Enabling Advanced Weather Modelling and Data Assimilation for Utility Distribution Operations

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Enabling Advanced Weather Modelling and Data Assimilation for Utility Distribution Operations

- Background and motivation
- Approach
- Example results
- Conclusions and future work

Other Presentations of Related Work

Conference on Weather, Climate, and the New Energy Economy:

- 8.1 Outage Prediction and Response Optimization (OPRO) – Wednesday at 4:00pm
- 9.1 Very High Resolution Coupled Weather and Wind Power Modeling
- 10.1 Improvements in short-term solar energy forecasting
- 10.2 Two methods in improving onshore wind forecast

Conference on Numerical Weather Prediction:

- 9.3 Ensemble Kalman Filter (EnKF) Assimilating the Dropsonde Observations to Reduce the Forecast Track Error of Typhoon Soulik (2013) Based On the Cloud-resolving Model
- 13.2 Recent Advances in High-Resolution Operational NWP, Utilizing WRF-ARW – Thursday morning

Conference on Artificial and Computational Intelligence and its Applications to the Environmental Sciences:

- J3.2 A multi-scale solar energy forecast platform based on machine-learned adaptive combination of expert systems

Conference on Climate Variability and Change:

- 8C.4 Simulation of the temporal and spatial characteristics of diurnal rainfall cycle over Borneo

Symposium on Advances in Modeling and Analysis Using Python:

- 3.5 A Python-Based Automatic Data Aggregation Framework for Hydrology Models

Superstorm Sandy and the Built Environment: New Perspectives, Opportunities, and Tools:

- 873 Forecast Performance of an Operational Mesoscale Modeling System for Post- Tropical Storm Sandy in the New York City Metropolitan Region – Thursday morning

Conference on Probability and Statistics in the Atmospheric Sciences

- 4.2 Customized Verification Applied to High-Resolution WRF-ARW Forecasts for Rio de Janeiro
- 6.5 Statistical forecasting of rainfall from radar reflectivity in Singapore

Symposium on the Urban Environment

- J12.2 High-Resolution, Coupled Hydro-Meteorological Modelling for Operational Forecasting of Severe Flooding Events in Rio de Janeiro – Wednesday afternoon

Background and Motivation

- The operation of the distribution system of an electric utility, particularly with an overhead infrastructure, can be highly sensitive to local weather conditions

- What is the potential to enable proactive allocation and deployment of resources (people and equipment) to minimize time for restoration?

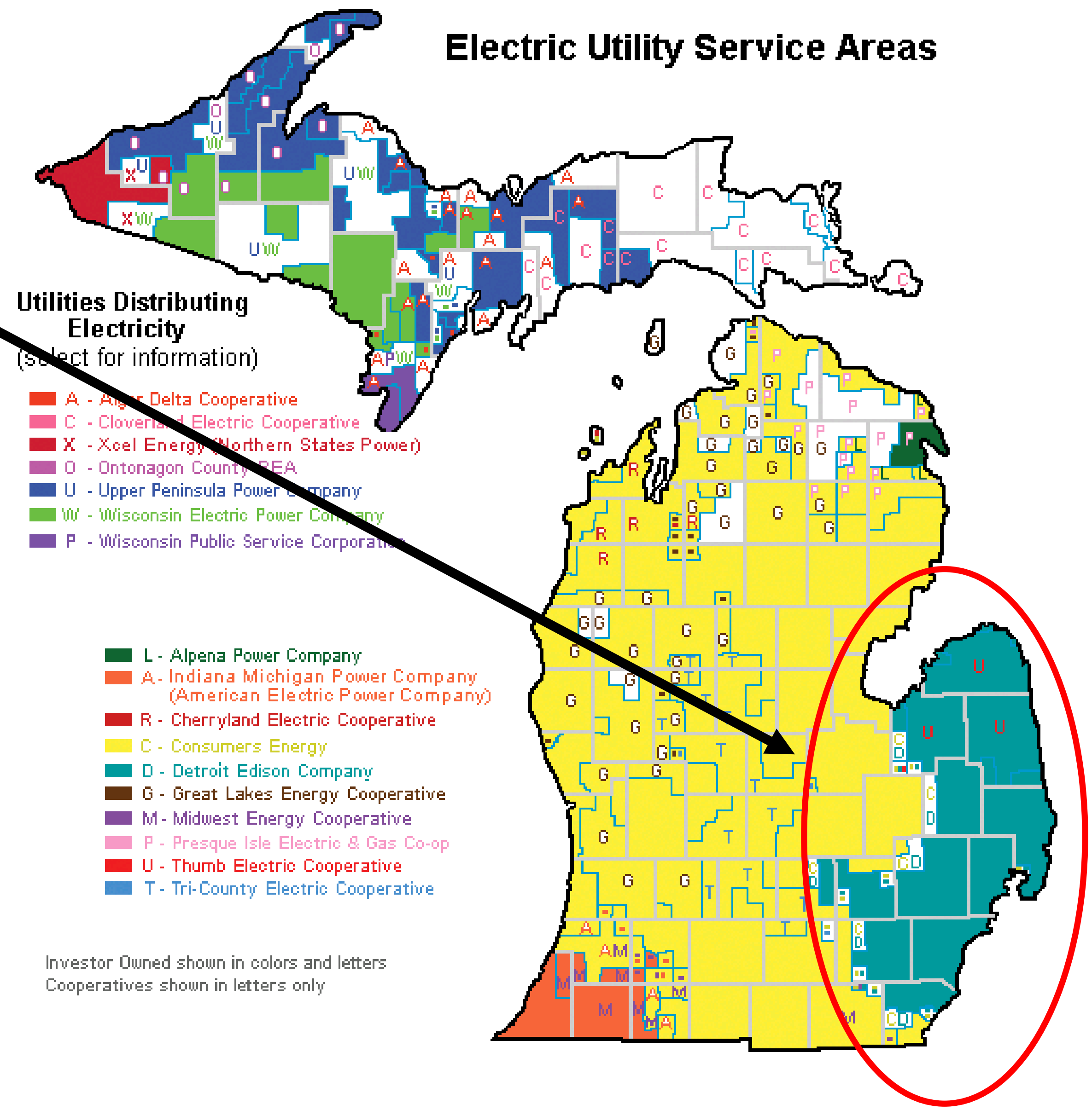
  – Ability to predict specific events or combination of weather conditions that can disrupt that distribution network with sufficient spatial (i.e., area substation level) and temporal precision, and lead time

  – Can highly localized, NWP-based forecasts be adapted to address these problems and reduce the uncertainty in decision making?

  – Can the link between weather and impact be quantified to improve preparation and response?

DTE Energy Service Territory

- **2.1 million electric customers in southeastern Michigan**
- **1.2 million gas customers in Michigan**
- **11084 MW of system capacity**



Approach: Coupled Weather and Impact Modelling

Custom Modelling for Predictions of Outages ("*Deep Thunder*")

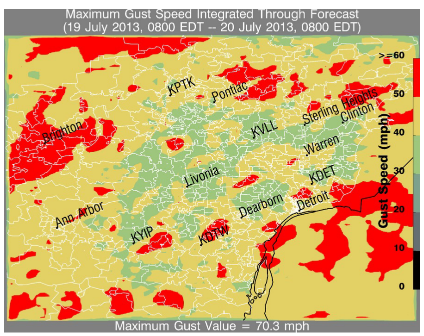
- (Severe) weather causes damage
- Damage requires restoration (resources)
- Restoration takes time, people, etc.
- Build predictive model from environmental observations, storm impact and related data
  - Damage location, timing and response
  - Wind, rain, lightning and duration
  - Demographics of effected area
  - Infrastructure impacted in effected area
  - Ancillary environmental conditions

Approach: Coupled Weather and Impact Modelling

Custom Modelling for Predictions of Outages (“*OPRO*”)

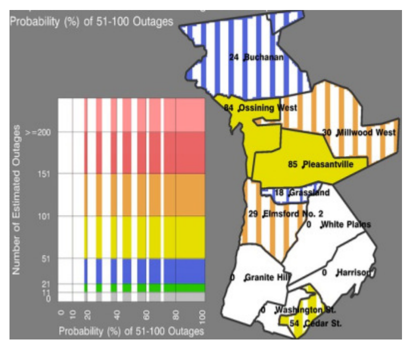
Weather Model → High Precision Weather Prediction → **Damage Model** → Damage/Outage Prediction → **Pre-Positioner** → Pre-Planning (2 - 3 days lead time)

NWP



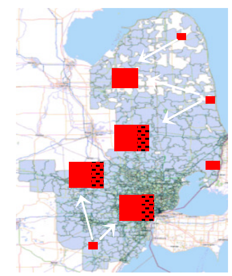
Wind Gusts, Ice, …

Advanced Statistical Model

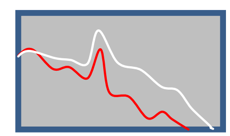


Expected Damage Locations & Timing

Optimization Model



Resource Mobilization



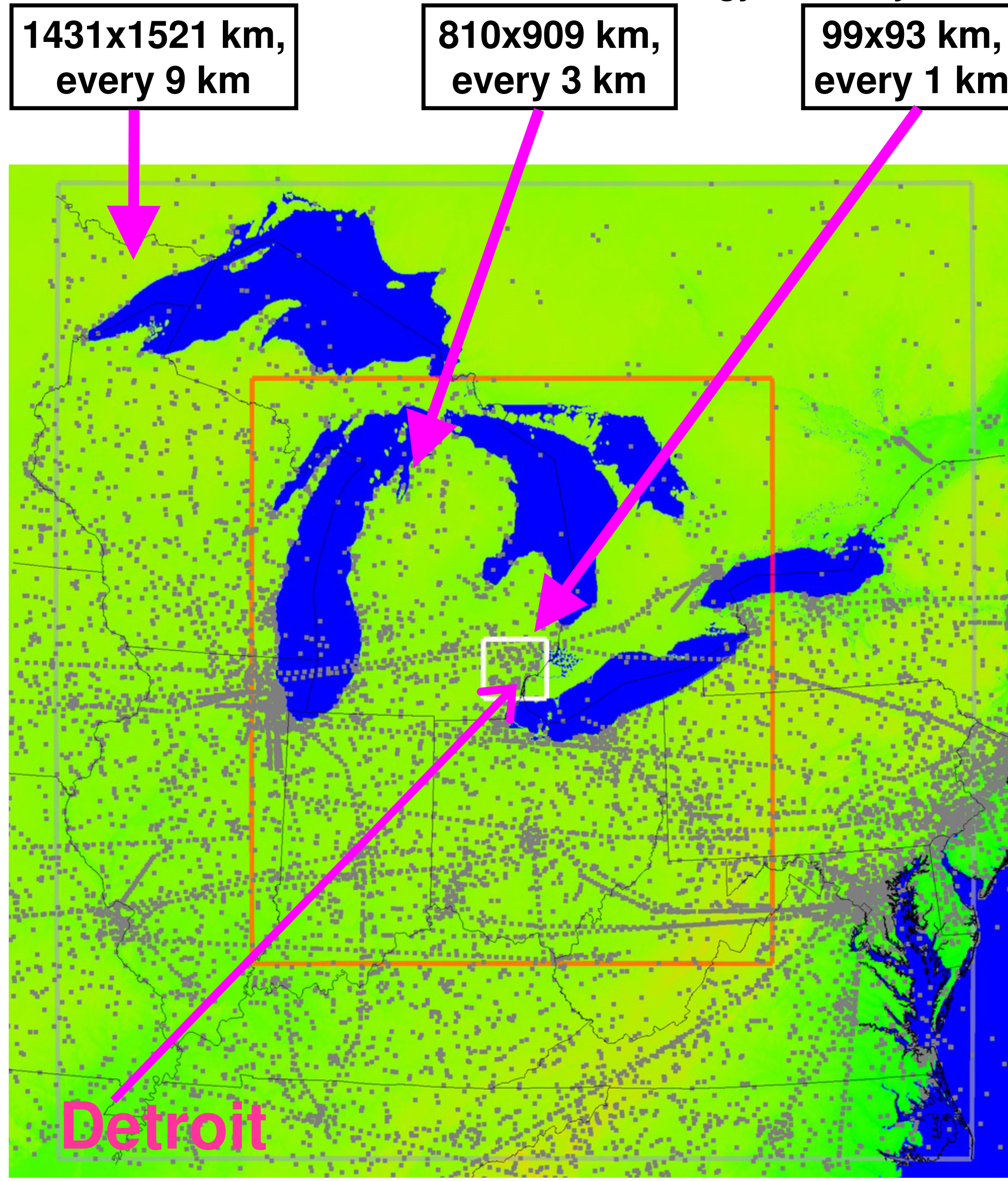
Restoration Response Scenarios

Methodology

- Retrospective analysis of impactful events
  - 15 March 2012: several tornadoes across the service territory (EF0-EF3)
  - 03-04 July 2012: ~ 440,000 outages -- rapidly-moving convective storms + extreme heat
  - 26-27 July 2012: ~ 55,000 outages -- thunderstorms
  - 19-20 August 2012: 8,924 outages -- clear/blue-sky day with high winds
  - 28-30 October 2012: 138,505 outages -- outer bands of extra-tropical storm Sandy
  - 20-21 December 2012: 44,065 -- heavy rain + snow + high winds
  - 14-15 January 2013: 3,352 outages -- clear/blue-sky day with high winds
  - 19-20 January 2013: ~ 148,000 outages -- high winds
  - 27-28 January 2013: ~ 65,000 outages -- wind + ice + rain
  - 26-27 February 2013: ~ 65,000 outages -- winter storm (heavy rain + wet snow + freezing rain + sleet)
- NWP customized to service territory, determined via numerical hindcast experiments
- Tailored dissemination and visualization
- "Coupled" modeling to integrate into decision making

Current Operational Weather Model Configuration

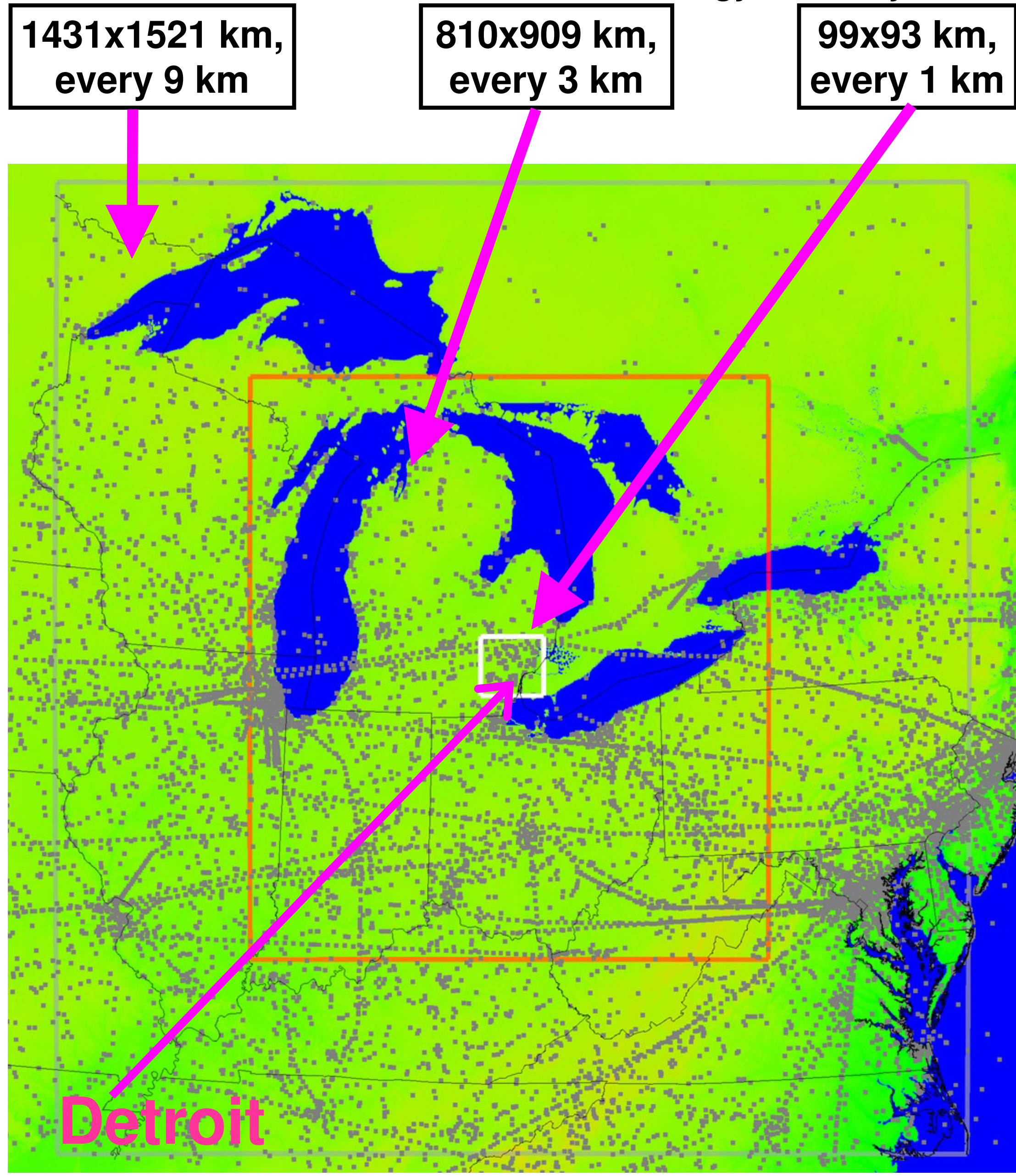
- **Modelling**
  - Weather: utilize WRF-ARW to enable effective forecasts with up to 72 hours lead time
  - Outages: spatial-temporal statistical modelling to enable predictions of damage and outages
  - Pre-planning tools
- **Dissemination**
  - Tailored weather visualizations available via a web browser, which are automatically updated for each forecast cycle
  - Gust and outage estimation
  - Uncertainty visualization for operational decision making
  - Customized verification



Forecasting Domain for DTE Energy
(Gray Dots Mark Locations of Weather Station)

Current NWP Configuration

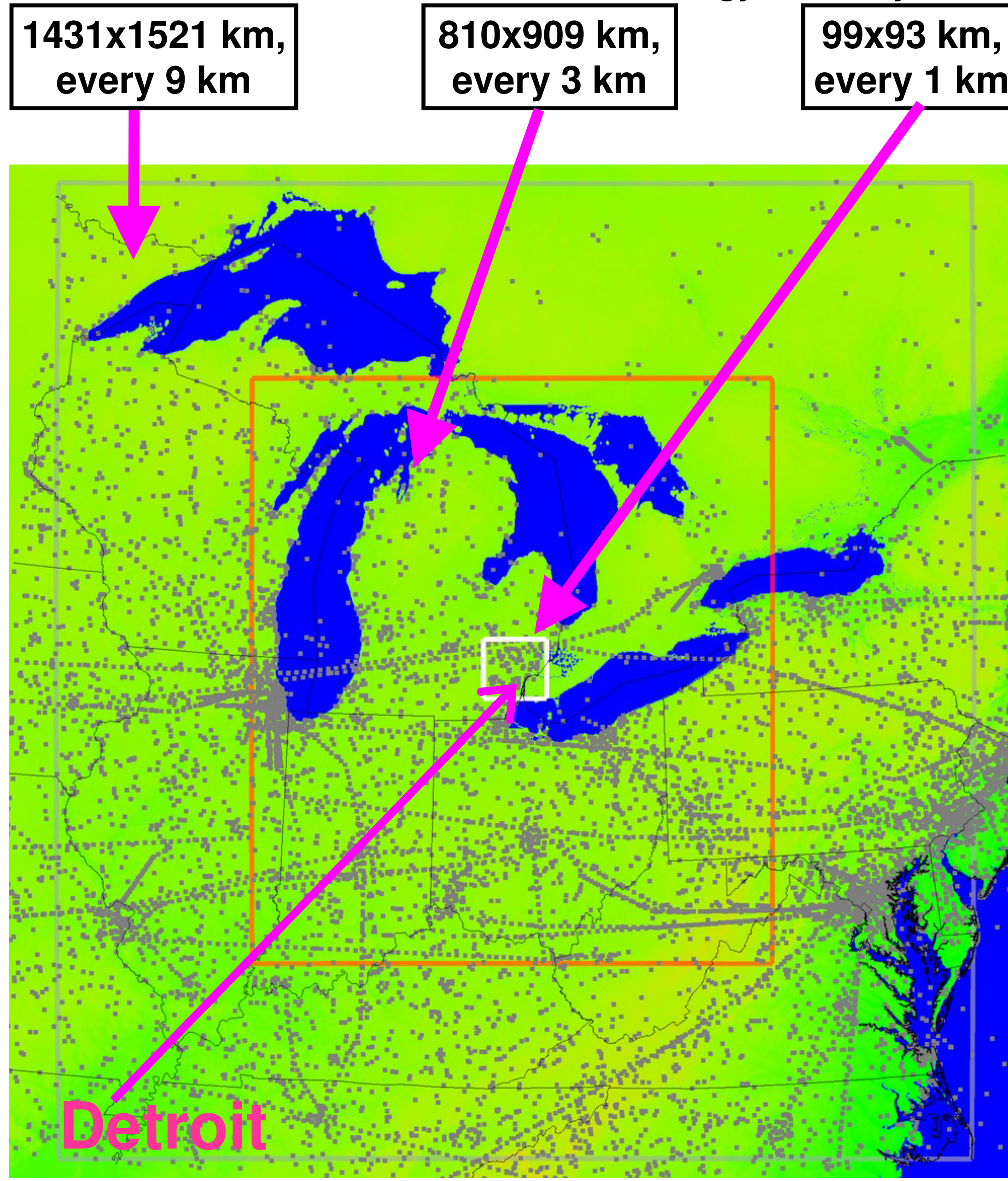
- WRF-ARW 3.4.1 since July 2013
- 9/3/1 km nested for 72 hours (41 vertical levels)
- Run twice daily (initialized at 0 and 12 UTC)
- RAP for background fields
- NAM for lateral boundary conditions
- Physics configuration for highly urbanized to rural domain
  - Thompson double-moment microphysics (includes explicit ice, snow and graupel)
  - Yonsei University non-local-K scheme with explicit entrainment layer and parabolic K profile in the unstable mixed layer for the PBL
  - NOAH land-surface modeling with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics
  - Grell3d cumulus parameterization
  - 3-category urban canopy model with surface effects for roofs, walls, and streets
  - New GSFC long- and short-wave radiation



Forecasting Domain for DTE Energy (Gray Dots Mark Locations of Weather Station)

Input Data

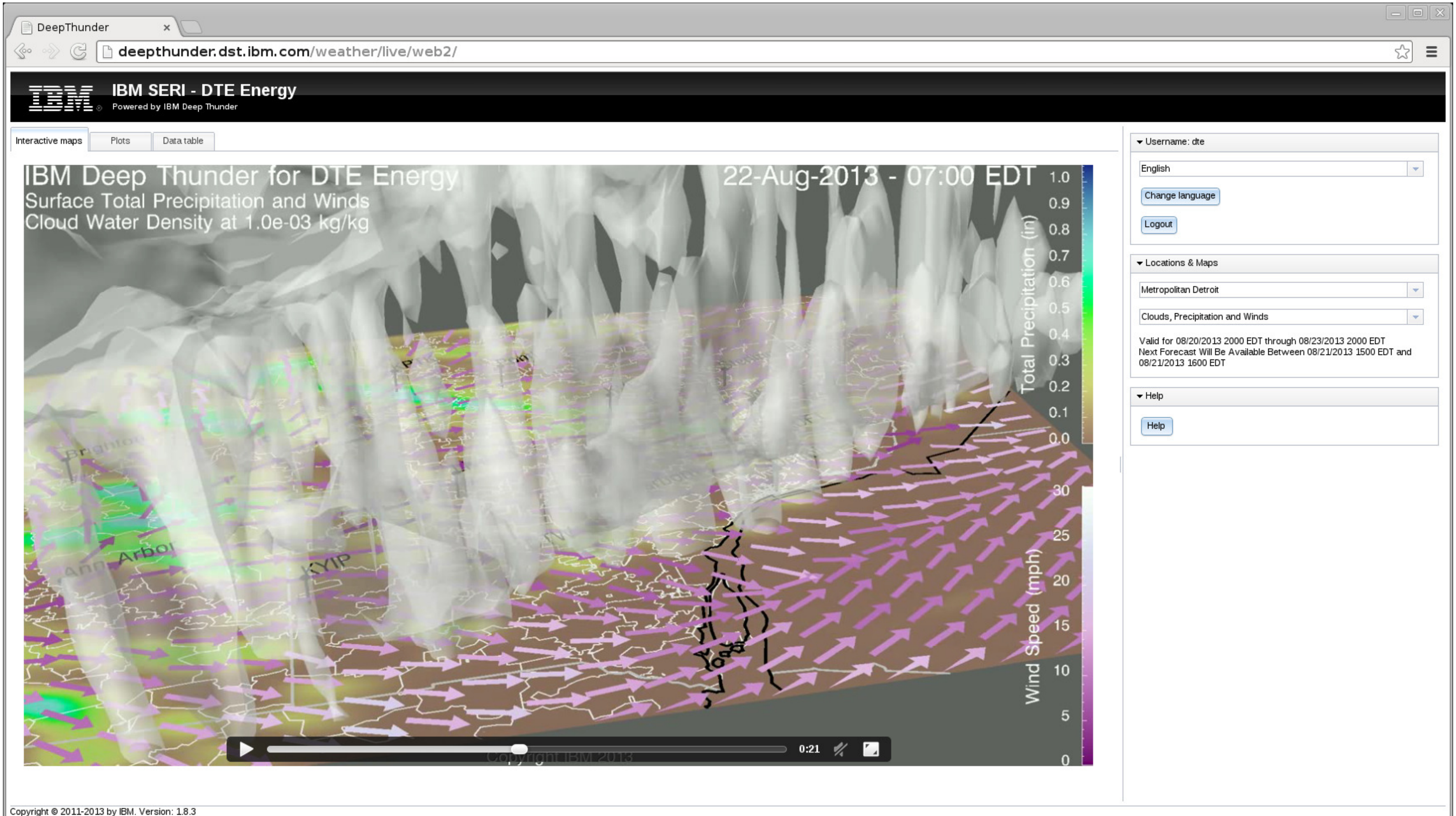
- **Direct input data sets**
  - SRTM 90m terrain (NASA)
  - Land use (USGS)
  - 1km SSTs (NASA – SPoRT)
  - MODIS-based vegetation (NASA)
- **Data assimilation (3dVAR) of near-real-time Earth Networks WeatherBug and MADIS data**
  - Surface stations, radiosondes, aircraft, ship, profiles, satellite, …
  - ~5500 stations (gray markers on map): 9km nest (~5500), 3km nest (~2200), 1km nest (~70) – varies for each forecast
  - Additional quality control



Forecasting Domain for DTE Energy
(Gray Dots Mark Locations of Weather Station)

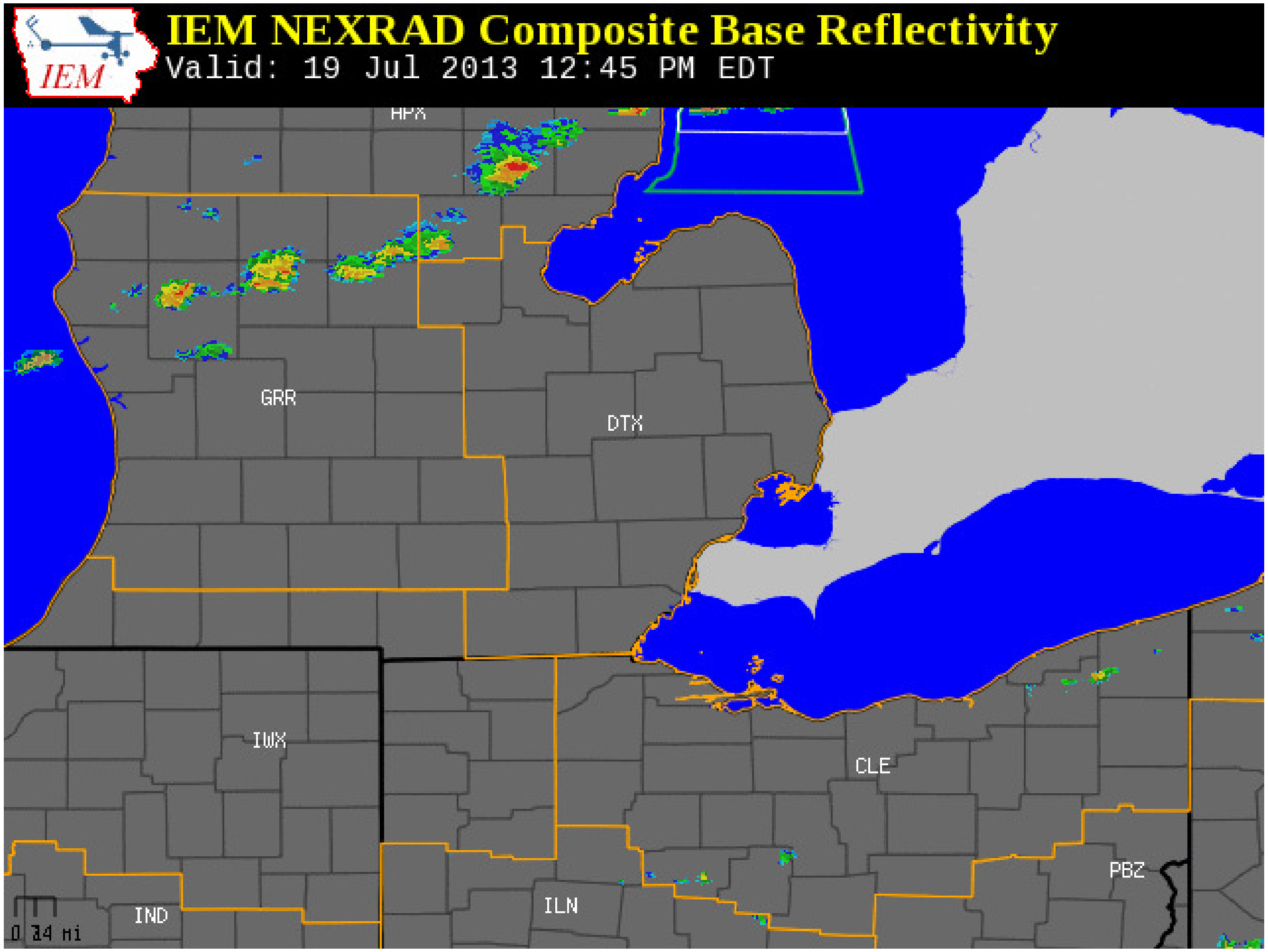
Deep Thunder Web Portal

72-Hour Forecasts for Metropolitan Detroit

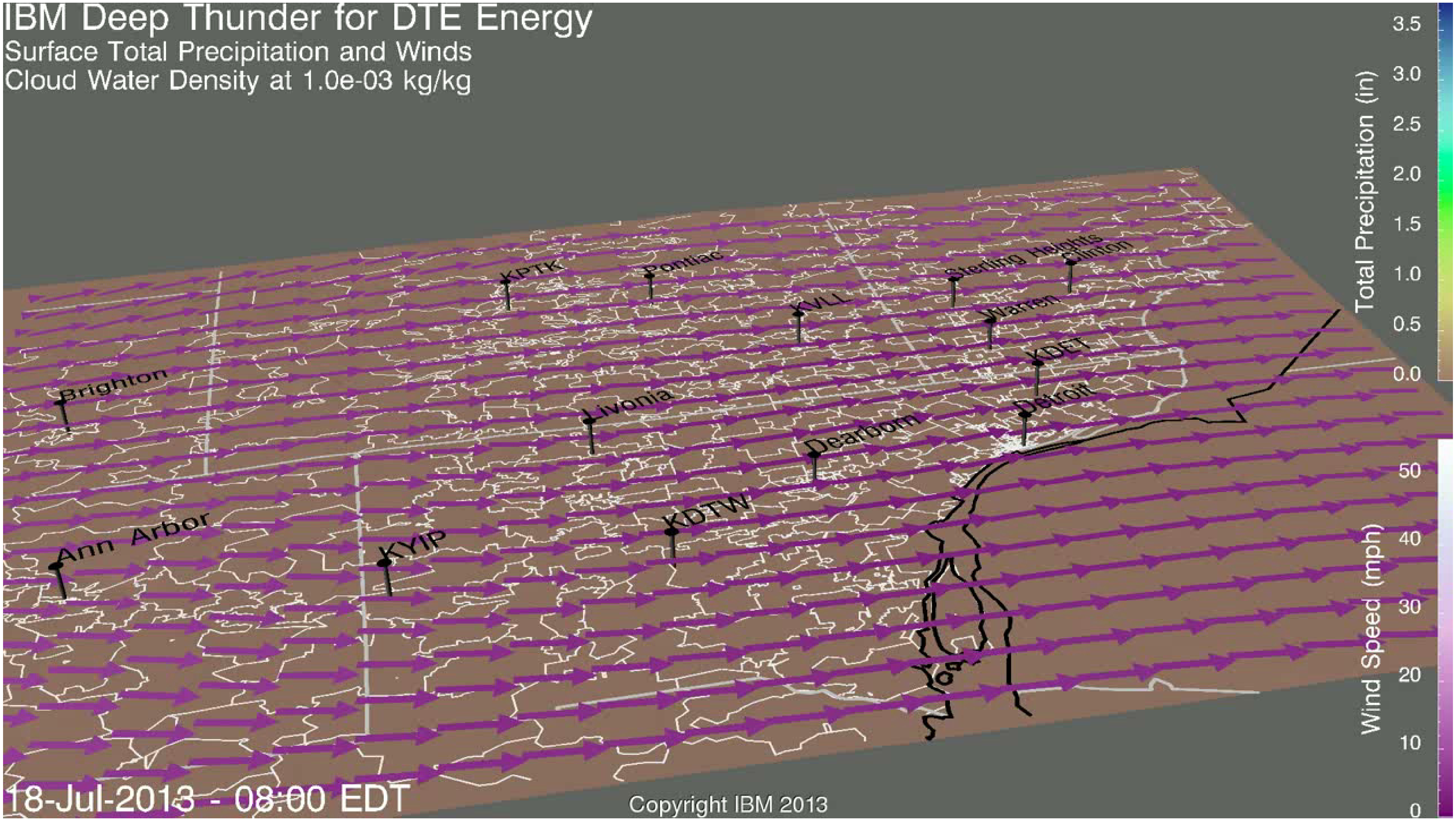


Example -- Severe Weather for 19 July 2013: Thunderstorms in Southeastern Michigan (170,000 Lost Power)

- Several rounds of severe thunderstorms tracked across southeast Michigan
- Afternoon of 19 July and early morning of 20 July
- Approaching cold front sinking south across the central Great Lakes
- Numerous reports of strong wind gusts and wind damage
- ~170000 DTE customers lost power

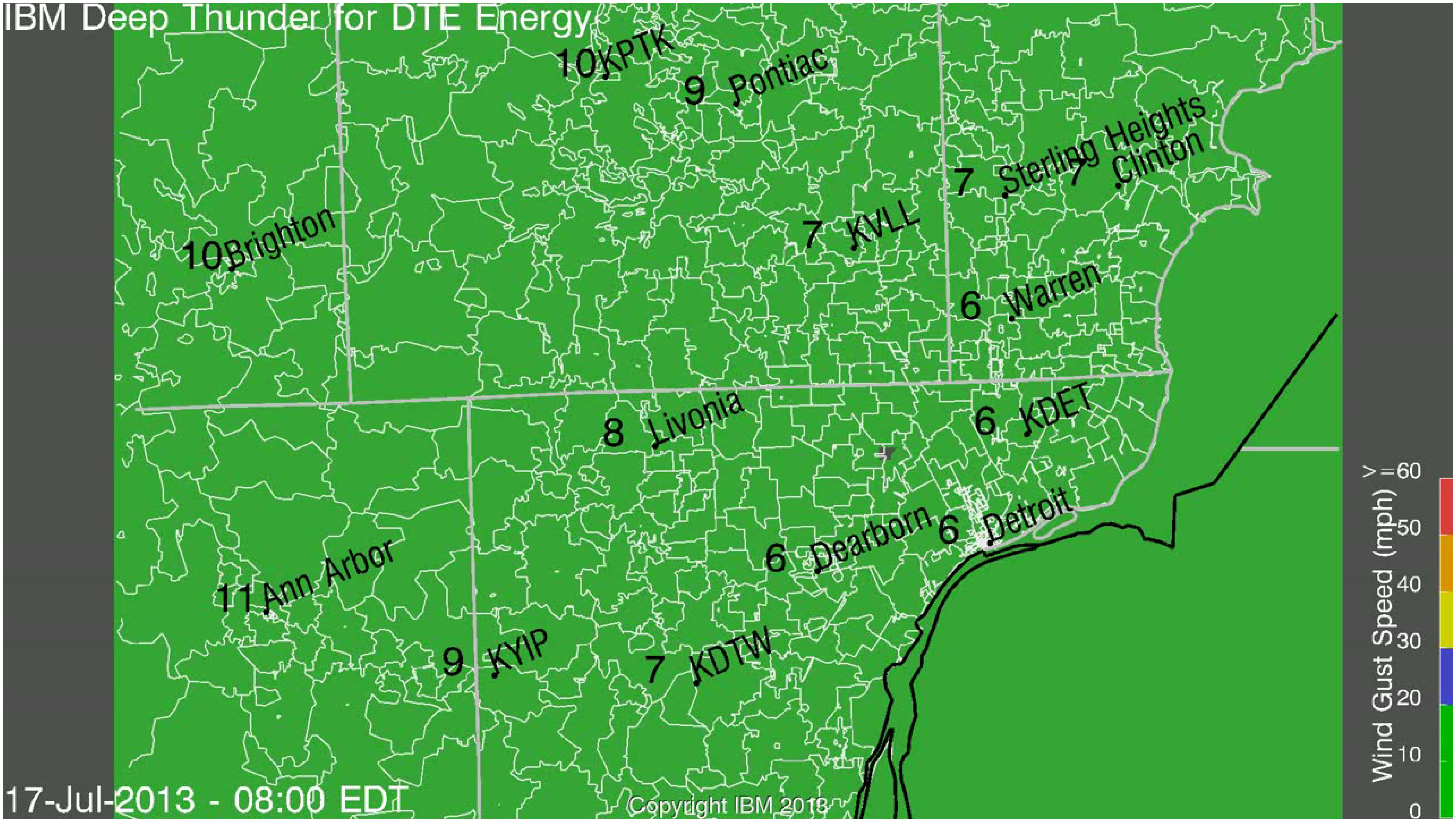


Example Deep Thunder Forecast for 19 July 2013 Thunderstorms in Southeastern Michigan (170000 Lost Power)



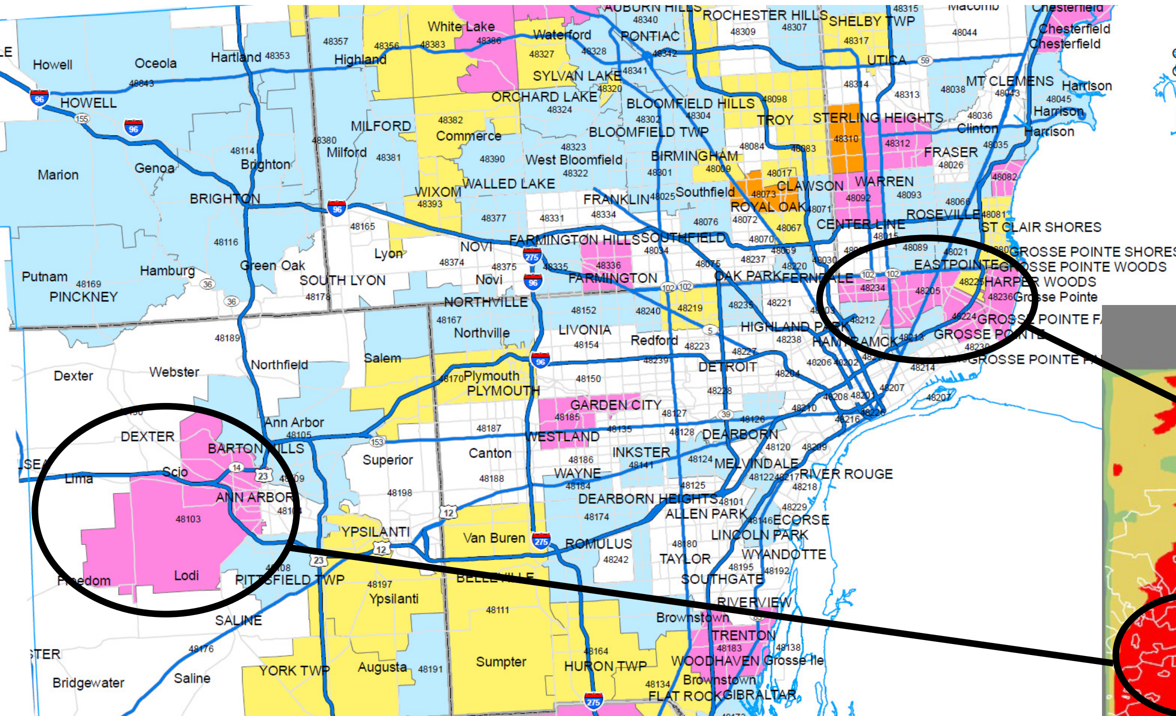
Visualization of Forecast Initialized on 18 July 2013, 1200 UTC

Example Deep Thunder Forecast for 19 July 2013 Thunderstorms in Southeastern Michigan (170000 Lost Power)



Visualization of Gust Forecast Initialized on 18 July 2013, 1200 UTC

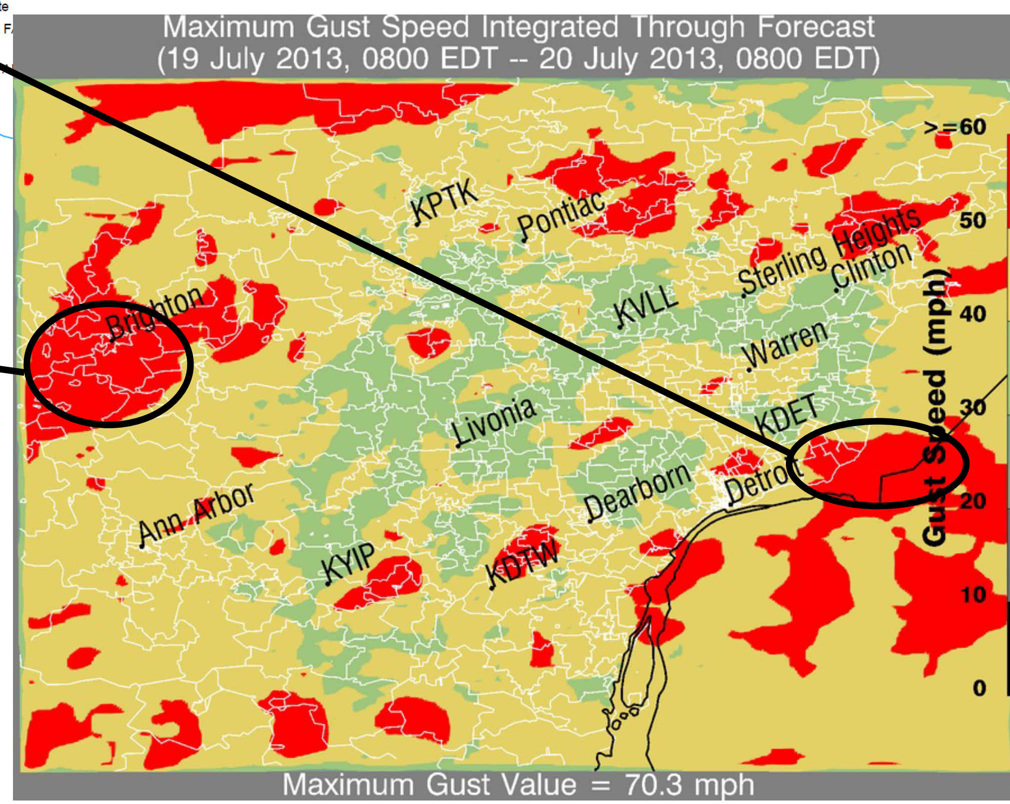
Example Deep Thunder Forecast for 19 July 2013 Thunderstorms in Southeastern Michigan (170000 Lost Power)



Reported Outages by Zip Code at 0116 EDT on 20 July 2013

Black	0 - 100	Yellow	1001 - 2000
Blue	101 - 1000	Pink	2001 - 5000

A Forecast with over 54 Hours of Lead Time



Deep Thunder Gust Maximums (Forecasted)

Forecast Analysis of Events

- Point-wise statistics (e.g., MAE, ME, RMSE, etc.),
- Categorical statistics
  - Wind speed >= 20 mph, >= 25 mph
  - Temperature >= 85 F, >= 95 F
  - Precipitation >= 0.1", >= 0.3", >= 0.5", 3- and 6-hour accumulation
- Utilized WeatherBug and MADIS data, initially within the 1km nest, decomposed by day of forecast
- Implemented using the MET package
- Only forecast cycles that covered events with a significant number of outages in 2013
  - 19 July, 11 September, 17 November et al

Example Statistics for Temperature, Dew Point, Wind Speed

Forecast Initialized at 12 UTC, 07/18/2013 (Mean Error/Bias)

	Day 1	Day 2	Day 3
Wind Speed (m/sec):	0.91	1.74	1.47
Temperature (°C.):	0.06	0.28	-0.63
Dew Point (°C.):	-0.83	-0.93	-1.68

Forecast Initialized at 00 UTC, 07/19/2013 (Accuracy, >= 85 F, >= 95 F)

	Day 1	Day 2	Day 3
Temperature (85):	0.83	0.81	0.99
Temperature (95):	0.95	1.00	1.00

Forecast Initialized at 00 UTC, 07/19/2013 (Accuracy, >= 20 mph, >= 25 mph)

	Day 1	Day 2	Day 3
Wind Speed (20):	0.98	0.99	1.00
Wind Speed (25):	1.00	1.00	1.00

Forecast Initialized at 00 UTC, 11/16/2013 (Mean Absolute Error)

	Day 1	Day 2	Day 3
Wind Speed (m/sec):	1.63	2.80	2.26
Temperature (°C.):	1.52	1.35	1.75
Dew Point (°C.):	1.20	1.37	1.94

Forecast Initialized at 12 UTC, 11/16/2013 (Accuracy, >= 20 mph, >= 25 mph)

	Day 1	Day 2	Day 3
Wind Speed (20):	0.99	0.91	0.97
Wind Speed (25):	1.00	0.98	0.99

Forecast Initialized at 00 UTC, 09/10/2013 (Mean Error/Bias)

	Day 1	Day 2	Day 3
Wind Speed (m/sec):	1.82	1.39	1.43
Temperature (°C.):	1.26	2.08	2.97
Dew Point (°C.):	-1.55	-2.64	-0.20

Example Statistics for Accumulated Precipitation

Forecast Initialized at 12 UTC, 07/18/2013 (Day 2, 6-hour Accumulation)

	>= 0.1”	>= 0.3”	>= 0.5”
CSI	0.60	0.53	0.37
Accuracy	0.85	0.88	0.88
PODN	0.95	0.91	0.89

Forecast Initialized at 00 UTC, 11/16/2013 (Day 2, 3-hour Accumulation)

	>= 0.1”	>= 0.3”	>= 0.5”
CSI	0.42	0.37	0.00
Accuracy	0.85	0.94	0.94
PODN	0.84	0.94	0.94

On-Going Challenges and Next Steps

- Quality and use of weather observations
  - Sampling highly variable with respect to service territory
  - Inconsistent reporting
  - Lack of availability of upper air data at the appropriate scale
  - Domain-specific 30-day covariance statistics need to be used
- Utilization
  - Need to build trust with diverse users
  - Deliver complex information succinctly
  - Must be integrated with utility company procedures
- Operational deployment of outage prediction and pre-positioner
- Continued operational evaluation and utilization, including further development of verification methods
- Evaluate and incorporate additional data sets to improve initial conditions
- Evaluate and incorporate enhancements in weather model

Summary

- Enabled an operational capability
- Collaborative and diverse team critical to success
- 72-hour weather model disseminated operationally
  - Updates every twelve hours
  - Multiple views of weather forecasts
  - Better results compared to other sources
- Continue to improve calibration of weather and outage models, and characterization of uncertainties
  - Operational statistics for evaluation
  - Retrospective analysis and tuning using new events that have impact
- Developing additional specialized visualizations and methods of dissemination
- Coupling the weather prediction to business impact forecasts is operationally viable, yet challenges remain

Backup Slides

Many Utilities Face Substantial Challenges in Outage Management

- **The location and cause of outages is difficult to determine without physical inspection, resulting in delayed restoration and excessive costs**
- **Regulators are pressing for improvements in outage duration and frequency as measured by CAIDI, SAIFI, and SAIDI**
- **Some well-publicized outage events are resulting in substantial pressure to improve outage management information and processes**
- **Many customers are dissatisfied with the lack of dependable information on outage cause and expected restoration time**
- **Planning and staging for storm events is based on broad storm expectations rather than focused forecasts, resulting in inefficient staging and slow response times**