Visualization Design Criteria for the Communication of Weather and Weather Impact Forecast Data with Explicit Uncertainty

Lloyd A. Treinish

IBM Thomas J. Watson Research Center
Yorktown Heights, NY

lloydt@us.ibm.com

http://www.ibm.com/green

Visualization Design Criteria for the Communication of Weather and Weather Impact Forecast Data with Explicit Uncertainty

- Background and motivation
- Visualization issues
- Approach
- Example results
- Discussion and future work

Other Presentations of Our Related Work

- **506 *Operational evaluation of a meso-scale weather and outage prediction service for electric utility operations* (First Conference on Weather, Climate, and the New Energy Economy)**

- **J11.3 *Statistical Solution to Forecasting Electric Power Outages Caused by Severe Storms* (First Conference on Weather, Climate, and the New Energy Economy)**

- **521 *Bayesian Hierarchical Modeling for Post-processing of Data from Numerical Weather Prediction Systems* (20th Conference on Probability and Statistics in the Atmospheric Sciences)**

- **J10.3 *What really happened in Altona?* (First Conference on Weather, Climate, and the New Energy Economy)**

- **J7.3 *Using AWS-WeatherBug observations and the WRF-ARW model for wind energy applications* (First Conference on Weather, Climate, and the New Energy Economy)**

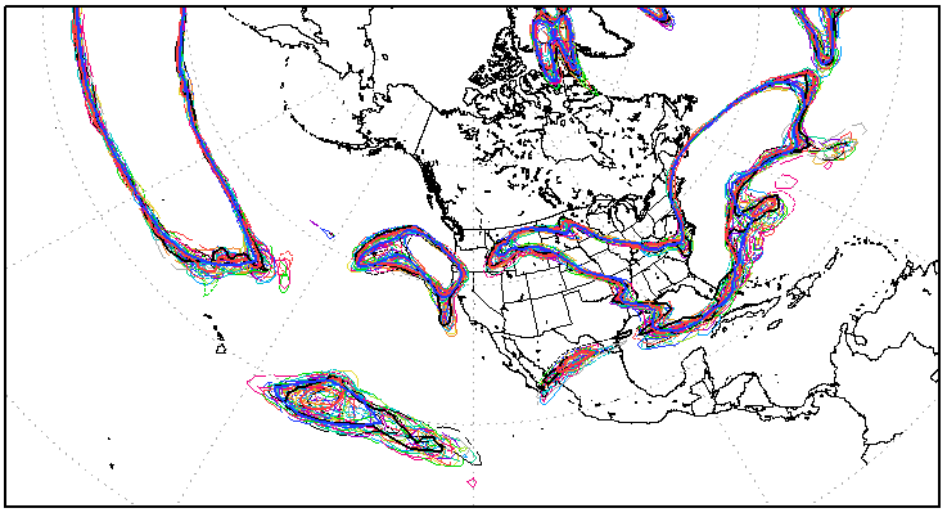
Background and Motivation

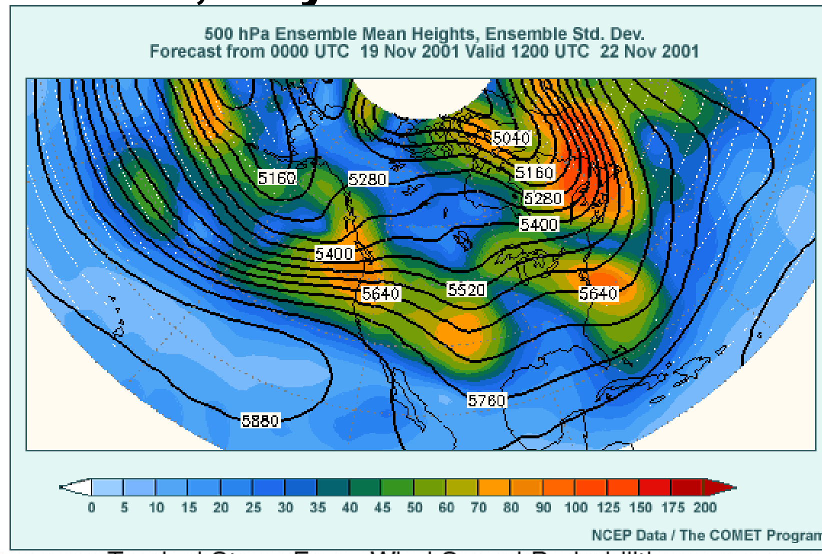
- **Probabilistic forecasts are often the most appropriate means to capture the range of potential weather and impact scenarios,**
  - **especially those that can disrupt business operations in industries as diverse as energy, water, transportation or agriculture, or drive decision making for public good like emergency management**
- **For such predictions to be useful, the information must be disseminated in a timely fashion**
- **Visualization is an essential means to communicate these predictions, but two challenges must be addressed**
  1. **How can the uncertainty associated with them be depicted? (depends on 2.)**
  2. **Given the variety of tasks that would be represented by the utilization of the forecasts by an analyst (e.g., an operational forecaster), decision maker (e.g., emergency manager) or a layperson (e.g., the public), what are the most appropriate visualization strategies?**
  - **Further, uncertainty in data is paralleled by uncertainty in reasoning processes**

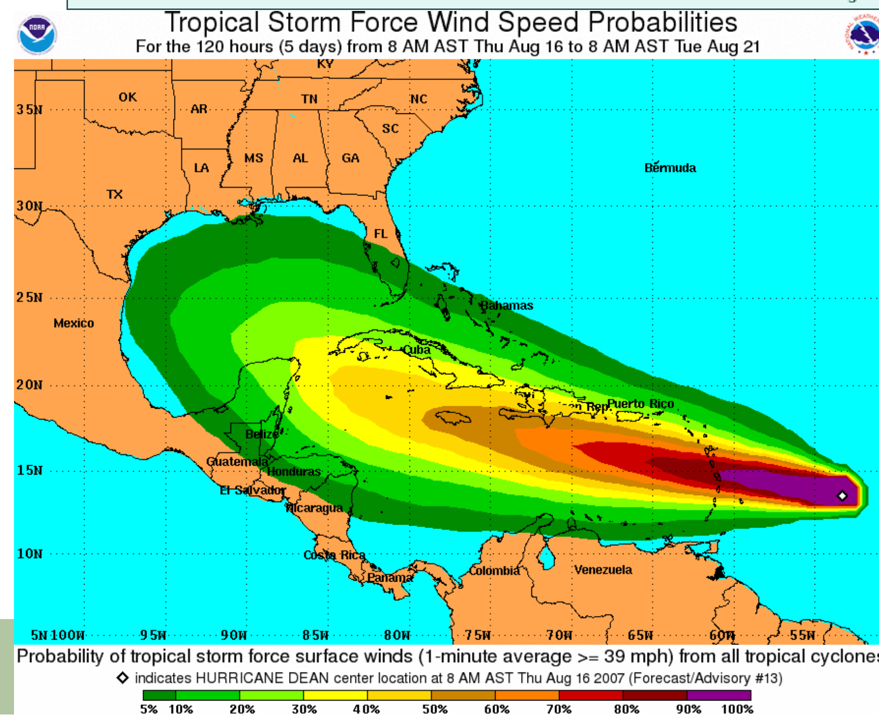
Commonly Used Techniques for Weather Data

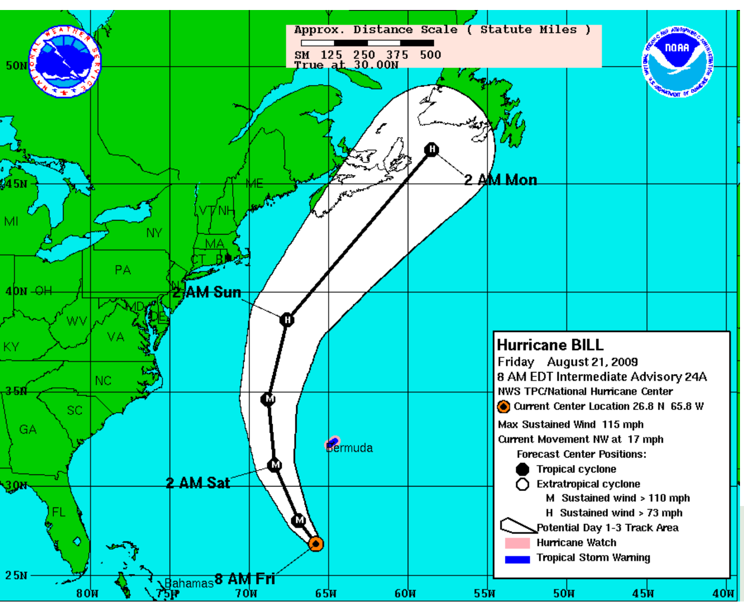
- **Traditional means may be suboptimal for some user tasks because they remove critical dimensionality in their realizations and therefore, may not illustrate essential features for those tasks**

NAEFS run for 00Z 02Jan2010 valid 00Z02JAN2010 90 wind velocity (kts) at 250-hPa, 1x1 degree resolution





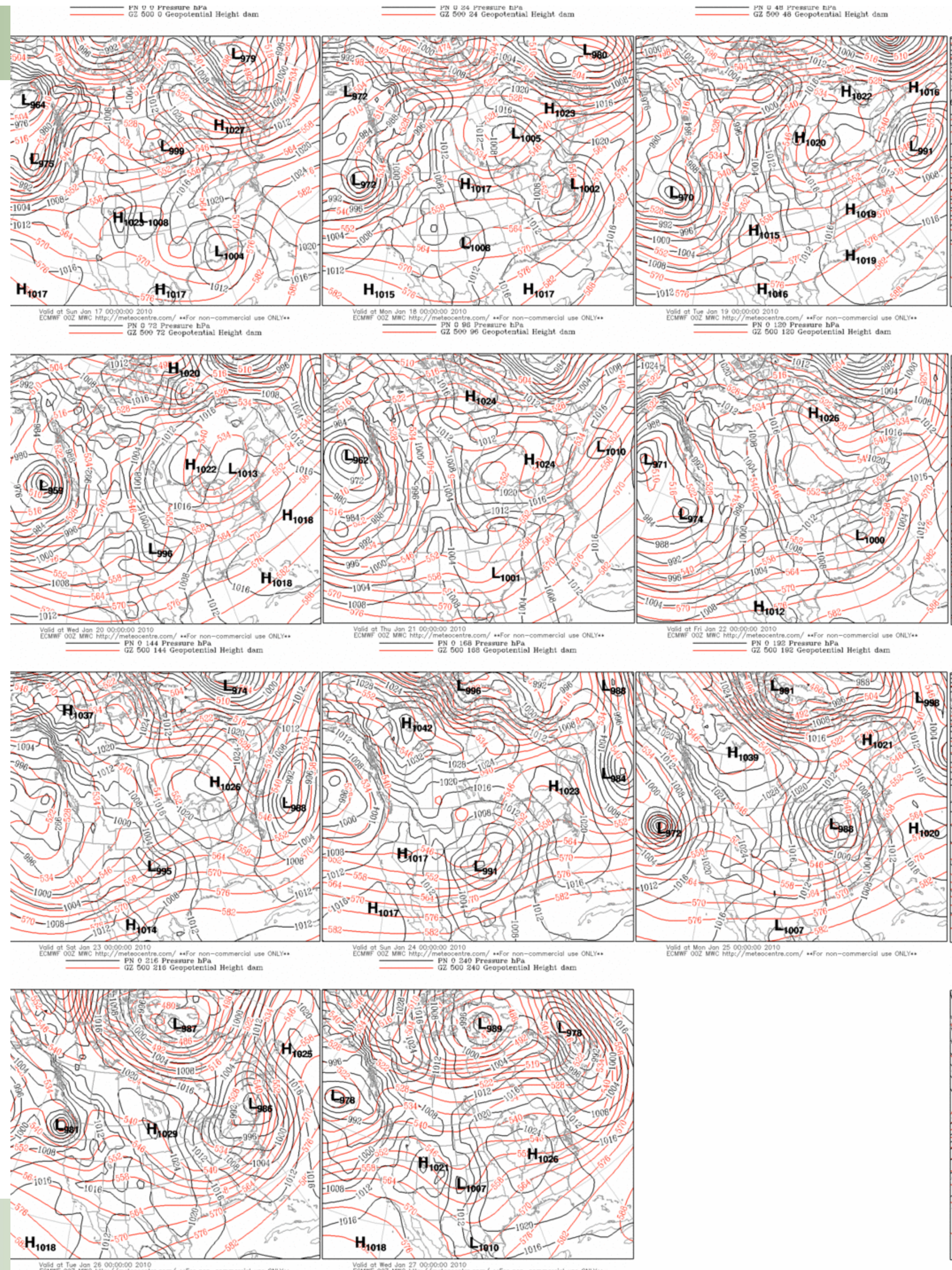




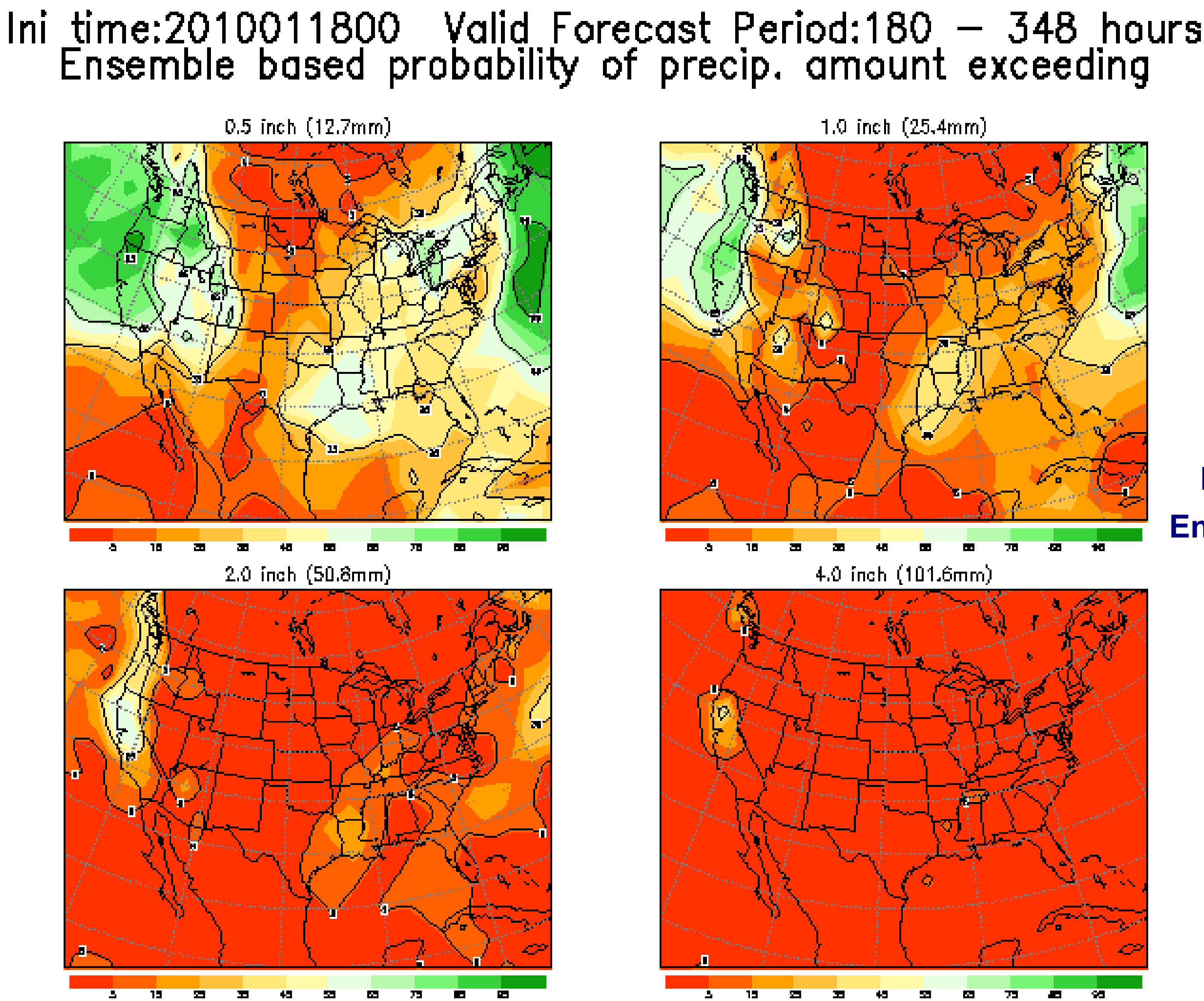
Visualization Issues

- Timely and effective usability requires the visualization designer to
  - –Understand how experienced people use their expertise in decision making, and how they work and interact
  - –Avoid an impedance mismatch between the data vs. how the data should be utilized
  - –Identification of user goals, which are mapped to visualization tasks and to data
  - –Design in terms relevant for user, employing familiar terminology and metaphors -- readily understood in real-time without expert interpretation and used with confidence
  - –Understanding how users perceive and interpret visualizations
- Leverage (design) work by both Tufte and Bertin, e.g.,
  - –Bertin presented eight visual variables and the plane as the richest of the variables using six retinal variables: size, value, grain, color, orientation, and shape

An Example of Tufte's "Small Multiples" Applied to an Ensemble Model



An Example of Tufte's "Small Multiples" Applied to an Ensemble Model



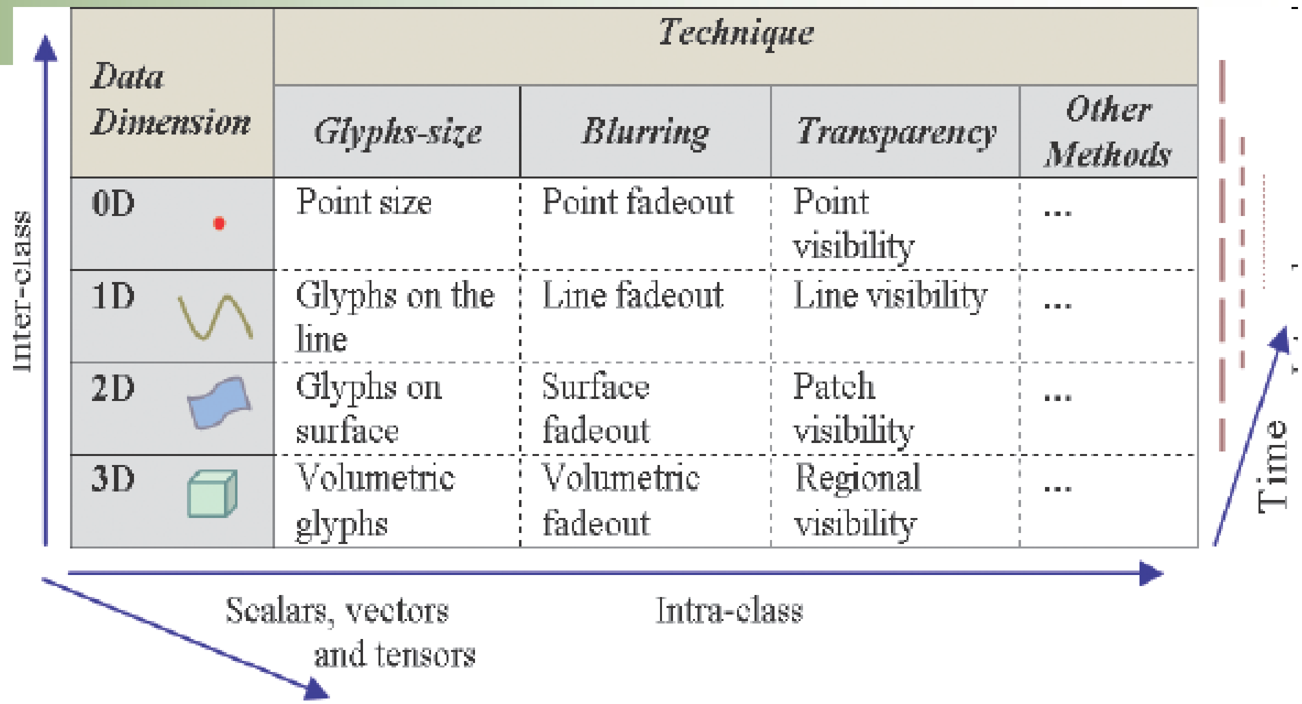
NCEP Global Ensemble: US 15 days PQPF

Examples of Relevant Work on Visualization of Uncertainty

- Sanyal, J. et al (2009). *A User Study to Compare Four Uncertainty Visualizations for 1D and 2D Datasets*. IEEE Trans. on Visualization and Computer Graphics, 15(6), pp. 1209-1218.
- Potter, K. et al (2009). *Visualization of uncertainty and ensemble data: Exploration of climate modeling and weather forecast data with integrated ViSUS-CDAT systems*. J. Phys.: Conf. Ser. 180 012089.
- Steiner, M. and J. Krozel (2009). *Translation of Ensemble-Based Weather Forecasts into Probabilistic Air Traffic Capacity Impact*. 28th Digital Avionics Systems Conference, pp. 2.D.6-1- 2.D.6-7.
- Li, H., C. Fu, Y. Li, and A. Hanson (2007). *Visualizing Large-Scale Uncertainty in Astrophysical Data*. IEEE Trans. on Visualization and Computer Graphics, 13(6), pp. 1640-1647.
- Zuk, T. and S. Carpendale (2006). *Theoretical Analysis of Uncertainty Visualizations*. Proc. SPIE & IS&T Conf. Electronic Imaging, Vol. 6060: Visualization and Data Analysis 2006, pp. 606007.
- Bisantz, A., S. Marsiglio, and J. Munch (2005). *Displaying Uncertainty: Investigating the effects of display format and specificity*. Human Factors, 47(4), pp. 777–798.
- Blenkinsop, S., P. Fisher, L. Bastin, and J. Wood (2000). *Evaluating the Perception of Uncertainty in Alternative Visualization Strategies*. Cartographica 37(1), pp. 1-13.
- Pang, A., C. Wittenbrink, and S. Lodha (1997). *Approaches to Uncertainty Visualization*. The Visual Computer, 13, 8, pp. 370-390.

Framework for Visualization of Uncertainty

(from Sanyal et al, 2009, MS State)



Data Dimension	Technique			
	Glyphs-size	Blurring	Transparency	Other Methods
0D	Point size	Point fadeout	Point visibility	...
1D	Glyphs on the line	Line fadeout	Line visibility	...
2D	Glyphs on surface	Surface fadeout	Patch visibility	...
3D	Volumetric glyphs	Volumetric fadeout	Regional visibility	...

- Studied effectiveness in conveying meaningful information and evaluated the perception of uncertainty

- For example, for 2D tasks, they report surface-coloring performed reasonably well for all questions except counting of uncertainty features
- Since shape of the surface is the primary visual cue for data features, they feel that color-mapping of the data surface with uncertainty reduces some of the strength of the shape information
- Use of surface shape reduces a user's awareness of the actual data

Approach

- **Given inherently high dimensionality of probabilistic forecasts compared to the visualization media**
  - **Restrict design choices to minimize the visual clutter associated with overloaded realizations**
  - **Limited color choices with natural ordinality applied to categorical data or imposing categories on interval data (e.g., contour banding)**
- **Categorize uncertainty and then map results to various visualization strategies which adds texturing to the original design**
  - **The use of textures in such compound presentations that reflect uncertainty have been shown to be effective in a number of user interpretation tasks via studies in the human factors community (e.g., Bisantz et al)**

Considerations for Decision Support

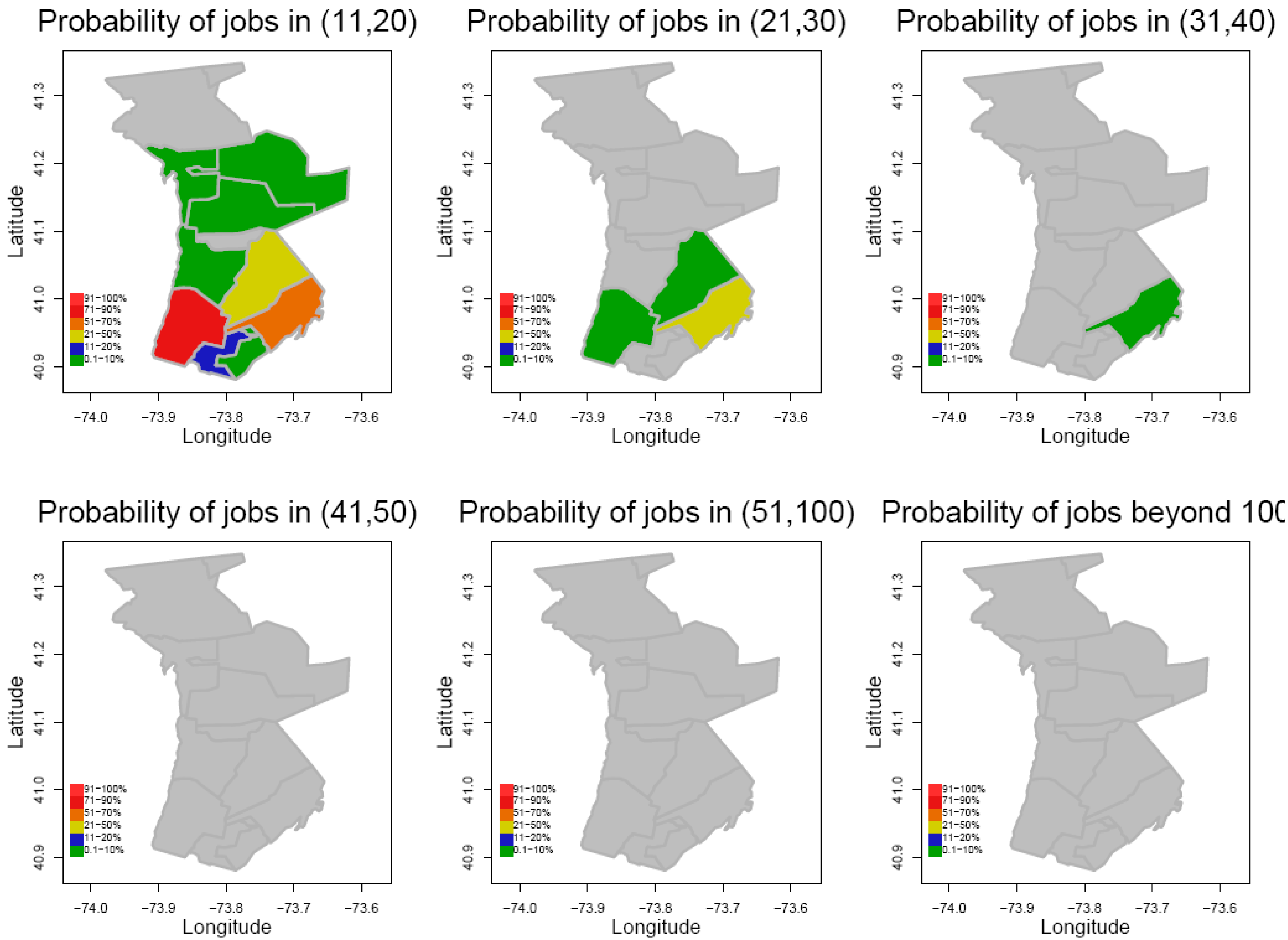
- Ease of use by diverse users who
  - are experts in operations, emergency management and weather impact
  - are not meteorologists, mathematicians or computer scientists
- Enable proactive decision making affected by weather
  - Rapid assessment important (visualizations may need to be almost pre-attentive)
  - Thresholds often more important than overall content
  - Little time for training
- Customized appearance and fused with ancillary data
  - Appropriate utilization of visualization elements (e.g., geometry, color)
  - Consistency with data
  - Incorporation of annotative spatial and temporal information to provide a familiar reference frame
  - Cartographic reprojection to minimize spatial distortion
- Presentation of derived properties critical to decisions
  - Weather or secondary physical phenomena may not be shown

Two Classes of Data and Users to Evaluate

- **Impact prediction**
  - Stochastic model of storm impact utilizing historical weather observations, forecasts and damage reports
- **NWP**
  - WRF-ARW-based 8-member ensemble with data assimilation

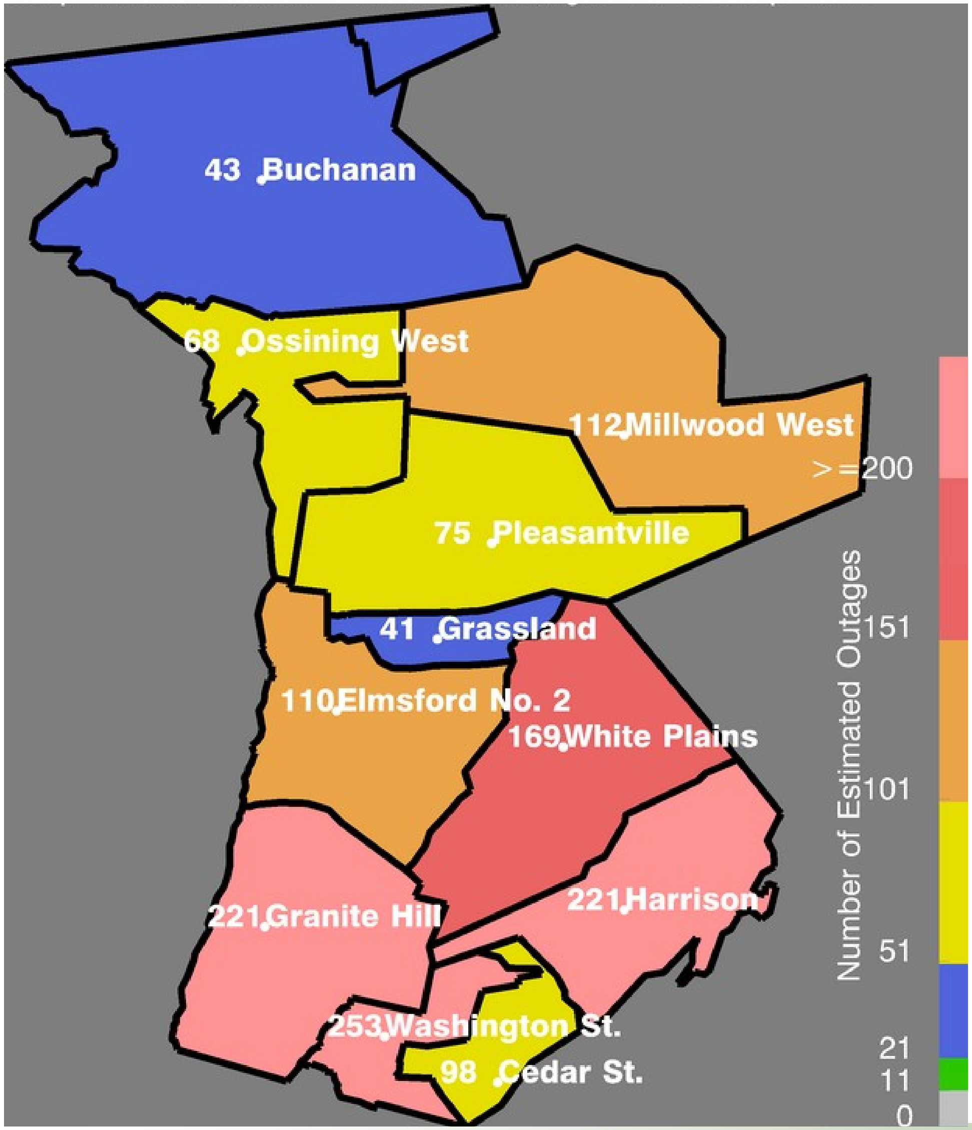
Examples of each and how the designs evolved

Probability of Storm Impact (Number of Repair Jobs)

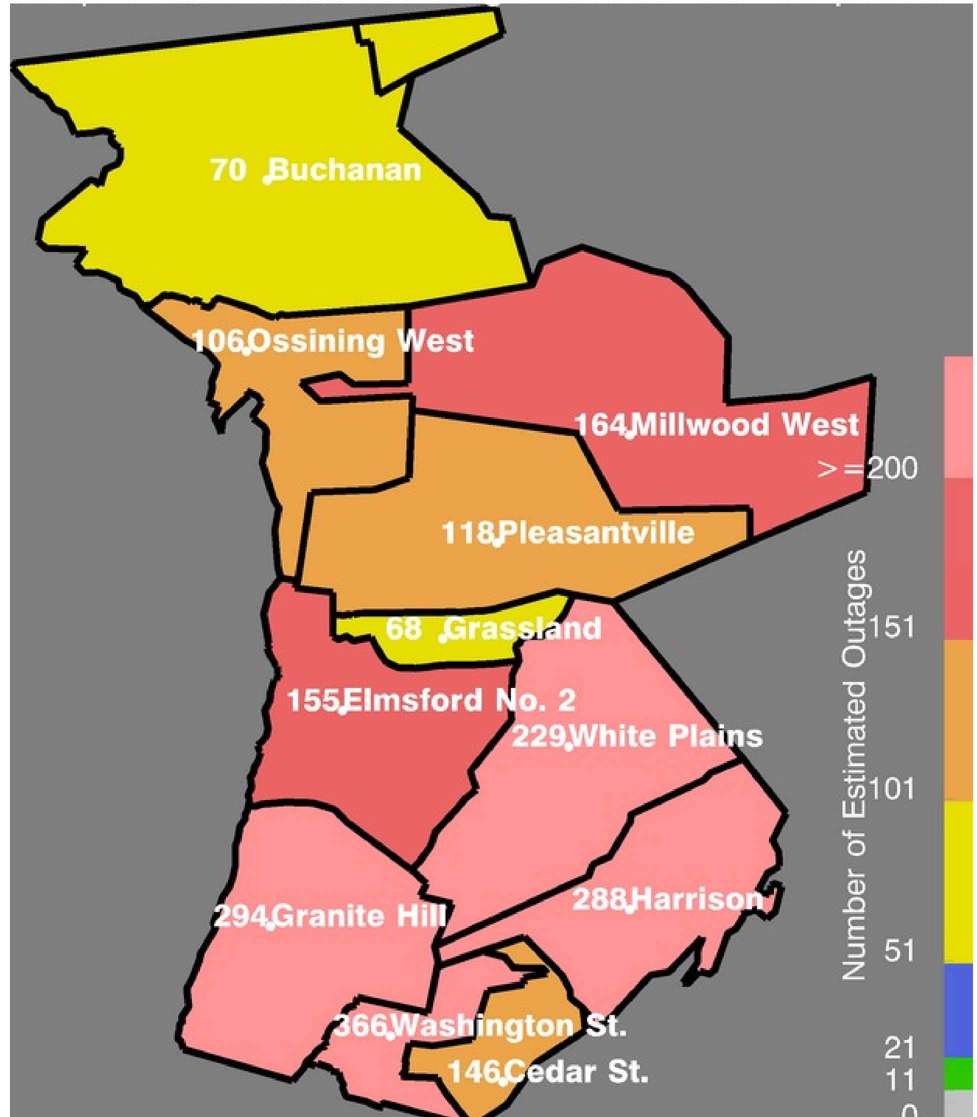


One Type of Dimensional Reduction – But Incomplete

Forecasted Jobs

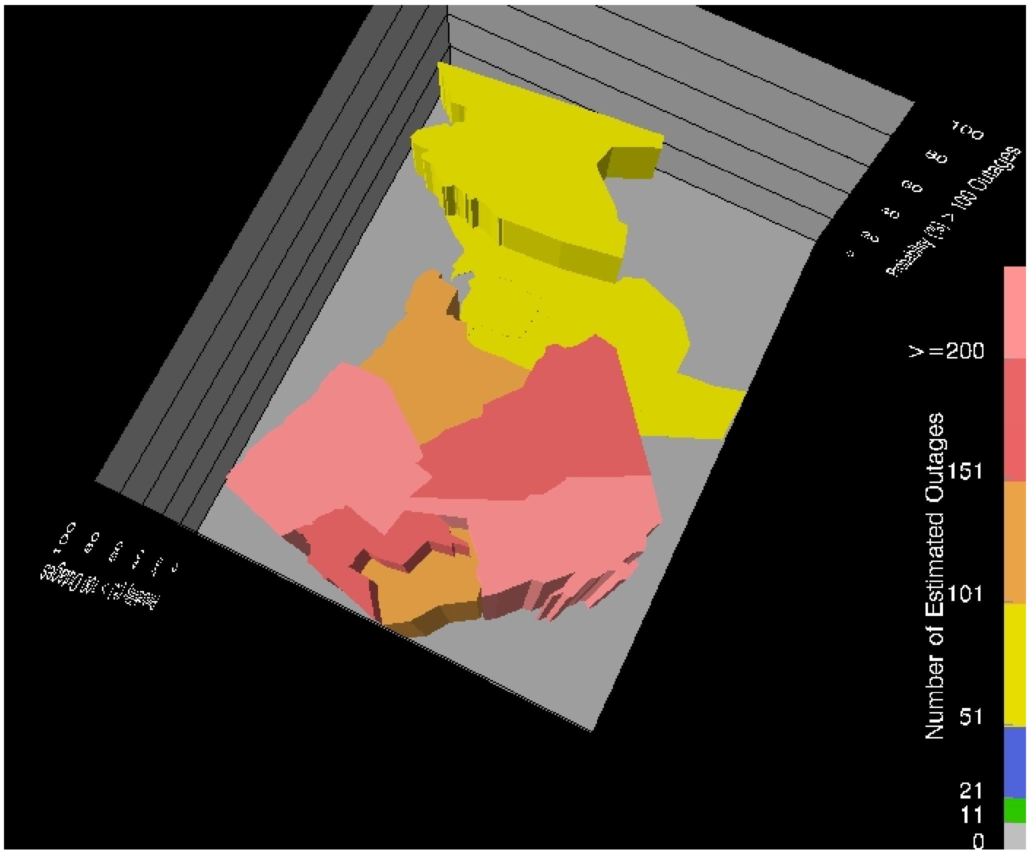


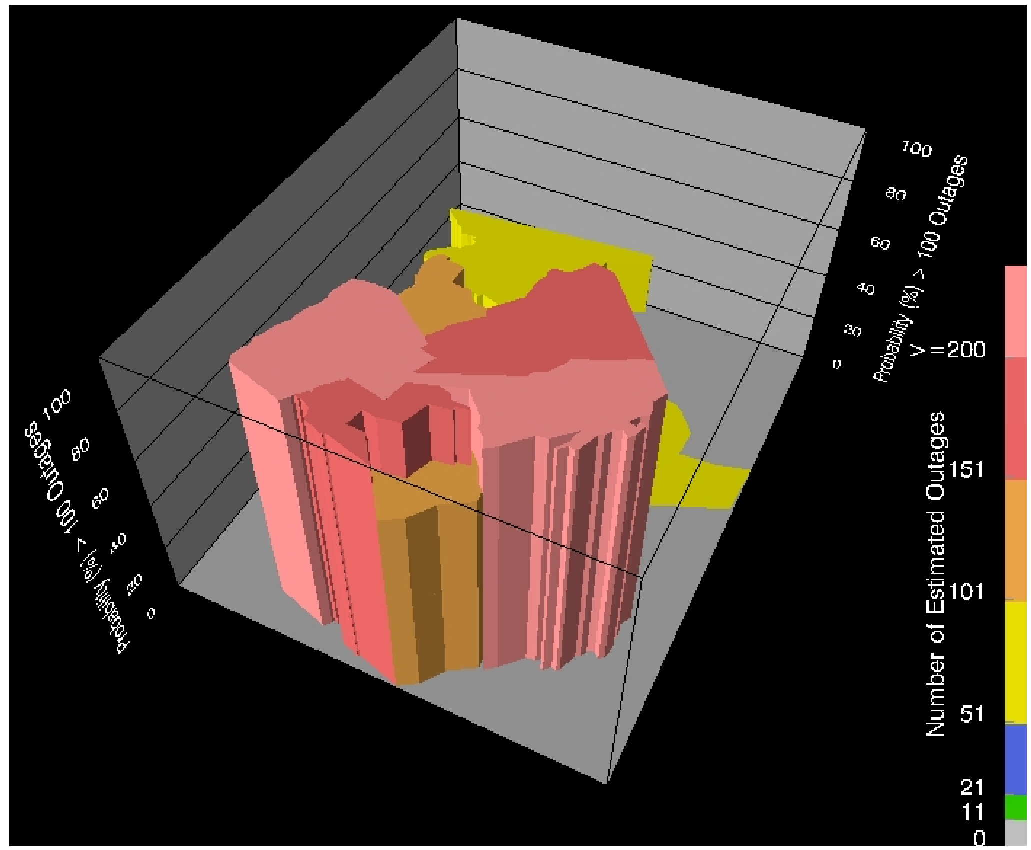
Upper Bound of Forecasted Jobs



Introduce Textures via Surface Representation

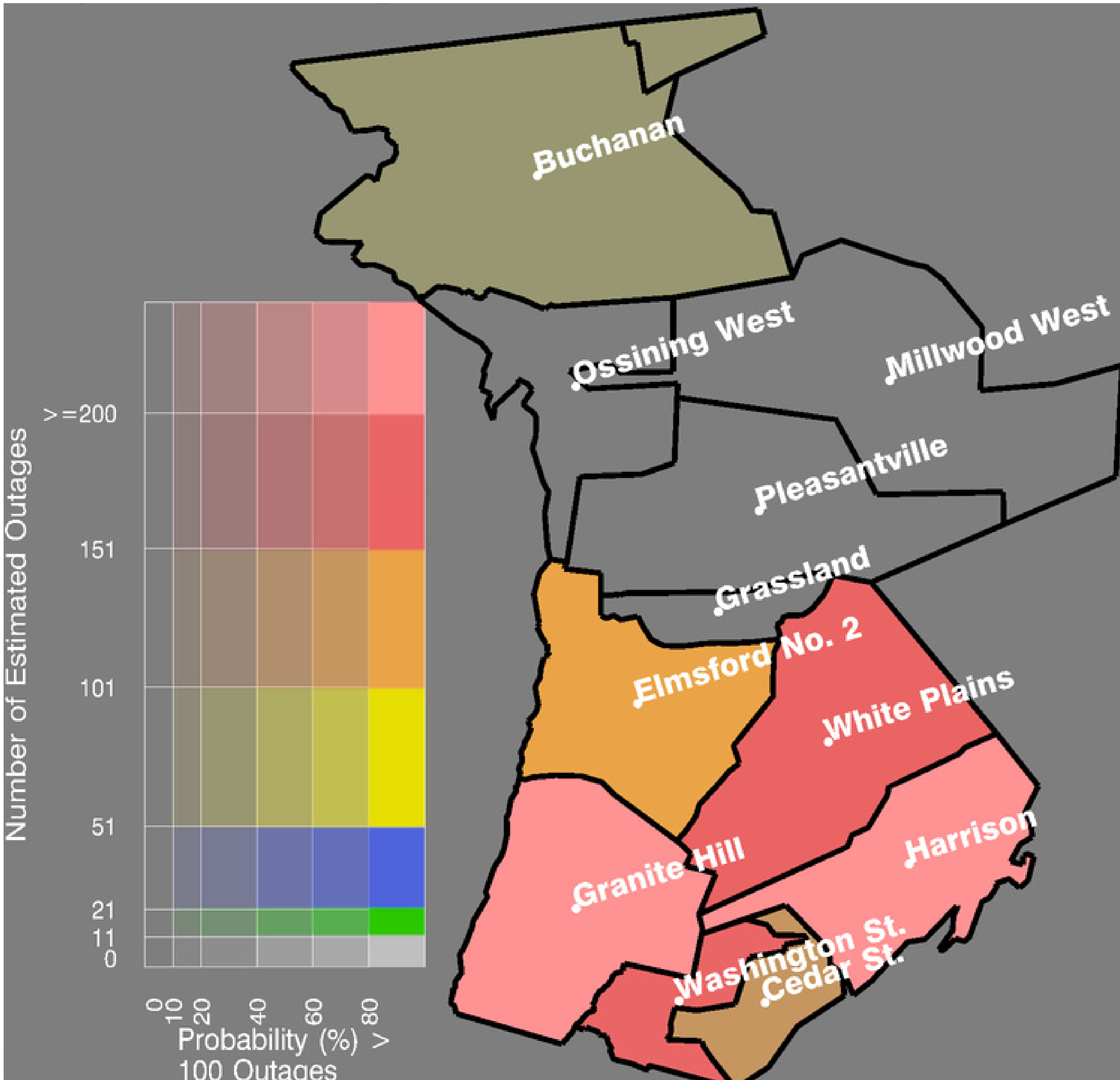
Forecasted Outages Combined with Probability of More than 100 Outages





Introduce Textures in Planar Representation

Forecasted Outages Combined with Probability of More than 100 Outages



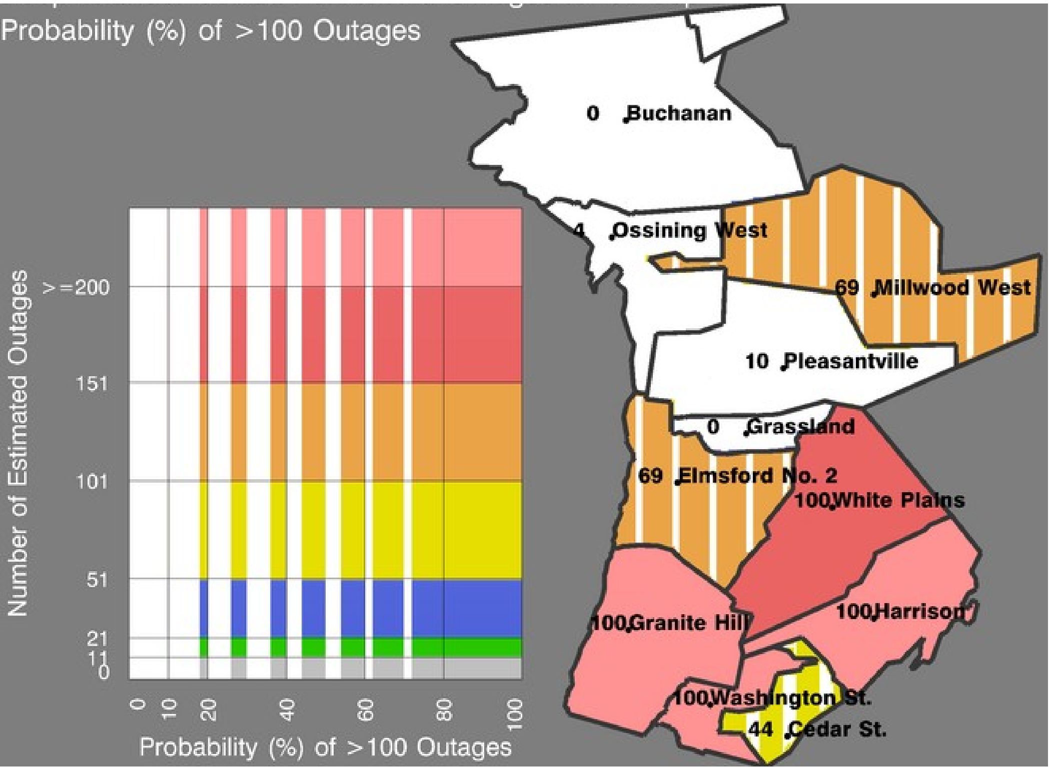
Opacity of Colored

Area Illustrates

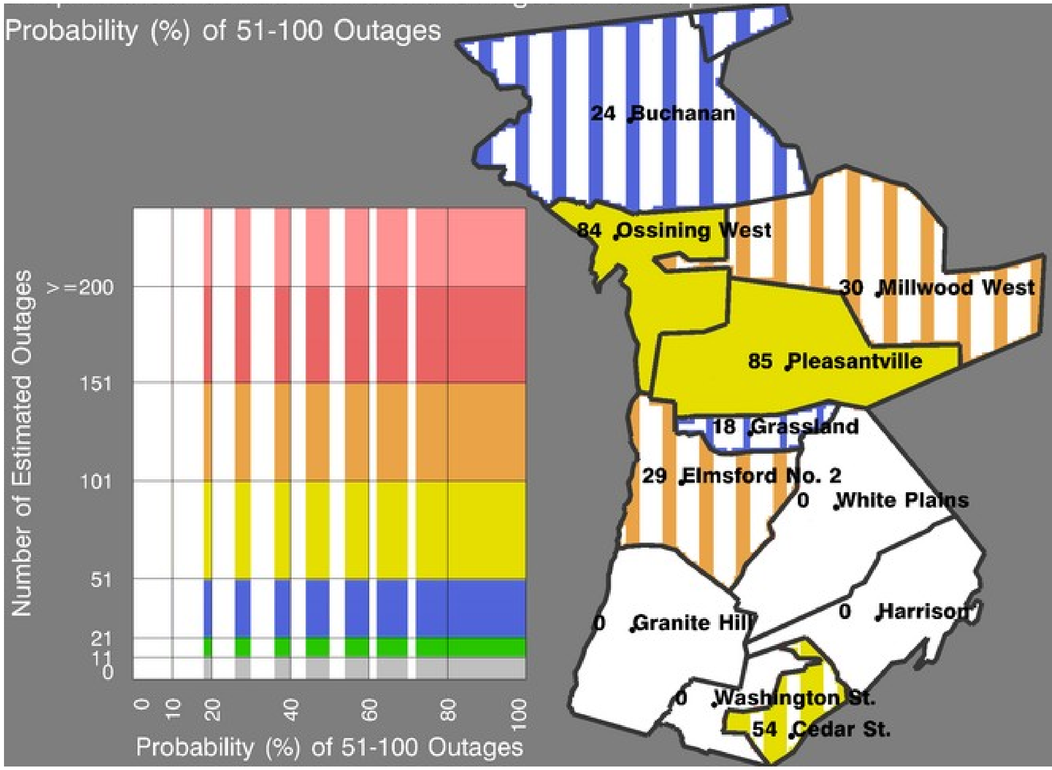
Probability

Refine Textures in Planar Representation

Forecasted Outages with Probability Exceeding 100 Outages



Forecasted Outages with Probability of 51 to 100 Outages



Opaque Texturing of Outage Color Illustrates Probability with Value with Simplified Small Multiple

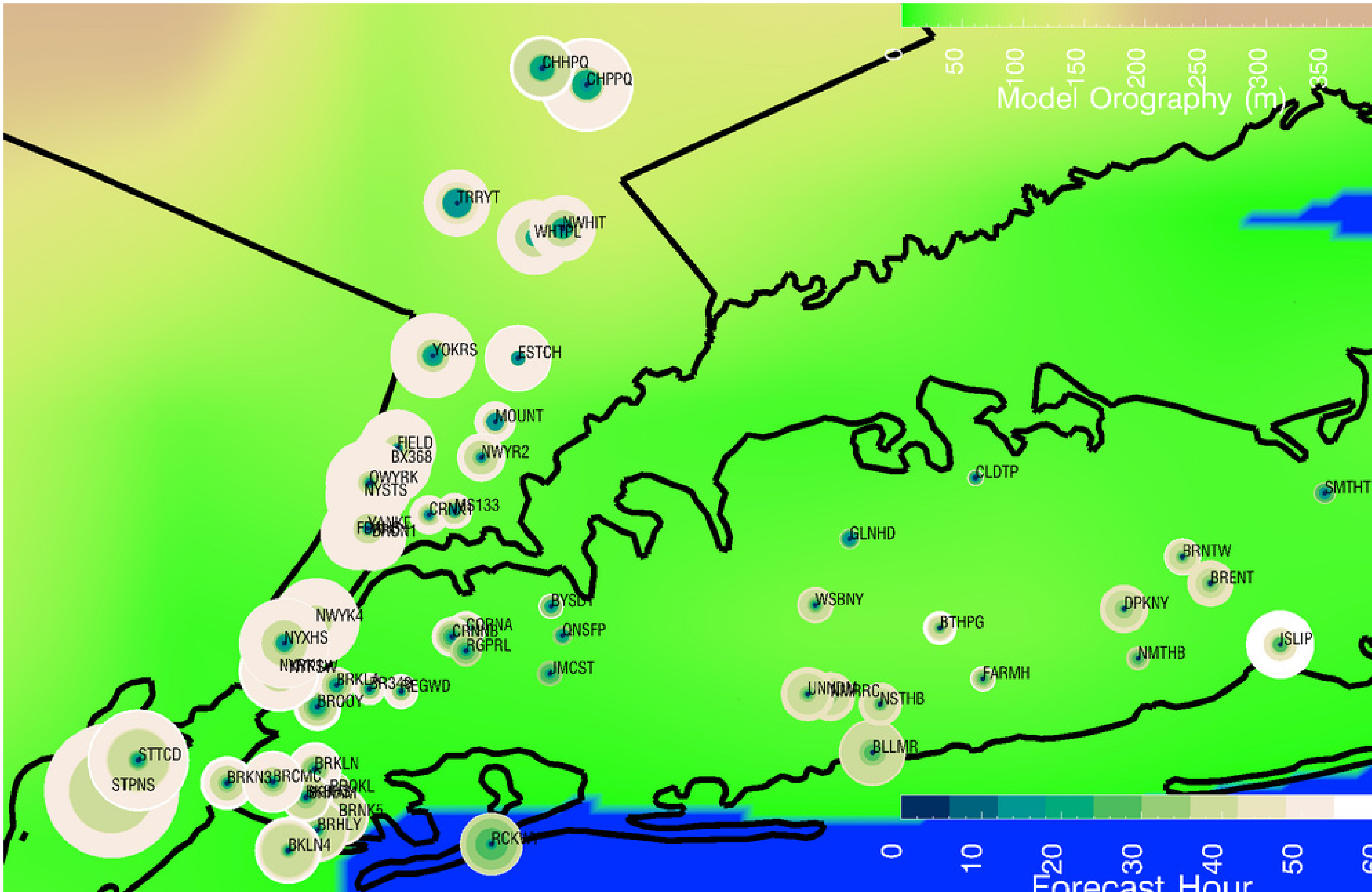
Two Classes of Data and Users to Evaluate

- **Impact prediction**
  - Stochastic model of storm impact utilizing historical weather observations, forecasts and damage reports
- **NWP**
  - WRF-ARW-based 8-member ensemble with data assimilation

Examples of each and how the designs evolved

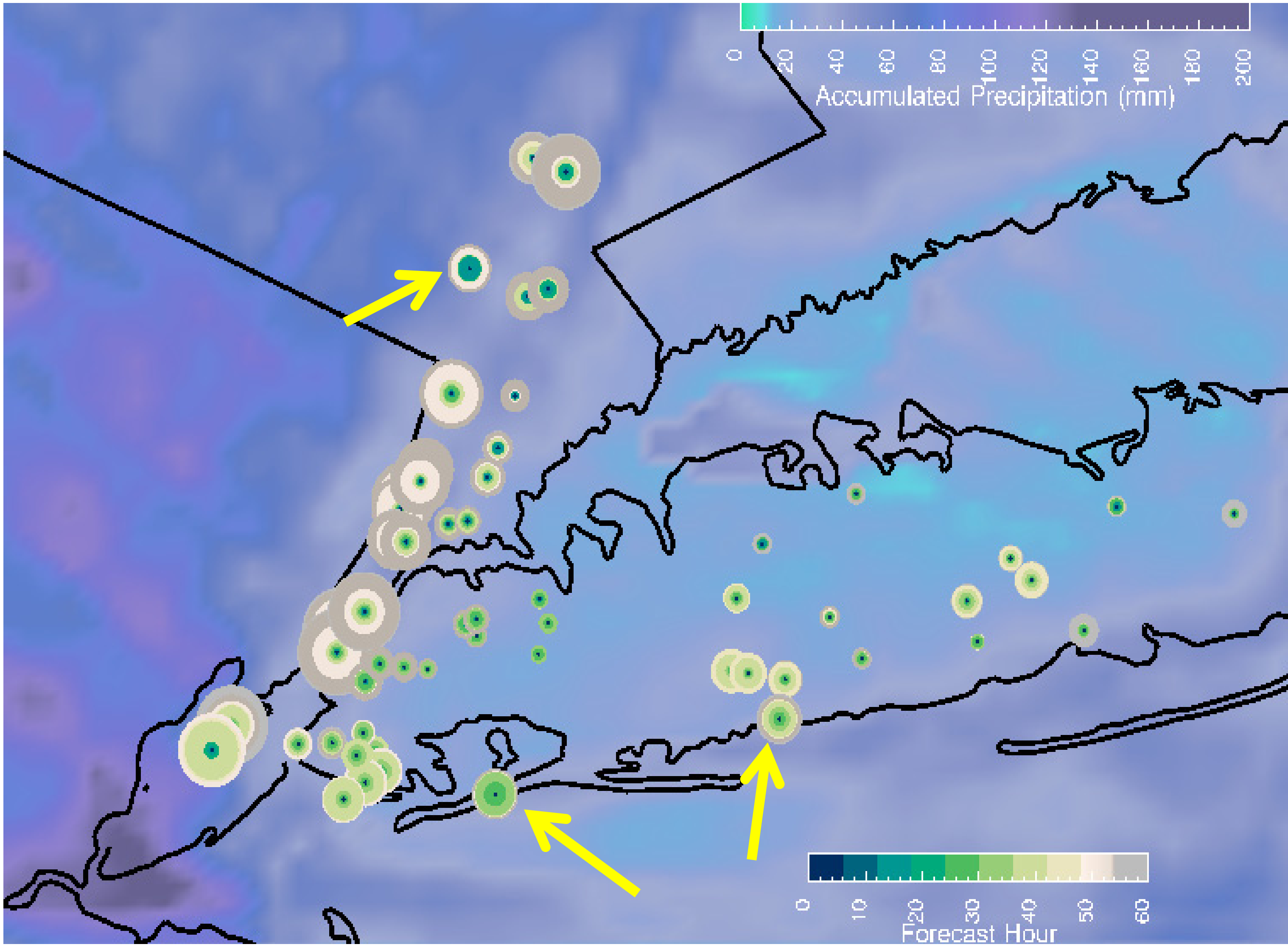
1D Textures Imposed on a Plane

- Uncertainty derived from ensemble variance
- Circle radius mapped to relative uncertainty
- Color mapped to time (each band is six hours)



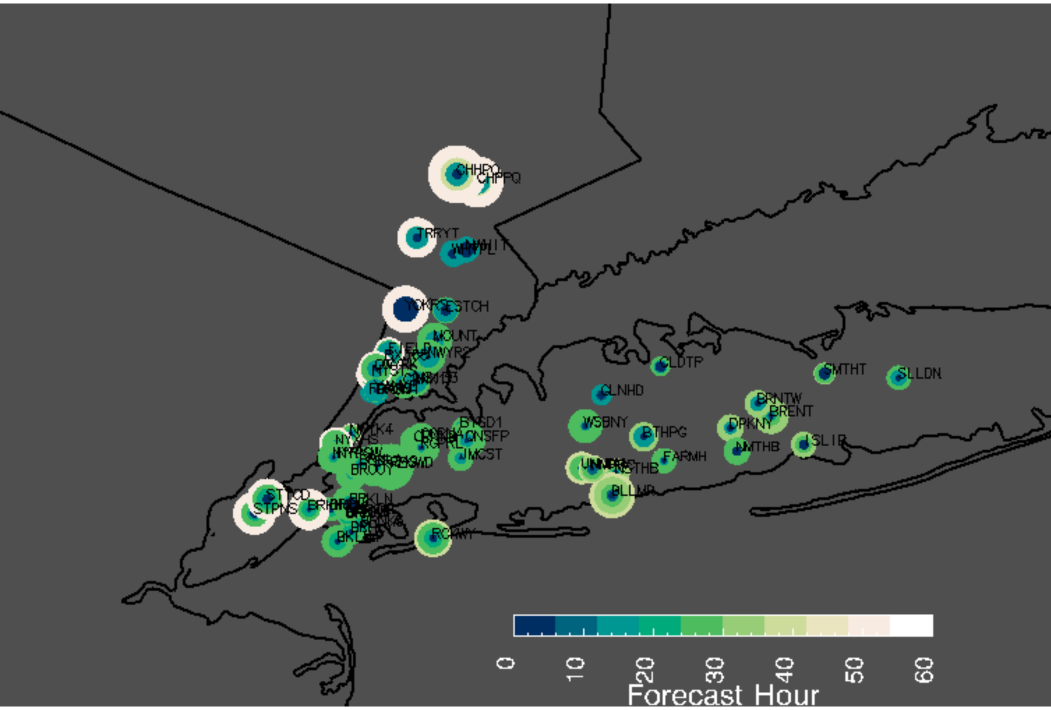
1D Textures Imposed on a Plane for Temporal Evolution of Rainfall Uncertainties

- Overlay of accumulated rainfall forecast and uncertainty estimates shows geographical location of sites with high uncertainty
- Higher uncertainties earlier in the forecast are related to temporal uncertainties (i.e., different rainfall onset time), especially sites marked with yellow arrows

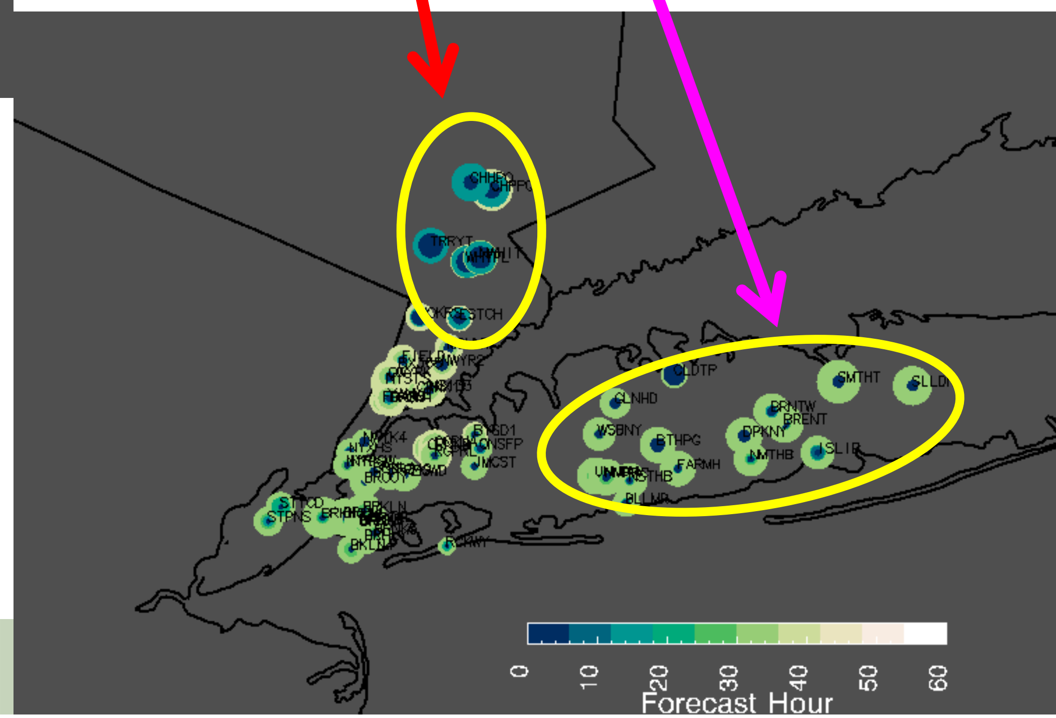


Texturing of Uncertainties Enables Spatial Clusters to Be Identified During Forecast

- **Time of maximum wind uncertainty varies with location**
- **Larger uncertainty earlier in the temperature forecast**
- **Larger uncertainty later in the temperature forecast**

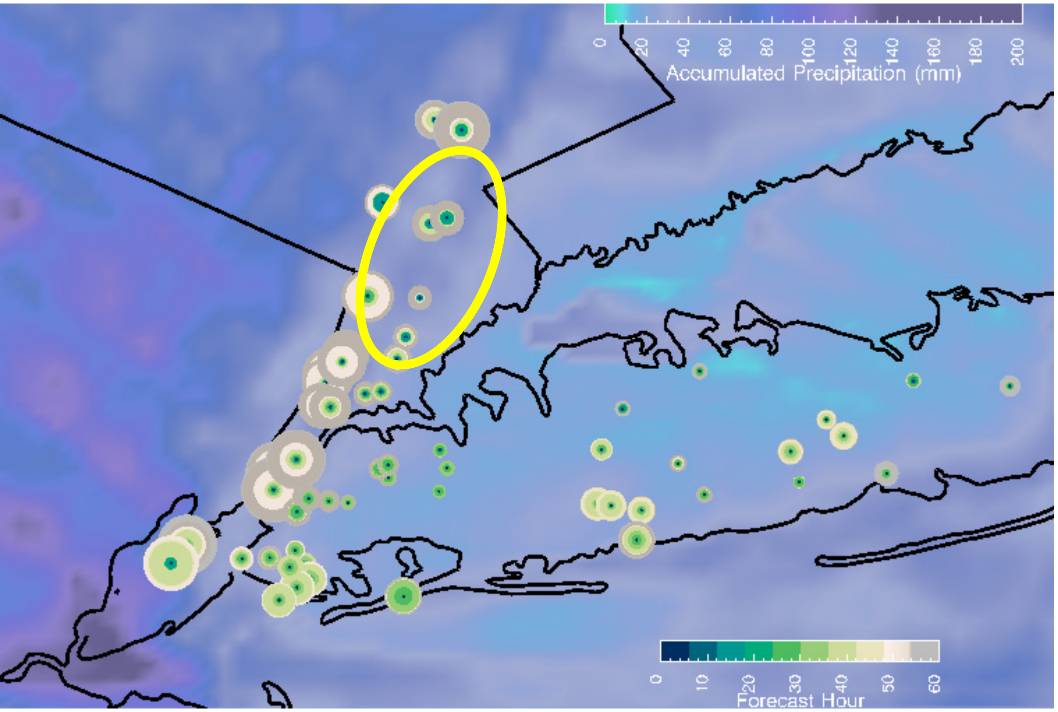


Surface winds show little clustering

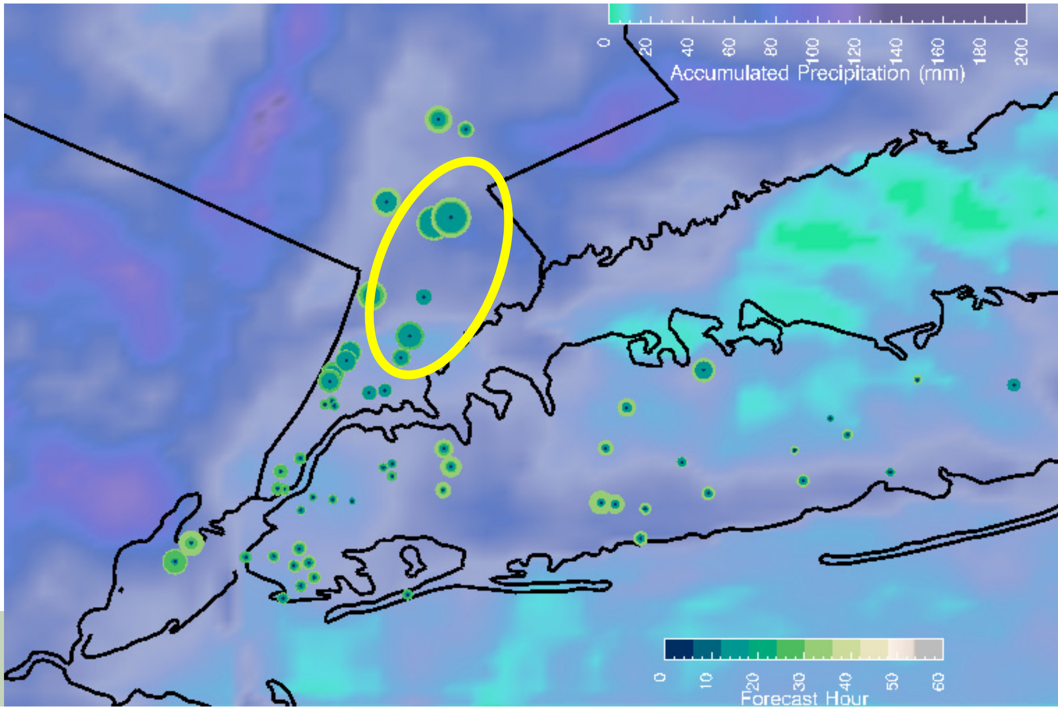


Surface temperatures show clustering

Texture Clusters of Uncertainties for Forecast Comparison



- Two forecasts (lower right initiated 24 hours later)
- Sites within the yellow ellipse have higher forecast uncertainty at earlier hour for later forecast
- Rainfall accumulation is similar in both clusters



Discussion and Future Work

- **Less is more…**

- **Familiar metaphors (colors, overlays) required for ease of use and in minimizing training for decision support**
- **Iteration with users critical to incorporate feedback into designs**

- **Apply concepts to other "dimensions" of impact models (e.g., categorical data)**
- **Extend ideas to other NWP ensembles, including volumetric data**
- **On-going user evaluation**

Backup

Slides

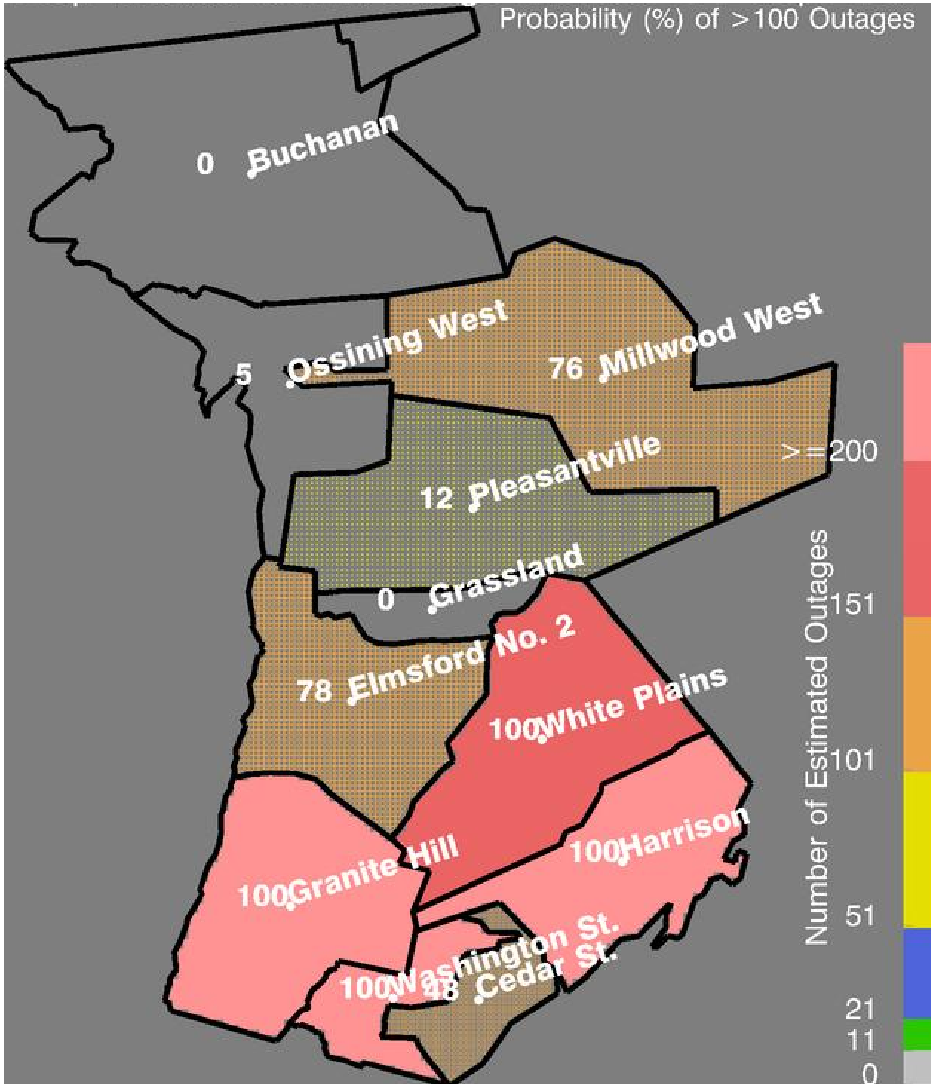
Disciplines Needed for Effective Visual Design

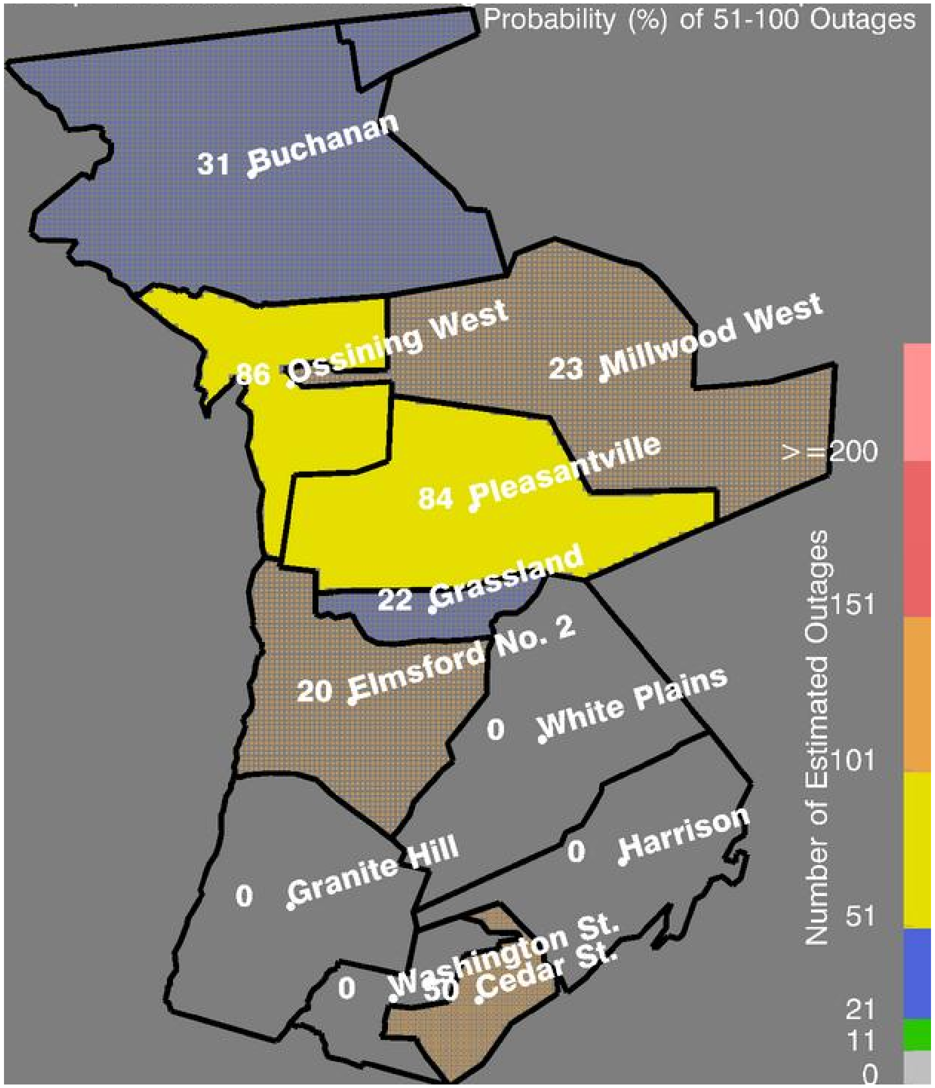
(Understand Limitations in Content and Interpretation)

- **Meteorology**
  - –Preserve data fidelity (and science)
- **Psychophysics and human vision**
  - –Perceptual rules for use of color, geometry, texture, etc.
- **Cartography**
  - –Rules for use of projections (i.e., making appropriate maps)
- **Computer graphics**
  - –Algorithms for transformation, realization, rendering, etc.
- **Workflow and decision-making process**
  - –Human factors, systems engineering, etc.

Refine Textures in Planar Representation

Forecasted Outages Combined with Probability of More than 100 Outages





Texturing of Outage Color Illustrates Probability with Value