2023 Tiny – Threats-In-Motion (Tiny TIM) HWT Experiment Summary

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Executive Summary

Threats-In-Motion (TIM) is a proposed approach for warning decisions and dissemination that aims to upgrade the current static polygon system used by the National Weather Service (NWS) for severe thunderstorm and tornado warnings. The main objective of TIM is to create warning polygons that dynamically update and move along with the storm, allowing for improved average warning lead time and more equitable (uniform) lead times for individuals in the path of long-tracked severe storms. Currently, severe thunderstorm or tornado warnings cannot be extended in area or time without the issuance of a separate new warning. To address this issue, a short-term solution called "**Tiny TIM**" has been developed, which incorporates the TIM concept by allowing current polygon-based warnings to be extended in area and/or time. Tiny TIM has been developed as an "add-on" feature to the Advanced Weather Interactive Processing System (AWIPS) Hazard Services (HS) - Convective workflow. It was tested in person at the National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (HWT) for two weeks in winter 2023 with participating NWS forecasters. This was the third Tiny TIM experiment, following a virtual HWT experiment and an in-person NWS Operations Proving Ground (OPG) experiment, both in 2022.

The Tiny TIM software adds functionality that allows forecasters to manually extend the warning polygon's area and time during warning updates when a hazard is expected to be long-tracked. When updating a warning, forecasters can choose to use "warning extension shortcuts" that automatically extend the polygon area and time. Additionally, the software offers an optional feature to track hazards using a 2D footprint tool, which provides a more precise description of the hazard area than the currently available point or line tracking tools. The new "dynamic" line tool offers the capability to utilize individual motion vectors for each vertex, which proves to be valuable when dealing with bowing line segments. The software explicitly prevents the "accordion effect" where downstream locations are removed from the warning if the storm's motion vector speed decreases, temporarily making the warning shorter until the locations are placed back within the warning during the next update as the storm continues to move forward. There are options to track manually-edited polygons as well as default polygons, and an option to auto-update the polygon immediately after changes are made to the track or geometry or when the radar frame updates. Forecasters can also issue warnings using the traditional process and choose not to extend the expiration time, only maintaining or shrinking the warning area.

The main findings from the 2023 HWT experiment are twofold: 1) Tiny TIM reduces the workload and mental demand on forecasters by eliminating the need to issue a new warning once a storm has exited a polygon, and 2) Tiny TIM improves messaging by maintaining the same Event Tracking Number (ETN) throughout the hazard's lifecycle and generating cleaner output fields by eliminating overlapping warnings.

Detailed Overview

Current severe weather warnings (tornadoes, wind, and hail) require the forecaster to issue multiple sequential warnings for long-tracked storms because the current policy prohibits extending a warning's area and time during updates. This situation frequently results in non-uniform lead times for users on the downstream border of a warning polygon. For instance, nearly adjacent locations can have dramatically different lead times if one location is just outside the upstream warning.

Threats-In-Motion (TIM) is a proposed warning decision and dissemination approach that would enable the National Weather Service (NWS) to upgrade severe thunderstorm and tornado warnings from the current static polygon system to continuously-updating warning polygons that move with the storm. Specifically, a warning polygon is attached to the threat and advances along with it. Warnings are automatically cleared from locations where the threat has passed. TIM represents an evolutionary step of the Forecasting A Continuum of Environmental Threats (FACETs) initiative for the convective weather warning scale. With TIM, forecasters would only need to issue a single warning, updated regularly as workload permits, aligning with a "one storm-one story" principle. This approach has the potential to alleviate forecaster workload, as the time-consuming process of issuing downstream warnings would be replaced by a less time-consuming warning update.

The "one storm-one story" concept is the primary advantage of TIM, as it also improves hazard communication. TIM ensures a continuous history for each storm, avoiding situations where multiple separate overlapping warnings may be active for the same hazard due to the issuance of a new downstream warning before the cancellation of the previous one. These enhancements can result in simplified and consistent messaging for key partners and improved event verification.

TIM can offer more equitable (uniform) lead times for individuals in the path of long-tracked severe storms because these storms are continuously tracked and warned. TIM can mitigate gaps in warning coverage and can improve the handling of changes in storm motion. Additionally, this change can lead to greater average lead times and reduced average time spent in a warning compared to the current warning system, with minimal impact on average false alarm time. This impact is particularly significant for storms that are expected to persist longer than the average warning duration (30-45 minutes), such as long-tracked supercells observed during major severe weather outbreaks. A comprehensive statistical analysis of the scientific benefits of TIM is available in Stumpf and Gerard (2021).

This promising and innovative approach is currently being considered for implementation in NWS operations. While the "full implementation" aspects are being evaluated as a long-term solution, a short-term approach is being explored to begin incorporating the TIM concept into existing convective warnings. This short-term interim solution, referred to as "**Tiny TIM**," enables the extension of current polygon-based warnings by area and/or expiration time. The software capability is integrated within a development version of the Advanced Weather Interactive Processing System (AWIPS) Hazard Services (HS). Specifically, the Tiny TIM capabilities are built upon the HS-Convective workflow, which serves as a modern replacement for the AWIPS Warning Generation (WarnGen) software.

NWS convective warnings are accompanied by a Valid Time Event Code (VTEC), which enables weather providers and vendors to automate and customize the product stream delivered to their clients. Within the VTEC, there are two relevant fields for this new functionality. The first is the Event Tracking Number (ETN), which serves as a unique identifier attached to each warning type (Severe Thunderstorm Warning or Tornado Warning). Currently, it is not possible to extend a warning in terms of time or area while maintaining the same ETN. Each subsequent warning issued for a specific hazard is assigned a different ETN. Once a warning has expired or been canceled, the ETN is not reused (NWS, 2020).

Presently, the only way to update an existing warning is by issuing a Severe Weather Statement – a warning continuation statement. The second field within the VTEC that is relevant to this new functionality is the Action Code. A warning continuation statement uses the action code "CON." With each "CON" update, the warning polygon is constrained to its original area, and forecasters are only allowed to reduce the area, without the ability to extend the expiration time of the warning.

To permit a single storm to retain the same ETN throughout its lifecycle, we propose allowing the extension of the area and time during warning updates by utilizing these existing product-extension VTEC action codes. These codes are currently used for other products but are not presently utilized for severe thunderstorm or tornado warnings:

- VTEC = EXA: Extension of the warning polygon's area (can enlarge the area).
- VTEC = EXT: Extension of the expiration time of the warning polygon.
- VTEC = EXB: Extension of BOTH the warning polygon's area (can enlarge the area) and expiration time.

With TIM, these product-extension VTEC action codes are intended to be used when a hazard is expected to persist beyond the typical duration of a severe thunderstorm or tornado warning (e.g., 30 or 45 minutes). For short-lived hazards or long-lived hazards nearing the end of their lifecycle, the traditional warning continuance (VTEC = CON) is used until the warning expires or is canceled early. Examples of a series of ETNs and action codes for current warnings and TIM warnings are illustrated in Table 1.

Figure 1 depicts a graphical representation of the current warning method and TIM. In this example, warning updates are issued every 15 minutes. Under the current warning methodology, the warning polygon can only be reduced in size with each update, and the expiration time remains constant. After 60 minutes, a new warning is issued, featuring a new polygon, ETN, and expiration time. With the TIM methodology, the warning can continue downstream with each update, allowing for the addition and removal of areas from the warning, as well as an extension of the expiration time. The TIM warning maintains the same ETN throughout its lifecycle.

Time (UTC)	NWS VTEC	ETN	TIM VTEC	ETN
1900	NEW	1	NEW	1
1910	CON	1	EXB	1
1920	CON	1	EXB	1
1930	NEW	2	EXB	1
1940	CON	2	EXB	1
1950	CON	2	EXB	1
2000	NEW	3	EXB	1
2010	CON	3	EXB	1
2020	CON	3	EXB	1
2030	NEW	4	EXB	1
2040	CON	4	EXB	1
2050	CON	4	EXB	1
2100	NEW	5	EXB	1
*2110	CON	5	CON	1
*2120	CON	5	CON	1
*2130	EXP	5	EXP	1

Table 1. *Warning decision times, VTEC action codes, and ETNs for a hypothetical storm case. Today's warnings use the blue columns on the left. TIM uses the green columns on the right.*

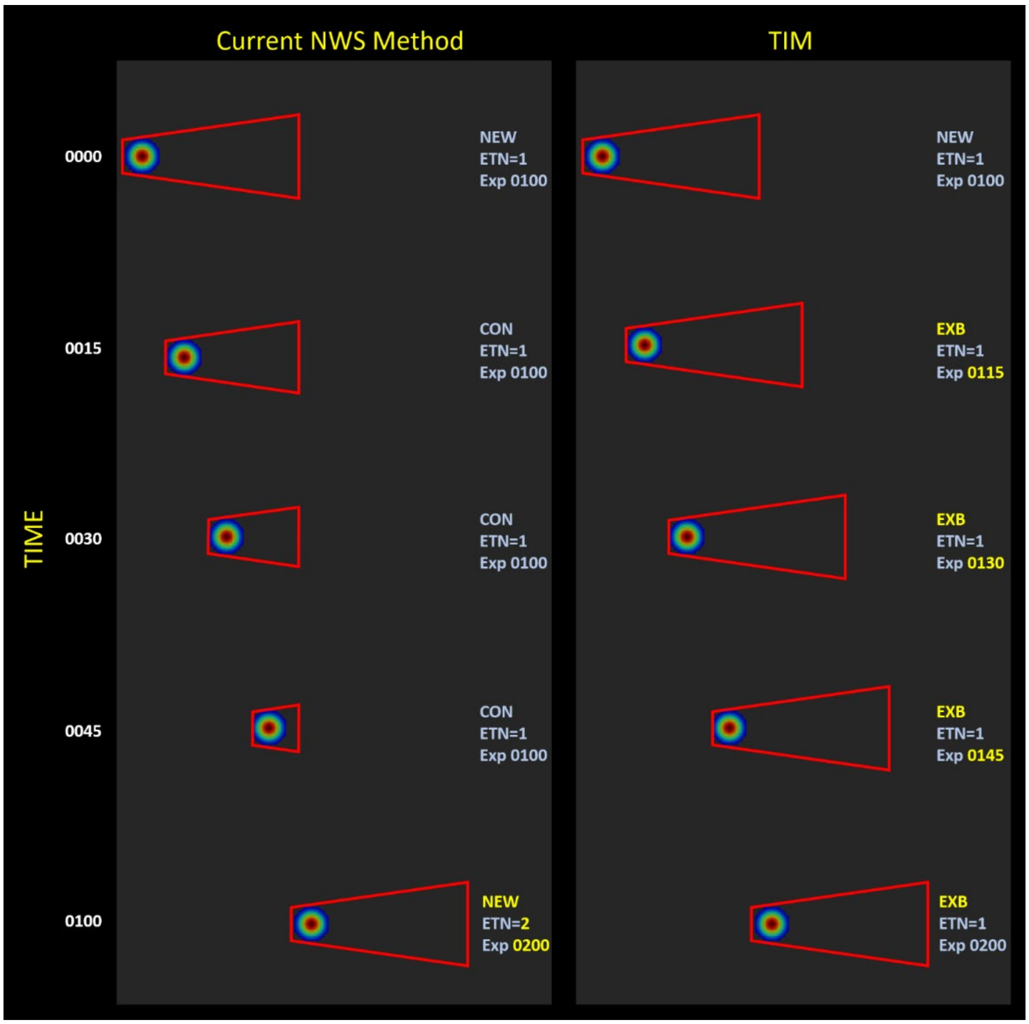

Fig. 1. *Comparison of (left) current NWS warning practice using separate polygons, (right) to TIM. Images are shown at 15-min intervals. For each time interval, the VTEC action code, ETN, and warning expiration time are shown. The colored circle represents a hypothetical hazard.*

Software Details

Because Tiny TIM is based on the yet-to-be-fielded HS-Convective software, this summary list highlights the main differences between WarnGen and HS-Convective that forecasters had to learn and understand. It should be noted that HS-Convective is not currently operational, and therefore, some of the issues discovered during testing may still be in the process of being resolved.

- The HS screen layout (Fig. 2; Spatial Display, Console, Hazard Information Dialog) differs from WarnGen. This layout is already available in other HS perspectives (e.g., HS-Hydro), so some forecasters already have some experience with it.
- When updating a warning, the user only needs to left-click the warning from the Console or spatial display (rather than having to find the specific warning from a drop-down menu with WarnGen).
- Dragging the warning polygon to a new position using the left mouse also requires pressing the Alt key.
- The HS Hazard Information Dialog (HID) "Details" selections are easier to navigate and, unlike WarnGen, automatically select appropriate Impact Based Warning (IBW) tags.

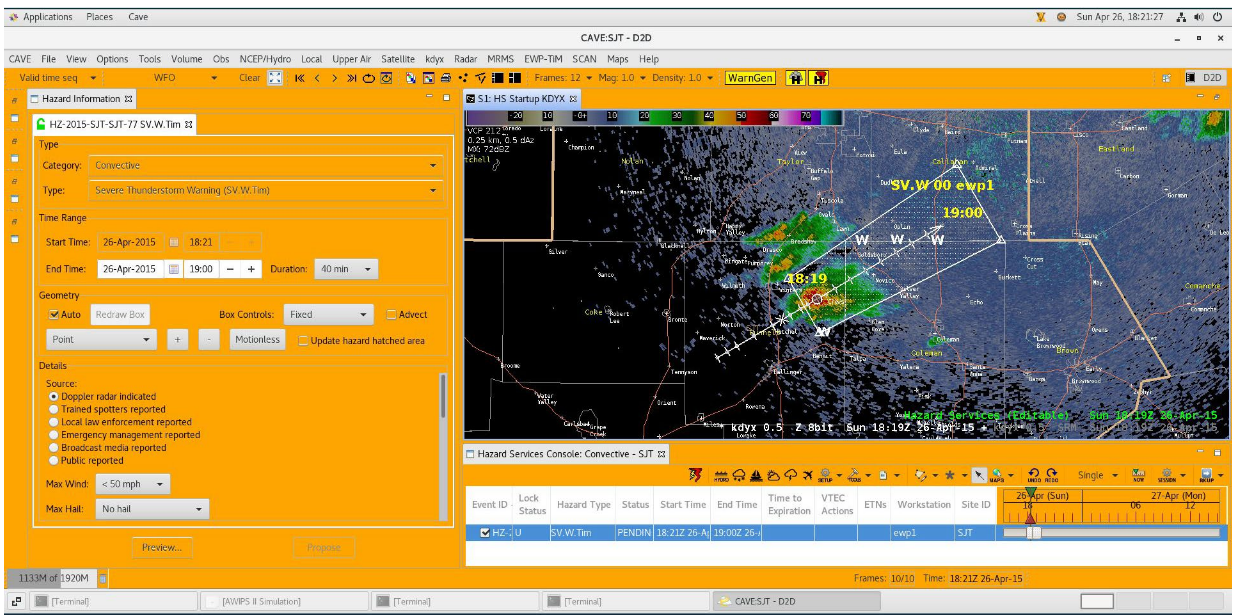

Fig. 2. *Tiny TIM output in AWIPS from the training scenario in Central Texas.*

The following changes were also made to the baseline HS-Convective to aid in the use of the new Tiny TIM functionality:

- Currently, warnings transition to the "Ending" status with 5 minutes until expiration, and there is no way to extend the warning after this point (only expiration is possible). This threshold was changed to 1 minute, allowing warnings to be extended until the final minute.
- The default alert thresholds for time to expiration were modified as follows:
    - Yellow alert: old (halfway to expiration), new (15 minutes from expiration)

- Red alert (includes a pop-up alert): old (10 minutes from expiration), new (5 minutes from expiration)

- New Tiny TIM default console columns:
    - Event ID, ETNs, Lock Status, Hazard Type, Status, Start Time, End Time, Time To Expiration, VTEC Actions, Workstation, Site ID [County Warning Area (CWA)]
- The local warning overlay in AWIPS (under the "Obs" menu) does not display warnings with partial county cancellations (CAN) combined with warnings featuring the new EXB, EXA, or EXT VTEC action codes. Consequently, an experimental warning grid overlay was developed to display warnings with these new VTEC combinations. This experimental warning overlay also offers improved data sampling capabilities, including the VTEC action code, ETN, and IBW tags, which are not available in the local warning overlay. High-end SVR and TOR warnings with Destructive and Catastrophic IBW intensity tags are depicted with thick lines.

The major new capabilities added to HS-Convective to specifically support Tiny TIM functionality are as follows:

1. Along with point and line tracking tools (Fig. 3: left), a new 2D Footprint tracking tool has been added (Fig. 3: right).

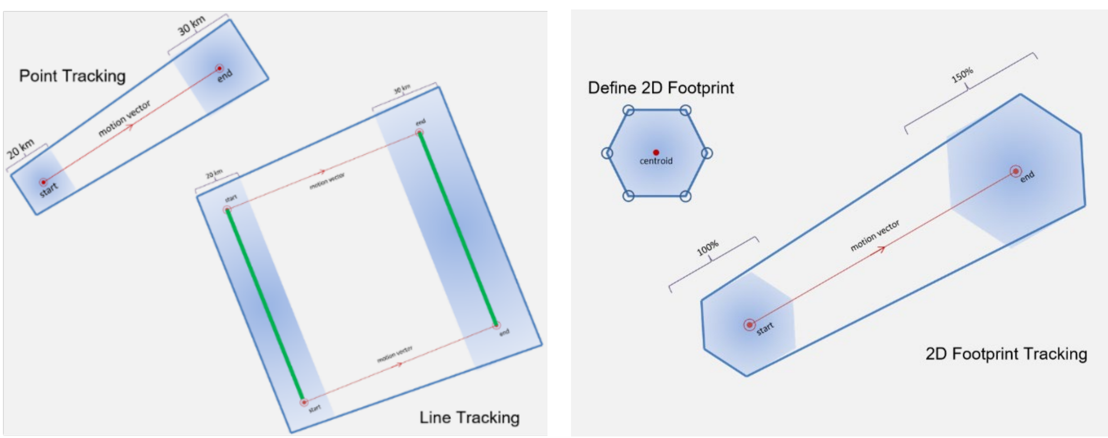

Fig. 3. *Left - The default warning polygon produced by AWIPS WarnGen for point and line tracking; Right - The warning polygon resulting from tracking a 2D footprint.*

2. Warnings can be extended in area and/or time automatically or manually:
    a. Automatic Extension: Utilizes shortcuts known as "**Box Controls**" available through a drop-down menu:
        i. Fixed
            1. For hazards not expected to persist beyond the warning duration (i.e., short-lived)
            2. The polygon's position remains fixed without any movement
        ii. Update Rear (the default for "**CON**" – see below)
            1. For hazards not expected to persist beyond the warning duration (i.e., short-lived)

        2. Automatically moves **only the Rear** of the warning polygon forward (subtracting area) based on point/line/footprint and the motion vector
        3. Keeps the same expiration time, with the duration aging off
    iii. Update Both
        1. For hazards expected to persist beyond the warning duration (i.e., long-lived or long-tracked)
        2. Automatically moves **both the Front and Back** of the warning polygon forward based on point/line/footprint and the motion vector
        3. Automatically extends expiration time based on previous warning duration, with the duration remaining constant
        4. Results in **EXB**
        5. This is the default for the first warning update, after which the previous setting is used for subsequent updates.
    iv. Update Front
        1. For back-building hazards expected to continue beyond the warning duration
        2. Automatically moves **only the Front** of the warning polygon forward based on point/line/footprint and the motion vector
        3. Automatically extends expiration time based on previous warning duration, with the duration remaining constant
        4. Results in **EXB**
b. Manual extension:
    i. Extending warning expiration time by increasing the duration via a drop-down menu.
    ii. Extending warning area by editing polygon vertices or dragging the entire polygon to a new location that includes locations outside the previous warning area.

Additional improvements have been made to the software following Tiny TIM experiments at the National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (HWT) and NWS Operations Proving Ground (OPG), both in 2022. Many of these improvements were suggested by forecasters in these experiments and can be found in those experiment summaries (Stumpf 2022a, 2022b). These include:

- Redesigned the functionality to track manually-edited polygons versus default polygons, as well as enabling auto-updates when manual changes are made to the motion vector, duration, or geometry, or when the radar frame updates. The Compute-Advect-Computing-Advecting choices (Stumpf 2022b) have been replaced with the following options:
    - Auto:
        - ON: Any change to the motion vector, duration, or point/line/footprint tool geometry, or when the radar frame updates, the warning polygon will immediately redraw for the new conditions.

        - OFF: The warning polygon will NOT automatically redraw. Pressing the "Redraw Box" button is required to redraw a polygon for any of the above new conditions.
    - Advect:
        - OFF: The warning polygon is drawn using the “default” shapes corresponding to the point, line, or 2D footprint tool (see Fig 3).
        - ON: This setting will automatically be enabled if the warning polygon is edited in any way (e.g., moving, adding, or deleting a vertex, or dragging the entire polygon). The edited polygon will be "advected" when there is a change to the motion vector or position of the tool.
    - Notes:
        - NEW warnings will have Auto turned on and Advect turned off by default.
        - The chosen settings will be saved for the next warning update.
- The End Time Extension feature for warning updates has been replaced with the same Duration selection used for new warnings. Forecasters were having difficulty making mental calculations of the new duration. Unless the warning is moving forward with the hazard, the duration will now "age off".
    - We have also added the capability to decrease the expiration time on a warning update if the forecaster believes the storm will not last as long as previously thought, but they are not ready to cancel the warning yet.
- Added the option to restrict warning updates to the current WarnGen policy (cannot extend the expiration time and can only shrink the warning area) using a "CON" toggle (where the VTEC action code of CON is used in the warning). If the forecaster attempts to redraw the polygon outside the previous area, it will automatically snap back to only include previously-warned areas. The forecaster also cannot extend the End Time when this condition is met.
- Developed a better method for selecting vertices when a footprint vertex overlaps a polygon vertex. The polygon was slightly expanded (1 km) beyond the edge of the footprint to prevent point overlap.
- The Line and Footprint tracking tools currently use a single motion vector for the entire tracking object. For the 2022 OPG experiment, new versions were introduced with individual motion vectors assigned to each vertex on the tracking tool. These updated versions are known as the Line* and Footprint* tracking tools.
    - Based on feedback from forecasters, it was suggested to rename Line* to Dynamic Line and Footprint* to Dynamic Footprint.
- Implemented a "buffer" functionality for polygons, allowing users to conveniently increase or decrease the size of the warning by 1km increments using the + and – buttons.
- During the OPG, it was discovered that when a warning was selected for viewing, if the radar frame updated before the forecaster had a chance to edit the warning, the warning would automatically enter Edit mode and become locked from being edited by another forecaster. To address this issue, we introduced a 2-minute "grace period" during which the warning would not enter Edit mode, allowing the forecaster to deselect it before the grace period expired. However, it was found that the 2-minute grace period occurred too frequently. As a result, we decided to eliminate the grace period entirely and instead

require forecasters to make a change to the warning, either by editing a value on the HID or adjusting the geometry on the display, before the warning enters Edit mode.

  - When a warning is updated and the Auto mode was previously enabled, the auto-update feature remains temporarily inactive until the "Redraw Box" button is pressed.

- Incorporated specific functionalities/modifications to address dissemination issues:
  - When extending a warning, a dashed "former" polygon should be shown in the spatial display when a warning is being updated so that forecasters can see what they are changing their polygon from. This helps alleviate the potential slight addition to the workload when the user has to decide how much to extend the warning, to avoid the windshield wiper and accordion effects.
  - Explicitly prevent the "accordion effect" where downstream locations are removed from the warning if the storm's motion vector speed decreases, temporarily making the warning shorter until the locations are placed back within the warning during the next update as the storm continues to move forward (Fig. 4).

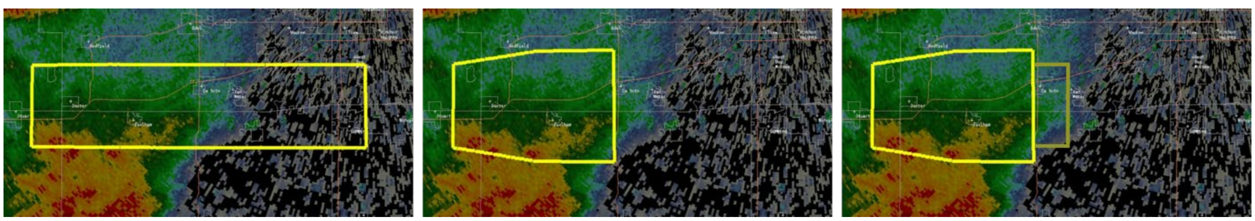

Fig. 4. *Left: A New warning; Center: An updated warning with a shorter polygon; Right: the darker yellow indicates the portion of the New warning (left) that has been added to the updated warning (center), mitigating the "accordion effect".*

Experiment Details

The NWS Meteorological Development Laboratory (MDL), in collaboration with the National Severe Storms Laboratory (NSSL), the Global Systems Laboratory (GSL), and the NWS Warning Decision Training Division (WDTD), conducted this experiment in person at the HWT for one shakedown (dry run) week and two operations weeks in 2023:

- Shakedown Week: Jan 30 – Feb 3
- Week 1: Feb 13 – Feb 17
- Week 2: Feb 27 – Mar 3

This was the first in-person experiment conducted at the HWT in about three years. This HWT experiment allowed the collaborators to explore several ideas to represent realistic challenges currently faced in warning operations with a broad range of forecasters. The primary focus was on workload and workflow differences compared to the traditional method of issuing warnings today. The aim was to assess functionality, identify any impacts on forecaster workload, identify any inconsistencies across CWAs/products/services, examine dissemination challenges, examine ideal timing updates, and suggest improvements and new functionality.

Each week, the experiment included three participants: two warning forecasters and one warning coordinator/mesoanalyst (WC/MesoA) (Figs. 5 and 6). For each scenario, a different participant would rotate into the WC/MesoA position. The two forecasters worked on a series of displaced real-time events with varying storm type/evolution scenarios. The WC/MesoA aided by providing information about the near-storm environment and its impact on storm evolution, as well as keeping track of all the warnings and storm reports and monitoring the forecasters' workload. The WC/MesoA would step in as a third warning forecaster when needed if the workload was too high for the other two.

For this experiment, only forecasters participated (no end users), so the resulting feedback is from the operational NWS forecaster perspective. The first week of the Tiny TIM HWT experiment was a "shakedown" of the system, involving three "test" forecasters from the Norman, OK, NWS Weather Forecast Office (WFO). The shakedown week was used to identify and fix any issues (software and logistical) that needed attention before the operational weeks of the experiment began.

On the first day (Monday), after an introductory presentation and software demo, forecasters learned how to use the software through a job sheet-guided, hands-on training exercise. Since the last experiment, we extended our training session by an additional hour and provided forecasters with more time to practice on their own.

On Days 2, 3, and 4 (Tuesday, Wednesday, and Thursday), forecasters issued Tiny TIM warnings for five different displaced real-time (DRT) severe weather scenarios (two scenarios per day). Each DRT case had unique domains and represented a variety of severe storm types, such as long-tracked tornadoes, squall lines with quasi-linear convective system (QLCS) tornadoes, right-turning supercells, and left-hooking occluding tornadoes (Table 2). Two new archive cases were added, in addition to those used in 2022, including an event spanning 5 ½ hours without breaks (forecasters ate lunch during operations). Storm reports, photographs, video clips, and Storm Prediction Center products were injected into a Slack channel using an automated "bot" and made available to the forecasters in real-time. For some scenarios, original television broadcasts were played, synchronized in time with the event.

	Type	Storm Modes	Length
Scenario 1	Training	Isolated supercells	2 hours
Scenario 3	Operations	Long-tracked supercells	2 hours 15 minutes
Scenario 7	Operations	Squall line with QCLS tornadoes	1 hour 45 minutes
Scenario 4	Operations	Multicell clusters and right-turning supercells	2 hours
Scenario 5	Operations	Long-tracked supercells	2 hours 15 minutes
Scenario 6	Operations	Multiple supercell areas; left-hooking tornadoes	5 hours 30 minutes

Table 2. *Scenario Descriptions.*

After each scenario, the forecasters filled out an online workload survey. Next, the entire group gathered for a 45-minute discussion of that specific scenario. At the end of all the scenarios on Thursday, the forecasters filled out an online usability survey. The final day (Friday), a half day, was spent conducting a 3-hour guided interview with the forecasters to gather their feedback and experiences during the experiment week.

Before the COVID-19 pandemic, we conducted in-person HWT experiments using physical workstations on site. During the pandemic, we conducted our experiments virtually using a version of the AWIPS software hosted by the NOAA Virtual Laboratory (VLab) within Amazon Web Services. The cloud-based software also allowed us to carry out software testing in a common environment, where developers could connect simultaneously in a collaborative, yet virtual, environment. We decided to use the virtual system within the HWT to conduct the experiment instead of maintaining the latest software builds on two systems (the physical and virtual systems). We learned to split a virtual instance across two monitors, expanding screen real estate, which enabled us to run one Common AWIPS Visualization Environment (CAVE) instance per monitor. One monitor was dedicated solely to Hazard Services, and the other could be used for one (or more) CAVEs to peruse and analyze any other data. There were some pros and cons to this approach:

- Pros: Developers had quick and convenient browser access to the cloud systems from anywhere, enabling quick software tests. Developers could diagnose problems quickly without having to ask forecasters to leave their workstations. Additionally, because we were operating with strict COVID protocols, if any of our participants fell ill with little or no symptoms, they could still participate virtually.
- Cons: The virtual instances ran slightly slower than the physical systems. Hopefully, this will improve as cloud computing technology advances.

Fig. 5. *Photos from the Tiny TIM experiment in action at the HWT.*

Fig. 6. *Group photos from Weeks 1 and 2.*

These were the specific objectives of the experiment:

- Technology: Evaluate HS-Tiny TIM components and performance to improve the software before operational implementation.

- Human Factors: Measure forecaster workload using HS-Tiny TIM, including ease of use and graphical design.

- Methodology: Assess how forecasters adopt their legacy warning methodology into the HS-Tiny TIM environment as they create and manage continuous, feature-following warnings.

- Conceptology: Collect and analyze data on forecasters' thoughts on the paradigm change from "static" warnings to continuously-updating warnings.

We gathered participant feedback on user experience, operational applications, and workflow considerations. The data collected will be used to further refine both the software and the concepts of operations of TIM. The following methods were used (those indicated with an asterisk were also recorded, and speech-to-text transcripts were created):

- Pre-operations online survey
- Discussions during events with meteorologists and developers
- Post-event online workload surveys
- Post-event discussion*
- End-of-week online usability survey
- End-of-week interview*

Results

The Tiny TIM software was relatively stable throughout the experiment, but a few issues were discovered that will be addressed post-experiment:

- Expired storms (EXP) were not disappearing from the experimental warning overlay.
- For certain durations (30 min), the accordion effect mitigation technique was adding too much area.
- When a warning crosses a CWA border, sometimes the warning edge is composed of many points rather than just two points.
- A "No projected tracking points found within polygon" pop-up sometimes appears when the footprint centroid is outside or nearly outside the current CWA.
- It is not possible to switch the storm track tool type in the HID for Tornado Warnings.
- Several times when expiring a warning, we received a warning text with two "EXP" sections instead of one.

Some other software changes were made during the experiment based on feedback from the forecasters. These included:

- The "CON" feature was initially designed to handle situations where certain warnings couldn't be extended in time, such as lower-end severe warnings. However, all forecasters unanimously agreed that any warning, regardless of intensity, should have the option for extension. As a result, the feature has been disabled and is unlikely to be included in the final software.
- The Dynamic Footprint option was deemed unnecessary and has been removed due to the absence of practical use cases.
- After a few scenarios, the Accordion Effect mitigation technique was disabled. This decision was made because the output was confusing to forecasters. They had difficulty distinguishing which parts of the warnings were being retained due to the mitigation, and whether the warning extension box controls were functioning as intended.

The forecasters made several notable software suggestions. For the Accordion mitigation feature, they recommended adding an alert when it is activated. This can be achieved by displaying a small accordion icon next to a toggle (ON) on the HID. Users should have the option to toggle accordion areas off and differentiate the new areas using "alternate" hatching or a different color shade.

Regarding the HID, the forecasters proposed replacing the Advect toggle with a "Reset Shape" button. This button should only become active or visible after a polygon is edited. Clicking the button would reset the shape to the default polygon. Additionally, the shape should automatically reset when switching Tool Type or editing footprint or line tool vertices (excluding when dragging the tool).

Regarding the Storm Track Tool, they suggested adding a centroid point to the footprint tool to assist with motion tracking. They also recommended that the buffer controls should adjust the size of the polygon even if the default polygon is not used. Additionally, they proposed implementing an automated method to "sense" the CWA border and suggest reducing the duration. A pop-up notification should appear if the warning extends outside the CWA, providing an option to decrease the duration or to press a button to do this automatically.

For the Console, the forecasters suggested adding a "Time Since Last Modified" column. They also proposed changing the default sorting of console columns to be based on the username, prioritizing the workstation's user as the first entry. The secondary sort should be in ascending order based on the expiration time. Furthermore, they recommended including a button to reset the default sorting if it has been modified.

Appendix A contains a comprehensive list of suggestions for improving the software functionality provided by the forecasters, including those mentioned above. Some of these suggestions will be considered for incorporation into future versions of the software, subject to funding and budget availability, in order to enhance its robustness. Certain enhancements fall within the broader scope of HS - Convective as a whole, rather than being specific to Tiny TIM, and are identified as such. Furthermore, the forecasters also made suggestions to enhance the logistics of future experiments, which are listed in Appendix B.

This experiment also incorporated a basic human factors analysis through online surveys, aiming to assess mental workload, confidence levels, and software usability. Further details regarding the human factors analysis can be found in Appendix C.

Tiny TIM offers the advantage of faster updates, with the forecasters suggesting an update rate of approximately every 10 minutes per warning, taking into account workload considerations. However, for high-impact events, more frequent updates, at least every 5 minutes, can be made. It is important to note that intervals of less than 5 minutes would significantly increase workload and diminish the overall impact. An exception to this general rule would be when a report is received, in which case the warning should be updated as soon as possible. If a forecaster is currently editing a warning but receives a tornado report for a different unwarned storm, they can "pause" the editing process for the current warning update and urgently address the tornado report by issuing a new TOR. This flexibility is enabled by Hazard Services, which allows for the simultaneous editing of multiple warnings (unlike WarnGen). Once the more-urgent warning is issued, the forecaster can then return to finish editing the original warning. However, there is a potential downside to the ability to conduct faster updates. Forecasters might feel compelled to update warnings more frequently than necessary, which could lead to a loss of focus on other storms within the CWA.

During the experiment, several discussions and considerations arose regarding the handling of QLCS vortices and the issuance of warnings. One question was whether to issue separate warnings per vortex or apply a blanket warning for the entire line. Additionally, there was a need to clarify the approach for Tornado Emergency (TOR-E) warnings. While it was customary to create a new warning for TOR-E (at least in Central Region), it was emphasized that with Tiny TIM, this practice was unnecessary, and the same warning could be utilized. It was suggested that dissemination systems should be designed to issue new alerts for the entire polygon whenever there is an upgrade to a TOR-E. Finally, there were discussions about the duration of a TOR-E (Tornado Emergency) warning, with a suggestion that it should only apply to the initial

15-20 minutes of the warning, rather than encompassing the entire duration. In this context, the use of a CAP-formatted warning was considered beneficial. It was proposed that an "inner" polygon could be implemented to specifically target the TOR-E area, ensuring that only those areas within the designated region would receive a new warning alert if they were already under an existing warning.

One of the experiment scenarios involved a classic left-hooking occluding tornado cyclone (4-5 May 2022 near Lockett, TX), which posed a challenge for the original warning forecaster due to the existing paradigm where warnings cannot be extended. Figure 7 illustrates the combined tornado warnings issued during the 0130-0230 UTC one-hour period, overlaid on the "rotation tracks" product depicting the left-hook path of the tornado cyclone. On the left side are the original NWS warnings for the event, while on the right side are Tiny TIM warnings created by the same NWS warning forecaster who issued the original warnings. Figure 8 presents a time series of the same warnings for this event. It is noteworthy that in some time frames, there were two, three, and occasionally *four* separate warnings in effect for the same single hazard. With Tiny TIM, there was only one warning in effect for the hazard at any given time. Throughout different time periods, that warning would be extended in time and area, following the path of the hazard.

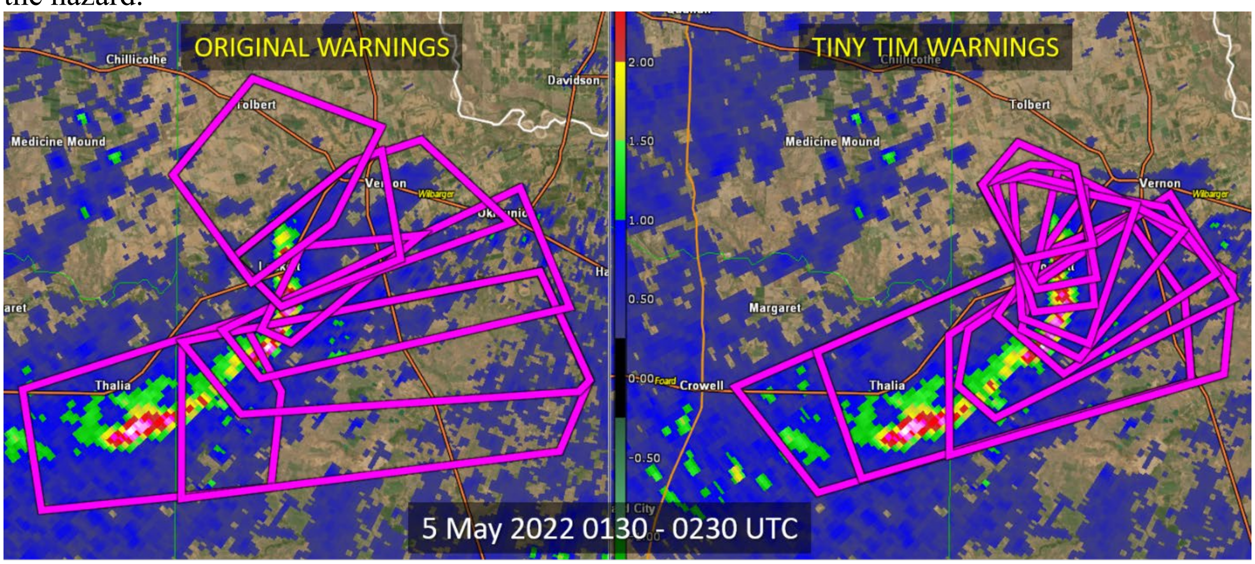

Fig. 7. *Rotation tracks for the Lockett, TX, tornado event of 4-5 May 2022. On the left is a composite of all the tornado warnings issued by the NWS Norman. On the right is a composite of all the Tiny TIM tornado warnings issued by the original NWS forecaster but within the HWT experiment setting.*

There are only a few remaining changes necessary to bring the Tiny TIM software to operational Readiness Level 7. The development team has identified the most important bug fixes and new features to be implemented within the remaining timeframe of the FY23 grant (September 30, 2023). Following FY23, the focus will shift towards advancing the infrastructure component to facilitate dissemination.

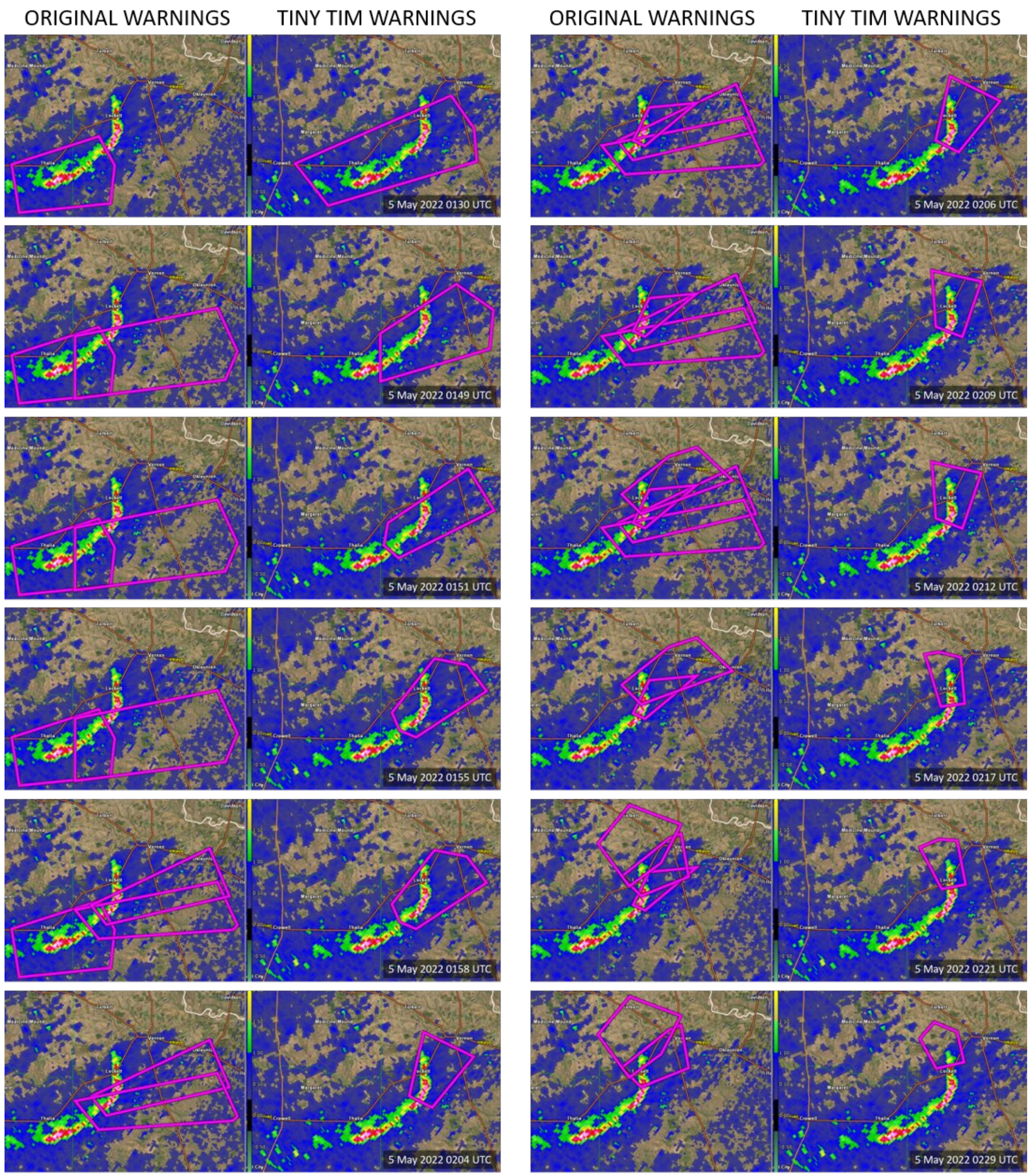

Fig. 8. Time mosaic of the original NWS warnings (displayed on the left side of each sub-figure) and the Tiny TIM warnings (displayed on the right side) from 0130 to 0230 UTC on 5 May 2022.

Emphasis will be on utilizing the Common Alert Protocol (CAP) Formatter instead of VTEC to enable warning extensions. CAP offers greater flexibility and aligns with the future dissemination path of the NWS. It allows for the inclusion of new fields using XML tags, which can be considered "optional" and utilized by compatible dissemination systems. For instance, multiple polygons can be defined for different portions of the warning: 1) areas that are added (triggering an alert), 2) areas that remain warned (no alert unless upgraded to a Tornado Emergency), and 3) areas that are removed (triggering potential "All Clear" alerts). Additionally, higher-resolution polygons can be incorporated, such as a 100-point maximum for enhanced precision, as well as "inner" TOR-E polygons. With this framework in place, future software experimentation will likely be conducted at the OPG, where a comprehensive dissemination test involving AWIPS Network Control Facility test system (NCF-Test), NOAA Weather Radio (NWR), Wireless Emergency Alerts (WEA), and private industry partners should be planned.

Finally, several functionalities have been developed for Tiny TIM which could be implemented between the initial operating capability of HS - Convective and the deployment of Tiny TIM. These functionalities can be utilized within the current warning paradigm and include the following features: Auto-Update, Reset Shape (replacing Advect), Update Rear (without extending the area or time), Buffer (-/+) controls, Dynamic Line Tool, and 2D Footprint Tool.

Testimonials

> "Less time spent on adjusting polygons/the polygonology, more time available to spend interrogating storm/environment data. Warning operations are always fairly complex, but the functionality of Tiny TIM removes a lot of the time sink that is tweaking vertices to perfection (especially as someone with minimal experience in warning ops in general)."

> "Overall, I felt I was doing minimal hands-on edits to my polygons... the software did almost everything for me (and with enough success that I didn't feel the need to make more than minor edits)."

> "Cannot understate how much of the time sink that is tweaking individual vertices/having to completely readjust polygons given storm motions Tiny TIM *completely* removes."

> "With TIM, I just readjusted my footprint and everything was righted -- a whole new set of warnings would've been necessary for our current system."

> "In my opinion, it is much simpler to use this, even when problems arise, than WarnGen on its best day."

> "The one very area that saves a lot of time is allowing the warning to shift slightly to account for changes in the storm motion, rather than issuing a brand-new warning with takes more time and causes dissemination/communication issues."

> "Using Tiny TIM left more time for me to interrogate storms and make warning decisions rather than fiddle with new warnings."

“Tiny TIM creates less confusion because there are fewer polygons (cleaner warning display).”

“This is one of the first times that felt I had enough time to issue separate tornado and severe warnings on supercells that had separated hazards without much additional workload overall.”

“Cannot underestimate how much having the Update Rear/Front/Both box controls improves workload and are way more efficient than WarnGen, and it makes me incredibly sad that I have to go back to regular warning ops in WarnGen where I have to fight with vertices in between updates.”

“The 2D Footprint Tool latches onto mesocyclones or hail cores extremely well, and the "customized" polygons that result from the shape of the footprint require little to no updates. The 2D Footprint Tool is a game changer in terms of accurately capturing the hazard.”

“I think the great majority of warning forecasters would be able to understand Tiny TIM without a complete paradigm shift in training.”

“After the initial learning curve, I was able to get very comfortable using this system. It was similar enough to WarnGen, but the added tools made it even better. It allowed me to warn for storms in a more intuitive and people-centric manner.”

“I think the learning curve could be a little steep for some forecasters, especially the OG (“old guard”), so having thorough training will be crucial to making the transition as smooth as it can be.”

“I was able to learn this system easily, but I also think using it for four days made it easier to learn how to use it. I think the field will have a little more growing pains than us since they'll be taking Commerce Learning Center modules and testing the software at random and infrequent times. It will take longer for the field to feel comfortable with and learn to use the system.”

“It is important to test every kind of possibility if this is going to be our new warning paradigm. For example, short-lived pulse storms with weak steering aloft won’t take much advantage of the Tiny TIM features, but even these could move out of polygon and require area extensions.”

“I am very satisfied with Tiny TIM and am sad to have to go back to using WarnGen when I go back to my office. I think Tiny TIM is going to be a big leap forward for our warning operations and will greatly decrease workload and frustration with polygons, and I hope that it is implemented as soon as possible!”

“Please let me take this system home with me. I dread issuing warnings with WarnGen when I know that this technology exists.”

Key Takeaways

- Tiny TIM significantly reduces forecaster workload and mental demand, particularly for long-tracked hazards.
  - Warning updates can be executed faster and with improved spatial accuracy.
  - The option to extend warnings eliminates the need for separate downstream warnings, reducing decision-making complexity.
  - Timely updates ensure that storms rarely exit the warning polygons, allowing for adjustments if the previous polygon is not optimal.
- The elimination of overlapping warnings for a single hazard results in a cleaner output field and improved messaging. There is no longer a need to issue a completely new warning and manage two separate warnings (the new warning and the imminent cancellation of the previous one) for the same hazard when it appears to be leaving the polygon. Tiny TIM addresses these situations:
  - When a new downstream warning overlaps with the previous one, canceling the previous warning can create confusion.
  - Overlapping warnings require the simultaneous broadcast of two warnings on NWR and television crawls, leading to potential confusion.
- There are only a few remaining software capabilities that need to be added, and these will be completed during the remainder of FY23. This will allow future efforts to focus on advancing the infrastructure component to facilitate dissemination.
- There is unanimous agreement among forecasters that warning extensions should be allowed for **any** long-tracked storm, regardless of the presence of observed significant hazards.

Future Plans

- Document, analyze, and prioritize newly identified and forecaster-suggested functionalities, modifications, and other software issues specific to Tiny TIM, including those listed in the Appendices.
  - Complete the remaining software work for FY23.
  - Regularly integrate the Tiny TIM code into the operational version of HS to stay current with HS-Convective development.
- Continue familiarizing forecasters with Tiny TIM and work toward starting a preliminary training plan for Tiny TIM that spans multiple divisions of the Office of the Chief Learning Officer within the NWS.
- Propose a multi-year NWS collaboration between the Office of Science and Technology Integration (STI), the Analyze, Forecast and Support Office (AFS), and the Office of Dissemination (DIS) to advance the infrastructure component to facilitate dissemination. The focus will be on adopting the CAP Formatter instead of VTEC to enable warning extensions. This effort includes planning a comprehensive dissemination test at the OPG involving NCF-Test, NWR, WEA, and private industry partners.
- Update the TIM transition plan for Tiny TIM based on the aforementioned points.

Web Presence

- NSSL Bite-Sized Science 3-minute video on Threats-In-Motion
- A Blog summary about Tiny TIM (use NOAA credentials to log in)
- The TIM Weather and Forecasting journal article (Stumpf and Gerard, 2021).

Personnel

Greg Stumpf	CIRA* and NWS/MDL	Experiment Coordinator / Project Co-PI
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Alyssa Bates	CIWRO** and NWS/WDTD	Project Scientist / Project Co-PI
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Disclosure

ChatGPT was used to help proofread portions of this summary.

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Stumpf, G. J., 2022a: 2022 Tiny – Threats-In-Motion (Tiny TIM) HWT Experiment Summary.

Stumpf, G. J., 2022b: 2022 Tiny – Threats-In-Motion (Tiny TIM) OPG Experiment Summary.

Appendix A: Software Functionality Suggestions

NOTE: Enhancements that fall within the broader scope of HS - Convective as a whole (and not specific to Tiny TIM) are indicated with an "(HS-C)" prefix.

Hazard Information Dialog (HID):

- Replace the Advect toggle with a “Reset Shape” button.
    - It should be inactive/invisible until a polygon is edited. Clicking it would reset the shape to the default polygon.
    - Also, the shape should automatically reset when:
        - Switching Tool Type.
        - Editing footprint or line tool vertices (excluding when dragging the tool).
- Add editable fields for motion vector speed and direction.
- Change the names of the Box Control options. Some suggestions include:

Current Name	Suggestion A	Suggestion B
Fixed	Fixed	Anchor Both
Update Rear	Remove Rear	Anchor Front
Update Both	Update Both	Anchor None
Update Front	Extend Front	Anchor Rear

- If the extension time does not equal 0 minutes, the label should turn red.
- (HS-C) Enclose the Tornado Emergency selection within a magenta-colored box to prevent accidental clicking.
- (HS-C) Add a pop-up alert if Preview is clicked before any edits are made.
- (HS-C) Add multiple "first-guess" locations to the DESTRUCTIVE tag's specific locations field.
- (HS-C) Add a previous text button for the DESTR/CATAS locations field.
- (HS-C) Make sure the highest IBW tag is “greater than” for hail and wind.

Object Editing (Storm Track Tool):

- Add a centroid point to the footprint tool to assist with motion tracking.
- The buffer controls should adjust the size of the polygon even if not using the default polygon.
- Implement an automated method to "sense" the CWA border and suggest a reduction in duration.
    - Include a pop-up if the warning extends outside the CWA, suggesting decreasing the duration or providing a button to do it automatically.
- The initial symmetric hexagon footprint for TOR should be half the size of an SVR, similar to what the point tool does for TOR.
- Introduce a "QuickWarn" feature to issue TOR warnings in less than 30 seconds using the hexagon footprint.
- For the Line and Dynamic Line Tools, provide separate controls for the front and rear buffers.
- Add the ability to set the default number of vertices for the 2D Footprint Tool (currently set to 6).

- Enable independent movement of the 2D Footprint centroid to the location of the greatest hazard (e.g., biggest hail) to emphasize that location in the warning text.
- Allow drawing a footprint from scratch (polygon, freeform, ellipse) instead of starting with a perfect hexagon.
- (HS-C) When initiating the STT on a past radar frame, reset the display to the latest radar frame.
- (HS-C) Include the ability to replace an SVR with a TOR (and vice versa) with a single action. The older warning should automatically be canceled (CAN) with a message stating that it has been replaced by the newer warning. The newer warning should include a message indicating that it replaces the older warning. This capability already exists in HS-Hydro.
- (HS-C) Allow "linking" (and "unlinking") of an SVR and TOR on the same storm, so that when updating the TOR, the SVR automatically updates (moves the polygon). Updating the maximum hail on the SVR would also update it on the TOR.
- (HS-C) Add a "snap to another polygon" feature.

Spatial Display:

- (HS-C) Add storm motion values to the StormTrackTool decorations.
- (HS-C) Require a Ctrl-Click to select a warning from the display, to prevent accidental selection while panning.

Console:

- Add a “Time Since Last Modified” column to the console.
- The default sorting of console columns should be by username (e.g., "my warnings"), prioritizing the workstation's user as the first entry. The secondary sort should be in ascending order based on the expiration time.
    - Include a button to reset the default sorting if it has been changed.
- (HS-C) Change default warning threshold alerts.

	Alert	**Time**	**Text Color**	**Background Color**	**Pop-up**	**Blink**
Current	1st	15 min	yellow	black	no	no
	2nd	5 min	red	white	yes	no
Proposed	1st	15 min	yellow	grey	no	no
	2nd	5 min	red	black	yes	yes

- (HS-C) Include a filter for warning type (TOR or SVR).
- (HS-C) Automatically re-enable some warnings in the Console after 5 minutes when they have been clicked off.

Accordion:

- Accordion mitigation should provide an alert when it becomes activated:
    - Display a small accordion icon next to a toggle (ON) on the HID. Users can toggle accordion areas off.
    - Use "alternate" hatching or a different color shade to distinguish the new areas.

Appendix B: Experiment Logistics Suggestions

- Best practices to add to training:
    - When handling warnings exiting CWAs, continue using EXB/Update Both, but reduce the duration so that the arrowhead is just outside the CWA. Then, on the next update, start using Update Rear.
    - When dragging to a storm on a past frame, do not step forward the same number of frames. Instead, use the "latest frame" hotkey to save time.
    - When there are many active warnings, toggle off the other warnings to make it easier to see your warning. Just remember to toggle them back on later.
    - If a forecaster is editing a warning and receives a report of a tornado for a different unwarned storm, inform users that they can "pause" the editing on the current warning update and move to the location of the tornado report to issue a new TOR. Afterward, they can go back and finish editing the first warning.
    - For most situations, use the following:
        - Footprint Tool for non-linear SVR warnings.
        - Line Tool for linear SVR warnings.
        - Point Tool for TOR.
    - Emphasize that even though updates are faster, it does not mean that forecasters should feel compelled to update more frequently.
- New scenario suggestions:
    - Include a scenario with marginally-severe pulse convection to challenge forecasters on whether or not to extend warnings.
    - Include a scenario with a simultaneous flash flood threat to increase workload and incorporate the use of HS-Hydro to handle flood hazards.
    - Consider using the system with real-time weather, where isolated long-tracked storms are not guaranteed, unlike in our archive scenarios.
- Experiment logistics:
    - Obtain Warn on Forecast System (WoFS) archive data for the MesoA.
    - Provide a quick reference guide for frequently encountered issues, questions, or best practices.
    - Include local county/city maps for each scenario since the forecasters are likely unfamiliar with those WFOs.
    - Include a recorded demo before the HWT visit.
    - Allow experiment non-participants to learn and practice with Tiny TIM via the virtual cloud instance and job sheet exercises.
    - Inform participants ahead of time that they will be starting from scratch regarding procedures, as their customized local procedures do not align well with the HWT's AWIPS system, which involves transitioning from WFO to WFO. In the initial email, add an action item to consider which procedures they would use for the warning desk and the MesoA desk.
- Outreach:
    - Arrange for one of the PIs to give a VLab Forum seminar.
    - Publish a journal article about Tiny TIM.

Appendix C. Human Factors Analysis Survey Results

HWT Participant Data

Six NWS forecasters participated in the 2023 Tiny TIM HWT experiment. The forecasters' work experience ranged from 2 years to 14 years, with an average of 7.0 years (standard deviation of 5.5). Their average NWS warning experience also ranged from 1 year to 13 years, with an average of 4.2 years (standard deviation of 4.5).

Mental Workload (NASA TLX) Survey

The NASA-TLX (Hart & Staveland, 1988; Hart, 2006) workload index is a questionnaire-based workload rating tool. The tool encompasses six aspects of workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. The raw scores for the mental workload range from 1 to 100, where 1 represents an extremely low workload and 100 represents an extremely high workload. The ratings were averaged from all sessions for each of the six aspects of workload.

Table 1 shows the average ratings for the six sub-dimensions and the overall workload for five archived hazardous weather scenarios. Forecasters who solely performed WC/MesoA duties without issuing warnings were not included in the count. The average workload for the 2023 Tiny TIM HWT experiment across all testing scenarios was 44.9 (out of 100, with a standard deviation of 24.2). Each of the five scenarios was chosen with an increasing level of difficulty (more storm coverage) throughout the course of the week. But note that after the middle scenario (#4), the workload ratings started to decrease as the forecasters became more accustomed to using the software.

Table 1. 2023 Tiny TIM NASA-TLX Mental Workload Ratings for Five Test Scenarios. Scenario 1, a training scenario, is not included in this table. The order of the scenarios in the table corresponds to the order in which each scenario was worked throughout the week (Tuesday: S3, S7; Wednesday: S4, S5; Thursday: S6).

	Scenario 3	Scenario 7	Scenario 4	Scenario 5	Scenario 6
	Mean (std)				
Mental Demand	55.2 (21.3)	58.3 (25.0)	64.2 (29.3)	46.3 (15.7)	54.2 (19.6)
Physical Demand	38.8 (14.8)	28.0 (9.1)	50.6 (31.3)	39.0 (25.8)	41.3 (16.3)
Temporal Demand	46.0 (19.7)	43.8 (34.7)	62.0 (30.7)	44.0 (23.1)	37.3 (23.0)
Effort	58.2 (23.2)	59.0 (28.1)	67.8 (28.0)	54.8 (21.8)	53.2 (26.6)
Frustration	30.2 (30.9)	42.8 (19.6)	58.8 (27.1)	28.5 (15.8)	23.8 (12.7)
Performance	40.6 (25.9)	40.5 (6.8)	40.8 (24.8)	33.2 (23.7)	18.3 (9.7)
Overall Workload	**44.8 (23.2)**	**45.4 (23.0)**	**57.4 (27.6)**	**41.0 (21.6)**	**38.0 (22.2)**

PSSUQ Usability Questionnaire

The Post Study System Usability Questionnaire (PSSUQ; Lewis, 2002) is a survey tool designed to evaluate the usability of a computer system. The tool consists of 19 usability questions that assess four different areas: System Usefulness (Questions 1–8), Information Quality (Questions 9–15), Interface Quality (Questions 16–18), and Overall Usability (Questions 1–19). The rating scale ranges from 1 to 7, where 1 corresponds to a low level of usability, 7 to a high level of usability, and 4 represents a neutral level of usability.

The participants completed the PSSUQ questionnaire after finishing all test scenarios in the testbed. Table 2 displays the average responses for each of the four categories: System Usability, Information Quality, Interface Quality, and Overall Usability.

Table 2. PSSUQ Usability Ratings for the three Tiny TIM experiments (7-point scale).

	2022 Tiny TIM HWT	2022 Tiny TIM OPG	2023 Tiny TIM HWT
System Usability	6.04	6.41	6.46
Information Quality	5.51	6.16	5.93
Interface Quality	5.67	6.67	6.44
Overall Usability	**5.79**	**6.36**	**6.25**

The overall usability was assessed at 6.25 (on a 7-point scale) for the 2023 Tiny TIM HWT experiment, with system usability rated at 6.46, information quality at 5.93, and interface quality at 6.44. It is worth noting that the usability rating improved from the first to the second Tiny TIM experiment and then remained relatively steady for the third experiment. This trend suggests that software improvements made between each experiment may be reaching a plateau, indicating that we are nearing the final version of the software before the first operational integration.

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Appendix D: And now for some fun!

Tiny TIM So Grand!

by Dr. SeussGPT

Oh, let me tell you a tale so grand,
About a system called Threats-In-Motion, on brand!
The National Weather Service, oh so wise,
Proposed an approach to open our eyes.

Severe thunderstorm warnings, they say,
And tornado warnings, in a better way,
Currently use polygons, static, and still,
But TIM will bring movement, with a thrill!

Warning polygons that move with the storm,
Continuous updates, a brand-new norm,
With TIM, the lead time will surely increase,
And fairness for all, a warning masterpiece!

But for now, a short-term solution we seek,
To take small steps and try something unique,
"Tiny TIM" is the name of the game,
Extending warnings, not staying the same.

Forecasters, with the software in their hand,
Can manually extend warnings across the land,
With "warning extension shortcuts," oh so neat,
The polygon grows, a storm's path to meet.

And there's a tool, a 2D footprint to see,
Describing hazards with great accuracy,
Motion vectors for each vertex, oh my,
For bowing lines and storms that multiply.

No more accordion effect, it won't be seen,
No shortening warnings, like it used to mean,
Locations downstream will find their way back,
As the storm moves forward along its track.

Manually-edited polygons, they can be tracked,
Auto-updates, when changes are packed,
Following NWS warning policy true,
Keeping expiration time within their view.

Now let's talk about what we learned so grand,
From the experiment, with Tiny TIM's hand,
First, a reduction in workload, oh what a dream,
No need for new warnings, it seems!

Messaging improved, as the same number stays,
For the hazard's whole life, no overlapping haze,
And lastly, we've seen, a lesson so true,
Extensions for all long-tracked storms, not just a few.

So, there you have it, the tale Tiny TIM,
A system that moves, bringing hope on a whim,
With improved warnings, and a forecaster's delight,
Tiny TIM shines, bringing safety in sight!