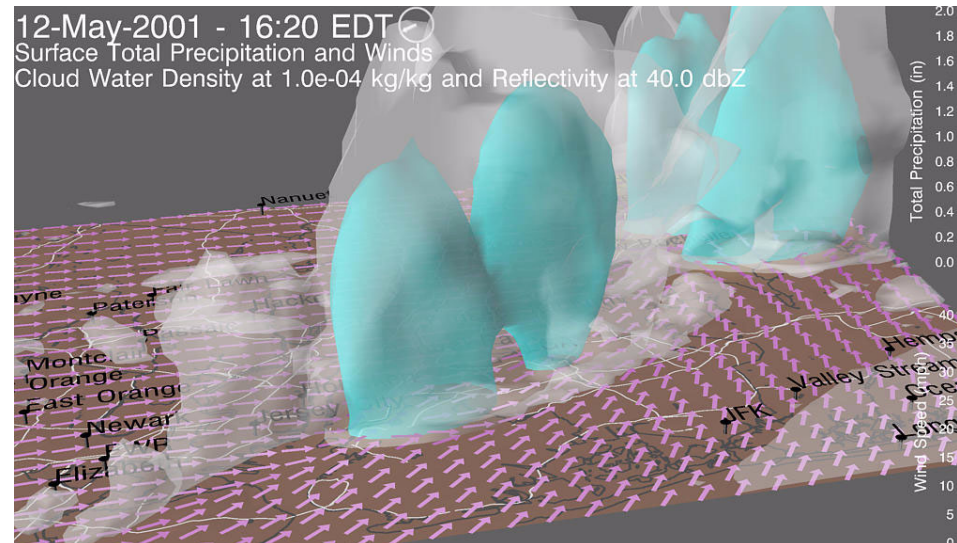


Customized Visualizations of NWP-based Forecasts for Decision Support in Emergency Management



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<http://www.research.ibm.com/people/l/lloyd>

<http://www.research.ibm.com/weather/DT.html>

Customized Visualizations of NWP-based Forecasts for Decision Support in Emergency Management

- **Background and motivation**
- **Visual design**
- **Examples (case studies) and discussion**
- **Conclusions and future work**

Background

- Apply meso- γ -scale NWP (*"Deep Thunder"*)
- Use "good" principles of visual design

Motivation

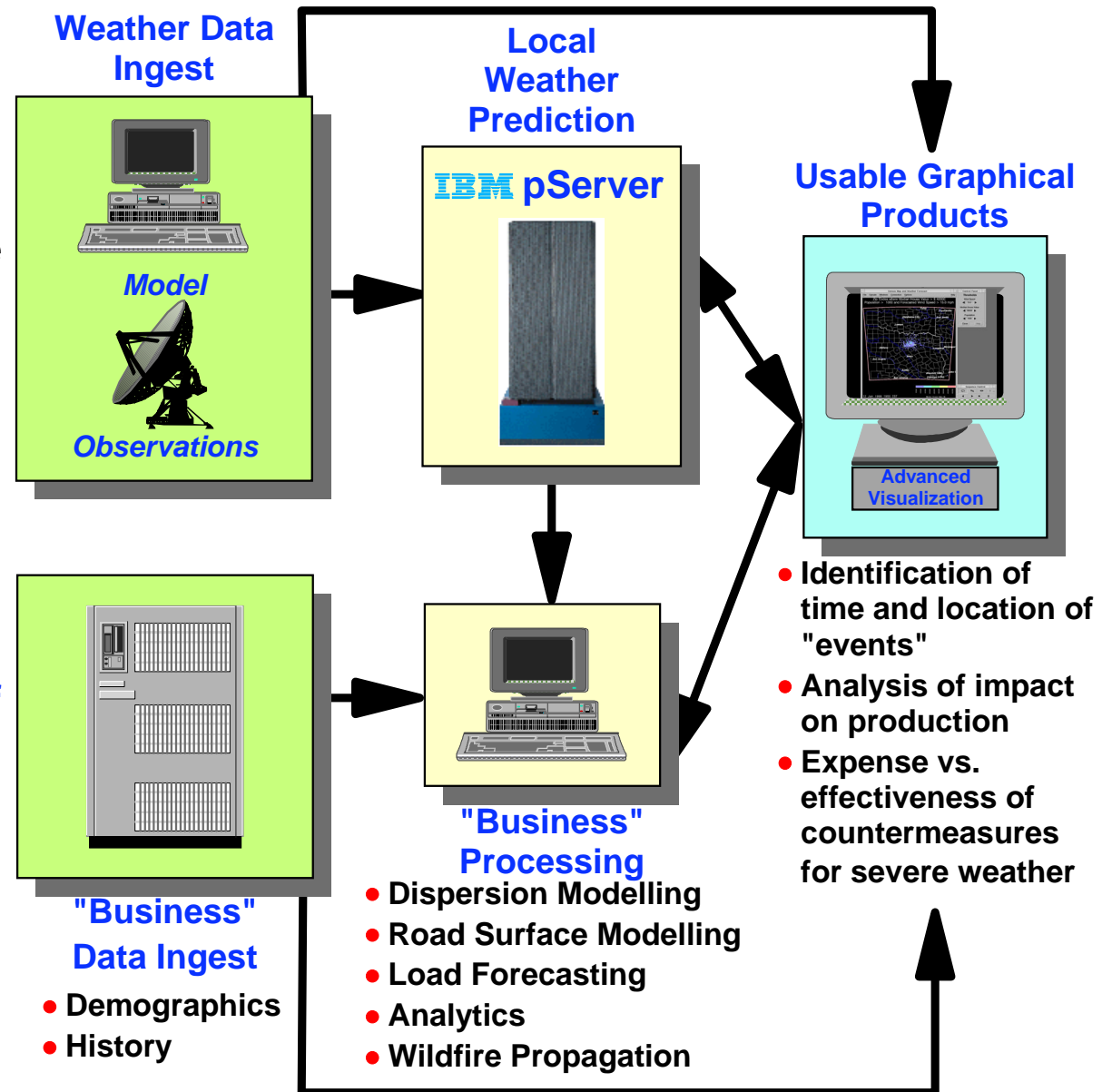
- Understand how experienced people use their expertise in decision making
- Enable more effective decisions with economic and societal value

Customized Model-Based Forecasts for Local Weather-Sensitive Decision Making

- Enable proactive decision making affected by weather
- Customize & integrate for different users
- Provide usable forecast products fast enough to enable timely decisions

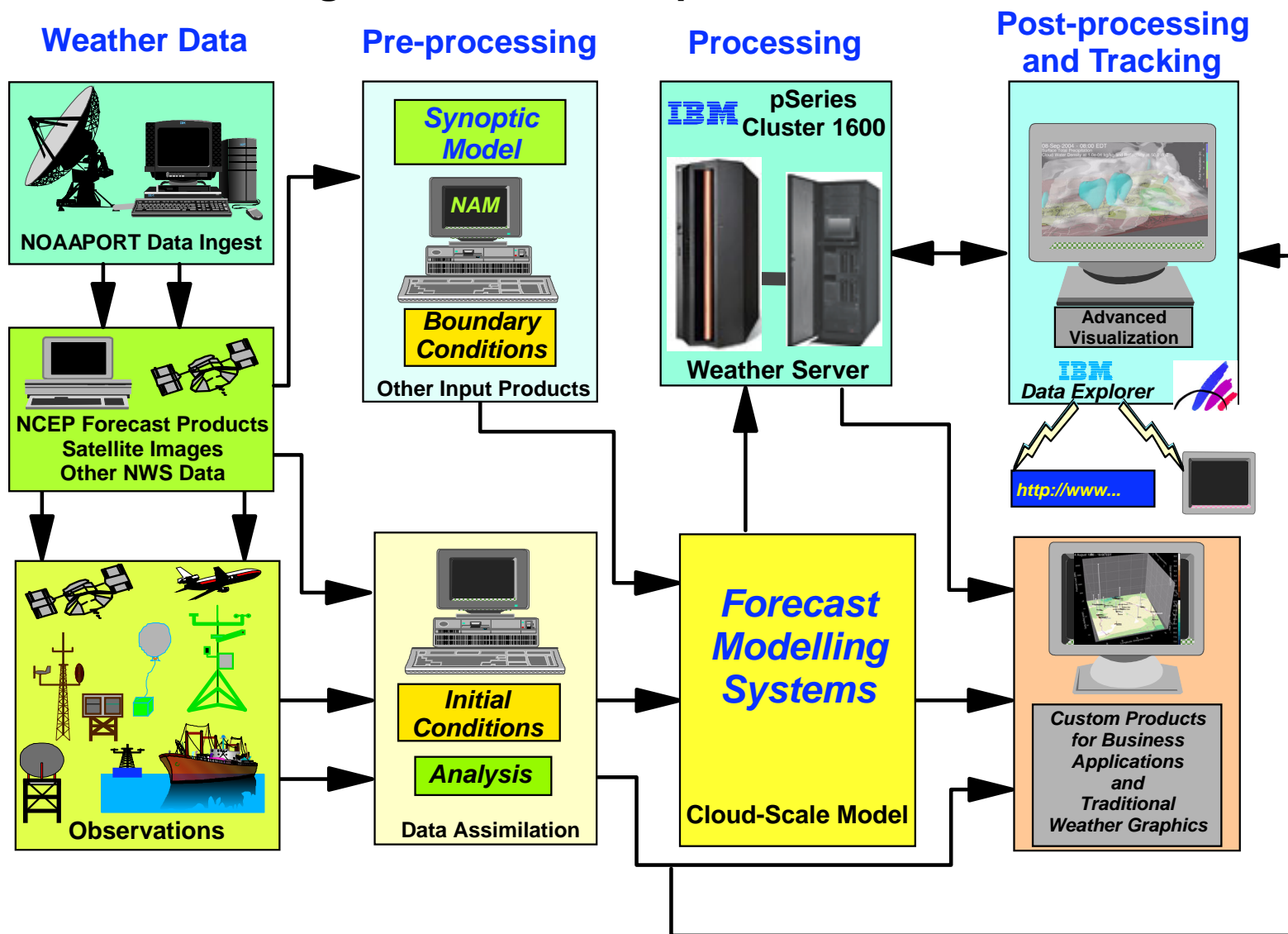
Visualized results produced within a few hours per day of forecast

- Couple to business processes & models
- Past forecasts useful for scenario planning

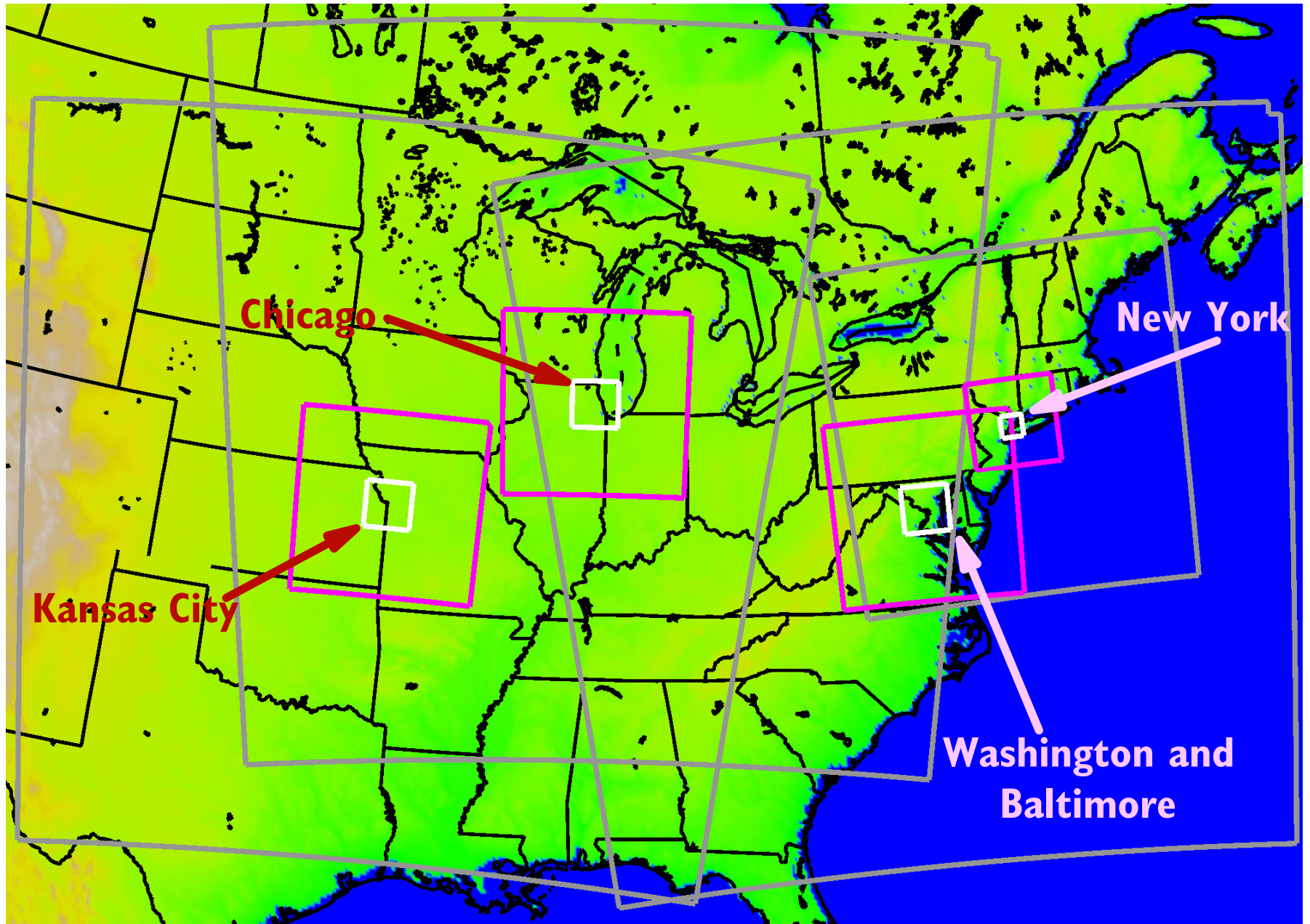


Deep Thunder Implementation and Architecture

- User-driven not data driven (start with user needs and work backwards)
- Sufficiently fast (>10x real-time), robust, reliable and affordable
 - For example, 30 minutes (20x1.7GHz Power4) for 32/8/2 km (three 66x66x31)
- Ability to provide usable products in a timely manner
- Visualization integrated into all components



Deep Thunder Testbeds



Visualization Issues

- Traditional meteorological visualization is driven by data for analysis, and is therefore, inappropriate
 - We must avoid an impedance mismatch between the compelling sophistication of the data vs. how the data should be utilized
 - Timely and effective usability of NWP results requires the visualization designer to
 - Understand how relevant data are used and why (e.g., human factors concerning how users work and interact)
 - Understand how users perceive and interpret visualizations
 - Design in terms relevant for user, employing familiar terminology and metaphors -- readily understood in real-time without expert interpretation and used with confidence
 - Reflect uncertainty in representation
1. Identification of user needs, goals and tasks
 2. Composition of design elements and interface actions

Visualization Tasks in Meteorology

- **Class I: 2d (traditional weather graphics)**
 - Quantitative
 - Users are forecasters
 - Minimal interaction
- **Class II: 2d, 2-1/2d Analysis**
 - Quantitative with potentially complex appearance
 - Users are forecasters, but techniques will be new
 - Support data comparison
 - Direct manipulation important
- **Class III: 3d Browse**
 - Qualitative with simplified appearance (not necessarily content)
 - Users may or may not be specialists (e.g., forecasters & public)
 - Animation with temporal and spatial coherence important
 - Event identification for potential later analysis
- **Class IV: 3d Analysis**
 - Quantitative with potentially complex appearance
 - Users are forecasters, but techniques will be new
 - Support limited data comparison
 - Direct manipulation important
- **Class V: *Decision Support***

Decision Support -- Class V

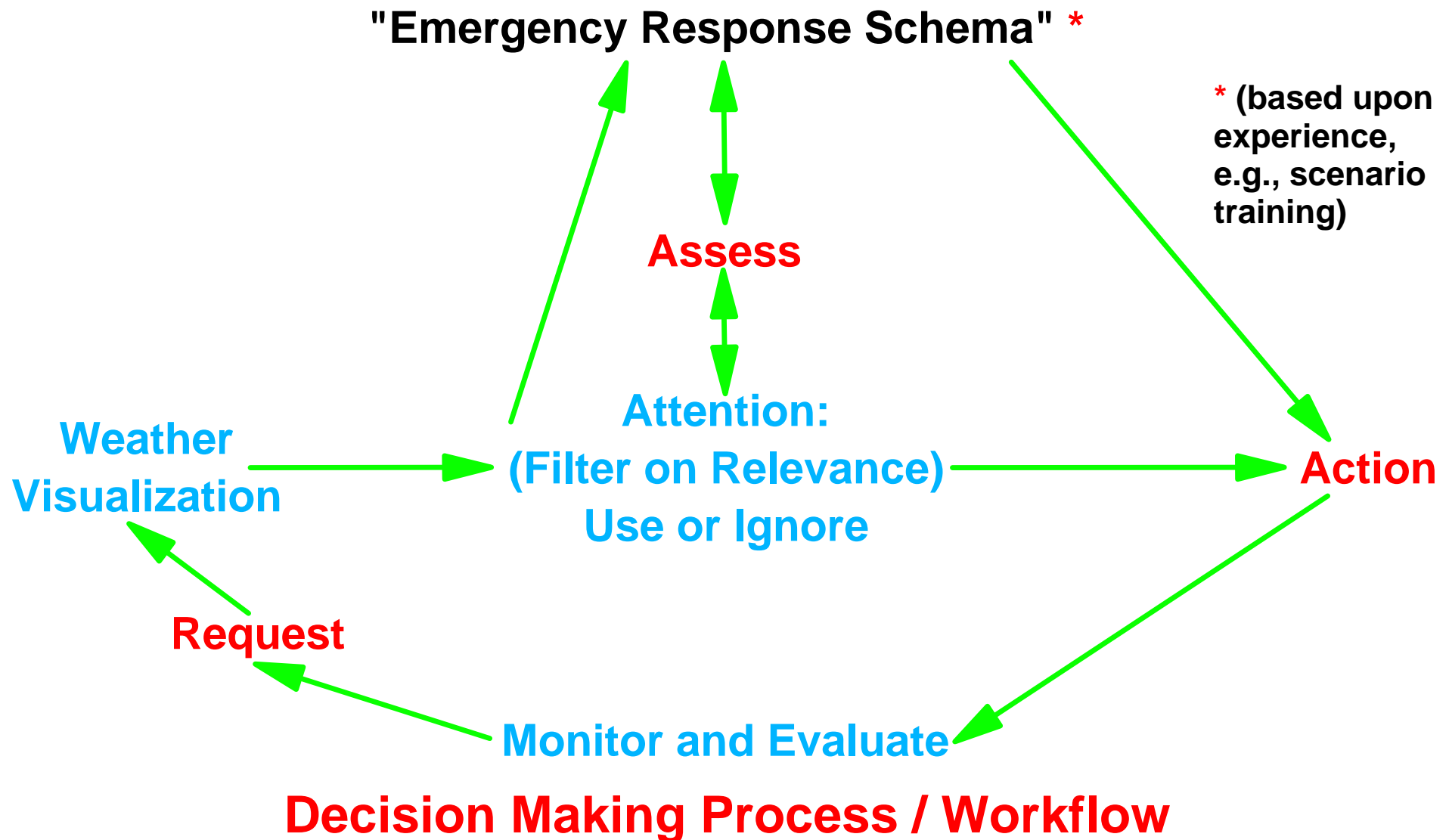
- **Enable proactive decision making affected by weather**
 - Rapid assessment important (visualizations may need to be almost pre-attentive) - threshold vs. content
 - Users are not meteorologists, but should understand the impact of specific weather events
- **Understand cognitive process by which skilled decision makers build a (visual) mental model in order to create effective designs**
- **Customized appearance by data and geography and fusion with ancillary data**
- **Presentation of derived properties critical to decisions**
 - Weather phenomena may not be shown
- **Many potential applications, not just emergency management**

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
- **Computer graphics**
 - Algorithms for transformation, realization, rendering, etc.
- **Workflow and decision-making process**

One Person's Emergency May Be Another's Routine

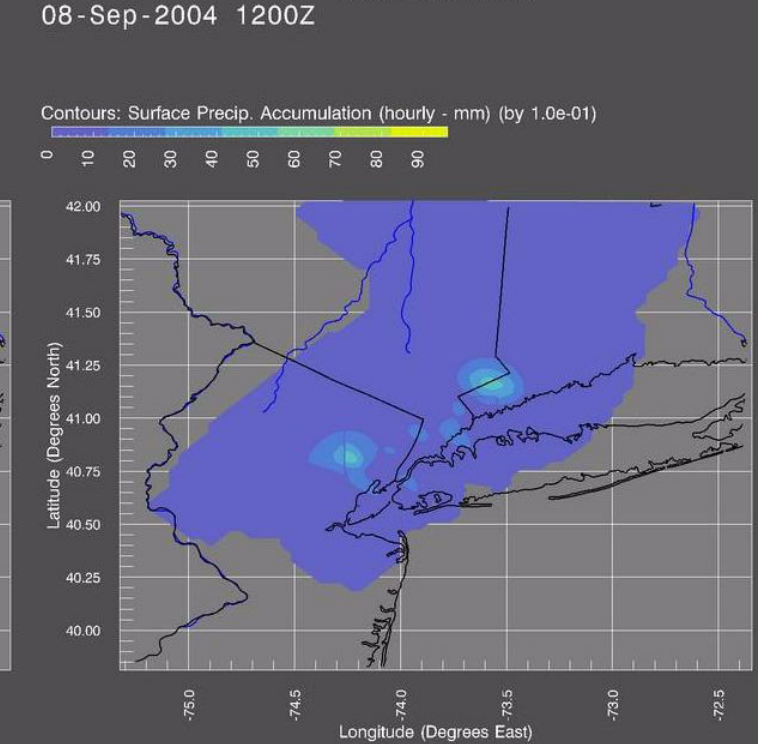
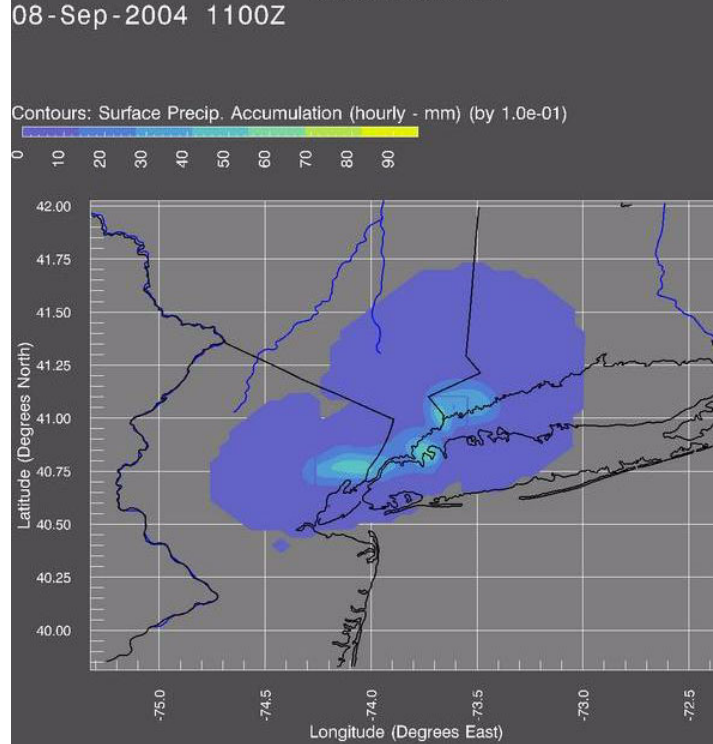
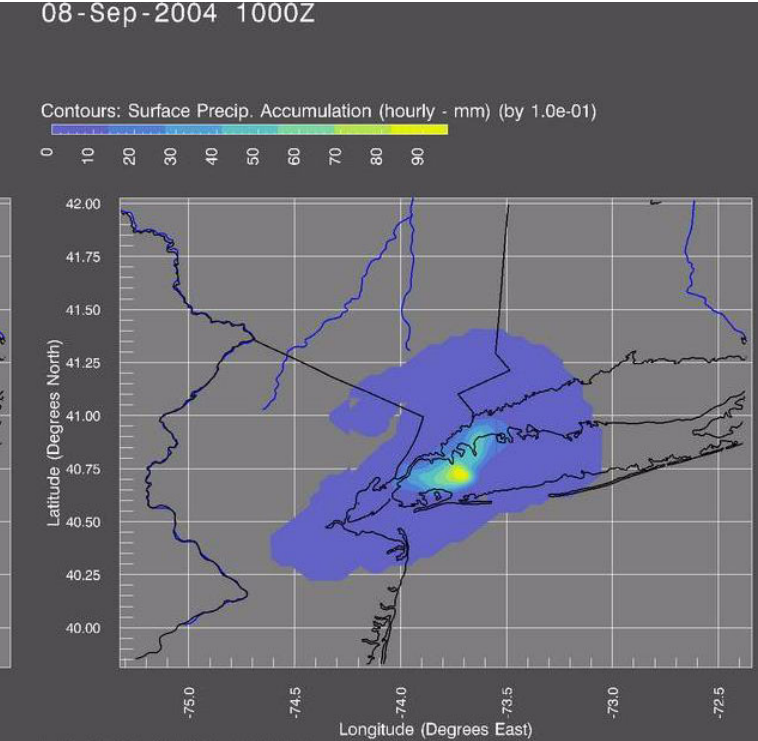
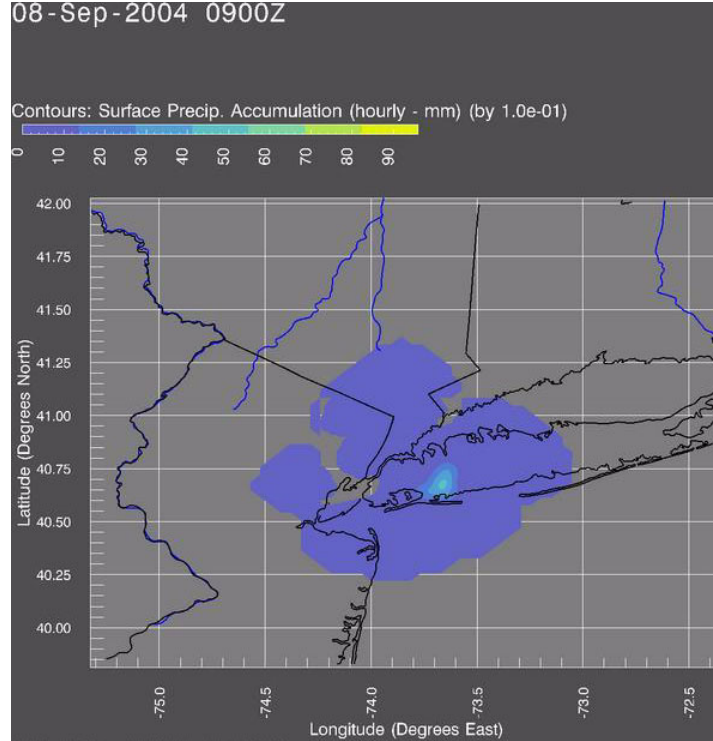


Many tasks are involved in how one looks at and assesses a situation, obtains and interprets information and communicates with others.

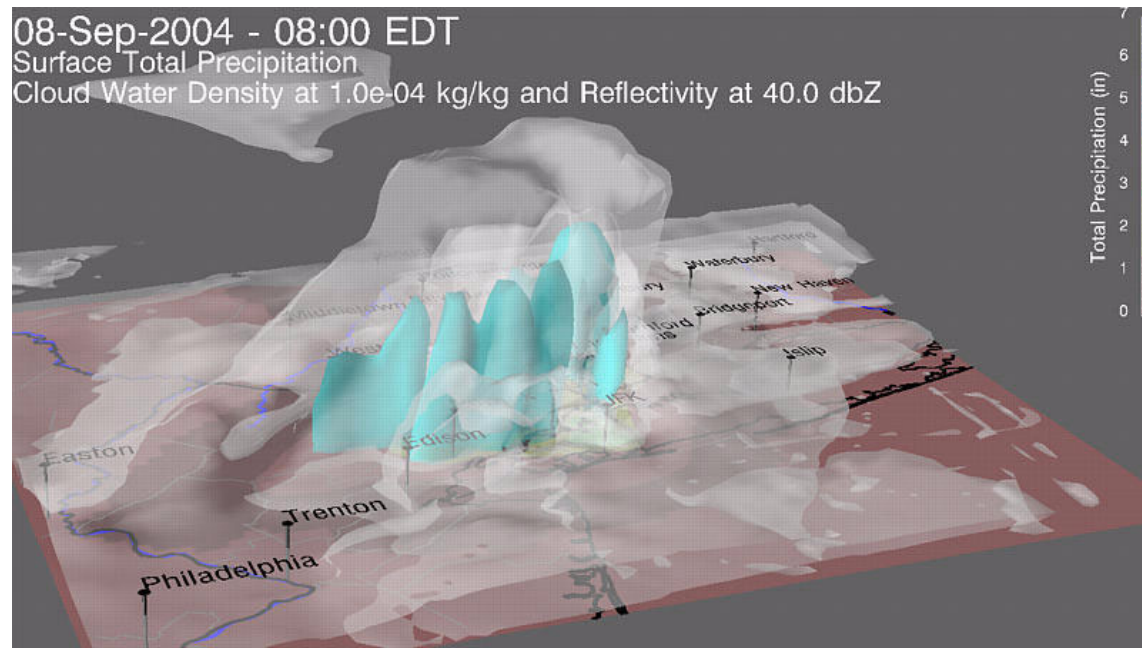
NYC Metropolitan Area Heavy Rainfall Event -- 8 September 2004

- **Remnants of Hurricane Frances moved into the New York City metropolitan area early in the morning of September 8**
- **The heaviest rainfall occurred in an area stretching from northeastern New Jersey through central Westchester County, NY with amounts in excess of 5" in some areas**
- **There was widespread disruption of transportation systems (e.g., road closures, flooded subways, airport delays) and significant flooding in several regions**
- **Evening NWS forecast (2130 EDT, 7 September) for the next day "showers and a slight chance of thunderstorms, rain may be heavy at times in the morning"**
- **Revised NWS forecast (0440 EDT, 8 September), adding "locally heavy rain possible"**
- **NWS issued a flash flood watch at 0748 EDT**

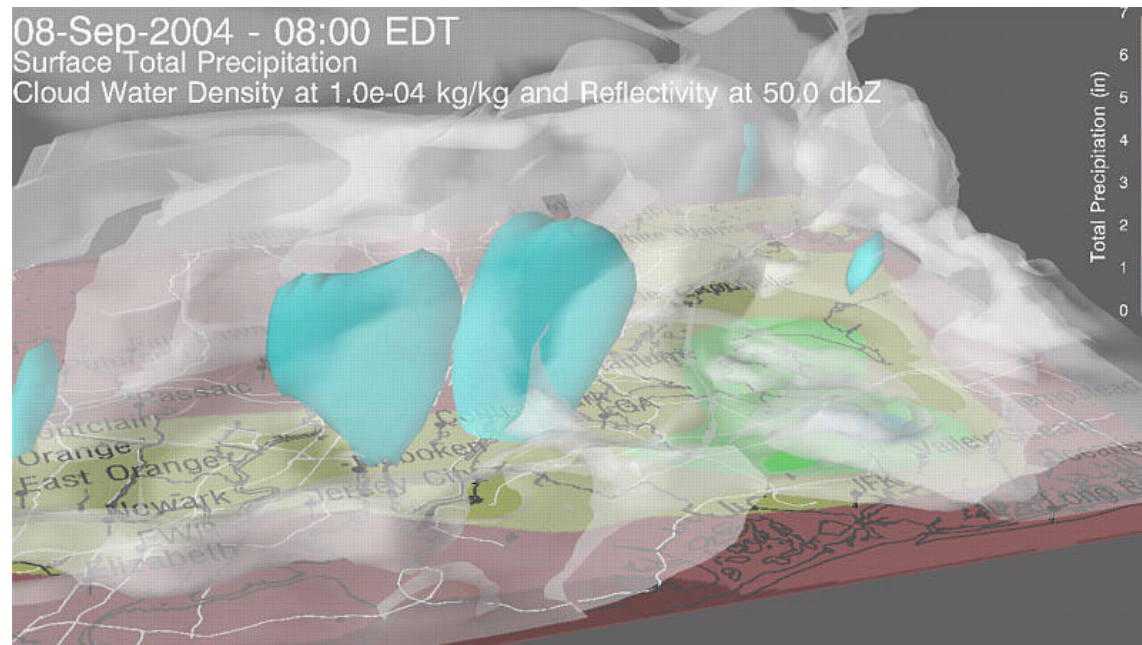
Forecast Results 07 September 2004 Late Evening



Forecaster View or User's View ?



***Deep Thunder* 4 km nest (above) and 1 km nest (below) at forecast hour 12 (0800 EDT)**

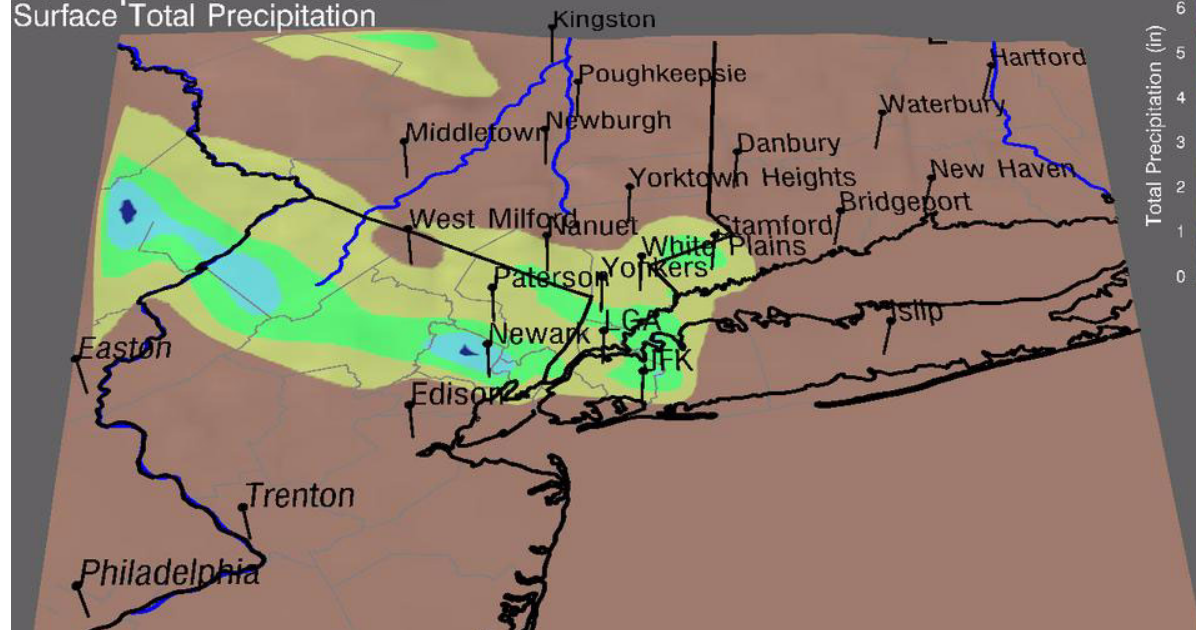


Is This a Better User View ?

For Which Users and Why ?

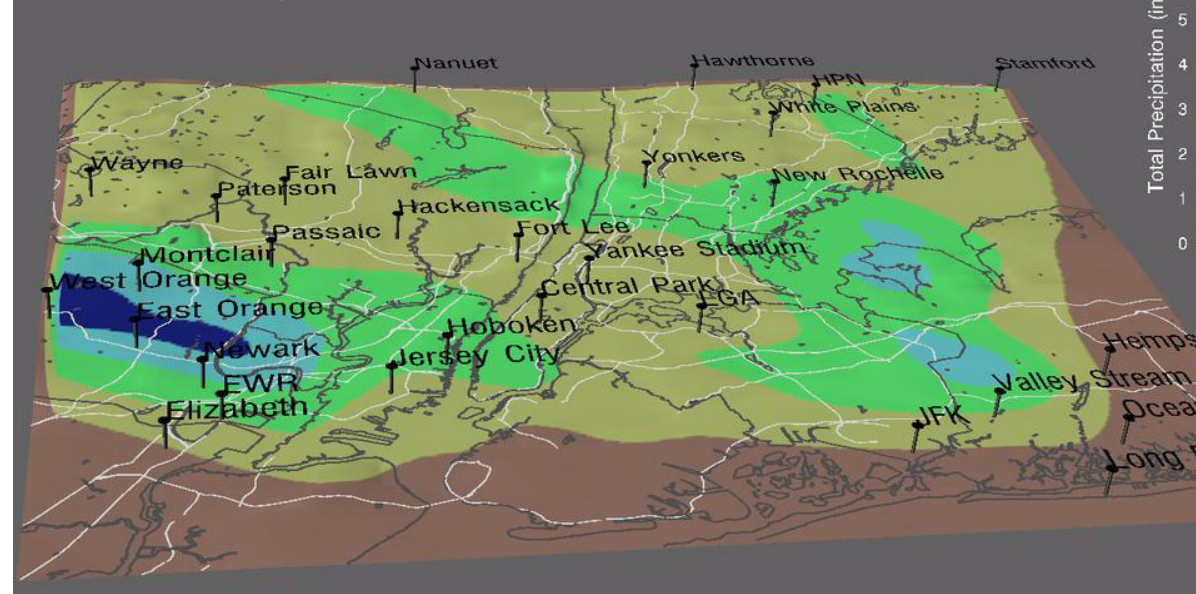
- Heavy rainfall predicted for the morning with similar distribution to reported rainfall, although some differences in totals
- Forecast initiated with data from 2000 EDT with results available about midnight
- Significantly different forecast compared to NWS forecast (available about 8 hours before flash flood warning)
- Despite some error, significant "heads-up" for event

08-Sep-2004 - 20:00 EDT
Surface Total Precipitation



Deep Thunder rainfall totals 4 km nest (above)
and 1 km nest (below) through 24 hours

08-Sep-2004 - 20:00 EDT
Surface Total Precipitation

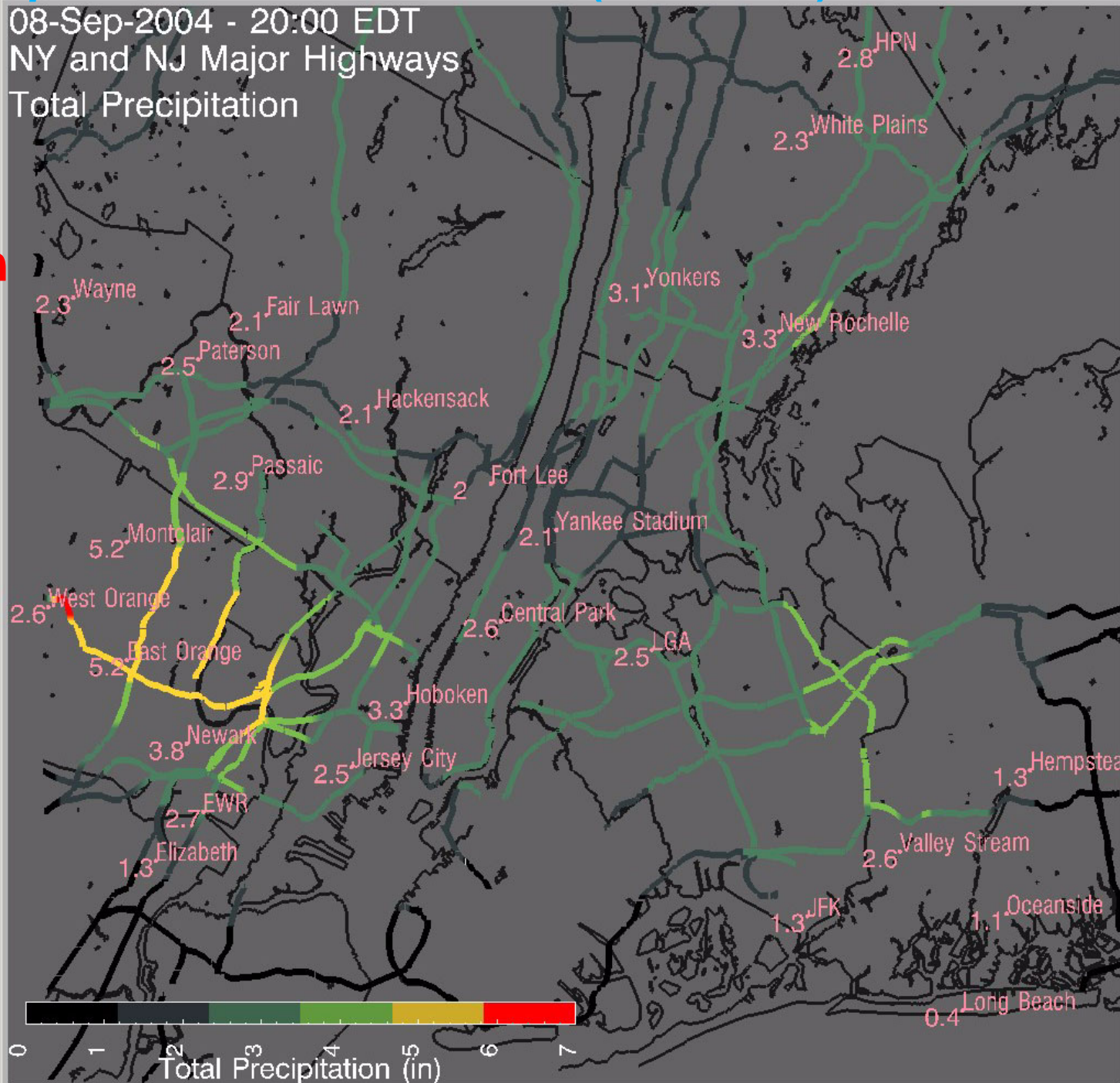


Is This a Better Visualization ?

- Heavy rainfall predicted for the morning with similar distribution to reported rainfall, although some differences in totals
- Forecast initiated with data from 2000 EDT (0 UTC) with results available about midnight
- Significantly different forecast compared to NWS forecast (available about 8 hours before flash flood warning)
- Despite some error, significant "heads-up" for event

Deep Thunder Road Forecast (1 km Nest) Rainfall Totals

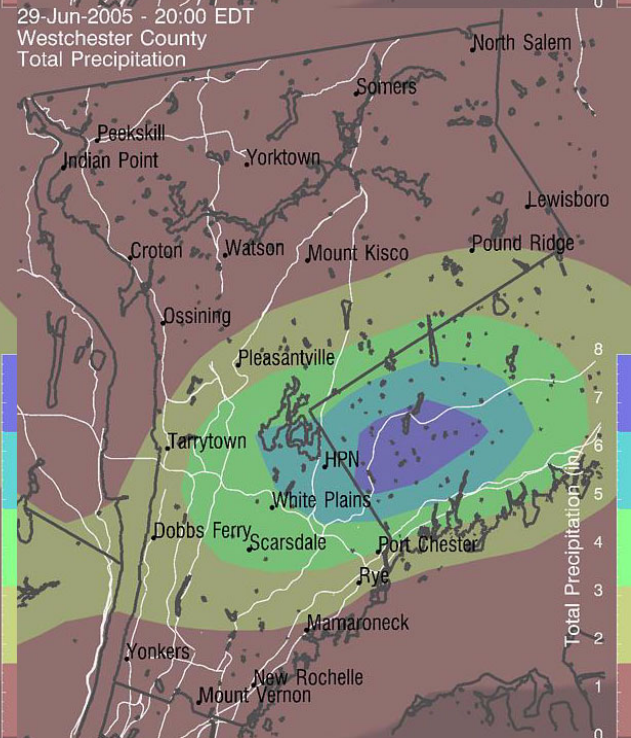
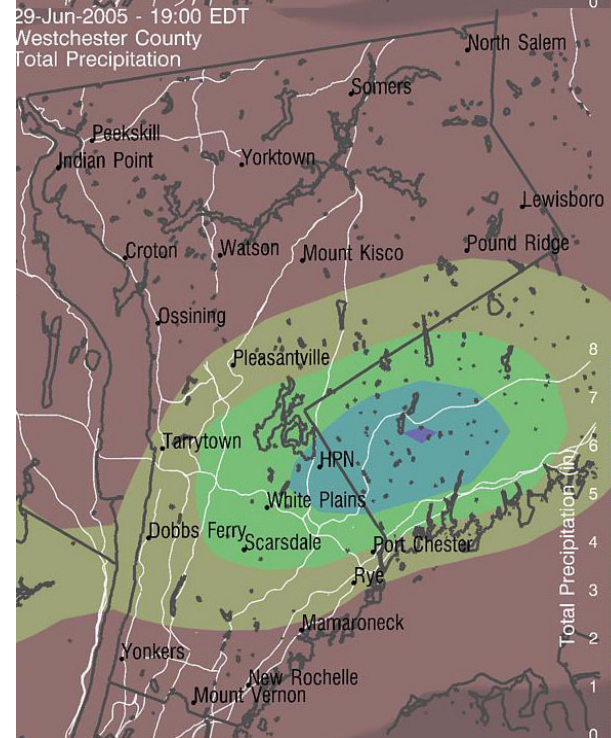
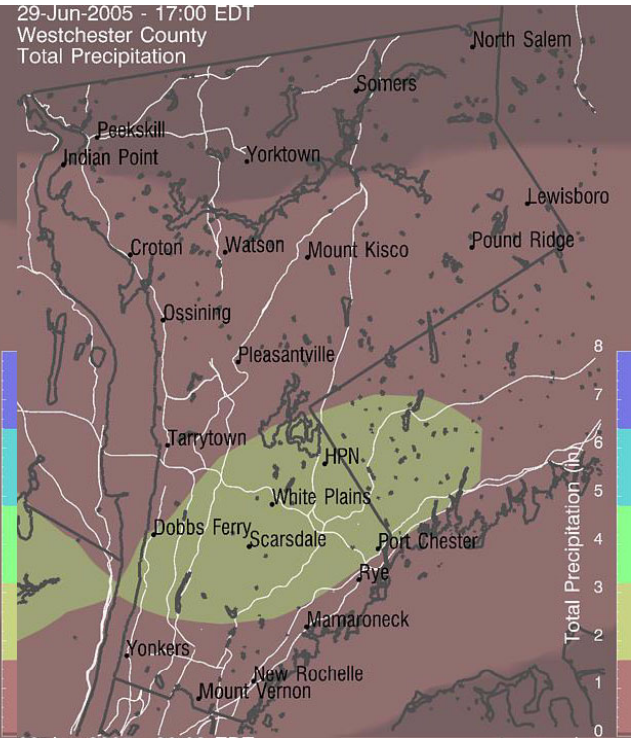
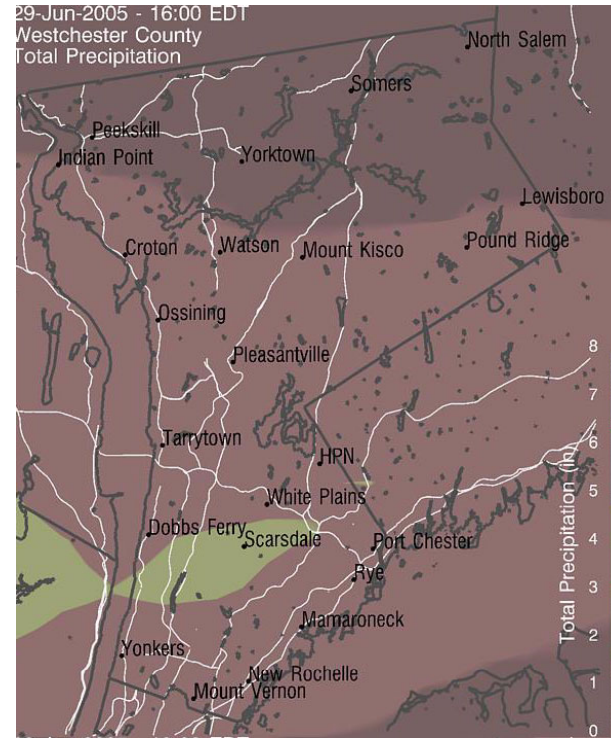
**Or Is This a
Better
Visualization
?**



Measured Rainfall (Inches)

JFK	2.76
Mamaroneck	3.73
LGA	3.83
Central Park	3.75
Norwalk	4.25
White Plains	5.85
Fair Lawn	1.50
Bethpage	5.20
Orange	2.30
EWR	2.07
Hoboken	3.87

Heavy Rainfall Event: Late Afternoon 29 June 2005

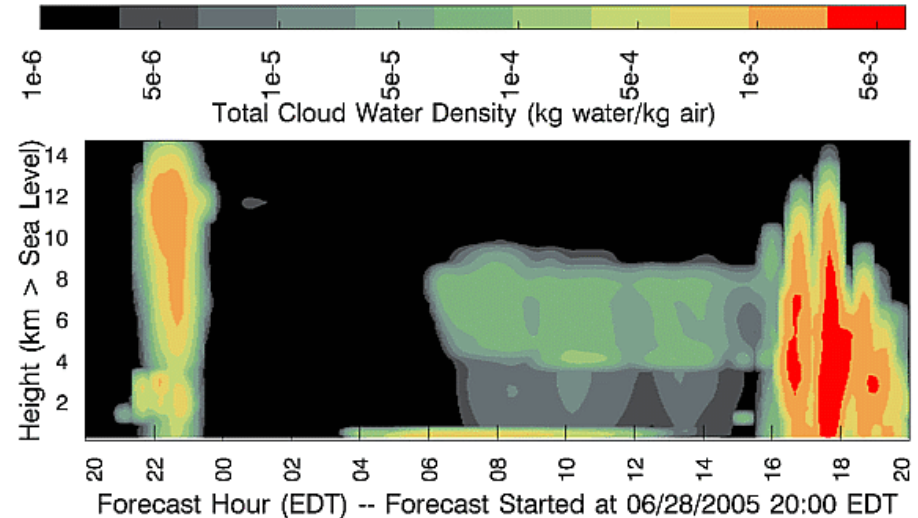
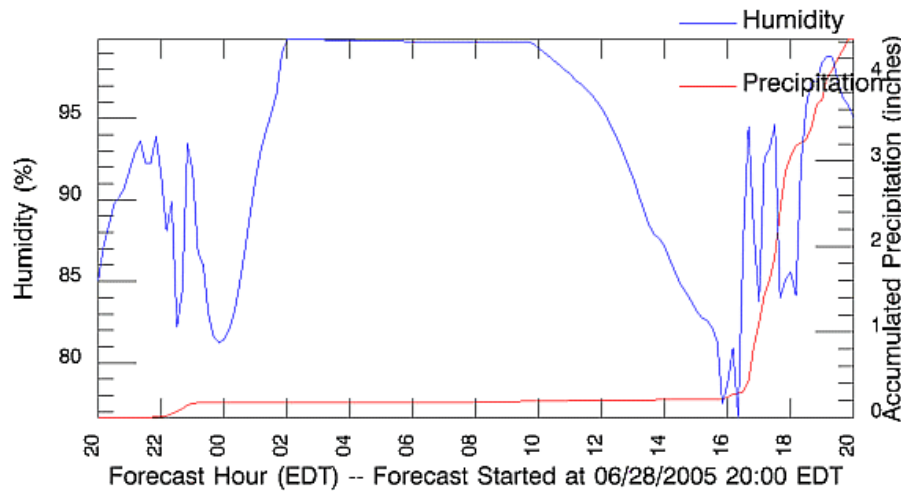
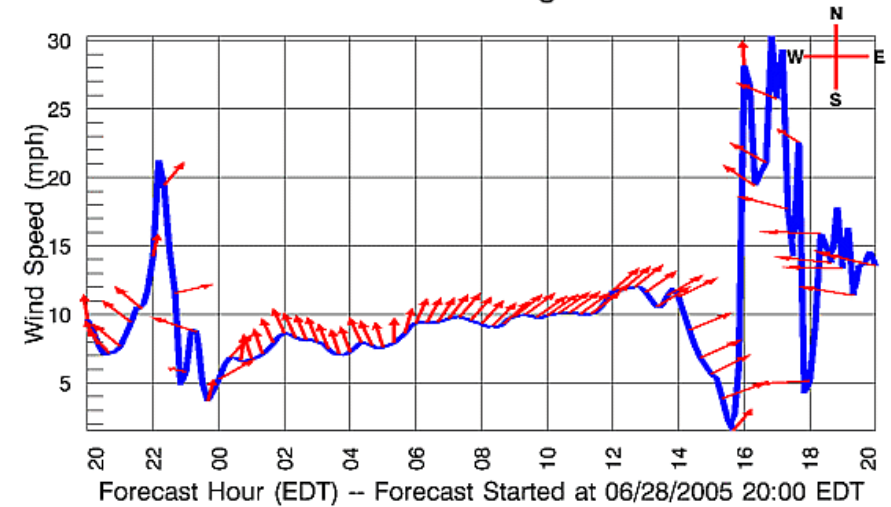
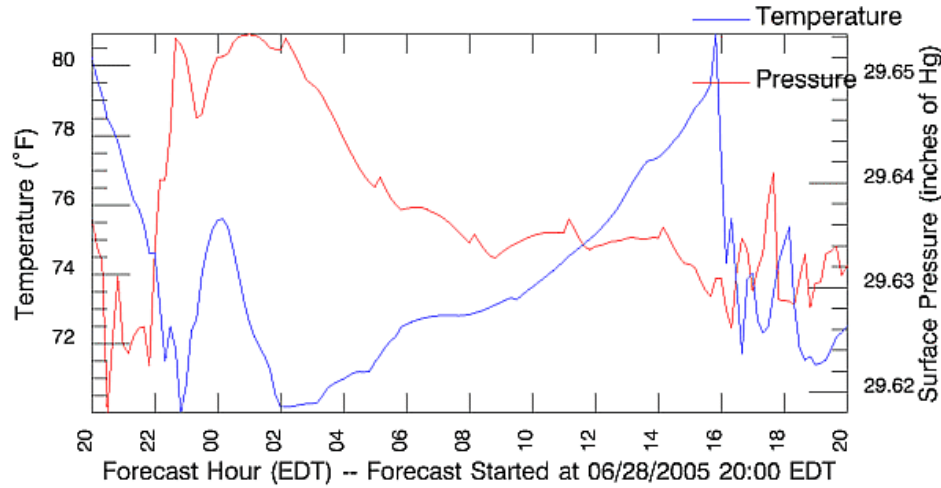


- Heavy rainfall predicted for the morning with similar distribution to reported rainfall, although some areas 2x too high
- Forecast initiated with data from 2000 EDT
- Results available about midnight -- about 15 hours before the event, which resulted in significant flooding in Westchester County
- Despite some error, significant "heads-up" for event

Heavy Rainfall Event: Late Afternoon 29 June 2005

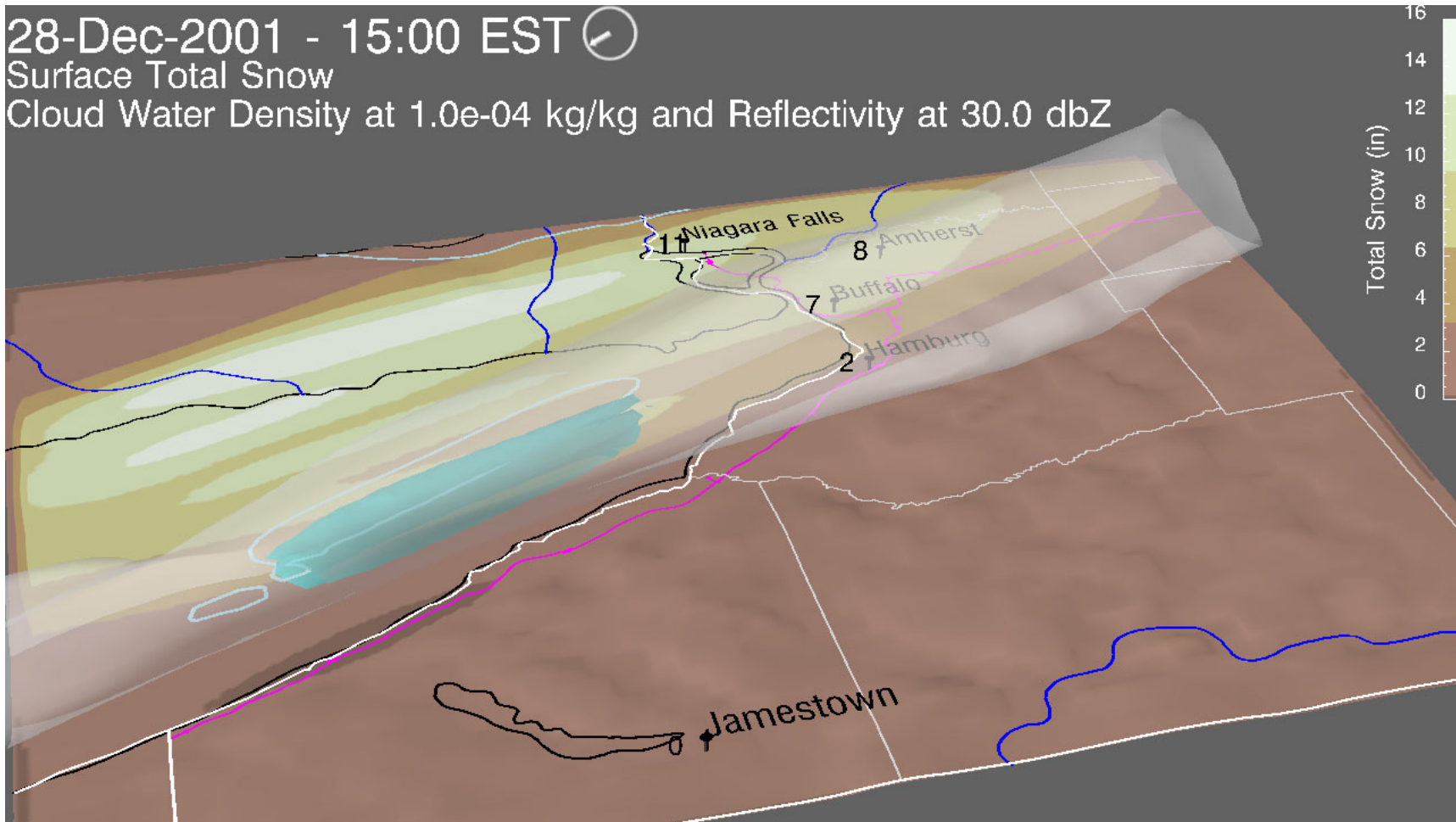
IBM Research, Hawthorne, NY [41.0807 N, -73.8182 W]

Valid for 06/28/2005 2000 EDT through 06/29/2005 2000 EDT



- **Significantly different forecast compared to NWS forecast, which called for about an order of magnitude less rainfall than occurred that would not have led to flooding**
- **Despite some error, significant "heads-up" for event**

December 27 - 28, 2001 Lake Effect Snow Hindcast

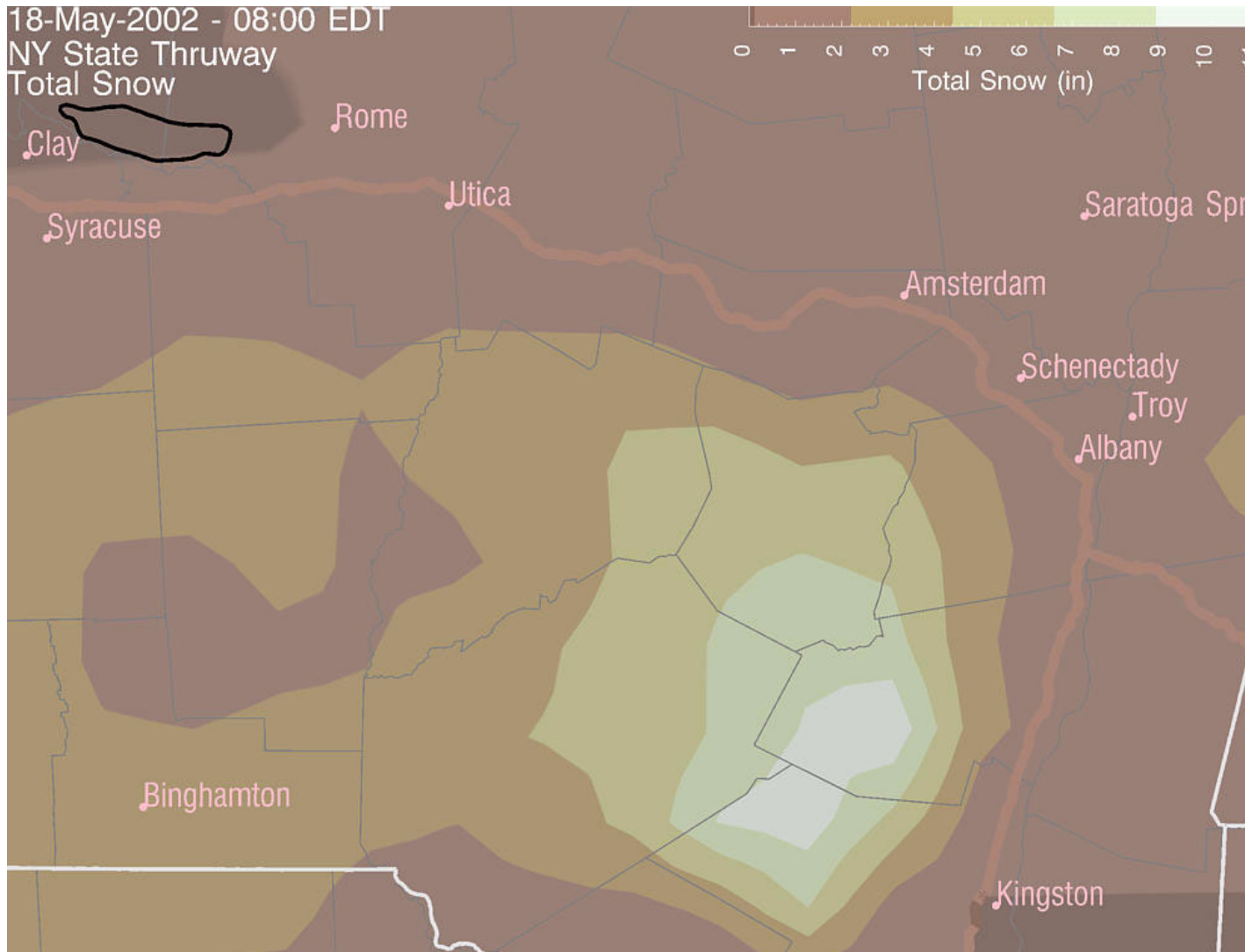


Appropriate Visualization of Snow Forecast ?

Late Spring Snowfall

18 May 2002 -- Early Morning

Better Visualization ?



- An area of low pressure developed over the middle Atlantic states, which tracked northeast, off into the Atlantic Ocean

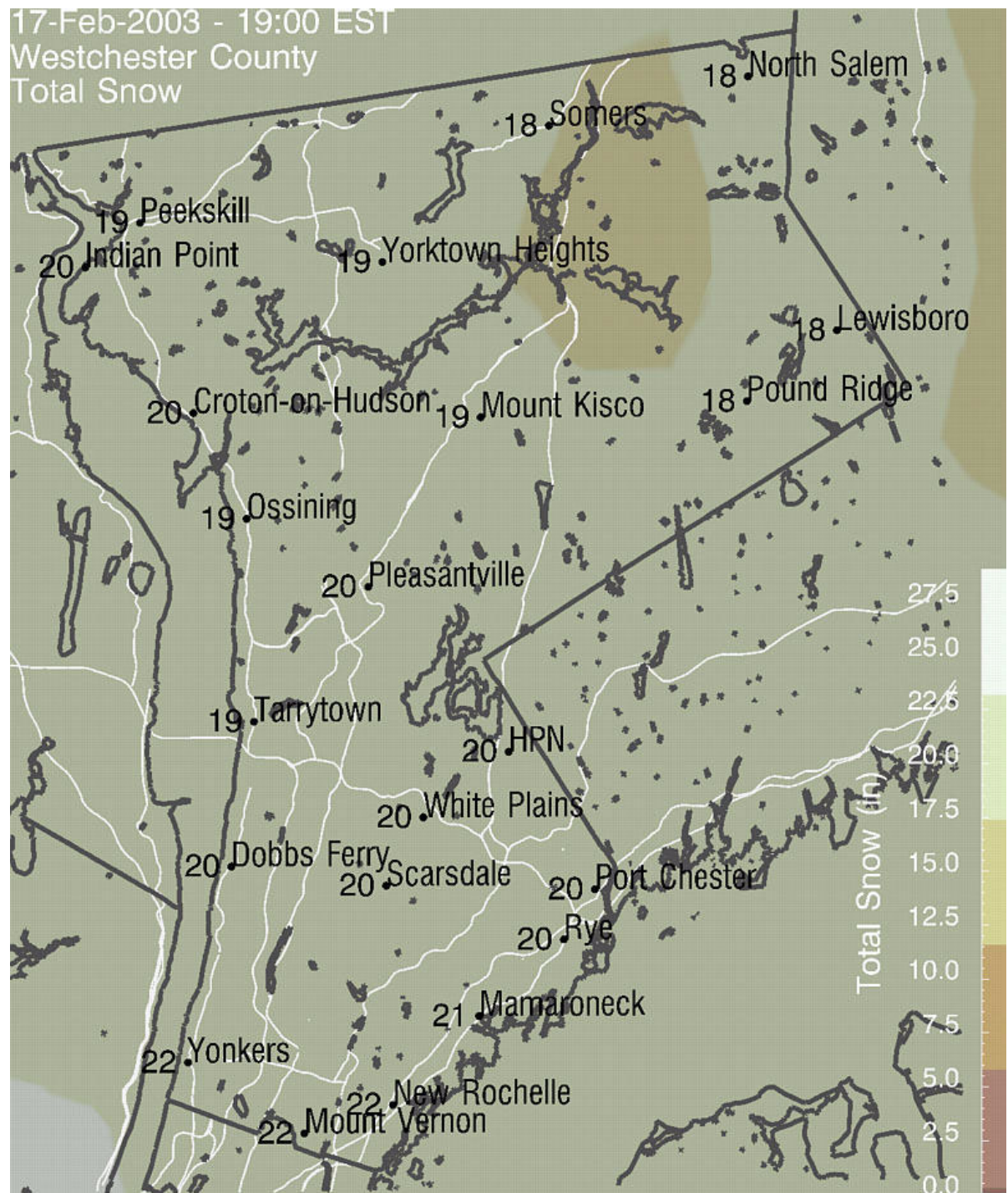
- The air north of the storm was marginally cold enough to turn rain into snow across eastern New York State
- Latest measurable snow in Albany (2") with reports up to 8"
- Forecast initiated with data from 0800 EDT, available about 1200 EDT, > 15 hour lead time
- Snow amounts may have positive bias
- Only *Deep Thunder* forecasted this event

Presidents' Day 2003 Blizzard (2/17/2003)*

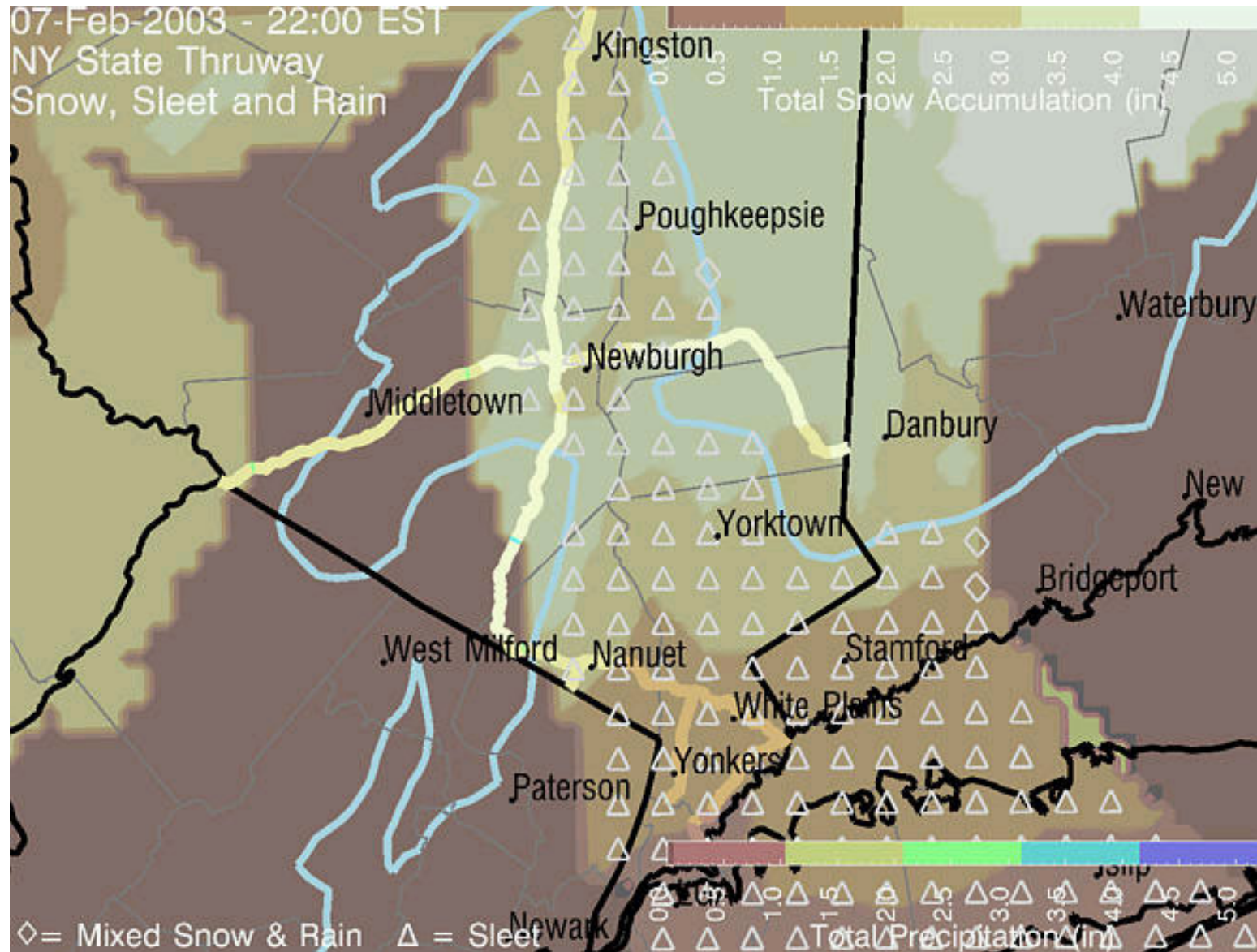
Measured Snowfall (Inches)

Thornwood	26.0
Mamaroneck	18.0
Croton	14.5
White Plains	17.0
Yorktown	21.0
Yonkers	19.0

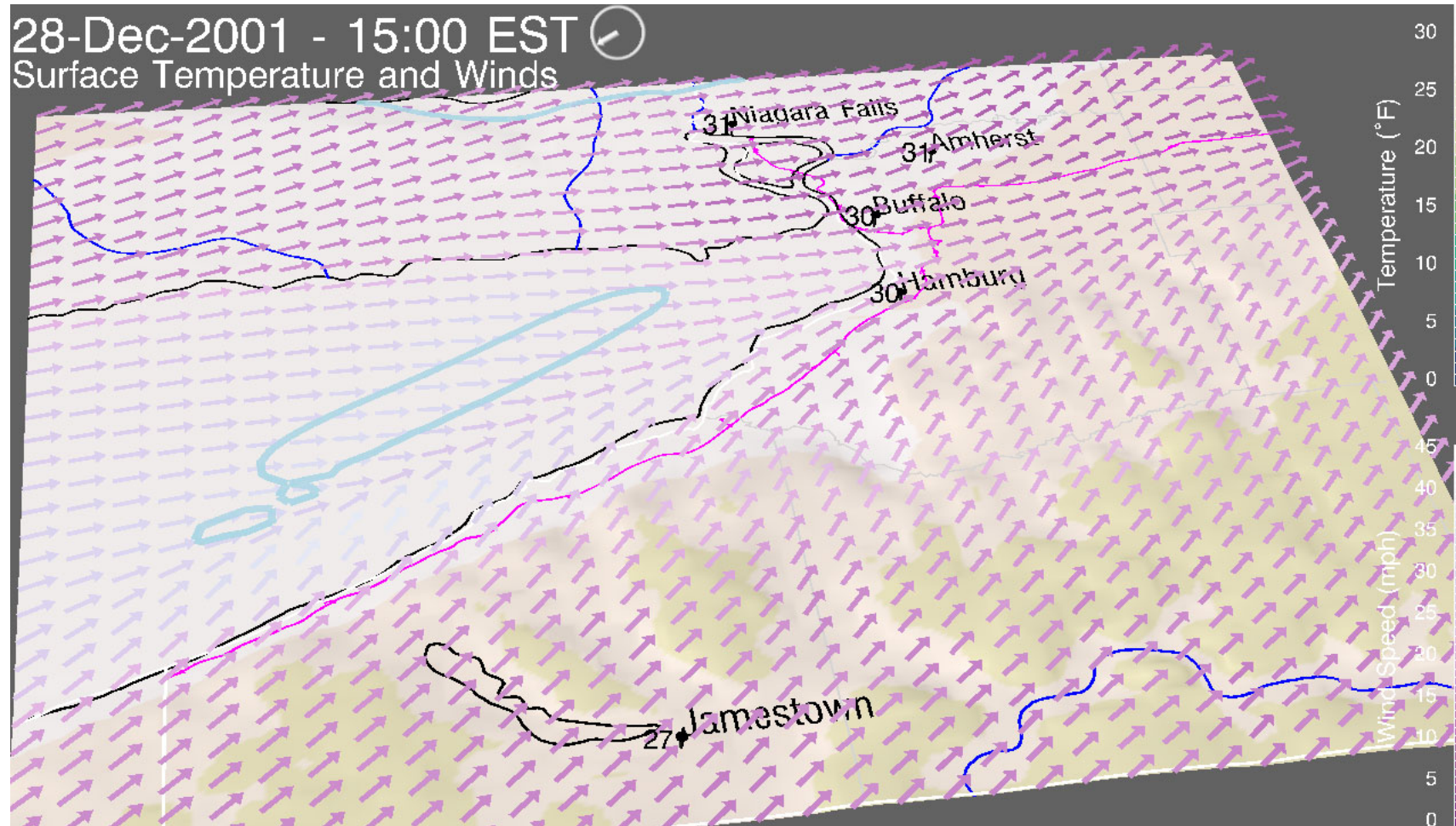
*Forecast initiated with data from 1900 EST on 2/16 with results available at about midnight on 2/17.



Example Precipitation Type and Total Accumulation Maps



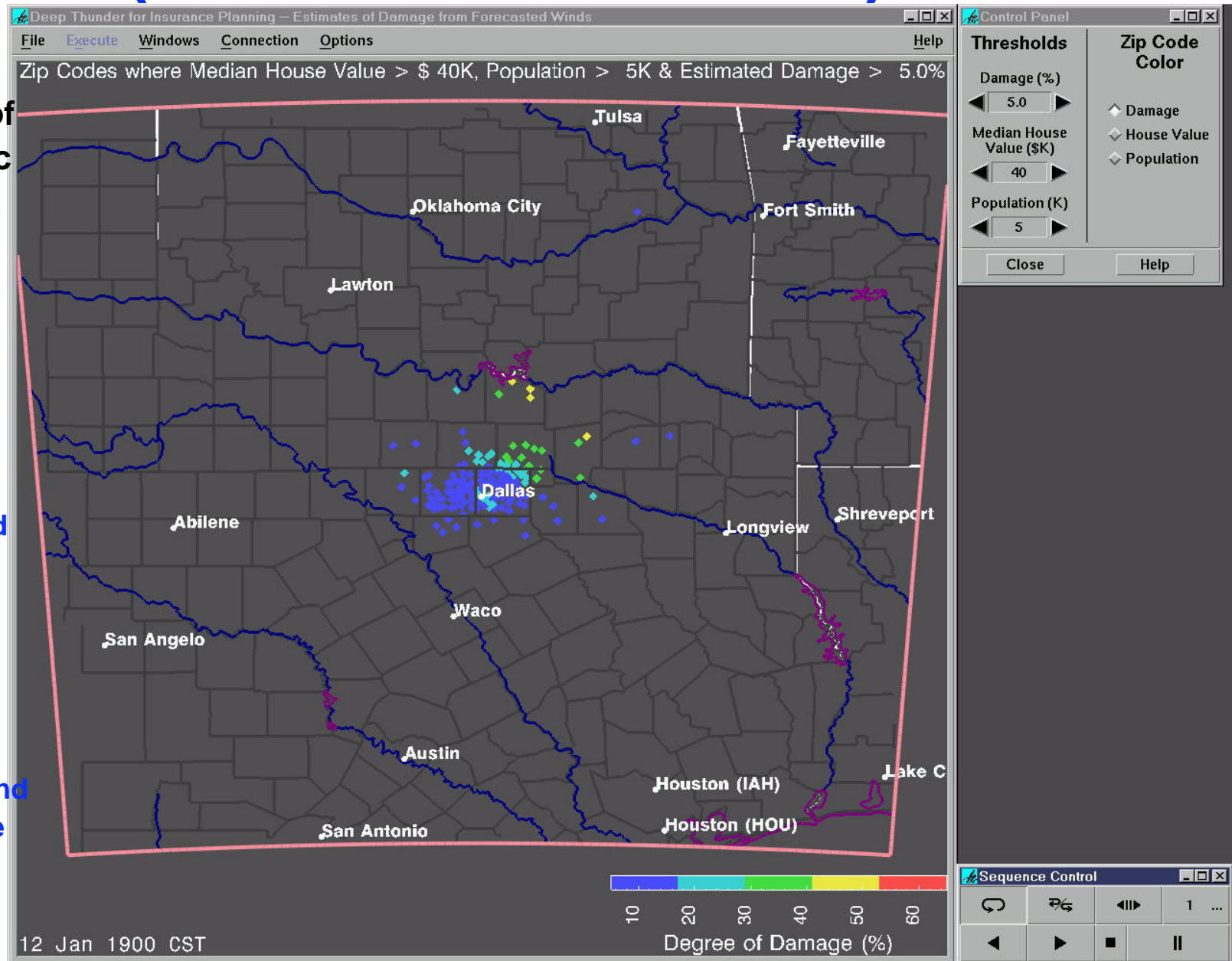
December 27 - 28, 2001 Lake Effect Snow Hindcast



Appropriate Visualization of Wind (and Temperature) Forecast ?

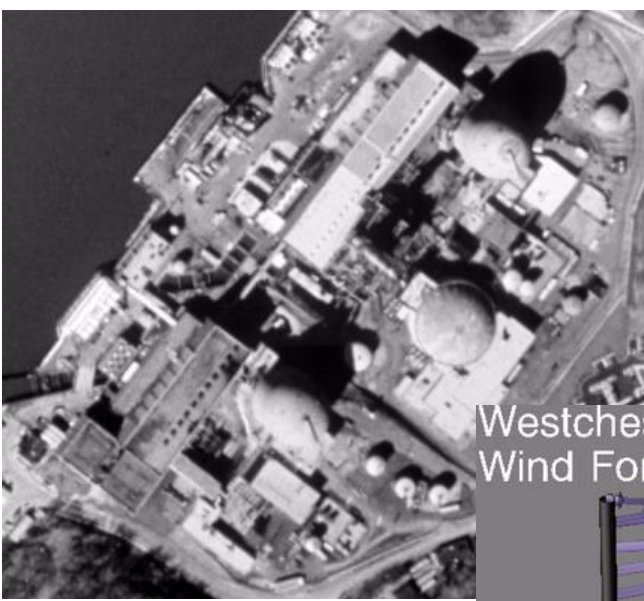
Emergency Planning for Severe Winds (Focused Visualization)

- **Geographic correlation of demographic and forecast data**
- **Map shows**
 - Zip code locations colored by wind-induced residential building damage
 - Constrained by value, population and wind damage above thresholds



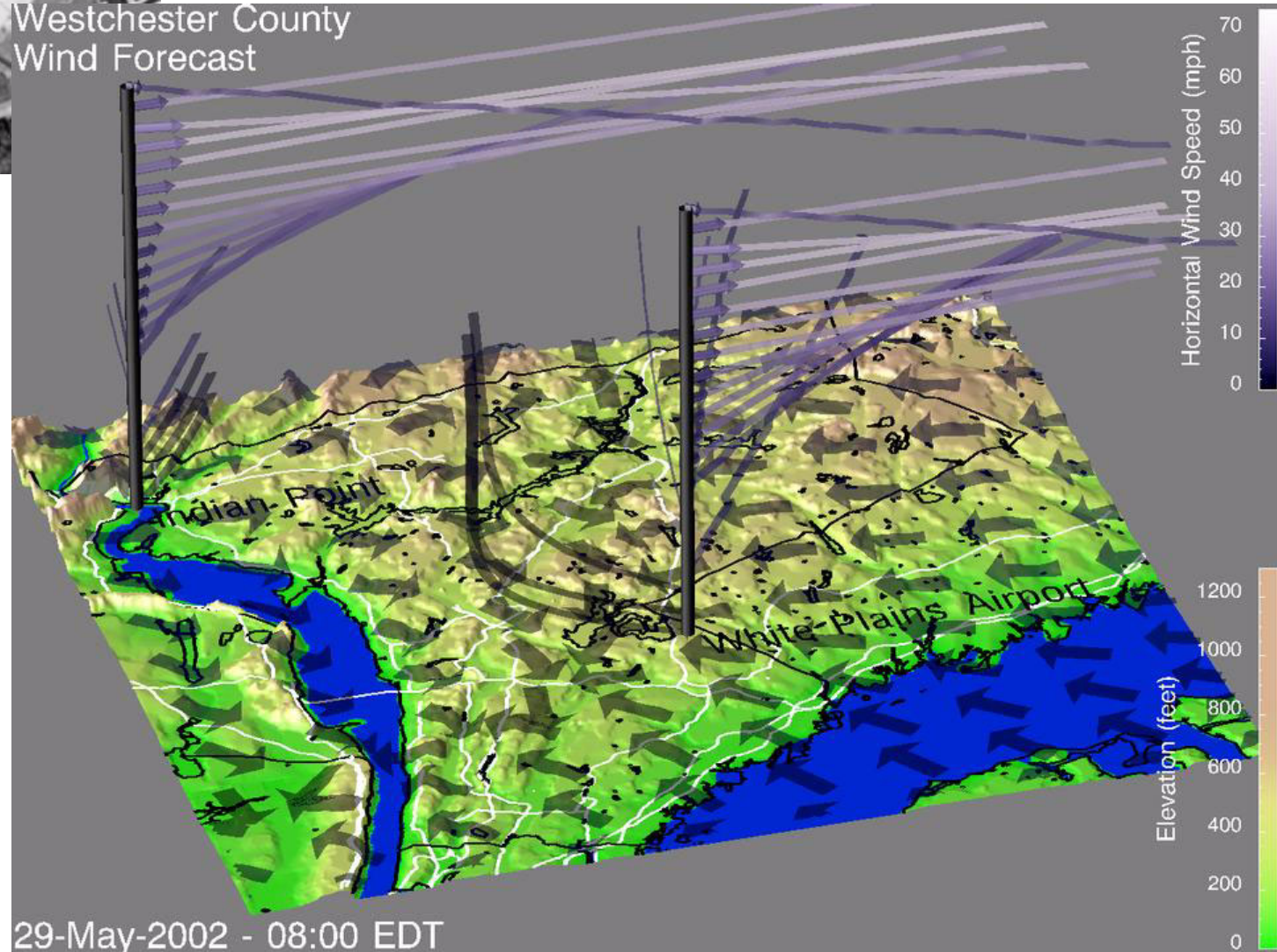
Example Wind Forecast

Indian Point, Westchester County, NY



Westchester County
Wind Forecast

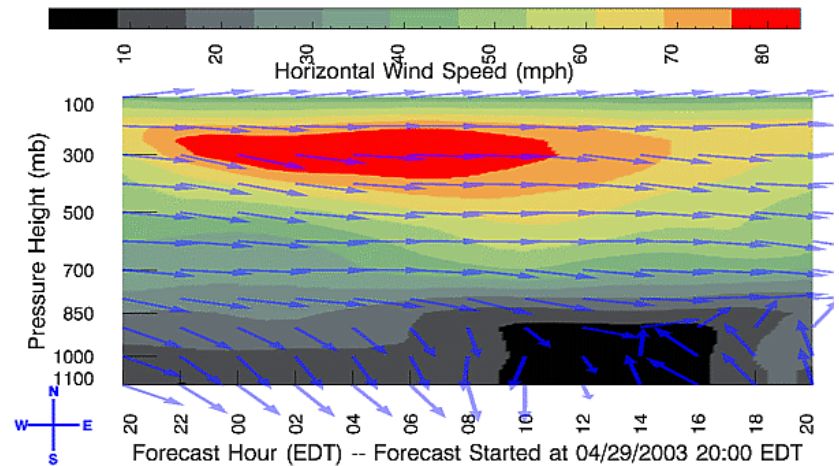
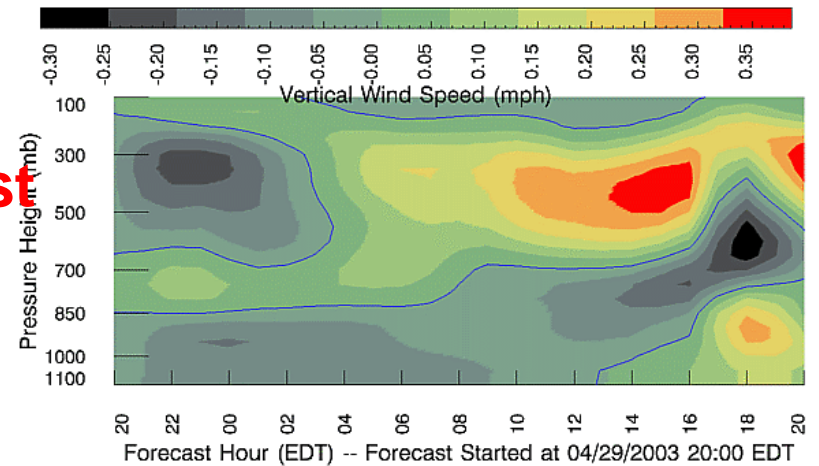
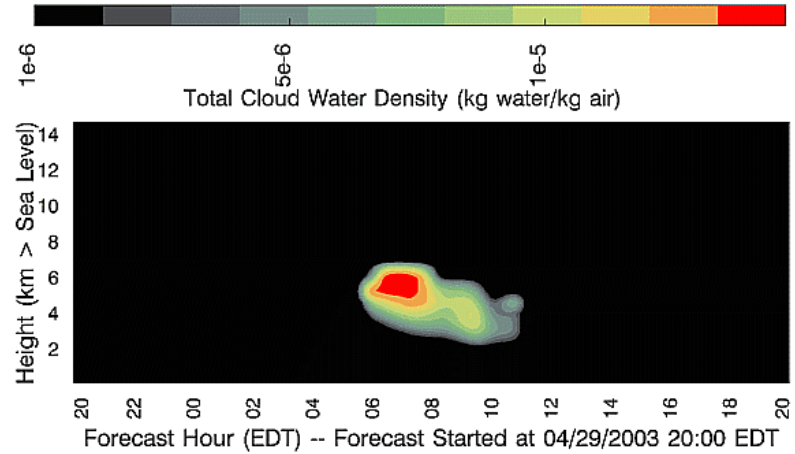
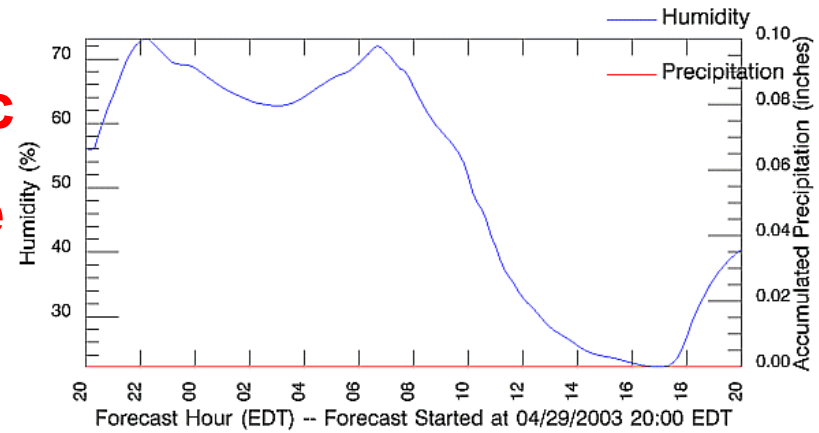
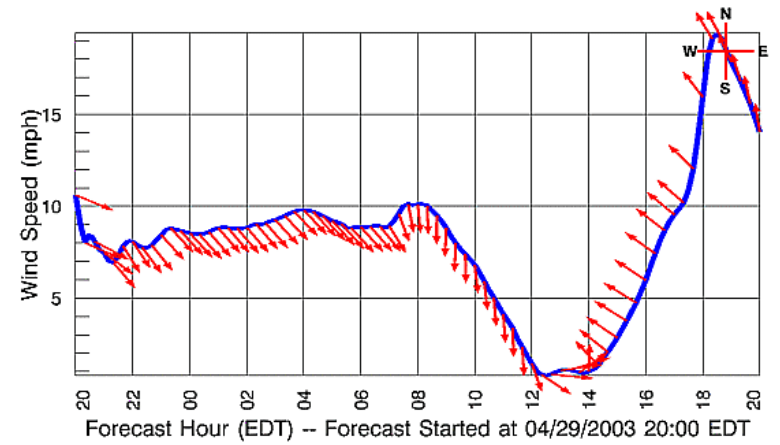
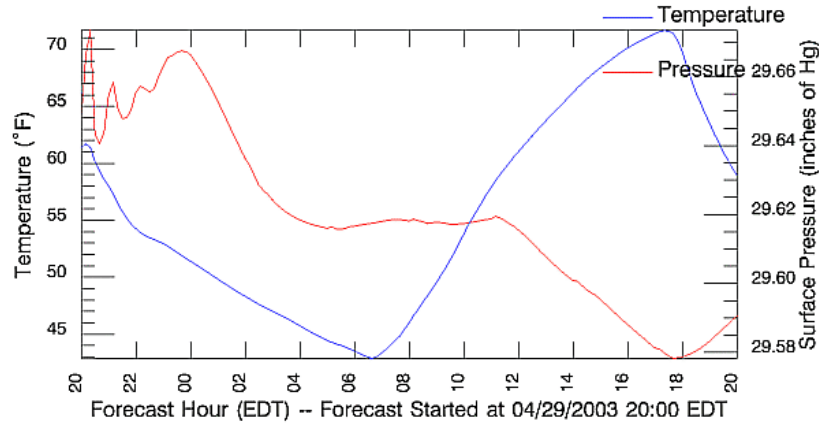
- Interest in surface and upper air winds dictates entirely different presentation
- “Virtual wind profilers” at two locations within 4 km nest enhanced with trajectories to show forecasted propagation



Indian Point Site-Specific Surface and Upper Air Forecast

Indian Point, Buchanan, NY [41.2714 N, -73.9525 W]

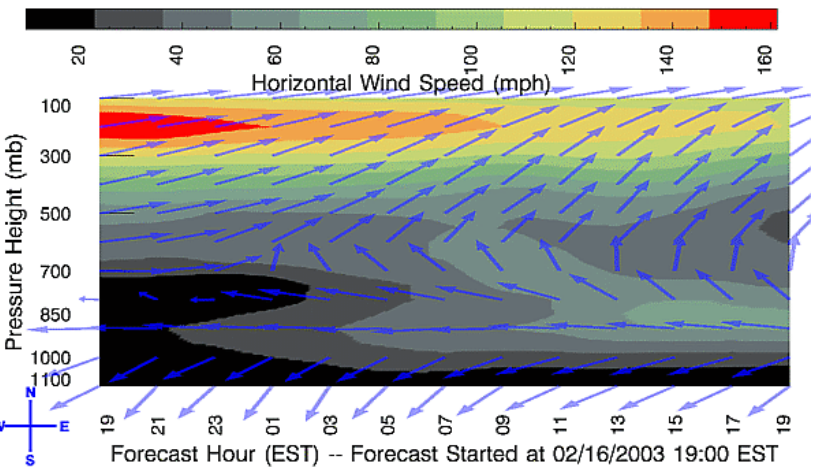
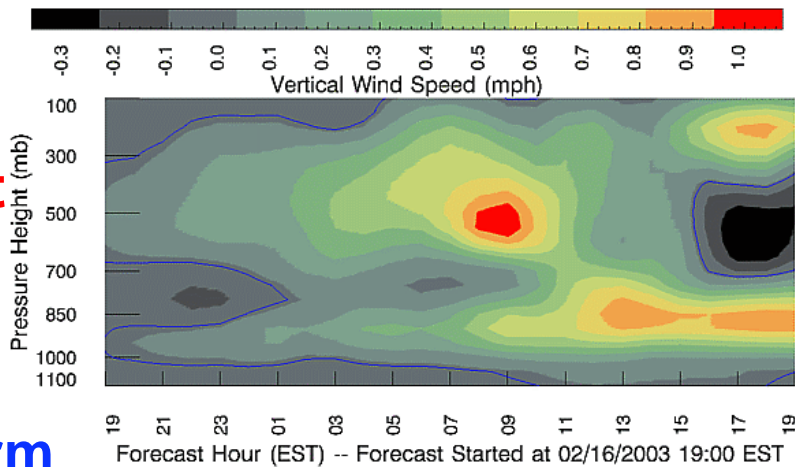
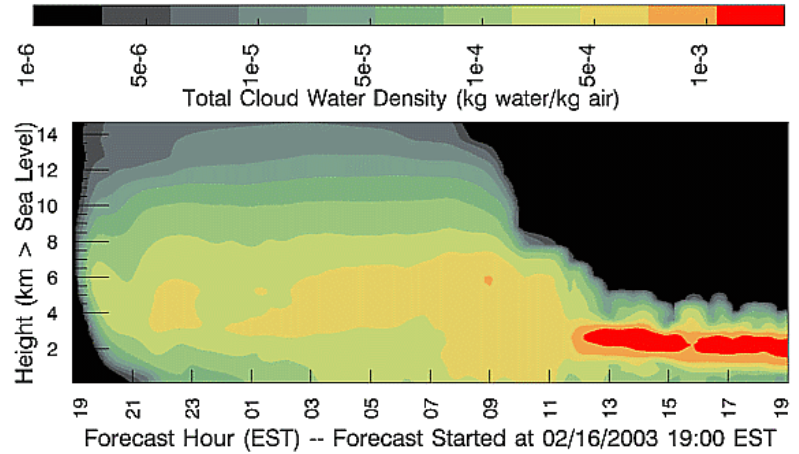
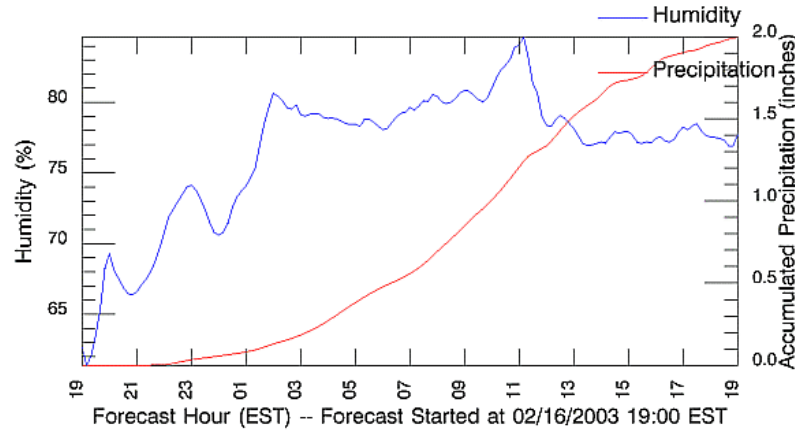
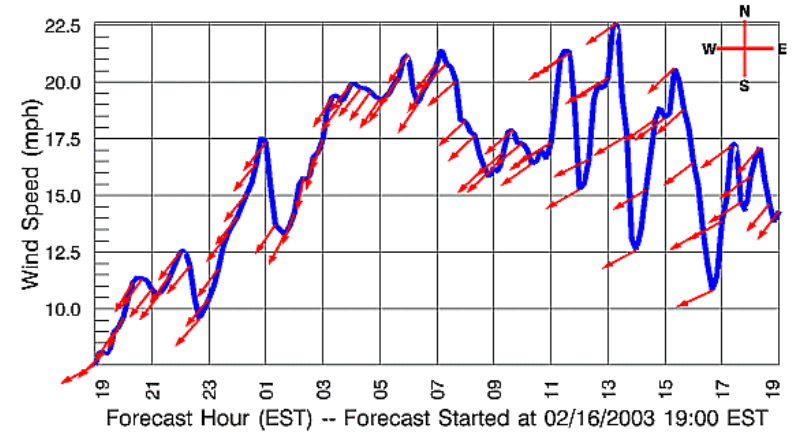
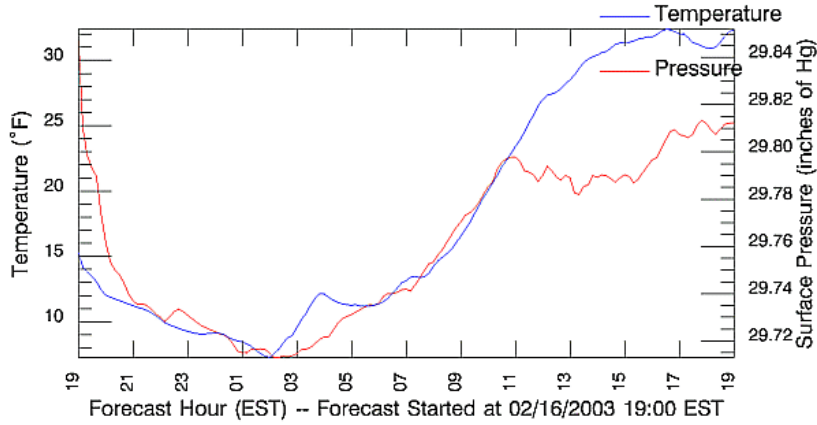
Valid for 04/29/2003 2000 EDT through 04/30/2003 2000 EDT



Indian Point Site-Specific Surface and Upper Air Forecast Snowstorm

Indian Point, Buchanan, NY [41.2714 N, -73.9525 W]

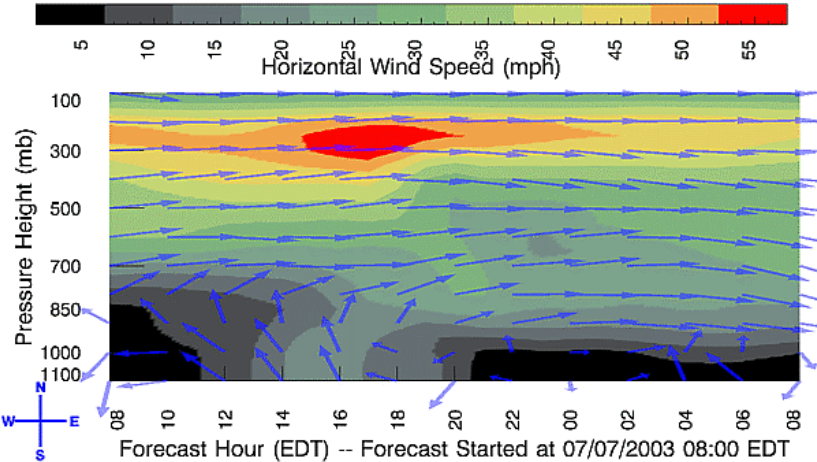
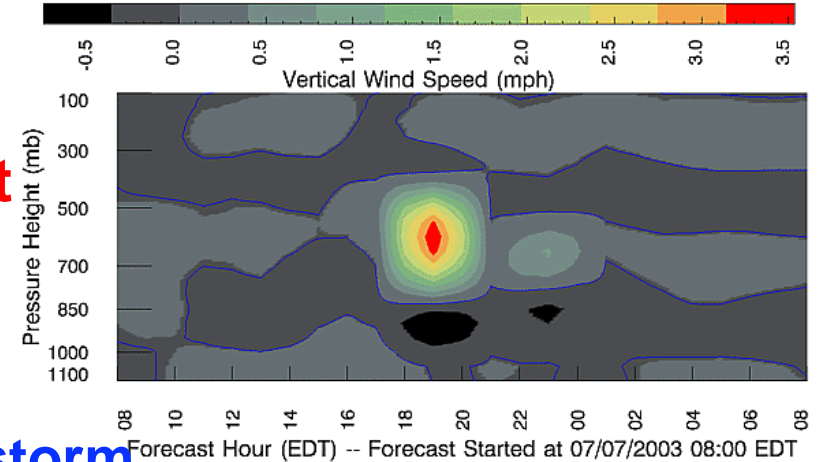
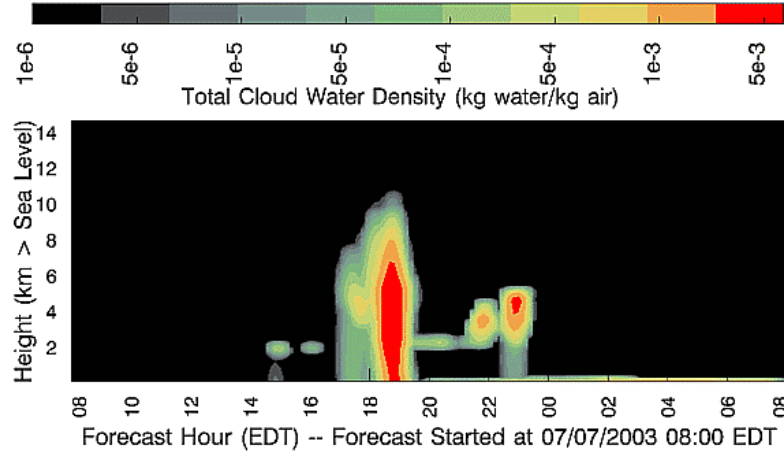
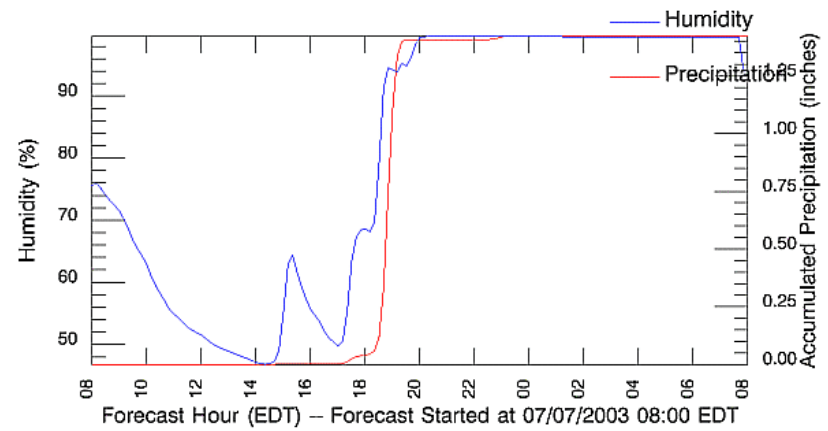
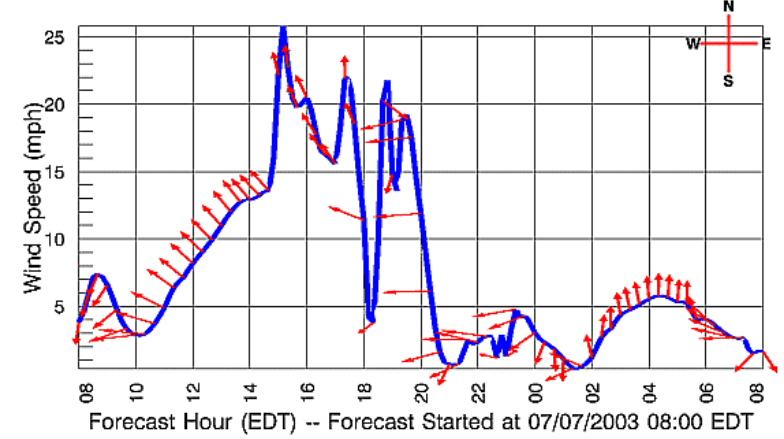
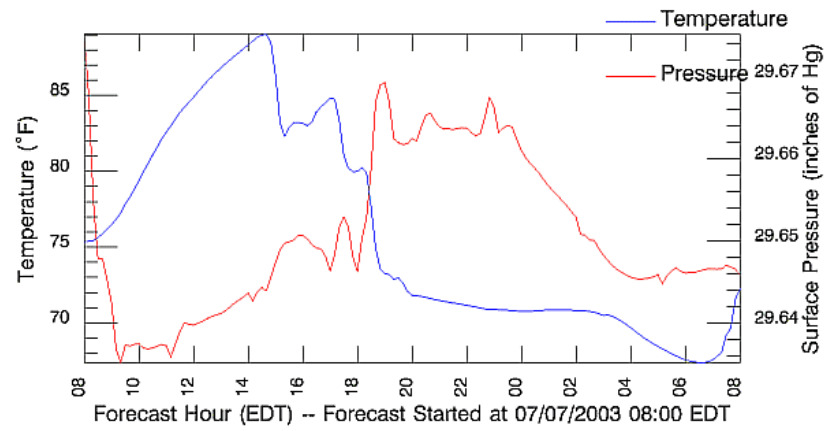
Valid for 02/16/2003 1900 EST through 02/17/2003 1900 EST



Indian Point, Buchanan, NY [41.2714 N, -73.9525 W]

Valid for 07/07/2003 0800 EDT through 07/08/2003 0800 EDT

Indian Point Site-Specific Surface and Upper Air Forecast Thunderstorm



Conclusions and Future Work

- **Encouraging results: positive feedback from users, but still much work to be done**
- **Fairly simple methods used to date, but will more comprehensive methods**
 - **Increase complexity for training**
 - **Require more design iterations (user interviews)**
- **Extend work to other applications and events (not just weather)**
- **Apply the same principles to determine dissemination**
 - **(workstation) interaction, web, e-mail, ...**
- **Represent user view of uncertainty in current deterministic forecasts**

Backup

Slides

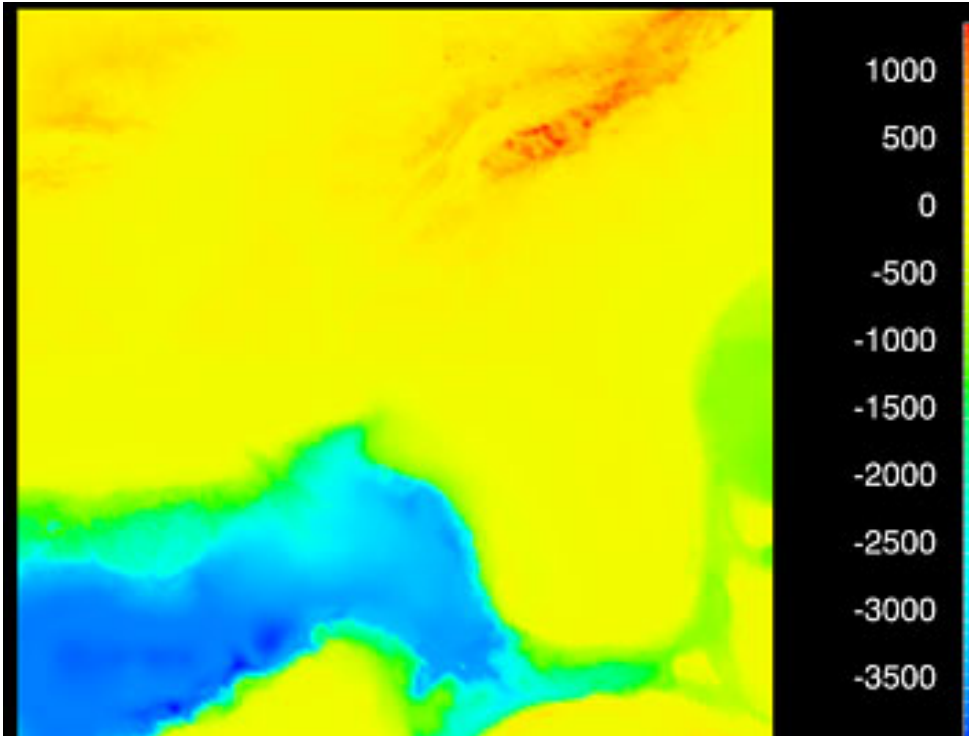
Composition Design Approach

- **Identification of distinct user goals and visualization tasks coupled with knowledge of human visual perception**
- **Each data set processed independently to maintain fidelity and consistency with data source**
- **Visualization and interaction in common, cartographic coordinates**
- **Physical and conceptual realization**
- **Simplified user interface, although multiple linked displays may be used**

Compositional Guidelines

(Task and User Metadata)

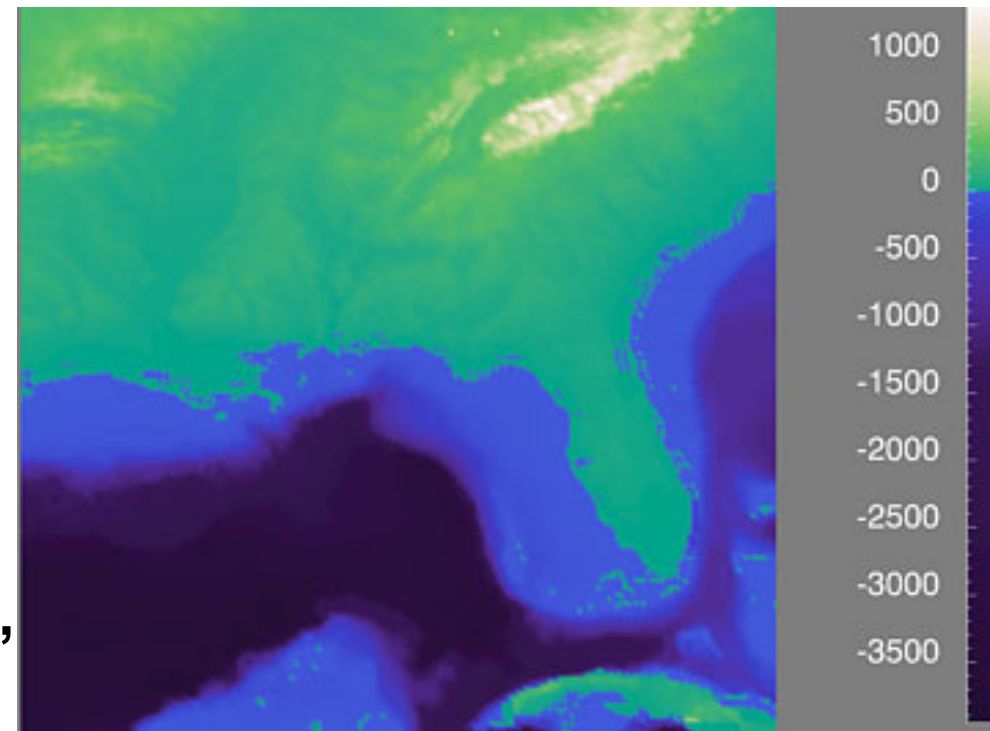
- **Coordinate system for display and interaction**
 - Cartographic projection (horizontal coordinates) dictated by task and/or data
 - Vertical coordinates (terrain-following vs. isobaric) dictated by task (assessment vs. analysis)
- **Color**
 - Colormaps dictated by task (isomorphic vs. segmented) and data (low vs. high spatial frequency, moisture vs. generic)
 - Perceptual rules used for design/selection
 - Individual color(map)s selected to minimize color mixing artifacts
 - Luminance and opacity used for direct volume rendering
 - Opacity mapping with constant color used for surface extraction



An Example of the Colormap Problem:

Which Picture is Better?

- Visualizations can be easily created today, but process is largely ad hoc
- How data are represented clearly affects interpretation
- Choosing effective strategies implies navigation through a complex design space
- Perceptual rules enable better, faster representations



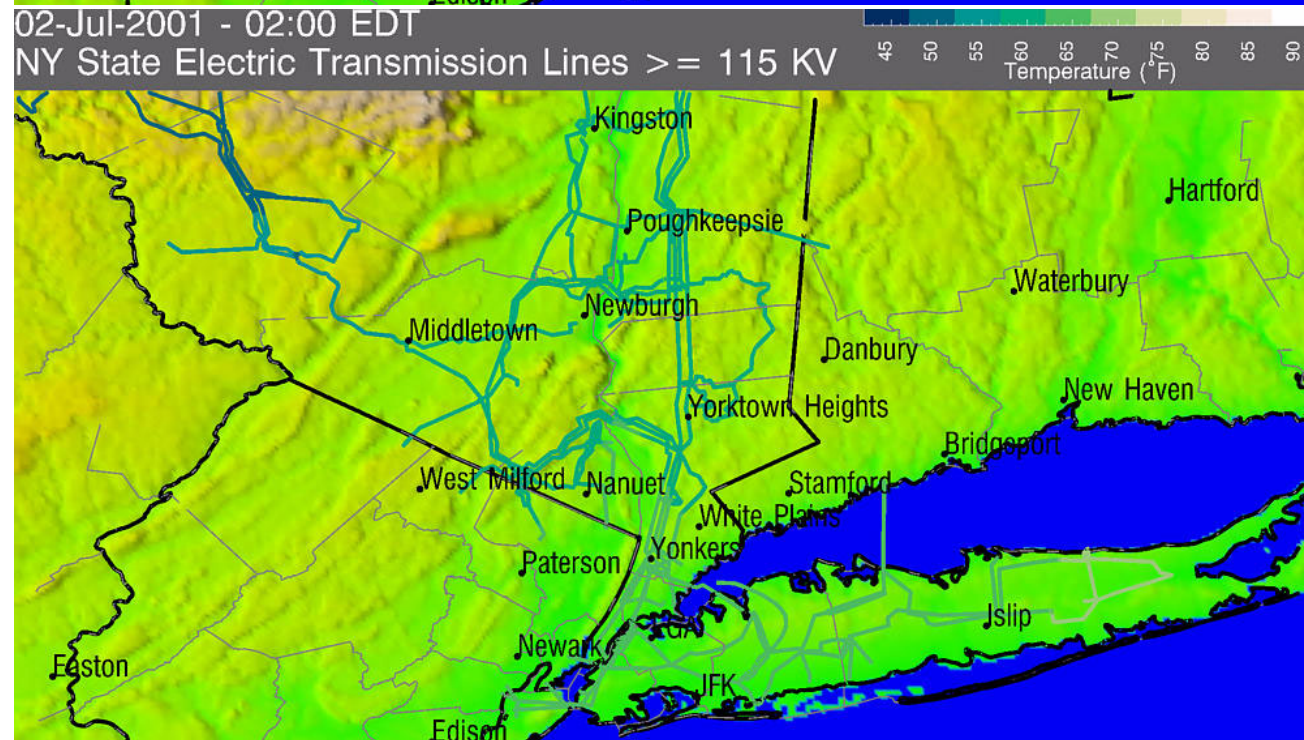
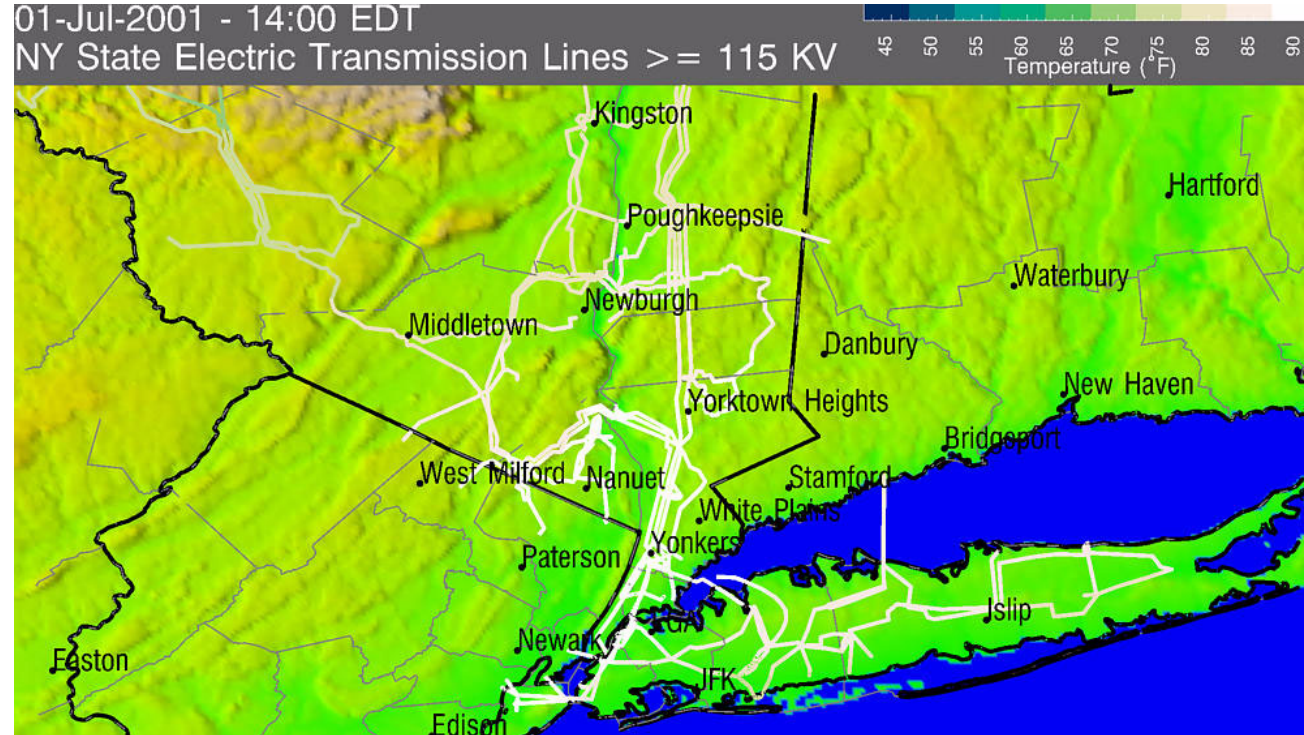
Compositional Guidelines (*continued*)

● Realization

- Surface data warped on terrain in 3d scene
- Overlay of vector maps and markers for annotation
- Color-filled contour banding used with segmented colormap
- Surface wind dictated by task
 - Fixed glyphs (2d arrows, 3d flags) as animated texture for global features
 - Streamlines with directional arrows for boundary (e.g., fronts, convergence zone) evolution
- *Virtual met station* for 3d analysis/interrogation tasks
- Multiple encodings for analysis/comparison tasks

● User tasks

- Assessment: surface conditions and cloud properties
- Analysis: variable selection and technique selection
- Decision support: impact of weather



Electricity Transmission

- **New York State Transmission System**
 - Color-contoured to show forecasted temperature
 - Available in 10 minute intervals from each 24-hour *Deep Thunder* forecast at 4 and 1 km resolution
 - Can be used to estimate transmission efficiency
 - 115 kV and above
- **Map also shows**
 - State and county boundaries
 - Major cities

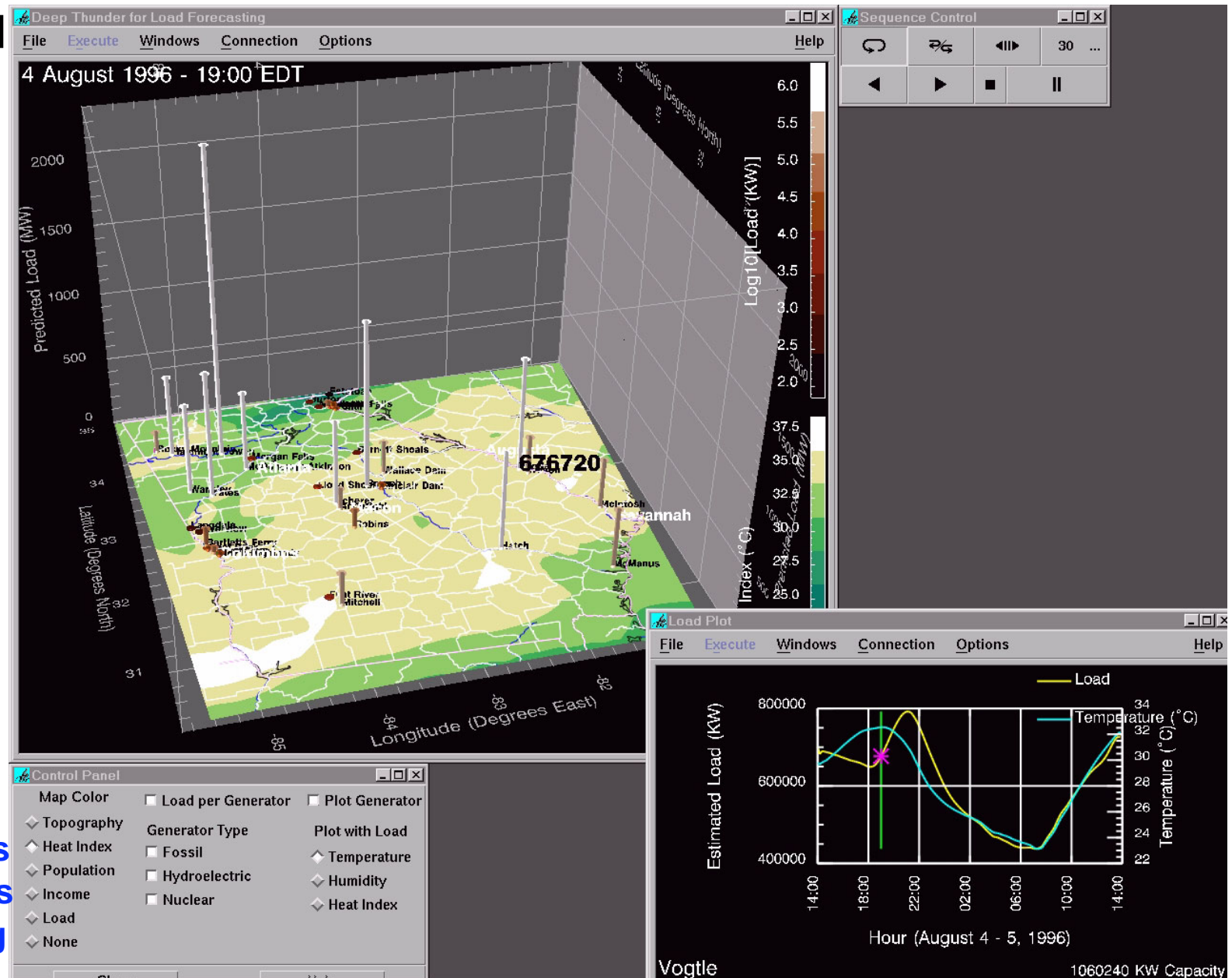
Example -- Electricity Demand Forecasting

- Simple estimated load

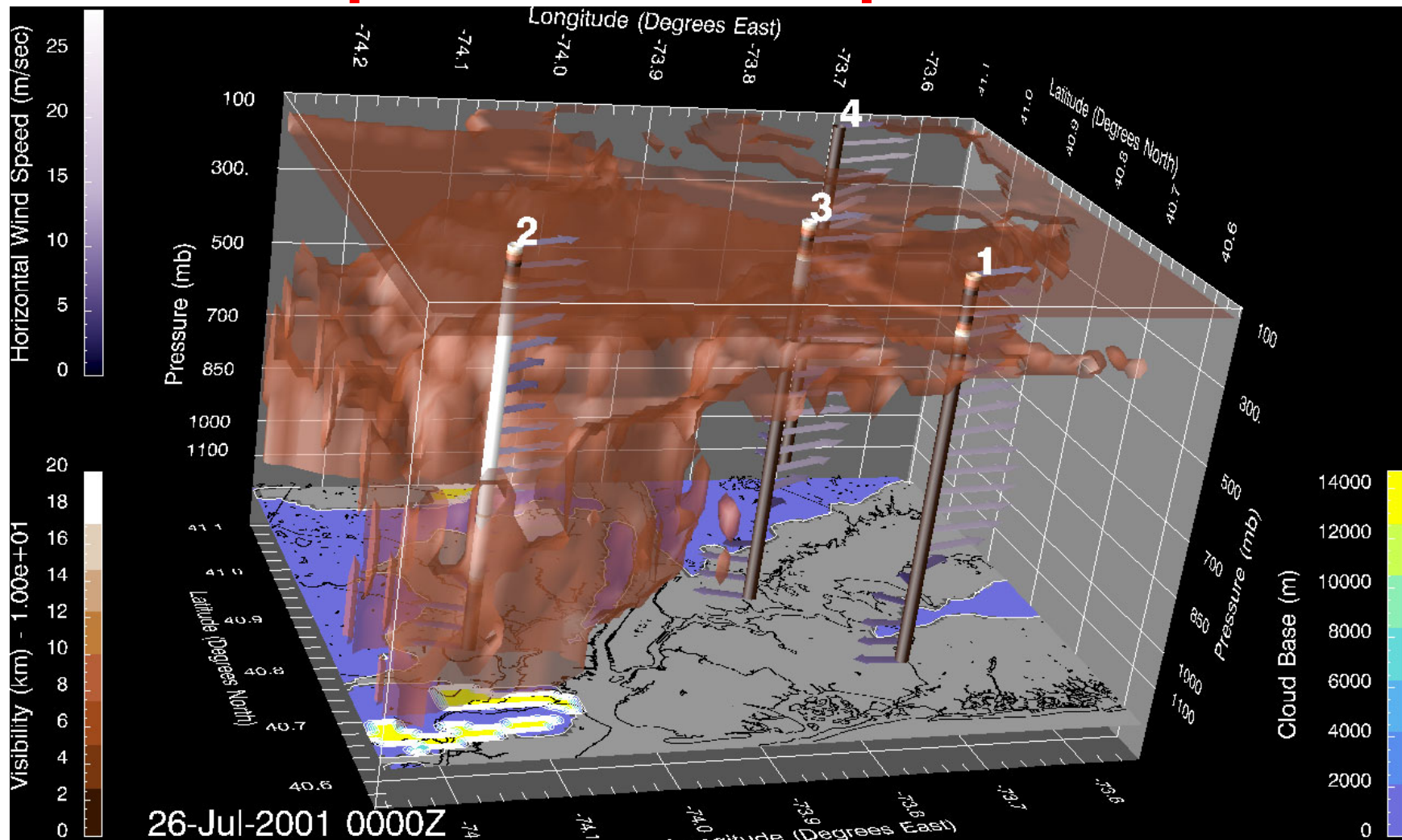
- $f(t, T, H)$ -- color and height
- Scaled by capacity
- Generator data from Georgia Power
- Deep Thunder forecast

- Map shows

- Heat index
- State & county boundaries
- Major cities
- Generating plants



Airport Terminal Operations

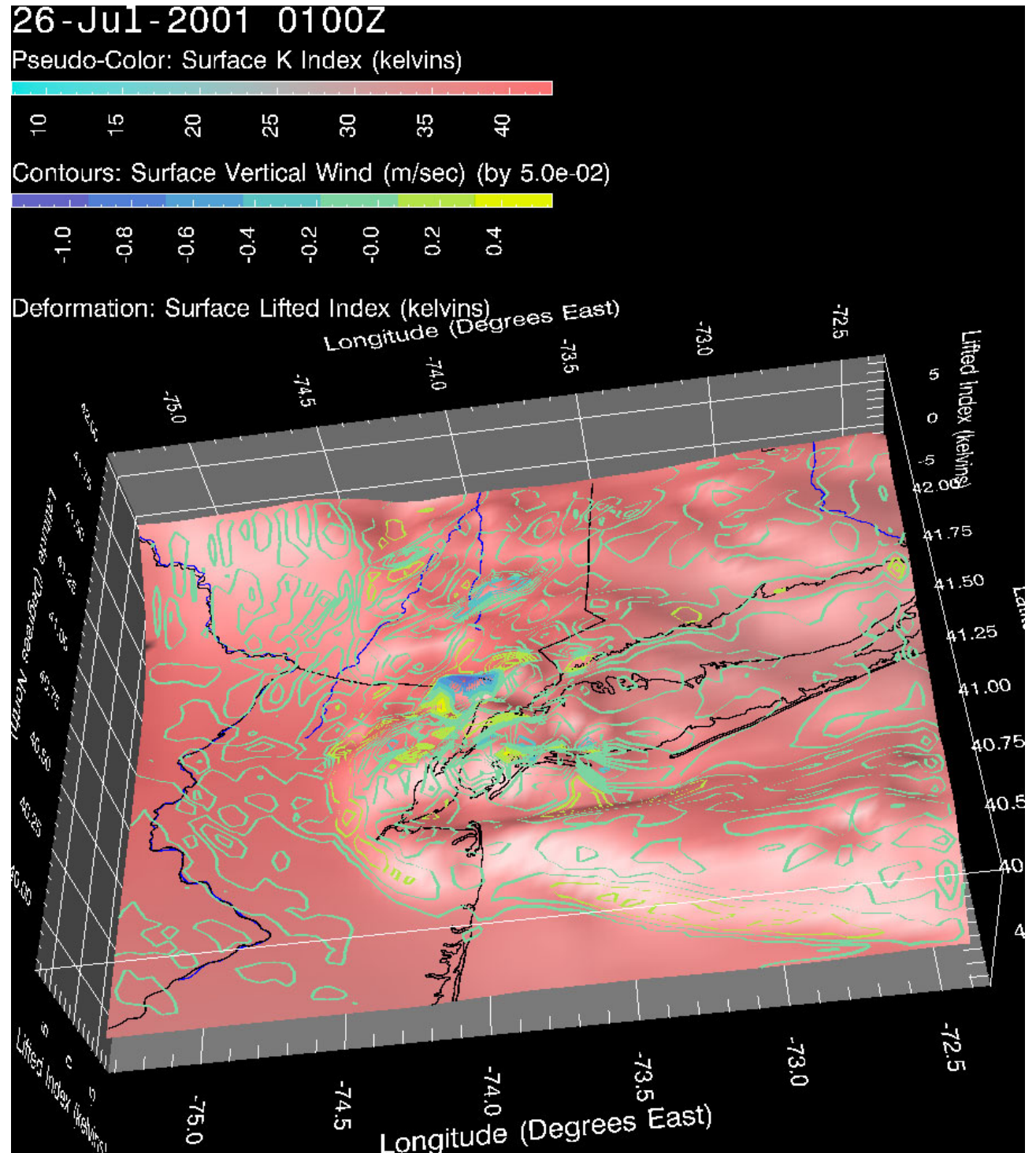


- **Visibility, clouds and winds**

- **Derived visibility: isosurface at 10km & profiles at airport locations**
- **Contours (2km) of height of cloud base**
- **Virtual wind profilers (speed and direction) at airport locations**

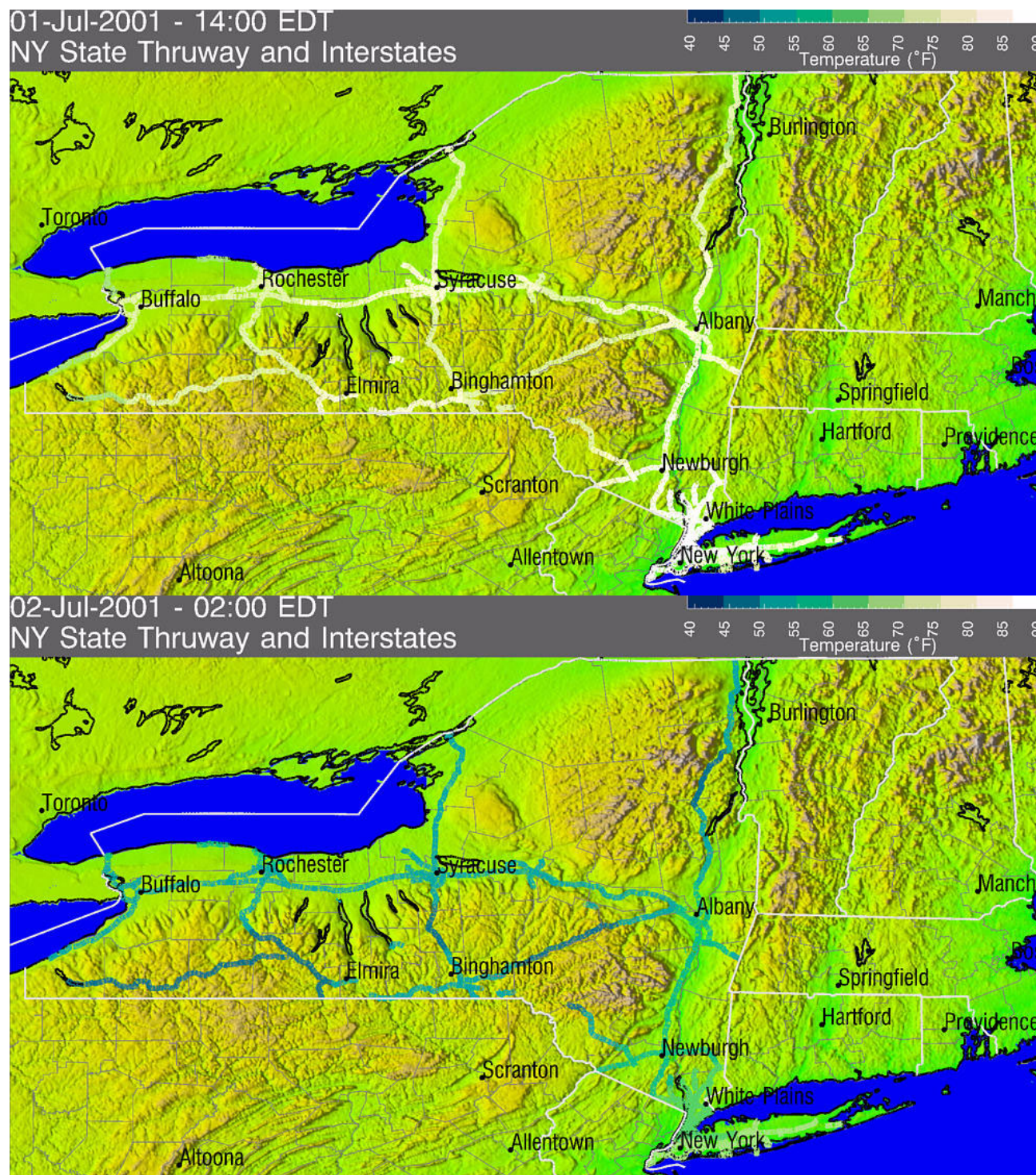
Atmospheric Stability

- Identify areas for potential of severe weather
 - Color = K Index, convective potential based on vertical lapse rate along with amount and vertical extent of low-level moisture
 - Height = Lifted Index, potential instability from the surface to 500 mb
 - Contours = vertical wind speed
 - Green to yellow contours in blue "valleys" would imply regions of significant potential for severe convective activity.
 - Available in 1 hour intervals

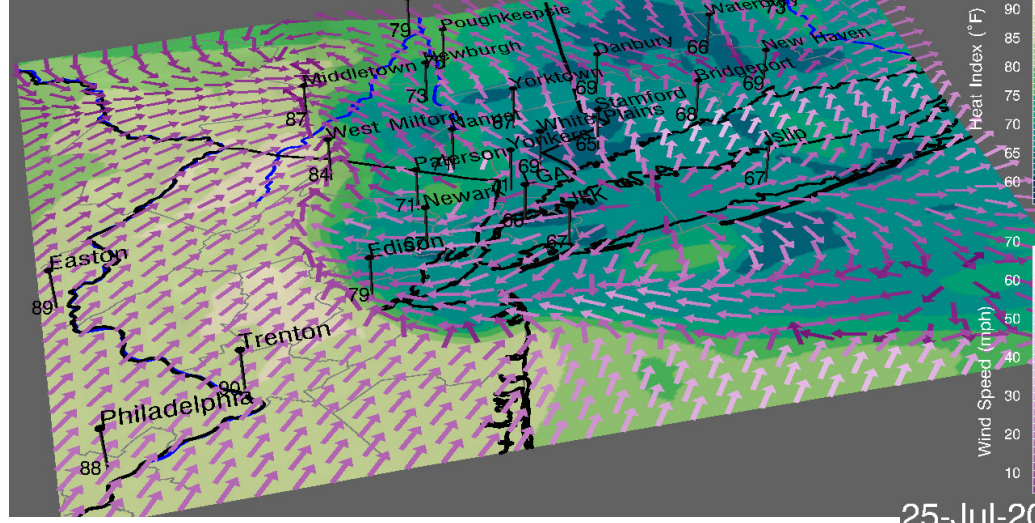


Road Conditions

- **New York State Thruway System and other interstate highways**
 - Color-contoured to show forecasted temperature
 - Available in 10 minute intervals from each 24-hour *Deep Thunder* forecast at 16, 4 and 1 km resolution
 - Can be used to plan road maintenance
 - Can be augmented with winds, precipitation
- **Map also shows**
 - State, national and county boundaries
 - Major cities

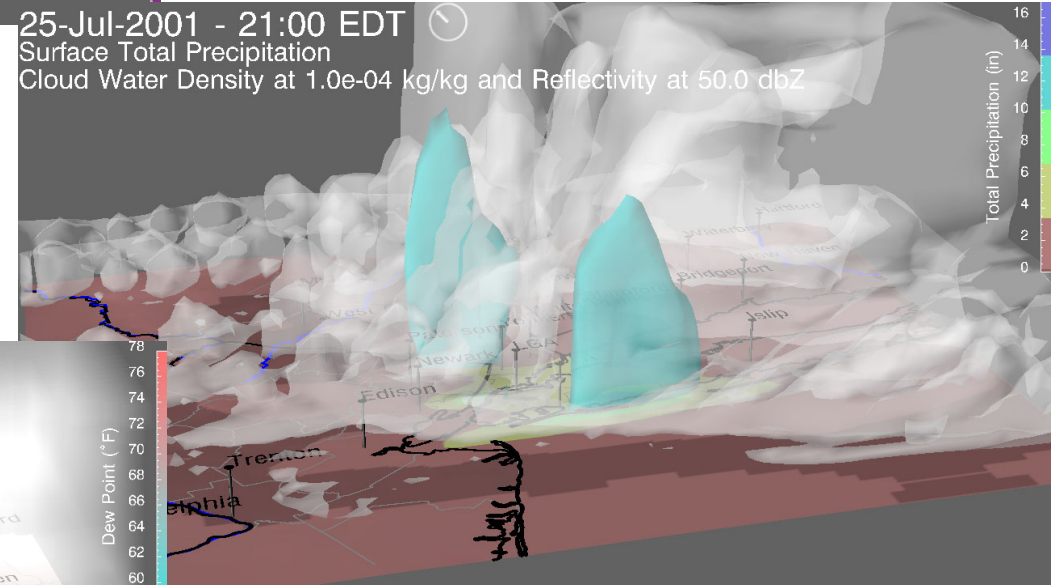


25-Jul-2001 - 21:00 EDT
Surface Heat Index and Winds

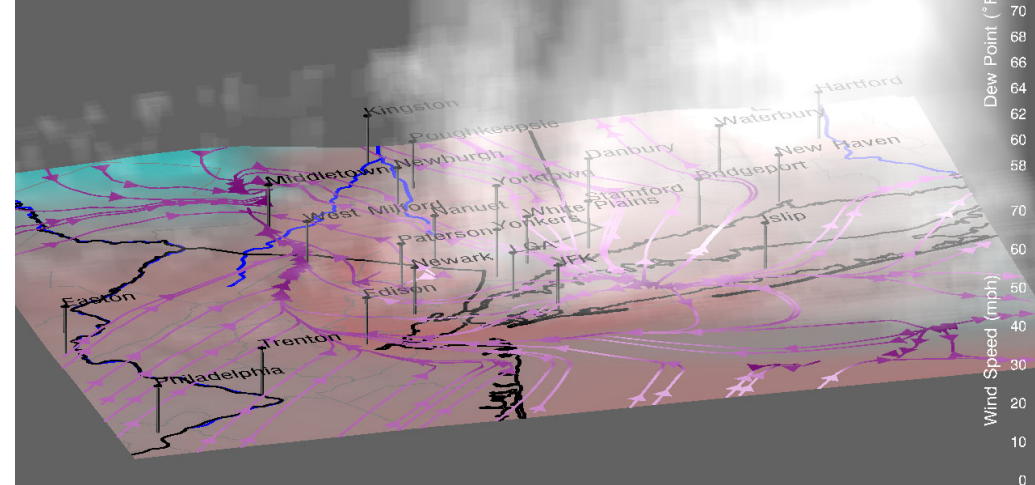


Different Visualizations of a Thunderstorm Forecast

25-Jul-2001 - 21:00 EDT
Surface Total Precipitation
Cloud Water Density at 1.0e-04 kg/kg and Reflectivity at 50.0 dbZ



25-Jul-2001 - 21:00 EDT
Surface Dew Point and Winds
Cloud Water Density



- Surface wind, heat index, dew point temperature, total precipitation
- Three-dimensional cloud water density and reflectivity
- 4 km resolution nest

Severe Thunderstorms Near White Marsh, MD -- 16 October 2004

- **A fast-moving line of late-afternoon thunderstorms occurred along Interstate 95 north of Baltimore between 1600 and 1630 EDT**
- **Heavy rain, zero visibility and "pea-size hail" (graupel?) were reported**
- **There were 17 multi-car accidents, involving over 90 vehicles from White Marsh to Bel Air, starting at about 1630 EDT**
- **50 people were sent to hospitals and caused widespread traffic disruption along I-95**
- **NWS forecast from 0330 EDT and through the day: mostly cloudy with a chance of showers and isolated thunderstorms**

White Marsh, MD -- 16 October 2004



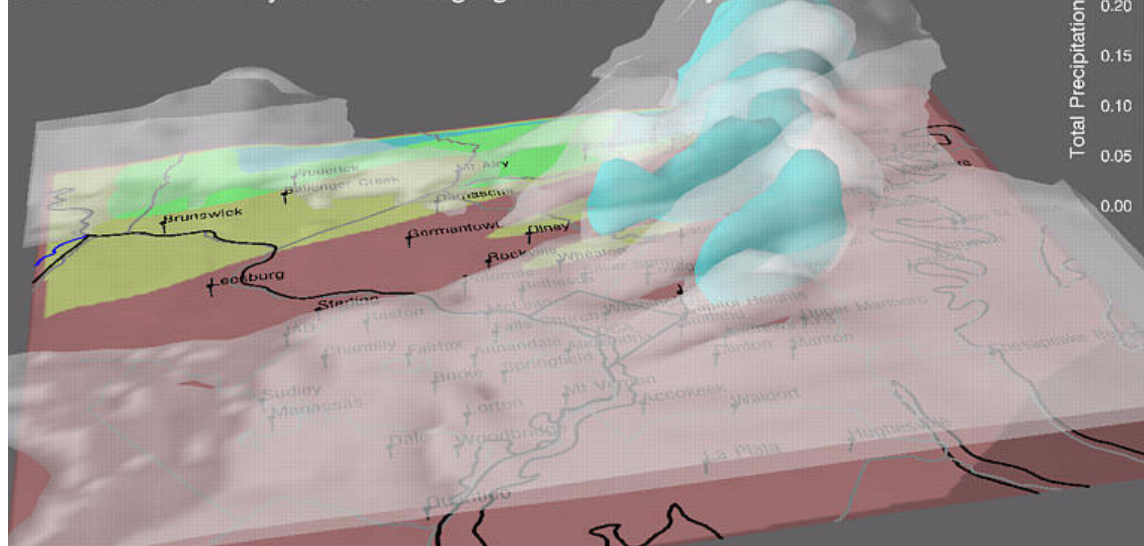
- Largest mass-vehicle crash in Maryland history
- Most of the accidents were within a 5-mile portion of I-95

- North- and south-bound lanes were closed for several hours



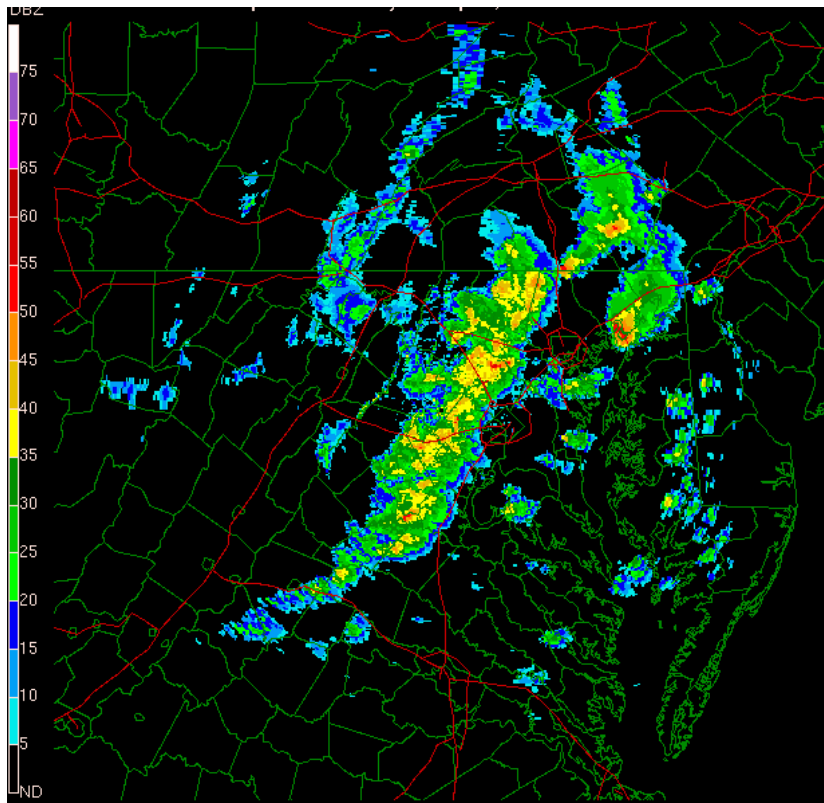
16-Oct-2004 - 16:30 EDT ☺

Surface Total Precipitation

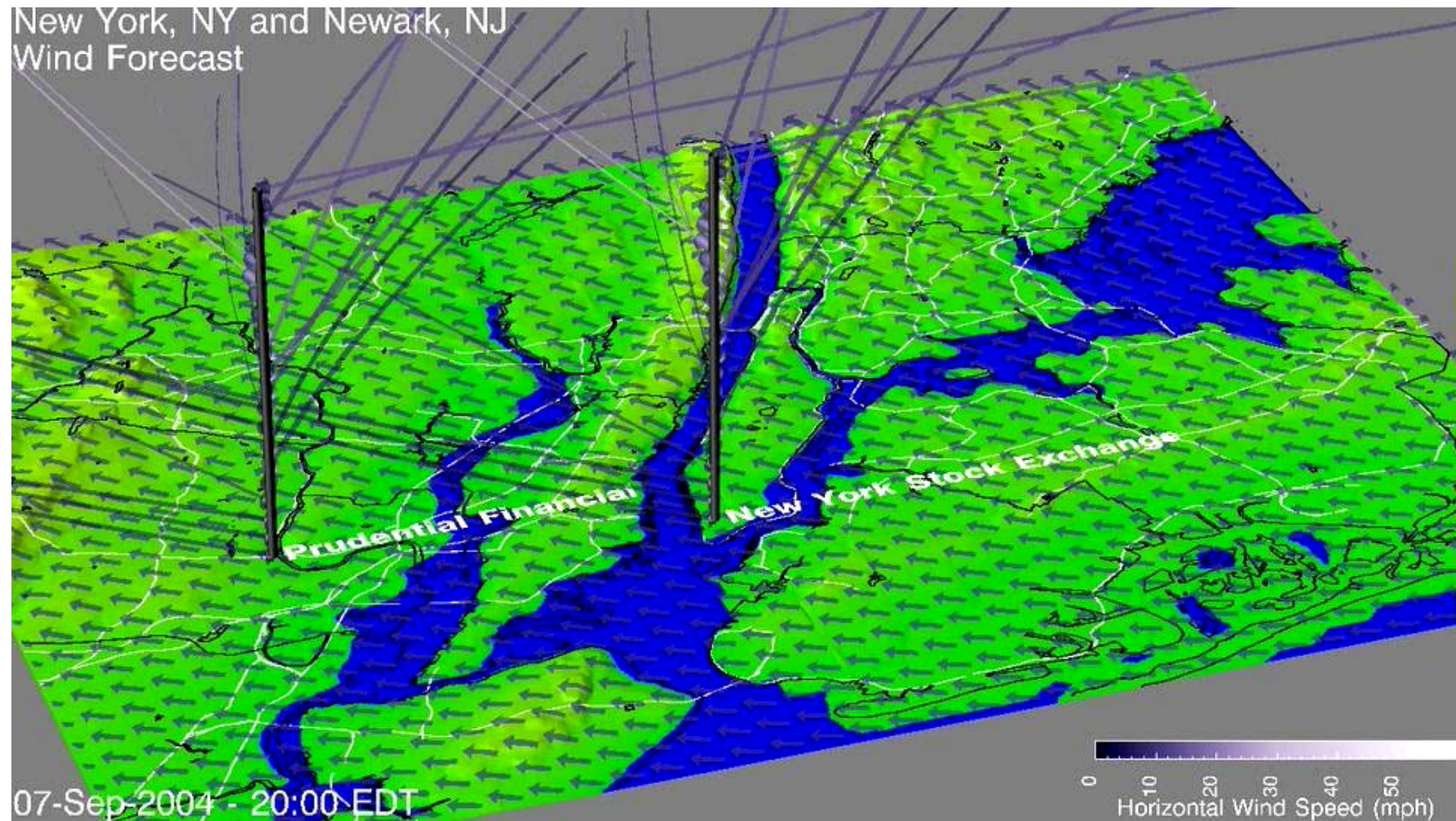
Cloud Water Density at 1.0×10^{-4} kg/kg and Reflectivity at 30.0 dbZ

Forecast Results 16 October 2004 Early Morning

- Line of thunderstorms predicted for the late afternoon with similar distribution to reported rainfall, except for the southern portion of the squall line
- Forecast initiated with data from 0200 EDT with results available about 0600 EDT
- Significantly different forecast compared to NWS forecast at any time during the day
- Lead time of about 10 hours before the event



Example Surface and Upper Wind Forecast



- Interest in surface and upper air winds dictates entirely different presentation
- “Virtual wind profilers” at two locations within 1 km nest enhanced with trajectories to show forecasted propagation

Snowstorms -- Maryland, Virginia, DC

