How can we build more effective weather visualizations ?

Task-Specific Visualization Design

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What's Wrong with Our Visualizations ?

There is a lot that's right, but we can do better.

- Generic methods (content and interface) often fail in operational environments
  - Lack of focus for specific forecasting tasks
  - Complexity and time-consuming in use and/or training
- Focused methods may also fail
  - Not necessarily a reflection on quality of system
  - Mismatch between design focus and user goals
  - Users may not be researchers or professional meteorologists
- Generic methods may be preferred for research
  - Need for flexibility and customization
  - Multiple user goals and visualization tasks

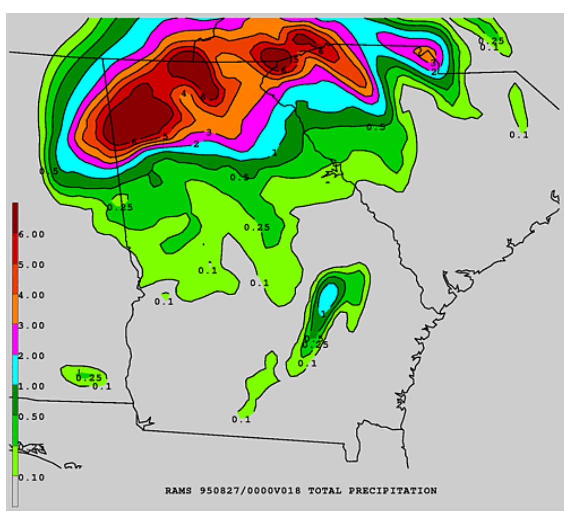
How Should We Start ?

1. **Identification of user needs, goals and tasks**
   - Assume user (intelligence) in the loop (domain knowledge)
   - Recognize distinction between requirements in research vs. operational environments
   - Build a taxonomy of visualization tasks and user goals
2. **Composition of design elements and interface actions**
   - Reflect user goals vs. visualization tasks
   - Incorporate knowledge of human perception (pattern recognition)
   - Be consistent with data sources
   - Constrain choices matched to user goals

- **Practical Matters**
  - Share common design elements to reduce development and training costs
  - Minimize iterative refinement with users
  - Need different visualizations for the same users
  - Need different visualizations for different users

Current Operational 2D Visualization

- **Static, batch, typically non-interactive**
- **Two-dimensional techniques with 2-3 variables at most for limited 2d or 2d slices of limited 3d data**
- **Flip-book animation and indirect interaction at best**
- **Single design/interface**
- **Many examples**
  - GEMPAK, AWIPS, MetView, HORACE, GrADS, NCAR Graphics, VAN, ...
- **Methods do not scale to large data volumes**
  - Observations, analyses and models
- **Poorly matched for non-analysis tasks and non-meteorologist users**



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Visualization Tasks in Meteorology

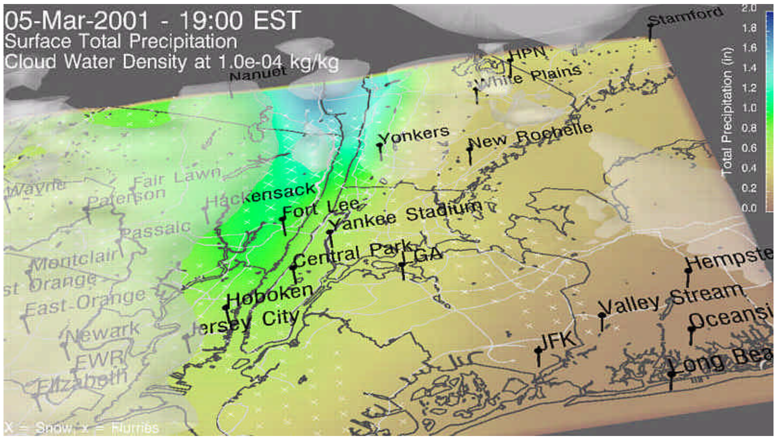
- *Class I*: 2d (Traditional Weather Graphics)
  - Quantitative
  - Users are forecasters
  - Minimal indirect interaction
- *Class II*: 2d, 2-1/2d Analysis (new)
  - Quantitative with potentially complex appearance
  - Users are forecasters, but techniques will be new
  - Support data comparison
  - Direct manipulation important
- *Class III*: 3d Browse (new)
  - 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

Visualization Tasks in Meteorology *(Continued)*

- *Class IV*: 3d Analysis (not new, but extended herein)
  - Quantitative with potentially complex appearance
  - Users are forecasters, but techniques will be new
  - Support limited data comparison
  - Direct manipulation important
- *Class V*: Decision Support (not new, but extended herein)
  - Rapid assessment important
  - Users are not modellers and typically not meteorologists
  - Inherent support for data fusion
  - Weather phenomena may not be shown

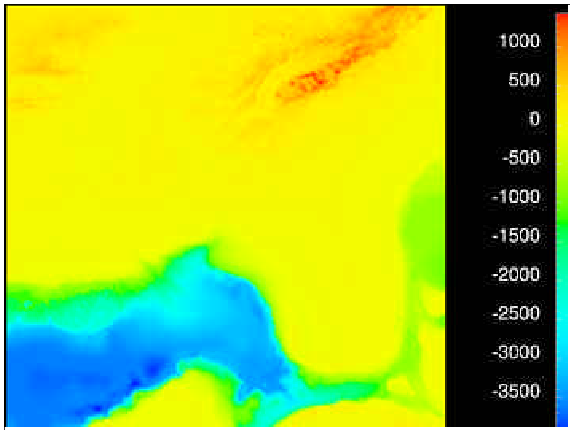
Composition Design Approach

- Identification of distinct user & visualization tasks by same or different users
- Detailed content under user control
- Consistency with data source
- Each data set processed independently
- Visualization and interaction in common, cartographic coordinates
- Both quantitative and qualitative techniques supported
- Multiple, linked displays, static and/or dynamic
- Physical and conceptual realization
- Simplified user interface



A Few Compositional Guidelines

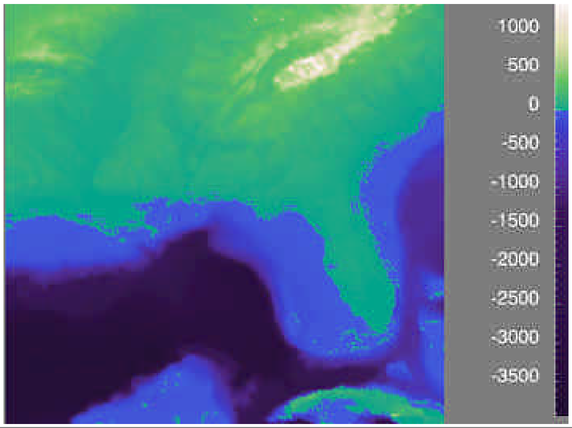
- **Coordinate system for display and interaction**
  - Cartographic projection (horizontal coordinates) dictated by task and/or data
  - Vertical coordinates (terrain-following vs. isobaric) dictated by task (assessment vs. analysis)
- **Color**
  - Colormaps dictated by task (isomorphic vs. segmented) 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
- **User tasks drive design**
  - Assessment: surface conditions and cloud properties
  - Analysis: variable selection and technique selection
  - Decision support: impact of weather



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



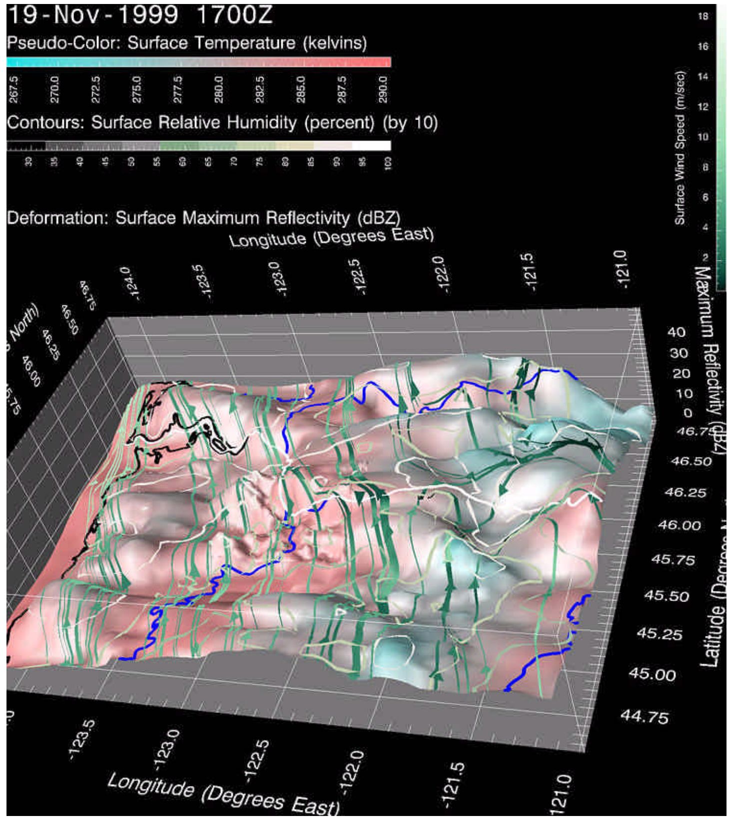
2, 2-1/2D Slice Analysis/View Task *Class II*

- Quantitative, interrogation and comparison
- Interaction by forecasters for analysis
- Direct manipulation supported
- Select different variables at specific pressure levels or at surface for use with diverse visualization methods (up to 5)
- Time-based animation
- Superset of Class I
  - Can utilize modern hardware (e.g., parallelism, 3d graphics)

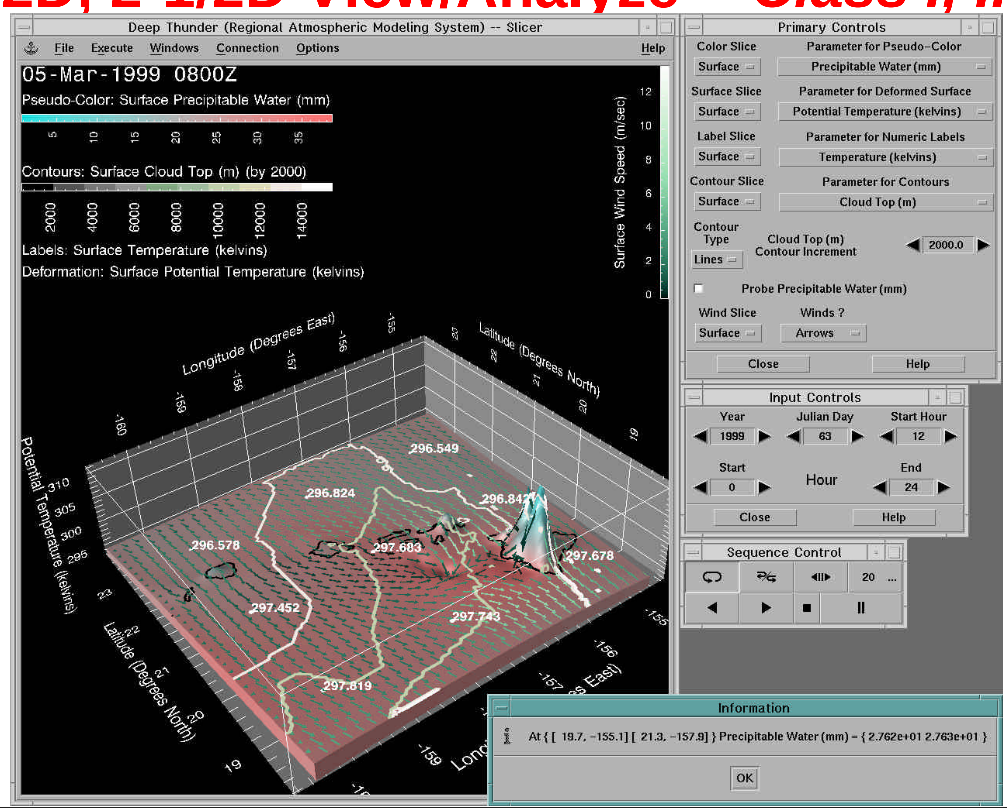
2-1/2D Slice Example

Class II

RAMS



2D, 2-1/2D View/Analyze -- *Class I, II*



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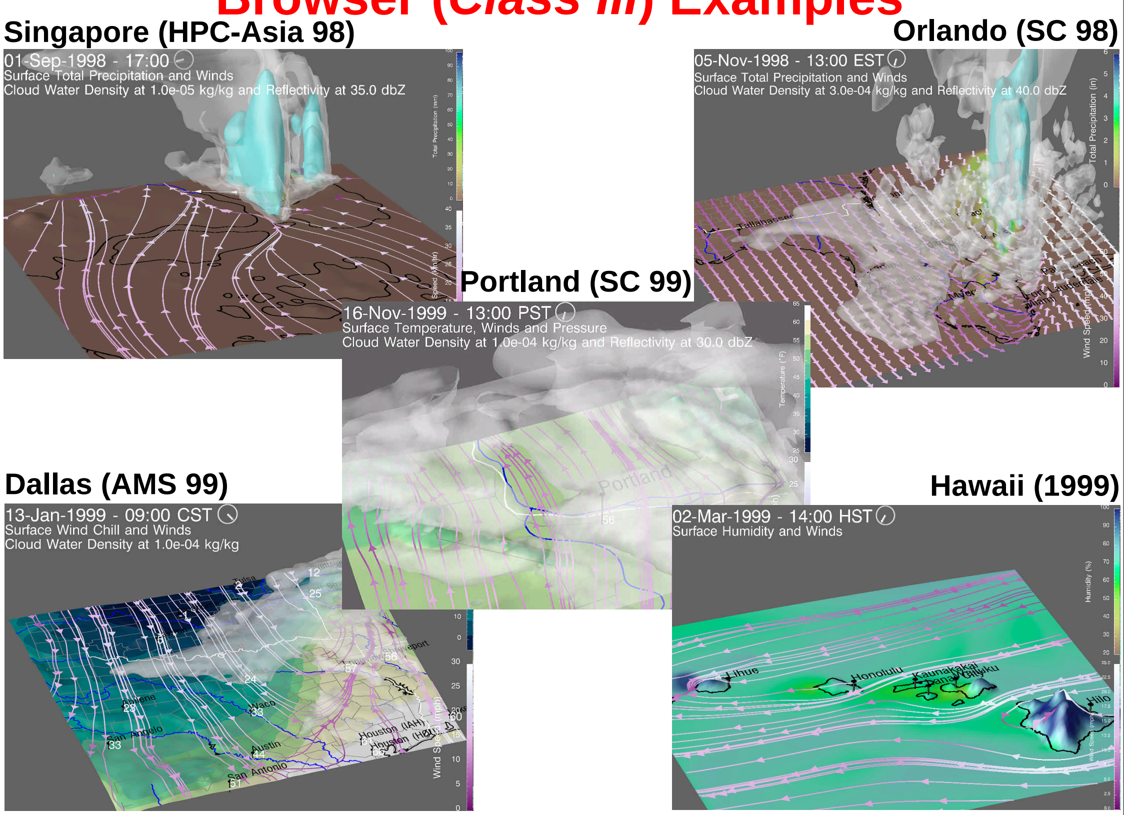
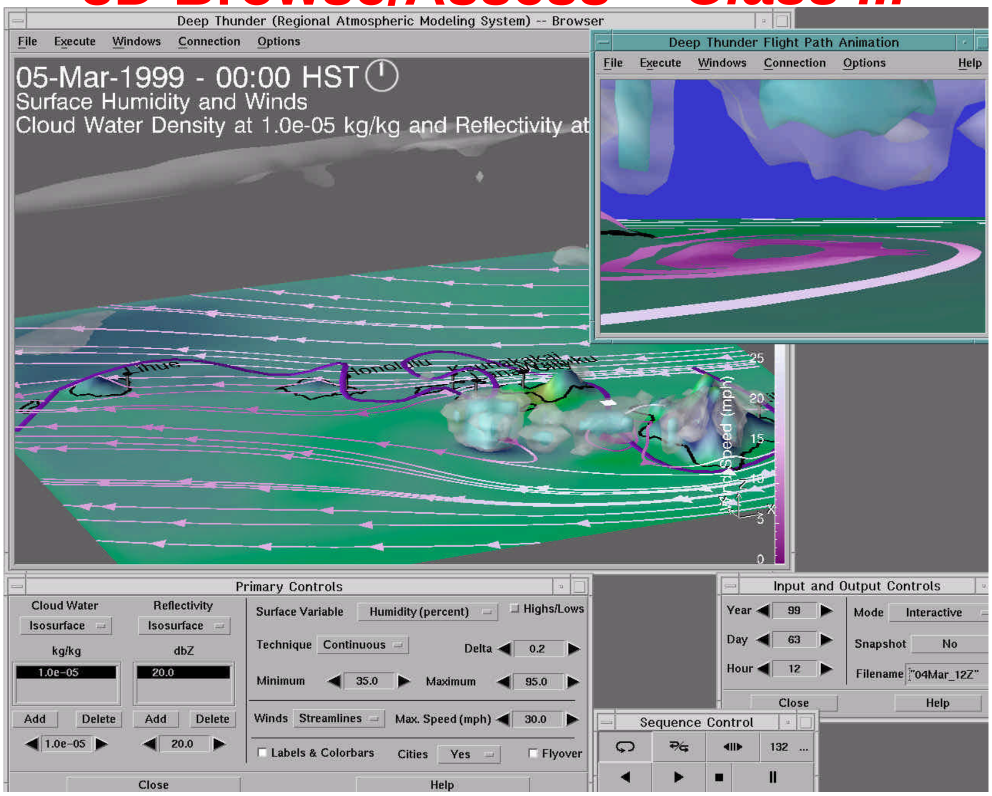
Browse Task -- *Class III*

- **Abstraction of results into single, easy-to-interpret, qualitative *4D* product**
  - Effective for data assessment and forecasting
  - Eliminate need to evaluate numerous 2d plots
  - Enables conceptual model for forecast development
  - Interact with and examine data with simple presentation
    - subset of variables for these tasks at high temporal resolution matching model
- **Simple model tracking during execution**
  - Quality control
  - Limited immediate analysis
  - Event identification for later analysis
- **Forecasters and public products (media & www)**
  - Users may or may not be specialists (e.g., forecasters)
  - Time-based animation with fixed view
  - Key-frame animation at fixed time
  - Creation of interactive and static "snapshots" for www

Browser (*Class III*) Examples



3D Browse/Assess -- *Class III*



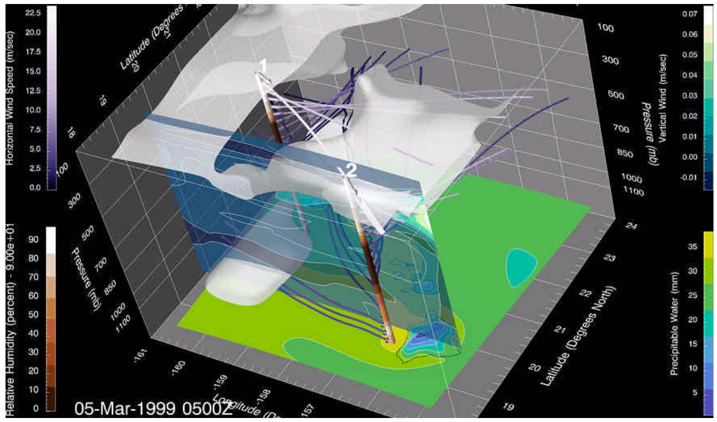
3D Analysis/View Task -- *Class IV*

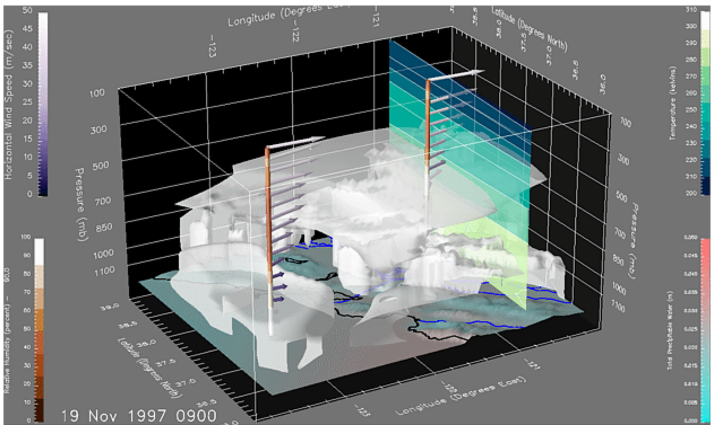
- Quantitative and interrogation
- Interaction by forecasters for analysis
- Limited data comparison
- Select different variables for use with diverse visualization methods (up to 5)
- Typical post-processed (model or analysis) data (e.g., all variables every hour of forecast time)
- Time-based animation
- Interaction with "virtual atmosphere": virtual met-station

3D View Examples

Class IV

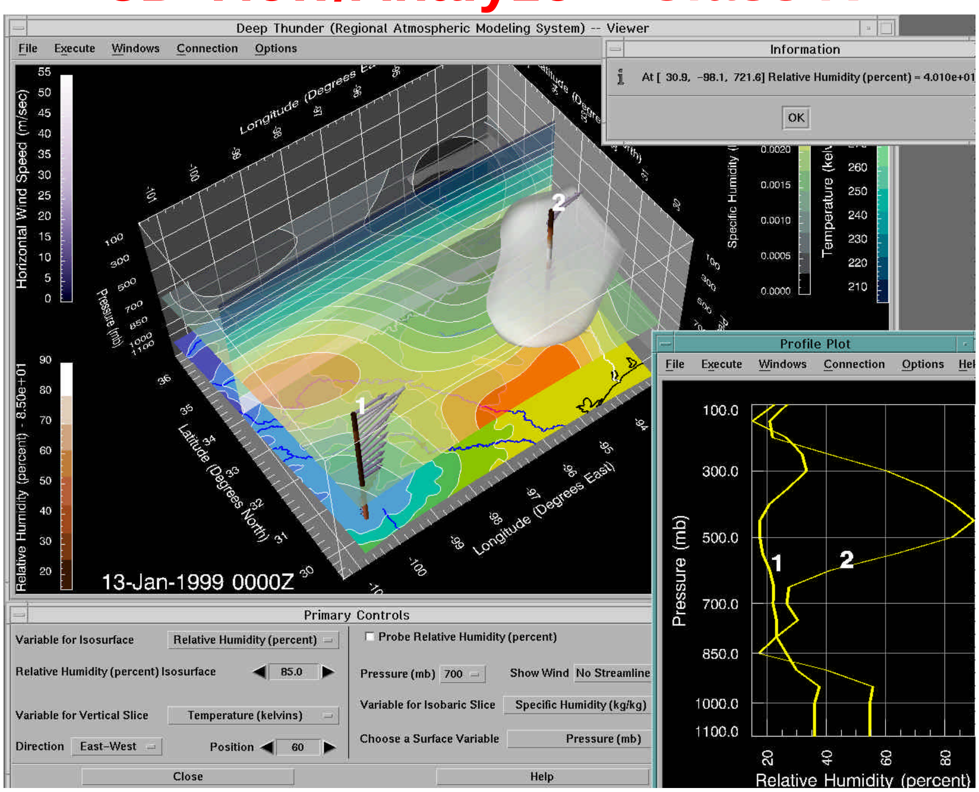
RAMS





LAPS

3D View/Analyze -- *Class IV*



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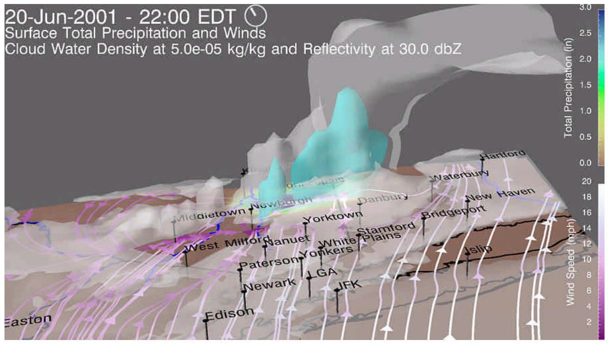
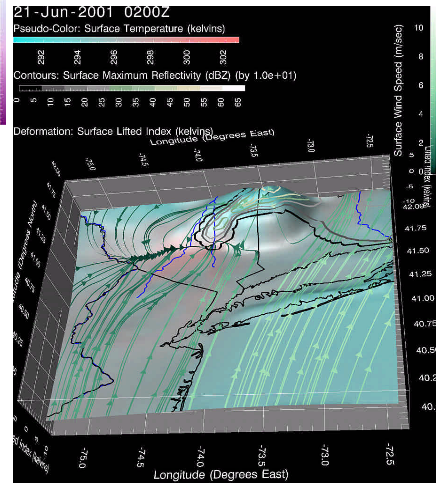
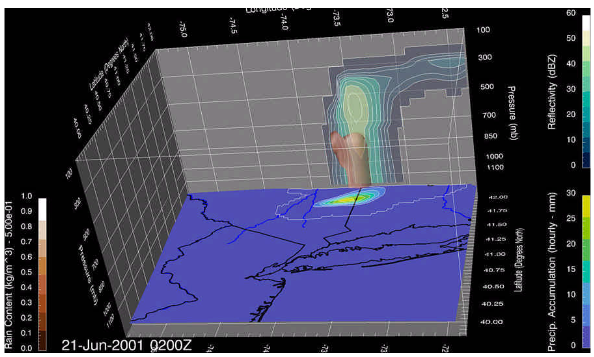
Deep Thunder
New York City Pilot

- 1-2 day forecast, nested to 1 km resolution for metropolitan area, 1-4 times/day
- Operational end-to-end infrastructure and automation (data ingest, pre-processing, simulation, post-processing, visualization, dissemination)
- Testbed for continued work in visualization and applications
- Operational implementation of Classes I, II, III and IV
- Extension of Class III for www

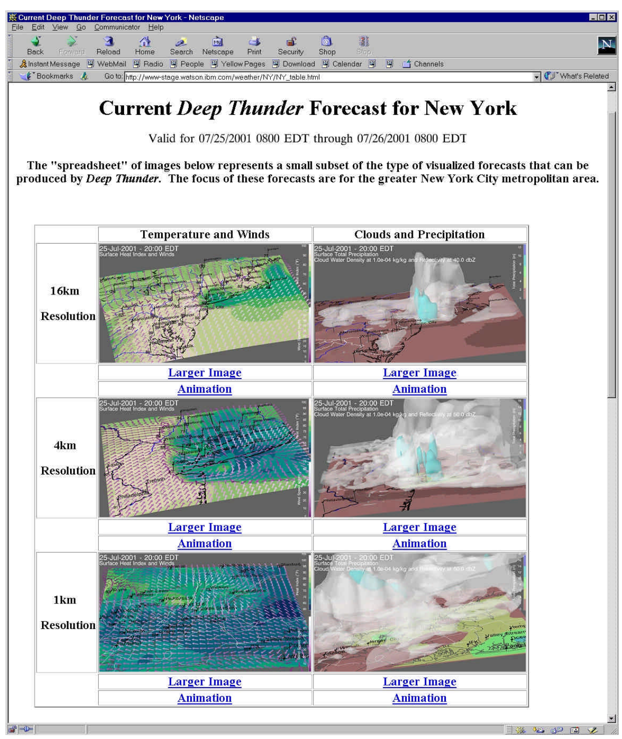






Extensions of *Class III* for WWW

- Typical web-based methods do not scale well -- many mismatches, for example
  - too few time steps
  - too hard to find relevant images
  - limited or no interactivity
- Interactive, 3d image spreadsheet -- high-level
  - Meteorological characteristics vs. model features -- meta-representation of model
  - Each interactive cell is one time step as an index into more visualizations and interactions -- extensible
  - MPEG video at moderate pixel-resolution, but high temporal resolution
  - Specialized (extreme) compression to address data sampling problem
- Interactive applications adapted for automated and parallelized batch execution to generate images & animations



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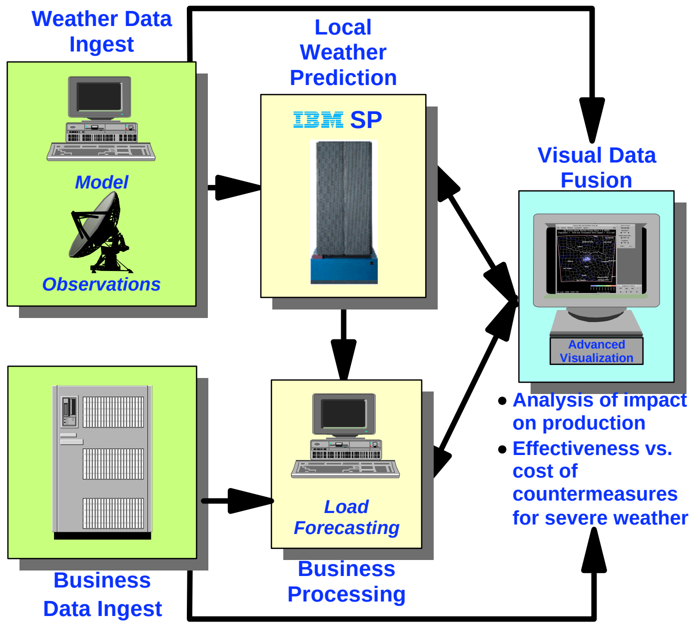
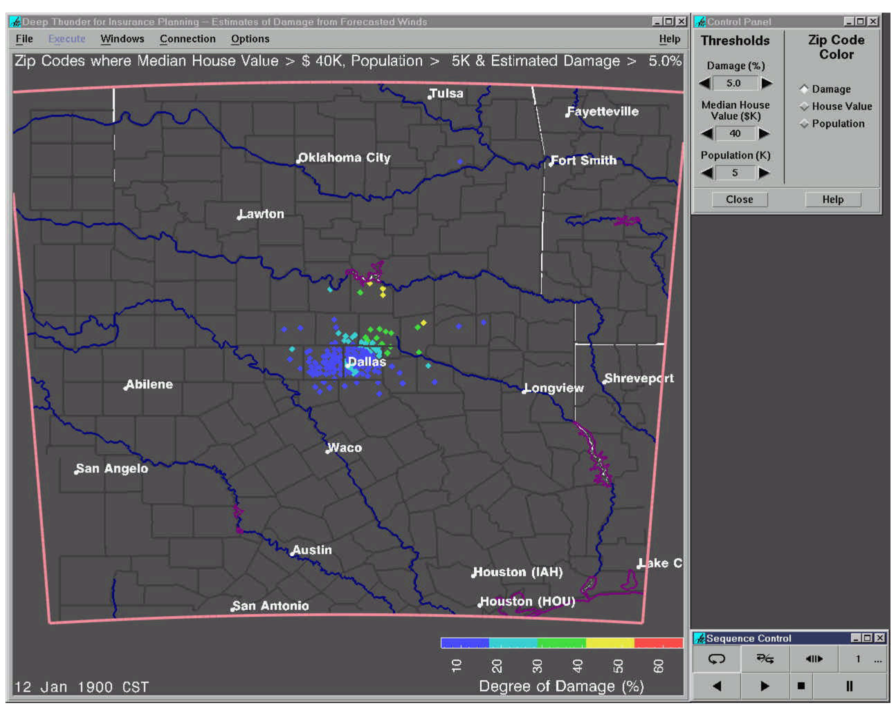
Decision Support -- *Class V*

- **Enable proactive decision making affected by weather**
- **User goals influence effective design via data fusion**
- **Customized appearance by data and geography**
- **Presentation of derived properties critical**
- **Many potential applications**
- **Couple to business processes & models:**
  Load forecasting, groundwater modelling, ...



Decision Support -- (*Class V*) Example: Insurance, Emergency Planning

- **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**



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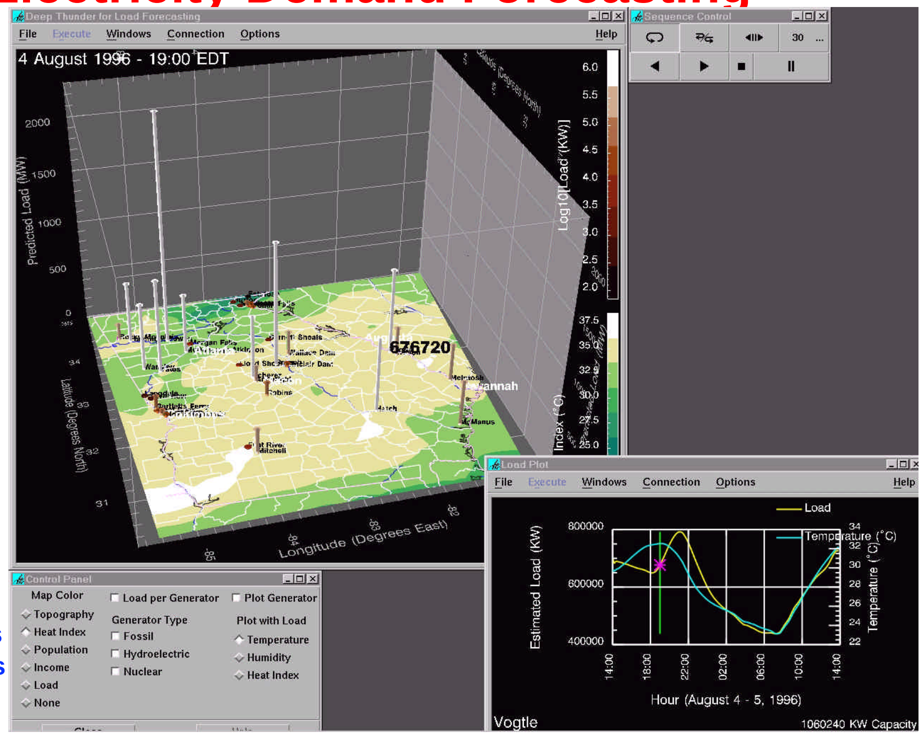
Decision Support -- (*Class V*) Example: Electricity Demand Forecasting

- 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



Visualization Implementation

- Core implemented via Data Explorer -- an open source visualization toolkit (www.opendx.org)
  - Custom tools for new visualization elements and derived meteorological variables
  - Custom tools/packaging for new output products
  - Shared tools and user interface components
  - Simple motif widgets for indirect interaction
  - Direct interaction in appropriate cartographic coordinates
  - *NO* transformation or compression of data or mesh(es)
  - Rule-based colormap tool used during design phase
  - Custom export/rendering www products
- Integrated with mesoscale forecasting system (*Deep Thunder*)
  - Custom I/O to balance communications, reduce latency
  - Custom filters for data import
- Supplemented with utilities for animation conversion (e.g., video, www) built upon ImageMagick

Conclusions

- Hierarchical decomposition of user goals and visualization tasks and design useful
- Avoid "kitchen sink" approach: Do NOT support too many tasks and users in one application
- No single visualization is typically adequate for a given user goal
- Same users may have different goals
- Although different users may have not have the same goals, they may share visualization tasks (and be able to utilize common tools)
- Operational activities expand the potential tasks from the traditional scientific visualization ones

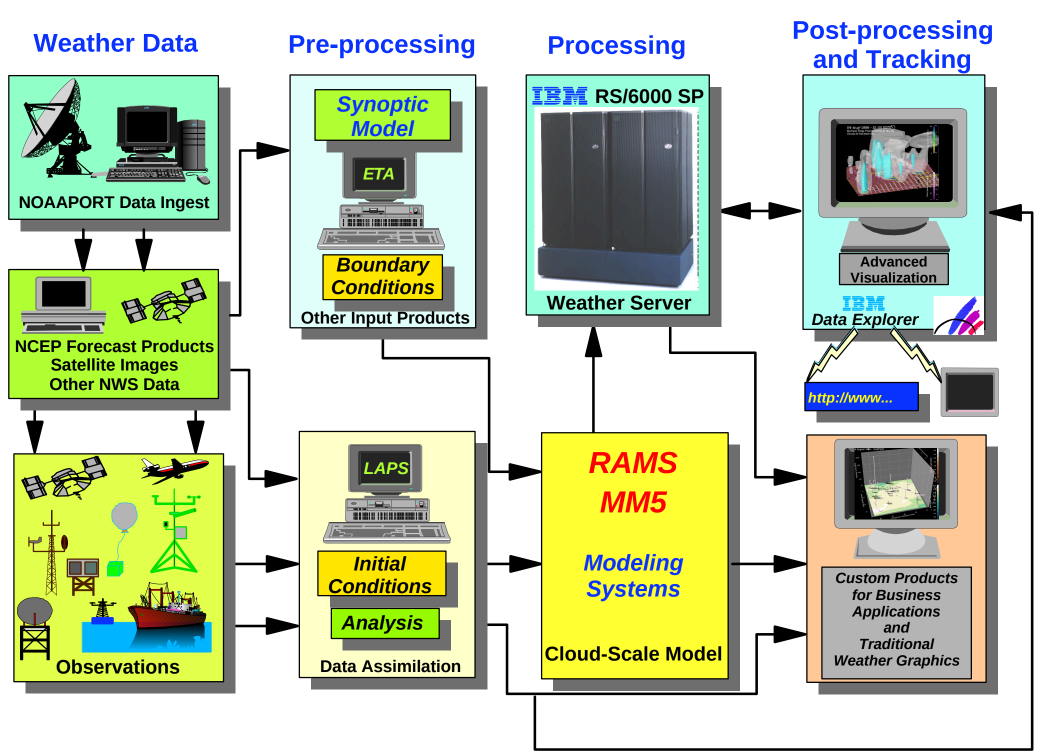
Future Work

- Develop task decomposition for other applications and implement customized interfaces, products and packaging
  - For example, aviation, broadcast, insurance, energy, agriculture
- Continue to develop specialized compression techniques for web deployment
- Extend tools to other models and data products and evaluate validity of decomposition
- Enhance model tracking/steering and interactivity (Class III)
- Improve model input/output (all classes)
- Incorporate new visualization techniques

Backup

Slides

Motivation: Applications of *Deep Thunder*



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Visualization in Meteorology

- Visualization in meteorology has rich tradition and history
  - Research community among earliest users of both modern visualization techniques and supercomputing (e.g., Wilhelmson et al, NCSA thunderstorm)
- Plethora of operational 2d tools with essentially same content design
  - Typical focus on analysis
  - Philosophy of "one size fits all", independent of user or task
  - 2d techniques dominate
  - Limited use of 3d mostly for post-processing
  - Potential mismatch between users and interface
- Good choice as a testbed

Related 3D Work in Operational Meteorology
(Derived from the Research Community)

- U. Wisconsin Vis-5D
  - Single design/interface for limited 3d data only, users & tasks
  - Home-grown (X/OpenGL), public domain
  - Optimized for performance on regular grids, compressed data
  - Assumption of an analysis task
- NOAA/Forecast Systems Laboratory D3D
  - Single design/interface for limited 3d data only, users & tasks
  - Originally utilized AVS, but now based upon Vis-5D
  - Assumption of an analysis task
  - Focus on user interface consistent with other applications
- Fraunhofer Institut für Graphische Datenverarbeitung (with Deutscher Wetterdientst)
  - Different systems and interfaces for different tasks AND users
  - Only share underlying renderer
  - Triton: 2d data for non-meteorologist
  - TriVis: 2d and 3d data for non-meteorologist via broadcast meteorologist
  - RASSIN: 3d analysis by meteorologist

Common Goals of Visualization

- Exploration (undirected search)
  - See relationships, test hypotheses
  - You don't know what you are looking for
- Analysis (directed search)
  - Gain insight to make decisions
  - You already have a sense of what you are trying to learn
- Communication (presentation)
  - Share results, convince, and promote
  - You already know the answer

"*you can see a lot by observing*" (Yogi Berra)

Stages of User-Centric Software Development

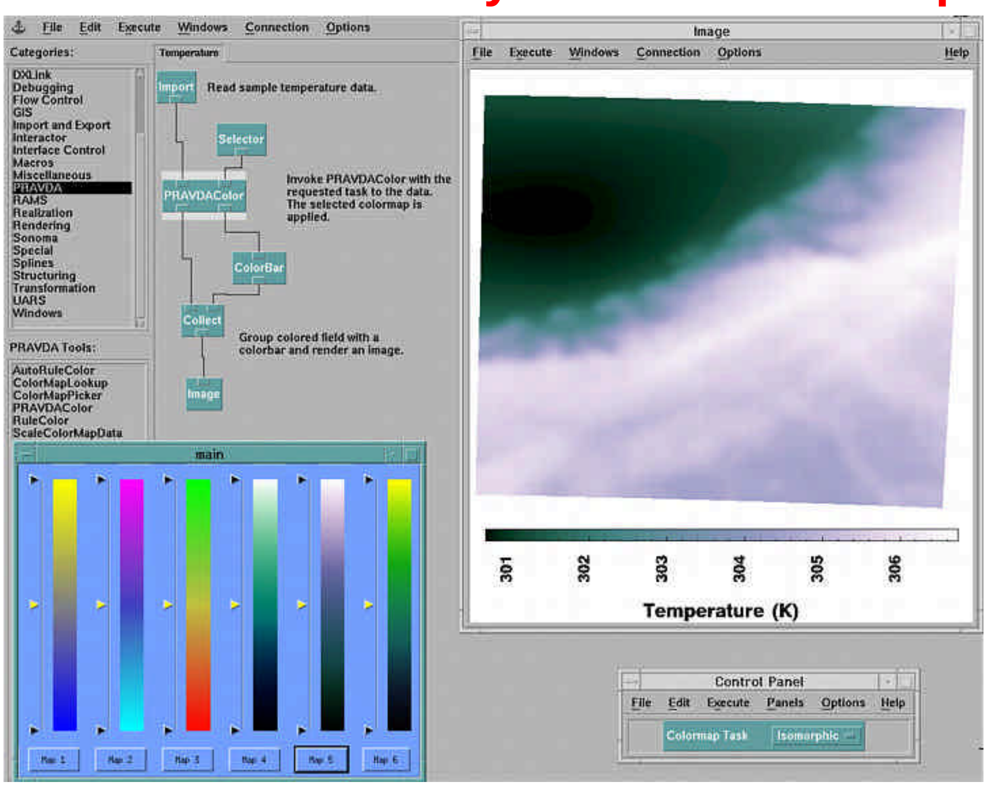
- Define the application in terms of its users, their goals and tasks
- Design the application and its interface to implement that definition
- Prototype the design
- Test the design with users to identify design flaws that prevent users from achieving their goals
- Fix the design flaws, then redesign, reprototype, and retest until an acceptable usability level is achieved
- Develop the application, do final testing and test the support documentation
- Deliver the final application and assess the design's success in field use

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

Rule-Based Advisory Tool for Colormaps



Compositional Guidelines *(continued)*

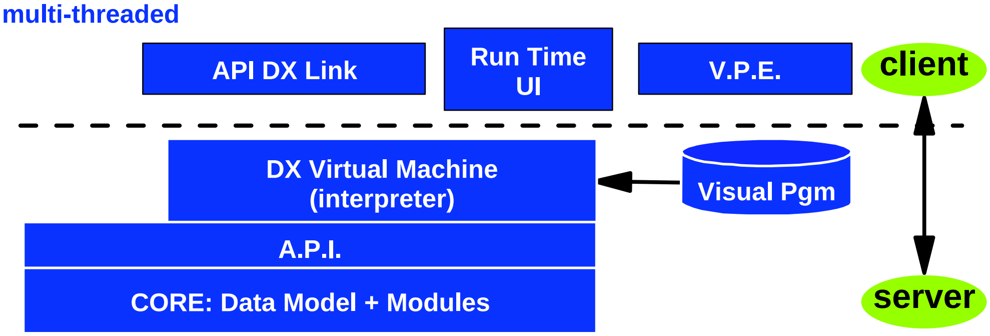
- Realization
  - Surface data warped on terrain in 3d scene
  - Overlay of vector maps and markers for annotation
  - Color-filled contour banding used with segmented colormap
  - Surface wind dictated by task
    - Fixed glyphs (2d arrows, 3d flags) as animated texture for global features
    - Streamlines 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

Browse Task *(Class III Continued)*

- Event/Feature identification
  - Gross atmospheric motion
  - Convective activity
  - Potential distribution of motion
  - Land-sea interaction
    - sea breezes
    - convergence zones
  - Orographic effects
  - Vertical Motion
- Visualization subtasks: continuous domain vs. segmentation
  - Volume rendering vs. isosurface(s) for cloud properties
  - Isomorphic colormap vs. contour banding with segmented colormap for surface data
  - Streamlines vs. glyph techniques for surface winds
  - Animation with temporal and spatial coherence important

Data Explorer - http://www.opendx.org

- Six main modular software components as client-server providing
  - API and turnkey development
  - Visualization authoring
  - Links to other applications
  - End-user tool
- Client (user interface) on same or different machines
- Server (compute engine)
  - parallelized on SMPs
  - distributed on networks
  - multi-threaded
- Open source development
- Multi-platform support
  - Unix: IBM, HP, Sun, SGI, DEC, Linux, etc.
  - Wintel: 95, 98, NT and 2000
- Single unified data model for all data types
  - Handles all data (imported & derived)
  - Supports building of applications and exchange of data
  - Promotes efficiency
  - Self-describing and user-extensible



Visualization Configuration

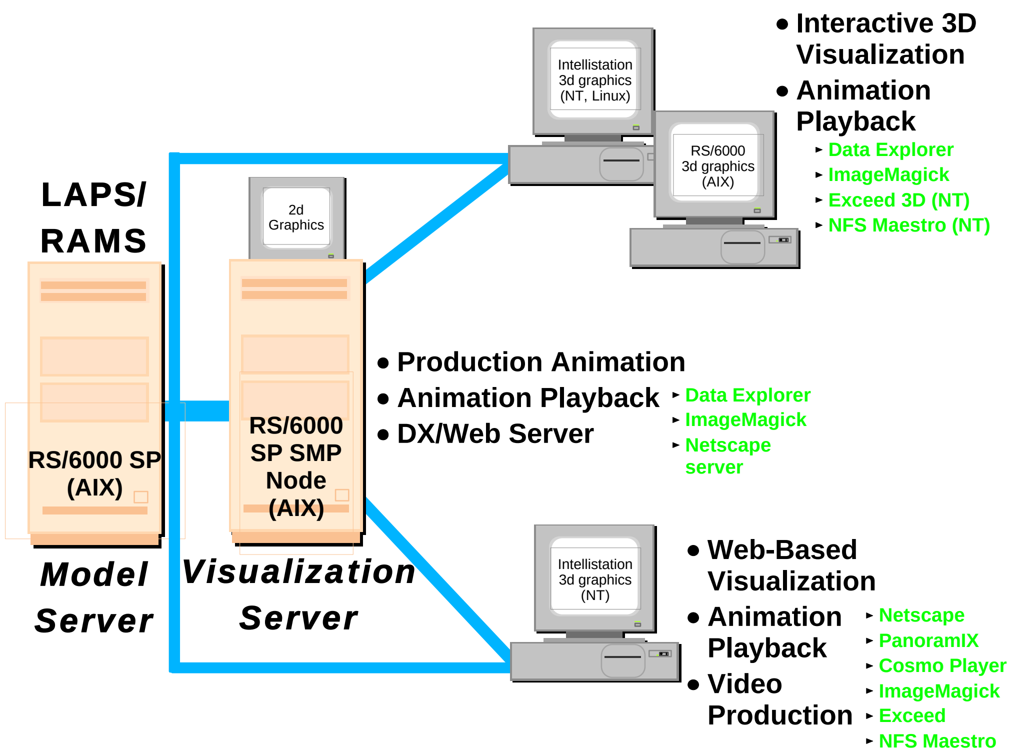


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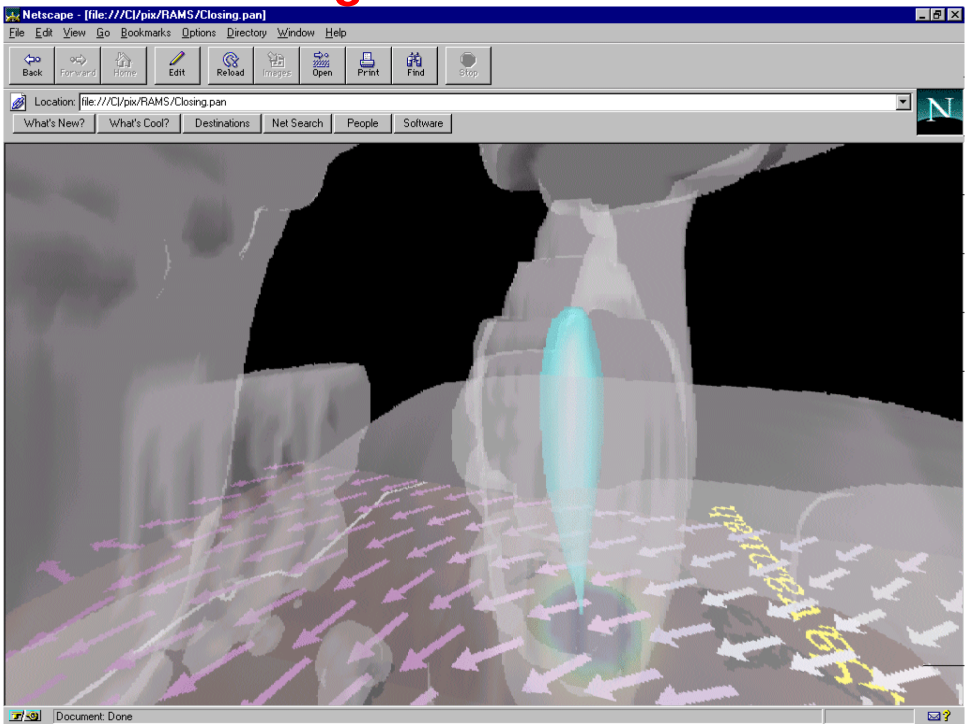
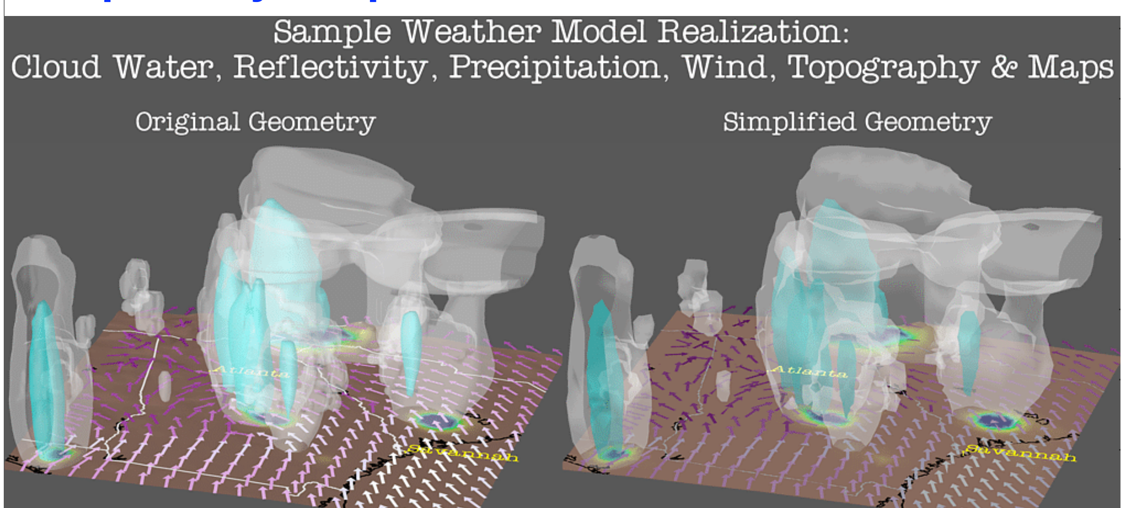
Image-based Interaction of Weather Forecasting Scene via PanoramIX



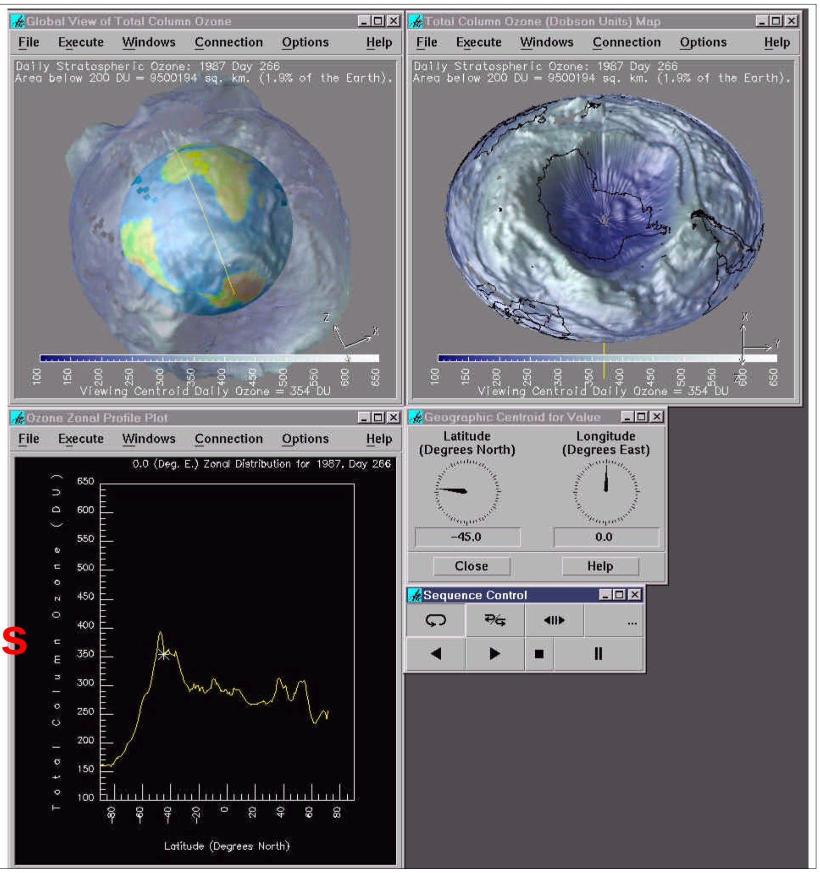
Geometric Simplification

- Reduce download time and improve interactivity
- Each component of the visualization is separately simplified with different constraints



343K to 40K triangles

Combined Tasks with Ozone Observations



Weather-Specific Conclusions

- **Class III more effective than expected for general forecasting tasks**
  - **Quick and accurate model assessment via compact representation, supporting conceptual and physical models**
  - **Eliminates need for tedious use of 2d methods**
- **Class II and IV:**
  - **Efficient approach to correlative analysis**
  - **Direct manipulation enables more than just display**
- **Limitations in data management**
  - **Data processing and model I/O poorly designed for interactive applications -- both direct or post-processing**
  - **Incomplete metadata management, primarily impacting Class II and IV applications**