Central Region Technical Attachment
Number 25-02
July 2025

Calculation of Lead Time for the Flash Flood 4-Panel Technique in NWS Central Region

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1.0 Introduction

In 2023, a nowcasting technique for flash flooding called the 4-Panel Technique published (Lincoln and Marquardt 2023). This technique utilizes custom color tables combined with data from Multi-Radar Multi-Sensor (MRMS) and Flooded Locations and Simulated Hydrographs (FLASH) to assist with National Weather Service warning decisions. Additional research was conducted to determine how published thresholds should be adjusted based upon significant land cover and soil moisture differences (Lincoln 2023). From fall 2024 through spring 2025, NWS Eastern Region's (ER) Flash Flood Improvement Project workgroup (FFIP) attempted to test the 4-Panel Technique within their region and determine if any adjustments may be needed to thresholds used by the method. Preliminary results indicated that the technique generally performed well, especially for higher-severity flood events (Zaff 2025). Preliminary results also indicated the 4-Panel Technique provided significantly larger lead time on average when compared to the flood hazard products issued by NWS offices in the study area.

These preliminary results were generally consistent with some anecdotal information collected from past flood events in the NWS Chicago hydrologic services area, including for the Seneca, Illinois, flash flood event of 2021 (Lincoln 2021a), the Gibson City, Illinois, flash flood event of 2021 (Lincoln 2021b), the central Cook County, Illinois, flood event of July 2023 (Lincoln 2023), and the southern Cook County flood event of September 2023 (Lincoln 2023). Data collection for the original publication of the 4-Panel Technique focused only on thresholds for MRMS and FLASH values, however, and did not investigate lead time nor compare recommendations to official NWS products. In this study, the effort of the ER FFIP to determine potential flash flooding lead time from the 4-Panel Technique is replicated using the original collection of cases from the Great Lakes.

2.0 Methodology

2.1 Collection of Flash Flood Cases

A detailed summary of how flash flood cases were collected can be found in the original Lincoln and Marquardt study that presents development of the 4-Panel Technique (Lincoln and Marquardt 2023). The list of cases used for this study was the same as the previous study, except that eight notable flash flood cases which occurred after September 2022 were added. The number of cases available for this study grouped by flash flood severity are summarized by Table 1.

Table 1. Number of flash flood cases based upon estimated severity level from Lincoln and Marquardt (2023) available for use by this study.

	Advisory	**Flash Flood Base**	**Flash Flood Considerable**	**Flash Flood Catastrophic**
Number of Cases Exceeding Severity	95 / 198	65 / 198	16 / 198	7 / 198

2.2 Determining Onset Time of Flash Flood Impacts

Unlike with other types of severe weather such as tornadoes and straight-line winds where remote-sensing tools such as radar can be used to estimate storm locations down to the minute, the time of flooding is often more difficult to determine. While some waterways have automated stream gauges that can indicate the time (at a 15-minute or sometimes 5-minute increment) when a particular threshold is reached (such as a documented flood stage), gauge information is only valid at a singular point along potentially miles of waterway, and most waterways do not have such sensors. Flooding that occurs away from streams, such as urban flooding of roadways, underpasses, basements, and other poor drainage areas generally cannot be observed by sensors, and knowledge of such events is almost entirely based upon reports received by the National Weather Service. It is widely accepted that reports of flooding can lag the actual onset time of the flood impacts, sometimes by minutes to hours. Because there is no easy method for adjusting the time of flood reports such as what can be done for reports of severe thunderstorm damage, flood reports are typically given a valid time corresponding to the time that the report was received. It thus must be understood that any analysis of lead time for flood and flash flood warnings is likely to encounter lead times that are biased toward higher values (longer lead times). For the purposes of this study, the time associated with a flooding report was used as the time that the flooding of a given magnitude began.

Another challenge with this study is the determination of onset time for flooding of a particular severity (as opposed to simply flooding in general). The criteria for estimating severity for a particular flash flood event presented by Table 1 in Lincoln and Marquardt (2023) were used as a guide while reviewing reports of flooding for a particular event. Flood reports were retrieved

using the Iowa Environmental Mesonet (IEM) Local Storm Report App (https://mesonet.agron.iastate.edu/lsr/). Reports of flooding associated with a particular flash flood case were carefully reviewed with information entered into the "remarks" section of the report used to estimate the relative flood severity. The onset time of a particular flood severity level was assigned based upon the valid time of the first report received that was estimated at that level.

2.3 Calculation of Lead Time

The issuance time of flood hazard products issued by the NWS, if any, was collected using the IEM Local Storm Report App (https://mesonet.agron.iastate.edu/lsr/). The 4-Panel Technique product recommendation time was also collected for each flash flood case, with the time corresponding to when three of four panels first indicated a given severity of flooding. Lead time for each flash flood case was calculated based upon the indicated report time for local storm reports received by the NWS which was then compared to the NWS product issuance time and 4-Panel Technique recommendation time.

MRMS and FLASH data was collected using a Google Collab script written by Steven Fleegel of NWS Aberdeen, South Dakota. This script retrieves archived MRMS and FLASH data in GRIB2 format from Amazon Web Services cloud storage, then creates a graphic that replicates the appearance of the 4-Panel Technique in the NWS operational system. Graphics created by this script were reviewed, timestep by timestep, to determine when a recommendation (3 of 4 panels) indicated a particular flood hazard severity level. Archived data in GRIB2 format were available on a 10-minute timestep from approximately August 2021 to present. For flash flood cases prior to August 2021, data were viewed manually using the MRMS Operational Product Viewer (https://mrms.nssl.noaa.gov/qvs/product_viewer/). Archived data visible on the MRMS Operational Product Viewer was available on a 10-minute timestep from 1 May 2019 to present with raw values that could be sampled using the web interface. Data on this website were reviewed, one product at a time, timestep by timestep, to determine when a recommendation (3 of 4 panels) indicated a particular flood hazard severity level. For cases prior to 1 May 2019, only hourly timestep data were available back to August 2018, and no data were available for earlier events. Hourly data were assumed to be too coarse of a temporal resolution to determine meaningful lead-time statistics, which removed all cases occurring between July 2016 and April 2019 from further review. In total, 140 cases remained which could have lead times calculated, although 87 of these cases were null events with no reports of flooding received.

Table 2. Number of flash flood cases which have archived data available archive data for lead time calculation.

	Advisory	**Flash Flood Base**	**Flash Flood Considerable**	**Flash Flood Catastrophic**
Number of Cases Exceeding Severity	53 / 140	47 / 140	14 / 140	1 / 140

3.0 Results and Discussion

3.1 NWS Eastern Region Study

In the NWS ER study, 235 flash flood events were reviewed from across the eastern CONUS (Zaff, 2025). These cases were based upon 235 instances of NWS offices issuing flash flood warnings with the “considerable” or “catastrophic” damage tags. Unlike the cases used for this study, no null events were collected by Zaff, nor were events associated with flood advisories or base flash flood warnings included. Of the 235 cases, 107 were removed because of missing data, obviously erroneous radar data, and warnings issued for non-thunderstorm situations. The Zaff study found that MRMS and FLASH values valid at the time of warning issuance were generally consistent with thresholds recommended for the 4-Panel Technique in the Great Lakes.

In addition to reviewing potential thresholds for MRMS and FLASH products, the Zaff study also reviewed potential lead time for flood hazards if the 4-Panel Technique would have been used. The study reviewed 69 instances of flash flood warnings where a “base” level warning was upgraded to the “considerable” damage tag. It was suggested that, on average, the 4-Panel Technique provided an average of 12 minutes additional lead time (median value 6 minutes) for initial issuance of the flash flood warning, and an average of 39 minutes additional lead time (median value 23 minutes) for the upgrade to “considerable.” While consistent with some anecdotal data collected in the NWS Chicago hydrologic service area, these significantly larger lead time values are surprising. It is difficult to determine the exact reason or reasons for this difference and their relative contributions, but differences in warning strategy and flood report verification may play a role. This illustrates the need to perform a similar test on cases retrieved for the original 4-Panel Technique study.

3.2 4-Panel Technique Lead Time for Western Great Lakes Cases

It was found that the 4-Panel Technique provided significant lead time, on average, for the 91 cases reviewed across the western Great Lakes. The average lead time provided by the 4-Panel Technique was slightly higher than that provided by the official NWS flood hazard products. Using the 4-Panel Technique recommendations exactly as provided could have potentially increased average lead time by 8 minutes for flood advisories, 27 minutes for flash flood warnings with base severity level, and 8 minutes for flash flood warnings with considerable severity level. The difference was smaller for flash flood warnings when using median instead of mean. The number of cases with “catastrophic” severity level (2 to 7 cases out of 91, depending on the exact criteria used) was likely too small for meaningful conclusions. For a summary of lead time differences between official NWS flood products and the 4-Panel Technique recommendation, see Table 3.

Table 3. Estimated lead time provided by recommendations from the 4-Panel Technique and by the official NWS warning products. Mean and median values calculated for the 140 cases with available archived data (see section 2.3).

MEAN (All Cases)	**4-Panel Lead Time**	**NWS Lead Time**
Advisory Severity	81 min	73 min
FFW-base severity	77 min	50 min
FFW-cons severity	32 min	24 min
MEDIAN (All Cases)	**4-Panel Lead Time**	**NWS Lead Time**
Advisory Severity	65 min	56 min
FFW-base severity	70 min	52 min
FFW-cons severity	0 min	4 min

With multiple cases, “considerable” severity flash flooding occurred with no such 4 Panel Recommendation and/or equivalent NWS flood hazard product issued. Those situations were included in the statistics using a value of “0 minutes” for lead time. This is a reasonable assumption in some instances, but does imply that a flood hazard product would be issued at roughly the same time as flooding of a particular severity began, which would not always be the case. In some instances, the report was received and no additional hazard products were issued, perhaps because the report was received after rainfall had ended. Another situation with a lack of “considerable” severity NWS flood hazard product would be for events prior to September 2019, when impact-based warning damage tags began for flash flood warnings.

Lead time estimates were also calculated separately for a filtered dataset where cases bring excluded if there was no 4-Panel Technique recommendation and/or no NWS flood hazard product issued. This filtered dataset had no lead time improvement from the 4-Panel Technique for events with a flood advisory severity, but there was an increased average lead time of 51 minutes for flash flood warnings with base severity level, and 31 minutes for flash flood warnings with considerable severity level (Table 4).

Reviewing histograms of lead time calculated for the 4-Panel Technique and official NWS flood hazard products shows significant overlap. Although the median lead time is higher for flood advisory severity events and flash flood warning base severity events, there is a very large range of lead times for the 91 events studied when looking at advisory level (Figure 1) and flash flood base level events (Figure 2). Flash flood considerable severity events appeared to have a much smaller range of lead times due to the small number of available cases and large proportion of such cases that did not have a 4-Panel recommendation or NWS flood hazard product at that severity level (Figure 3). Ignoring events where the considerable severity flash flood event was missed by the 4-Panel Technique and NWS flood hazard products, the

provided lead time by the 4-Panel Technique was significantly larger than that provided by official products (Figure 4). These values must be used with significant caution due to the small number of cases.

A one-tailed t-test was performed to determine if the higher average lead time value for the 4-Panel Technique was statistically significant. For all tested severity levels (excluding the “catastrophic” severity level due to small sample size), using the 95% confidence level, the indicated difference in average lead times between the recommendations provided by the 4-Panel Technique and the official NWS products was not statistically significant. For the Flash Flood Warning base severity level, however, the increase in average lead times was statistically significant at the 90% confidence level. Reaching statistical significance with differences in lead time is likely made very difficult by the large range in values between individual flood events.

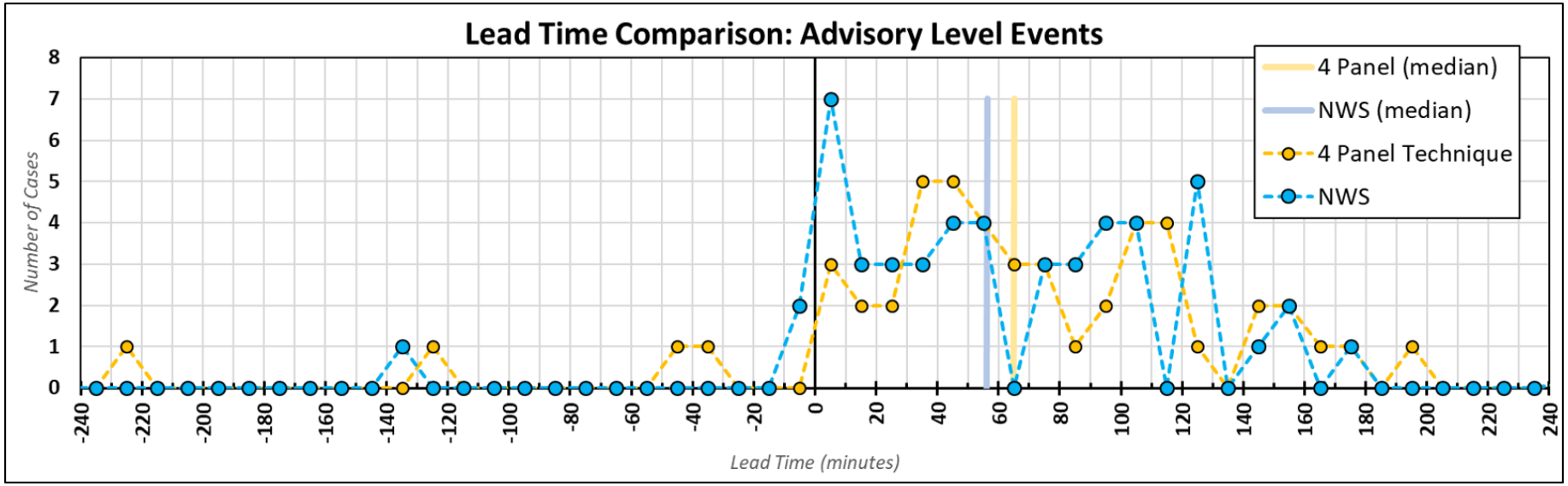

Figure 1. Histogram of estimated lead time values for flood events with advisory severity impacts calculated for the 4-Panel Technique and official NWS Flood Advisories.

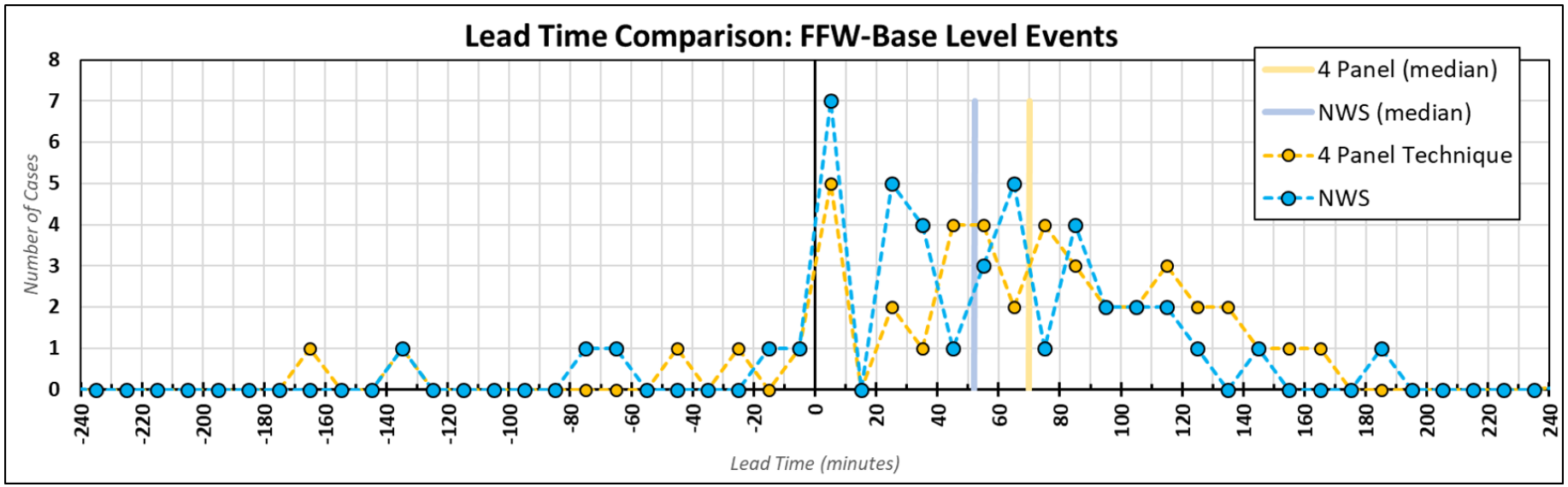

Figure 2. Histogram of estimated lead time values for flood events with flash flood base severity impacts calculated for the 4-Panel Technique and official NWS Flash Flood Warnings.

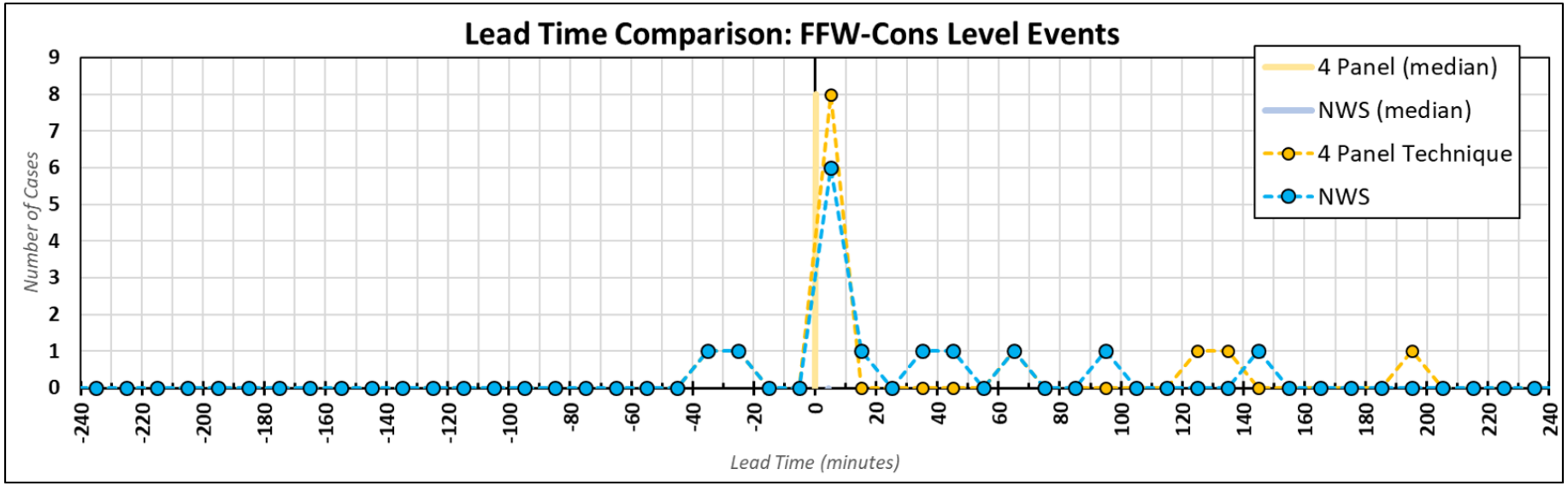

Figure 3. Histogram of estimated lead time values for flood events with flash flood considerable severity impacts calculated for the 4-Panel Technique and official NWS Flash Flood Warnings (with "considerable" damage tag).

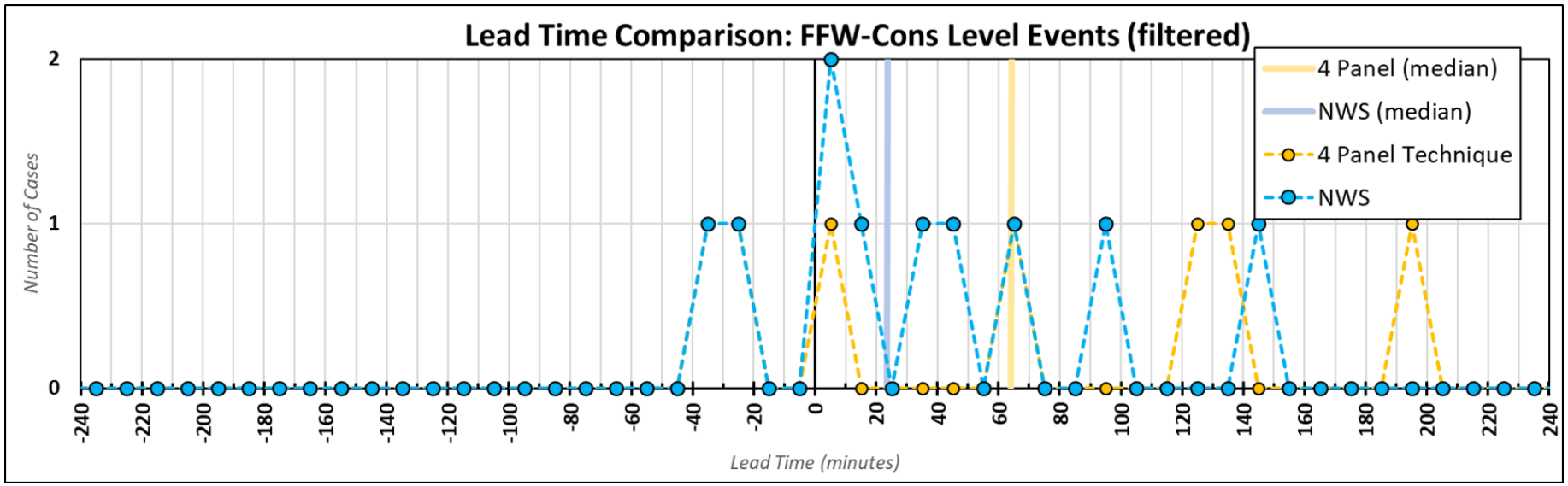

Figure 4. Same as with Figure 3, but filtered to include only events that have a 4-Panel Recommendation and an NWS hazard product for flash flood warning considerable severity flooding.

Table 4. Same as Table 3, but only for events with a 4-Panel Technique recommendation and an NWS flood hazard product issued. Of the 140 cases with available MRMS/FLASH data, 48 of these cases had both a 4-Panel Technique recommendation and an NWS flood hazard product issued.

MEAN (only events with calculable lead time)	**4-Panel Lead Time**	**NWS Lead Time**
Advisory Severity	81 min	81 min
FFW-base severity	83 min	32 min
FFW-cons severity	65 min	34 min
MEDIAN (only events with calculable lead time)	**4-Panel Lead Time**	**NWS Lead Time**
Advisory Severity	65 min	78 min
FFW-base severity	73 min	60 min
FFW-cons severity	64 min	23 min

3.3 4-Panel Technique Comparison to NWS Official Products

A comparison was made between the flash flood severity suggested by the 4-Panel Technique, the severity indicated by official NWS flood hazard products, and the estimated severity from the resulting flood reports. For reference, relative flood severity in the original 4-Panel Technique study (Lincoln & Marquardt, 2023) was indicated by a number from 0 to 4, with 1 representing Flood Advisory level impacts, 2 representing Flash Flood Warning (base) level impacts, 3 representing Flash Flood Warning (considerable) level impacts, and 4 representing Flash Flood Warning (catastrophic) level impacts. A majority of the time, both the 4-Panel Technique recommendation and the official NWS flood hazard product indicated the correct flood severity (Figure 5), although the 4-Panel Technique indicated the correct severity slightly less (65% of the time) compared to the official products (80% of the time). The next most likely situation was a one-category overestimate of the eventual flood severity, with the 4-Panel Technique overestimating the severity by one category 21% of the time and the official flood hazard products overestimating the severity by one category 9% of the time. A one-category underestimate occurred with the 4-Panel Technique and the official flood hazard products 7% and 8% of the time, respectively. While a two-category overestimate occurred with the 4-Panel Technique in 7% of the cases, no two-category underestimates occurred. Two-category overestimations or underestimations only occurred with the official flood hazard products about 2% of the time (1% each). It was found that the 4-Panel Technique's ability to indicate the correct flood severity was the same as NWS official products about 66% of the time, better about 7% of the time, and worse about 26% of the time (Figure 6).

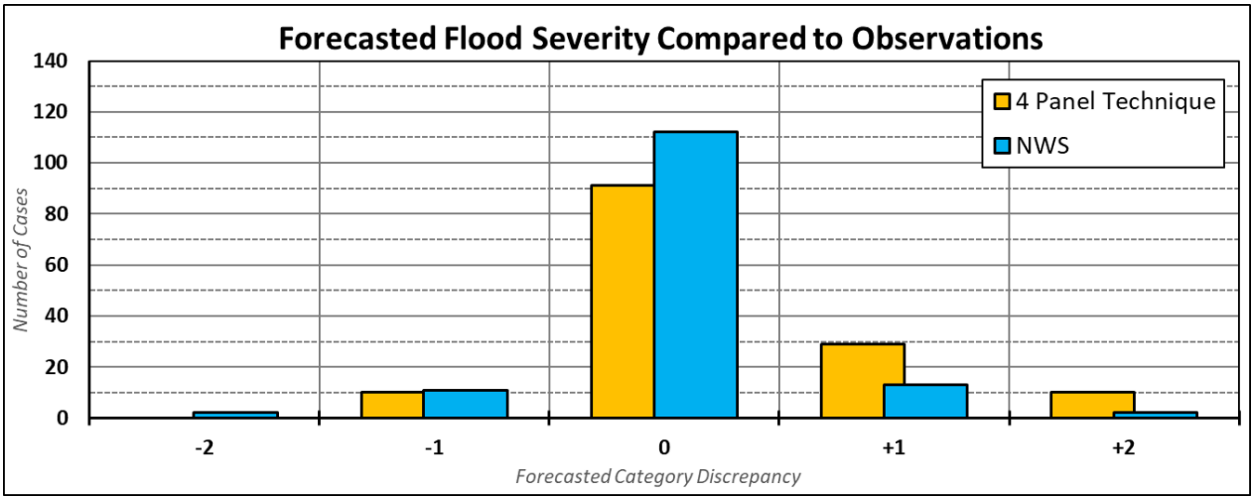

Figure 5. A comparison of expected flood severity to the estimated observed flood severity between the 4-Panel Technique recommendations and NWS official flood products.

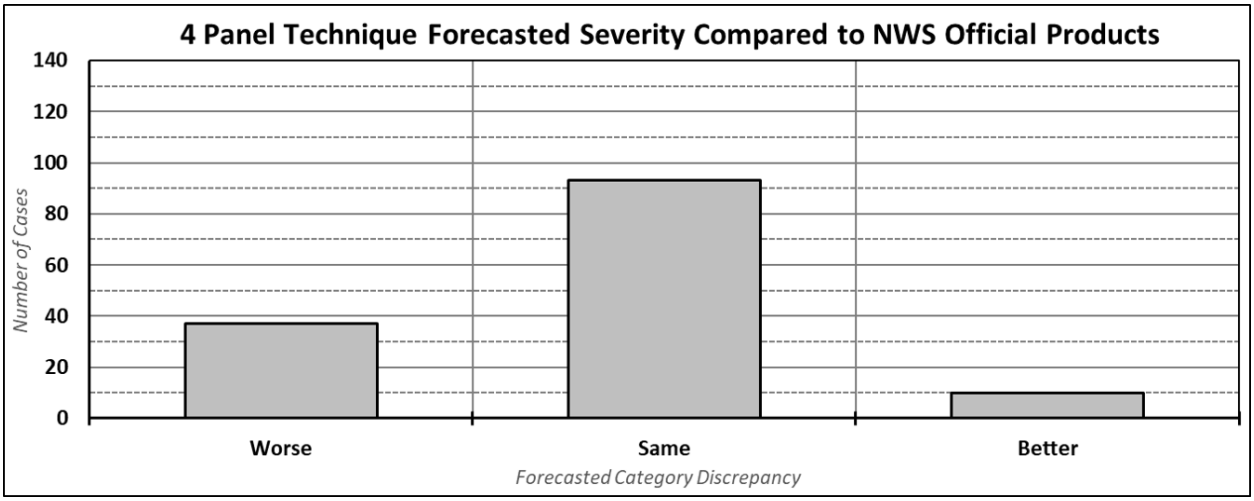

Figure 6. Distribution of 4-Panel Technique performance compared to NWS official flood products with regards to forecasting the estimated observed flood category.

3.4 Discussion

The average lead times provided by recommendations from the 4-Panel Technique were generally higher than lead times provided by official NWS flood hazard products, similar to the findings of Zaff (2025), but this difference was not found to be statistically significant at the 95% confidence level. Given the broad range in lead times for flash flood events, it is possible that statistical significance would still not be reached if the study were to be repeated to include future events. Although other attempts to evaluate lead time for the 4-Panel Technique did not include calculations of statistical significance, their sample sizes were similar to or smaller than

the current study, which may also suggest low confidence in their indicated differences. Despite the relatively low confidence in a higher lead time for the 4-Panel Technique compared to official NWS products, results found in this study are generally consistent with preliminary research currently underway in the NWS Fargo/Grand Forks, North Dakota, area, which suggests an average of 60 minutes and 35 minutes of additional lead time for advisory-level impacts and flash flood warning base-level impacts, respectively (Christian 2025). While the Fargo/Grand Forks research suggested the biggest increase in lead time for advisory-level impacts, this research and that of Zaff indicated the largest increases in lead time values for flash flood warning base-level impacts. Multiple additional caveats exist with the presented data and conclusions.

Biases may exist in the data used for this study that affect different components of the lead-time calculation differently. Valid times associated with reports of flash flooding can be uncertain, with times often corresponding to when an impact was reported, not when it began. These potential biases would affect calculated lead times for the 4-Panel Technique and official NWS flood hazard products equally by potentially increasing values artificially. In addition, biases may occur with MRMS radar-only data used as the forcing for products in the 4-Panel Technique. These biases may be accounted for by NWS warning forecasters reviewing additional sources of information, such as rain gauges, during an ongoing event. This theoretically should allow for improvement of lead time and flood severity assessment associated with NWS flood hazard products in certain cases. NWS warning forecasters also often monitor the movement of heavy rainfall areas and issue flood hazard products in anticipation of continued heavy rainfall causing or worsening flood impacts. In these situations, lead time associated with NWS flood hazard products would be improved while the 4-Panel Technique lead time remains unchanged. Because some of these biases are likely to negatively impact the lead times from 4-Panel Technique recommendations more than the lead times from NWS flood hazard products, the lead time differences found by this study and by Zaff (2025) may be even more notable.

It was found that the 4-Panel Technique generally indicated the correct flood severity a majority of the time, although official NWS flood hazard products indicated the correct severity slightly more often. This difference is not particularly surprising due to the aforementioned realtime monitoring of MRMS rainfall estimates for biases and review of incoming reports of flooding performed by NWS warning forecasters. Even without these manual adjustments, the 4-Panel Technique indicated the right flood severity for 65% of the flash flood cases, and was within one category of the correct severity 93% of the time. This study combined with earlier work suggests that without bias correction or any realtime manual adjustment, the 4-Panel Technique can provide a good recommendation for potential flood severity that provides significant lead time.

4.0 Conclusions

In this study, an attempt was made to replicate the work of Zaff (2025) in which lead times for the 4-Panel Technique were calculated for flash flood events with “base” and “considerable” severity levels. For a subset of flash flood cases used in the original 4-Panel Technique

research study, issuance times for official NWS flood hazard products were collected along with times associated with flood hazard recommendations from the 4-Panel Technique. The onset time of flash flooding of a particular severity was estimated based upon flood reports received by the NWS. The average lead time provided by recommendations from the 4-Panel Technique was generally higher than the average lead time provided by official NWS flood hazard products, similar to the findings of Zaff (2025), but the difference was generally not statistically significant.

While biases likely exist in the valid times associated with reports of flash flooding, those biases would affect calculated lead times for the 4-Panel Technique and official NWS flood hazard products equally. Biases may also occur with MRMS radar-only data used as the forcing for products in the 4-Panel Technique. These biases may be accounted for by NWS warning forecasters reviewing additional sources of information during an ongoing event, so NWS lead time may not be affected to the same extent as the 4-Panel Technique recommendations. Also noteworthy is the fact that official NWS flood hazard products may include some forecasting of heavy rainfall movement which would not occur with the 4-Panel Technique. Despite biases that may affect the 4-Panel Technique more than flood hazard products issued by the NWS offices, the average lead time was still higher. These results add to previous studies on the 4-Panel Technique which illustrate the usefulness in NWS warning operations by providing additional evidence for potentially significant lead times prior to the onset of flood impacts.

5.0 Acknowledgements

The author would like to thank David Zaff of NWS Eastern Region headquarters for his work testing the 4-Panel Technique, from which the idea of testing lead times was developed. The author would like to thank Katy Christian of Cooperative Institute for Severe and High-Impact Weather Research and Operations for her recent testing of the 4-Panel Technique in a new area. The author would also like to thank Steven Fleegel of NWS Aberdeen, South Dakota, for his work on the Google Collab script that allows for easy creation of graphics depicting archived MRMS & FLASH data in the format of the 4-Panel Technique. The author would also like to thank NWS Chicago Science and Operations Officer Kevin Donofrio and Jeff Manion of NWS Central Region Headquarters for their helpful comments and review.

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