Uncertainty Visualization of Weather Ensembles

Jibonananda Sanyal

People

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    - Assistant professor CSE
- Philip Amburn
    - Assistant research professor GRI
- Jamie Dyer
    - Assistant professor Geosciences
- Andrew Mercer
    - Assistant professor Geosciences
- Robert J. Moorhead
    - Professor ECE

Outline

- Motivation
- Weather forecast ensembles
- Uncertainty of ensembles
- Uncertainty visualization techniques
- Noodles
- Improvements
- Noodles 2
- Future directions

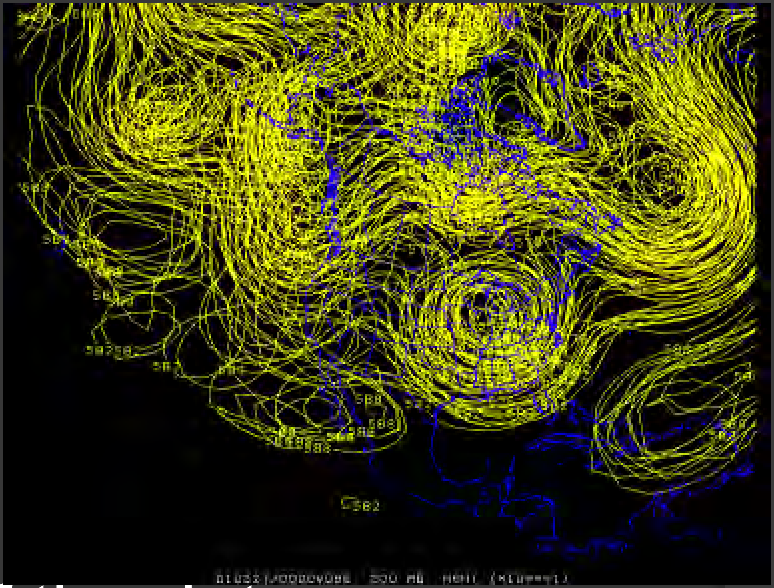
Motivation

- We try to forecast future weather conditions
  - Social and economic factors
- Advent of supercomputing has made large scale weather forecasting computationally feasible
- Huge datasets – often larger than available RAM
- Visualization is indispensable

Numerical Weather Modeling

- The atmosphere exhibits complex non-linear behavior
- Numerical simulations approximate atmospheric processes
  - Actual measurement samples are very sparse
- Simulation challenge
  - Vast array of possible parameters and conditions
  - Ensembles are used operationally
  - Reduces the uncertainty in the forecast
  - Very large amounts of data are generated
- Operational challenge
  - To make sense of this data in a short period of time
  - "I see", "We see", and "They see" (Courtesy: Dr. Robert Moorhead)

Current state-of-the-art

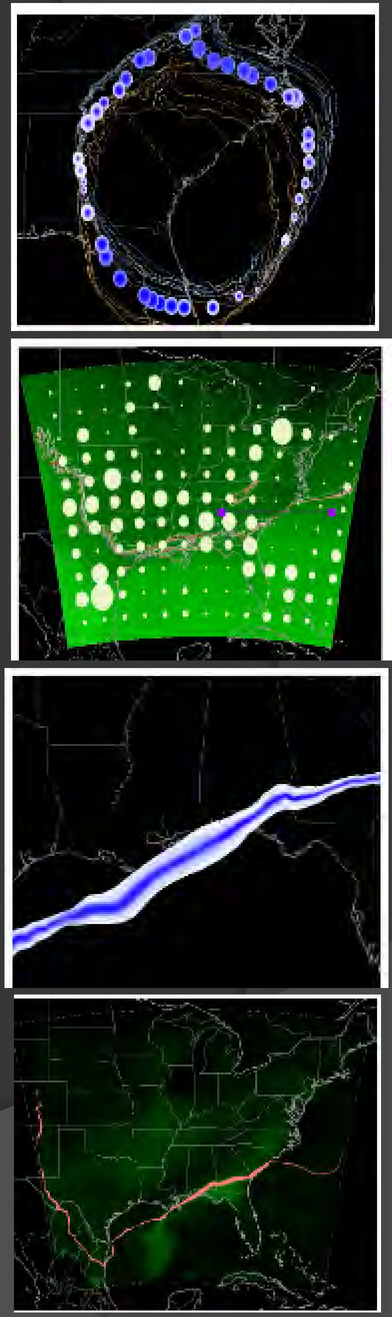


- Spaghetti plots
- Also, the underlying gradient of the variable is important!
  (reiterated in Sanyal 2010)
- Operational personnel simply throw away most of the data
- A large part of the training of meteorologists is to train themselves to understand the 3-D nature of atmosphere from these 2-D slices

Image:
http://www.hpc.ncep.noaa.gov/ensembletraining/ensembletraining.htm

Visualization

- PhD thesis
  - Develop and evaluate new 1D, 2D, and 3D visualization techniques for ensemble simulations
  - Weather model (WRF) parameter ensembles
  - River flow and inundation (HEC-RAS) ensembles
  - Learn what works and what doesn’t
  - “I see” and “we see”: Closed feedback loop with domain experts



Data sets

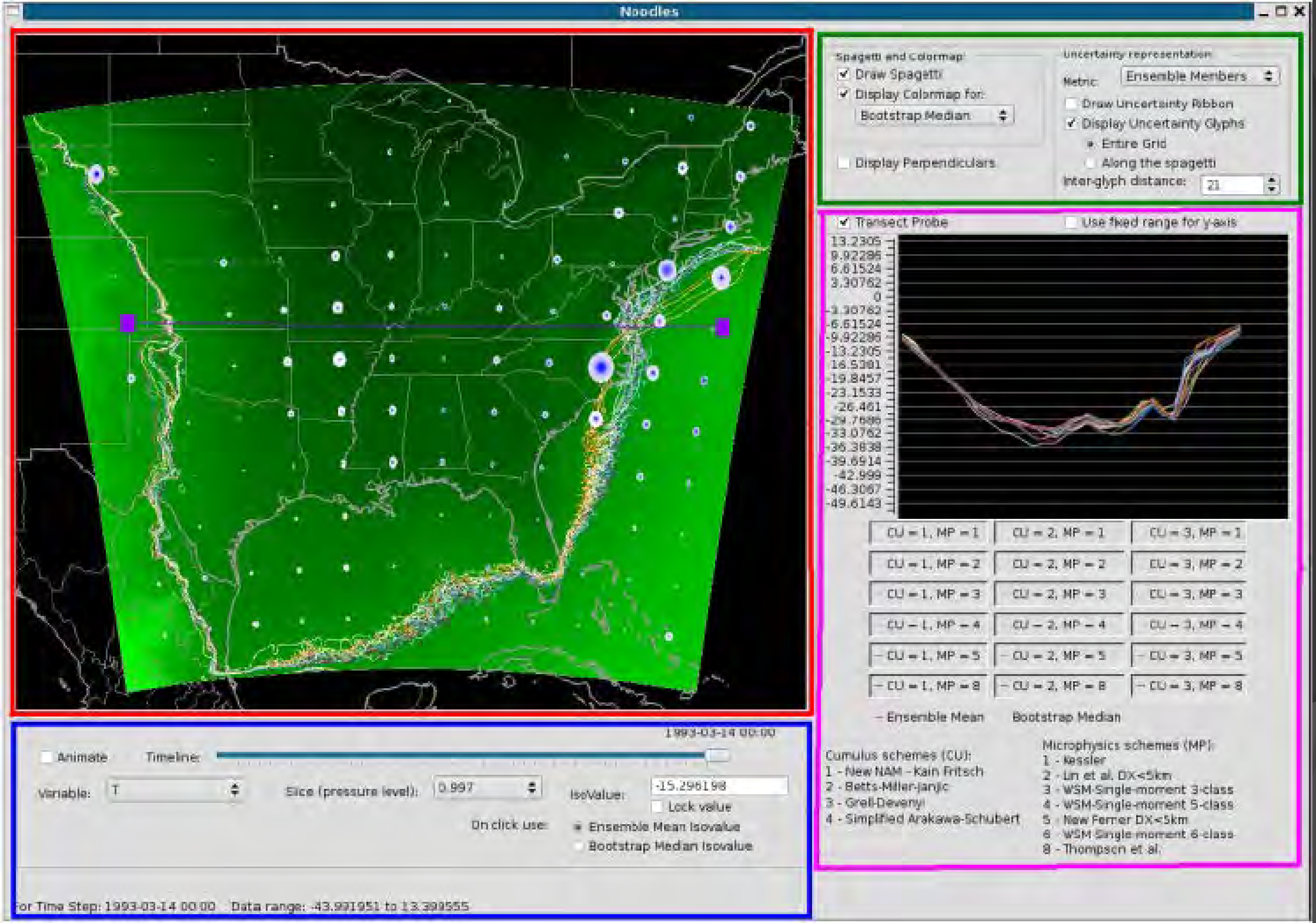
- Parameter ensemble
  - 6 microphysics schemes
  - 3 cumulus precipitation schemes
  - 6x3=18 member ensemble
- 1993 Superstorm
  - 12-14 Mar 1993
- Hurricane Fran
  - Aug – Sep 1996
- Oklahoma tornado outbreak
  - May 1999



Uncertainty estimation

- Initially, we looked at three variables:
  - Pressure (P)
  - Temperature (T)
  - Water-vapor mixing ratio (Q)
- Uncertainty estimation:
  - Standard deviation, IQR, 95% CI
  - Performed bootstrapping on the data with 1000 resamples
    - Width of the 95% CI or IQR

Noodles



☑ Draw Spagetti
☑ Display Colormap for: Bootstrap Median
☐ Display Perpendiculars

Metric: Ensemble Members
☐ Draw Uncertainty Ribbon
☑ Display Uncertainty Glyphs
● Entire Grid
○ Along the spagetti
Inter-glyph distance: 21

☑ Transect Probe
☐ Use fixed range for y-axis

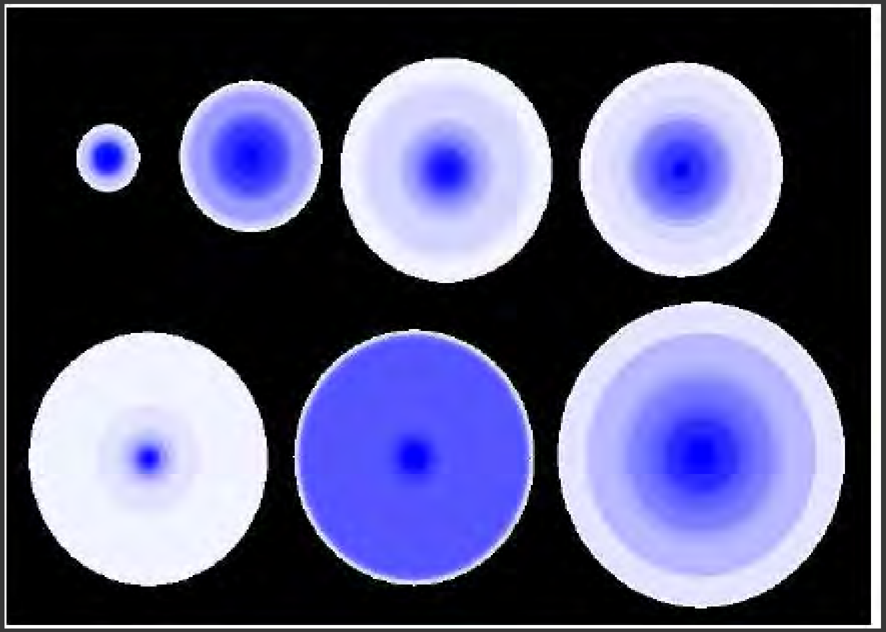
Cumulus schemes (CU):
1 - New NAM - Kain Fritsch
2 - Betts-Miller-Janjic
3 - Grell-Deveny
4 - Simplified Arakawa-Schubert

Microphysics schemes (MP):
1 - Kessler
2 - Lin et al. DX<5km
3 - WSM-Single-moment 3-class
4 - WSM-Single-moment 5-class
5 - New Ferrier DX<5km
6 - WSM Single-moment 6-class
8 - Thompson et al.

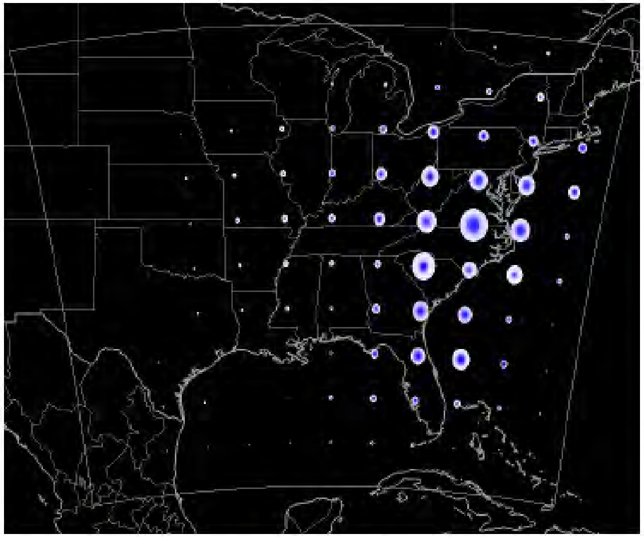
1993-03-14 00:00
☐ Animate
Timeline:
Variable: T
Slice (pressure level): 0.997
IsoValue: -15.296198
☐ Lock value
On click use:
● Ensemble Mean Isovalue
○ Bootstrap Median Isovalue

For Time Step: 1993-03-14 00:00 Data range: -43.991951 to 13.399555

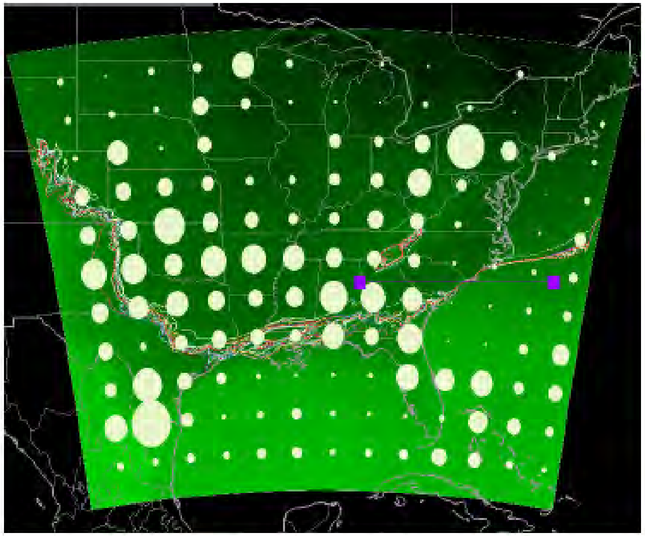
Graduated Uncertainty Glyphs



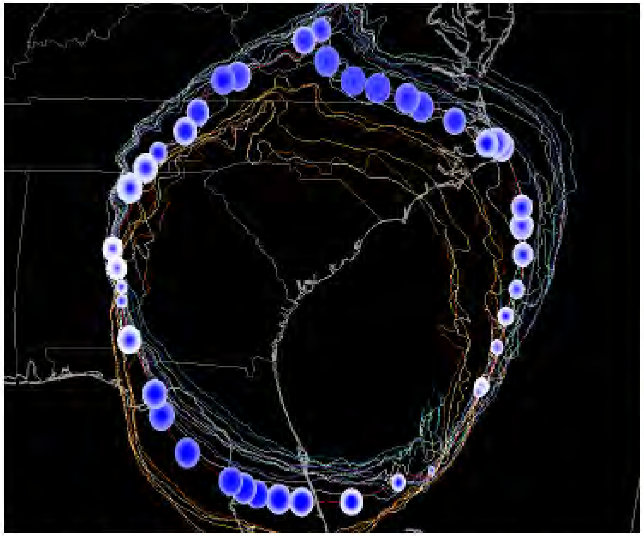
Visualization techniques – spagetti and glyphs



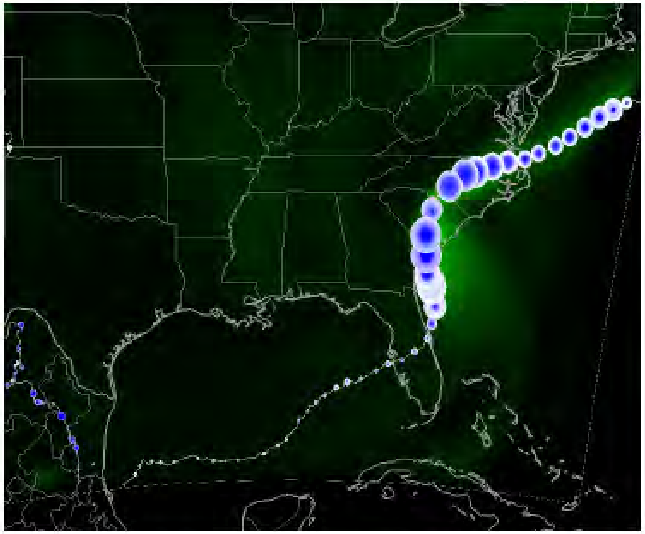
(a) Graduated uncertainty glyphs on the entire grid calculated for pressure at 1800 on 13 March.



(b) Glyphs showing the width of the 95% CI of the ensemble mean for temperature at 1200 on 12 March. The background colormap shows the ensemble mean for temperature.

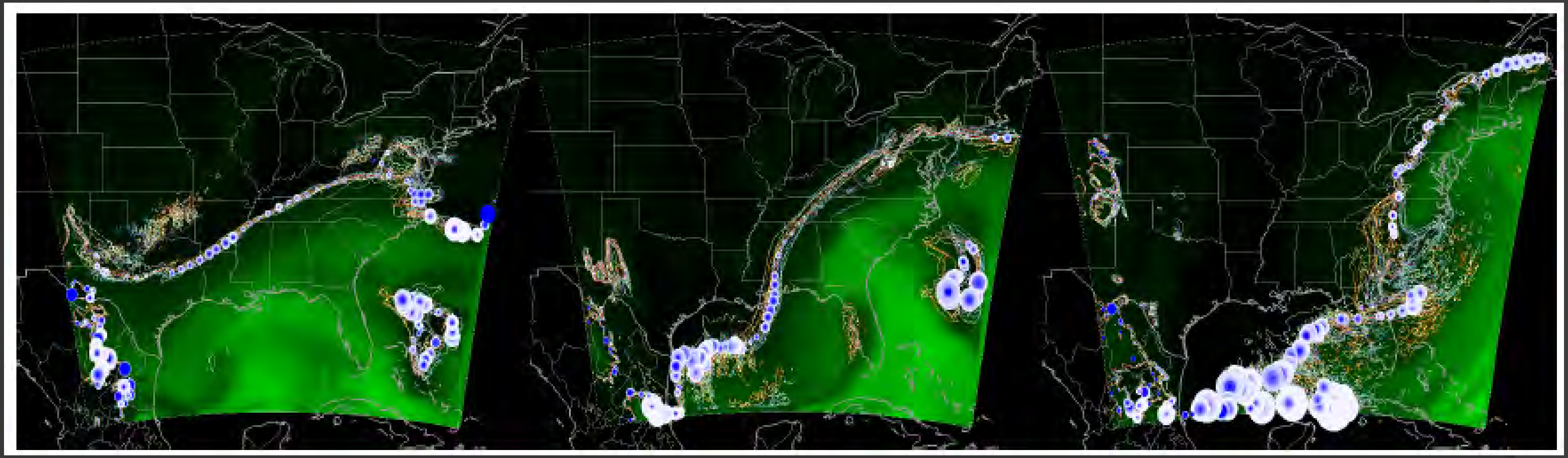


(c) Graduated glyphs along a pressure contour along with a spaghetti plot at 1500 on 13 March.

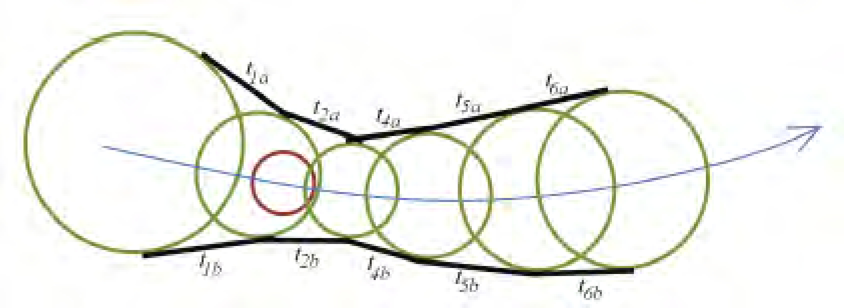


(d) Graduated glyphs along a temperature contour and 95% CI colormap at 1800 on 13 March.

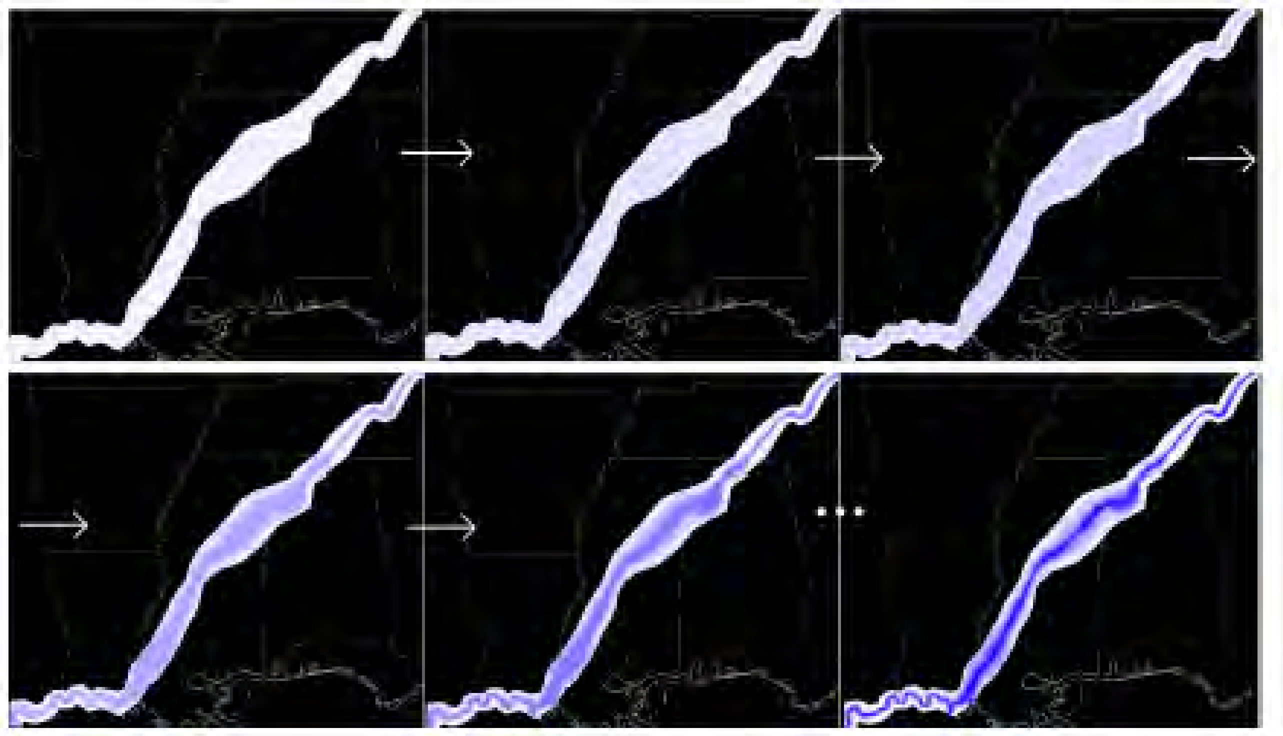
Spagetti and glyphs



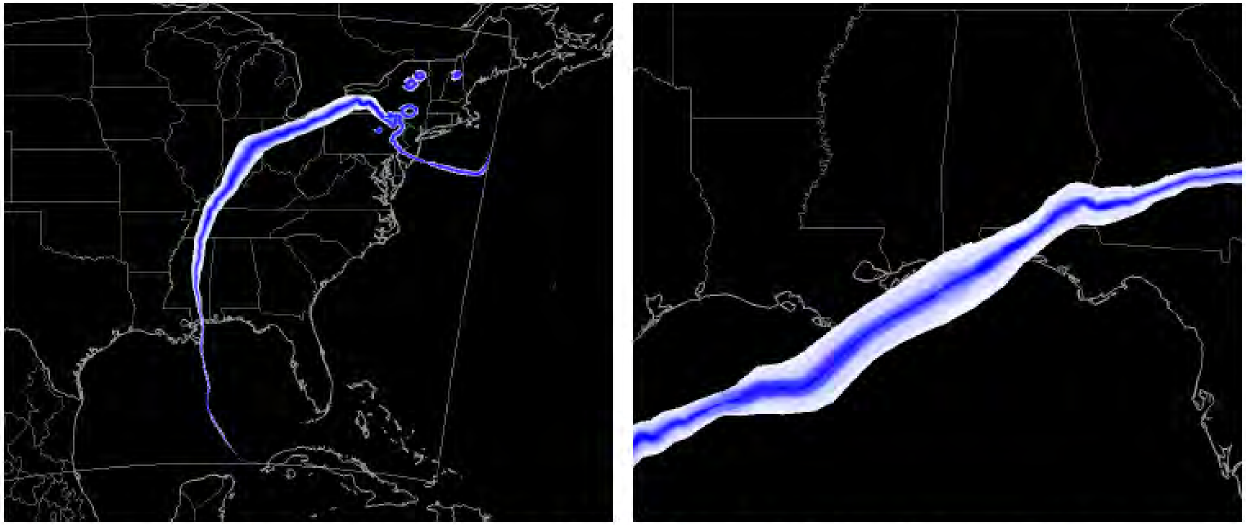
Uncertainty Ribbon



Graduated Uncertainty Ribbon

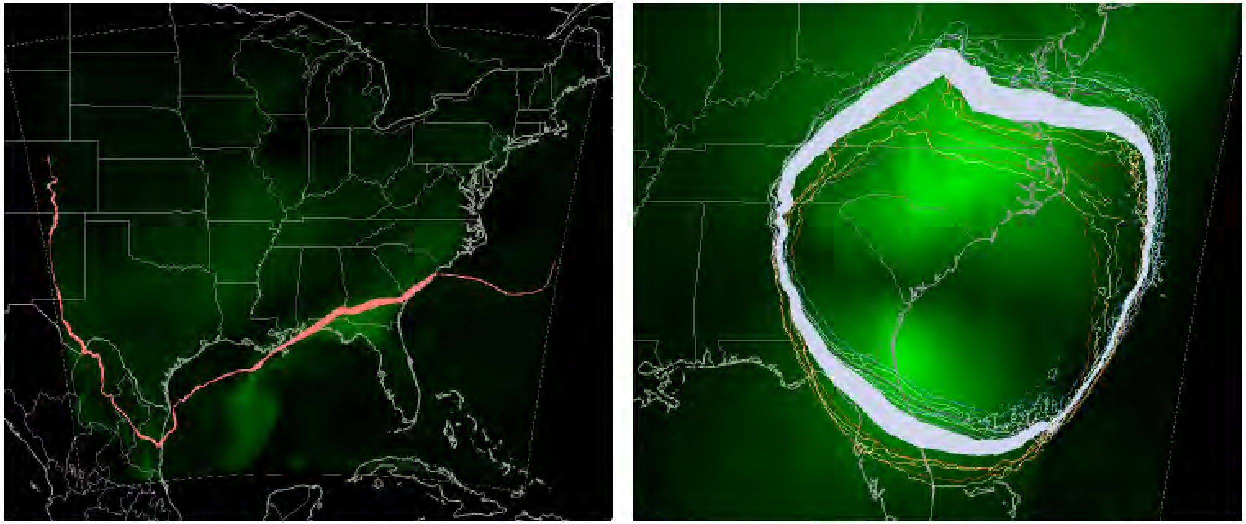


Uncertainty ribbons



(a) Use of a graduated ribbon to illustrate uncertainty of pressure at 1400 on 13 March.

(b) Close up of a graduated uncertainty ribbon illustrating the distribution of values for temperature at 2300 on 12 March.



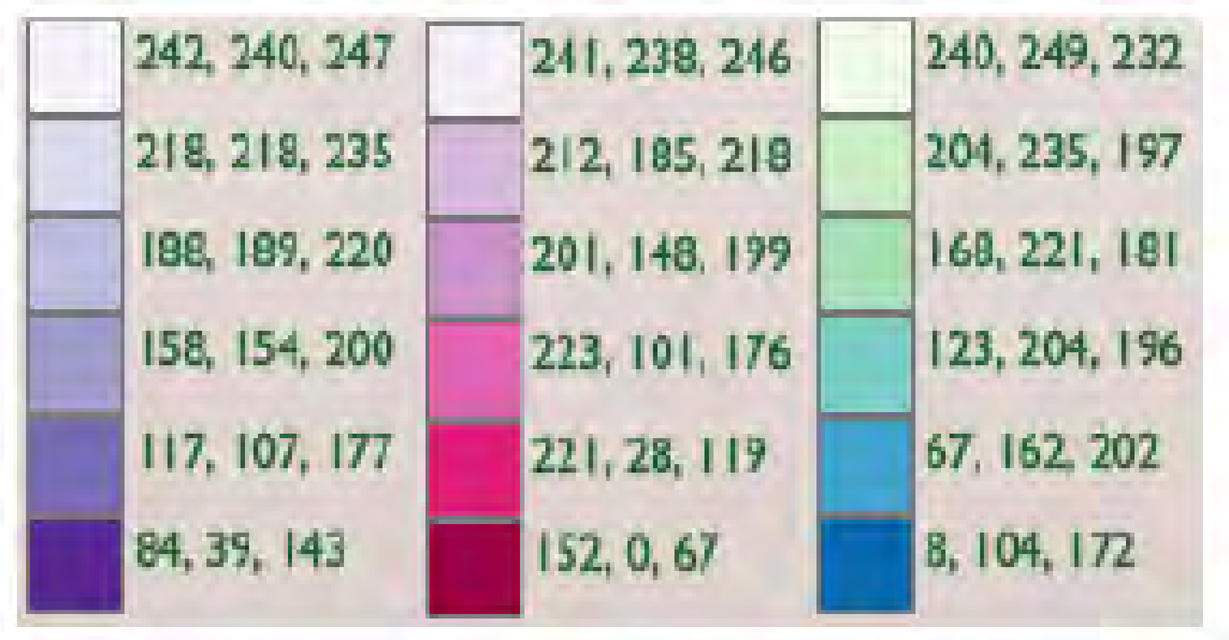
(c) Uncertainty ribbon showing the bootstrap IQR for temperature with a colormap of the ensemble IQR at 2300 on 12 March.

(d) Uncertainty ribbon showing the bootstrap IQR for pressure with a colormap of the ensemble standard-deviation at 1700 on 13 March.

Perception based design

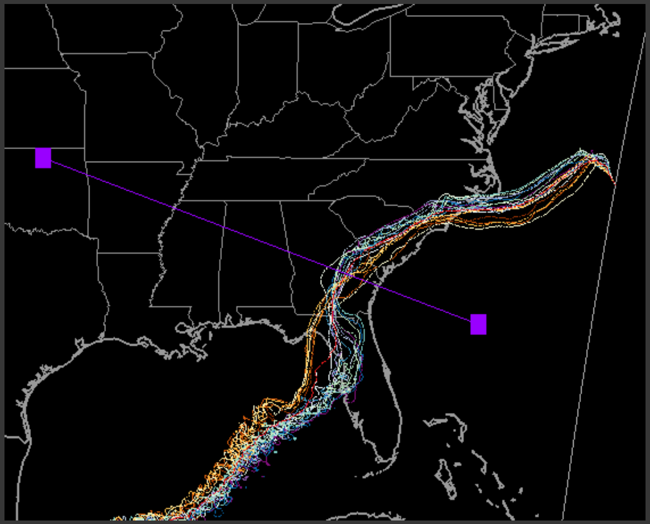
Cumulus parameterizations

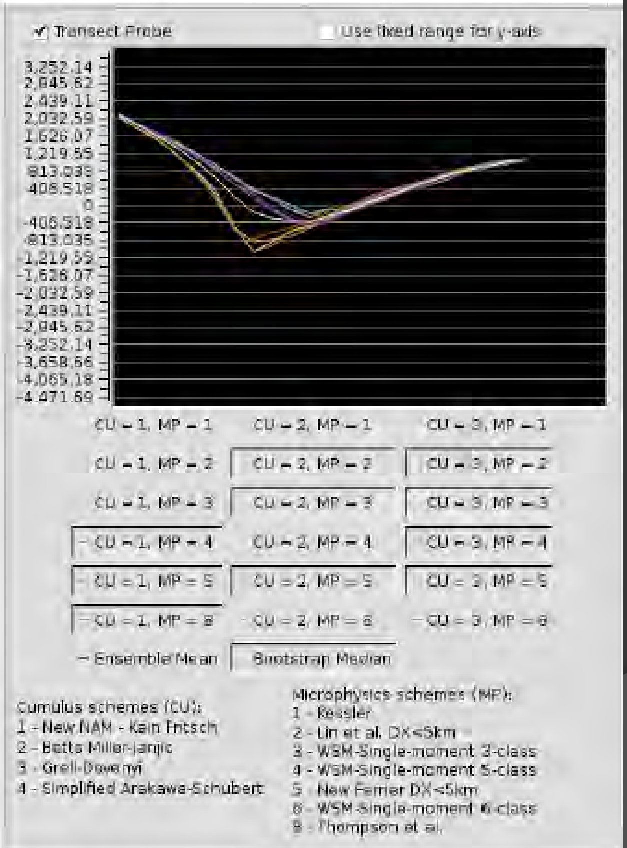
Microphysics



242, 240, 247	241, 238, 246	240, 249, 232
218, 218, 235	212, 185, 218	204, 235, 197
188, 189, 220	201, 148, 199	168, 221, 181
158, 154, 200	223, 101, 176	123, 204, 196
117, 107, 177	221, 28, 119	67, 162, 202
84, 39, 143	152, 0, 67	8, 104, 172

Interactivity





☑ Transect Probe

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Improvements

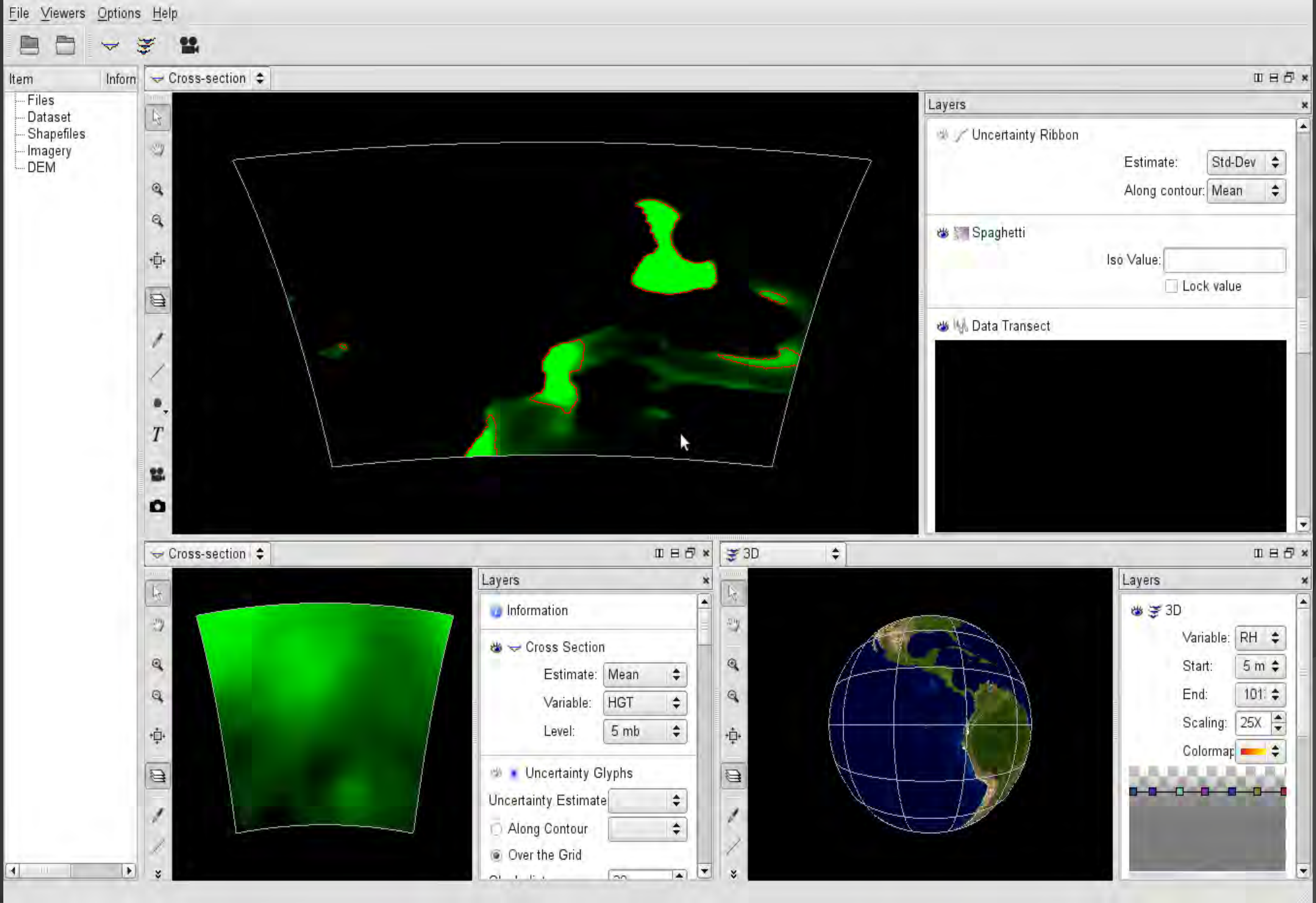
- More variables

  a. Temperature
  b. Wind magnitude, direction
  c. Geopotential height
  d. Surface temperature
  e. 2M temp
  f. 2m specific humidity
  g. 10 m u and v winds
  h. skin temperature
  i. surface latent heat flux
  j. Sensible heat flux
  k. storm helicity
  l. CAPE
  m. CIN
  n. Accumulated total precipitation
  o. Precipitation rate
  p. Composite radar reflectivity
  q. MSLP

Improvements

- Multi-view, multi-variable visualization
- Multi-technique uncertainty visualization
- 3D volumetric visualization
- Smart data management

Noodles 2



Uncertainty Ribbon

Estimate: Std-Dev

Along contour: Mean

Spaghetti

Iso Value:

☐ Lock value

Data Transect

Information

Cross Section

Estimate: Mean

Variable: HGT

Level: 5 mb

Uncertainty Glyphs

Uncertainty Estimate

○ Along Contour

● Over the Grid

3D

Variable: RH

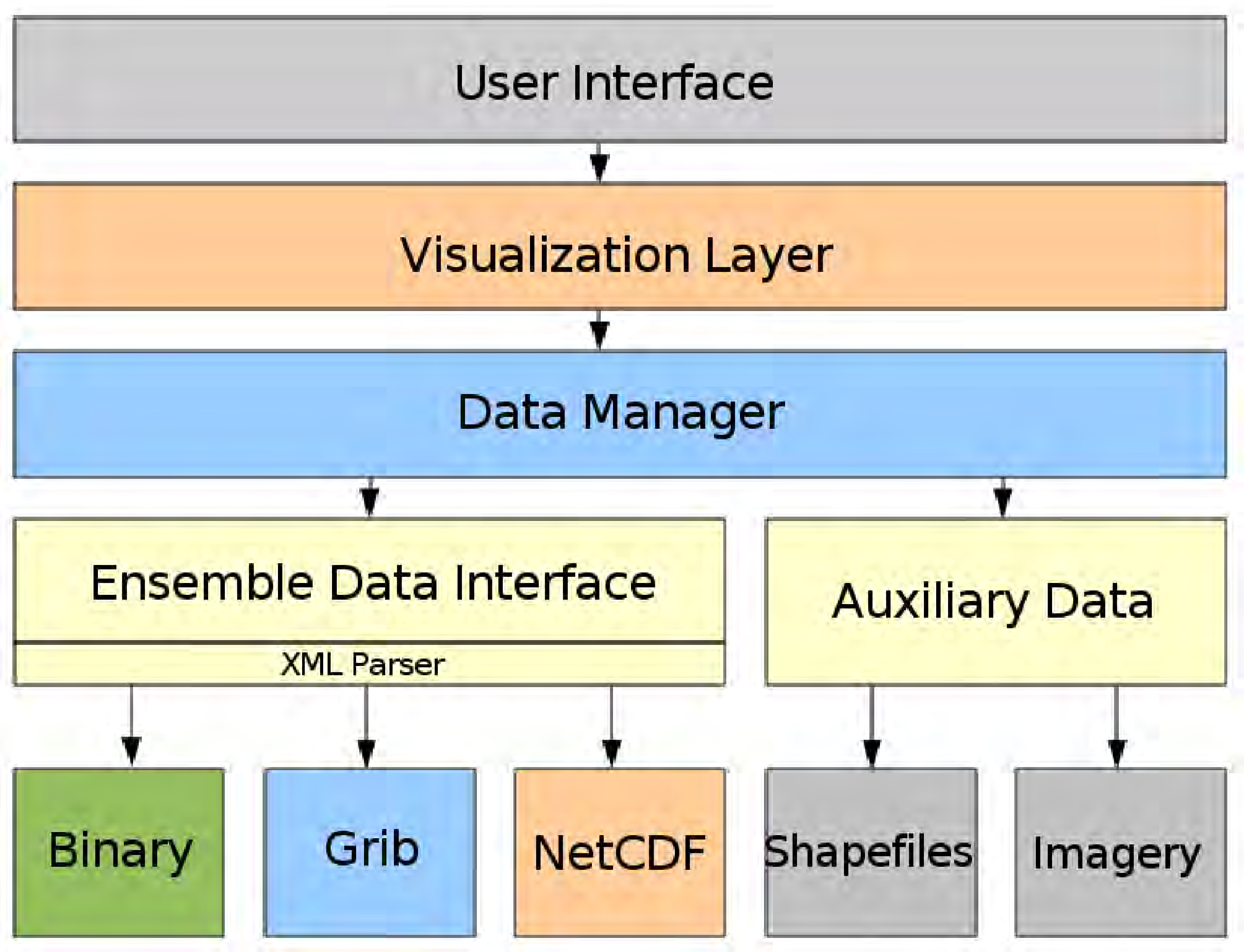
Start: 5 m

End: 101

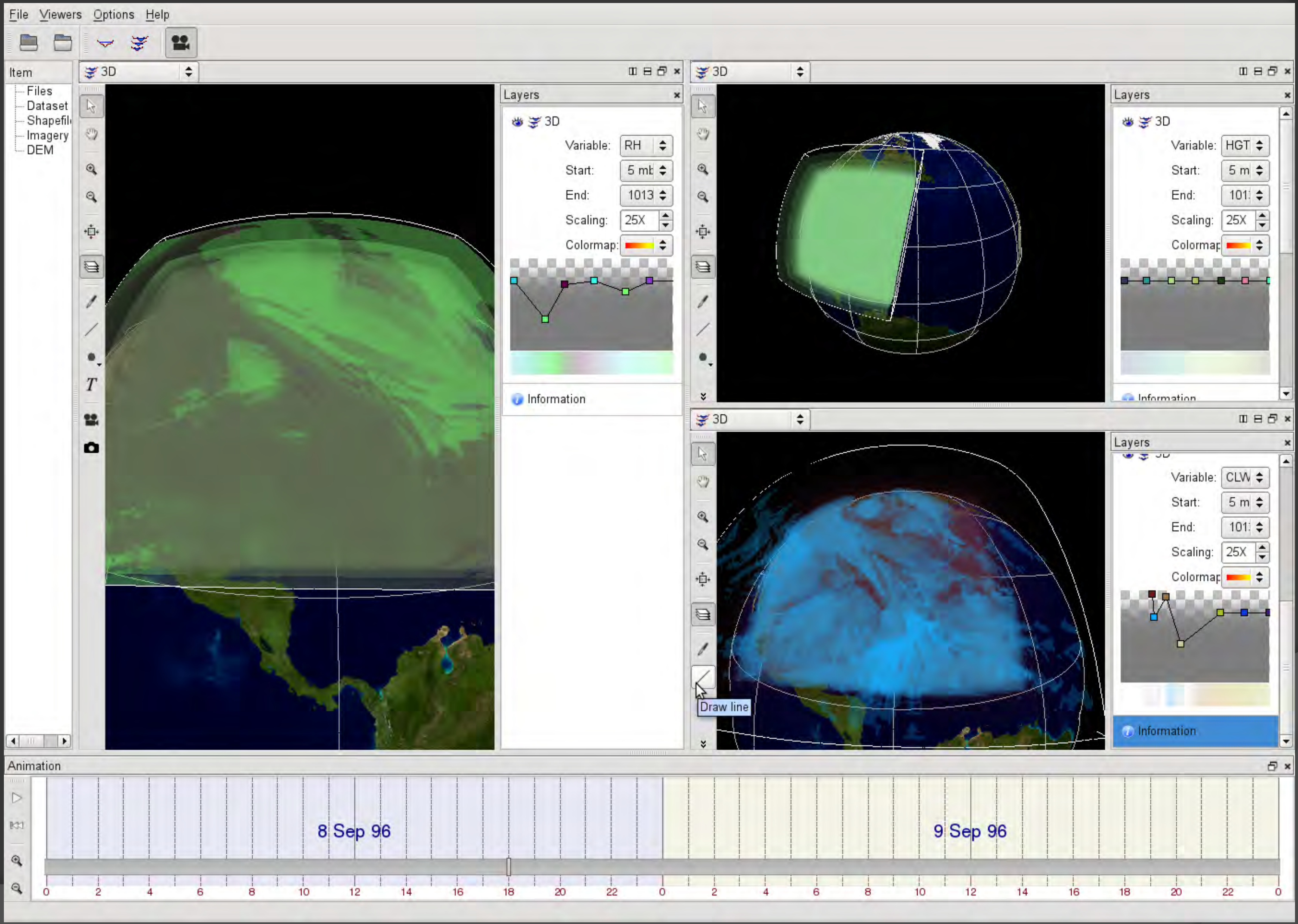
Scaling: 25X

Colormap

Architecture



Another image



3D

Variable: RH

Start: 5 mt

End: 1013

Scaling: 25X

Colormap:

3D

Variable: HGT

Start: 5 m

End: 101

Scaling: 25X

Colormap

Variable: CLW

Start: 5 m

End: 101

Scaling: 25X

Colormap

Impact of success

- For the scientists:
  - Improved forecasting techniques and tool
  - Informed decision making
  - Improved knowledge discovery framework
  - Possible insight into simulation design
- For the public:
  - More life and property can be saved
  - Economic benefits
    - Better utilization of resources
    - Improvement in efficiency of efforts like evacuation

Future directions

- Robust 1D , 2D, and 3D ensemble visualization techniques
  - Data format support
- 3D visualization of weather is least understood
  - Strive to bridge the gap
  - Possible challenges: data size, feature identification, feature driven uncertainty visualization, knowledge discovery
- Explore ways to study temporal uncertainty
- Result of research should lead to products (Dr. Philip Amburn)
  - Hopefully produce tools or prototypes of tools
- “They see”: problem of knowledge dissemination
  - Explore ways to tell the public
  - Explore ways to tell the emergency responders

Thank you!