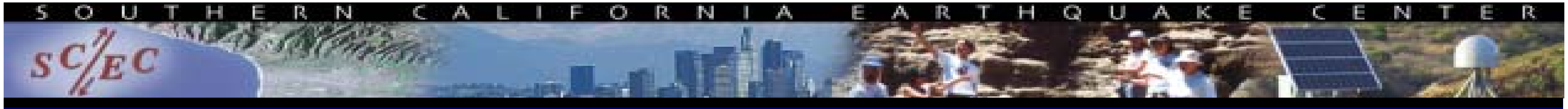


The Southern California Earthquake Center Information Technology Research Initiative

Toward a Collaboratory for System-Level Earthquake Science

Tom Jordan – USC

Kim Olsen - UCSB

4th Meeting of the US-Japan Natural Resources Panel on Earthquake Research
Morioka, November 6-9, 2002

Collaboratory Concept

“The fusion of computers and electronic communications has the potential to dramatically enhance the output and productivity of U.S. researchers. A major step toward realizing that potential can come from combining the interests of the scientific community at large with those of the computer science and engineering community to create *integrated, tool-oriented computing and communication systems to support scientific collaboration*. Such systems can be called ‘collaboratories’.”

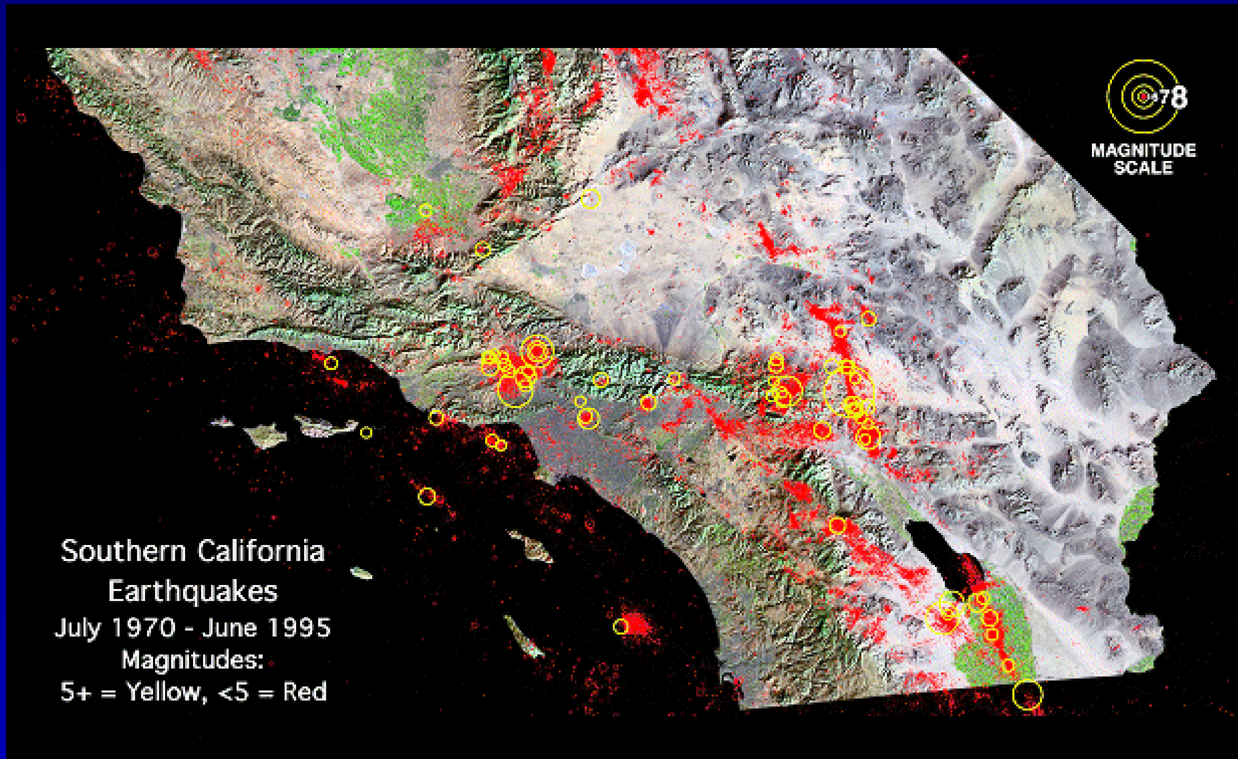
From *National Collaboratories: Applying Information Technology for Scientific Research,* Computer Science and Telecommunications Board, National Research Council, 1993.

SCEC Collaboratory

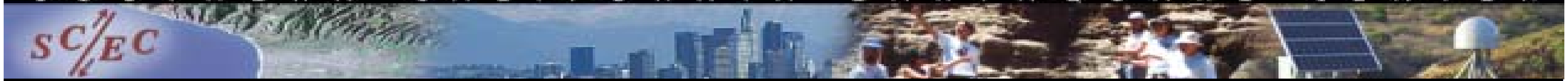
An information infrastructure organized and maintained to support the distributed scientific activities and product development essential to seismic hazard analysis and emergency response to earthquake disasters.

Southern California: a Natural Laboratory for Understanding Seismic Hazard and Managing Risk

- Tectonic diversity
- Complex fault network
- High seismic activity
- Excellent geologic exposure
- Rich data sources
- Large urban population with densely built environment ⇒ high risk



- Extensive research program coordinated by Southern California Earthquake Center (SCEC) under NSF and USGS sponsorship



Southern California Earthquake Center

Core Institutions

California Institute of Technology
Columbia University
Harvard University
Massachusetts Institute of Technology
San Diego State University
Stanford University
U.S. Geological Survey (3 offices)
University of California, Los Angeles
University of California, San Diego
University of California, Santa Barbara
University of Nevada, Reno
University of Southern California (lead)

- Consortium of 14 core institutions and 26 other participating organizations, founded as an NSF STC in 1991
- Co-funded by NSF and USGS under the National Earthquake Hazards Reduction Program (NEHRP)
- Mission:
  - Gather all kinds of data on earthquakes in Southern California
  - Integrate information into a comprehensive, physics-based understanding of earthquake phenomena
  - Communicate understanding to end-users and the general public to increase earthquake awareness, reduce economic losses, and save lives

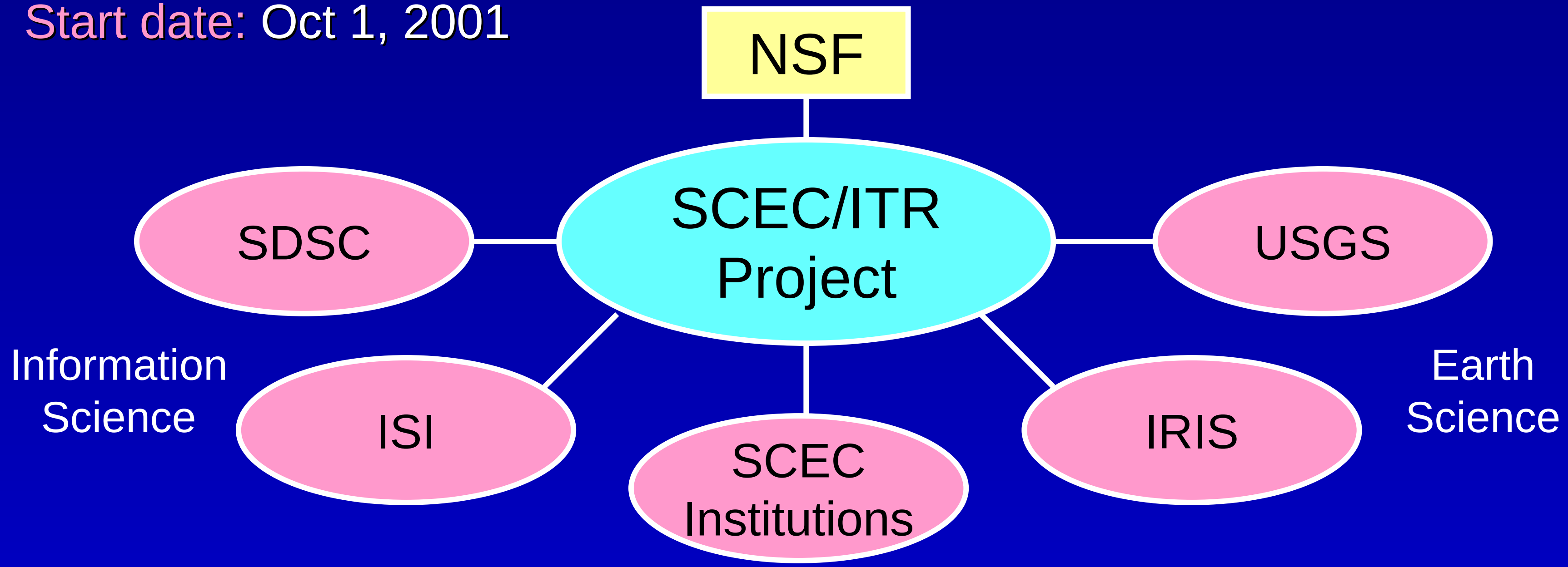
http://www.scec.org

SCEC/ITR Project

Goal: To develop a cyberinfrastructure that can support system-level earthquake science – the SCEC Collaboratory

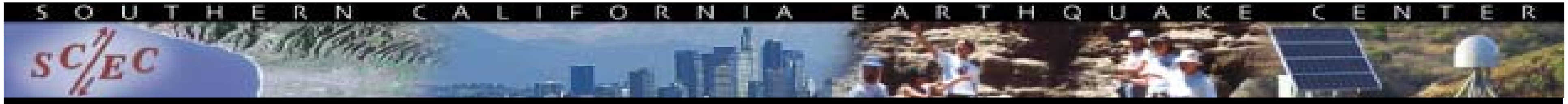
Funding: $10M grant over 5 yrs from NSF/ITR program (CISE and Geoscience Directorates)

Start date: Oct 1, 2001



Problem Focus of SCEC ITR

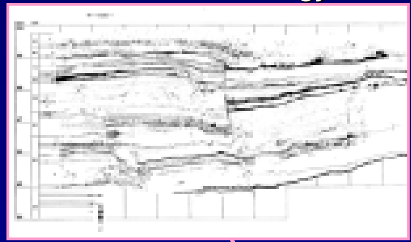
Use physics-based earthquake forecasting and wavefield simulation to improve seismic hazard analysis for performance-based design.



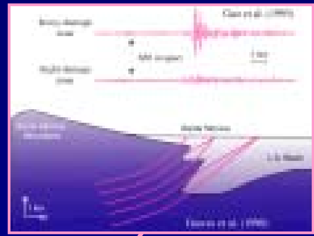
Components of Seismic Hazard Analysis

Seismicity (ANSS)

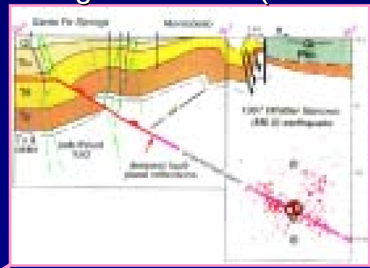
Paleoseismology



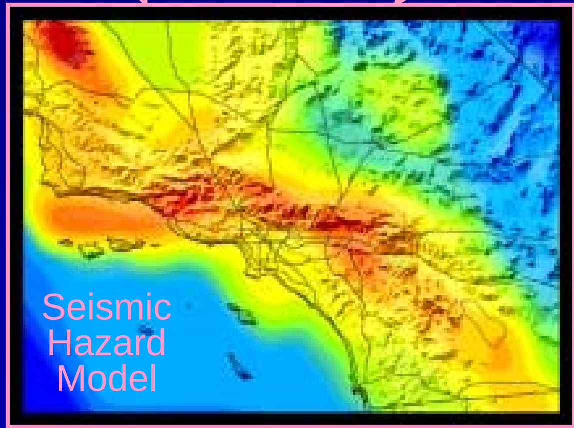
Local site effects

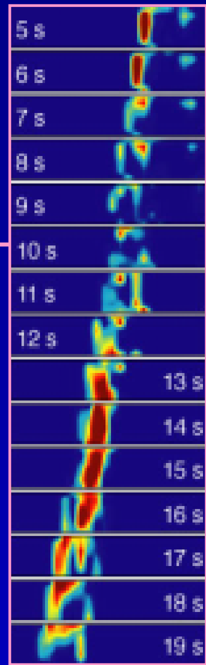


Geologic structure (USArray)

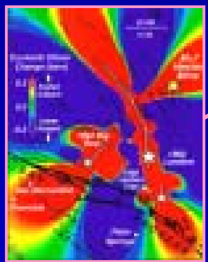


Faults (USArray)



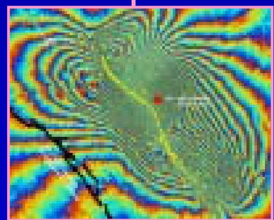


Rupture dynamics (SAFOD, ANSS, & USArray)

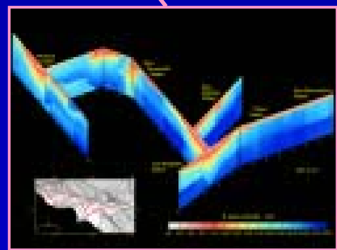


Stress transfer (InSAR, PBO, & SAFOD)

Crustal motion (PBO)



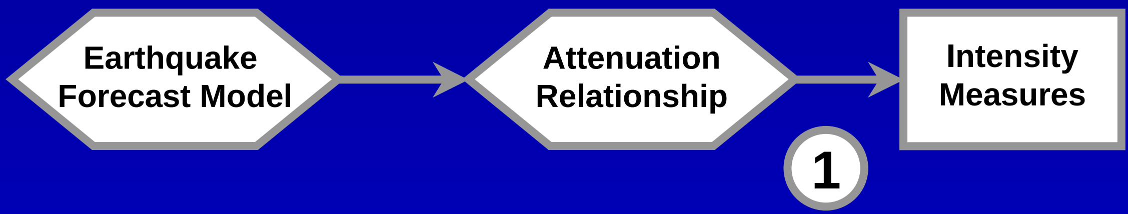
Crustal deformation (InSAR)



Seismic velocity structure (USArray)

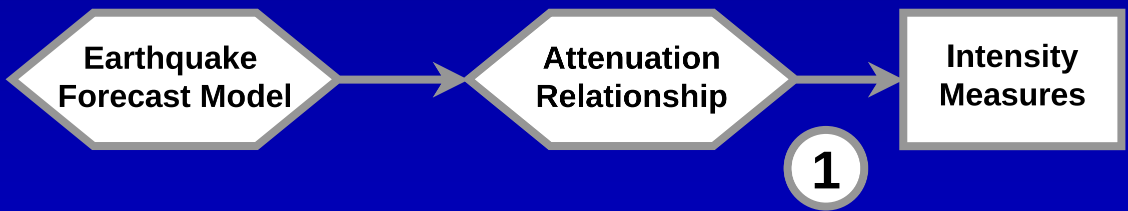
Computational Pathways

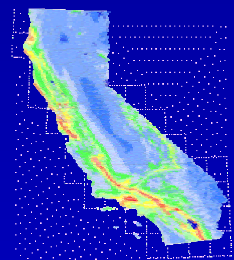
Pathway 1: Standard Seismic Hazard Analysis

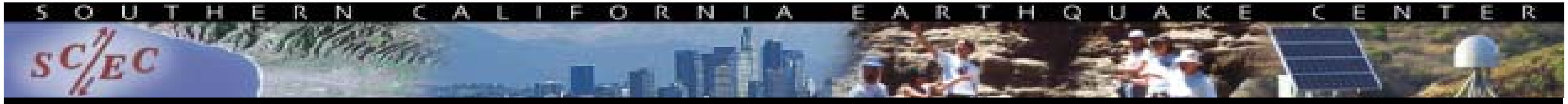


Computational Pathways

Pathway 1: Standard Seismic Hazard Analysis

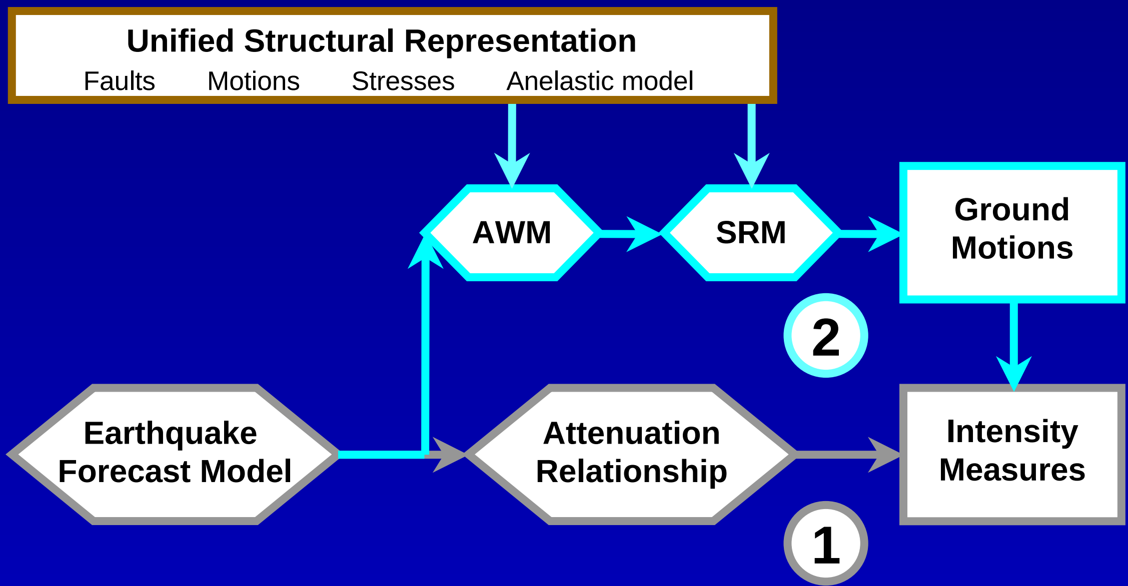


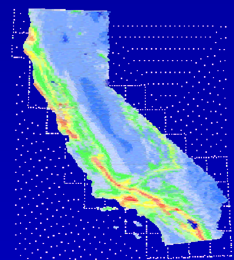




Computational Pathways

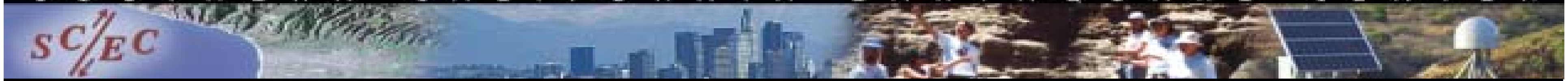
Pathway 2: Ground motion simulation





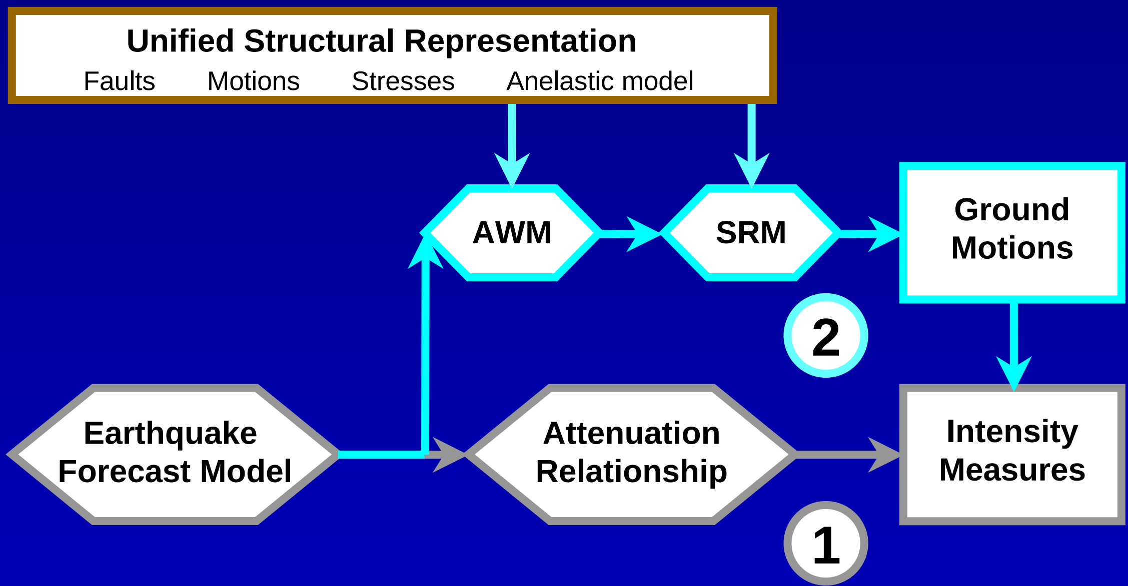
AWM = Anelastic Wave Model

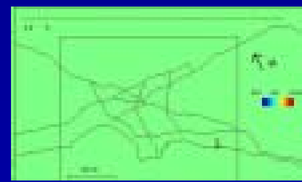
SRM = Site Response Model

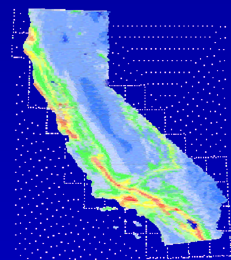


Computational Pathways

Pathway 2: Ground motion simulation



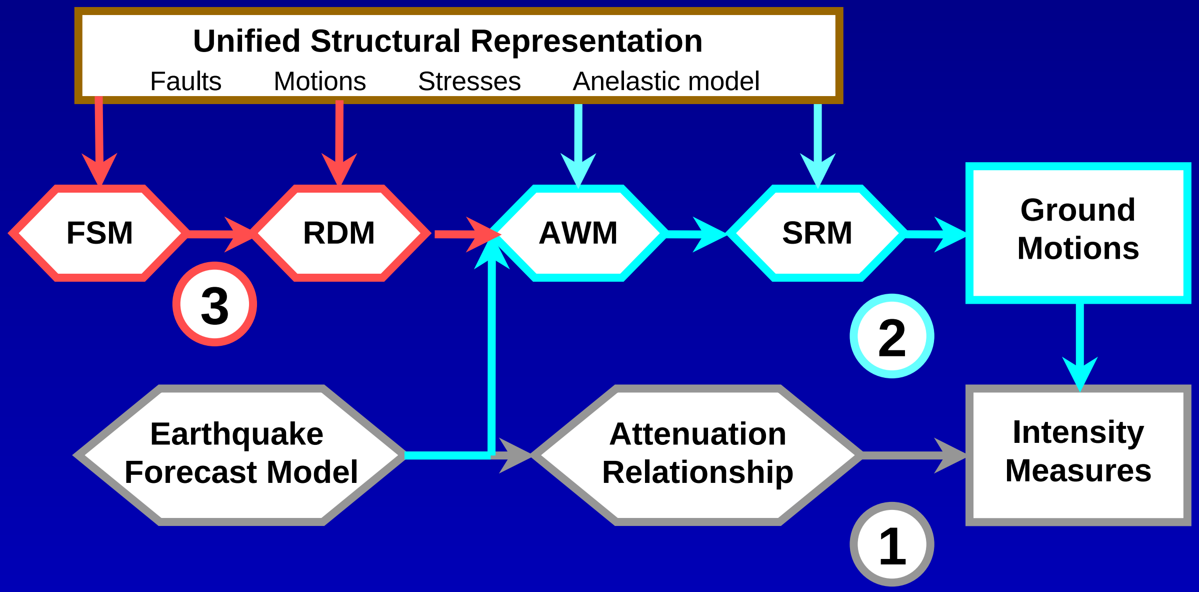


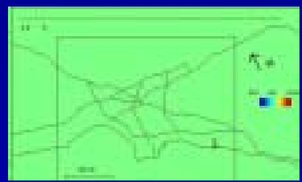


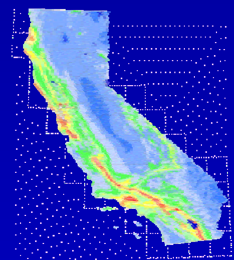
AWM = Anelastic Wave Model
SRM = Site Response Model

Computational Pathways

Pathway 3: Physics-based earthquake forecasting





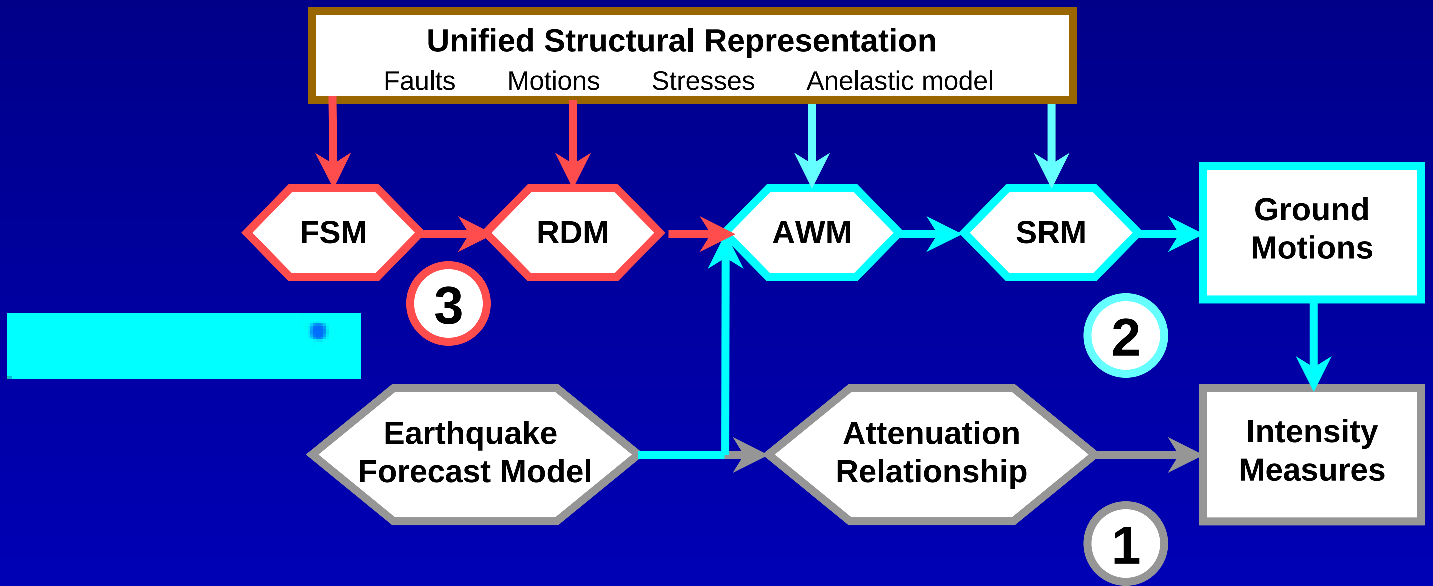


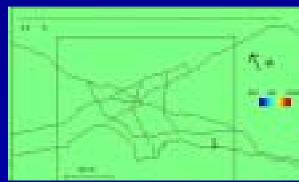
FSM = Fault System Model
RDM = Rupture Dynamics Model

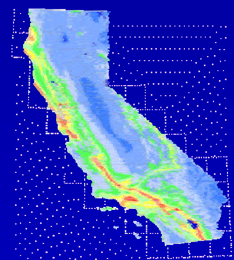
AWM = Anelastic Wave Model
SRM = Site Response Model

Computational Pathways

Pathway 3: Physics-based earthquake forecasting





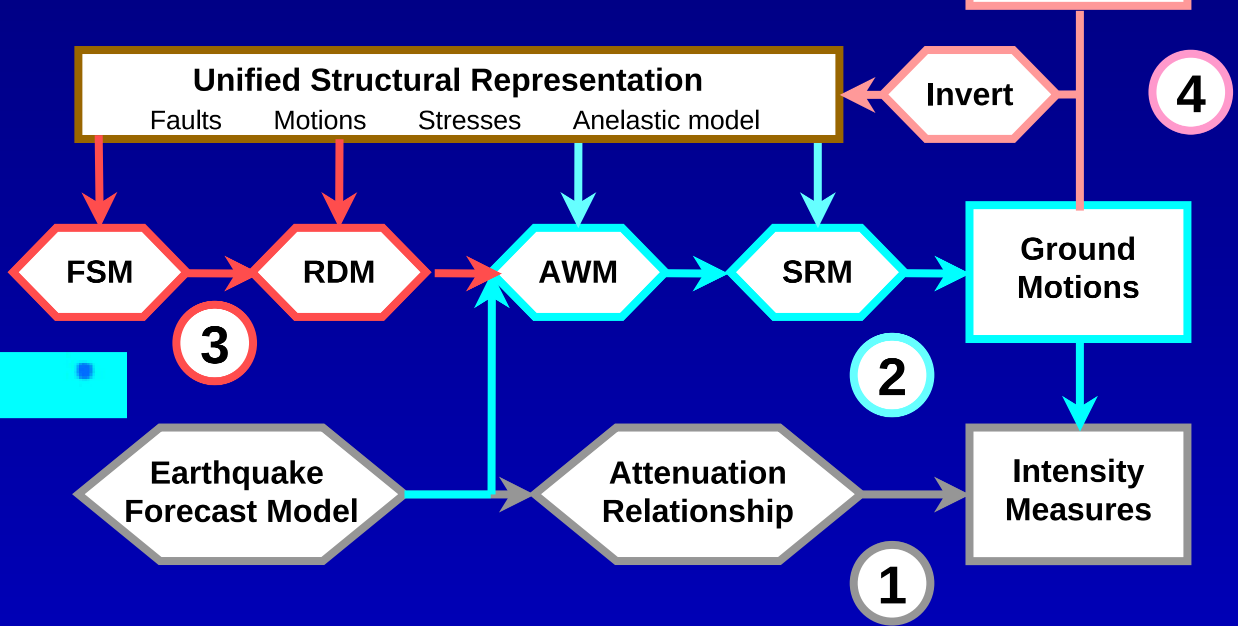


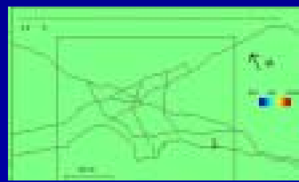
FSM = Fault System Model
RDM = Rupture Dynamics Model

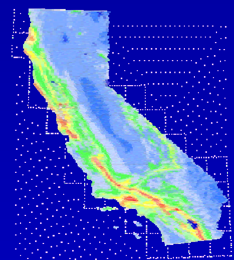
AWM = Anelastic Wave Model
SRM = Site Response Model

Computational Pathways

Pathway 4: Ground motion inverse problem



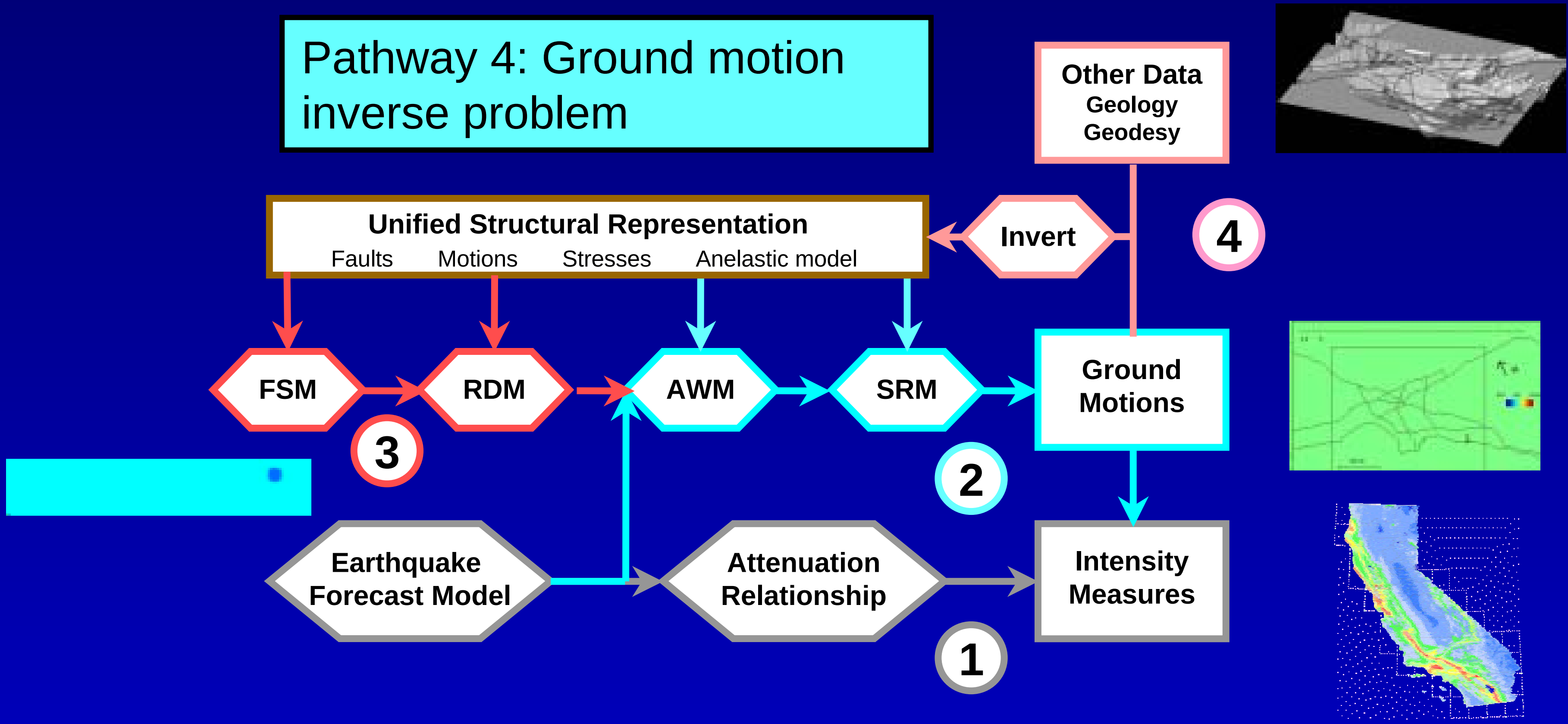




FSM = Fault System Model
RDM = Rupture Dynamics Model

AWM = Anelastic Wave Model
SRM = Site Response Model

Computational Pathways



FSM = Fault System Model
RDM = Rupture Dynamics Model

AWM = Anelastic Wave Model
SRM = Site Response Model

Science Goals

Science Goals

- Construct an open-source, object-oriented, and web-enabled framework for SHA computations that can incorporate a variety of earthquake forecast models, intensity-measure relationships, and site-response models

Science Goals

- Construct an open-source, object-oriented, and web-enabled framework for SHA computations that can incorporate a variety of earthquake forecast models, intensity-measure relationships, and site-response models
- Utilize the predictive power of dynamic-rupture and wavefield simulations in modeling time-dependent ground motion for scenario earthquakes and constructing intensity-measure relationships

Science Goals

- Construct an open-source, object-oriented, and web-enabled framework for SHA computations that can incorporate a variety of earthquake forecast models, intensity-measure relationships, and site-response models
- Utilize the predictive power of dynamic-rupture and wavefield simulations in modeling time-dependent ground motion for scenario earthquakes and constructing intensity-measure relationships
- Incorporate fault-system models into time-dependent earthquake forecasts

ITR Goals

To develop an information infrastructure for system-level earthquake science to create a *SCEC collaboratory* that can:

ITR Goals

To develop an information infrastructure for system-level earthquake science to create a *SCEC collaboratory* that can:

– Capture and manipulate the knowledge that will permit a variety of users with different levels of sophistication to configure complex computational pathways.

ITR Goals

To develop an information infrastructure for system-level earthquake science to create a *SCEC collaboratory* that can:

- Capture and manipulate the knowledge that will permit a variety of users with different levels of sophistication to configure complex computational pathways.
- Enable execution of physics-based simulations and data inversions that incorporate advances in fault-system dynamics, rupture dynamics, wave propagation, and non-linear site response.

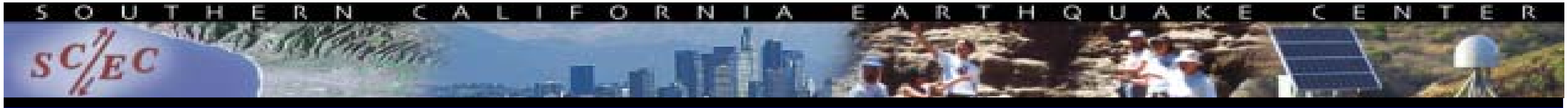
ITR Goals

To develop an information infrastructure for system-level earthquake science to create a *SCEC collaboratory* that can:

– Capture and manipulate the knowledge that will permit a variety of users with different levels of sophistication to configure complex computational pathways.

– Enable execution of physics-based simulations and data inversions that incorporate advances in fault-system dynamics, rupture dynamics, wave propagation, and non-linear site response.

– Manage large, distributed collections of simulation results, as well as the large sets of geologic, geodetic and seismologic data required to validate the simulations and constrain parameter values.



ITR Goals

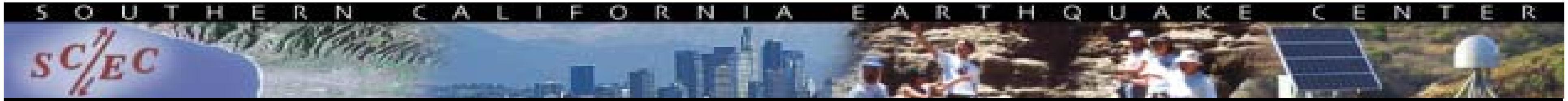
To develop an information infrastructure for system-level earthquake science to create a *SCEC collaboratory* that can:

- Capture and manipulate the knowledge that will permit a variety of users with different levels of sophistication to configure complex computational pathways.
- Enable execution of physics-based simulations and data inversions that incorporate advances in fault-system dynamics, rupture dynamics, wave propagation, and non-linear site response.
- Manage large, distributed collections of simulation results, as well as the large sets of geologic, geodetic and seismologic data required to validate the simulations and constrain parameter values.
- Provide access to SHA products and methodologies to end-users outside of the SCEC community, including practicing engineers, emergency managers, decision-makers, and the general public.

Educational Goals

Educational Goals

- Cross-train earth scientists and computer scientists
  - Terminology and problem orientation
  - Methodology
  - Current capabilities and research goals

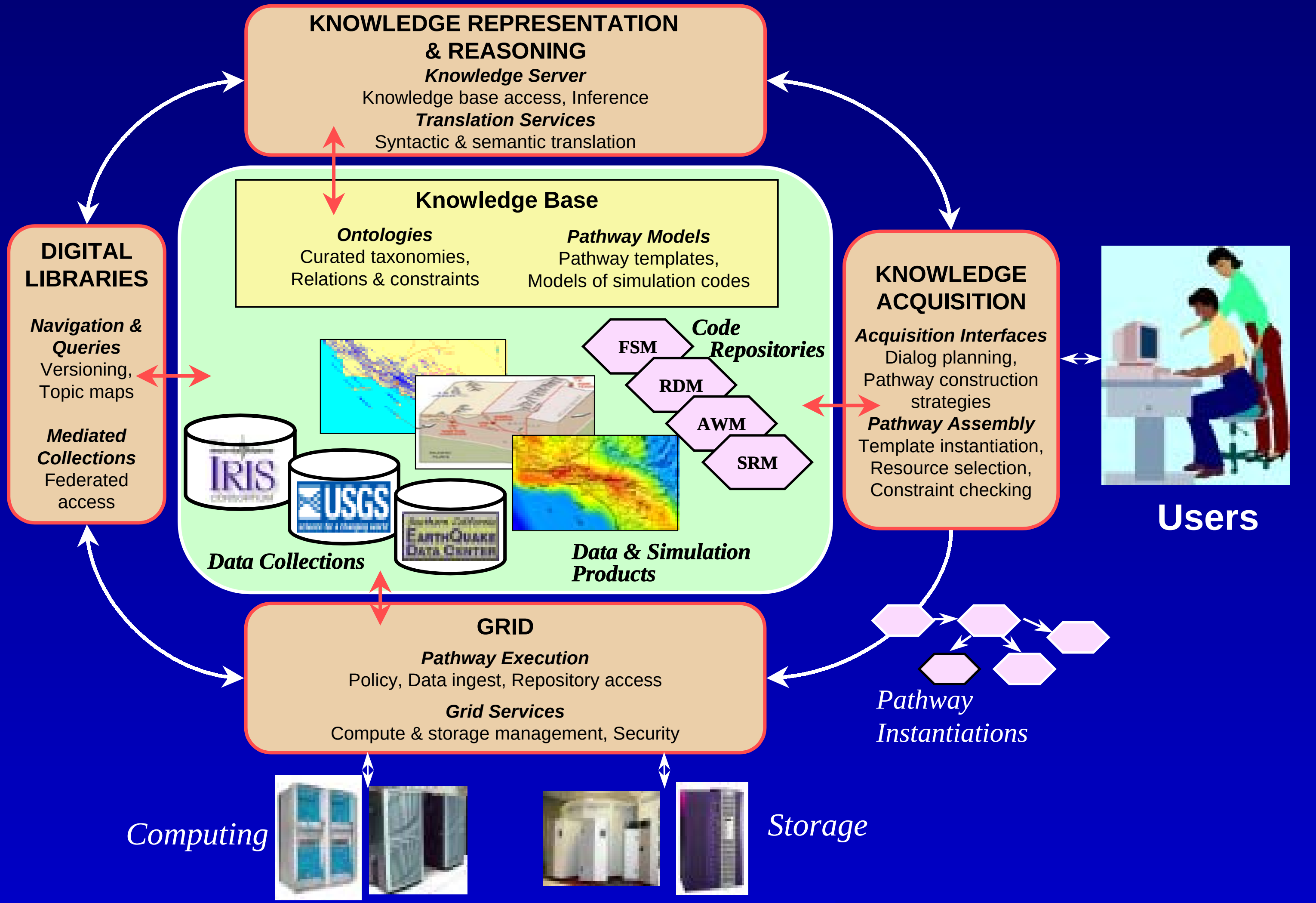


Educational Goals

- Cross-train earth scientists and computer scientists
  - Terminology and problem orientation
  - Methodology
  - Current capabilities and research goals
- Provide IT tools for the SCEC communication, education, and outreach mission
  - Better public access to earthquake information
  - Knowledge transfer to end-users in engineering, emergency response, and public policy

SCEC Collaboratory

An information infrastructure for system-level earthquake science



Short-Term Objectives

Short-Term Objectives

- Development and verification of the computational modules

Short-Term Objectives

- Development and verification of the computational modules
- Standardization of data structures and interfaces needed for model interoperability

Short-Term Objectives

- Development and verification of the computational modules
- Standardization of data structures and interfaces needed for model interoperability
- Development of object classes, control vocabularies, and ontologies for knowledge management and model interoperability

Short-Term Objectives

- Development and verification of the computational modules
- Standardization of data structures and interfaces needed for model interoperability
- Development of object classes, control vocabularies, and ontologies for knowledge management and model interoperability
- Construction of SCEC computational and data grid testbeds

Short-Term Objectives

- Development and verification of the computational modules
- Standardization of data structures and interfaces needed for model interoperability
- Development of object classes, control vocabularies, and ontologies for knowledge management and model interoperability
- Construction of SCEC computational and data grid testbeds
- Development of user interfaces for knowledge ingest and acquisition, code execution, and visualization

Application Targets for KR&R

- Ontology construction and management
  - Extension of IRIS's FISSURES seismological data model
  - Development of a comprehensive earthquake ontology
- Management of complex collections
  - Pathway 1 model components
  - Pathway 2 simulations
  - Ingest of geologic data into fault activity data base
- SHA
  - Input validation and error advice
  - Evaluation of alternative models
  - Incorporation of Pathway 2

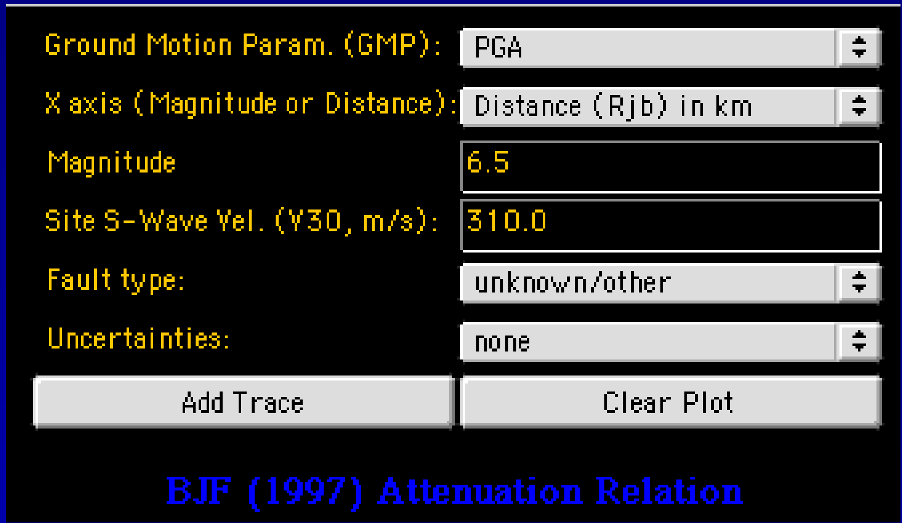
Distributed Operations of Code with Knowledge-based descriptions for Earthquake Research (DOCKER)

- Ties model descriptions to overarching SCEC ontology
- Enforces proper use of code through knowledge-based constraint reasoning (Powerloom)
  - Guides users to make appropriate use of models
  - Suggests alternative models more appropriate for user's analysis
- Supports distributed access to models and code through a layered view of service-based interaction (eventually) through the Open Grid Services Architecture (OSGA)
- Facilitates code publication by generating the code wrappers that enable the code to function at appropriate service layers

Application of KR&R to SHA

Input validation and error advice

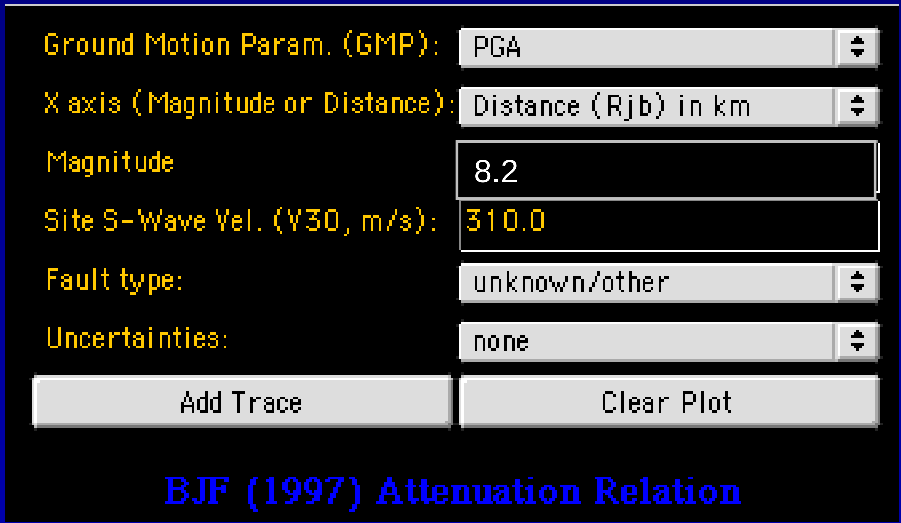
Model verified for magnitudes ≤ 7.0



Application of KR&R to SHA

Input validation and error advice

Model verified for magnitudes ≤ 7.0

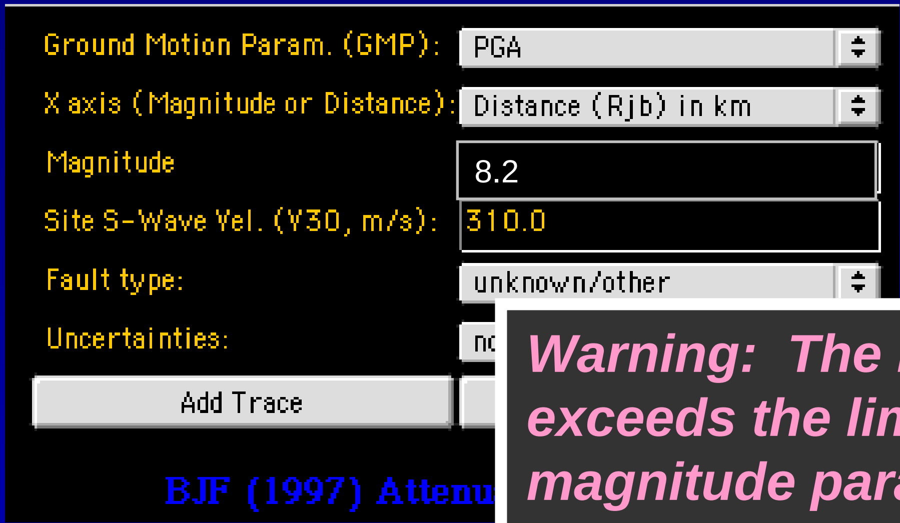


User attempt to enter a magnitude of 8.2

Application of KR&R to SHA

Input validation and error advice

Model verified for magnitudes ≤ 7.0



User attempt to enter a magnitude of 8.2

Warning: The magnitude of 8.2 exceeds the limits of this model's magnitude parameter (7.0). For best results, choose a magnitude less than or equal to 7.0

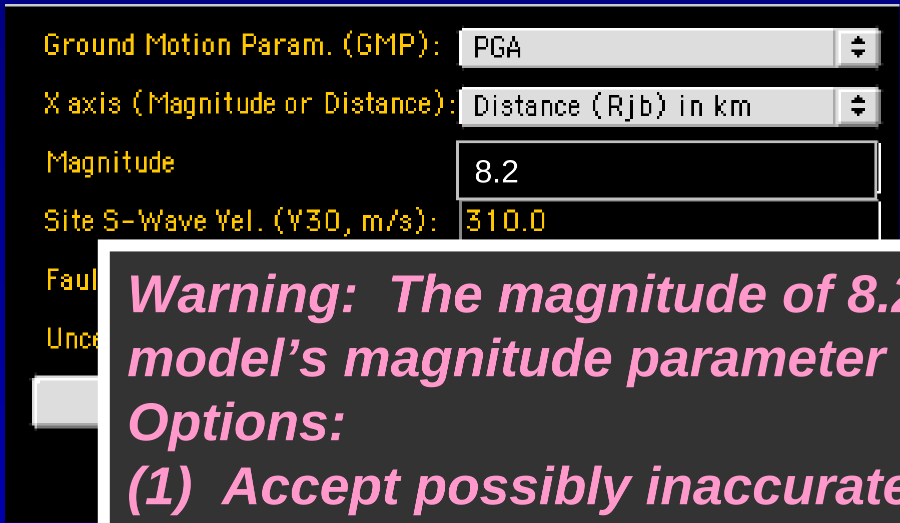
Standard Warning

Application of KR&R to SHA

Input validation and error advice

Model verified for magnitudes ≤ 7.0

User attempt to enter a magnitude of 8.2



Warning: The magnitude of 8.2 exceeds the limits of this model's magnitude parameter (7.0).

Options:

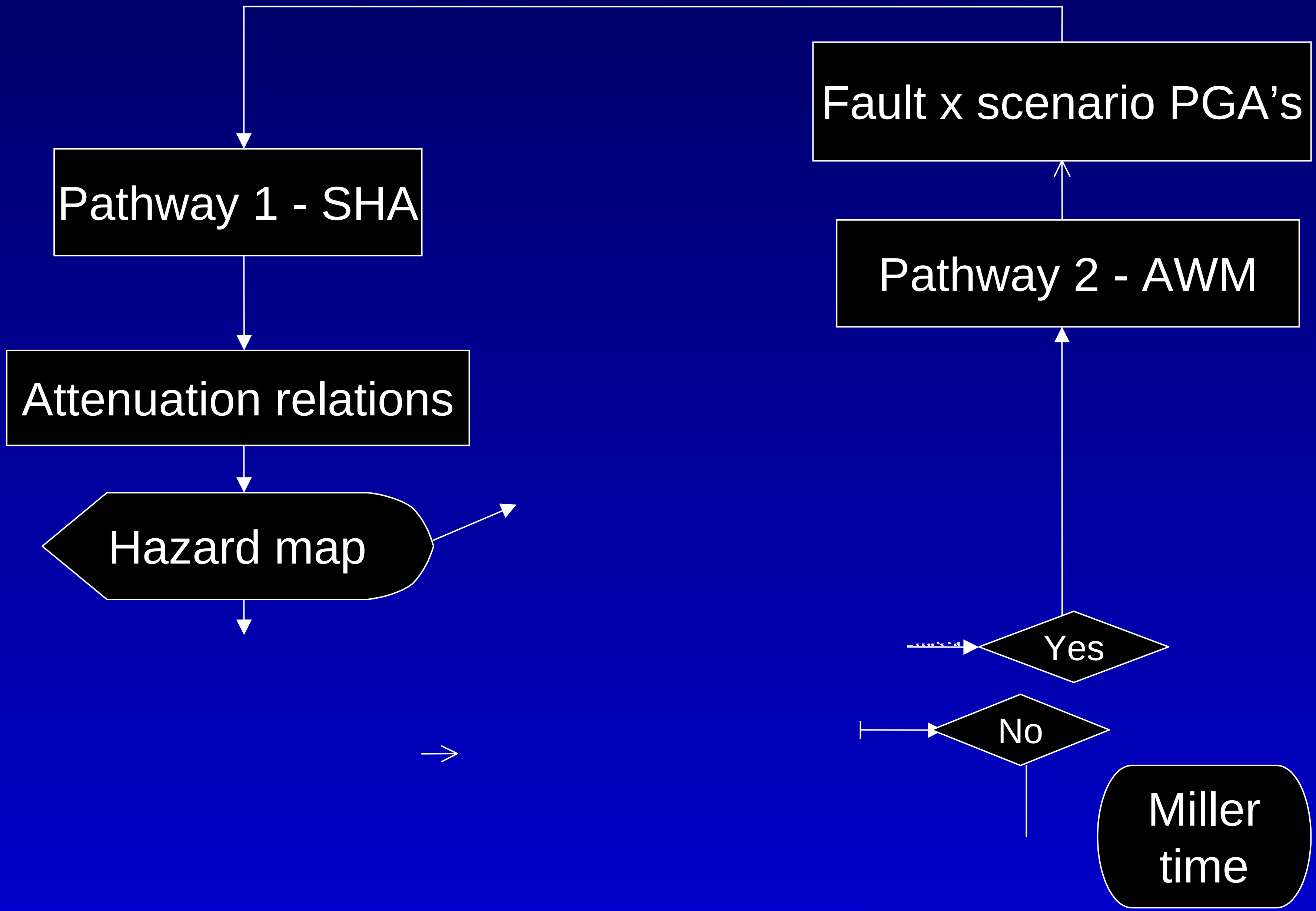
(1) Accept possibly inaccurate results

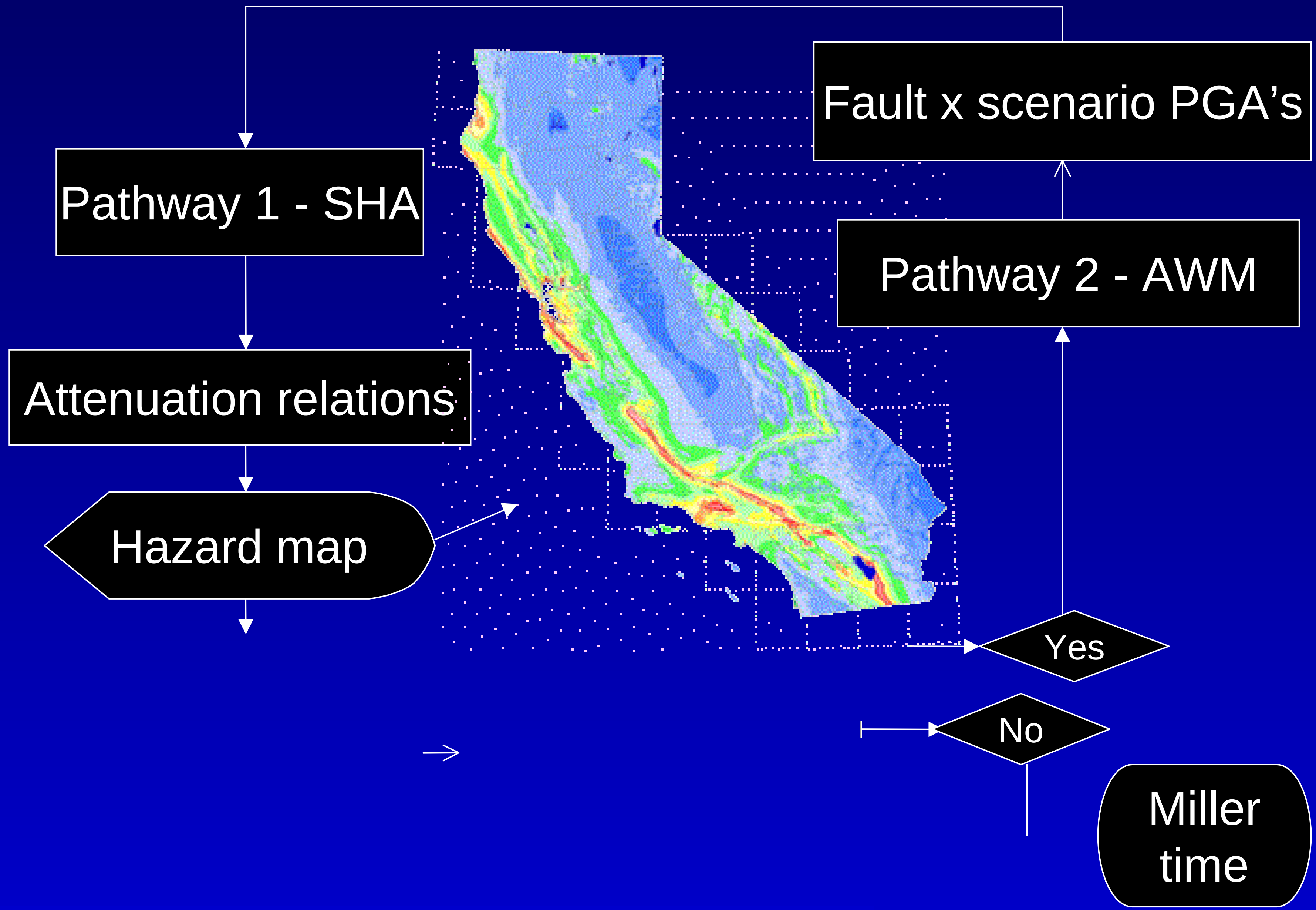
(2) Choose a magnitude less than or equal to 7.0

(3) Use a different model

- ***A&S 97 with magnitude 8.2 and soil type = "rock"***
- ***Steidl 2000 with magnitude 8.2, site type = "Q"***

Warning Using KR&R


Fault x scenario PGA's
Pathway 1 - SHA
Pathway 2 - AWM
Attenuation relations
Hazard map
Yes
No
Miller time

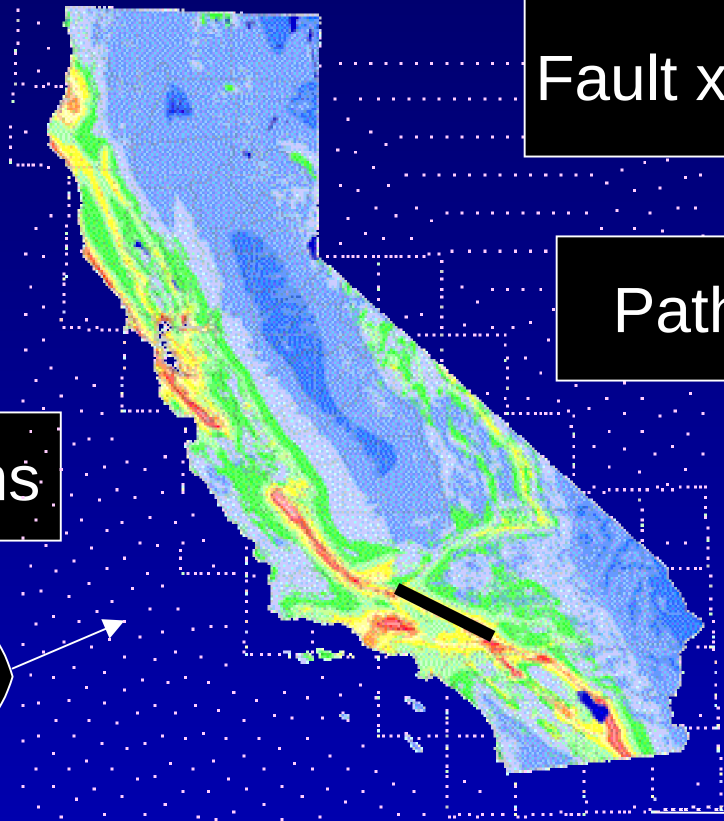

Pathway 1 - SHA
Attenuation relations
Hazard map
Fault x scenario PGA's
Pathway 2 - AWM
Yes
No
Miller time

Fault x scenario PGA's

Pathway 1 - SHA

Pathway 2 - AWM

Attenuation relations



Hazard map

Yes

No

Miller time

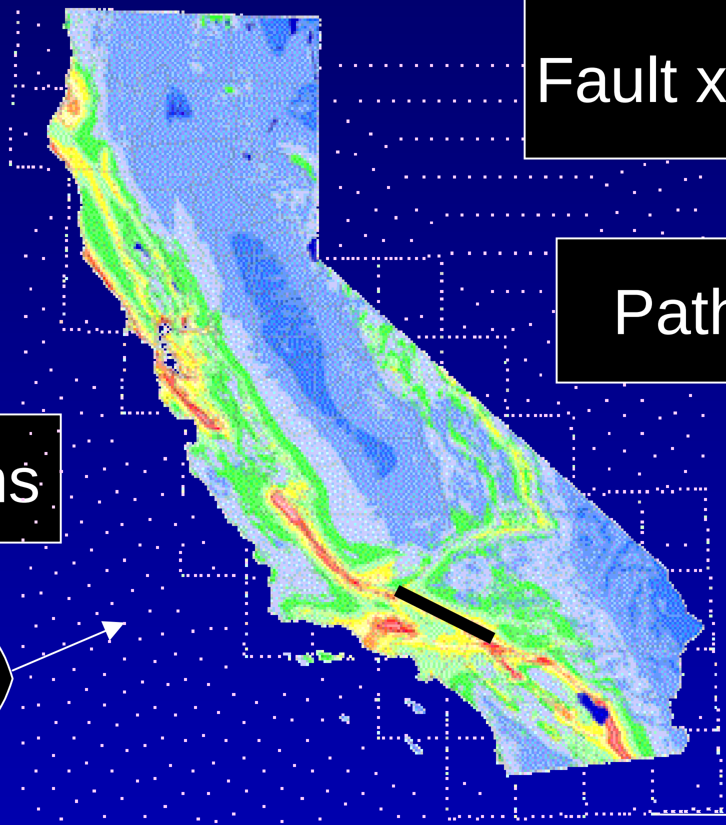
Pathway 1 - SHA

Attenuation relations

Hazard map

Breakdown of contributions

Example: Fault x critical (accounts for 50% of hazard)



Fault x scenario PGA's

Pathway 2 - AWM

Yes

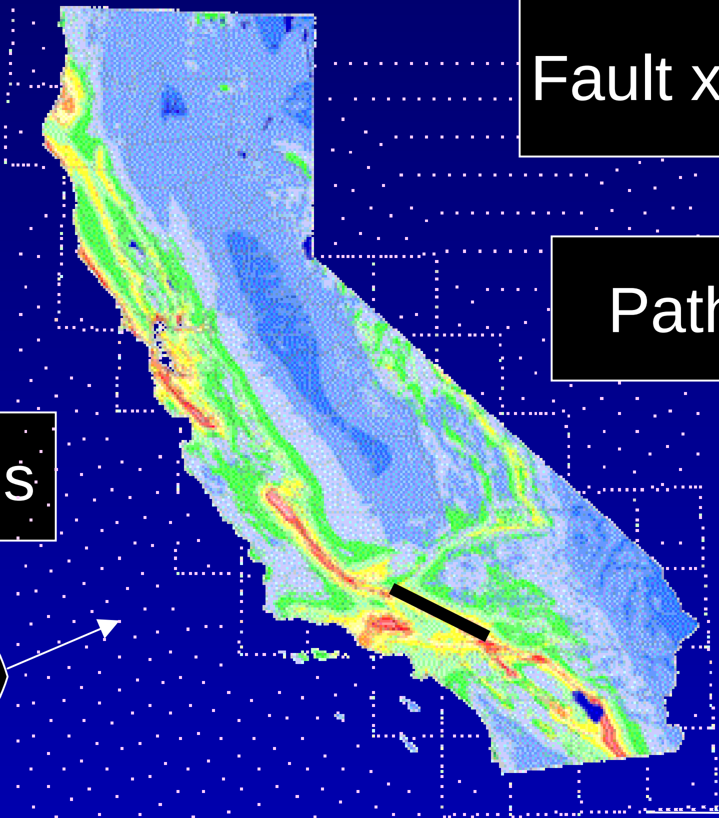
No

Miller time

Pathway 1 - SHA

Attenuation relations

Hazard map



Fault x scenario PGA's

Pathway 2 - AWM

Yes

No

Breakdown of contributions

Example: Fault x critical (accounts for 50% of hazard)

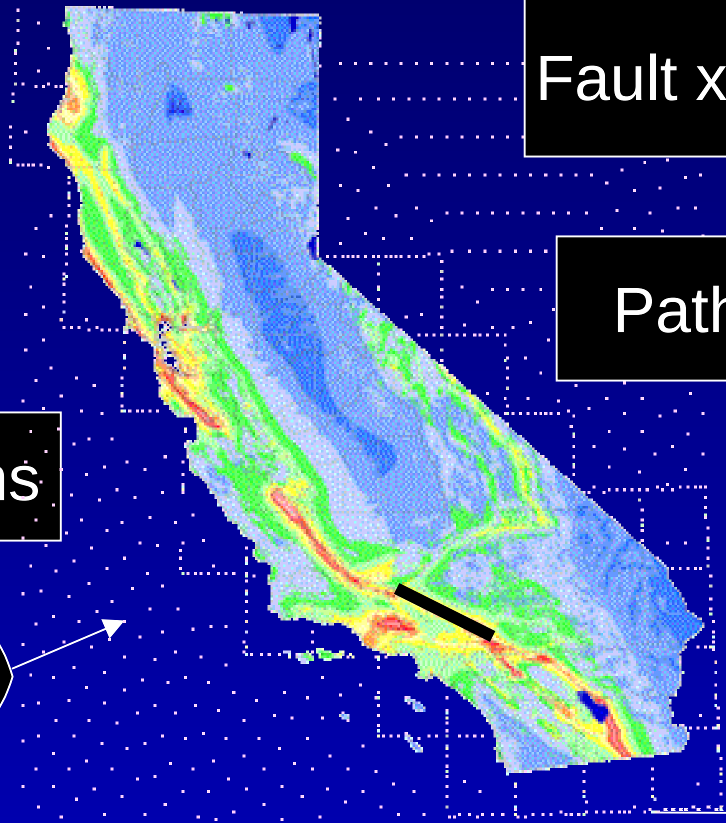
Would you like to perform physics-based simulation?

Miller time

Pathway 1 - SHA

Attenuation relations

Hazard map



Fault x scenario PGA's

Pathway 2 - AWM

Yes

Breakdown of contributions

Example: Fault x critical (accounts for 50% of hazard)

Would you like to perform physics-based simulation?

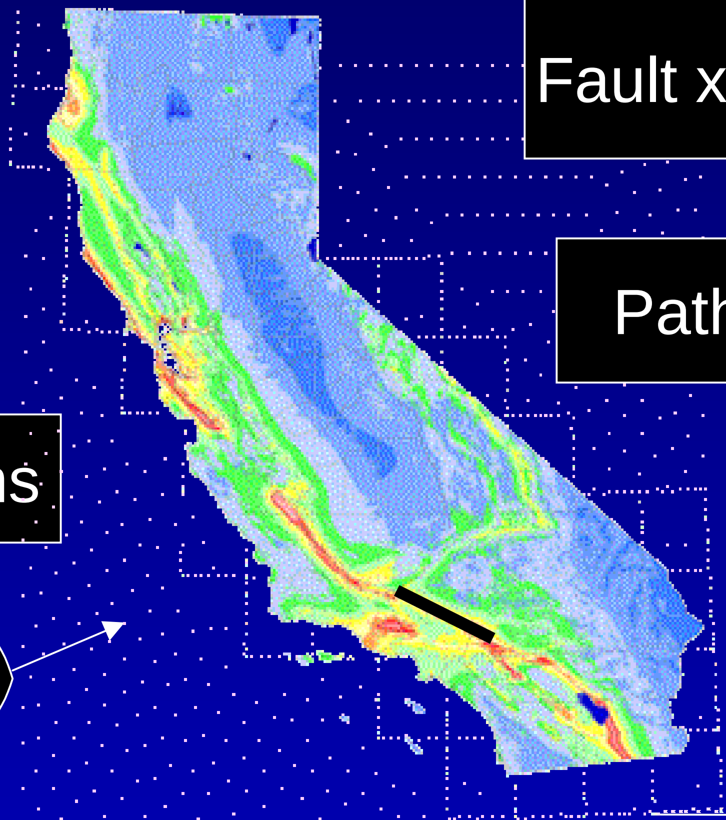
No

Miller time

Pathway 1 - SHA

Attenuation relations

Hazard map



Fault x scenario PGA's

Pathway 2 - AWM

Yes

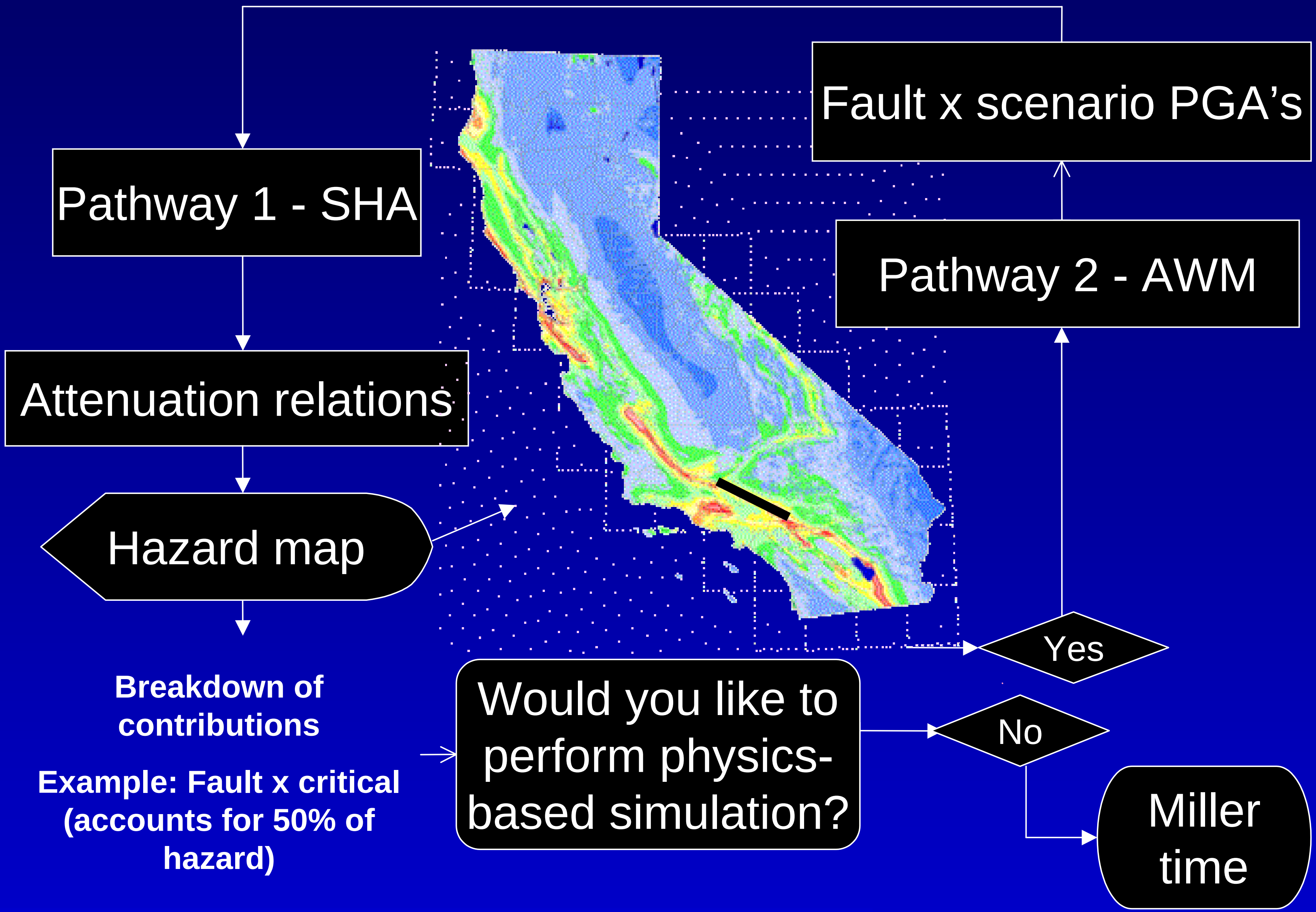
Breakdown of contributions

Example: Fault x critical (accounts for 50% of hazard)

Would you like to perform physics-based simulation?

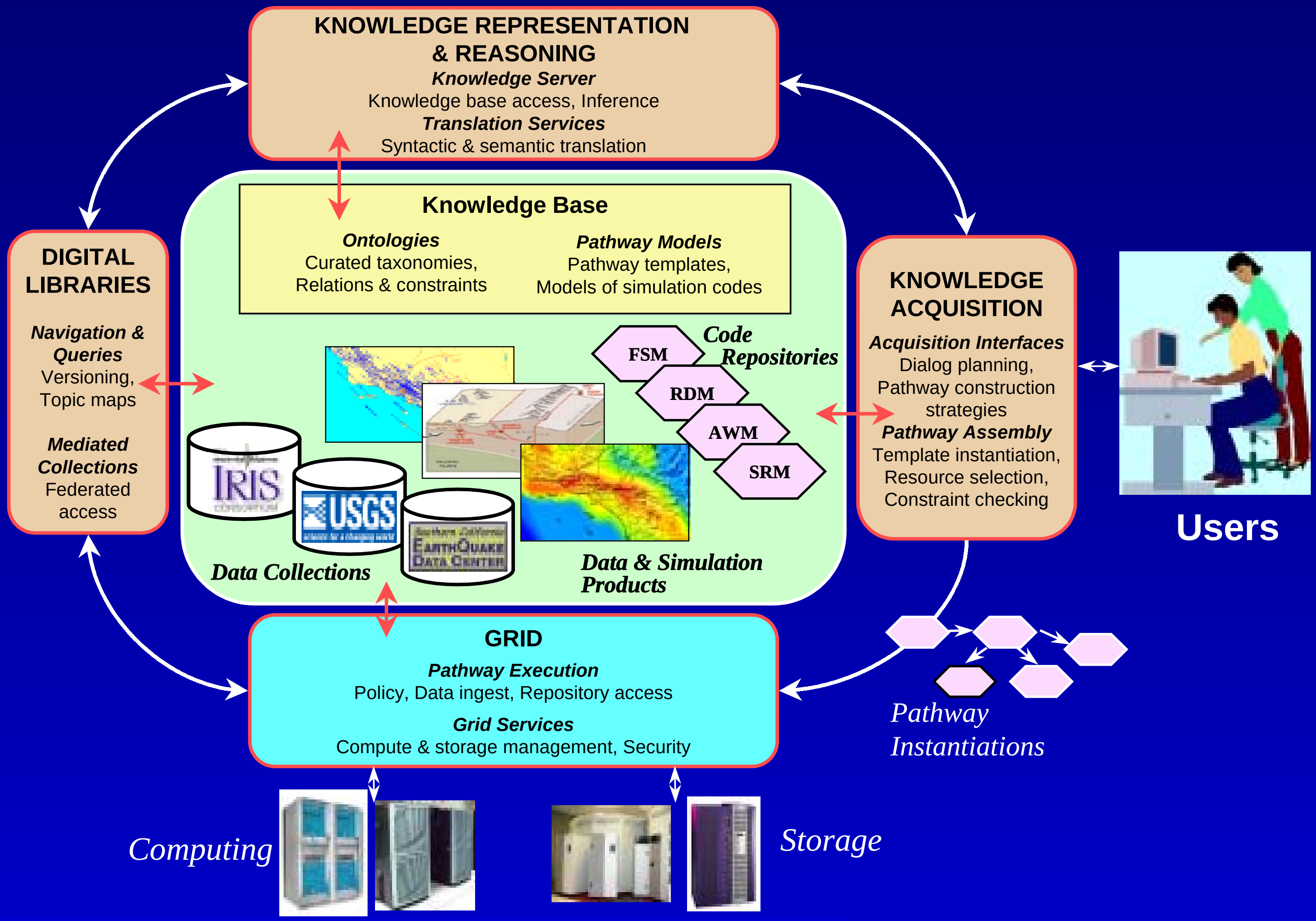
No

Miller time

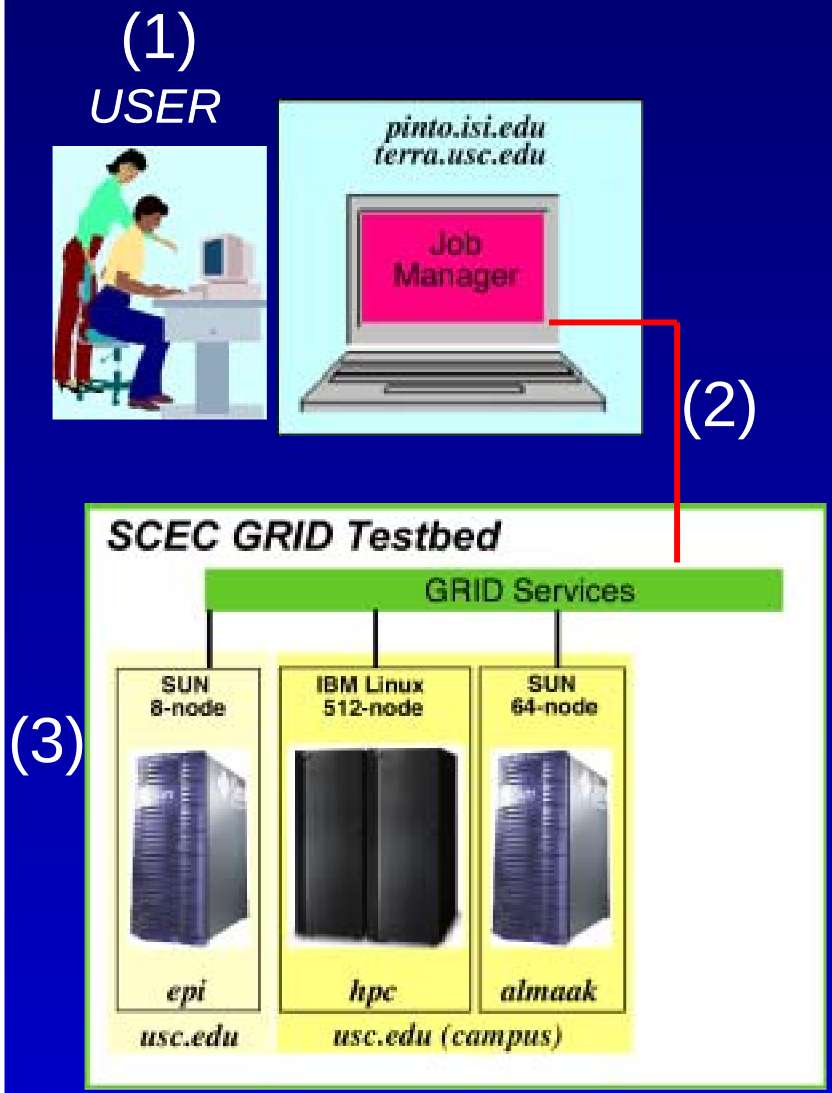

Fault x scenario PGA's
Pathway 1 - SHA
Pathway 2 - AWM
Attenuation relations
Hazard map
Yes
Breakdown of contributions
Example: Fault x critical (accounts for 50% of hazard)
Would you like to perform physics-based simulation?
No
Miller time

SCEC Collaboratory

An information infrastructure for system-level earthquake science



SCEC Computational Grid Testbed

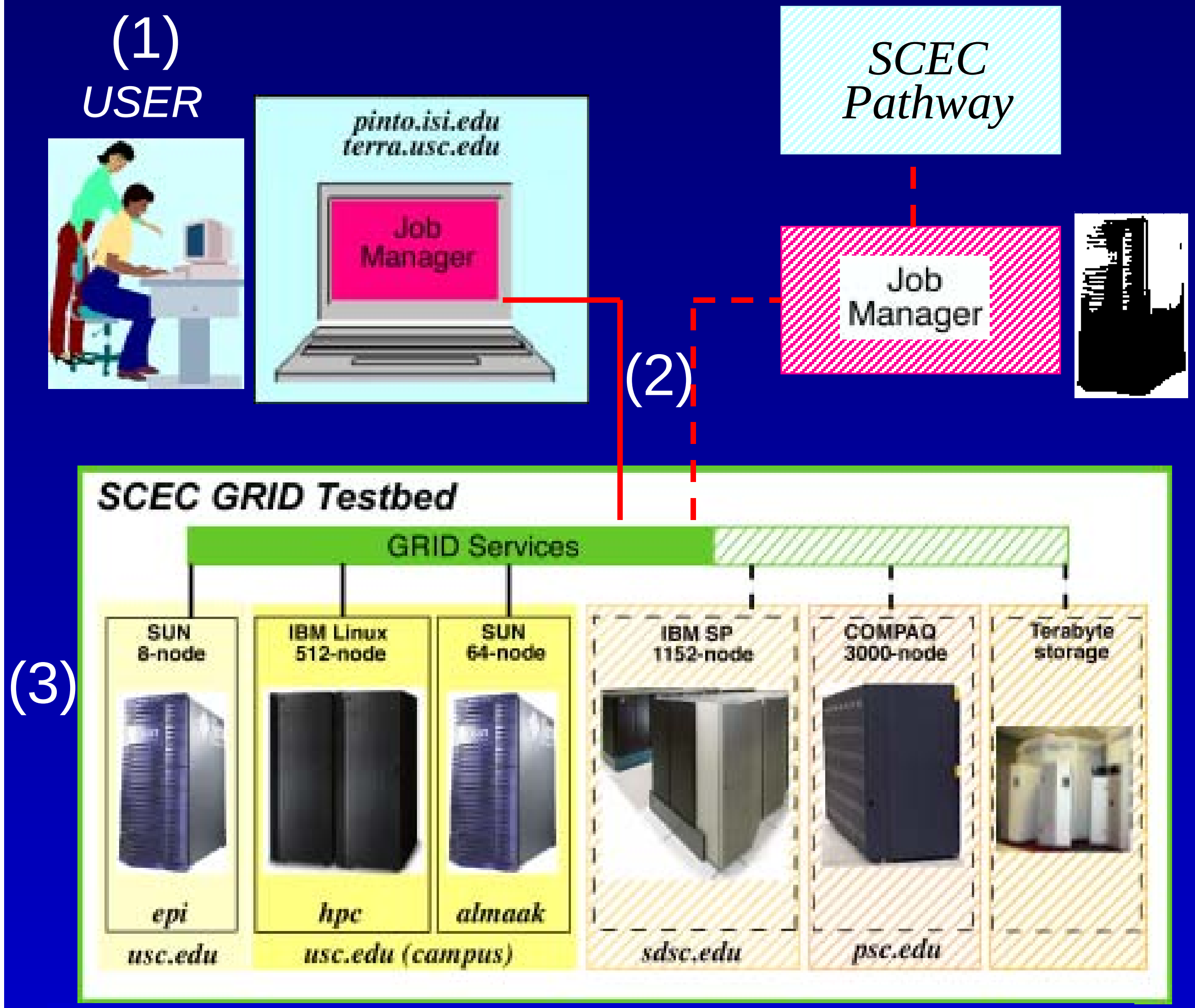


(1) *Scientist issues a request (compute or data retrieval) to "Job Manager"*

(2) *Job Manager talks to a Testbed computer via GRID service communication protocals.*

(3) *Testbed computer performs the requested actions.*

SCEC Computational Grid Testbed



(1) *Scientist issues a request (compute or data retrieval) to "Job Manager"*

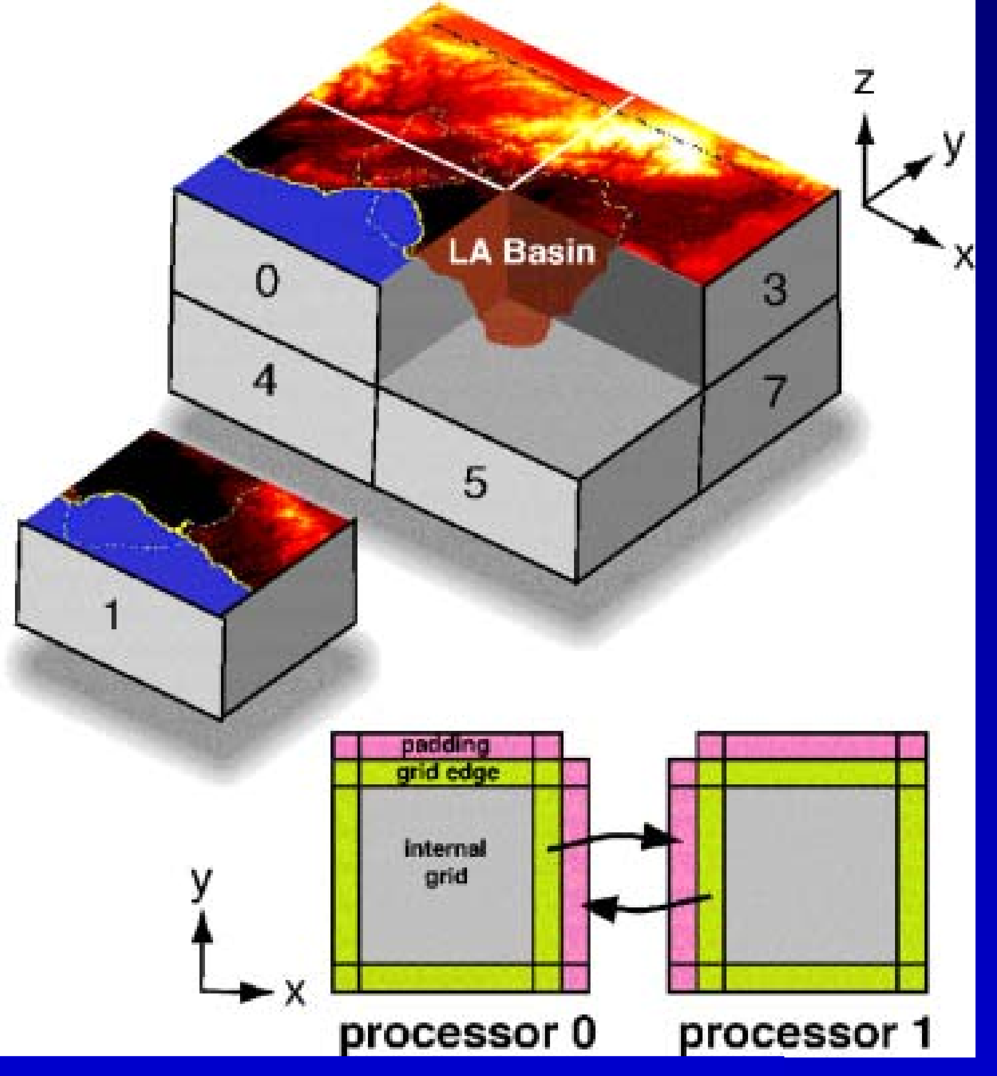
Future complex pathways require a more versatile Job Manager.

(2) *Job Manager talks to a Testbed computer via GRID service communication protocals.*

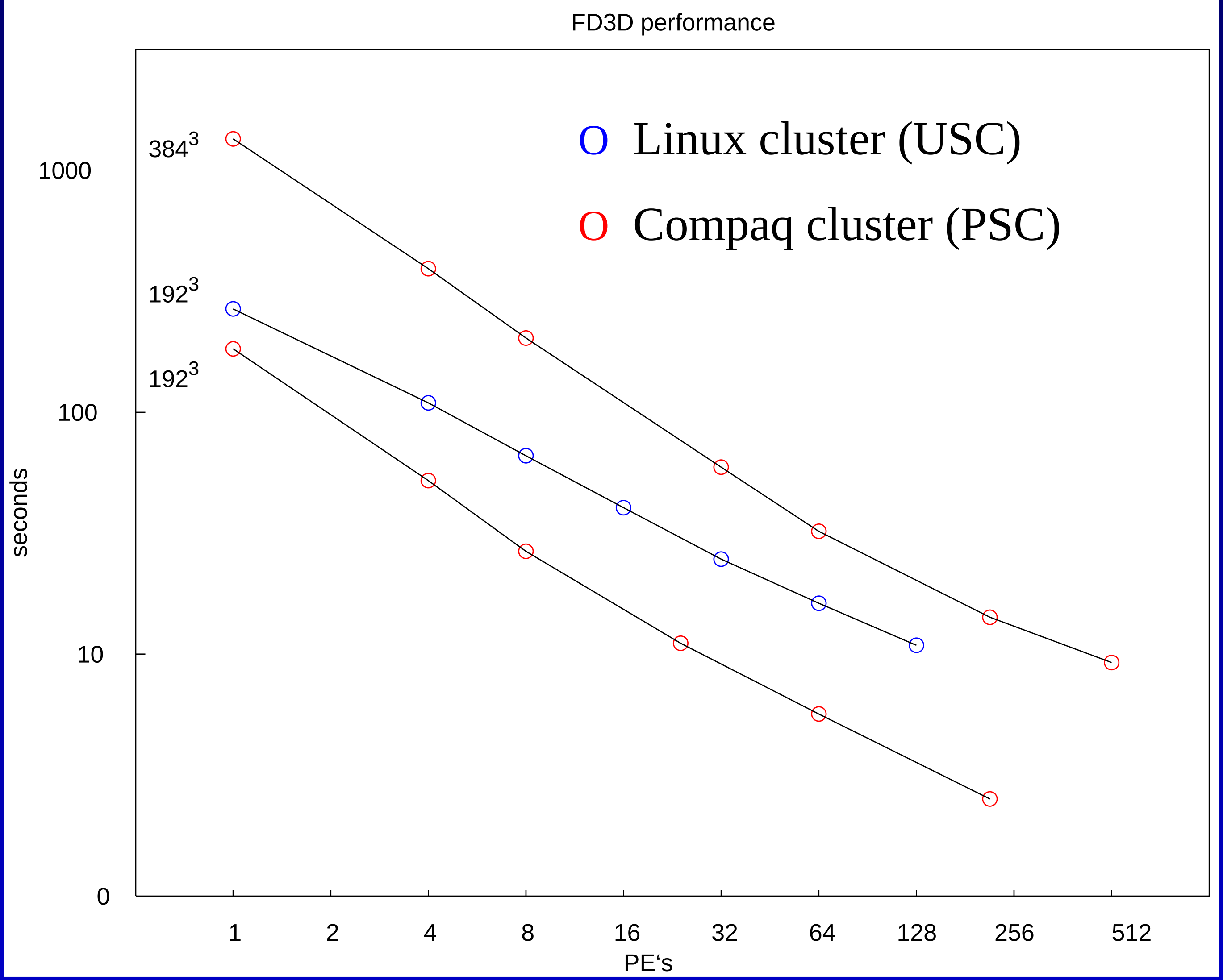
(3) *Testbed computer performs the requested actions.*

Parallelized and Scalable AWM

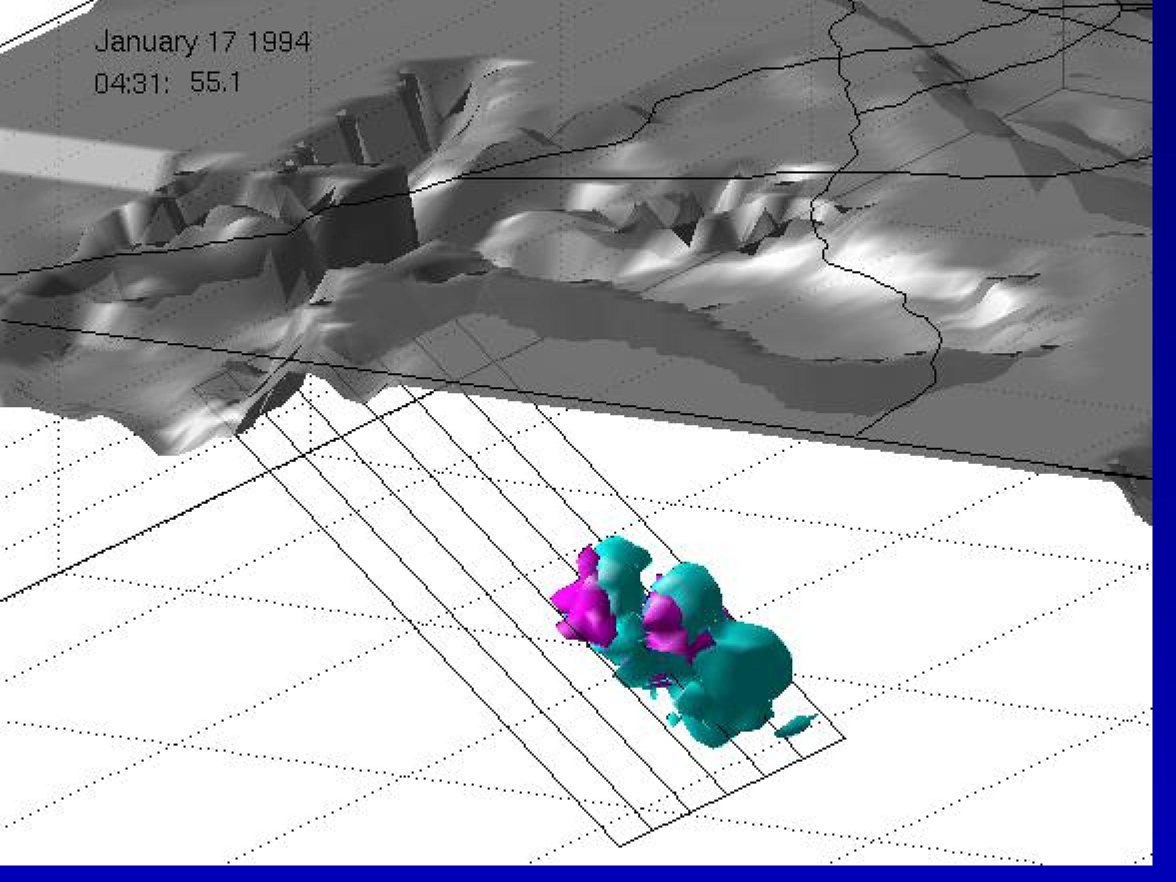
Parallelized and Scalable AWM

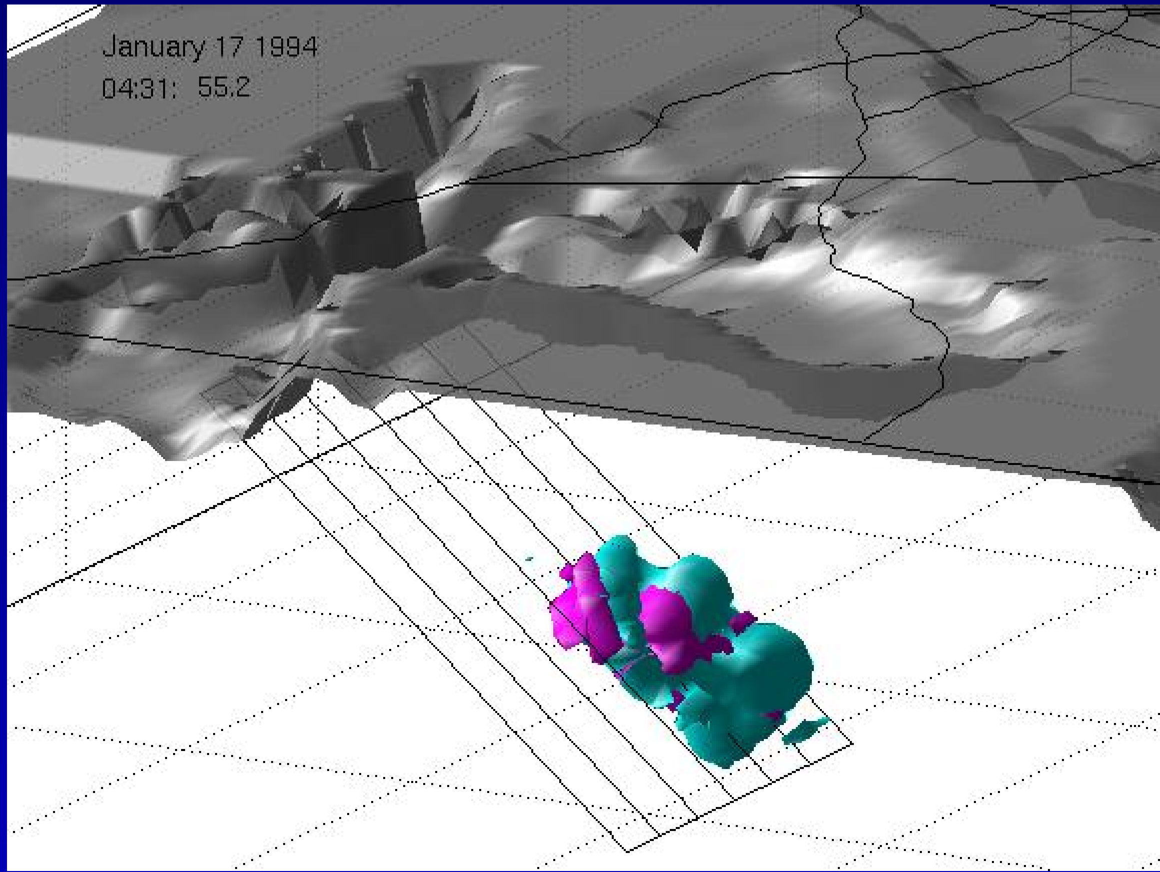


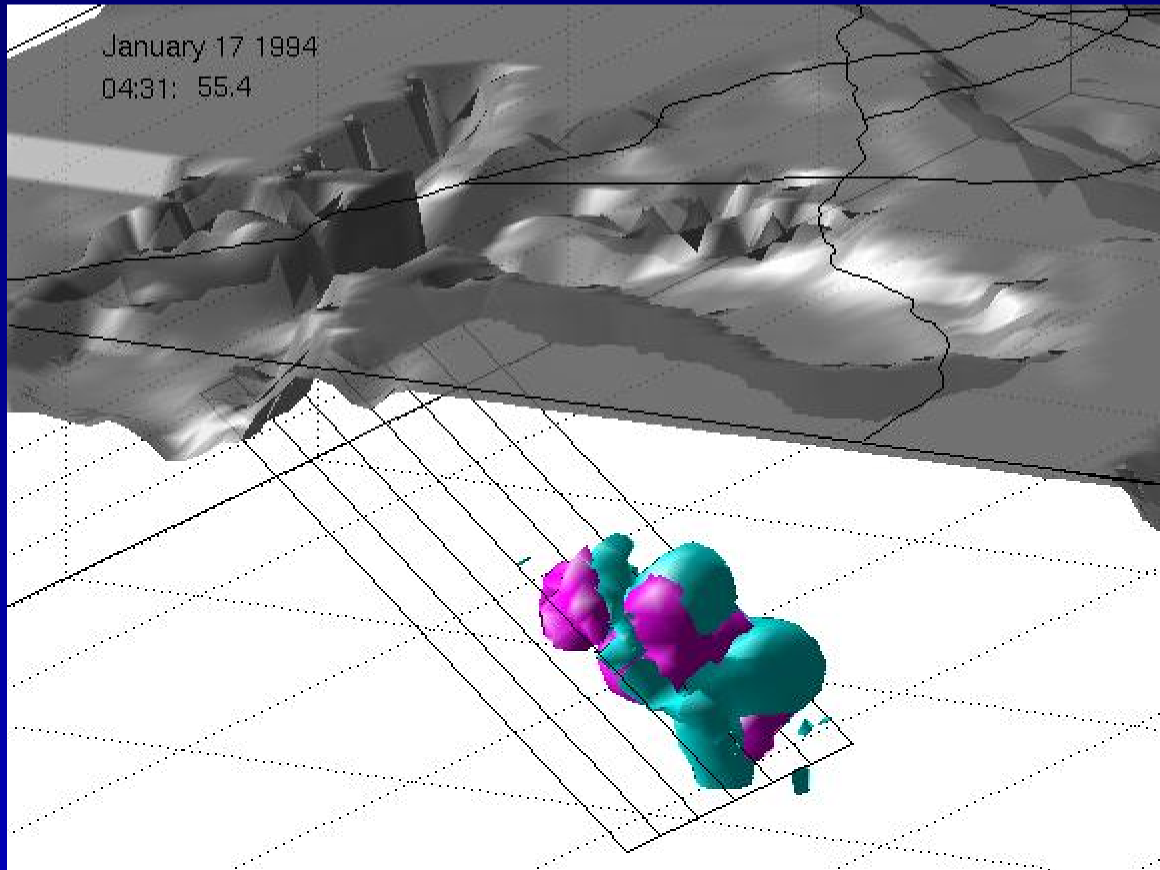
Parallelized and Scalable AWM's

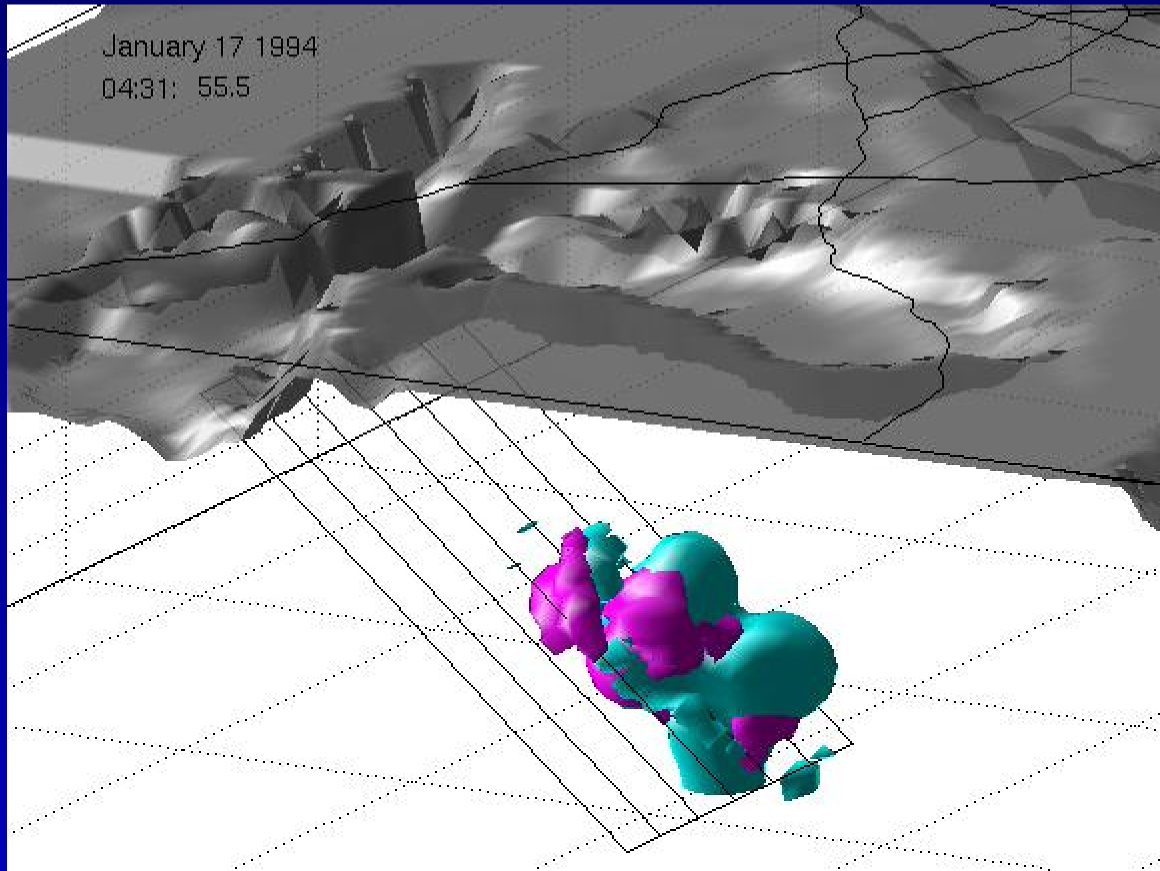


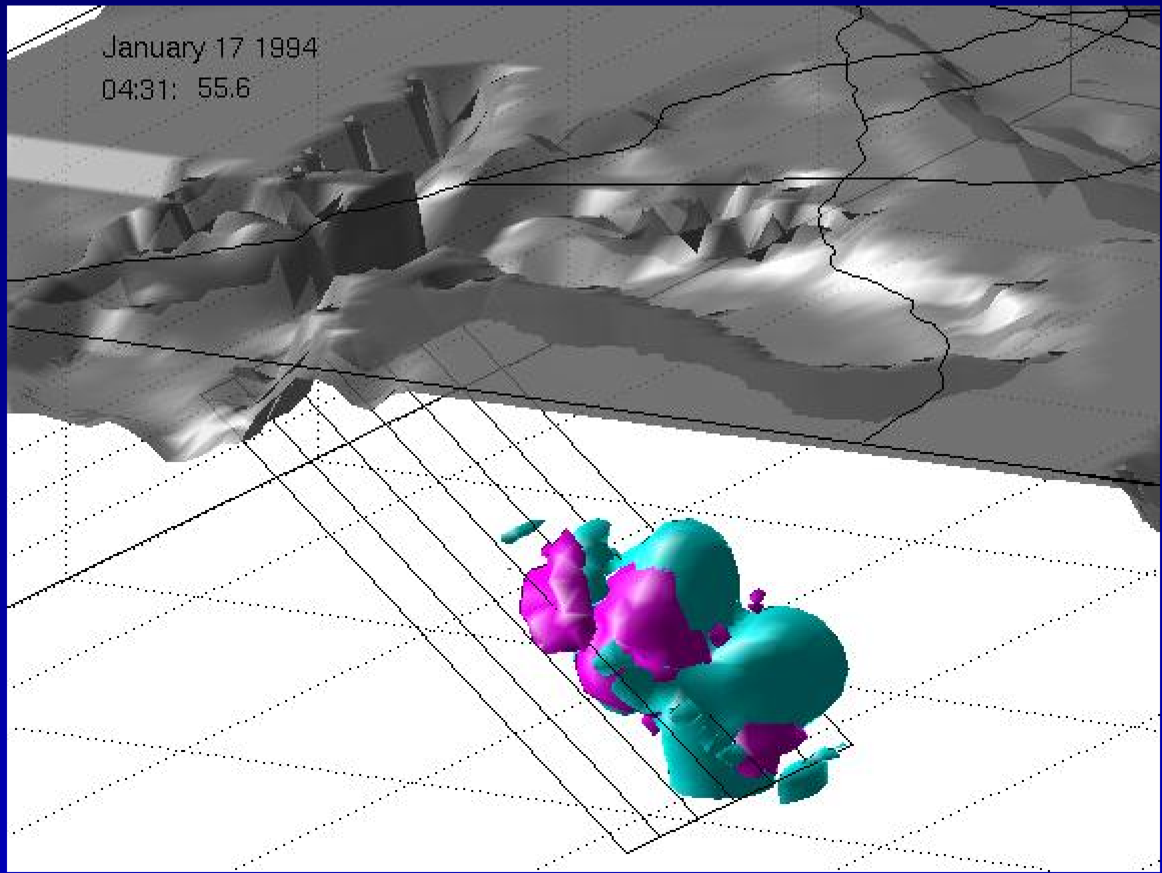
Visualization…

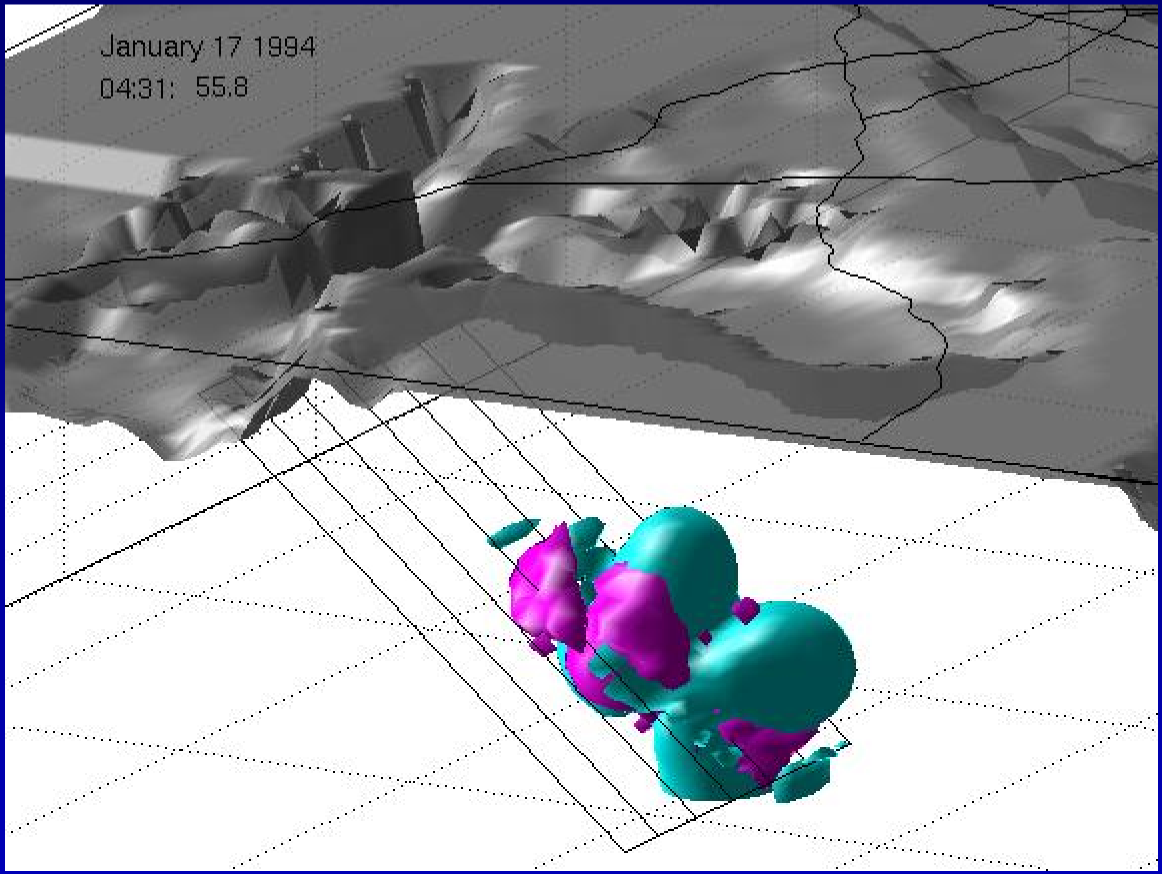

January 17 1994
04:31: 55.1

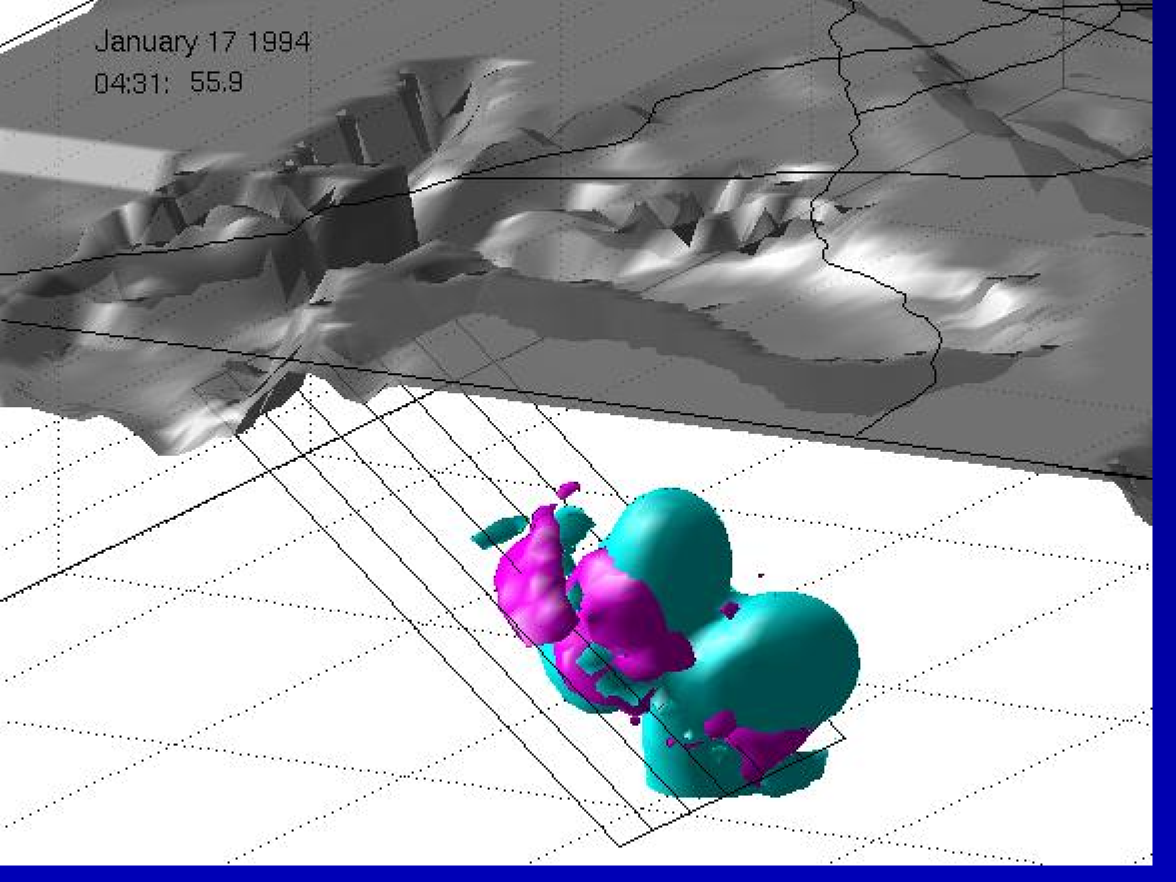

January 17 1994
04:31: 55.2

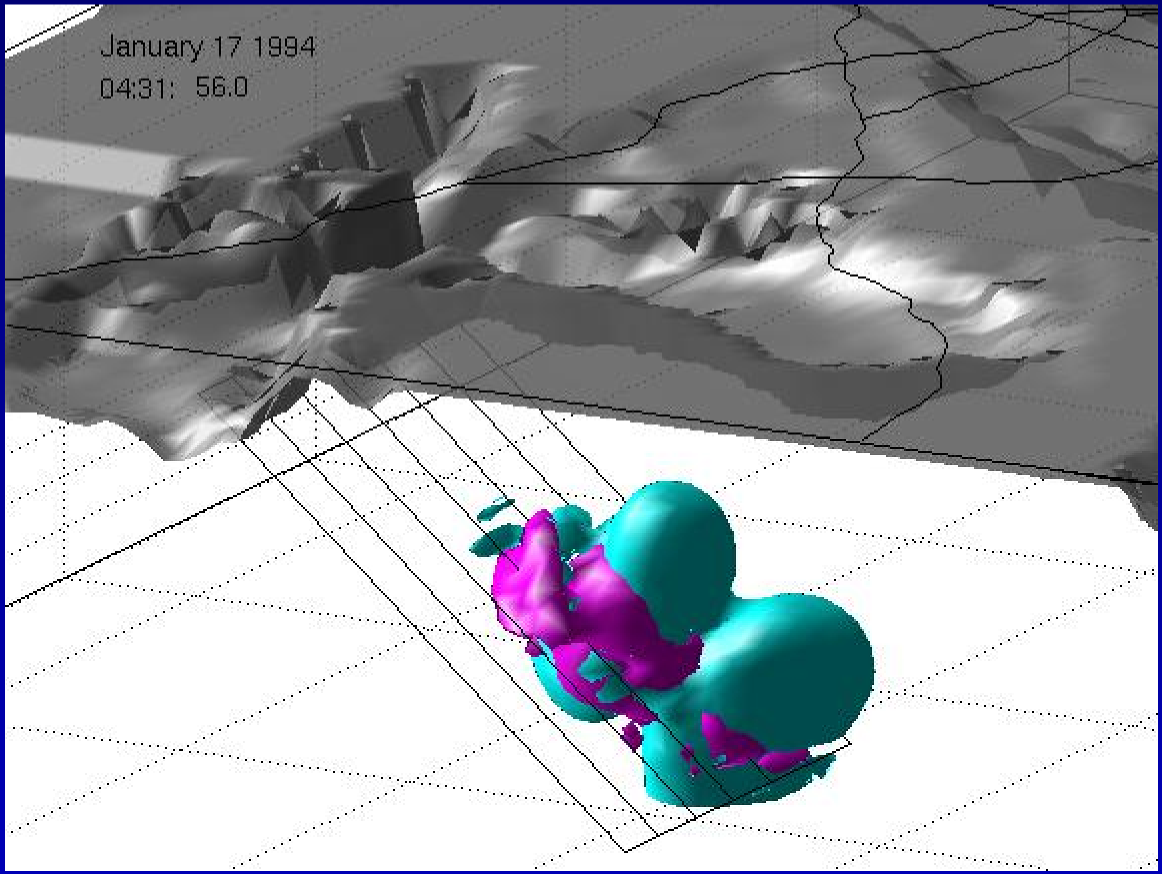

January 17 1994
04:31: 55.4

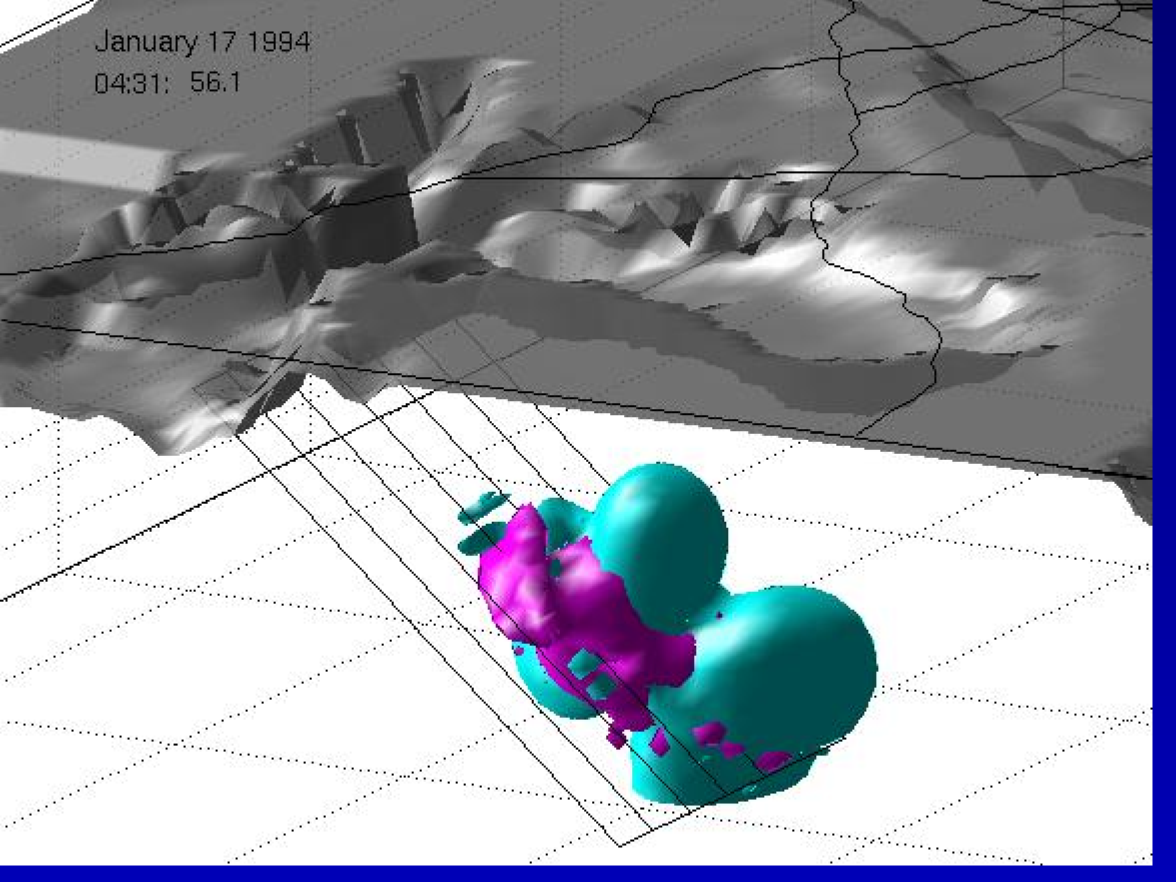

January 17 1994
04:31: 55.5

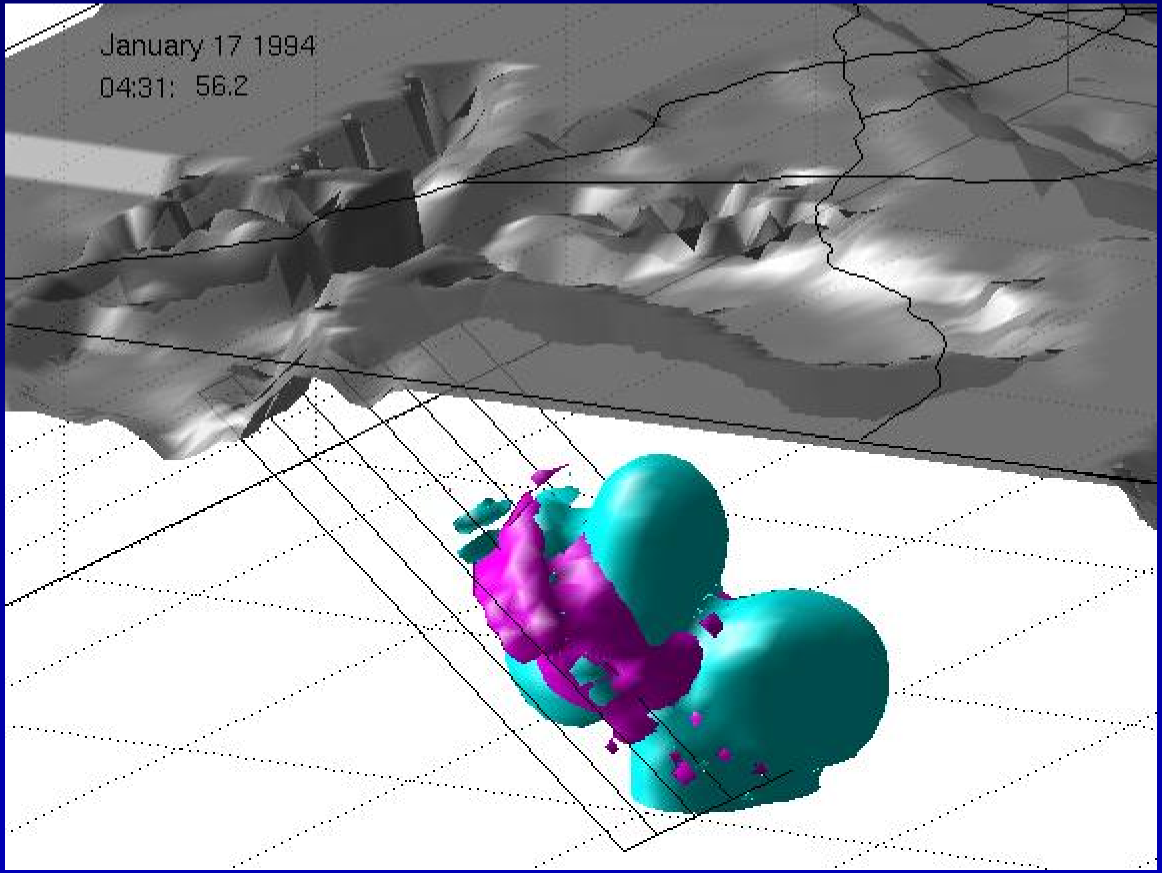

January 17 1994
04:31: 55.6

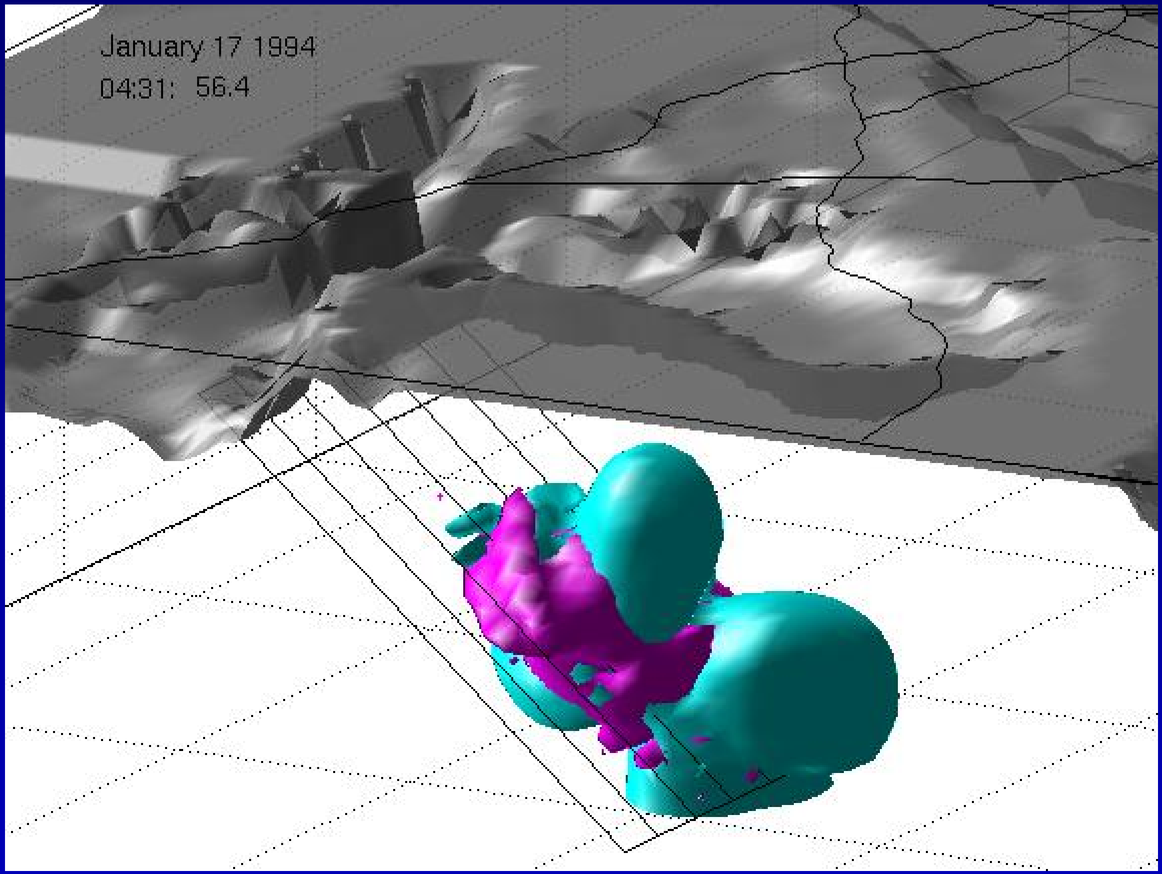

January 17 1994
04:31: 55.8

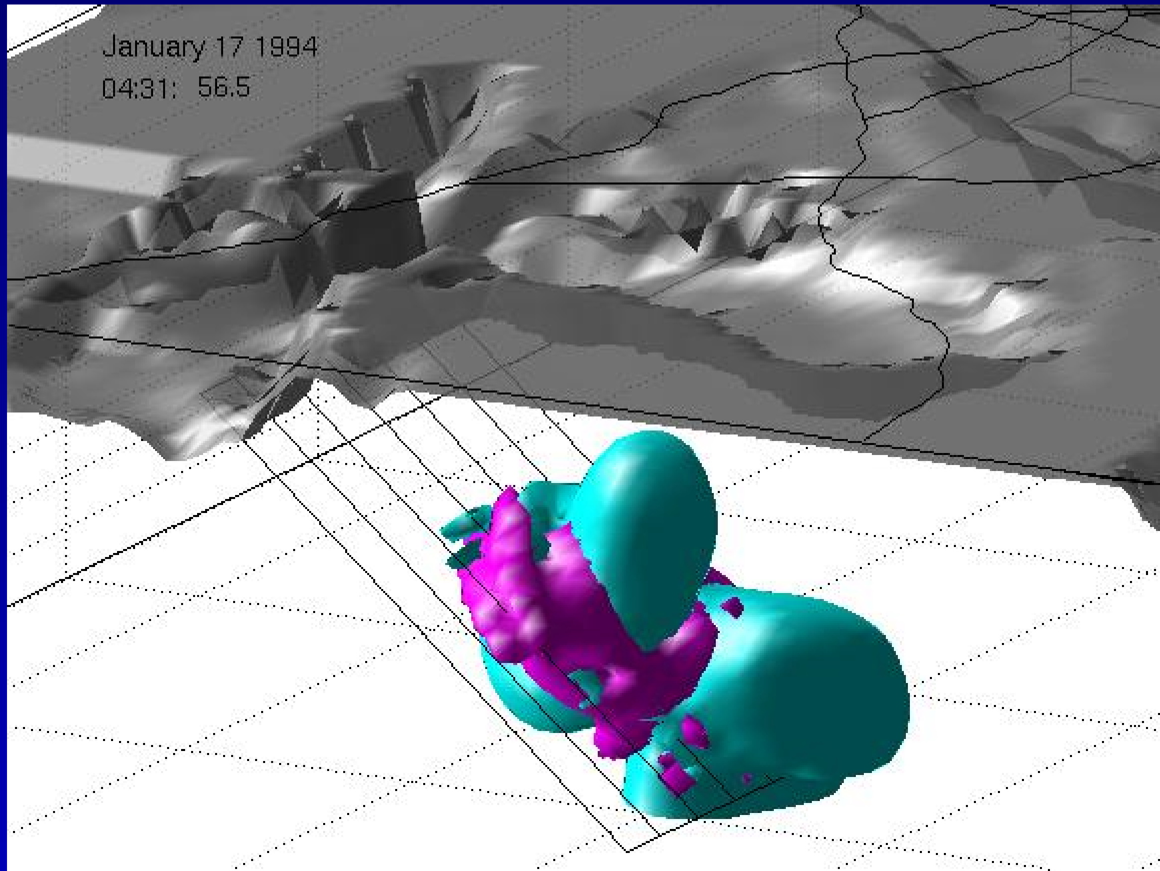

January 17 1994
04:31: 55.9

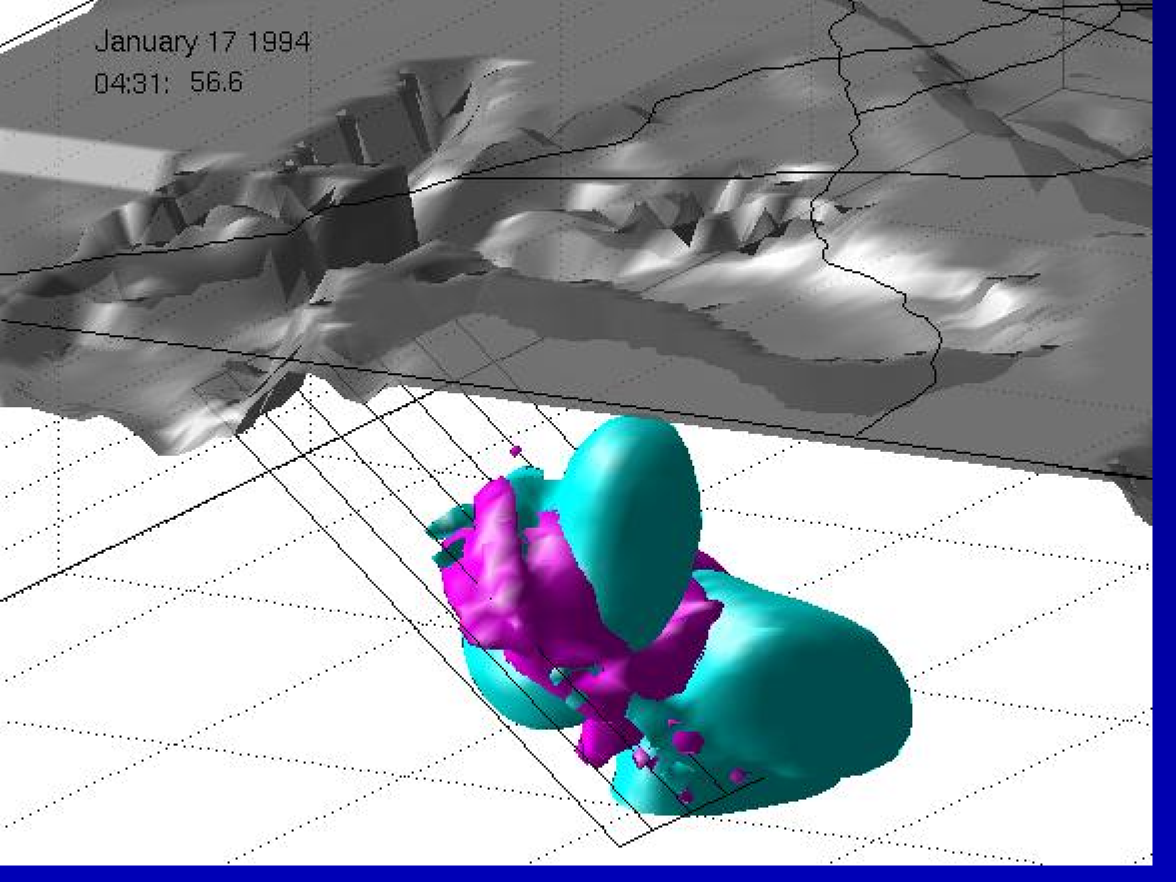

January 17 1994
04:31: 56.0

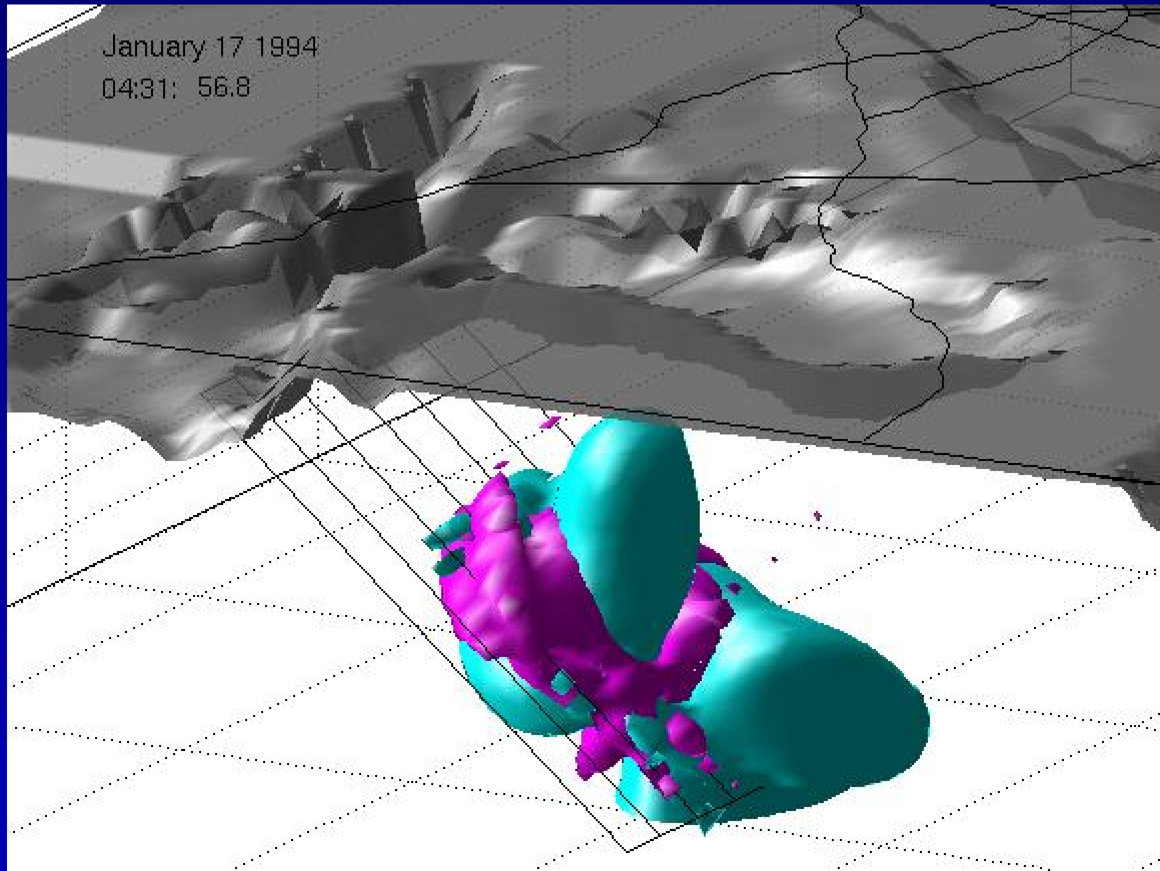

January 17 1994
04:31: 56.1

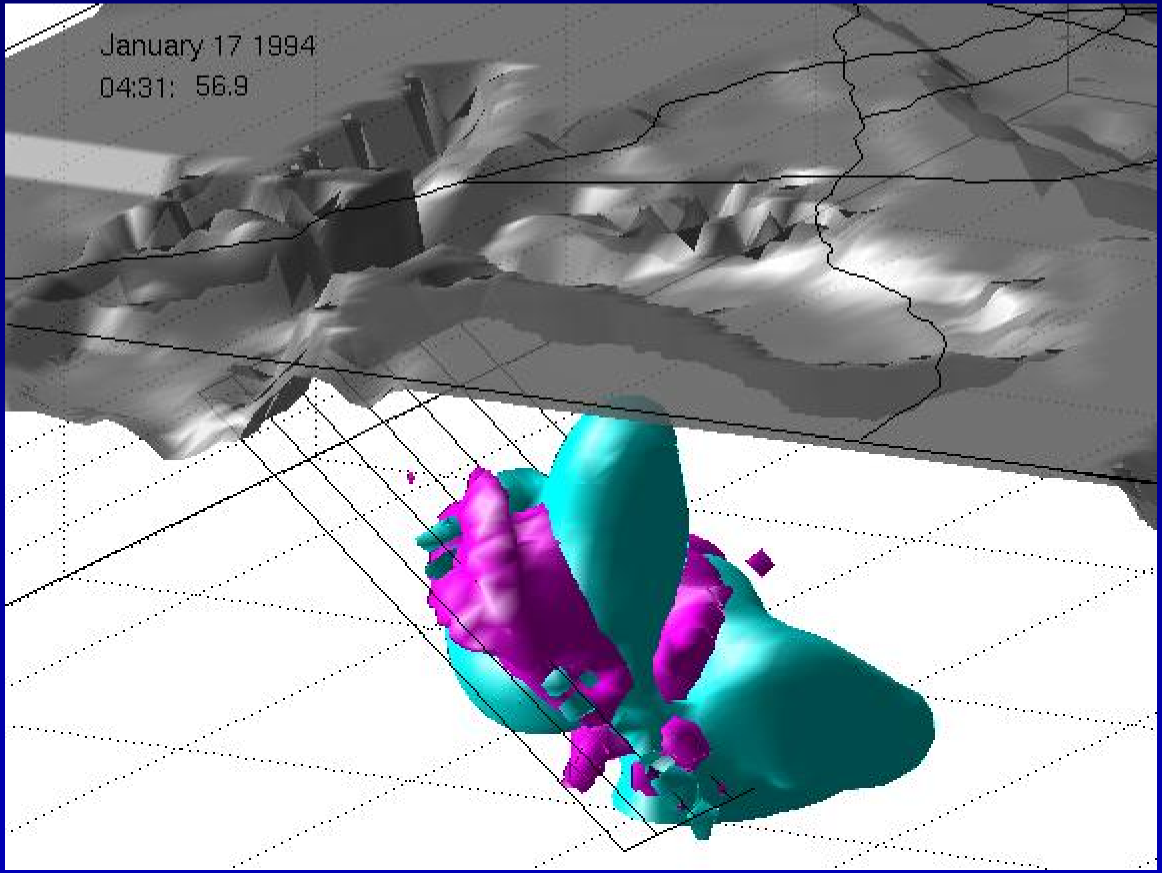

January 17 1994
04:31: 56.2

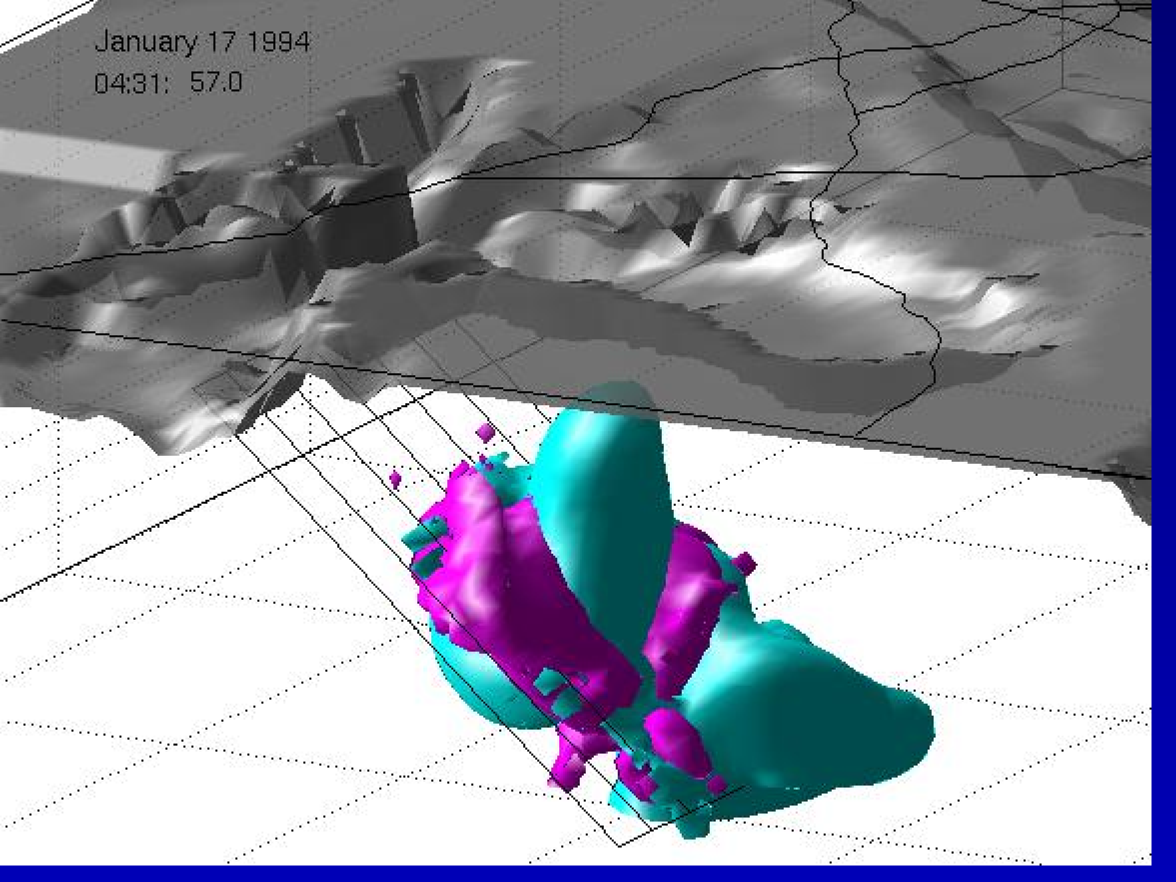

January 17 1994
04:31: 56.4

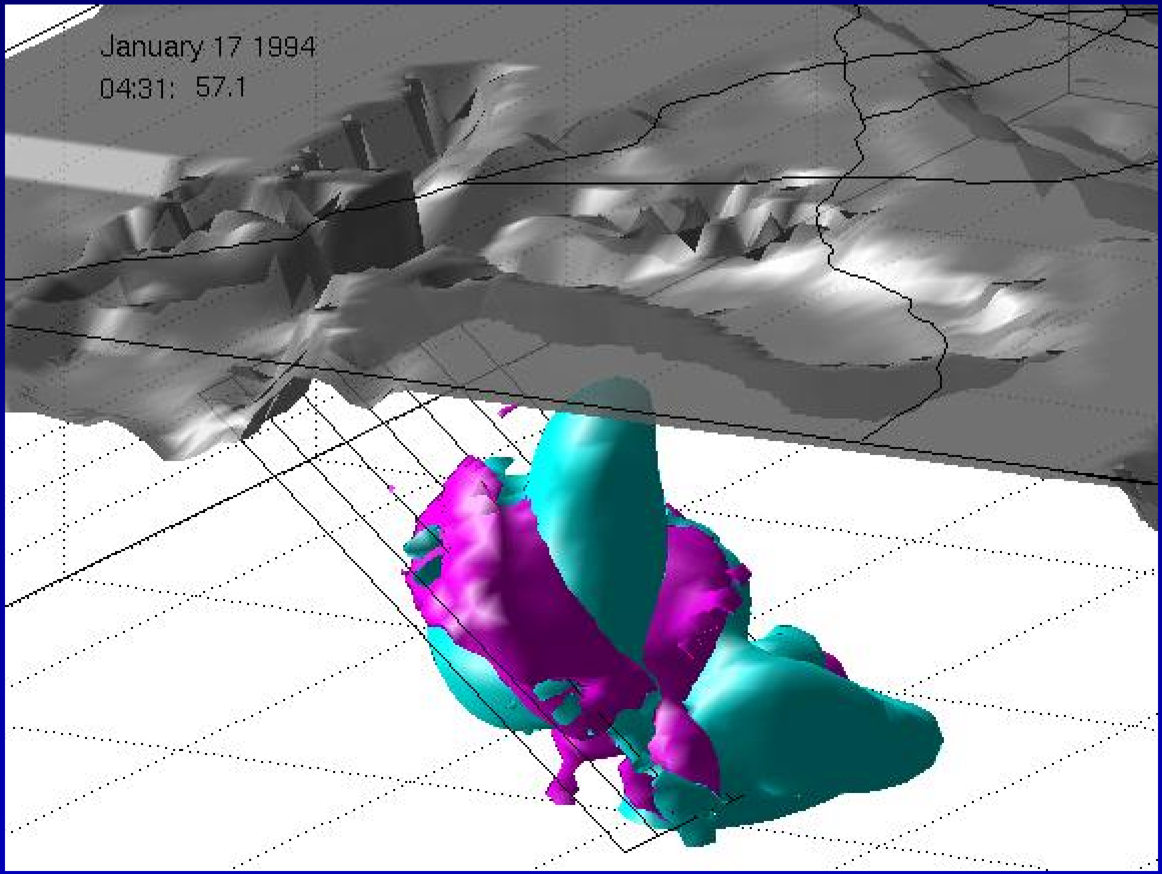

January 17 1994
04:31: 56.5

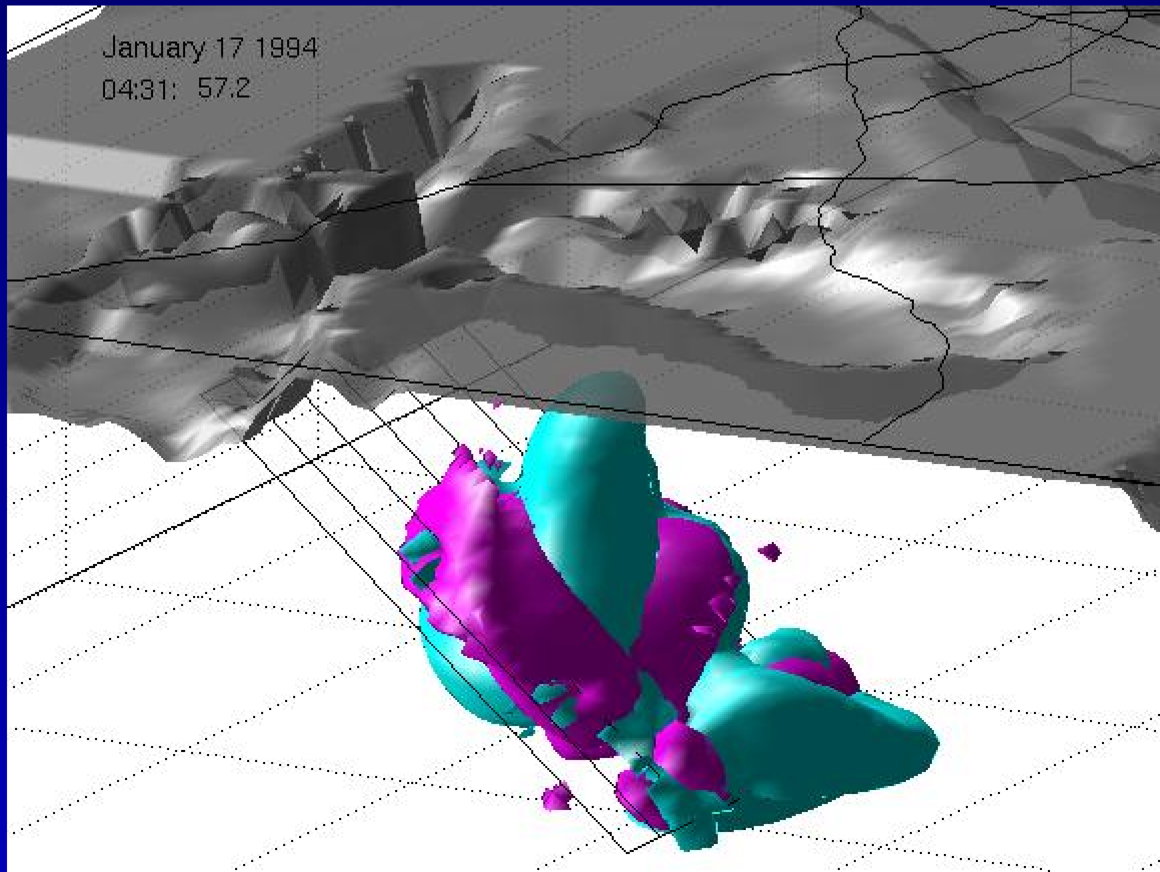

January 17 1994
04:31: 56.6

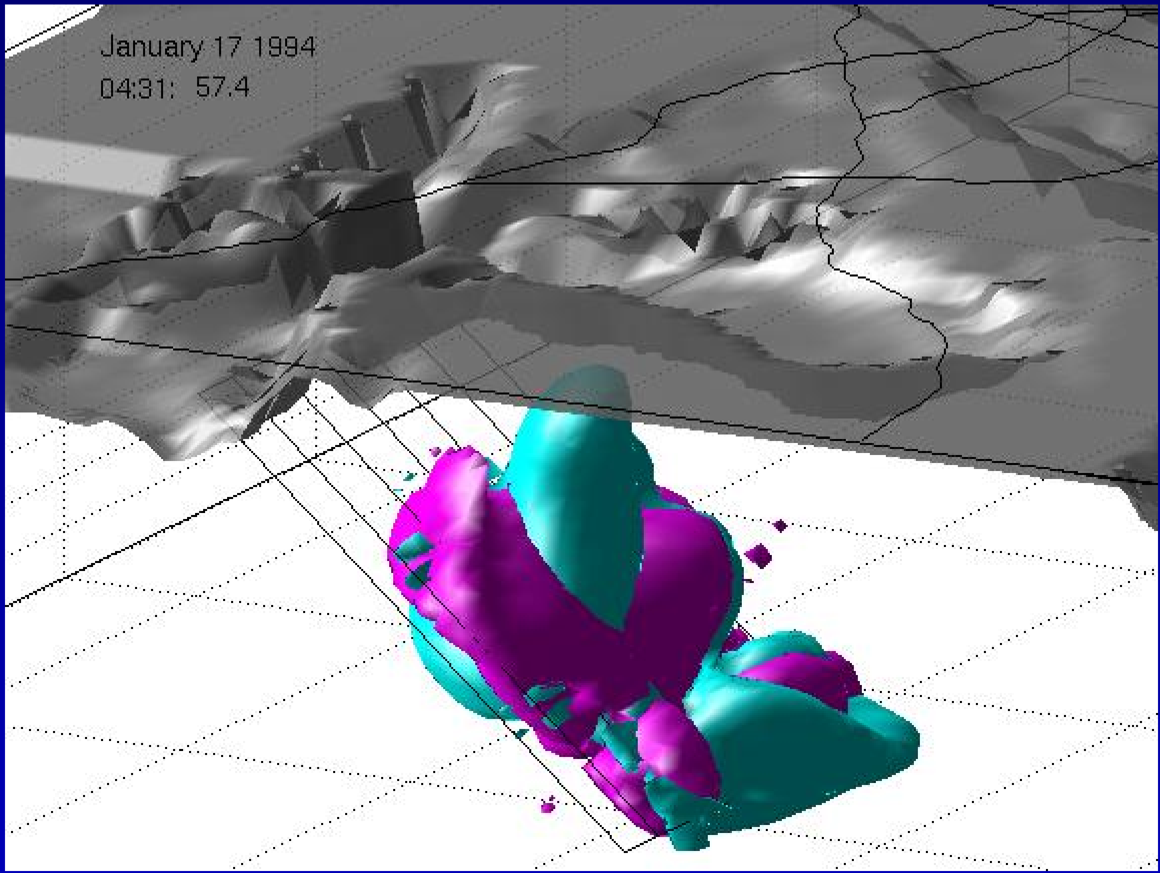

January 17 1994
04:31: 56.8

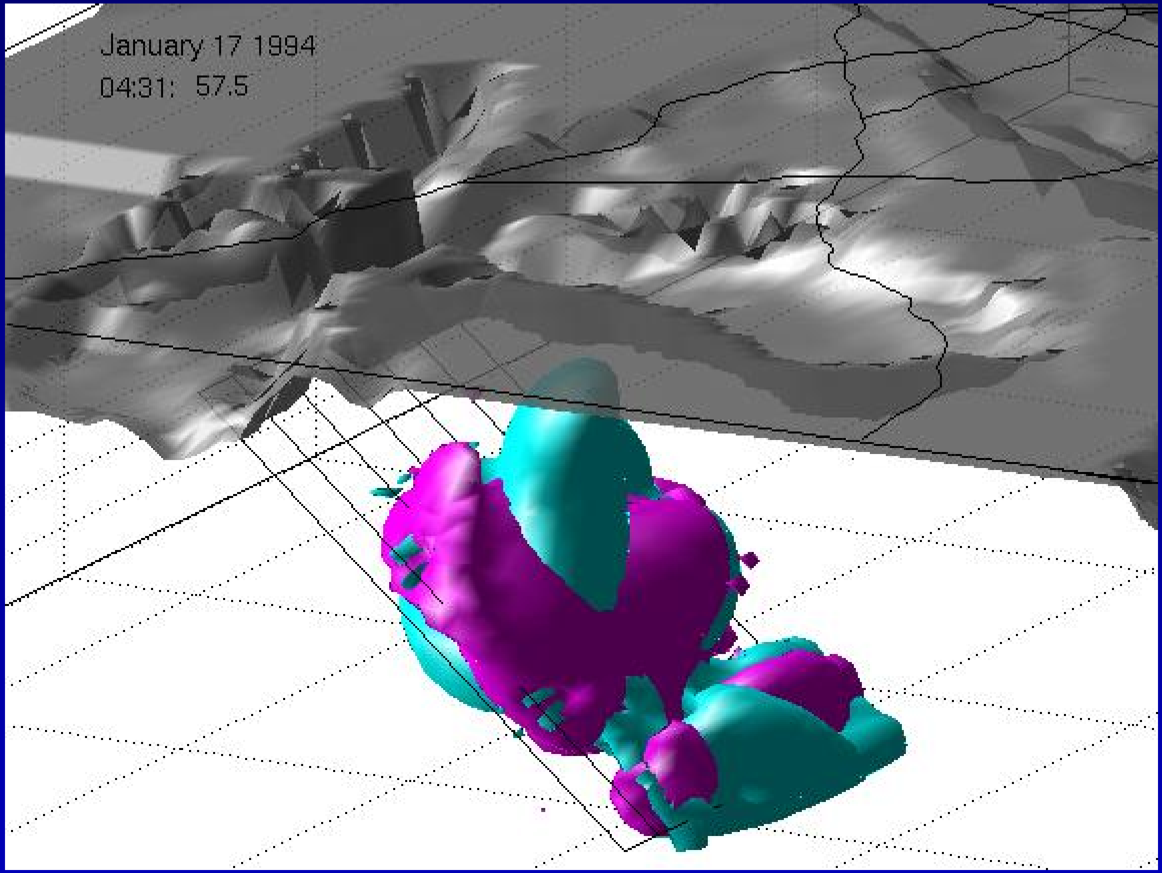

January 17 1994
04:31: 56.9

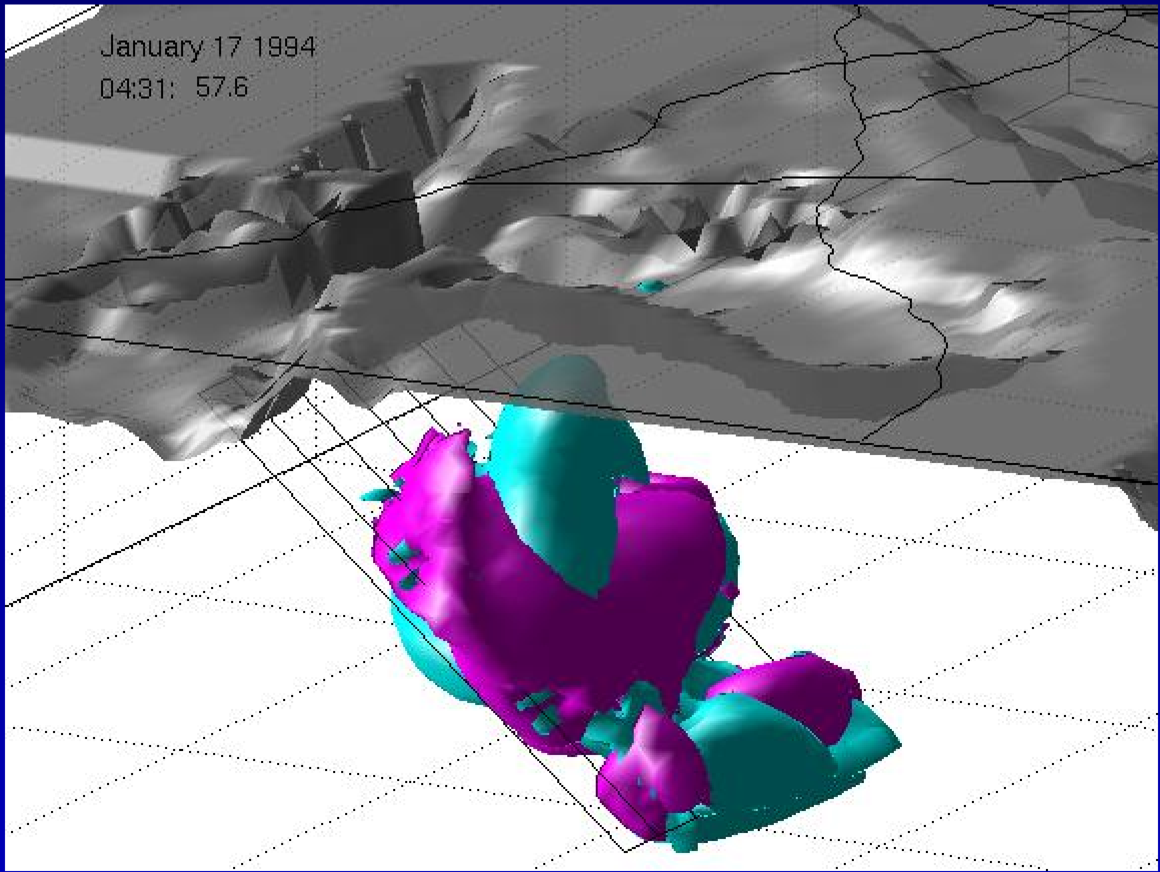

January 17 1994
04:31: 57.0

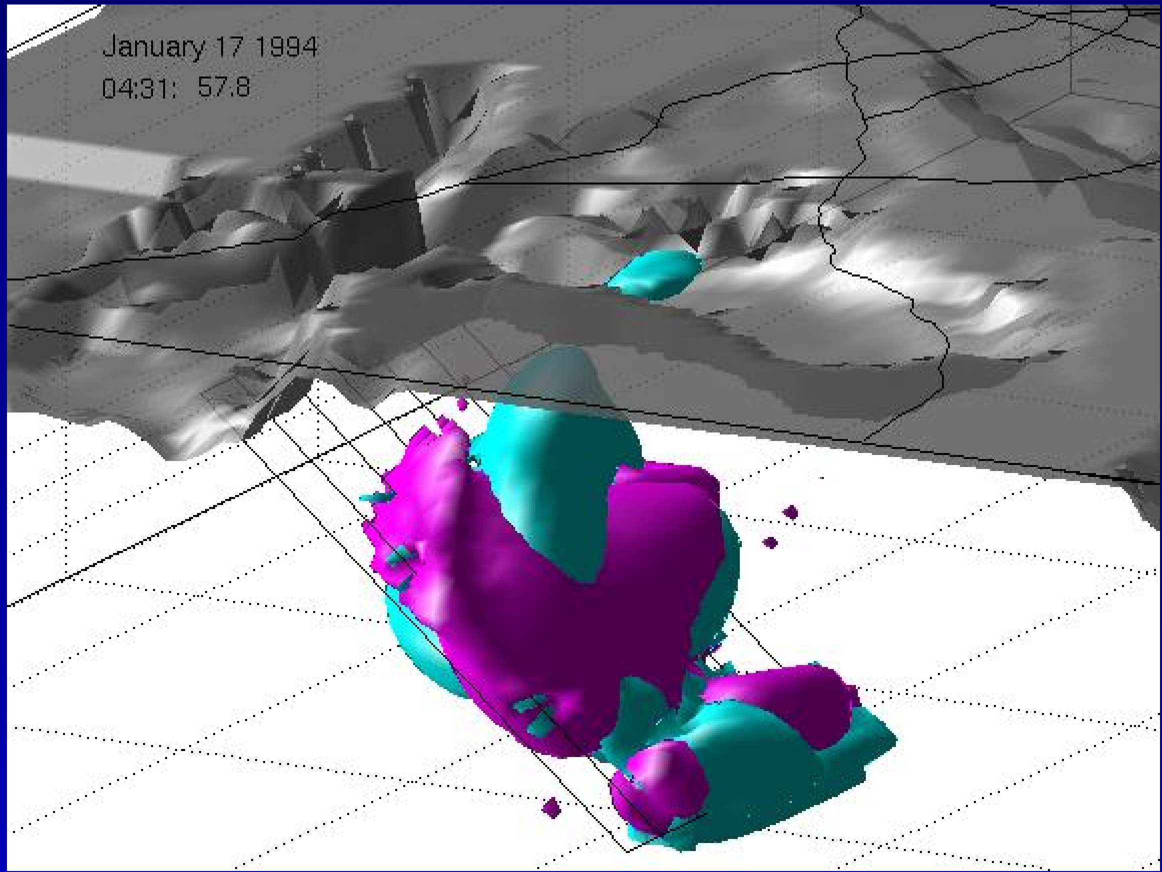

January 17 1994
04:31: 57.1

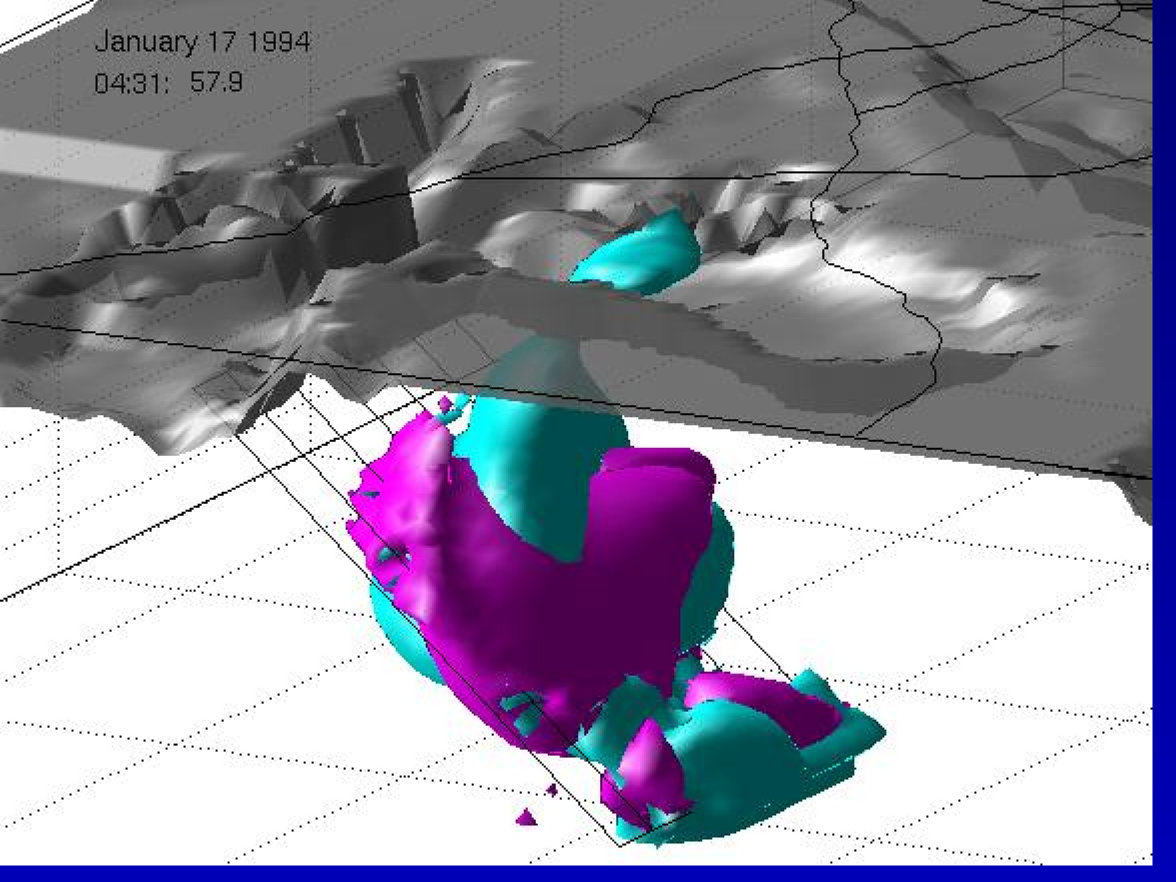

January 17 1994
04:31: 57.2

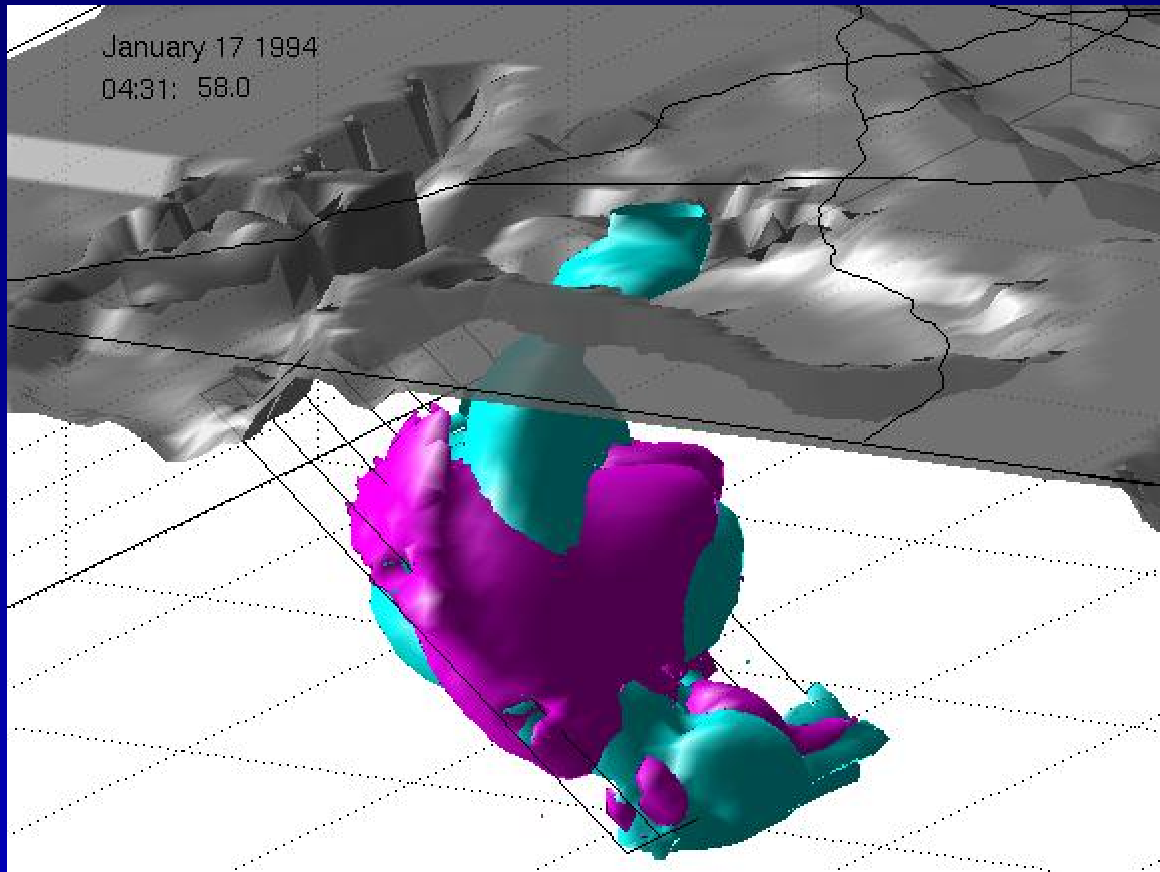

January 17 1994
04:31: 57.4

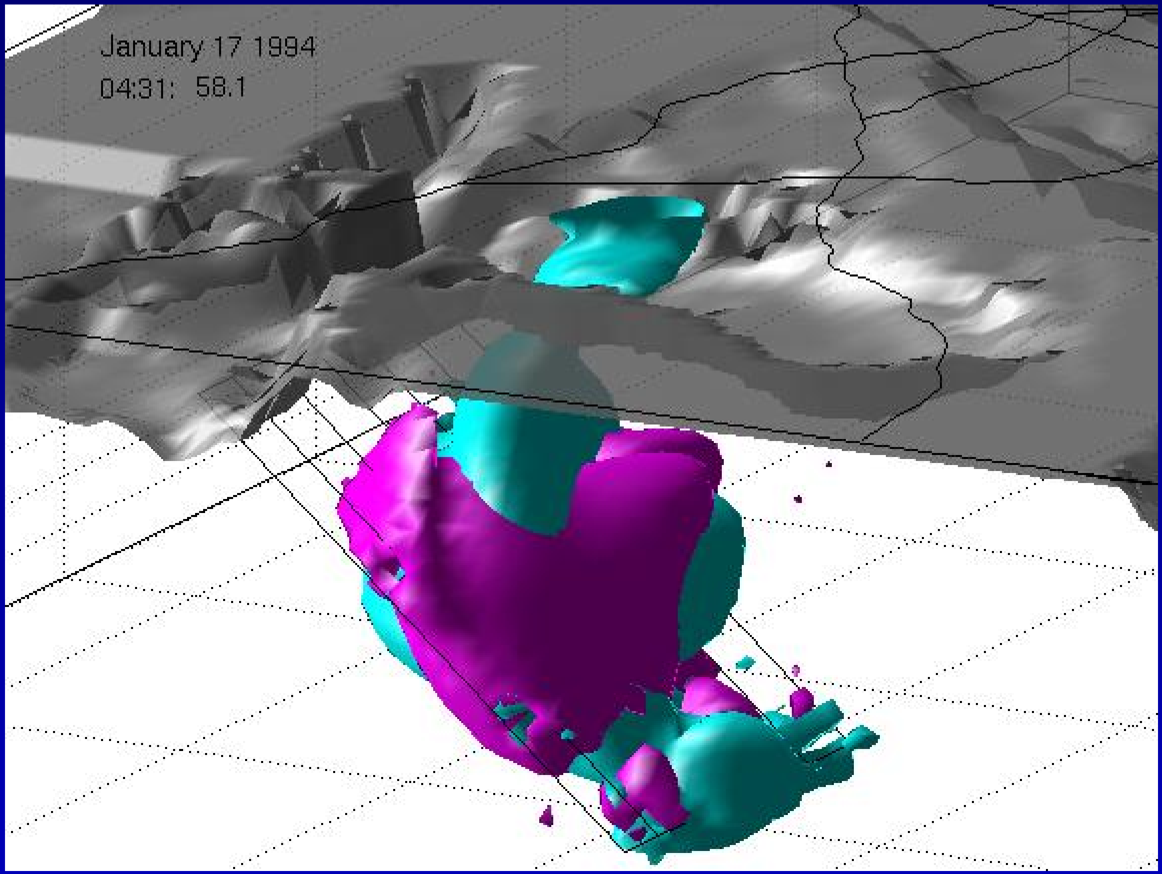

January 17 1994
04:31: 57.5

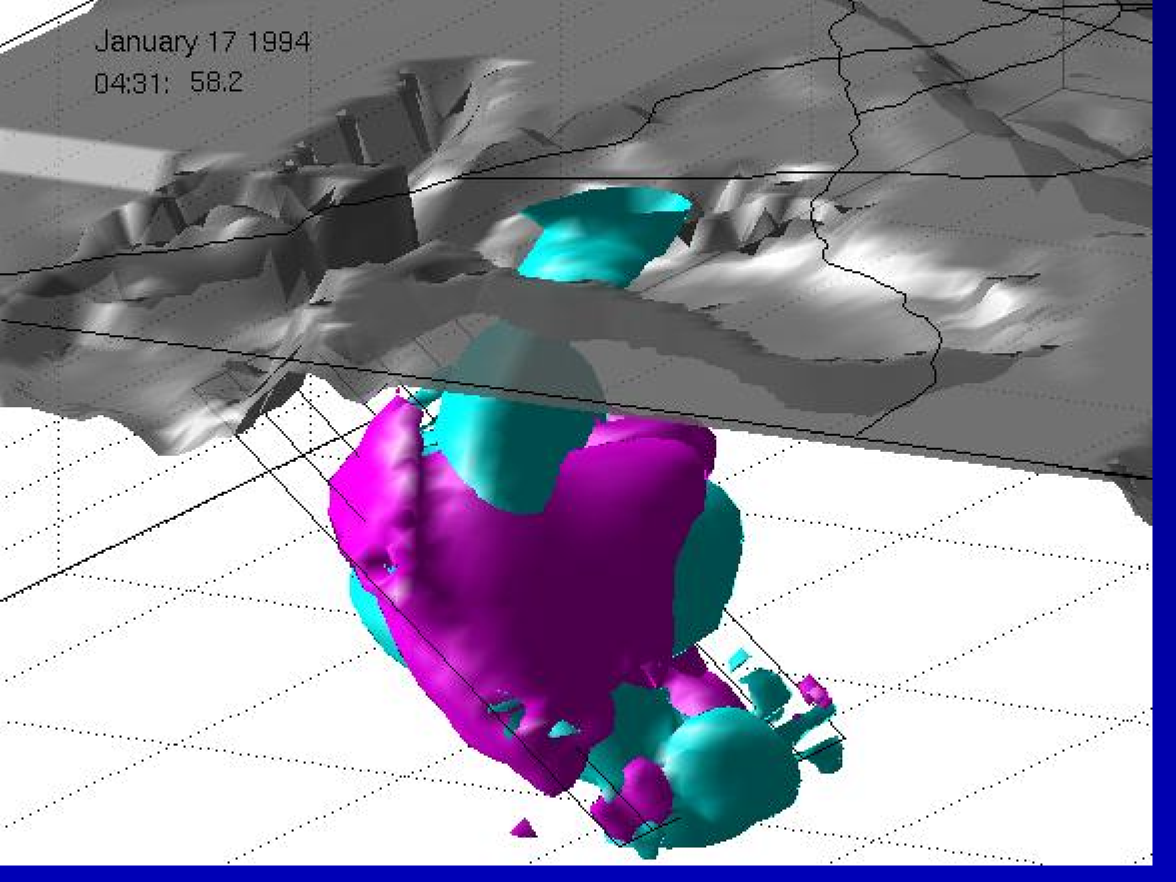

January 17 1994
04:31: 57.6

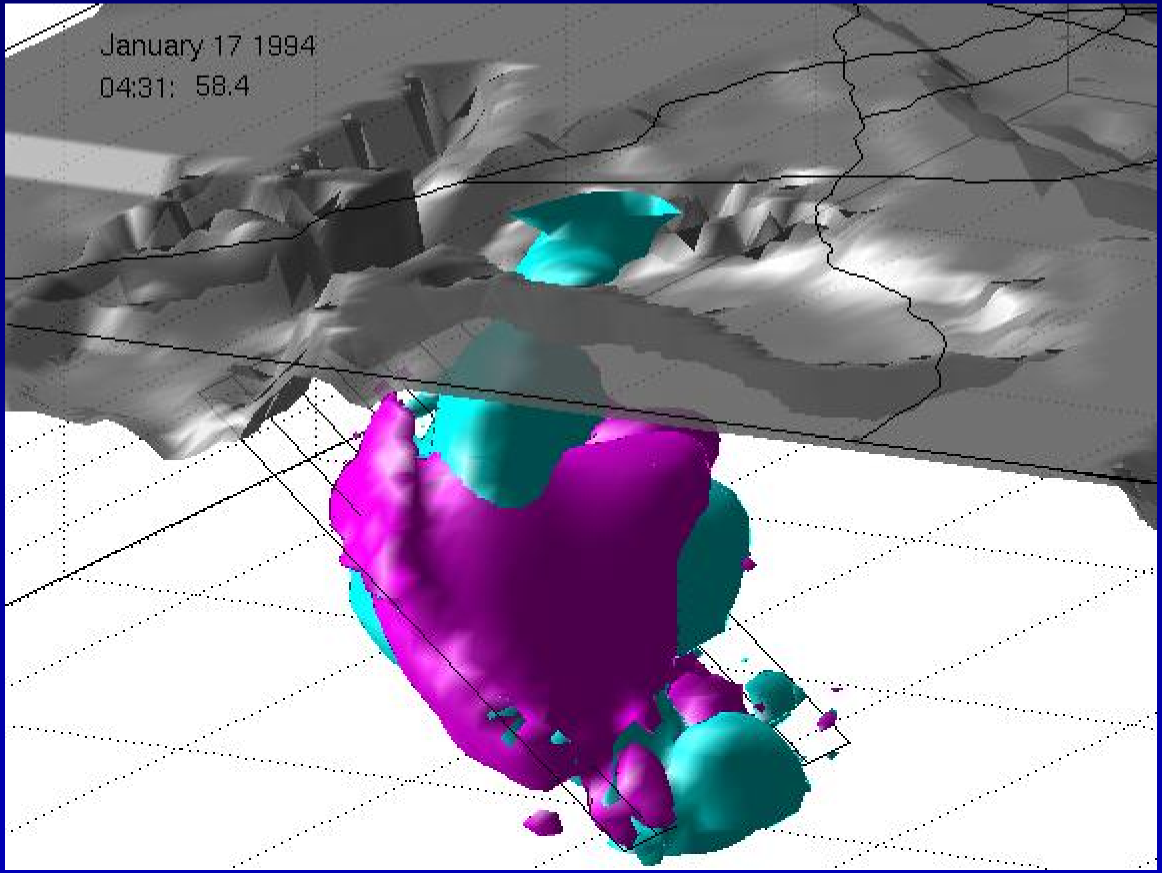

January 17 1994
04:31: 57.8

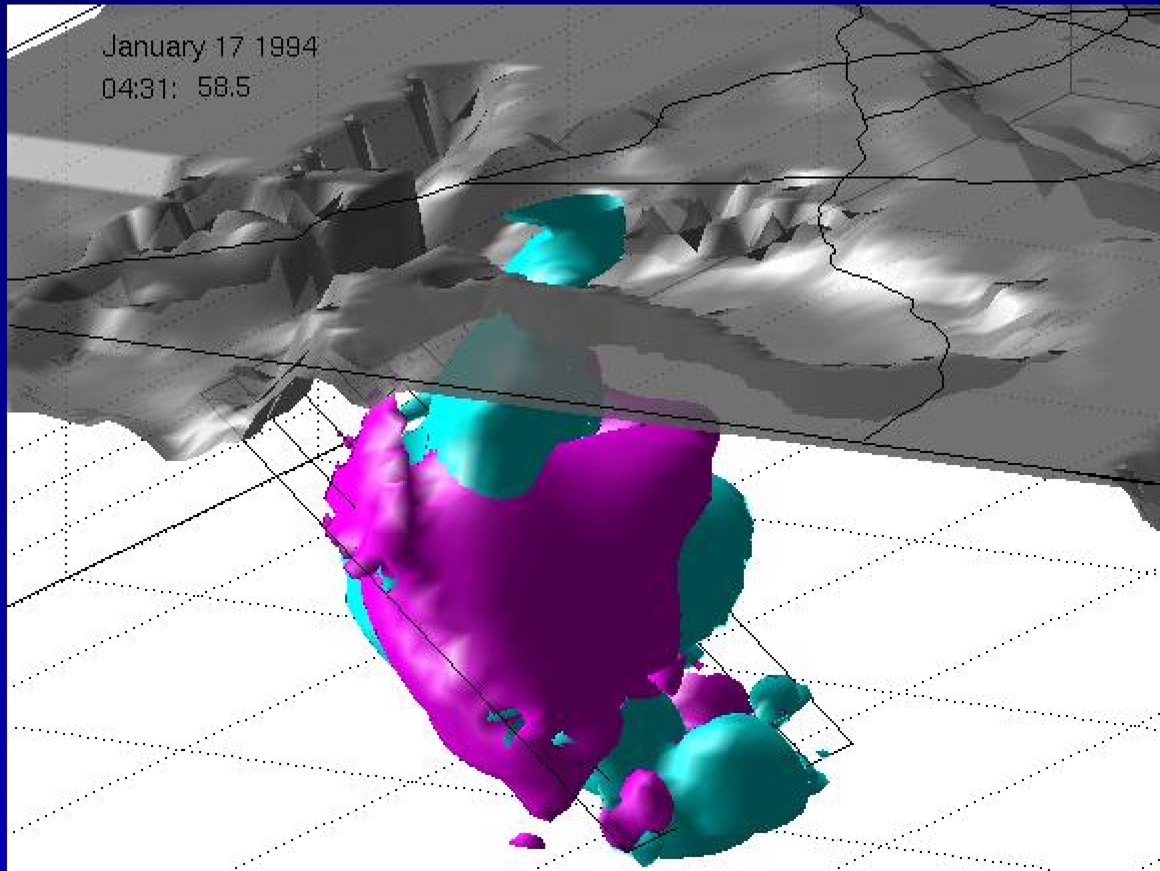

January 17 1994
04:31: 57.9

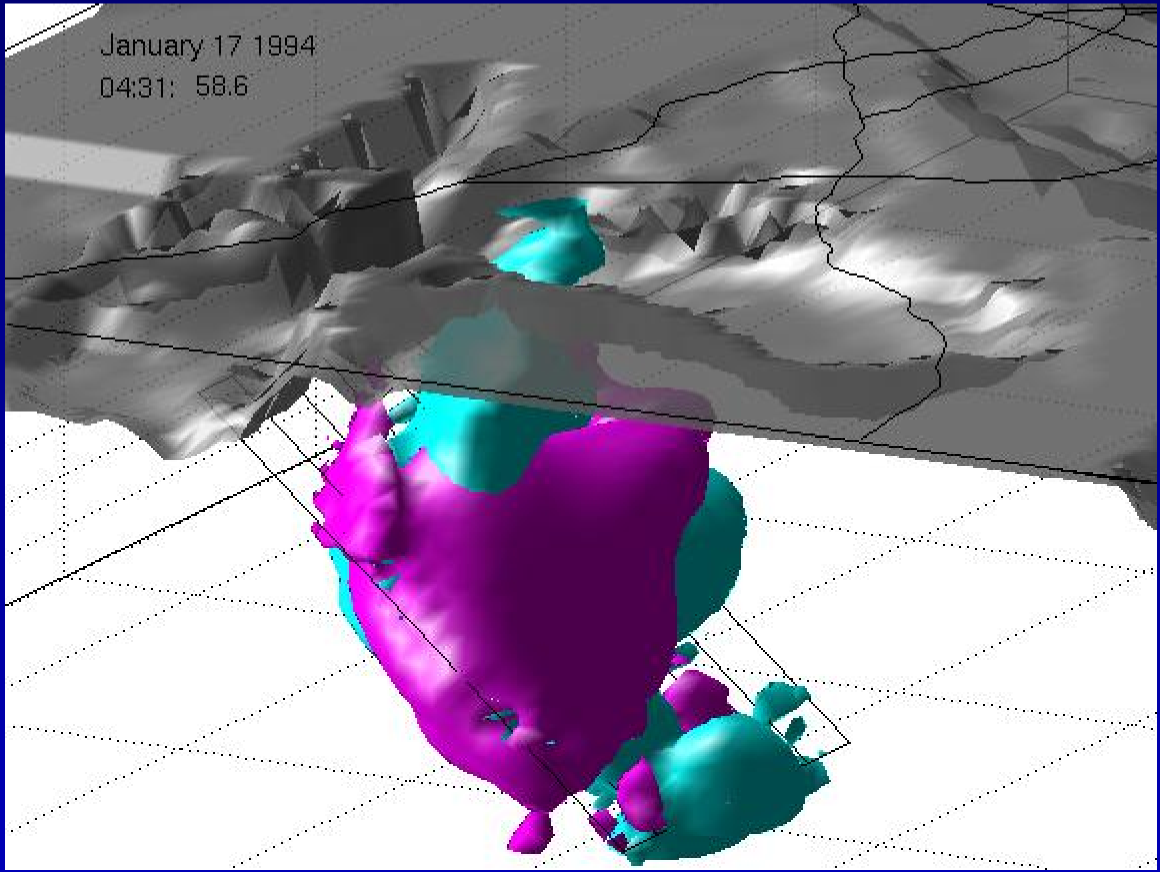

January 17 1994
04:31: 58.0

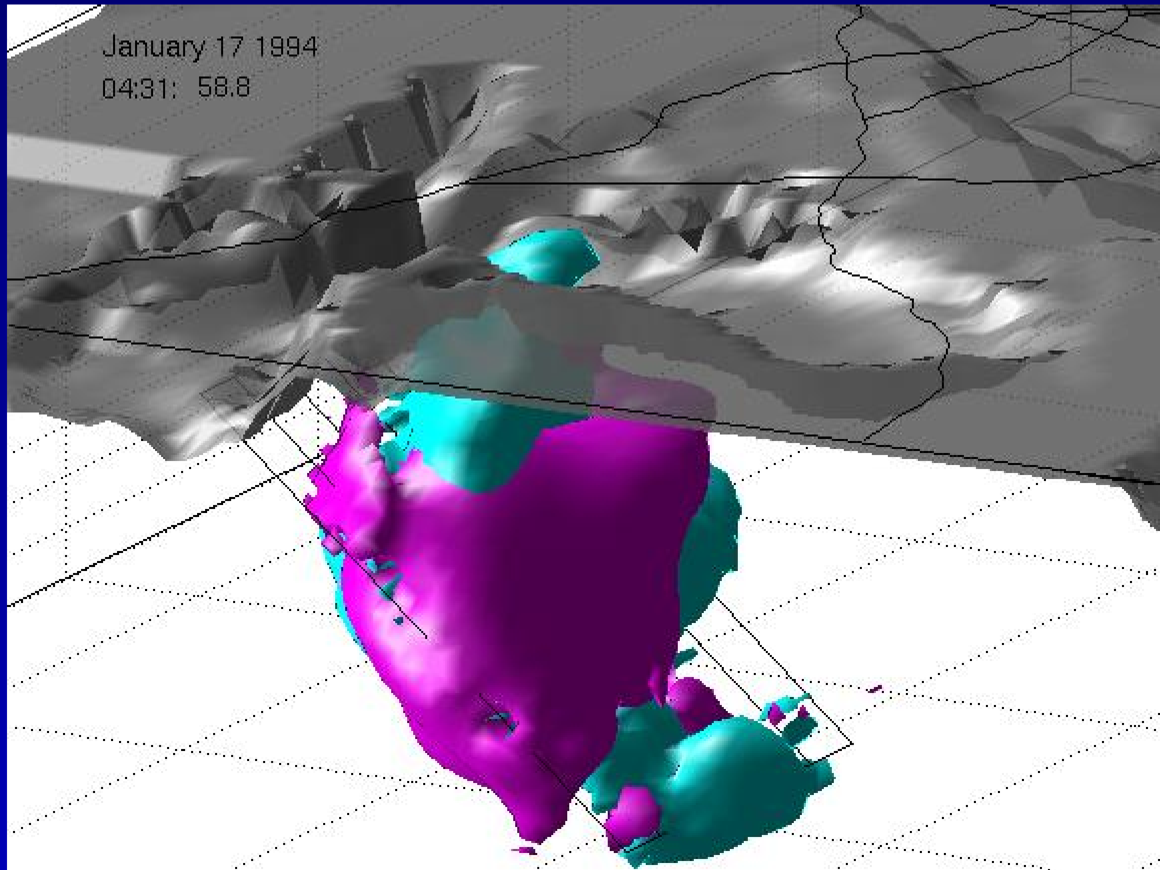

January 17 1994
04:31: 58.1

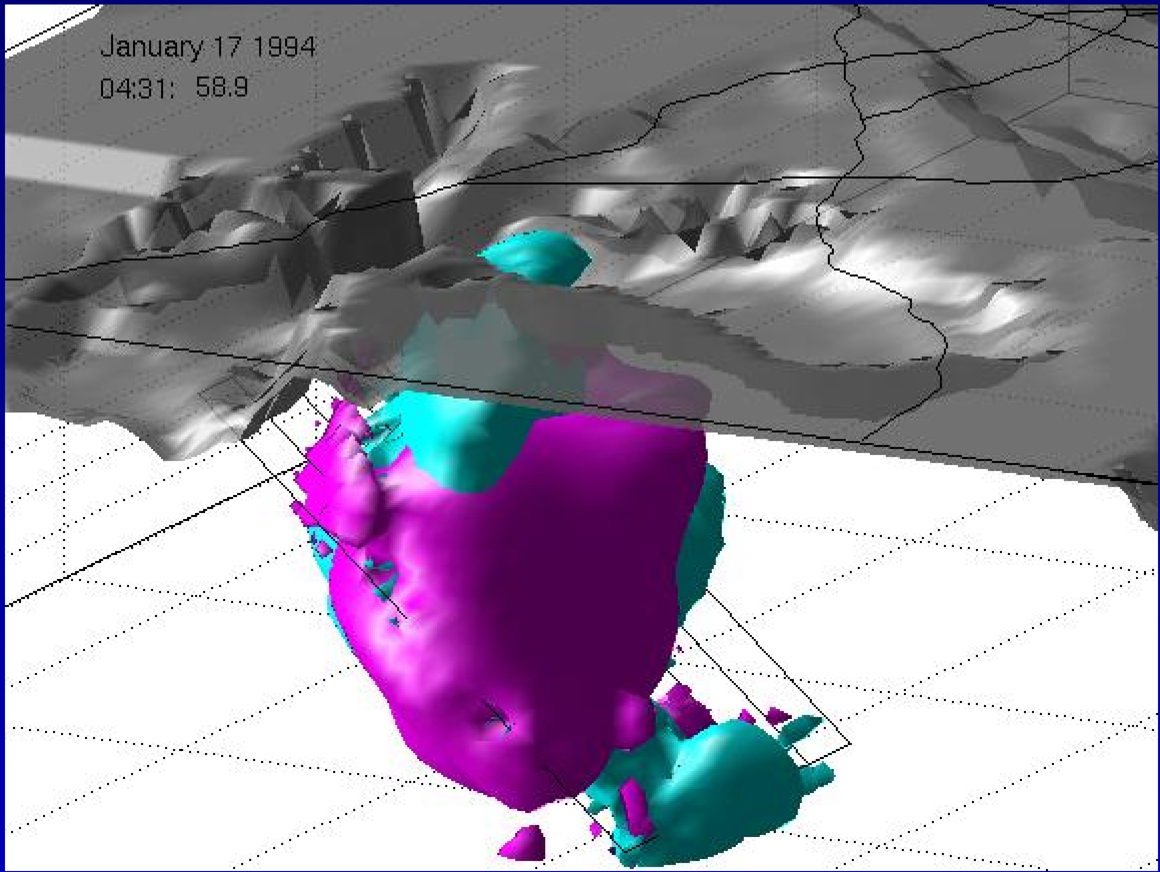

January 17 1994
04:31: 58.2

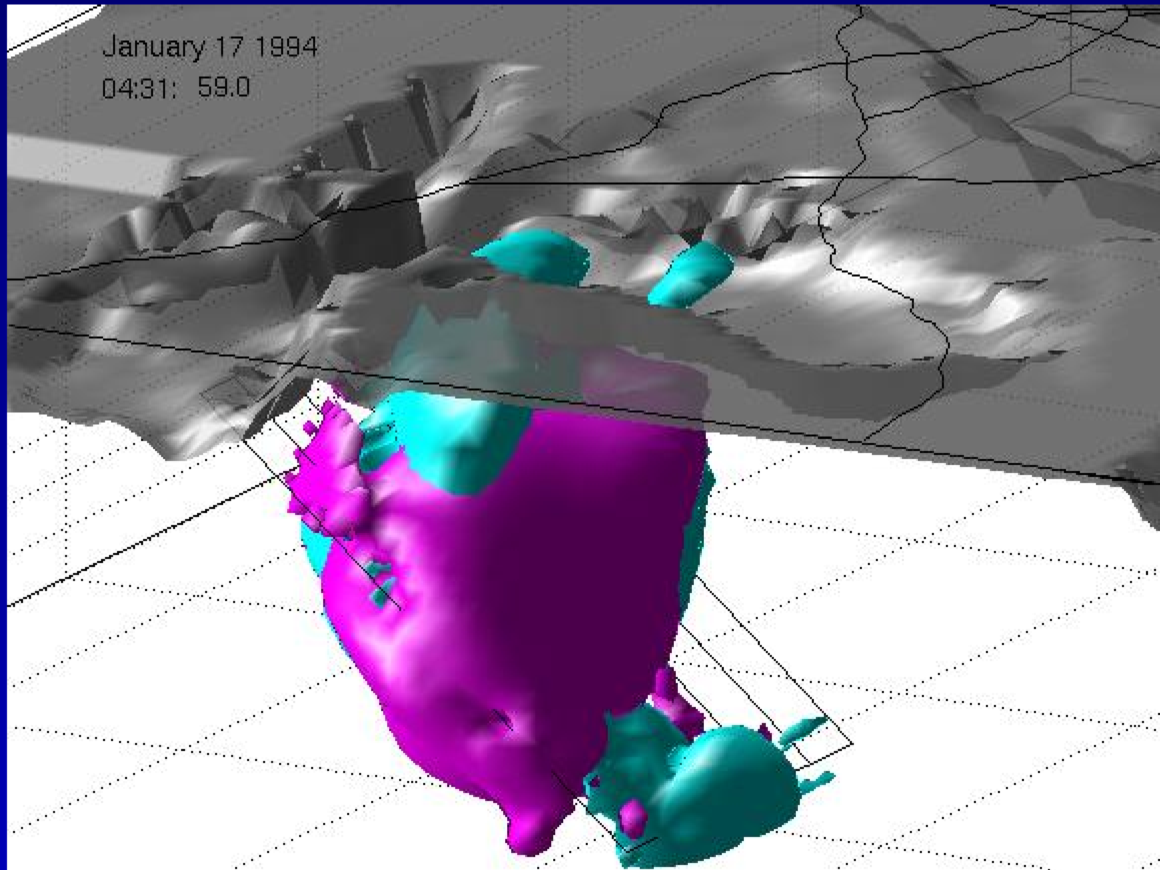

January 17 1994
04:31: 58.4

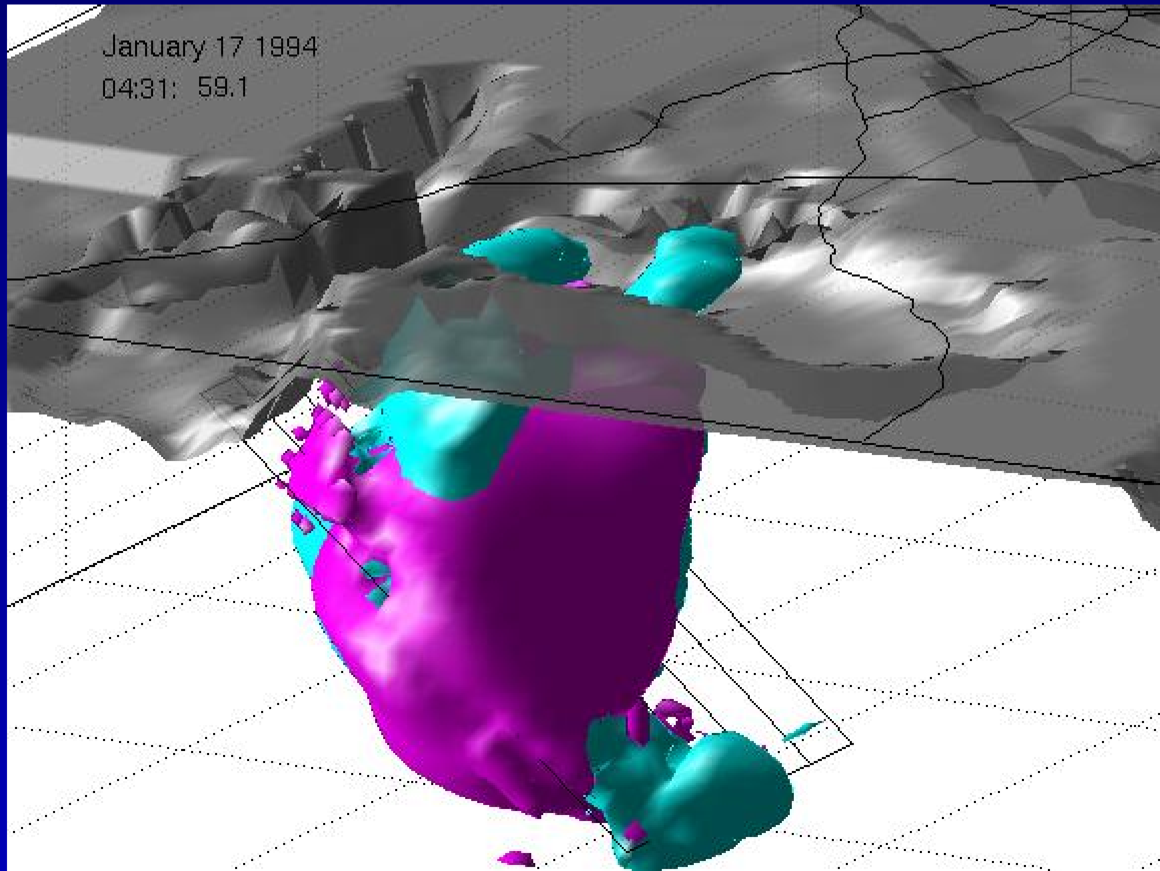

January 17 1994
04:31: 58.5

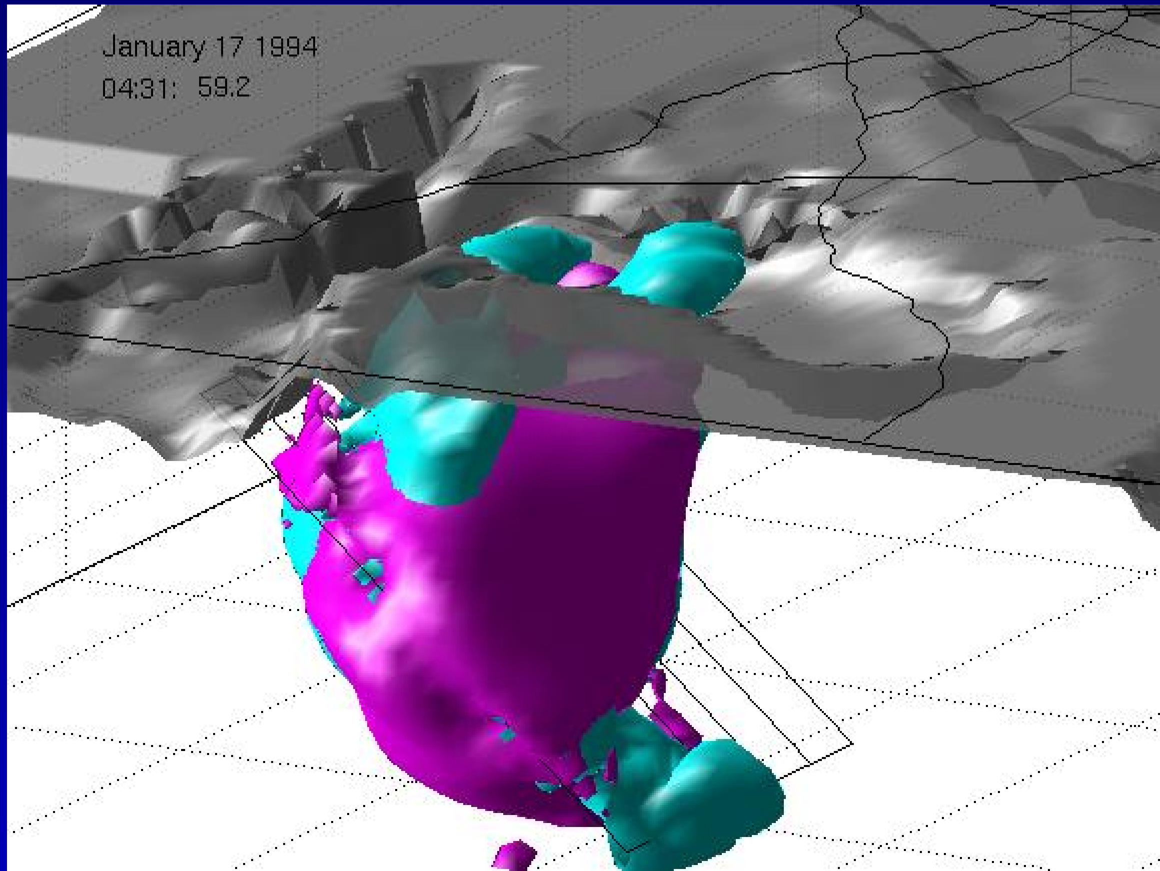

January 17 1994
04:31: 58.6

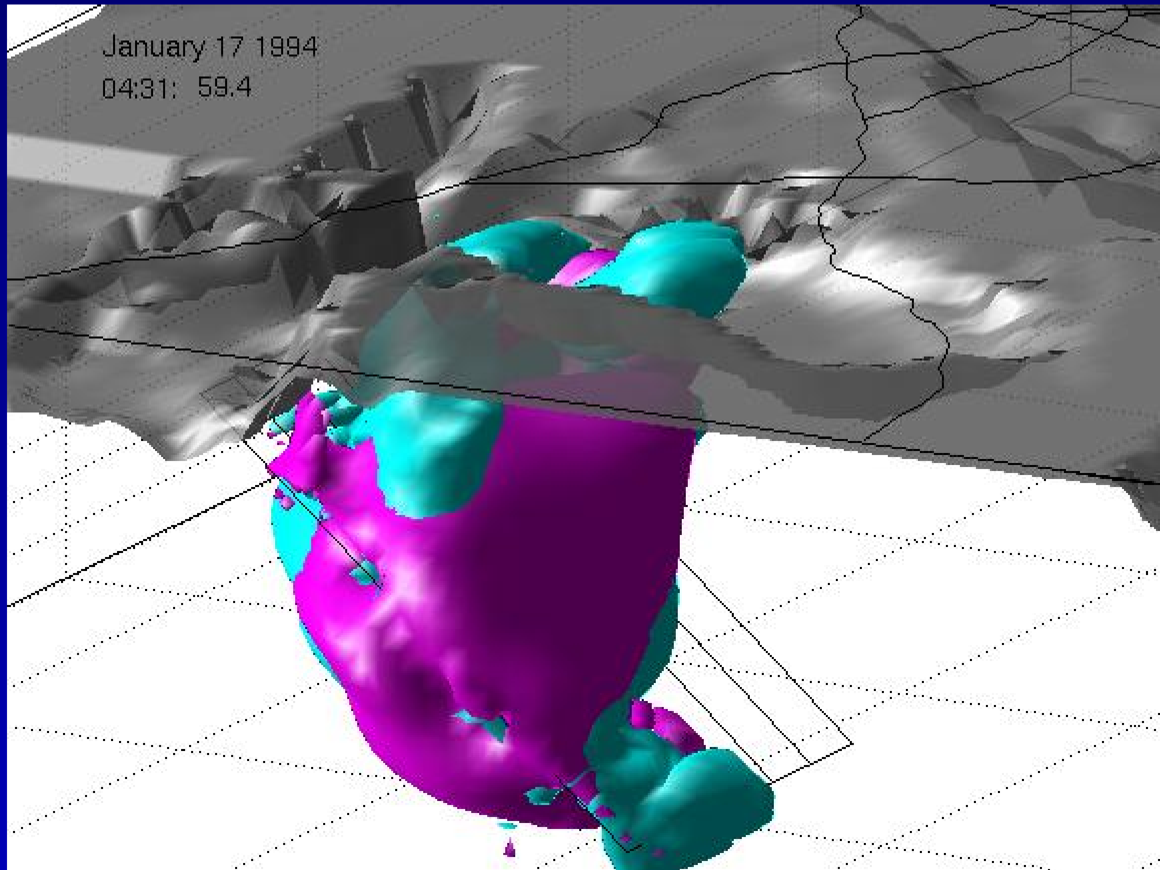

January 17 1994
04:31: 58.8

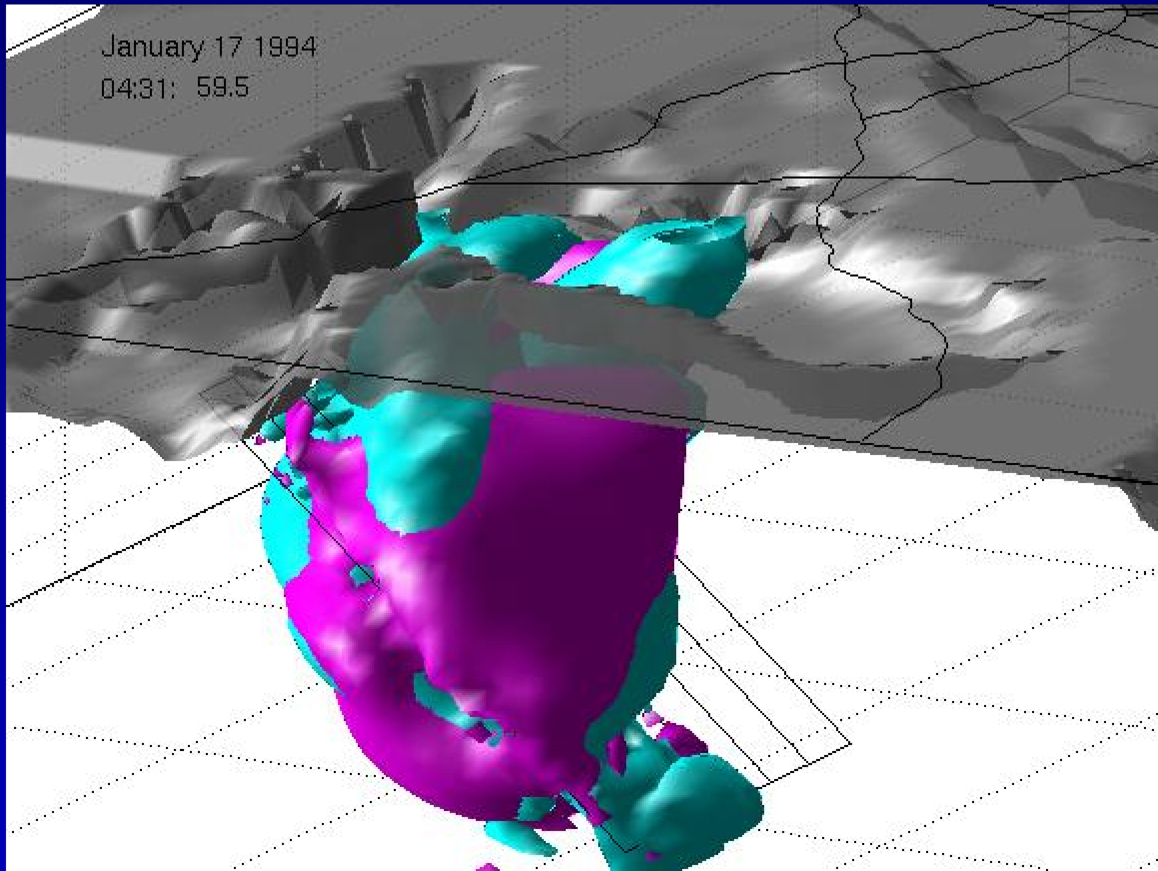

January 17 1994
04:31: 58.9

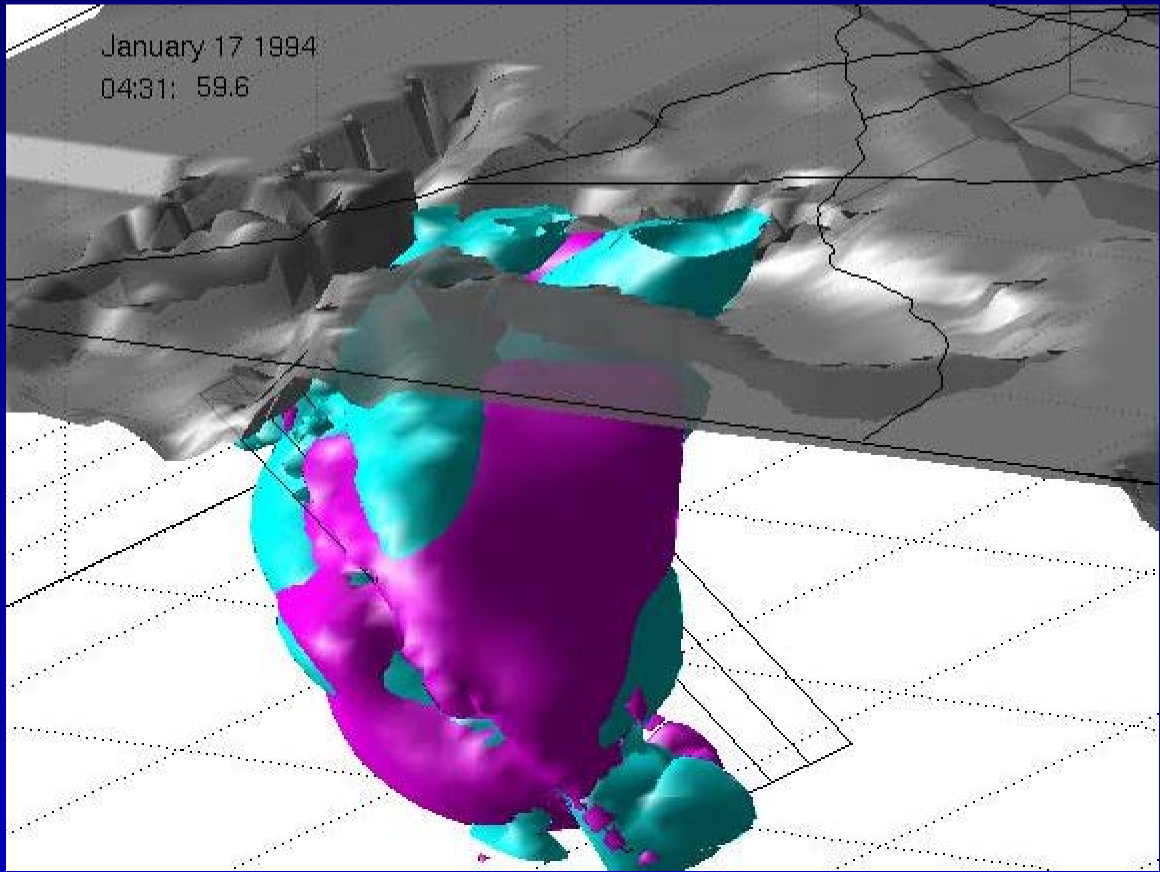

January 17 1994
04:31: 59.0

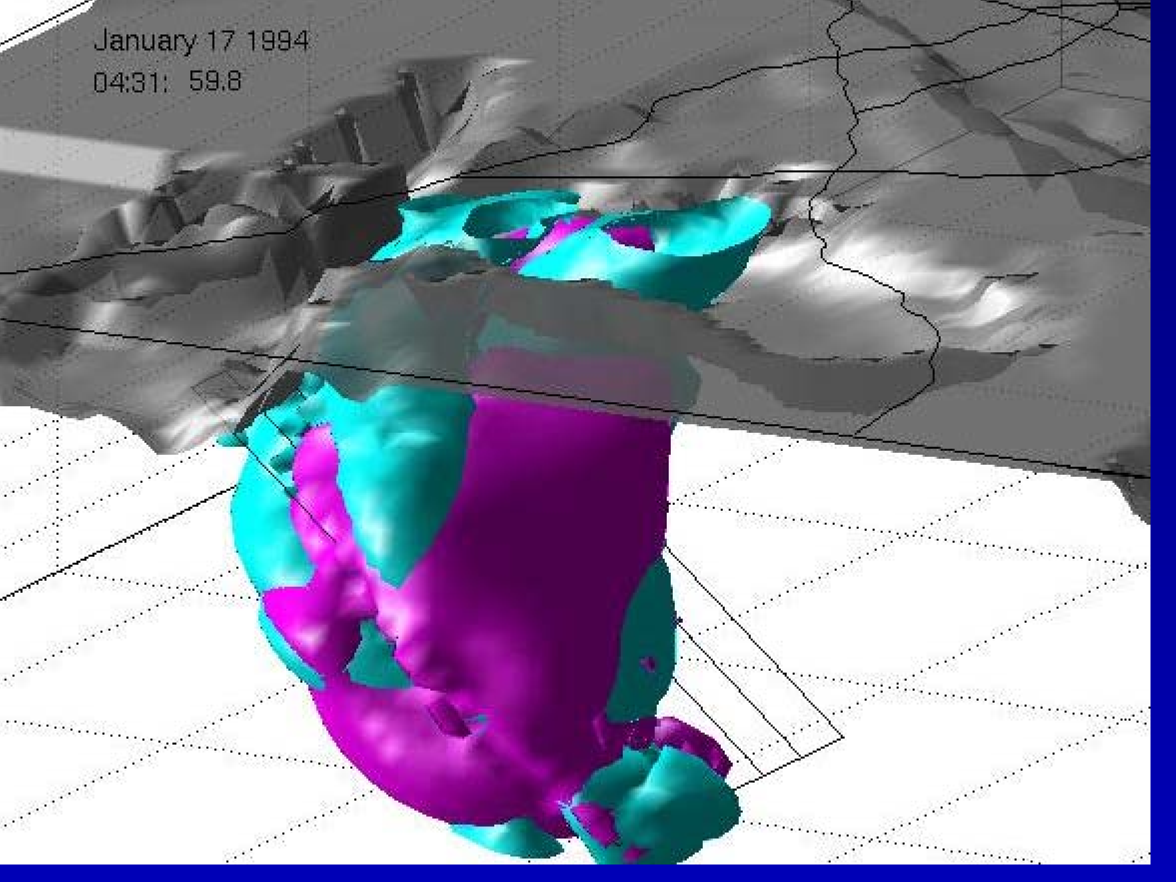

January 17 1994
04:31: 59.1

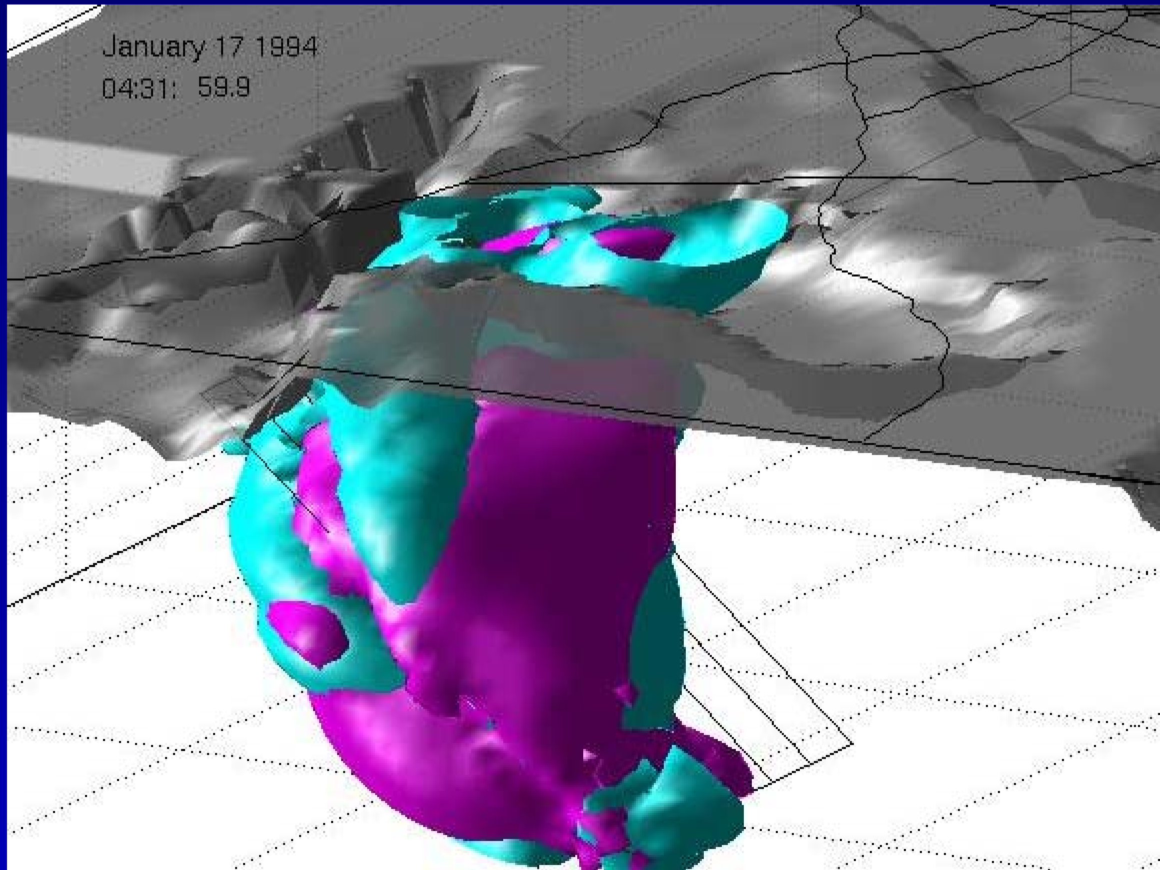

January 17 1994
04:31: 59.2

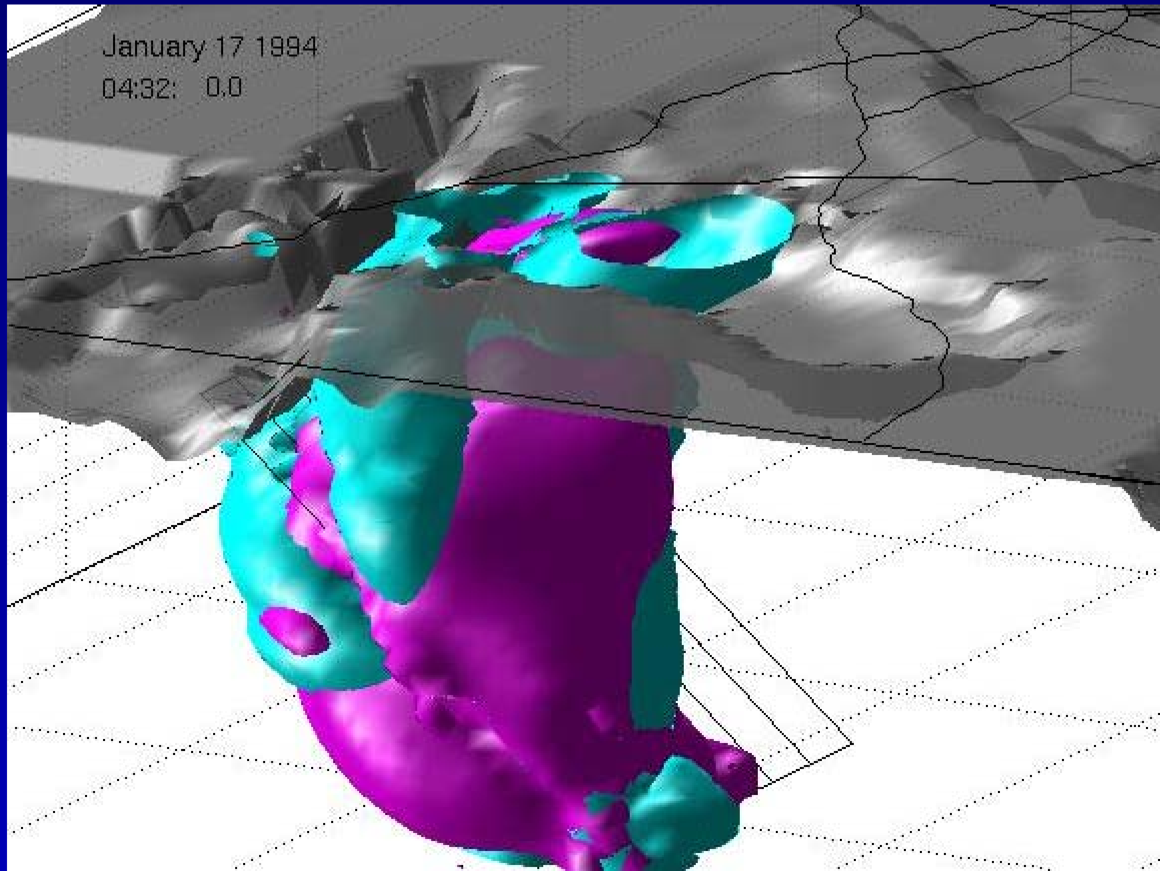

January 17 1994
04:31: 59.4

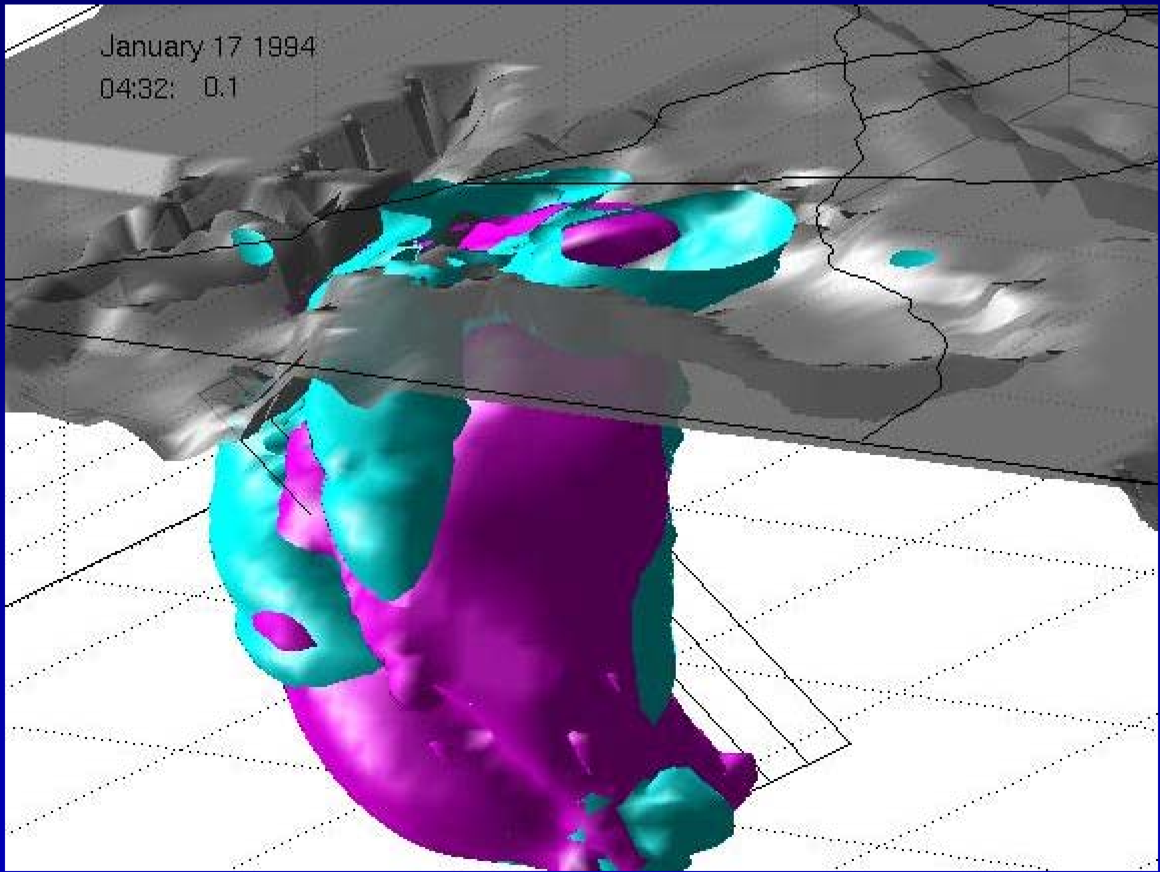

January 17 1994
04:31: 59.5

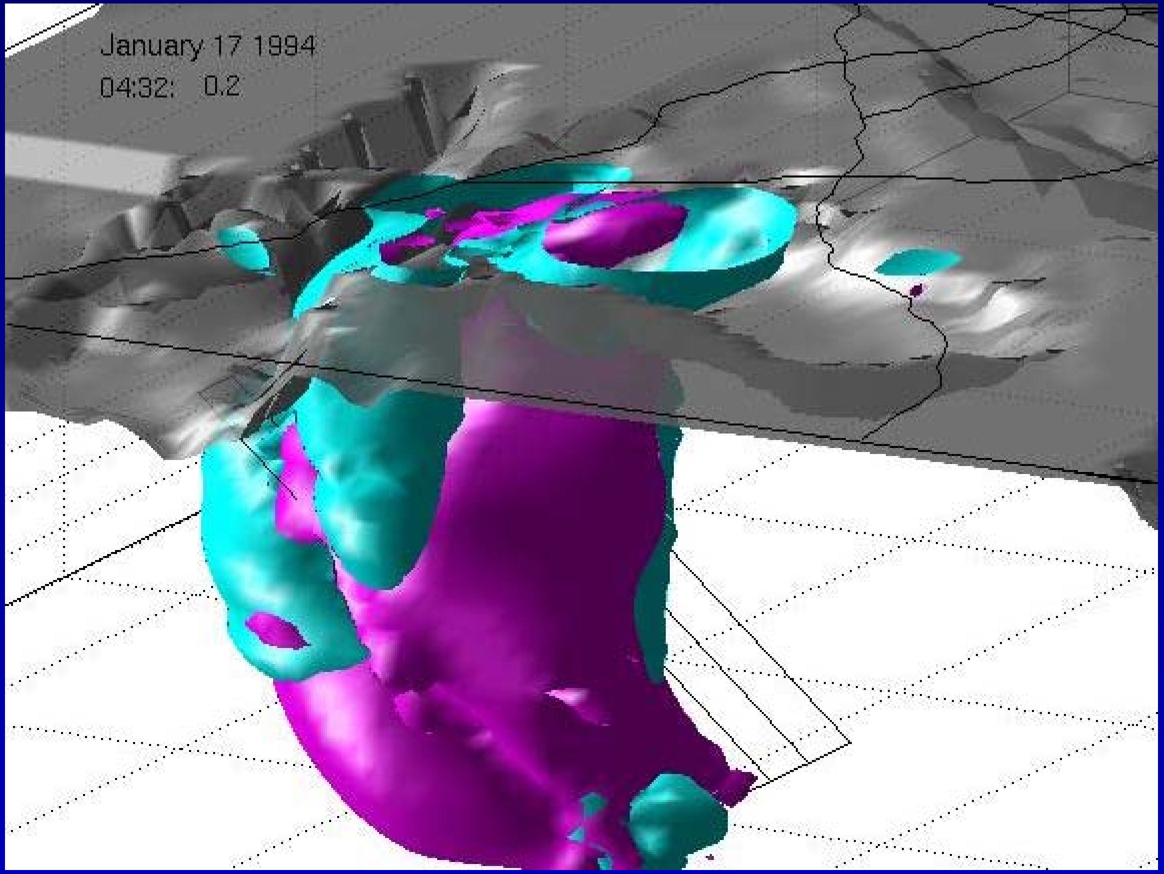

January 17 1994
04:31: 59.6

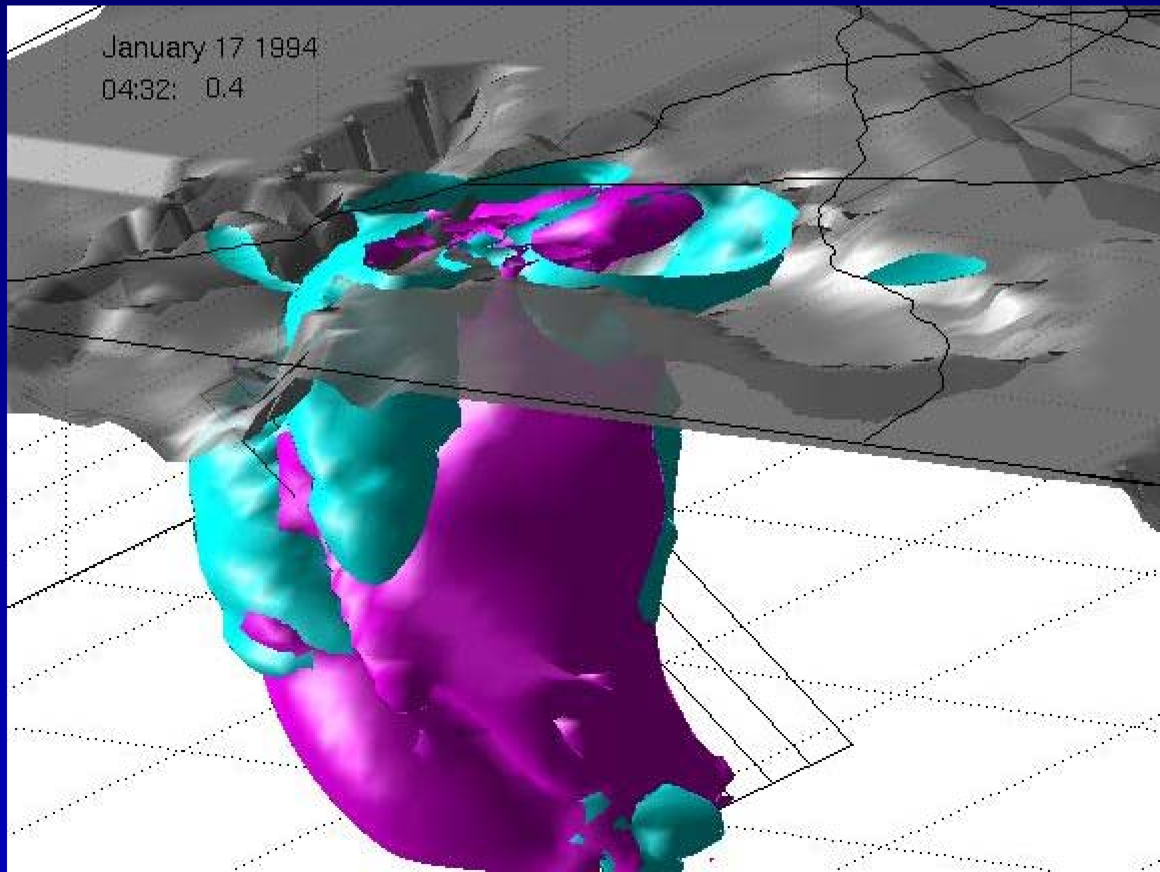

January 17 1994
04:31: 59.8

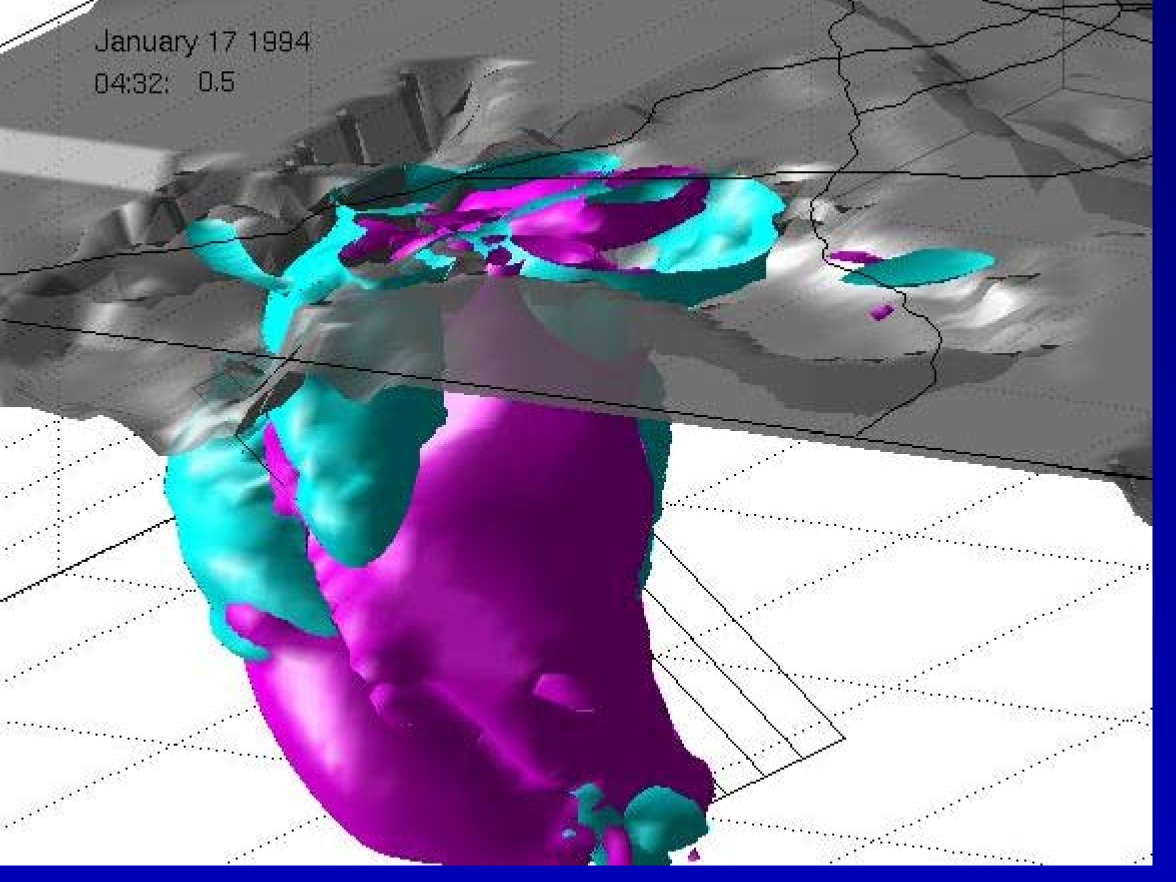

January 17 1994
04:31: 59.9

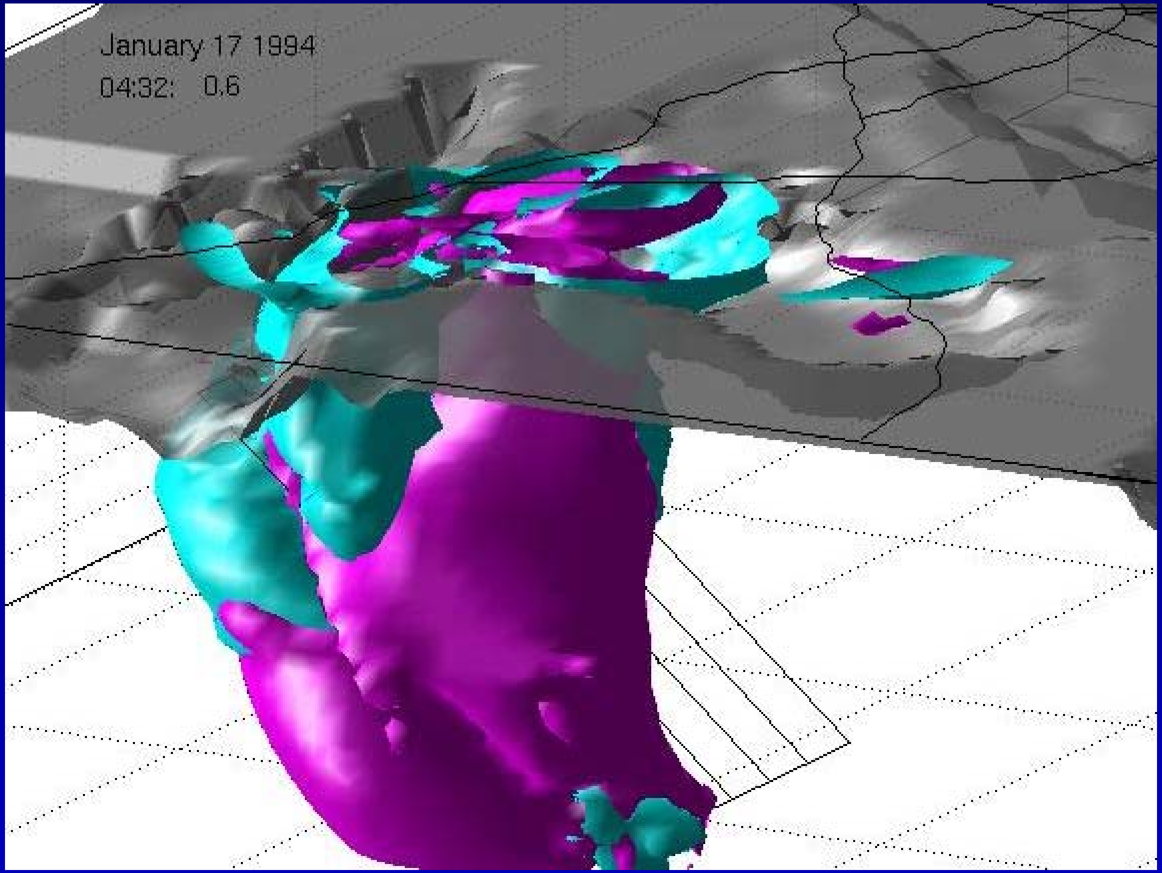

January 17 1994
04:32: 0.0

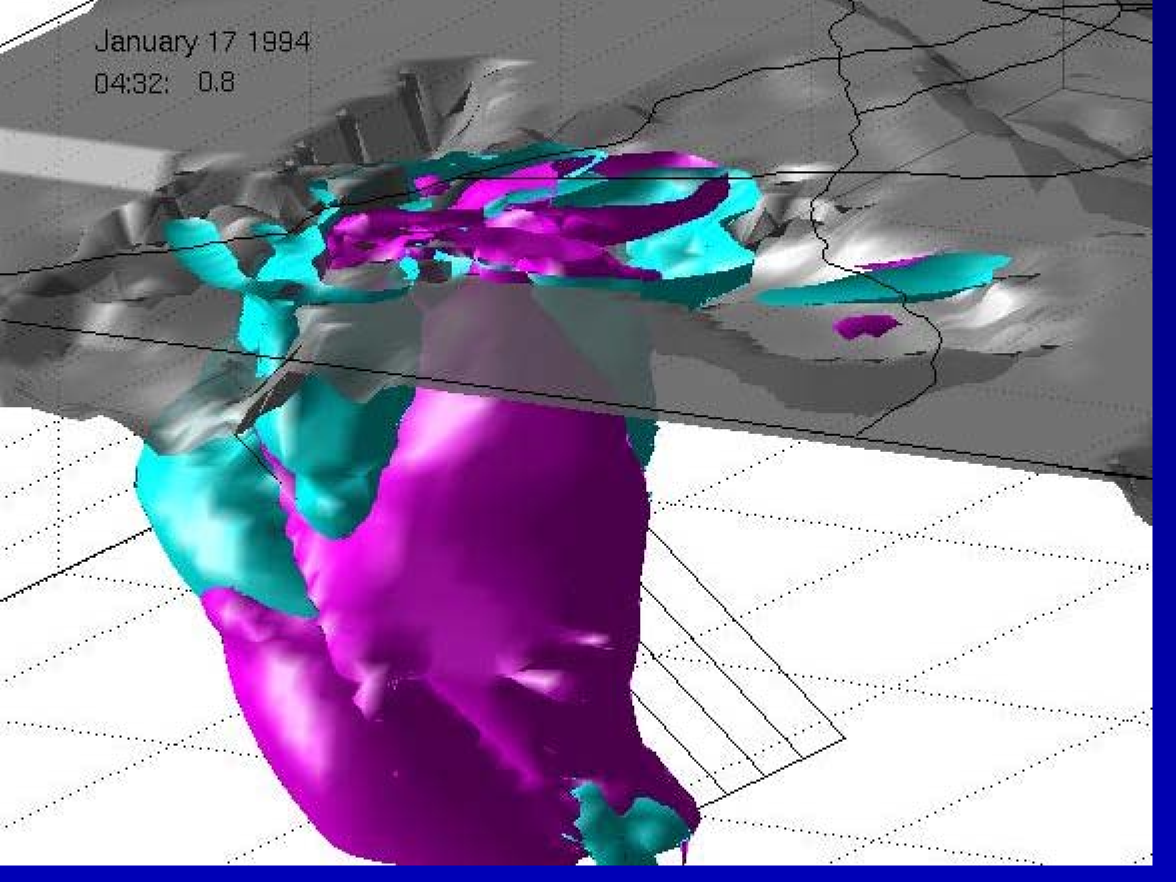

January 17 1994
04:32: 0.1

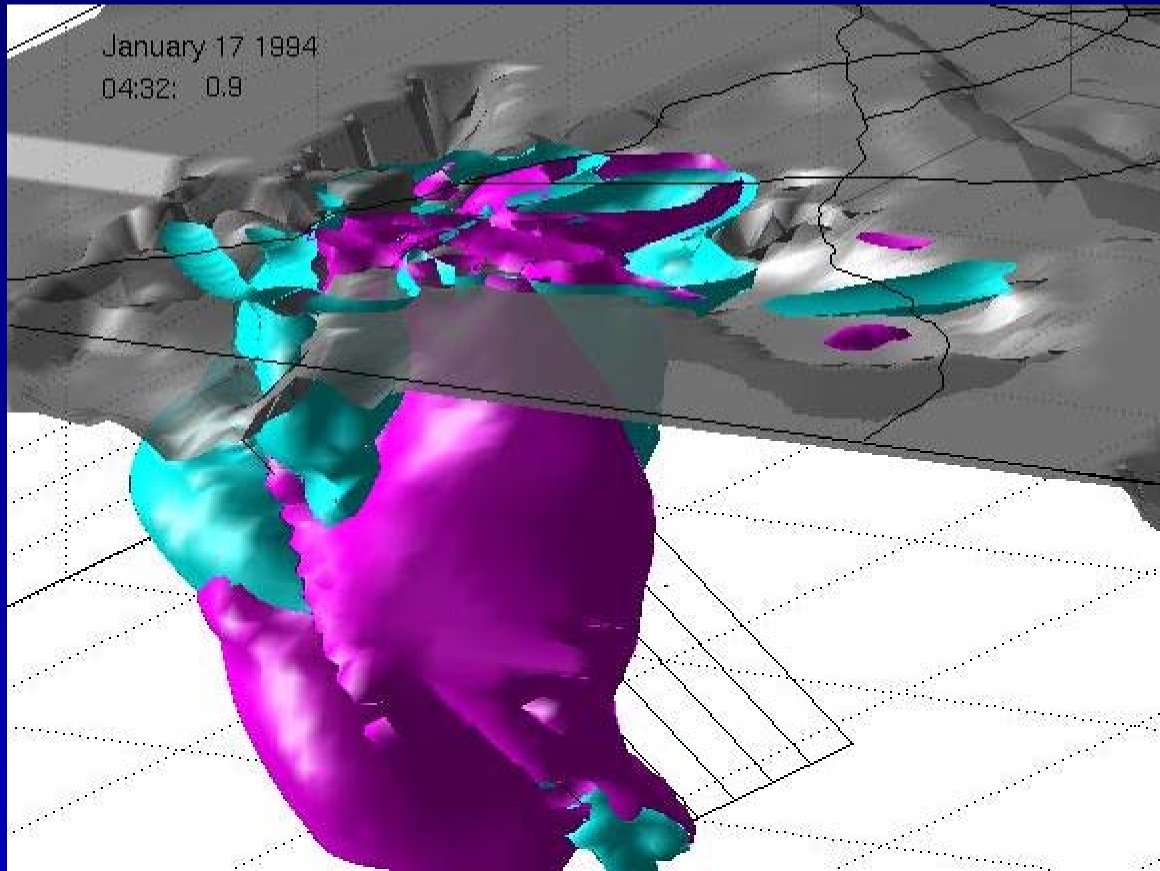

January 17 1994
04:32: 0.2

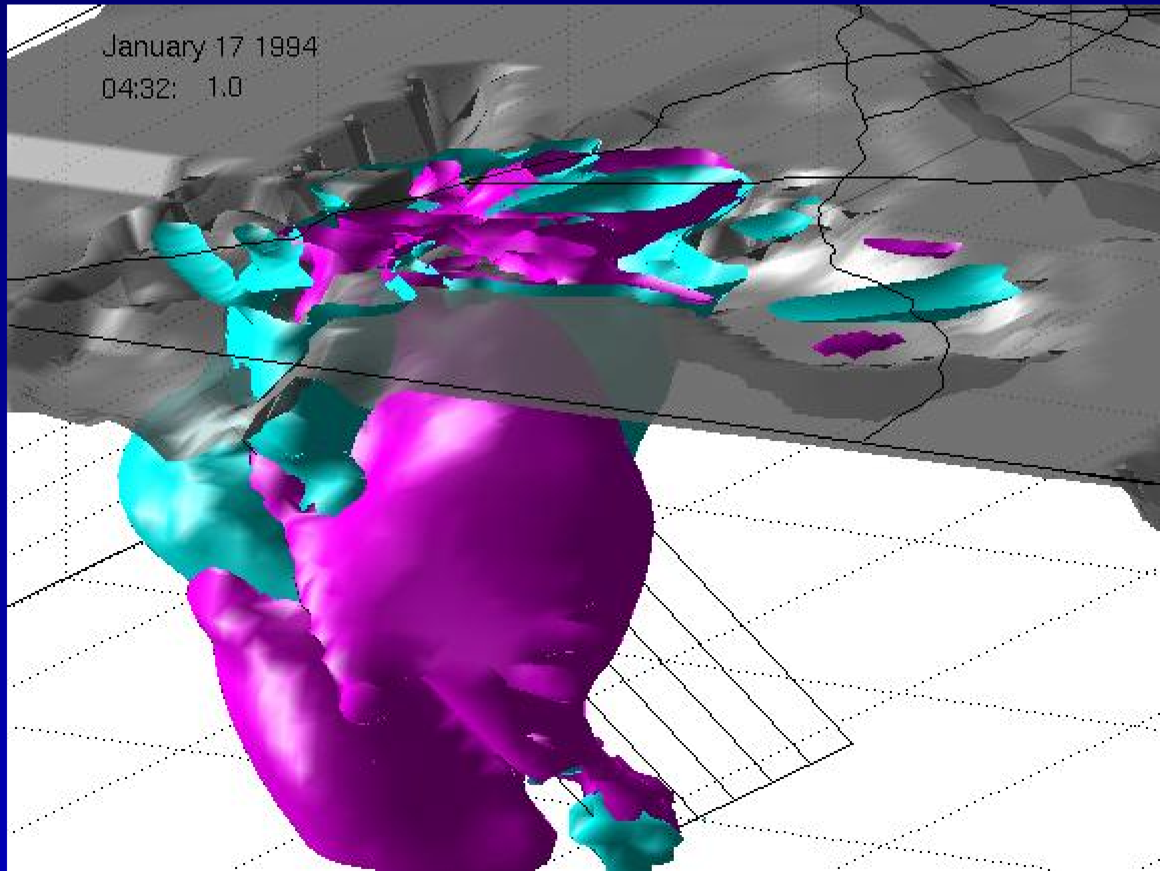

January 17 1994
04:32: 0.4

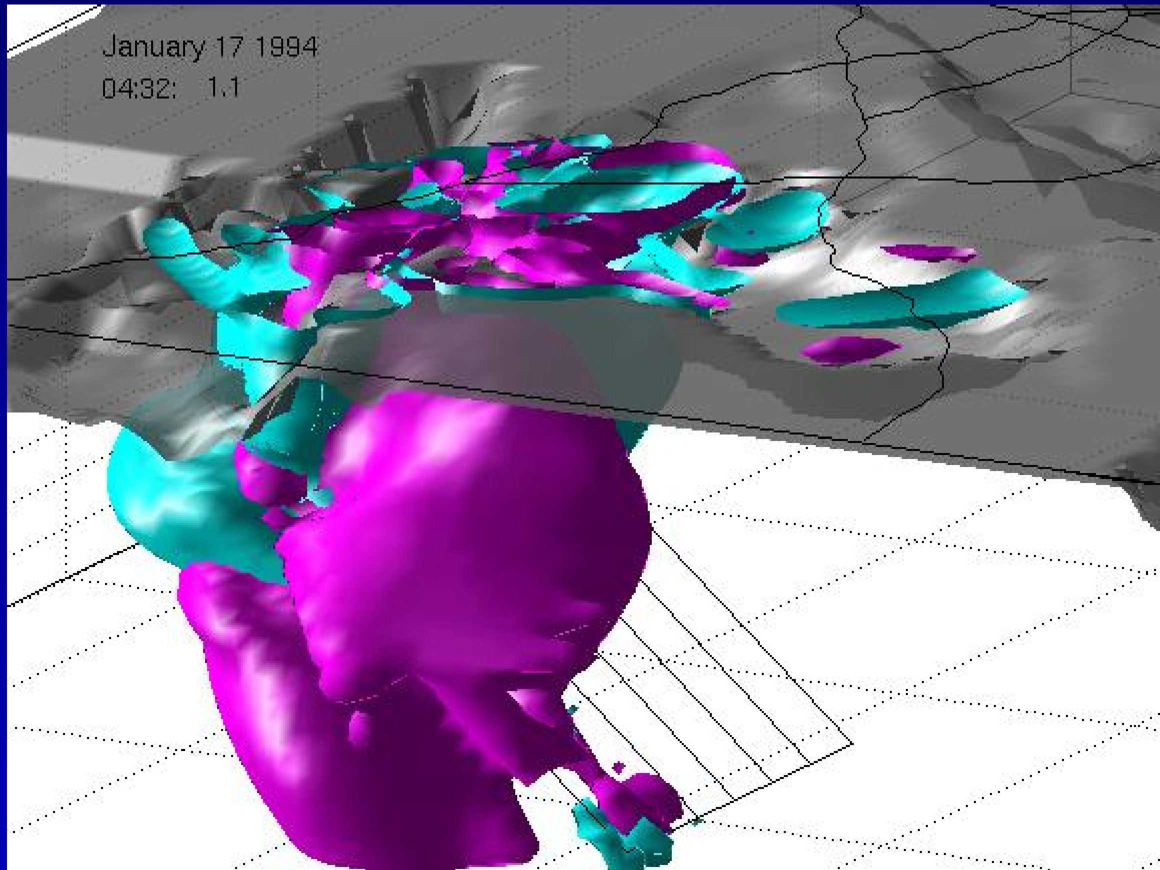

January 17 1994
04:32: 0.5

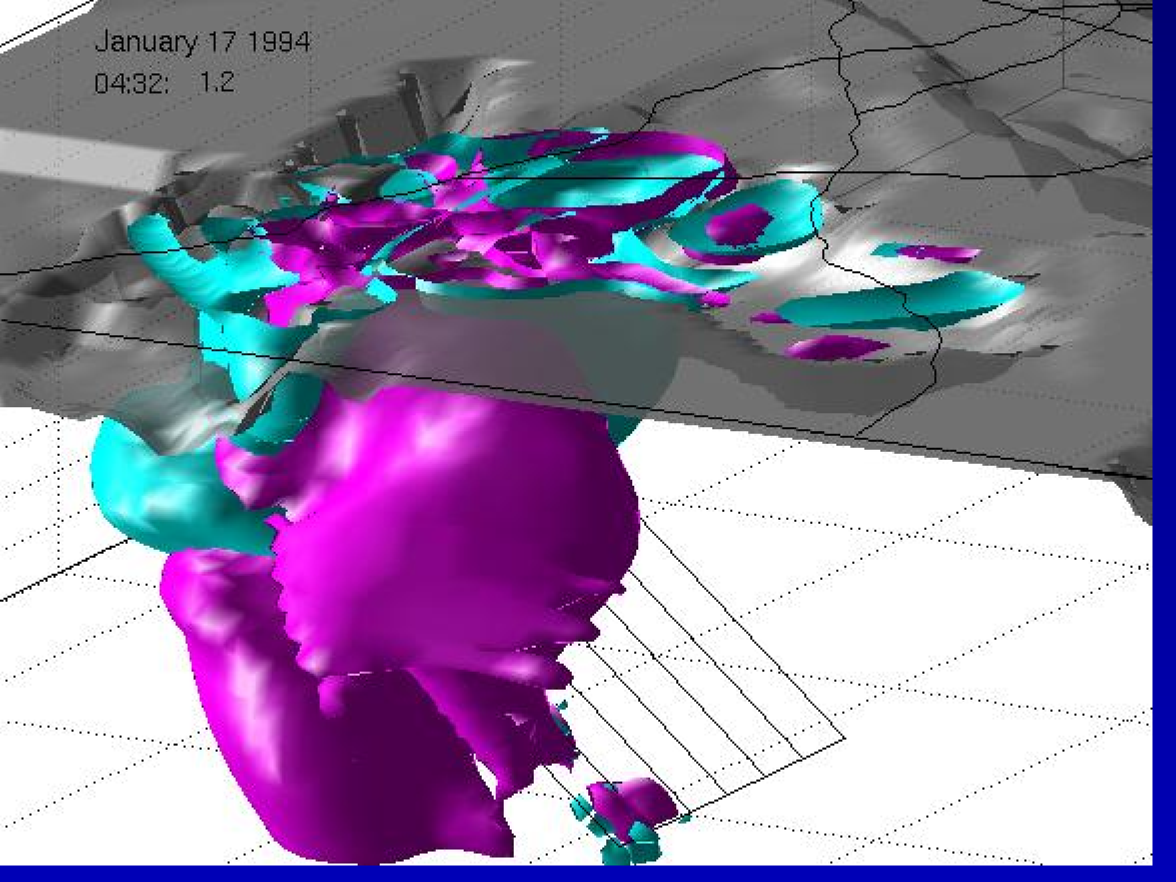

January 17 1994
04:32: 0.6


January 17 1994
04:32: 0.8


January 17 1994
04:32: 0.9


January 17 1994
04:32: 1.0


January 17 1994
04:32: 1.1


January 17 1994
04:32: 1.2

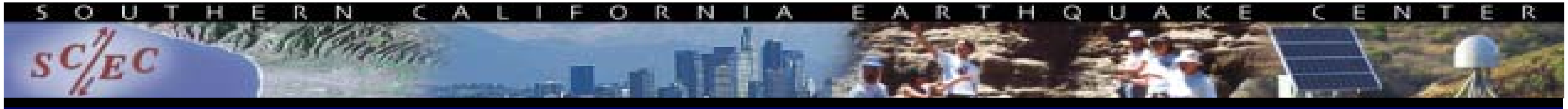
Lessons Learned So Far

Lessons Learned So Far

- Well-defined system-level problems such as SHA provide the focus needed for collaboratory development

Lessons Learned So Far

- Well-defined system-level problems such as SHA provide the focus needed for collaboratory development
- Interoperability is <u>the</u> key problem for information flow in the system-level approach to SHA



Lessons Learned So Far

- Well-defined system-level problems such as SHA provide the focus needed for collaboratory development
- Interoperability is <u>the</u> key problem for information flow in the system-level approach to SHA
- Development of domain ontologies should lead efforts to construct computational pathways in system-level science

Lessons Learned So Far

- Well-defined system-level problems such as SHA provide the focus needed for collaboratory development
- Interoperability is <u>the</u> key problem for information flow in the system-level approach to SHA
- Development of domain ontologies should lead efforts to construct computational pathways in system-level science
- KR&R tools will be required for curation of complex collections managed by SCEC Collaboratory

Lessons Learned So Far

- Well-defined system-level problems such as SHA provide the focus needed for collaboratory development
- Interoperability is the key problem for information flow in the system-level approach to SHA
- Development of domain ontologies should lead efforts to construct computational pathways in system-level science
- KR&R tools will be required for curation of complex collections managed by SCEC Collaboratory
- Computational and data grids offer great advantages for distributed scientific communities such as SCEC

SOUTHERN CALIFORNIA EARTHQUAKE CENTER

Typical Questions

Typical Questions

- What the hell is an ontology?

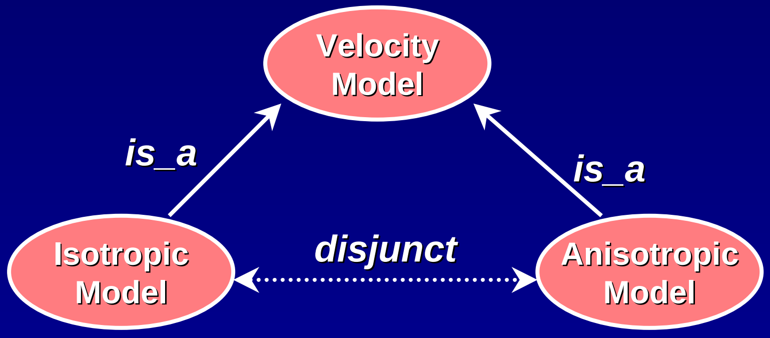
Typical Questions

- What the hell is an ontology?
- What can it do for me?

A Simple Ontology

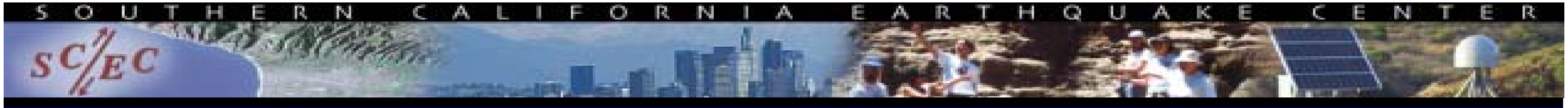
Velocity Model

A Simple Ontology

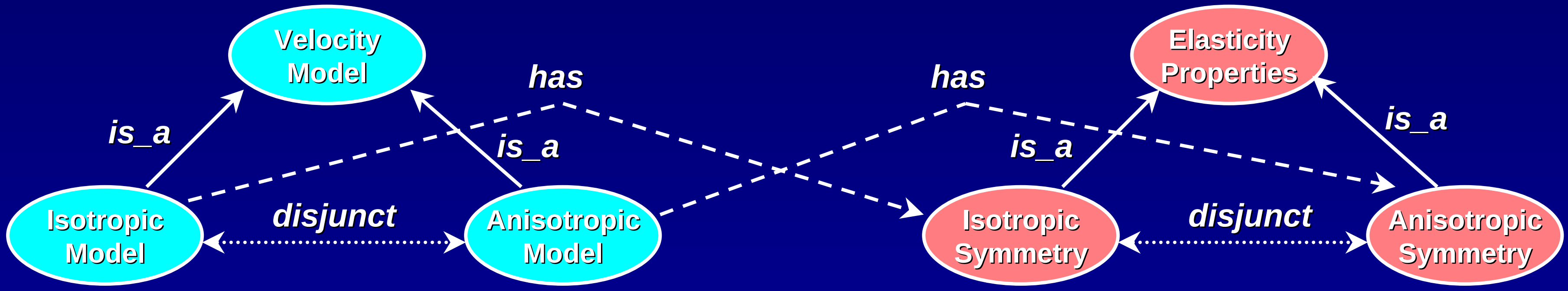


Construction, Part 1:

“A seismic velocity model is either isotropic or anisotropic.”



A Simple Ontology



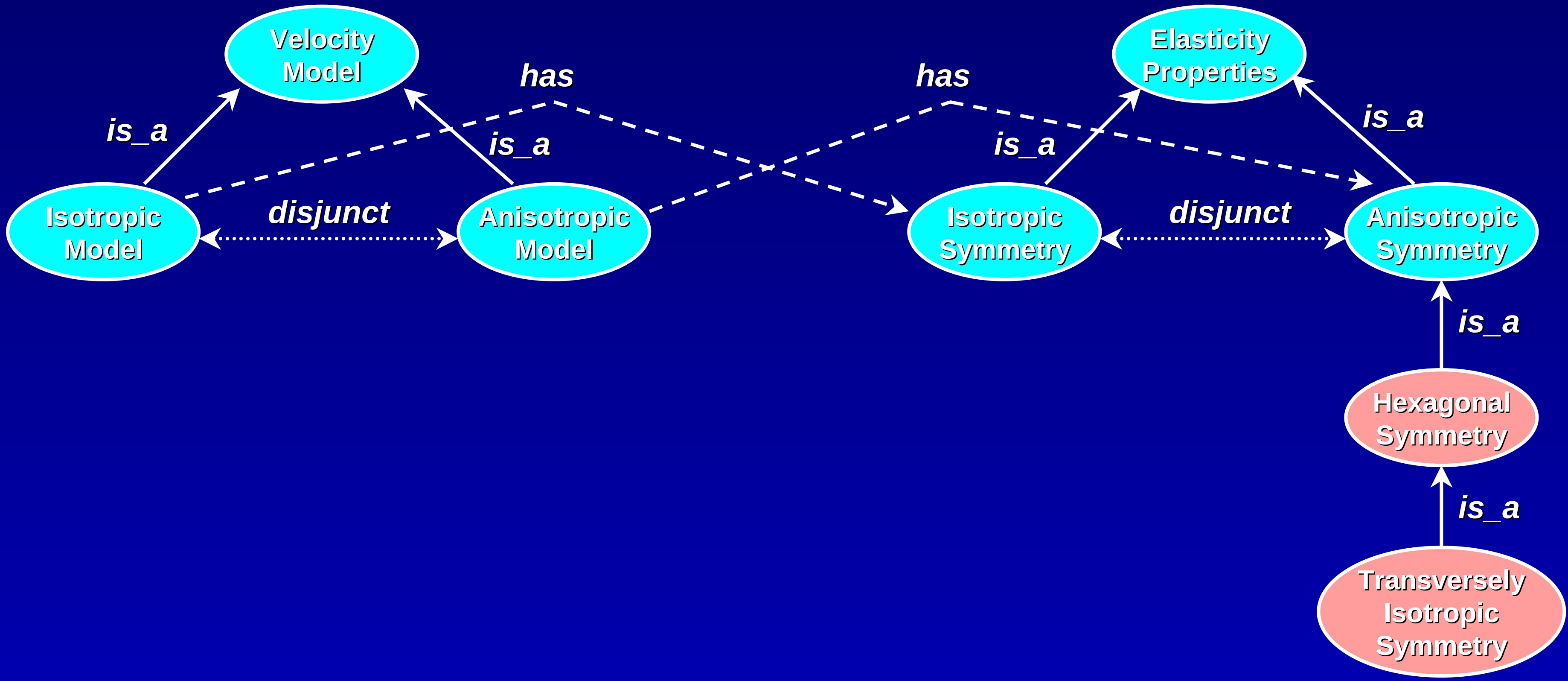
Construction, Part 2:

"Elastic properties are either isotropic or anisotropic."

"An isotropic model has isotropic elastic properties."

"An anisotropic model has anisotropic elastic properties."

A Simple Ontology

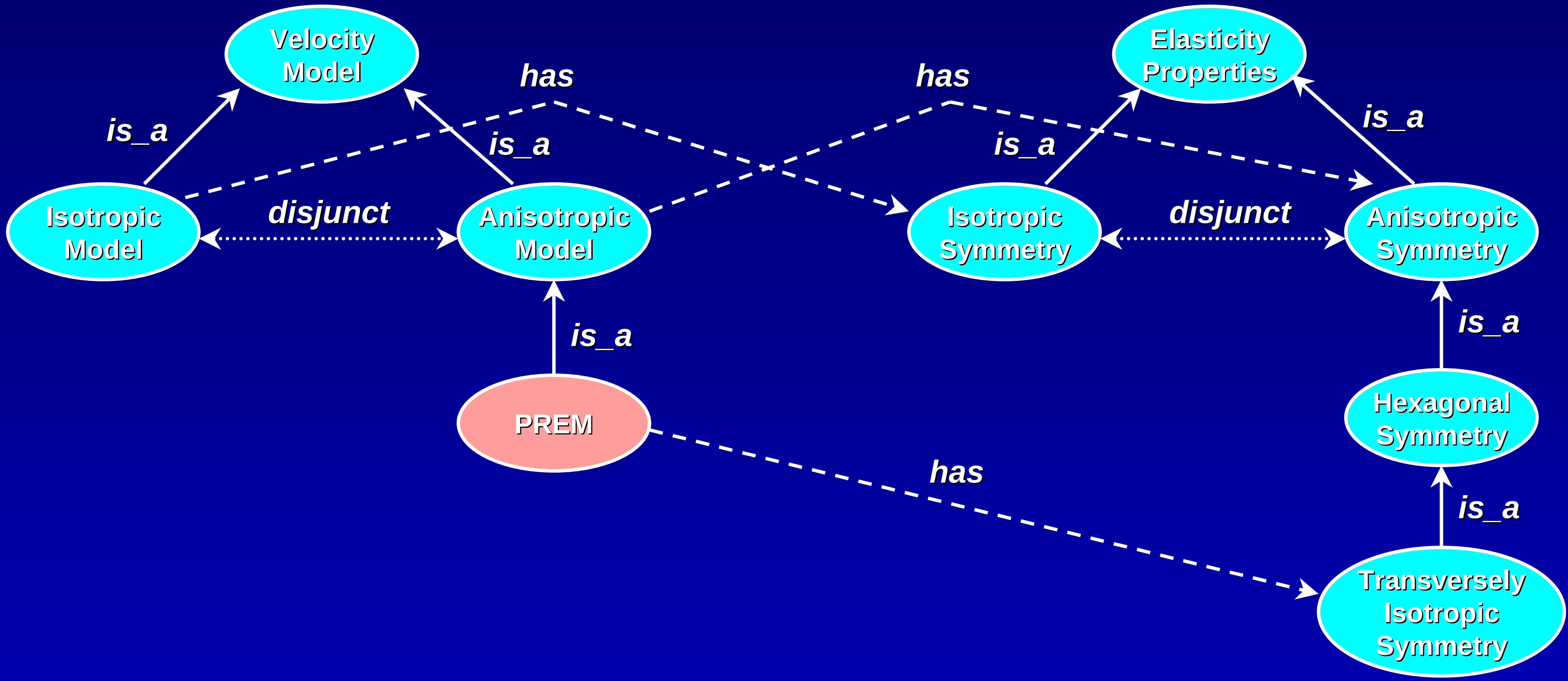


Construction, Part 3:

"Hexagonal symmetry is a special case of anisotropic symmetry."

"Transversely isotropic symmetry is a special case of hexagonal symmetry."

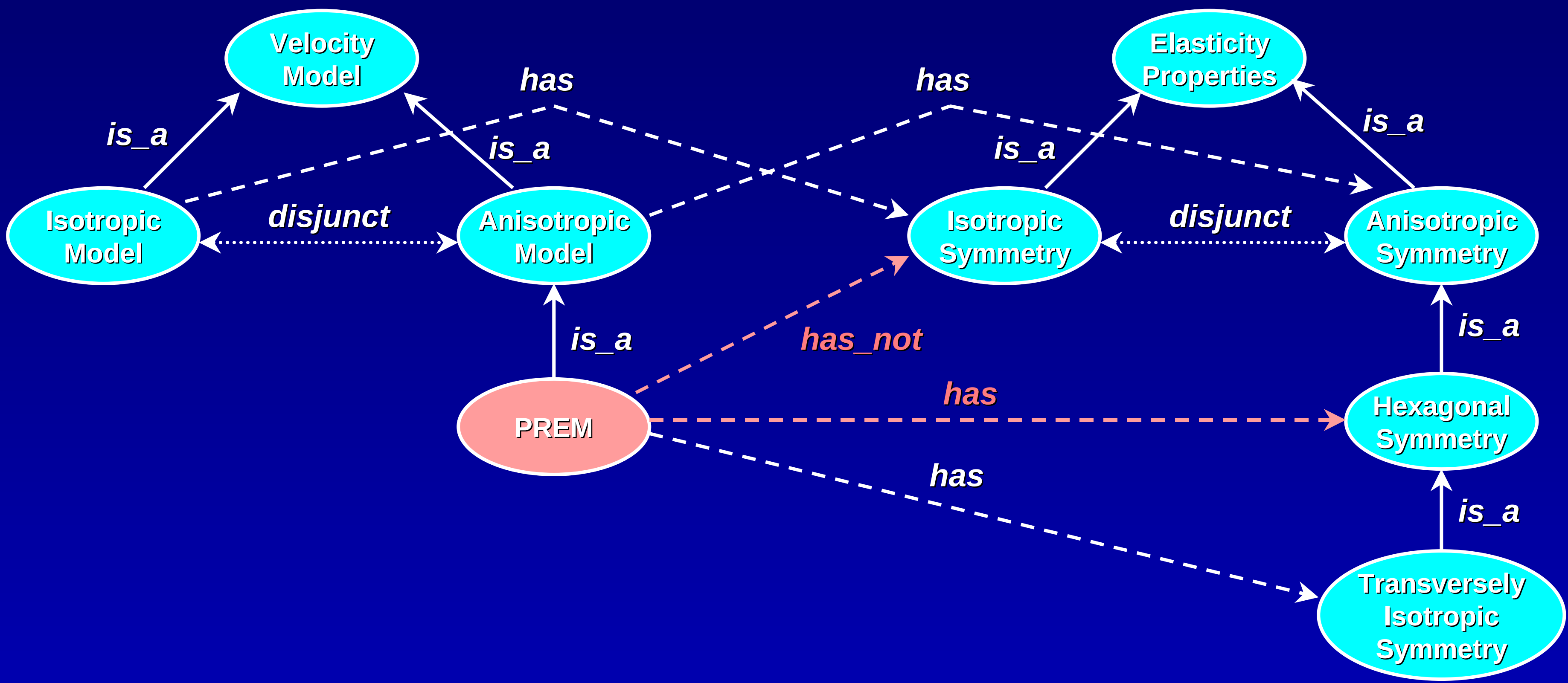
A Simple Ontology



Consider a particular model:

"PREM is an anisotropic model with transversely isotropic symmetry."

A Simple Ontology

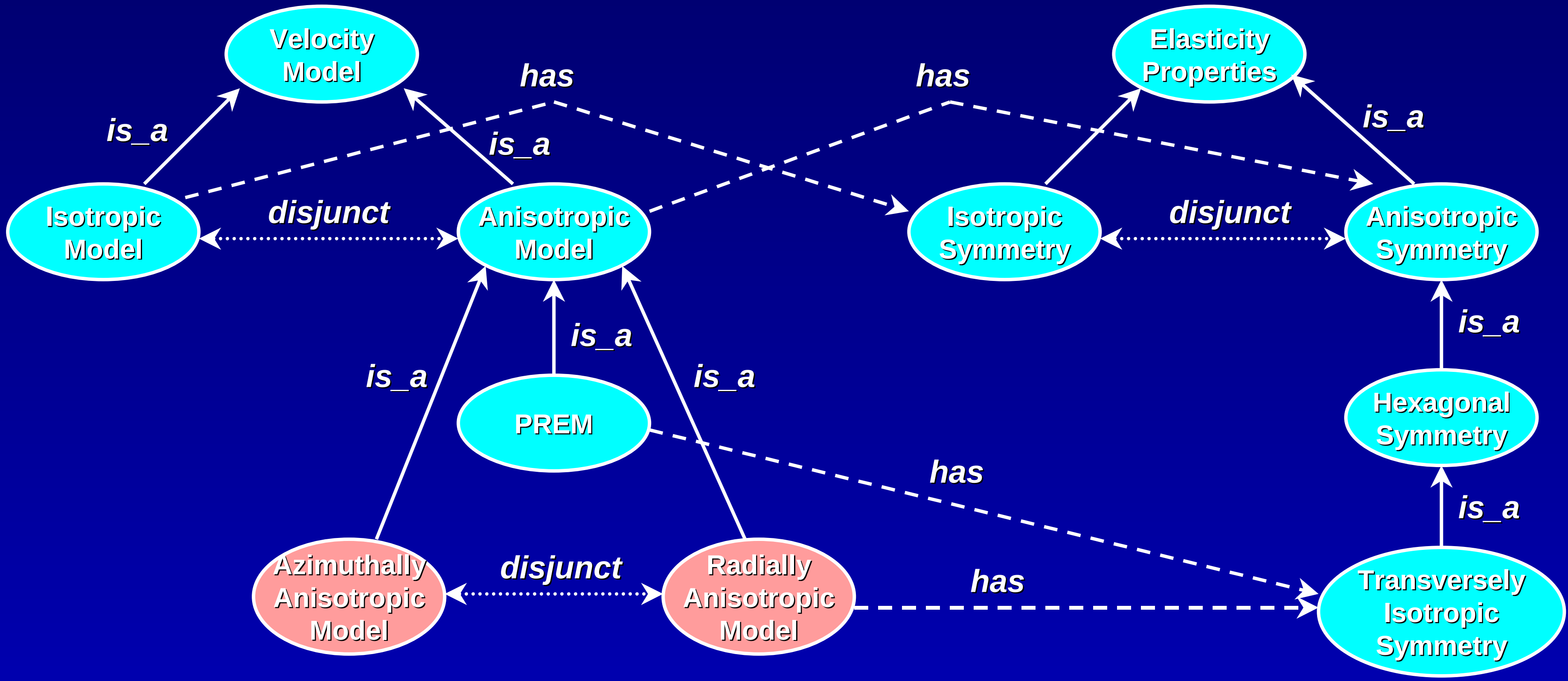


KR&R classifiers and inference engines (e.g., PowerLoom) can automatically infer new relationships:

"PREM does not have isotropic symmetry."

"PREM has hexagonal symmetry."

A Simple Ontology



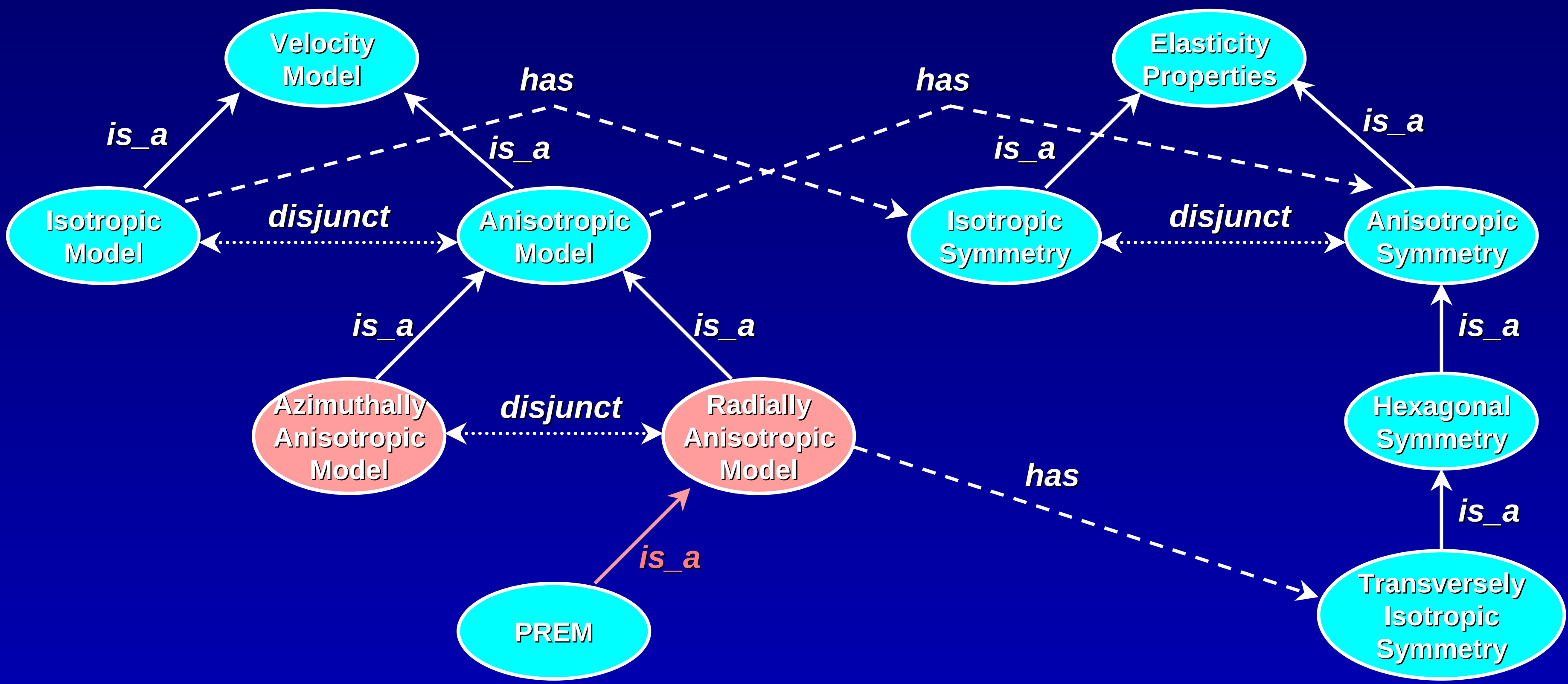
Consider the addition of new terms:

"An anisotropic model is either azimuthally anisotropic or radially anisotropic."

"A radially anisotropic model has transversely isotropic symmetry."

"An azimuthally anisotropic model does not have transversely isotropic symmetry."

A Simple Ontology



KR&R classifier can automatically position new concepts in taxonomy and infer new relationship:

"PREM is a radially anisotropic model."