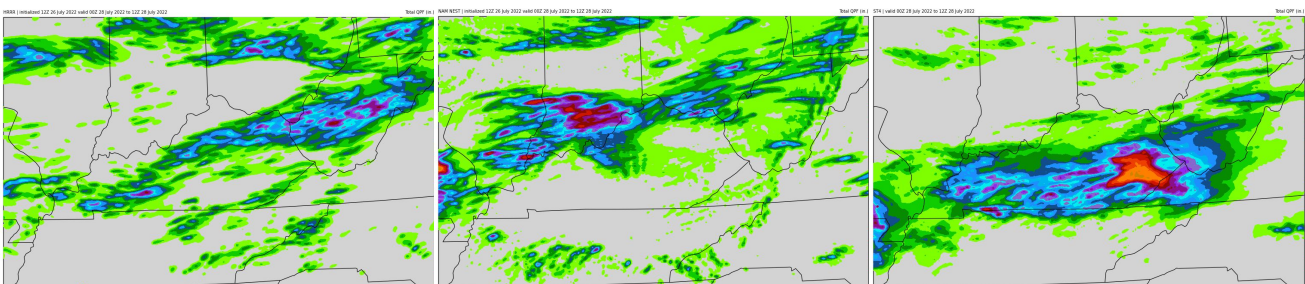
HRW-FV3



HREF Mean

HREF PMMN

HREF LPMM



HRRR

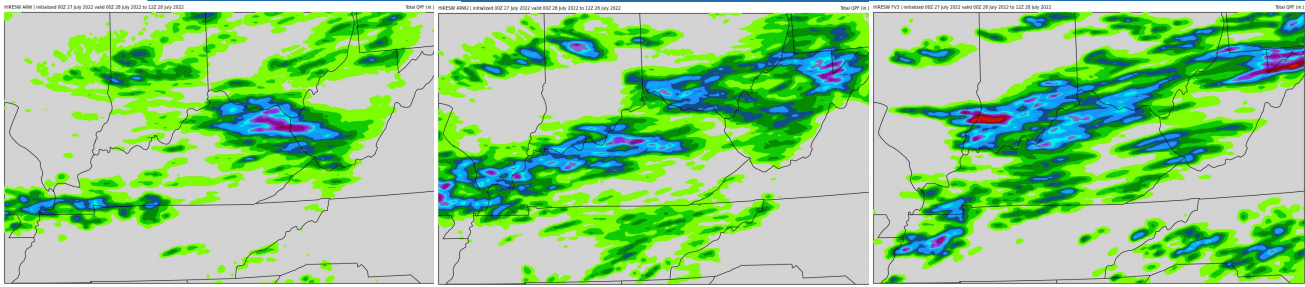
NAM Nest

ST4

- High res. models forecasted heavy precipitation that was more scattered across the domain and less heavy compared to the analysis
- HREF output types had among the most widespread precipitation with the lowest maxima, particularly the Mean
- NAM Nest had the largest single region of >1 inch precipitation (none of it in KY)
- HRW-ARW2 best captured the large swath of heavy precipitation in southern KY



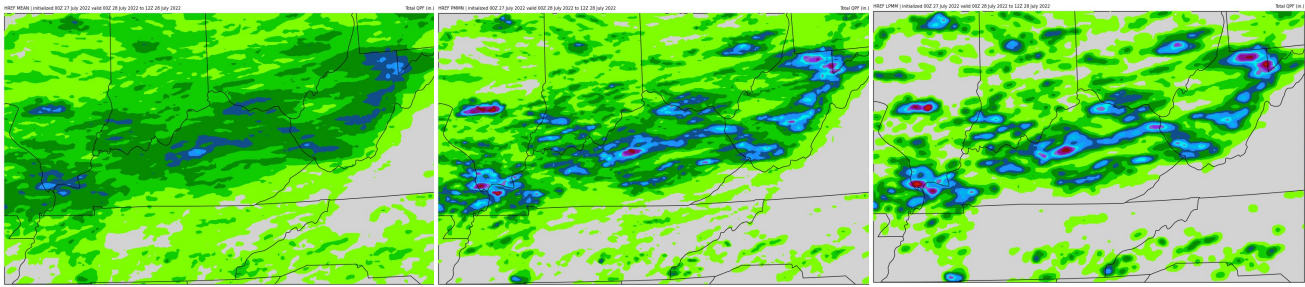
12-h QPFs



HRW-ARW

HRW-ARW2

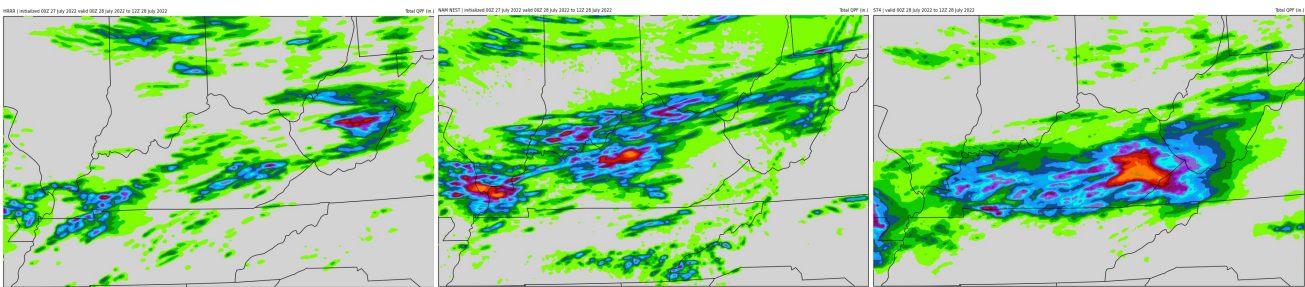
HRW-FV3



HREF Mean

HREF PMMN

HREF LPMM



HRRR

NAM Nest

ST4

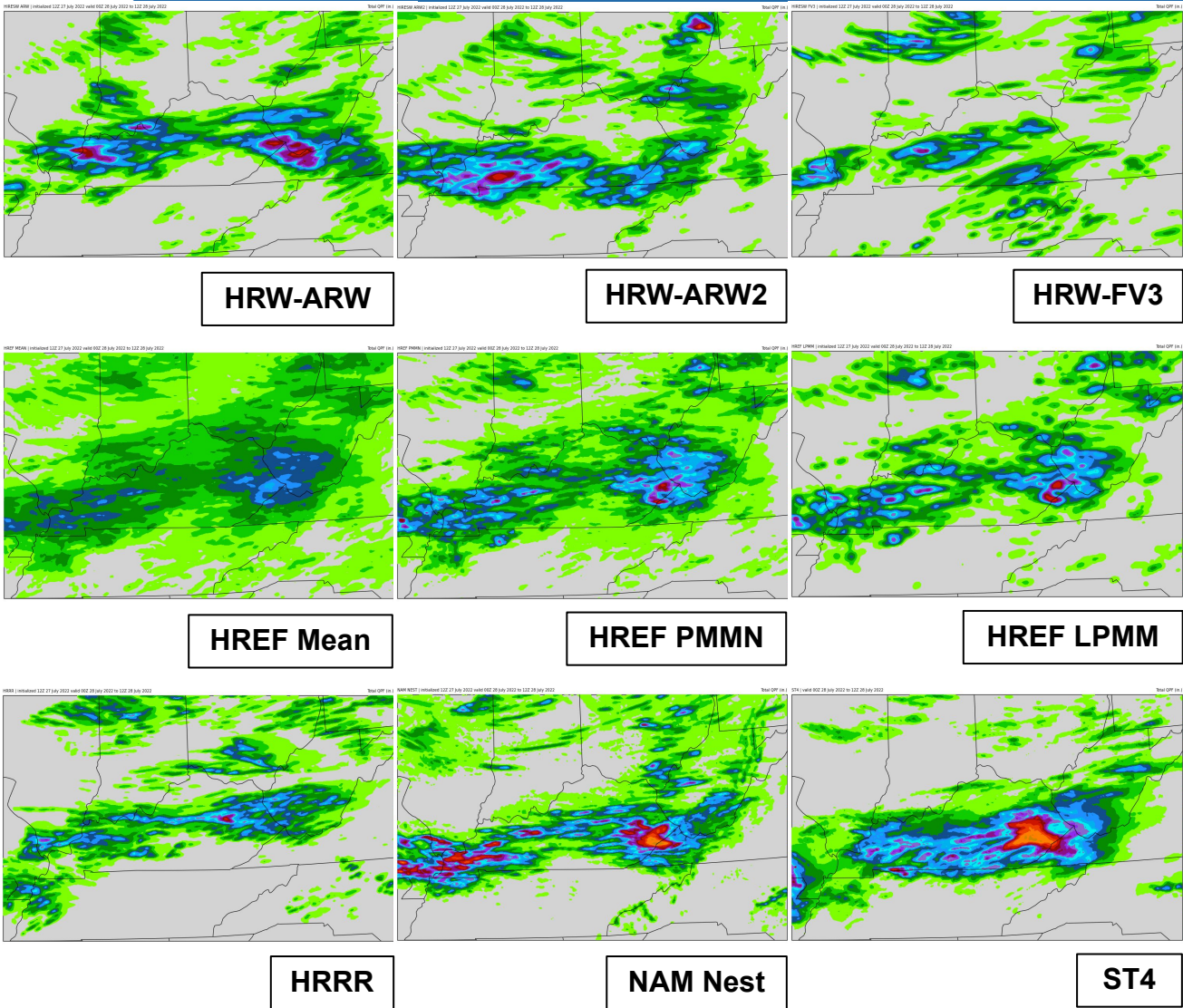
Initialized: 00Z 7/27/22
Valid: 12Z 7/28/22 (F036)

- Models continued to forecast mostly scattered heavy precipitation overall
- None of the models indicated widespread heavy precipitation across southern KY
- Some, like the NAM Nest and HRW-ARW, forecasted a large area of heavy precipitation elsewhere in KY



12-h QPFs

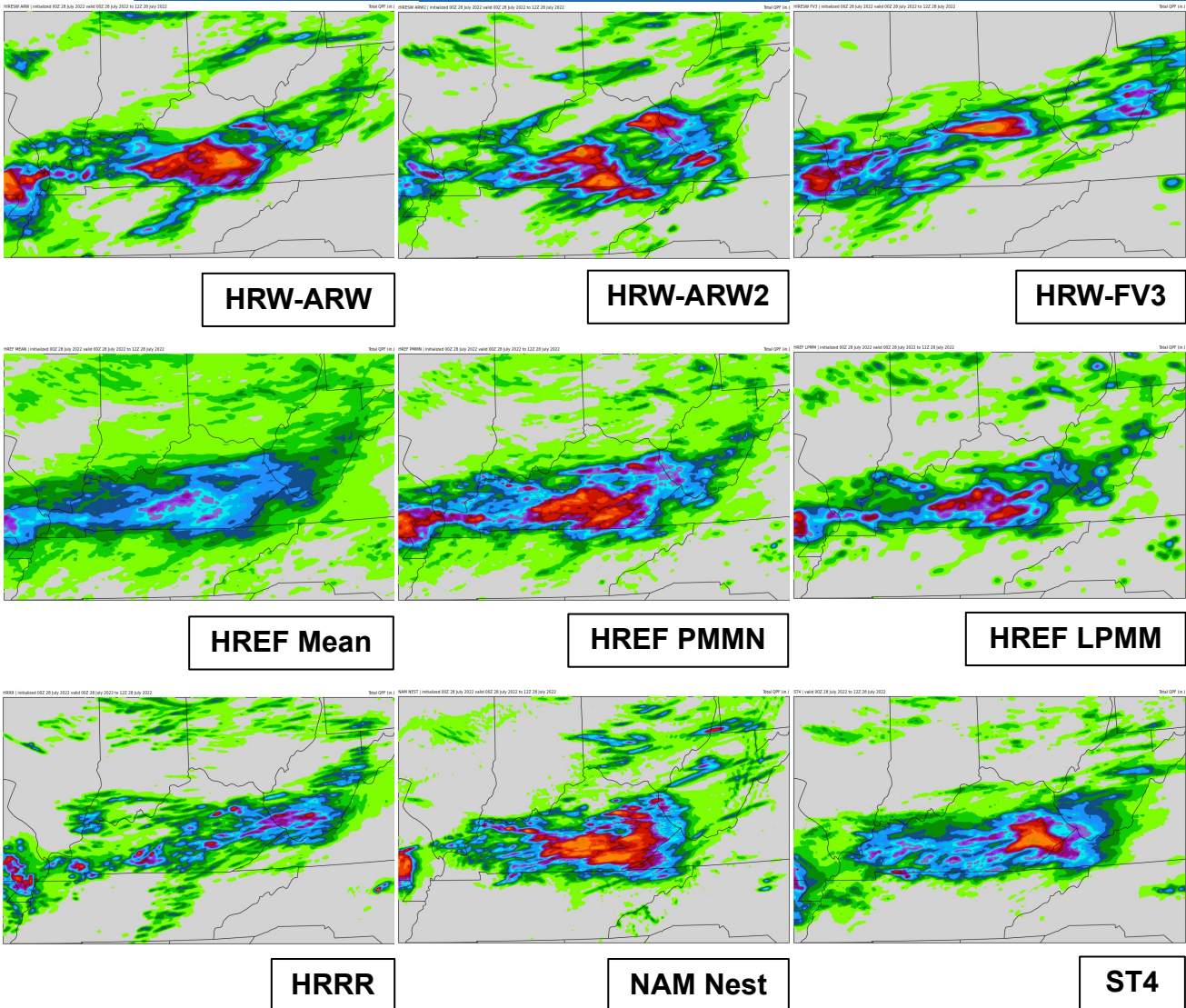
Initialized: 12Z 7/27/22
Valid: 12Z 7/28/22 (F024)



- Models overall shifted precipitation to southern KY across a ~zonally oriented area
- Most models forecasted two areas of heavy precipitation in eastern and western KY, with lighter precipitation in between
- Overall, the placement of the eastern area matched somewhat with analysis, but its magnitude did not
- Exception in the NAM Nest, which did capture the magnitude of the event in eastern KY (12.49 inch max)



12-h QPFs



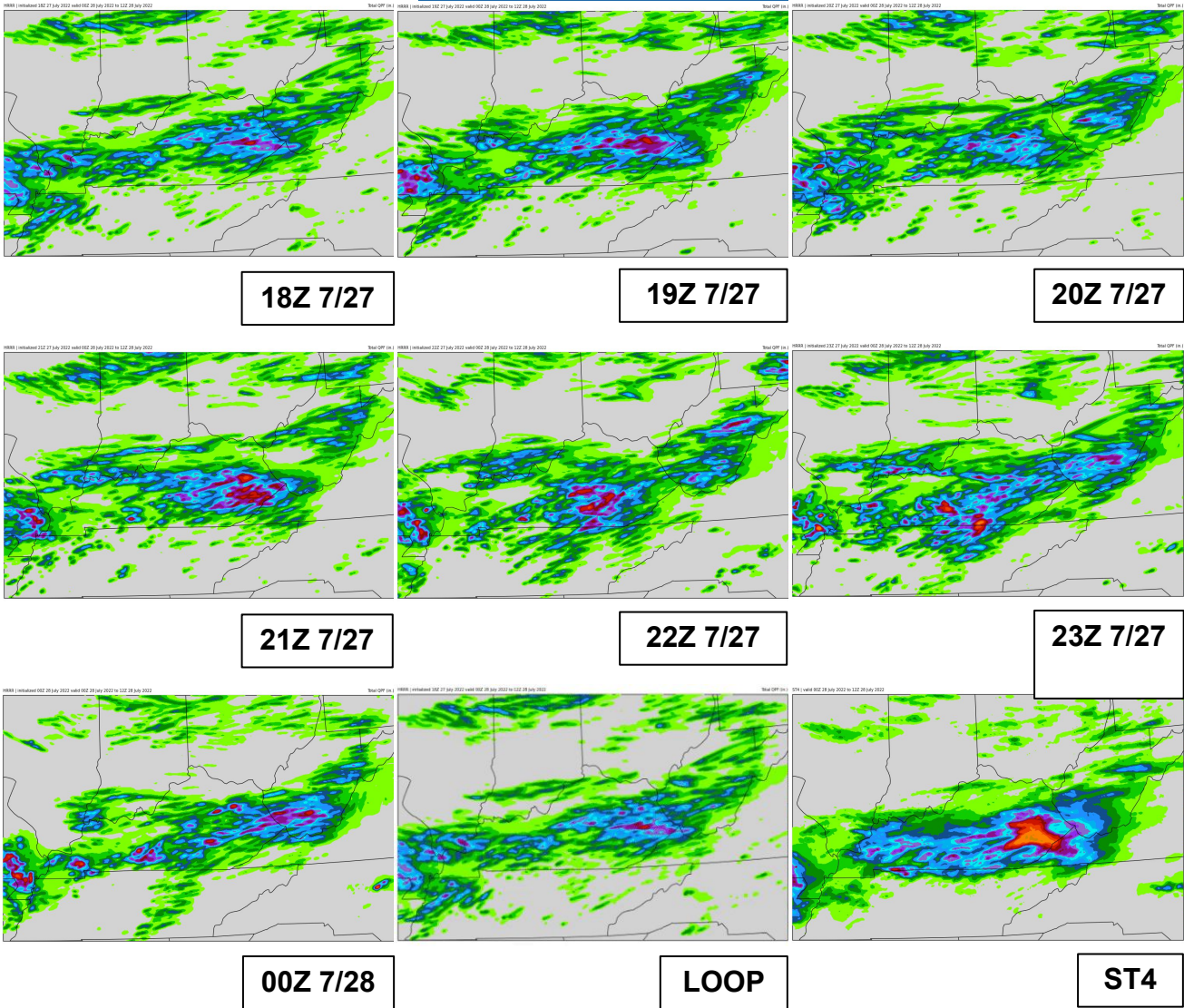
Initialized: 00Z 7/28/22
Valid: 12Z 7/28/22 (F012)

- Models substantially increased the magnitude of precipitation in southern KY overall
- The HRW-ARW and NAM Nest correctly forecasted large areas of very heavy precipitation in southeastern KY, but these areas were too large
- HREF placed similar areas of heavy precipitation too far west, but the PMMN correctly restored amplitude to the Mean
- HRRR was still too weak



HRRR Trends: 12-h QPFs

Init: 18Z 7/27 to 00Z 7/28/22
Valid: 12Z 7/28/22 (F012-018)



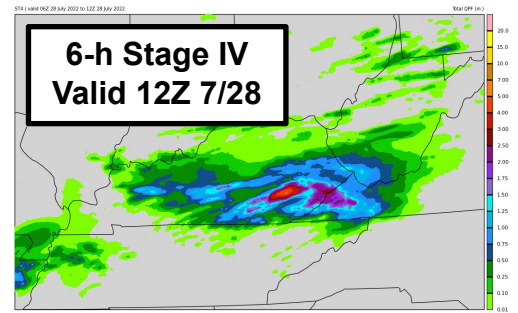
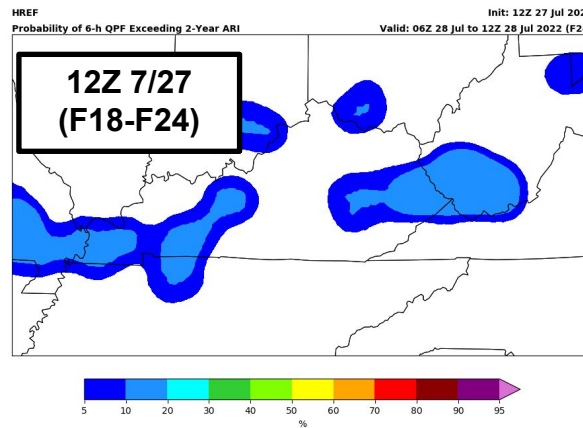
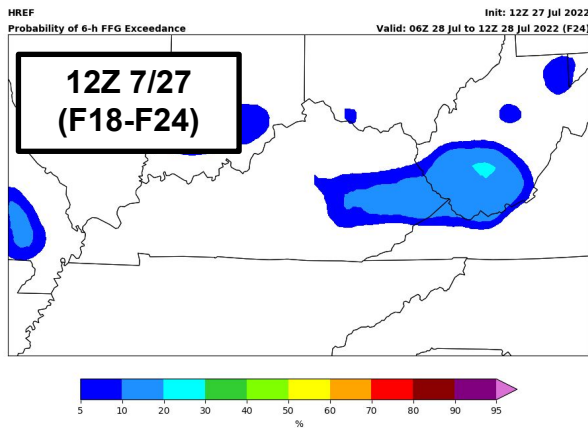
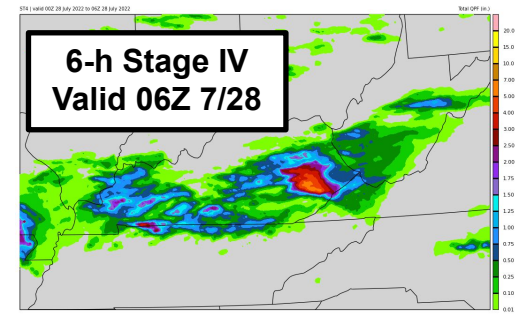
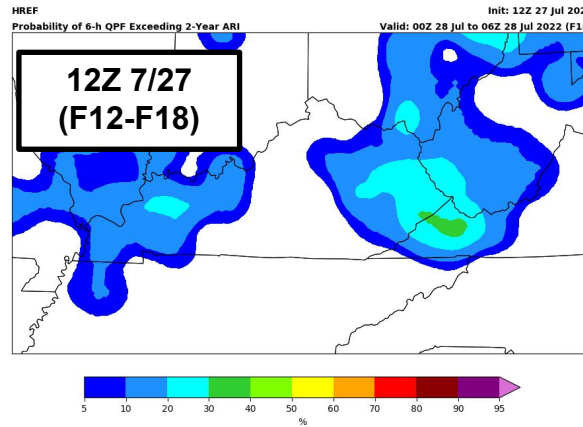
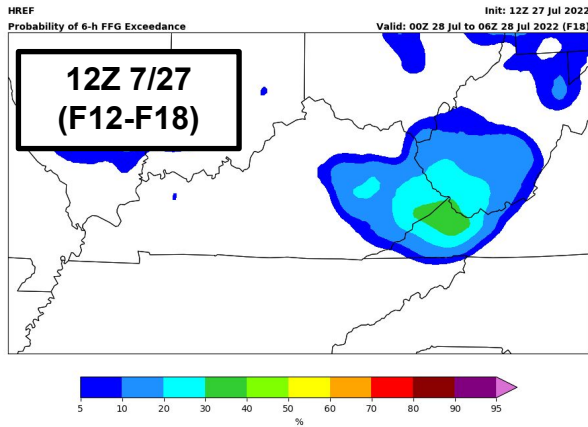
- Later HRRR cycles trended toward a correctly more intense precipitation feature in eastern KY from 18Z-21Z 7/27
- The same feature incorrectly trended southwestward from 21Z-23Z, and incorrectly weakened at 00Z 7/28.



HREF Probabilities Were Not Especially Useful

6-h QPF FFG Probabilities

6-h QPF 2-Year ARI Probabilities



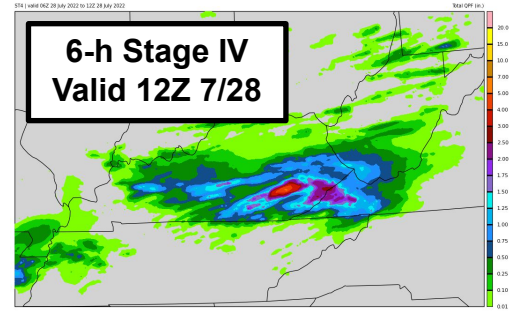
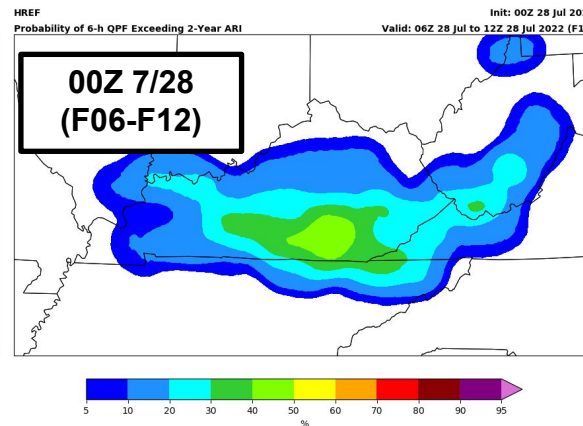
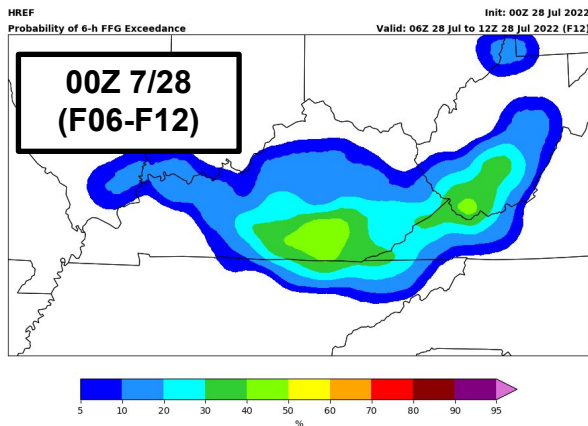
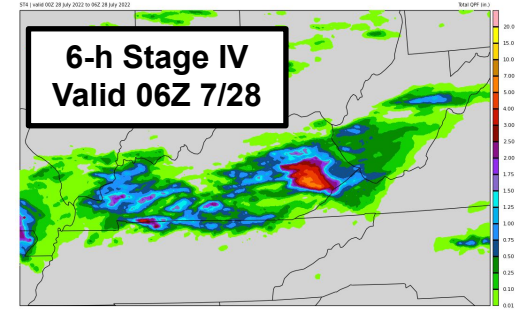
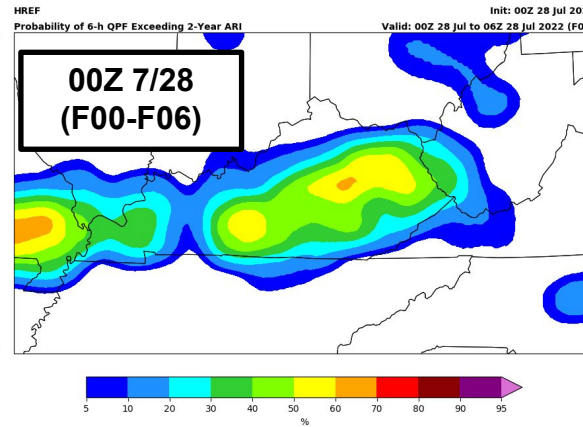
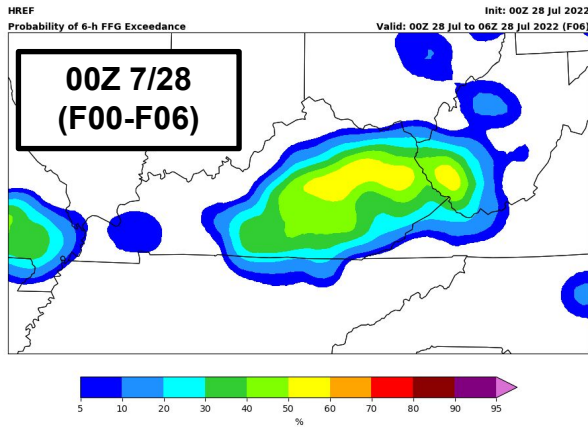
- Probabilities in 12-24-h forecasts were not particularly notable



Very Short-Term Forecasts Showed Some Signal

6-h QPF FFG Probabilities

6-h QPF 2-Year ARI Probabilities

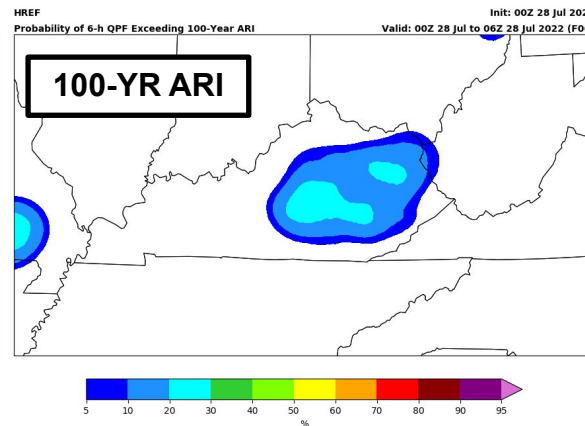
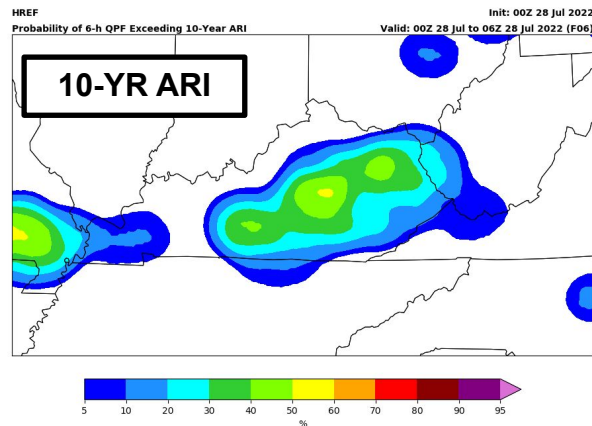
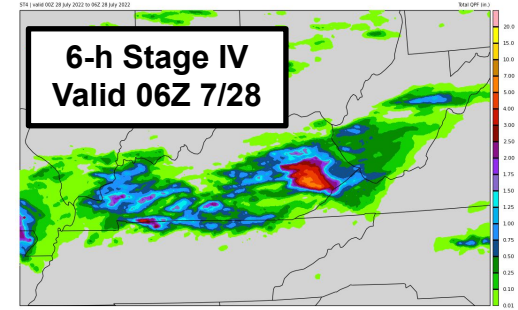
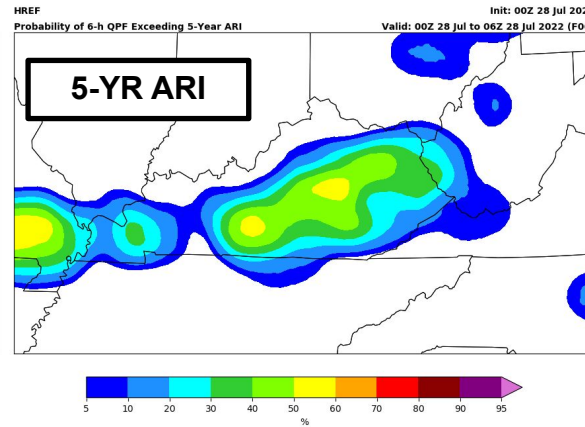
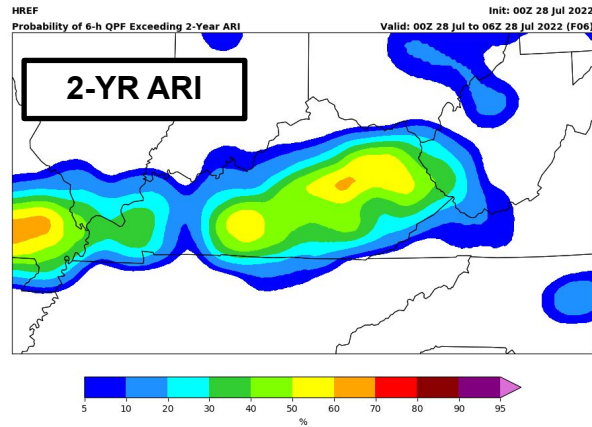


- As with the STL event, heavy rain began before these HREF forecasts would have been available



Very Short-Term Forecasts Showed Some Signal

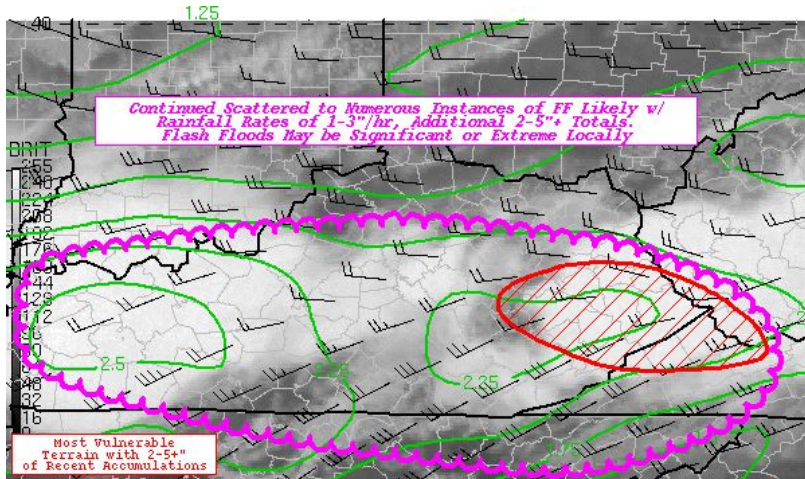
00Z 7/28/2022 Cycle: Valid 00Z-06Z 7/28/22 (F06)



- HREF ARI exceedance probabilities indicated a relatively good chance of a heavy rain event, but the probability maxima were displaced to the northwest of the observed maximum
- Again, with the heavy rain beginning before these HREF products would have been available, these forecasts likely had limited utility in messaging during the overnight hours



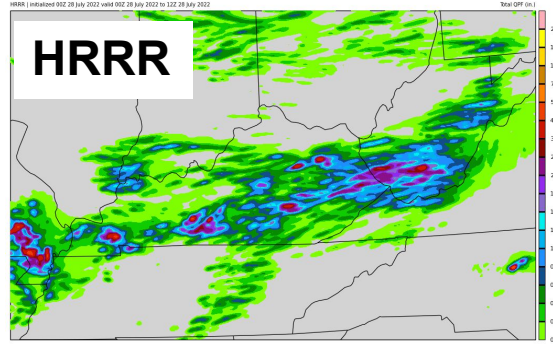
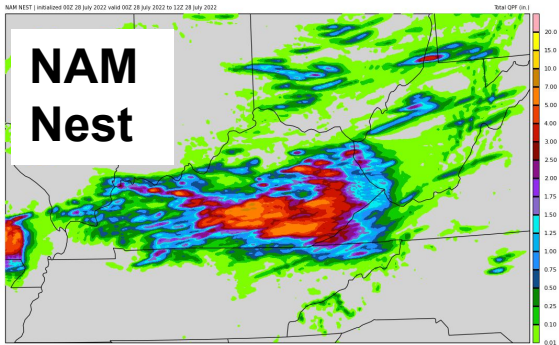
One MPD of Note (Text Included Below)



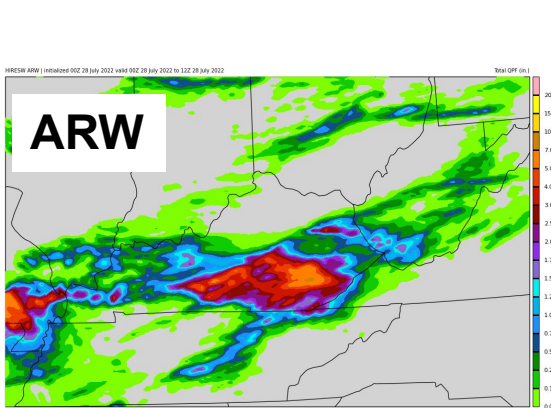
220728/0540 GOES16 RGB PROXYVIS
RAP32 PRECIP WATER 220728/0500f1
RAP32 850 MB WINDS 220728/0500f1
WPC MPD #0607

- “Continued scattered to numerous instances of flash flooding are likely with rainfall rates of 1-3"/hr supporting additional localized totals of 2-5"+. Some flash floods may be significant or extreme locally, given antecedent conditions.”
- “The ARW and NAM-nest appear to have the best handle on ongoing convection with southern KY (and perhaps far northern Middle/East TN) having the best odds of realizing these additional amounts. More recent HRRR runs agree with this placement as well, though the HRRR is notably much more tempered with rainfall intensity overall (indicating localized totals of only ~1-2"). The ARW and NAM-nest magnitudes make more sense given what has occurred thus far, though the spatial extent of these indicated totals are likely a bit overdone.”

One MPD of Note (Text Included Below)



00Z Cycles 7/28/22



- “The ARW and NAM-nest appear to have the best handle on ongoing convection with southern KY (and perhaps far northern Middle/East TN) having the best odds of realizing these additional amounts. More recent HRRR runs agree with this placement as well, though the HRRR is notably much more tempered with rainfall intensity overall (indicating localized totals of only ~1-2”). The ARW and NAM-nest magnitudes make more sense given what has occurred thus far, though the spatial extent of these indicated totals are likely a bit overdone.”



July 2022



Flooding - Messaging from NWS Jackson

<https://drive.google.com/drive/folders/1jrNVUN3NFrMDrpI3TPZvjKSJGBjZgzCp>

- The main thing to note is that despite the Jackson NWS Office advertising the flash flood potential, none of our briefing packages on any updates that we made had any wording with “significant flash flooding threat is increasing”.
- We talk about enhanced warning on the warning operations side, but what about during the watch side. We didn’t use any stronger language to alert people to anticipate the signal for more dangerous/intense flash flooding.
 - Why!?
- **It just wasn’t clear! We didn’t have the *confidence* to elude to this being a highly impactful event - certainly not to the magnitude that the actual event unfolded**





July 2022 Flooding



<https://www.weather.gov/jkl/July2022Flooding>



Building a Weather-Ready Nation



July 2022 Flooding



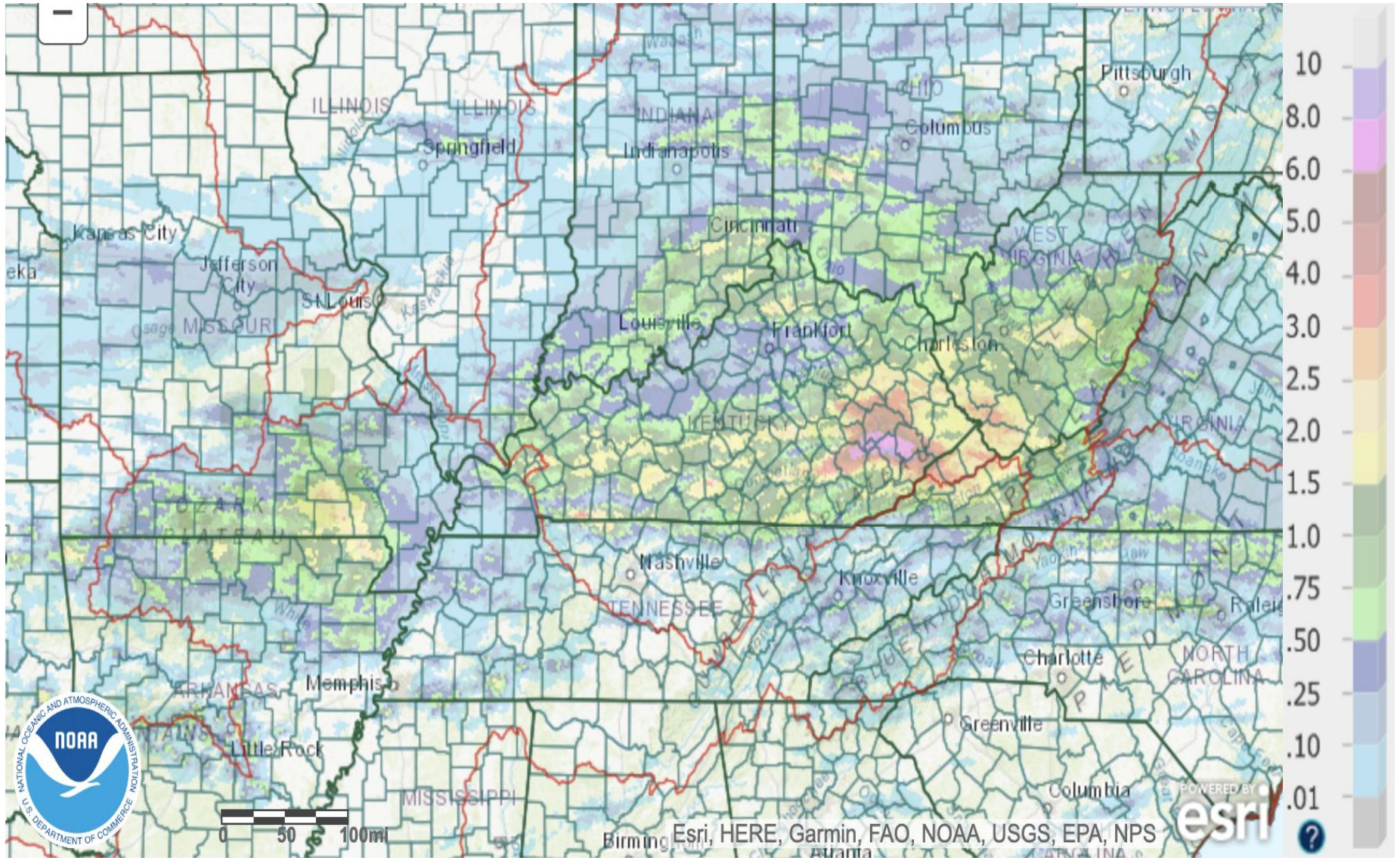
Experimental Warn on Forecast (WoFS)...

How did it do?

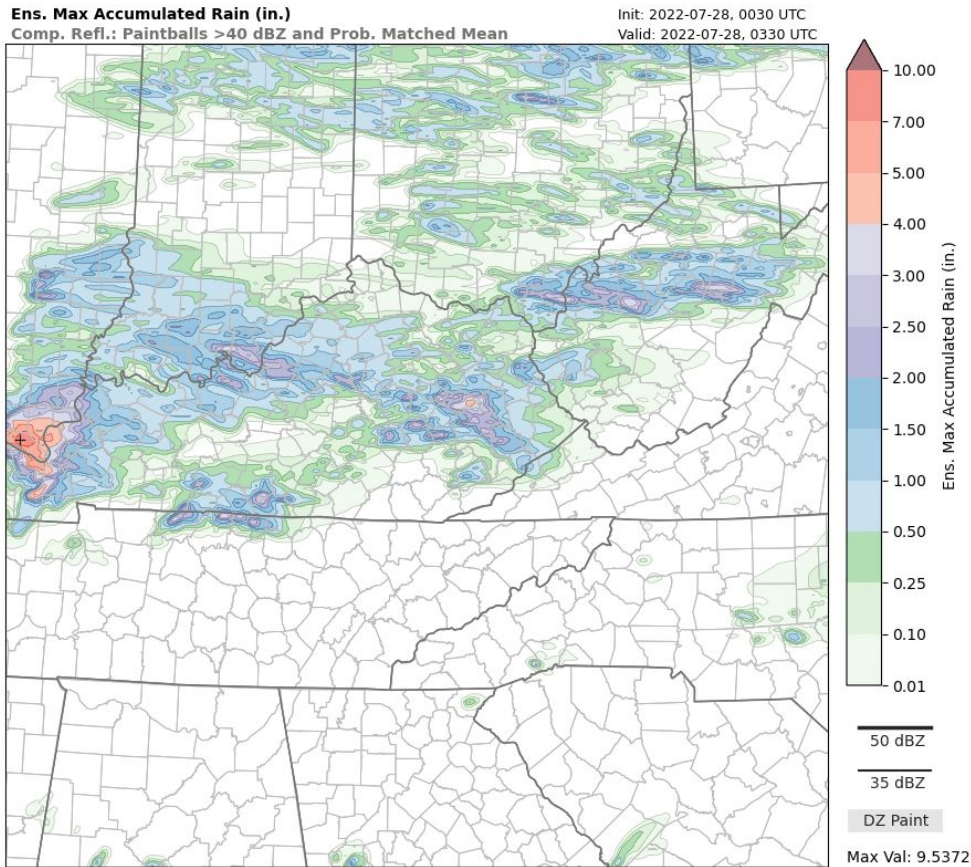
(Patrick Burke)



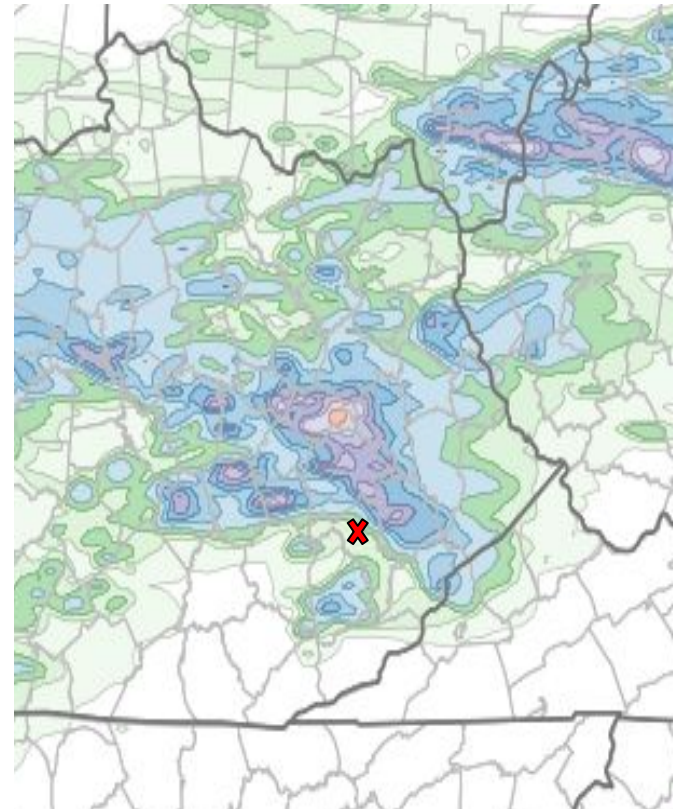
STAGE-IV Precip from water.weather.gov/precip, 24 hours ending 12Z on 28 July



Best WoFS signal we could find...



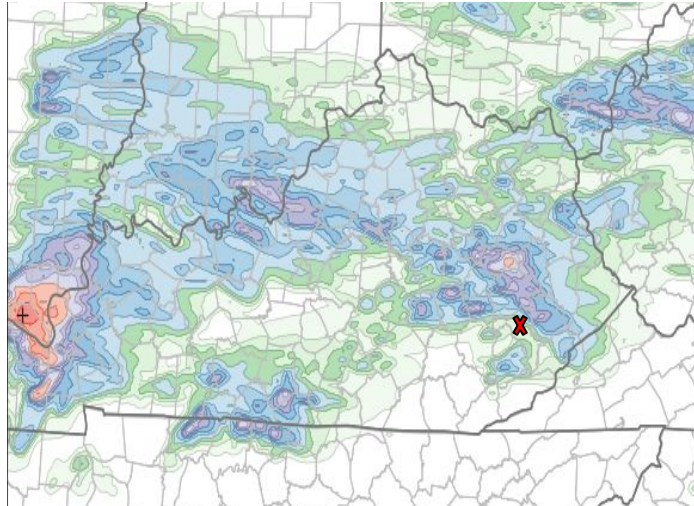
0030 Z WoFS run,
Max percentile QPF valid
0030-0330 Z



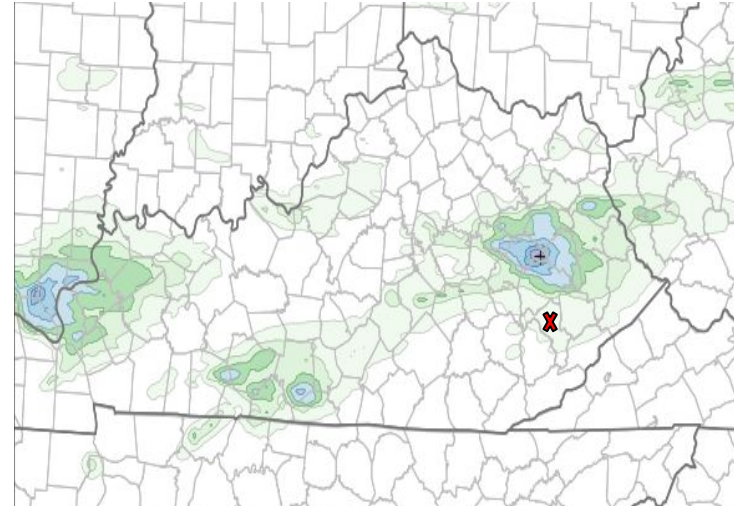
5 inch rain max located approx.
80 km north of the observed max
at Hazard, KY.

0030Z WoFS Run

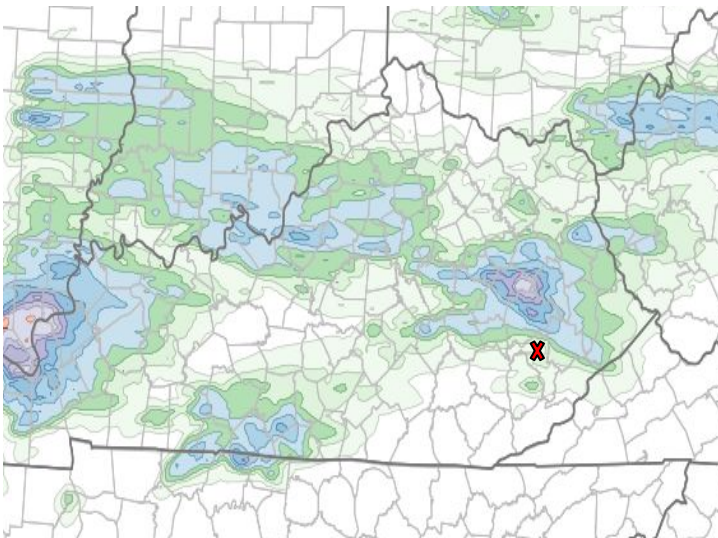
Max Percentile



50th Percentile



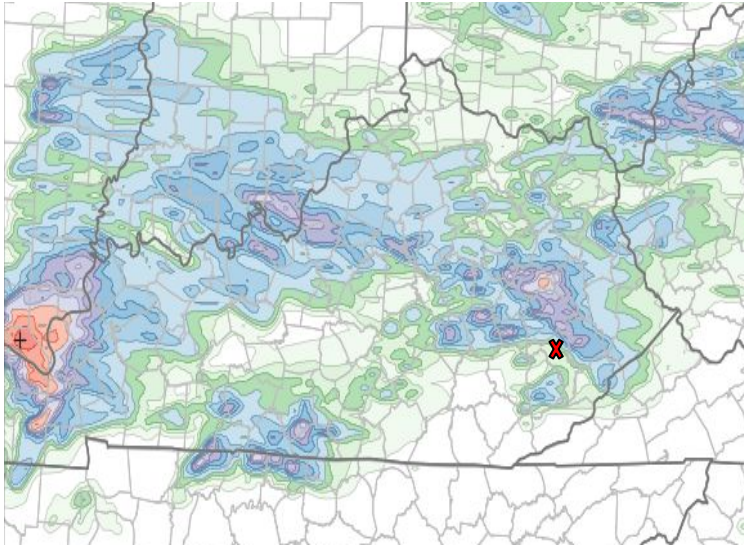
90th Percentile



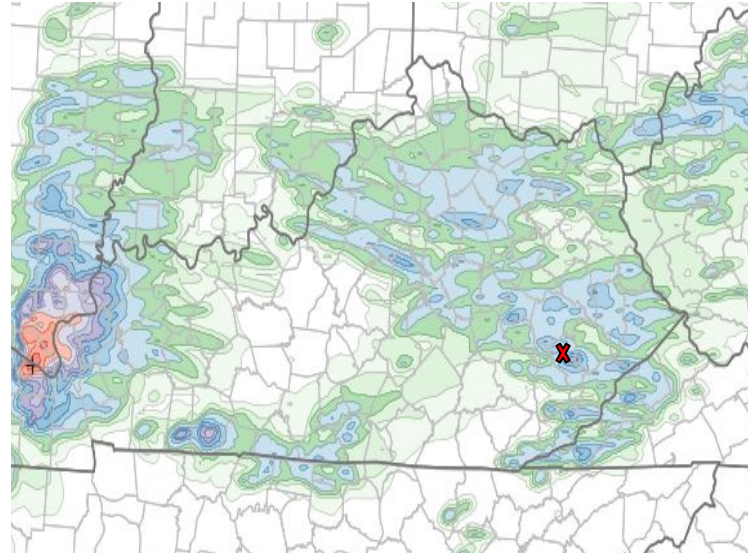
Although WoFS was hitting western KY harder, at least this 0030Z run had some bolstered signal over eastern KY, if still displaced from the actual event.

The tiny black crosshair on the 50th percentile plot means the spot 80km north of the event had the highest forecast QPF in the domain (2.60") for that product. (For other products the crosshair was in western KY)

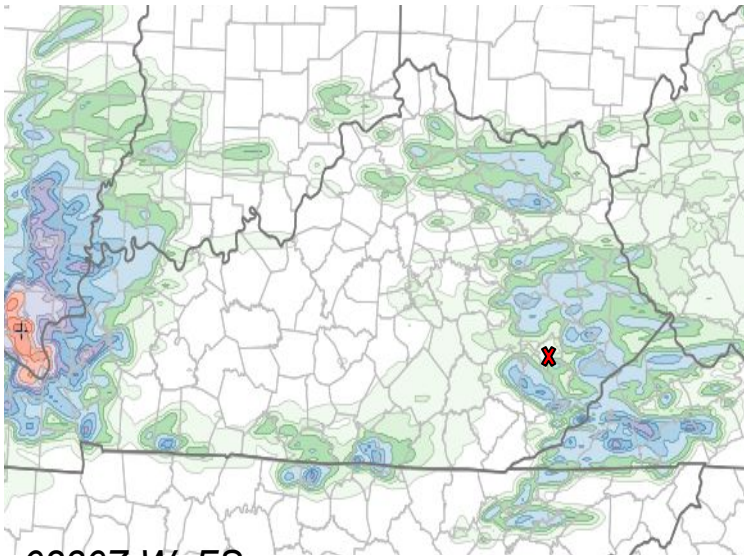
3-hour accumulated forecast rainfall, max percentile



0030Z WoFS



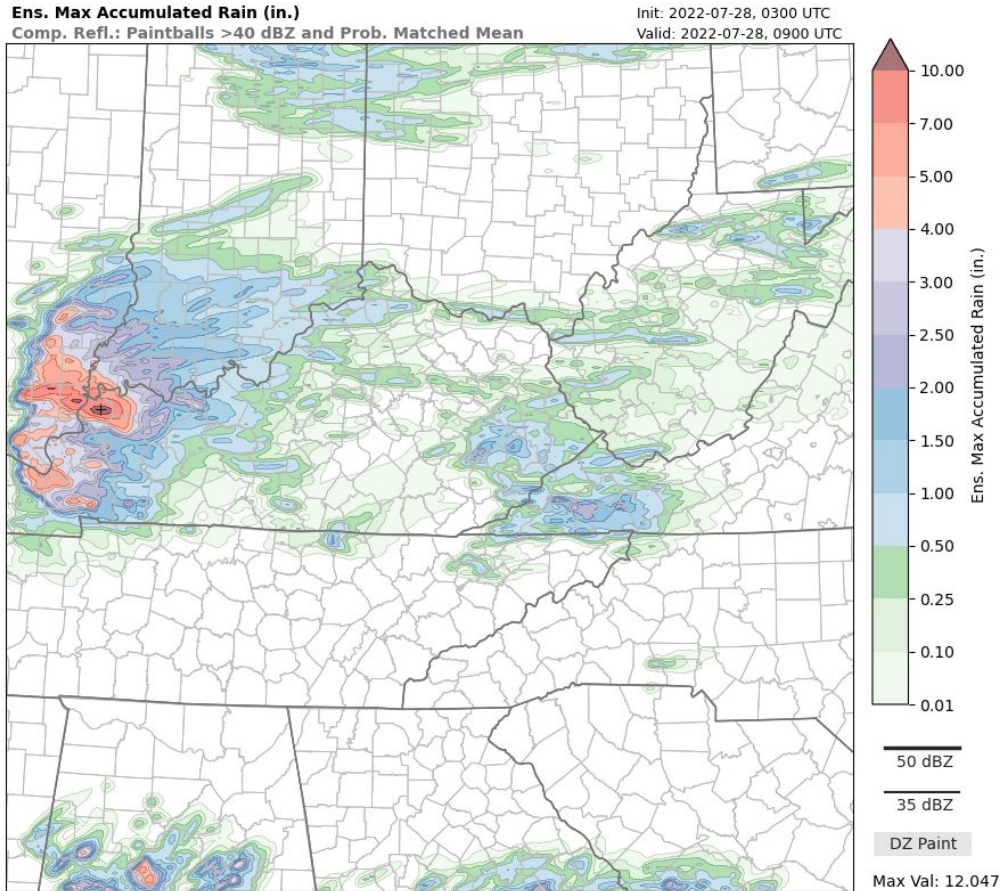
0130Z WoFS



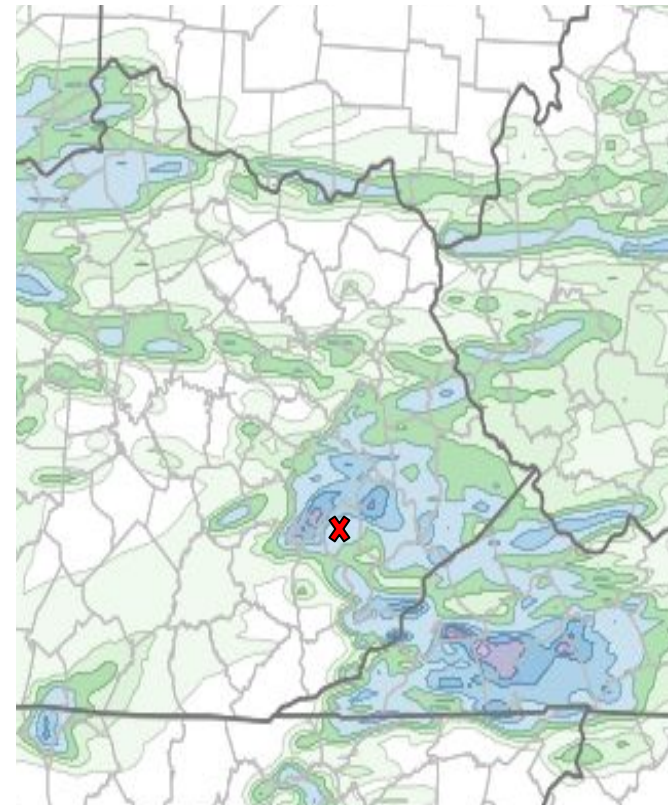
0230Z WoFS

Unfortunately, even the displaced signal in the 0030Z run was not consistent across runs to have inspired any confidence in it.

By 0300Z, with the event in progress at Hazard, KY...



0300 Z WoFS run,
Max percentile QPF valid
0300-0900 Z



Small 2 inch rain in northwest Perry County. WoFS still failing to sustain the convection.

Member 01 Simulated Composite Reflectivity (dBZ)
Member 01 2-5 km Updraft Helicity ($m^2 s^{-2}$)

Init: 2022-07-28, 0200 UTC
Valid: 2022-07-28, 0200 UTC

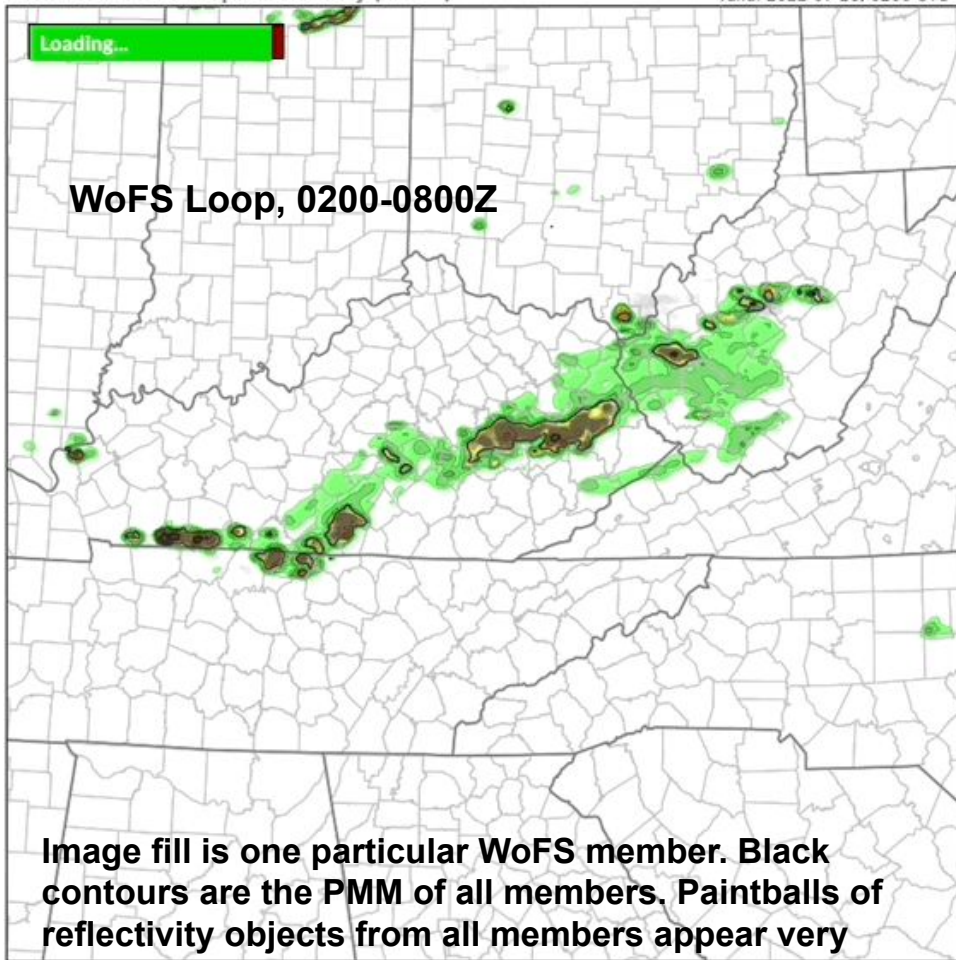
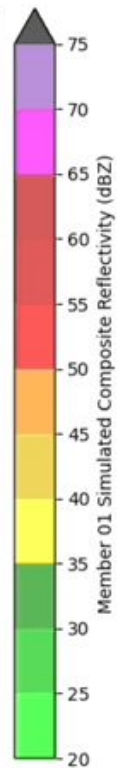


Image fill is one particular WoFS member. Black contours are the PMM of all members. Paintballs of reflectivity objects from all members appear very light gray.

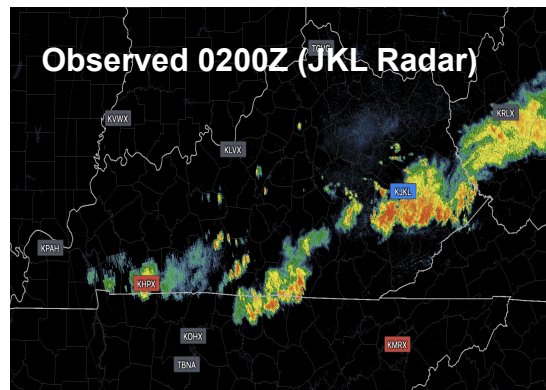
This is the 0200Z run, when the fledgling MCS was already assimilated. But WoFS fails to hold it or anchor it or develop repeating convection.



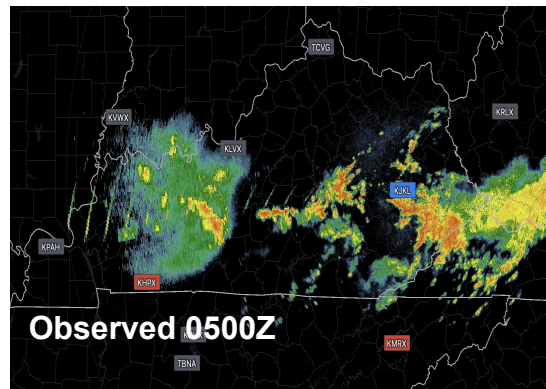
240.0 $m^2 s^{-2}$

60.0 $m^2 s^{-2}$

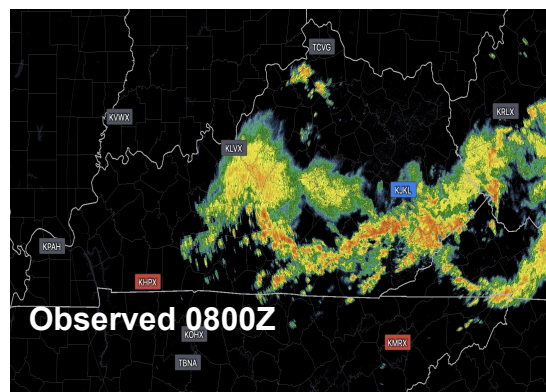
Observed 0200Z (JKL Radar)



Observed 0500Z



Observed 0800Z



Conclusion...

Need to investigate why WoFS didn't predict the observed behavior even at zero lead time (across the board - no members did well)



Bridging the Gap

Understanding The Region We Serve



our mission at the NWS is to protect lives, property, and commerce. A key way to accomplish this is to understand the vulnerabilities of the communities that we serve.

If we know what our vulnerabilities and impacts are, we can find ways to provide better services and support.





Vulnerabilities in East Kentucky

...to list a few



ENVIRONMENTAL

- Mountains and hills
 - Runoff/Headwaters
 - Flashy!
 - Where do you build in the mountains?
 - Where it's flat!
 - Floodplains
 - On top of old strip mines
- Mining operations
 - Sluice and retention ponds
 - Mountaintop removal
- Streams and rivers turn abruptly because of the nature of the geography





Vulnerabilities in East Kentucky

...to list a few



INFRASTRUCTURE

- Lack of Cell Phone and Internet coverage
- Housing
 - Building codes
 - Mobile homes
- Water/Electric
 - Where it's running/located
 - Water Quality
- Roadways!!
 - Roads on mountain sides
 - Many culverts and bridges
 - One way into a community, and one way out.
- Limited access to speciality healthcare





Vulnerabilities in East Kentucky

...to list a few



SOCIO-ECONOMIC

- Public Perception
- Poverty/low-income
 - Few high-paying jobs
- Lack of money in the communities
 - Low taxation
 - Less funding for the city/county
 - ...schools
- Education Level
- Government Assistance
- Drugs/Mental Health

Outdoor Tourism





So What Can We Do About It?

Serving Vulnerable Populations in East KY



Building a Weather-Ready Nation



Off-Grid populations

Serving Vulnerable Populations in East KY



Building a Weather-Ready Nation

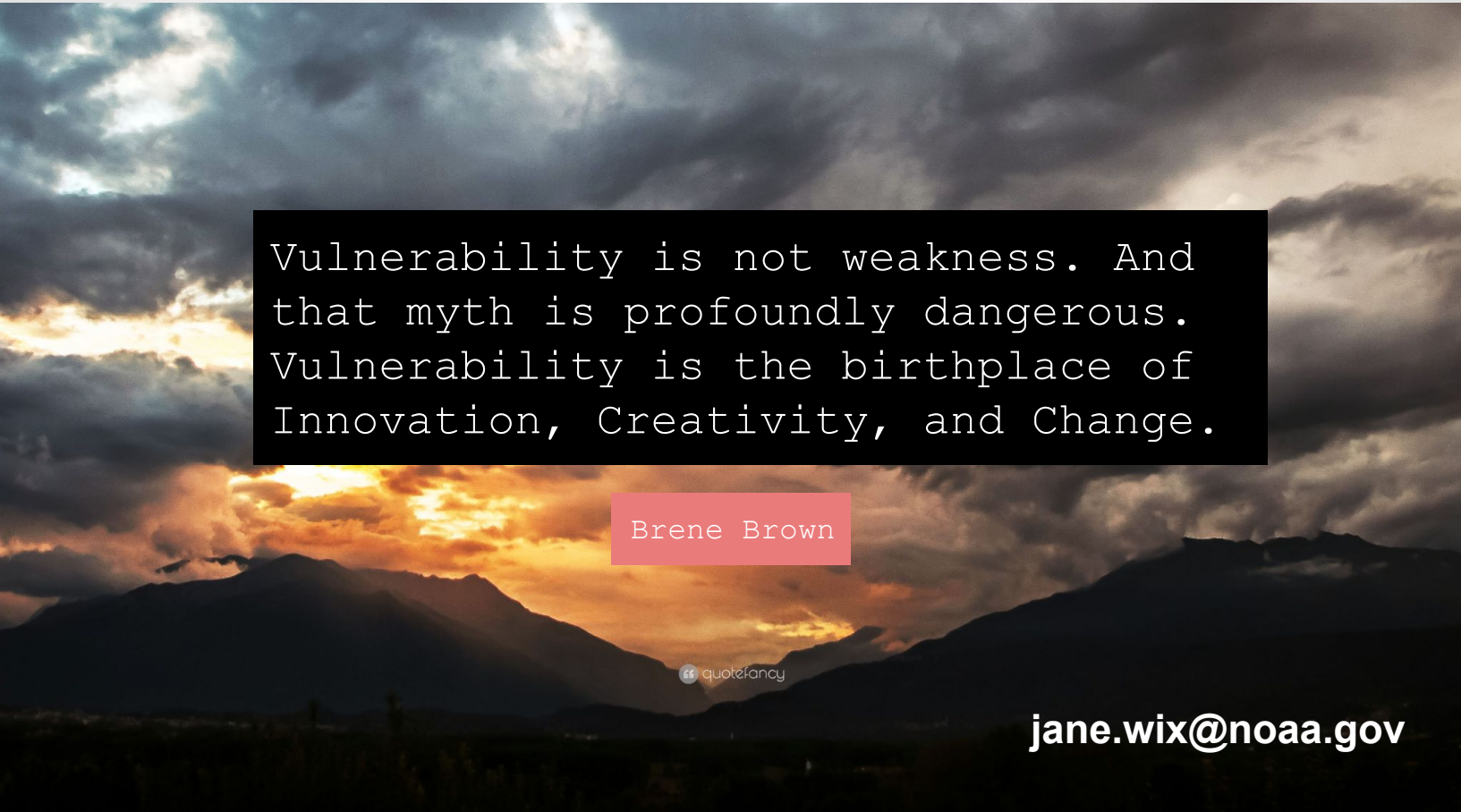


Taking A Grassroots Approach

Serving Vulnerable Populations in East KY



Thank you!



Building a Weather-Ready Nation