GOES-R and JPSS Proving Ground Demonstration Proposal:
Hazardous Weather Testbed – 2024 Spring Experiment

1. **Project Title**: 2024 Geostationary Operational Environmental Satellite R-series (GOES-R) and Joint Polar Satellite System (JPSS) Proving Ground – Hazardous Weather Testbed (HWT) Experimental Warning Program (EWP) Product Demonstrations

2. **Organization:** HWT/EWP, Norman, OK

3. **Products to be Demonstrated as a GOES-R and JPSS Proving Ground activity at the HWT in 2024:**
    a. GLM Background and Data Quality Product
    b. GREMLIN (GOES Radar Estimation via Machine Learning to Inform NWP)
    c. OCTANE Suite (Speed, Direction, Cloud-Top Cooling and Divergence)
    d. Polar Hyperspectral Soundings with Microwave and ABI data (PHS) Model
    e. NOAA/CIMSS ProbSevere LightningCast

4. **Demonstration Project Summary:**
    a. **Overview:** As a GOES-R and JPSS Proving Ground (herein, Satellite Proving Ground) activity, GOES-R/JPSS products and capabilities will be demonstrated in the HWT during the 2024 Spring Experiment. Satellite Proving Ground activities during the Spring Experiment will take place during the weeks of May 13-17, May 20-24, and June 3-7 in the EWP. The EWP provides a conceptual framework and a space to foster collaboration between research and operations to test and evaluate new and emerging technologies and science to advance National Weather Service (NWS) warning operations. Products will be demonstrated within a simulated warning operations environment using a real-time cloud-based AWIPS-II framework. NWS forecasters will be the primary evaluators. Various project scientists and subject matter experts will also be in attendance throughout the experiment to provide project expertise and to communicate directly with the user community. The exposure to appropriate GOES-R series and JPSS products and capabilities during the height of the spring severe weather season will provide NWS forecasters and scientists an opportunity to help determine best practices and operational applicability as well as critique and suggest improvements for algorithms in different stages of their development cycle. For the 2024 Spring Experiment, live GOES-16/18 imagery and products will once again be evaluated along with experimental GOES-R and JPSS algorithms.

    b. **Plan, Purpose, and Scope:** The HWT provides the Satellite Proving Ground with an opportunity to demonstrate Baseline, Future Capabilities, and experimental products associated with the next-generation GOES-R series geostationary and JPSS polar satellite systems that have the potential to improve short-range hazardous weather forecasting, decision support services (DSS), and warnings. Additionally, the testbed allows forecasters to test and develop best practices for using GOES-R/JPSS data in convective situations, and will gauge the effectiveness of the NWS-wide satellite training. The structure of Satellite

Proving Ground activities at the 2024 Spring Experiment in the HWT/EWP will be as follows.

Approximately 16 participants will be involved in the 2024 Satellite Proving Ground, with 4 forecasters per week attending two weeks of in-person demonstrations and 8 forecasters attending one week of virtual demonstrations. Participants will receive training beforehand in the form of product user guides, PowerPoint slides, and online learning modules for the products being demonstrated. Each week will begin with a short overview of the evaluated products by subject matter experts, forecaster expectations for the week, introducing the HWT blog, and familiarizing participants with the AWIPS cloud instances. Additionally, more detailed summaries, applications, and caveats for each product will be provided to the forecasters in small groups with sufficient time for discussion and questions.

The first day of each in-person demonstration week will begin at 11 am CDT and end at 7 pm CDT. The start times for Tuesday through Thursday will happen between 10 am CDT and 1 pm CDT, and end eight hours later. The variable start time will be decided the day before, and depend on when the primary convective activity is expected to start. During the virtual demonstration week, the first day will start at 1 pm CDT and end at 6pm CDT. Tuesday through Thursday may begin between 12 pm CDT and 2 pm CDT, end five hours later, and will follow the same variable start time procedure as previously described for the in-person demonstration weeks.

In both demonstration formats, Tuesday through Thursday will begin with an open discussion from the previous day's events, followed by a brief discussion of the day's anticipated convective threat (location/timing/mode/hazards). Forecasters will then work in pairs of 2 or 3 with real-time simulated short-term forecasts, warning operations, and decision support services (DSS) in County Warning Areas (CWAs) across the CONUS. Using the GOES-R HWT blog, participants will document their short-term experimental mesoscale forecast updates in real-time, highlight the impact of satellite-based imagery on these short-term forecasts, and provide verification on the quality of experimental products and the forecasts they produce. Warnings and advisories will be issued using AWIPS-II/WarnGen, with forecasters providing the motivation for their warnings and DSS messaging in a separate form. Additionally, forecasters will have the ability to create graphical forecast images to highlight how NWS forecasters can communicate hazardous weather information to the public using the demonstrated products. Feedback will be gathered throughout the experiment in the form of: 1) surveys to be completed at the end of each day and week, 2) real-time blogging, 3) daily and weekly forecaster debriefs, 4) real-time discussions during operations, 5) submitted warnings and DSS messaging, and 6) graphical forecasts.

Monday through Thursday, live operations will end 30 minutes prior to the scheduled end time for the day, and the participants will complete their daily surveys. Each Friday will begin with the distribution of a weekly survey, followed by a weekly debrief session to summarize the week's activities, feedback, and recommendations. For the in-person demonstration weeks, operations will end early on Thursday such that participants can take the necessary daily and weekly surveys, and develop presentations sharing their experiences in the Spring Experiment and to. The slides will be presented virtually Friday as part of a "R2O/O2R Tales" (ROOTs) webinar, in which scientists and NWS entities outside of Norman are encouraged to participate. Figures 1 and 2 (below) provide a visual representation of the schedule described.

On-Site Demonstration Schedule

Hour (From start)	0:00	0:30	1:00	1:30	2:00	2:30	3:00	3:30	4:00	4:30	5:00	5:30	6:00	6:30	7:00	7:30
Monday	Orientation				Product Training				Operations							Daily Survey
Tuesday	Discussion/ Forecast		Operations													Daily Survey
Wednesday	Discussion/ Forecast		Operations													Daily Survey
Thursday	Discussion/ Forecast		Operations										Daily Survey	Webinar Prep		Weekly Survey
Friday	Weekly Debrief		Webinar													

Figure 1: The in-person demonstration schedule (13-17, 20-24 May) in Norman, OK.

Virtual Demonstartion Schedule

Hour (From start)	0:00	0:30	1:00	1:30	2:00	2:30	3:00	3:30	4:00	4:30
Monday	Orientation			Product Training/Operations						Daily Survey
Tuesday	Discussion/ Forecast		Operations							Daily Survey
Wednesday	Discussion/ Forecast		Operations							Daily Survey
Thursday	Discussion/ Forecast		Operations							Daily Survey
Friday	Weekly Survey	Weekly Debrief								

Figure 2: The virtual demonstration schedule (3-7 June).

c. **Goals:** The main objective of the Satellite Proving Ground demonstrations within the HWT is to demonstrate and evaluate baseline, future capability and experimental products that have the potential to improve short-term forecasts, nowcasts and warnings of hazardous weather across the CONUS. Highlights of forecaster feedback will be organized in a final report which will be submitted to the Satellite Proving Ground and provided to product developers so that recommended changes and improvements to products can be addressed. The one-on-one interactions between the project scientists and NWS forecasters allow for valuable discussions during real-time hazardous weather events, maximizing research-to-operations-to-research (R2O2R) feedback, a key goal of the Proving Ground. Additionally, the real-time demonstration of experimental and baseline products ensures the algorithms work properly in AWIPS-II. Finally, exposing NWS forecasters to GOES-R series and JPSS baseline products and capabilities shortly after availability allows for the development of best practices for using the data in severe weather operations.

5. **Participants Involved:**
    a. **Providers:**
        i. GLM Background Imagery and Data Quality Product (DQP) (Eric Bruning – TTU, Phillip Bitzer – UAH)
        ii. GOES Radar Estimation via Machine Learning to Inform NWP (GREMLIN) (Kyle Hilburn – CIRA/CSU)
        iii. OCTANE Suite (Speed, Direction, Cloud-Top Cooling and Divergence) **(**Jason Apke – CIRA/CSU)
        iv. Polar Hyperspectral Soundings with Microwave and ABI data (PHS) Model (Scott Lindstrom – UW, Bill Smith – UW, Lee Cronce – CIMSS, Anthony DiNorscia – SSAI)
        v. ProbSevere LightningCast (Mike Pavolonis – NESDIS)
    b. **Consumers:**
        i. Hazardous Weather Testbed

6. **Project Schedule/Duration**:
    a. Training sent to participants: 1 May 2024
    b. Product demonstration period: 13 May 2024 - 7 June 2024
        i. Week 1: 13 May 2024 - 17 May 2024 (In-person)
        ii. Week 2: 20 May 2024 - 24 May 2024 (In-person)
        iii. Week 3: 3 June 2024 - 7 June 2024 (Virtual)

7. **Project Decision Points and Deliverables:**
    a. Proving Ground Operations Plan: 7 March 2024
    b. Proving Ground Final Report: 1 September 2024

8. **Responsibilities and Coordination:**
    a. Kevin Thiel, OU/CIWRO and NOAA/SPC - Principal Investigator for Satellite Proving Ground activities taking place in the HWT in 2024
    b. Anthony Lyza, NOAA/NSSL - HWT Executive Officer

9. **Budget and Resource Estimate:** Funded through the GOES-R and JPSS Science Offices.

Product Name: GLM Background Imagery and Data Quality Product (DQP)
Primary Investigator: Eric Bruning (Texas Tech) and Phillip Bitzer (U. Alabama-Huntsville)

Hazardous Weather Testbed, Experimental Warning Program Relevance:

- Operational users of GLM data have requested information about how the sensitivity of GLM varies across the field of view, and have also requested information about where in the field of view certain known artifacts are occurring (e.g., the Bahama Bar).
- Additional studies with forecasters showing them the GLM background as an additional visible imagery channel have received positive feedback.
- Trials this year are aimed at testing a concrete product implementation for feedback on readiness to be implemented as a routine product included in the GLM gridded imagery product stream.
- The GLM backgrounds should be evaluated for their utility as a visible channel replacement in the event of an ABI outage. The GLM DQP should be evaluated for its utility in understanding flash detection efficiency and other anomalies as have been reported in prior HWT GLM activities.

Product Overview:

- GLM backgrounds are near-IR imagery at 0.777 µm, between ABI band 2 (red) and 3 (veggie). Products have about 10 km native resolution, and update every 2.5 min, and are oversampled onto the 2 km ABI fixed grid.
- The GLM Data Quality Product provides a maximum flash detection efficiency and also indicates known locations with reduced data quality.

Product Methodology:

- GLM backgrounds are derived from the raw L0 data, and are calibrated to account for non-uniformity in sensitivity across the sensor.
- GLM processing sets the lightning event trigger threshold using the background, and this minimum detectability threshold is used to make an image of flash detection efficiency based on a calibration against historical TRMM-LIS observations. This is the basis of the GLM DQP image.
- At times the background value is near its maximum (saturation), and pixels in this state are flagged in a special color in the GLM DQP.

Products:

- GLM background image
- GLM data quality product image

Concept for Operational Demonstration:

- GLM raw L0 data obtained from GOES GeoCloud bucket at UAH (feed supported by NWS TOWR-S), and converted every 2.5 min into GLM background and DQP images in a NetCDF format matching the GLM gridded products.
- Delivery of background and DQP in a single NetCDF file over NASA SPoRT or TTU LDM. Ingest and display by HWT AWIPS systems.
- Custom menu items for displaying these products will be needed. A color table will be provided for each.
- Long-term, pending final refinements and review, we expect these products to be processed and packaged within the NWS TOWR-S IsatSS infrastructure, and included as part of the bytes reserved for the DQP variable in the current operational GLM L3 (gridded imagery) product stream.

Product Name: GOES Radar Estimation via Machine Learning to Inform NWP (GREMLIN)
Primary Investigator: Kyle Hilburn (CIRA/CSU)

Hazardous Weather Testbed, Experimental Warning Program Relevance:

- GREMLIN provides synthetic radar reflectivity fields to assist forecasters in areas lacking good ground-based radar coverage.
- As a situational awareness tool, GREMLIN provides information (a) when radars are down for maintenance, (b) in sparsely populated areas with gaps between radars, (c) in areas where radar beams are so high above the ground that echoes are missed, (d) over areas of complex topography where beam blockage is an issue, and (e) offshore locations.
- GREMLIN will be evaluated on its ability to increase forecaster confidence in diagnosing convective initiation and in warning issuance where radar coverage is a limiting factor.
- Since GREMLIN responds primarily to cloud-top features, it can anticipate the development of echoes on radar by 10-20 minutes, and it is possible GREMLIN may offer additional lead time in diagnosing convective initiation.

Product Overview:

- GREMLIN uses machine learning to perform ABI+GLM data fusion to estimate radar reflectivity from GOES.
- GREMLIN uses 3.9 μm shortwave IR (C07), 6.9 μm water vapor (C09), and 10.3 μm longwave IR (C13) predictors from ABI and lightning group extent density from GLM.
- GREMLIN was originally developed for the HRRR CONUS grid, but this demonstration applies the model over the ABI Full Disk grid.
- Each output pixel synthesizes information over an area of about 50 pixels or 100 km in the input fields, thus GREMLIN is most appropriate for meso-alpha scales and smaller.

Product Methodology:

- GREMLIN uses a convolutional neural network trained to transform GOES ABI radiances and GLM lightning inputs to MRMS Composite Radar Reflectivity output.
- Explainable and Interpretable AI techniques have found that GREMLIN's estimates are based on (1) presence of lightning, (2) cold brightness temperatures, (3) strong brightness temperature gradients, (4) shortwave-longwave differences to see through thin cirrus, and (5) longwave-water vapor differences to identify deep convection.
- GREMLIN provides estimates over the range 0-60 dBZ, and was tuned to balance overprediction and underprediction of radar echoes at each intensity level.
- The Version-1 GREMLIN model will be demonstrated, which was trained on warm season convection producing storm reports over the eastern two-thirds of CONUS.
- For this demonstration, a parallax correction has not been applied to GREMLIN.
- Version-1 GREMLIN is known to produce spurious echoes over very cold surfaces.

Products:

- Synthetic composite radar reflectivity
- Spatial coverage is the portion of the ABI Full Disk domains (GOES-East and GOES-West) with GLM coverage. Spatial resolution is the 2 km ABI grid.
- Temporal refresh is every 10 minutes with a latency of 10 minutes or less.

Concept for Operational Demonstration:

- GREMLIN is processed and made available through NOAA GeoCloud.
- NetCDF data files are created for display in AWIPS.
- The build is for 23.2.1 or higher, and the plugin is the GOES-R plugin.

Product Name: OCTANE Suite (Speed, Direction, Cloud-Top Cooling and Divergence)
Primary Investigator: Jason Apke (CIRA/CSU)

Hazardous Weather Testbed, Experimental Warning Program Relevance:

- Provides relevant information on environmental winds, convection initiation, and convective intensity inferred from cloud-drifts within each mesoscale-sector image
- Products will be assessed in their capability to complement rawinsonde, radar and lightning data in forecaster monitoring of pre-storm environments, storm development, intensification, and decay

Product Overview:

- The Optical flow Code for Tracking, Atmospheric motion vector, and Nowcasting Experiments (OCTANE) Suite includes products which highlight cloud-drift motion (speed and direction), cloud-top cooling (from 10.3 µm imagery), and cloud-top divergence (derived using the motion fields) blended with the textures (brightness) from the 0.64 µm (10.3 µm) imagery during the day (night; Solar Zenith Angle > 80°) using a Hue-Saturation-Value approach.
- Provided with each GOES-16 and -18 mesoscale sector, with ~0.5 km (~2 km) spatial resolution during the day (night)

Product Methodology:

- *Speed/Direction:* Computes motions by tracking brightness features (e.g., minima/maxima/gradients) in 0.64 µm (10.3 µm) satellite imagery sequences during the day (night), *Cloud-top Divergence:* Retrieves the horizontal divergence using layer-aware finite differencing on the motion fields, *Cloud-top Cooling*: Uses derived 10.3 µm motions to track and compute 5-min semi-Lagrangian brightness temperature changes
- Frequency: 1-min/30-sec (same as GOES-R mesoscale sectors), Latency: ~3 to 5-min, Input: Two sequential 0.64 µm and 10.3 µm images, separated by 1-min (or 30-sec depending on mesoscale sector overlaps)

Products:

- AWIPS: All products and necessary procedures for producing HSVs will be provided for each GOES-East/West mesoscale sector

Concept for Operational Demonstration:

- AWIPS-ready NETCDF data will be delivered to HWT via the LDM for each product (48 MB/ File, ~192 MB / min uncompressed, ~24 MB/file compressed)
- Speed and direction will be evaluated with a specific focus on the nocturnal products that were not explored last year. We will work with HWT to a) provide relevant files for a nocturnal case for forecasters to evaluate, b) switch off the day-time optical flows for a day, and/or c) provide nocturnal-only optical flow motions to compare with daytime.

Product Name: NOAA/CIMSS ProbSevere LightningCast
Primary Investigator: Michael Pavolonis (NESDIS)

Hazardous Weather Testbed, Experimental Warning Program Relevance:

- LightningCast assists forecasters with probabilistic guidance of convective/lightning initiation, sustainment, and cessation.
- LightningCast can be a decision support tool that directly enables users to take action, such as seeking shelter in advance of lightning onset.
- Products will be evaluated on their ability to increase forecaster confidence and situational awareness of lightning initiation, sustainment, and cessation.

Product Overview:

- LightningCast is an AI model that uses images of GOES ABI data to predict the probability that GLM will observe lightning (in-cloud or cloud-to-ground) in the 60 minutes following an ABI scan.
- LightningCast uses the 0.64-µm (CH02) and 1.6-µm (CH05) reflectances, and the 10.3-µm (CH13) and 12.3-µm (CH15) brightness temperatures from ABI as predictors.
- The spatial resolution is reduced from 2 km to approximately 8 km to reduce noise in output.

Product Methodology:

- At one scan time, radiance data is extracted from ABI L1b files and converted into reflectances or brightness temperatures.
- These data are predictors of the trained AI model, a convolutional neural network.
- The LightningCast model predicts probabilities of lightning in the next 60 minutes (as observed by GLM) for every pixel in the scan domain.

LightningCast Products:

- Probability of 1 or more flashes in 60 minutes P(≥ 1 fl in 60 min)
- Probability of 10 or more flashes in 60 minutes P(≥ 10 fl in 60 min)
- LightningCast generates products for 6 ABI scan domains:
    - GOES-East CONUS and both Mesoscale domains
    - GOES-West PACUS and both Mesoscale domains
        - GOES-West will only have P(≥ 1 fl in 60 min)
- Each product for each domain will have a parallax-corrected analog or complement.
    - Parallax correction is performed with a constant cloud-height assumption of 9 km.
- LightningCast's latency for the CONUS/PACUS domains is 20 seconds and for the Mesoscale domain is 3 seconds.

Concept for Operational Demonstration:

- netCDF4 data will be delivered to the HWT via the LDM for each domain/product.
- The data will be viewed by forecasters in AWIPSII with the gridded product resource.
- Forecasters will also be able to view output from a web-based meteogram tool.

Concept for Operations:

- LightningCast v1 will be transitioned to NOAA operations in 2024.

Product Name: Polar Hyperspectral Soundings with Microwave and ABI data (PHS) Model
Primary Investigators: Scott Lindstrom, Bill Smith Sr., Lee Cronce, Anthony DiNorscia

Hazardous Weather Testbed, Experimental Warning Program Relevance: Forecasters gain situational awareness for convection via short-term (i.e., 0 to 4-hr) forecasts of instability parameters that are useful for nowcasting when combined with GOES-R ABI Imagery, GLM, and Radar data. PHS also provides longer-term f (i.e., 4- 9 hour) forecasts of STP for future convective initiation.

Product Overview: The forecast parameters are obtained from HRRR WRF model output. Model initialization includes assimilated profiles of atmospheric temperature and humidity that are derived from soundings obtained by fusing direct readout polar infrared and microwave sounding radiance data during the previous seven hours to real-time 60-minute interval GOES ABI imagery data. The vertical soundings to be fused are derived from full spectrum radiance differences between the polar satellite infrared (i.e., CrIS and IASI) and microwave (i.e., ATMS and AMSU) observed spectral radiances and the radiances produced for the CrIS/IASI and ATMS/AMSU spectral channels, by a radiative transfer calculation that uses as input RAP model 2-hour forecast vertical profiles for the same time and location of the polar satellite radiance measurements. Thus, the assimilated PHS soundings represent the best adjustment of the RAP model 2-hr forecast model profiles needed to satisfy the satellite observed spectral radiances. Hourly interval 2-km (i.e., ABI) spatial resolution combined polar and geostationary satellite radiance data derived soundings are then used as input to 4-km resolution HRRR-WRF forecasts that yields the same forecast parameters/products as produced by the operational HRRR.

Product Methodology: Each forecast starts with a satellite water vapor profile assimilation cycle that uses the latest RAP model analysis (which analysis contains the influence of all operational surface and upper air observations assimilated to produce that analysis) as the background. Only the PHS fusion water vapor profiles are assimilated to drive maximum sensitivity of the resulting water vapor analyses to the high-resolution satellite moisture observations. The high-resolution, satellite water vapor profile data are continuously assimilated over a 3-hour period so that the HRRR-WRF model dynamics (i.e., horizontal and vertical velocity field) can adjust so as to be consistent with the time and spatial variations in the hourly 2-km resolution satellite water vapor profile measurements being assimilated. At the end of the three-hour satellite data assimilation period, the latest available satellite water vapor data is assimilated and the resulting analysis is used as the initial condition for the 4-km resolution HRRR-WRF model forecast cycle, from which hourly interval 4-km resolution forecast model output is produced for from 0-hr (i.e., the initial analysis) to 9-hours.

Products: Hourly interval Atmospheric temperature and moisture profile retrievals, hourly interval forecasts of temperature, humidity, wind velocity, CAPE parameters, STP, and other forecast parameters provided by the NOAA operational HRRR model, mesoscale analyses, forecast radar reflectivity.

Concept for Operational Demonstration: PHS output can be displayed in AWIPS-II. Profile retrieval parameters (e.g., temperature and humidity profiles, cloud height, and surface-skin temperature) will be available via a satellite profile retrieval product website.