Applications and implementation of a mesoscale numerical weather prediction and visualization system

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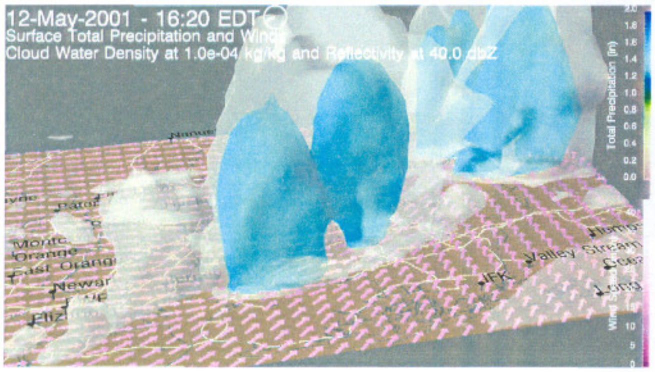
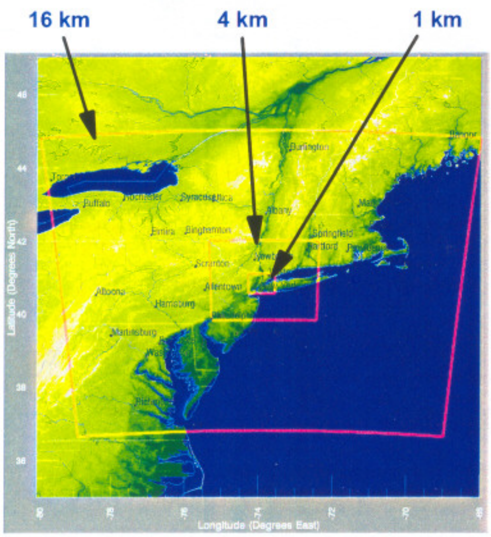


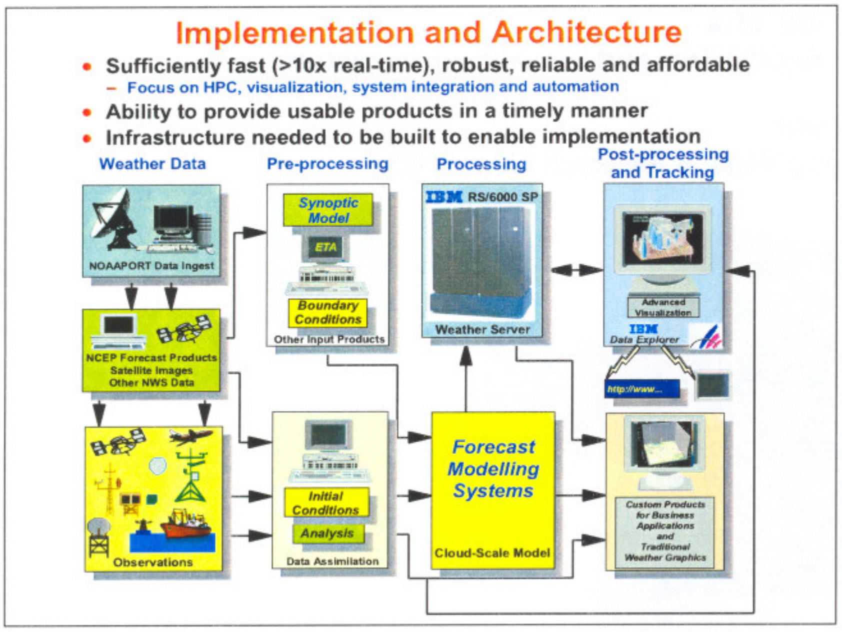
Background and motivation

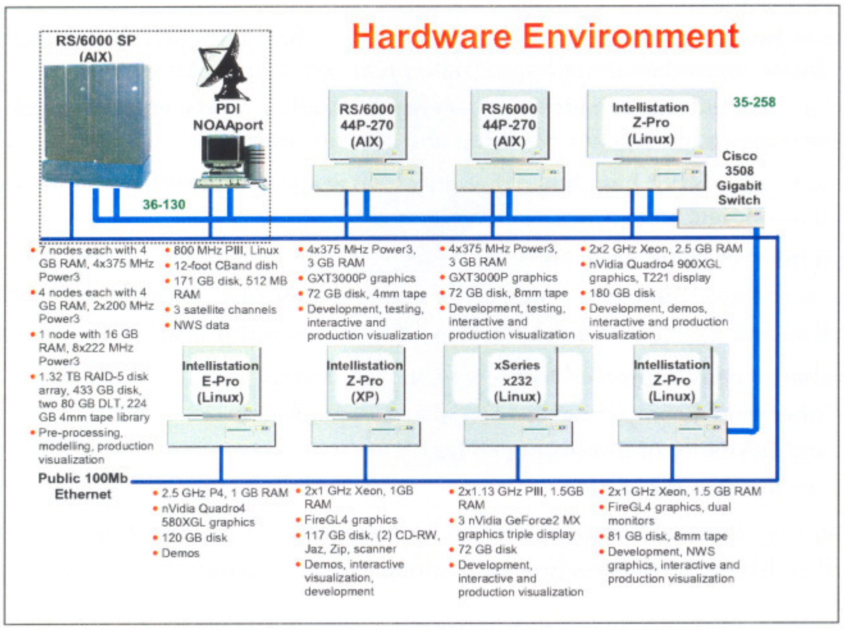
- Weather-sensitive business operations are often reactive to short-term (3 to 36 hours), local conditions (city, county, state) due to unavailability of appropriate predicted data at this scale
  - Transportation, agriculture, broadcasting, energy, insurance, sports, entertainment, tourism, construction, communications, emergency planning and security warnings
- Mesoscale (cloud-scale) NWP has shown 'promise' for years as a potential enabler of proactive decision-making for both economic and societal value. However, . . .
- Despite the 'promise' of cloud-scale NWP
  - Can business and meteorological value be demonstrated beyond physical realism?
  - Can a practical and usable system be implemented at reasonable cost?
- Improved feasibility today compared to a few years ago due to
  - Affordable operational computing and visualization platforms
  - Reliability and flexibility of forecasting codes
  - Availability of relevant input data
- Evaluate concept via a test bed implementation for New York City - Deep Thunder
  - Operational end-to-end infrastructure and automation with focus on HPC, visualization and system integration
  - Forecasts to 1 km resolution for metropolitan area with 3 to 18 hours lead-time
  - Prototype business applications with actual end users

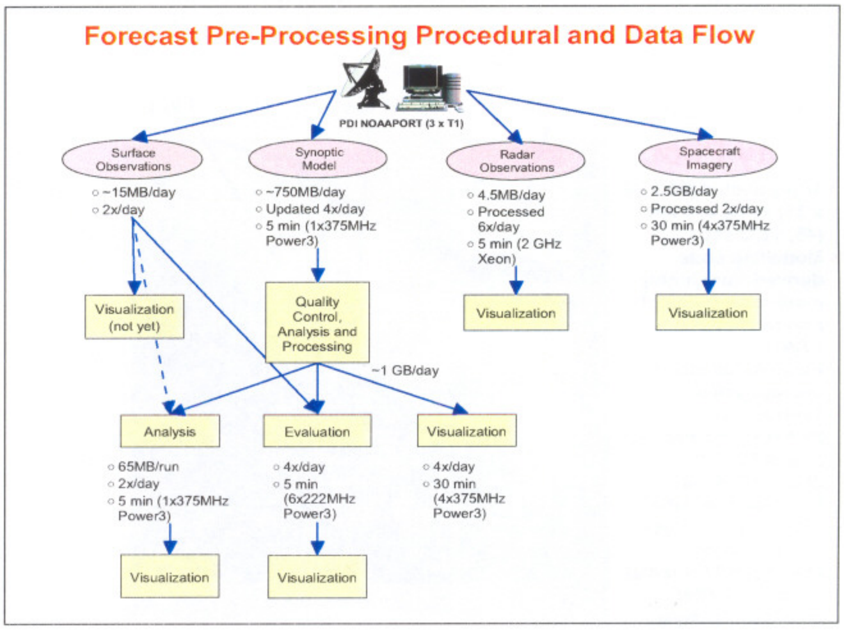
New York City Pilot

- **Triply nested (62 x 62 x 31) at 16, 4, 1 km (48, 12, 3 sec.)**
- **Modelling code derived from highly modified version of non-hydrostatic RAMS**
- **Explicit, full cloud microphysics**
- **Typically, two 24-hour runs per day (0 and 12 UTC)**
- **Eta-212/215 via NOAAport for lateral boundaries nudged every 3 hours**
- **Eta-212/215 for initial conditions after isentropic analysis**



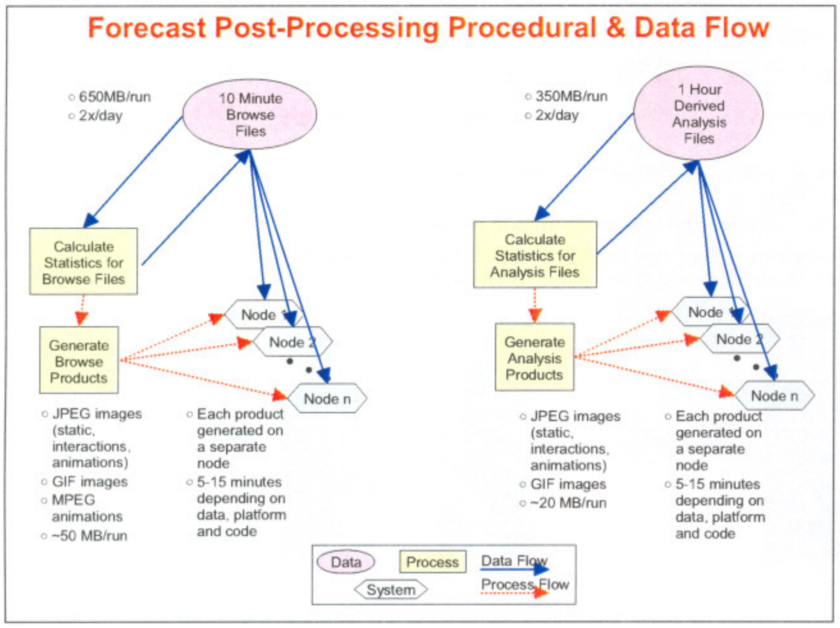

Implementation and Architecture
Sufficiently fast (>10x real-time), robust, reliable and affordable
– Focus on HPC, visualization, system integration and automation
Ability to provide usable products in a timely manner
Infrastructure needed to be built to enable implementation
Weather Data
Pre-processing
Processing
Post-processing and Tracking
NOAAPORT Data Ingest
NCEP Forecast Products
Satellite Images
Other NWS Data
Observations
Synoptic Model
ETA
Boundary Conditions
Other Input Products
Initial Conditions
Analysis
Data Assimilation
IBM RS/6000 SP
Weather Server
Forecast Modelling Systems
Cloud-Scale Model
Advanced Visualization
IBM Data Explorer
http://www...
Custom Products for Business Applications and Traditional Weather Graphics


Hardware Environment
RS/6000 SP (AIX)
PDI NOAAport
36-130
RS/6000 44P-270 (AIX)
RS/6000 44P-270 (AIX)
Intellistation Z-Pro (Linux)
35-258
Cisco 3508 Gigabit Switch
7 nodes each with 4 GB RAM, 4x375 MHz Power3
4 nodes each with 4 GB RAM, 2x200 MHz Power3
1 node with 16 GB RAM, 8x222 MHz Power3
1.32 TB RAID-5 disk array, 433 GB disk, two 80 GB DLT, 224 GB 4mm tape library
Pre-processing, modelling, production visualization
800 MHz PIII, Linux
12-foot CBand dish
171 GB disk, 512 MB RAM
3 satellite channels
NWS data
4x375 MHz Power3, 3 GB RAM
GXT3000P graphics
72 GB disk, 4mm tape
Development, testing, interactive and production visualization
4x375 MHz Power3, 3 GB RAM
GXT3000P graphics
72 GB disk, 8mm tape
Development, testing, interactive and production visualization
2x2 GHz Xeon, 2.5 GB RAM
nVidia Quadro4 900XGL graphics, T221 display
180 GB disk
Development, demos, interactive and production visualization
Intellistation E-Pro (Linux)
Intellistation Z-Pro (XP)
xSeries x232 (Linux)
Intellistation Z-Pro (Linux)
Public 100Mb Ethernet
2.5 GHz P4, 1 GB RAM
nVidia Quadro4 580XGL graphics
120 GB disk
Demos
2x1 GHz Xeon, 1GB RAM
FireGL4 graphics
117 GB disk, (2) CD-RW, Jaz, Zip, scanner
Demos, interactive visualization, development
2x1.13 GHz PIII, 1.5GB RAM
3 nVidia GeForce2 MX graphics triple display
72 GB disk
Development, interactive and production visualization
2x1 GHz Xeon, 1.5 GB RAM
FireGL4 graphics, dual monitors
81 GB disk, 8mm tape
Development, NWS graphics, interactive and production visualization


Forecast Pre-Processing Procedural and Data Flow
PDI NOAAPORT (3 x T1)
Surface Observations
~15MB/day
2x/day
Synoptic Model
~750MB/day
Updated 4x/day
5 min (1x375MHz Power3)
Radar Observations
4.5MB/day
Processed 6x/day
5 min (2 GHz Xeon)
Spacecraft Imagery
2.5GB/day
Processed 2x/day
30 min (4x375MHz Power3)
Visualization (not yet)
Quality Control, Analysis and Processing
Visualization
Visualization
~1 GB/day
Analysis
65MB/run
2x/day
5 min (1x375MHz Power3)
Evaluation
4x/day
5 min (6x222MHz Power3)
Visualization
4x/day
30 min (4x375MHz Power3)
Visualization
Visualization

Visualization component

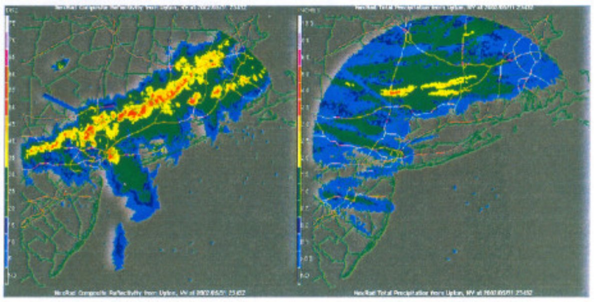
- Traditional meteorological visualization is typically driven by data for analysis - inappropriate for business applications
- Timely usability of cloud-scale NWP results requires
  - Understanding of how weather data are used
  - Identification of user goals, which are mapped to visualization tasks
  - Mapping of data to visualization tasks
  - Forecaster has control over content by design or simple interaction
  - Non-forecaster has limited control over content (targeted design) and simple interaction
  - Products designed in terms relevant for user
- Approach and implementation as presented at the ECMWF 2001 workshop is integrated operationally
- Wide range of generic capabilities needed
  - Line plots to 2D maps to 3D animations – but customized
  - Assessment, decision support, analysis and communications
  - Automated (parallelized) generation of products for web dissemination
  - Highly interactive applications on workstations



Visualized case studies

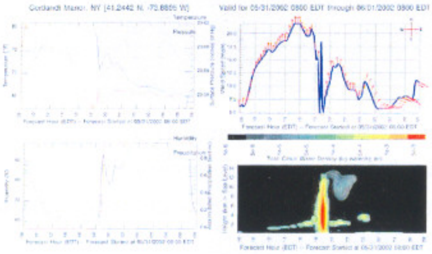
Severe Convective Event
31 May 2002 – Early Evening

- **In the late afternoon and early evening, a strong cold front clashed with a very unstable air mass across eastern New York State coupled with strong and divergent winds aloft**
- **Resulted in widespread severe damage to buildings plus downed trees and power lines in eastern New York State – mostly strong winds associated with thunderstorms as well as large hail**
- **Funnel cloud visible in 1km nest while two F1 tornados confirmed north of 4km nest (in 16km nest)**



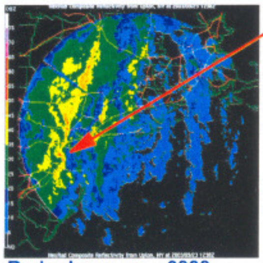
Forecast Results
31 May 2002 -- Early Evening

- Forecast initiated with data from 12 UTC
- Results available about 17 UTC, > 6 hour lead time
- Negative bias in timing ~25 minutes
- Intensity roughly correct
- Missed southeastern portion (beyond 4km domain)

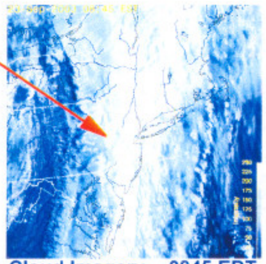


Severe Convective Event
23 September 2003 -- Early Morning

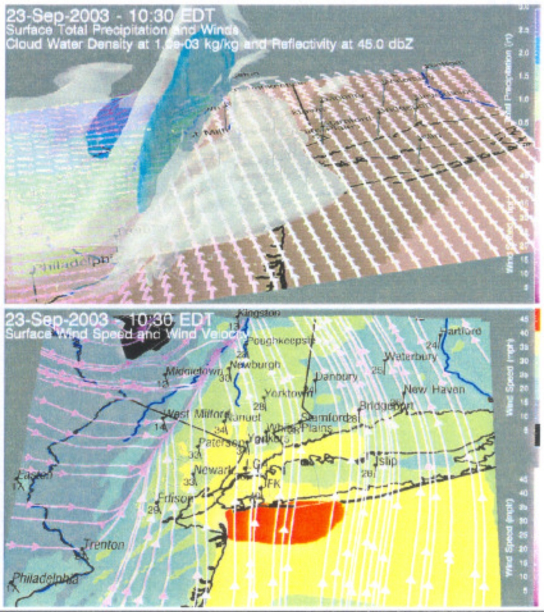
- Weak cold front in Pennsylvania and New Jersey clashed with a surprisingly unstable air mass
- Resulted in 100 trees uprooted, downed power lines and damage to buildings in New Jersey
- Gusts up to 130 km/hr and heavy rain (> 60mm in 30 minutes)
- Two F1 tornados confirmed in 4km nest (New Jersey) between 1205 and 1235 UTC, two additional F1s confirmed in 16km nest (Pennsylvania)



Radar Imagery -- 0838 EDT

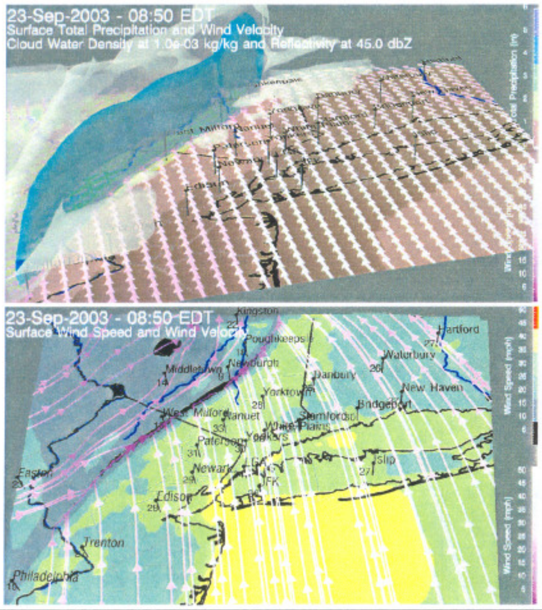


Cloud Imagery -- 0845 EDT



Forecast Results
23 September 2003
Early Morning

- Well-formed squall line is forecasted, associated with strong convection in northern New Jersey after 12 UTC with the potential for tornado genesis
- Location biased to the north and positive bias in timing of 90 to 120 minutes
- Despite error, significant "heads-up" for event (> 7 hours) with roughly correct intensity
- Forecast initiated with data from 0 UTC with results available about 5 UTC

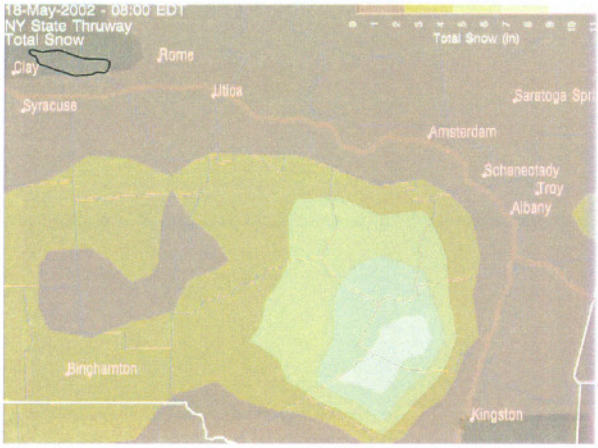


Forecast Results 23 September 2003 Early Morning

- Could a later forecast have provided better results ?
- Hindcast initiated with data from 6 UTC, which operationally would have been available by 1030 UTC
- Bias in location and time corrected, which would have still provided a lead time for the event

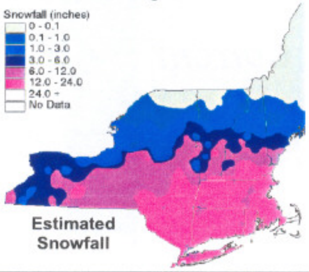
Late Spring Snowfall 18 May 2002 -- Early Morning

- 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 (5.5 cm) with reports up to 20 cm
- Forecast initiated with data from 12 UTC, available about 17 UTC, > 15 hour lead time
- Snow amounts may have positive bias



Blizzard -- February 17, 2003

- An exceptionally strong (Arctic) high pressure system pushing over New England, a low pressure system developed in the Tennessee Valley and tapped into moisture from the Gulf of Mexico, and then redeveloped rapidly off the middle Atlantic coast
- Periods of light snow developed as northeast winds increased to around 15 mph across the New York City area on the afternoon of February 16th
- Snow became widespread and heavy, falling at rates up to 2 to 3 inches per hour that night and the next day
- Heavy snow blown by northeast winds 20 to 30 mph caused near blizzard conditions throughout the area, crippling transportation
- In New York City, the cost estimate for total snowfall operations was ~$20M
- Widespread moderate beach erosion and minor tidal flooding occurred
- The storm tracked northeast and was east of Cape Cod by early February 18
- Storm totals ranged from about 30 to 70 cm

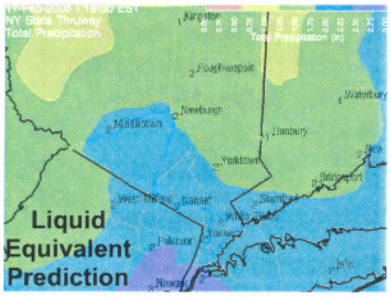


Measured Snowfall (Inches)

JFK	25.6	Middletown	15.0
Nyack	18.0	LGA	16.5
C. Park	19.8	White Plains	17.0
Upton	21.1	Bridgeport	17.0
Yorktown	21.0	W. Milford	28.0
Yonkers	19.0	EWR	22.1
Islip	14.0	Danbury	19.5

Forecast Results
February 17, 2003

- Forecast initiated with data from 0 UTC
- Results available about 5 UTC, hours before heavy snow began
- Good agreement in both snow totals ("dry" algorithm) and geographic distribution



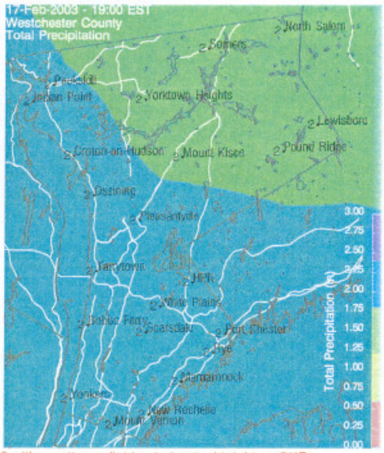
2/17/2003 Snowfall and Forecast*

Measured Snowfall (Inches)

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

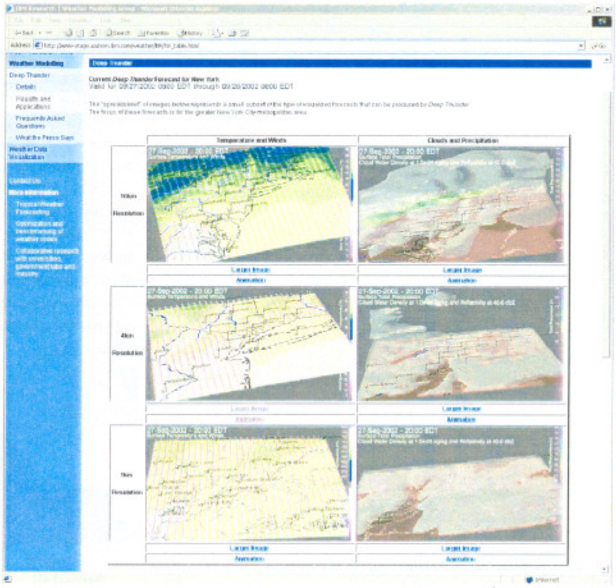
"Dry" Snow Prediction

Liquid Equivalent Prediction

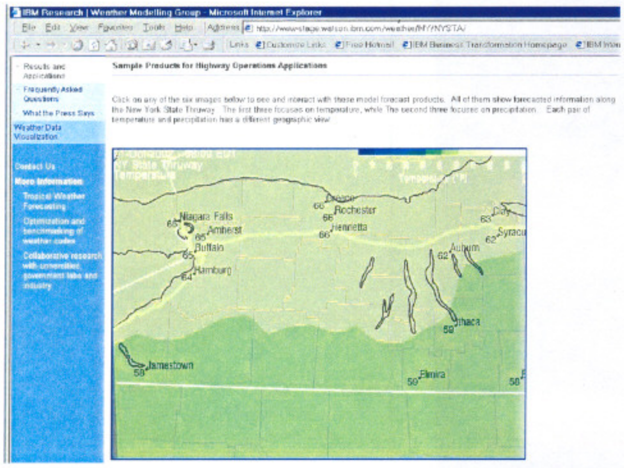


*Forecast initiated with data from 1900 EST on 2/16 with results available at about midnight on 2/17.

Example Web Products Current Forecast



New York State Thruway Forecasted Road Conditions

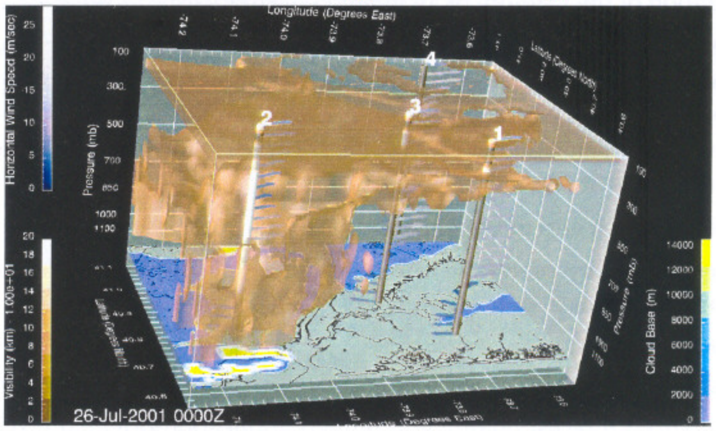


- Choice of weather variable and geographic region
- Color-contoured animated maps every hour

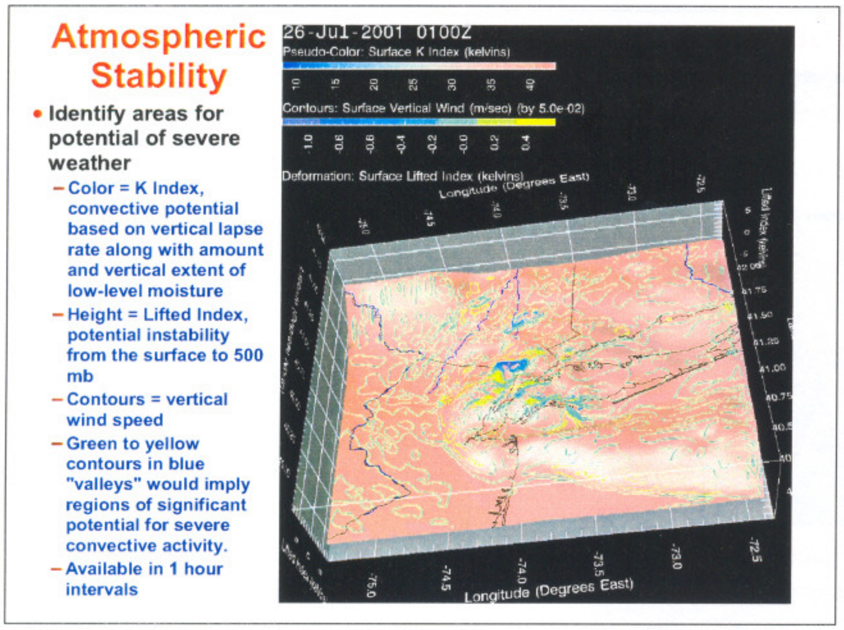
Westchester County Forecasted Conditions

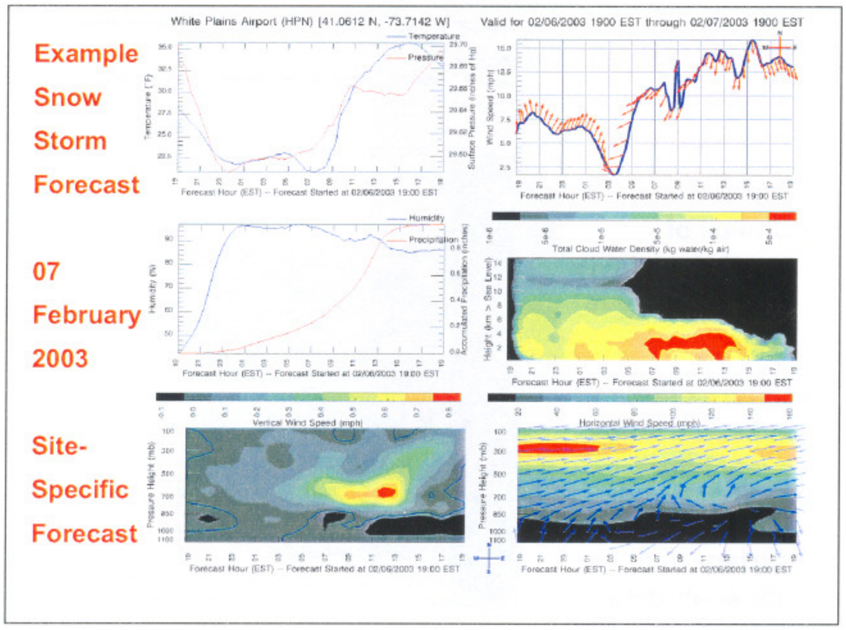
- Choice of weather variable and geographic region
- Color-contoured animated maps every hour
- Location-specific surface and upper air data

Aviation Flight Planning



- 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
- Adaptation of analysis techniques for operational application





Deep Thunder – summary

An illustration of the viability of an integrated, cloud-scale, NWP-based forecasting system. Observations by users:

- Usable forecast produced are available automatically, in a timely, regular fashion
- Favourable view of the ability to provide more precise severe weather forecasts compared to conventional sources
- Focused visualizations have been critical to effective utilization but improved throughput and forecast quality is still needed

Continued research and development

- New York City prototype as platform for development and collaboration as well as evaluation of practical business applications

Future work

- Better computational performance and throughput coupled with additional model runs
- Enhanced forecast quality and refined application-oriented product delivery
- Deployment of small mesonet to aid in forecast verification and model tuning
- Targeted verification (by area and application, e.g., travel delays, resource scheduling)
- Improved initial and boundary conditions incorporating data assimilation