GEON Cyberinfrastructure Developments in the Earth Sciences

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Unidata Seminar, 1 October 2004

Outline of Talk

EarthScope IT systems and some future needs

Developing Cyberinfrastructure Resources
(e.g GEON NSF Information Technology Research Project)

Education and Outreach
(Map Tools for EarthScope Science and Education)

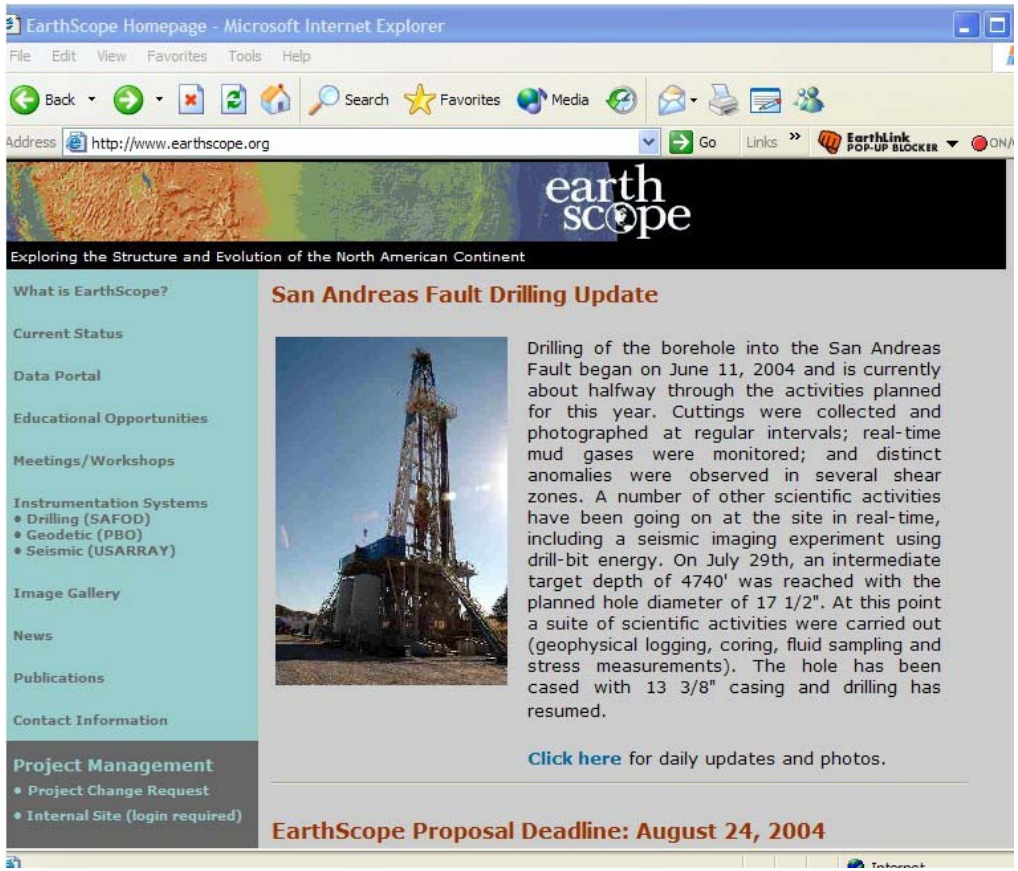
With thanks to many contributors to this talk, both direct and indirect via the web!

EarthScope: Exploring the Structure and Evolution of the North American Continent

How do we achieve this?

Instrumentation
Information Technology
Community Research
Education and Outreach
Emerging Cyberinfrastructure

…all contributing to an Integrated EarthScope Project

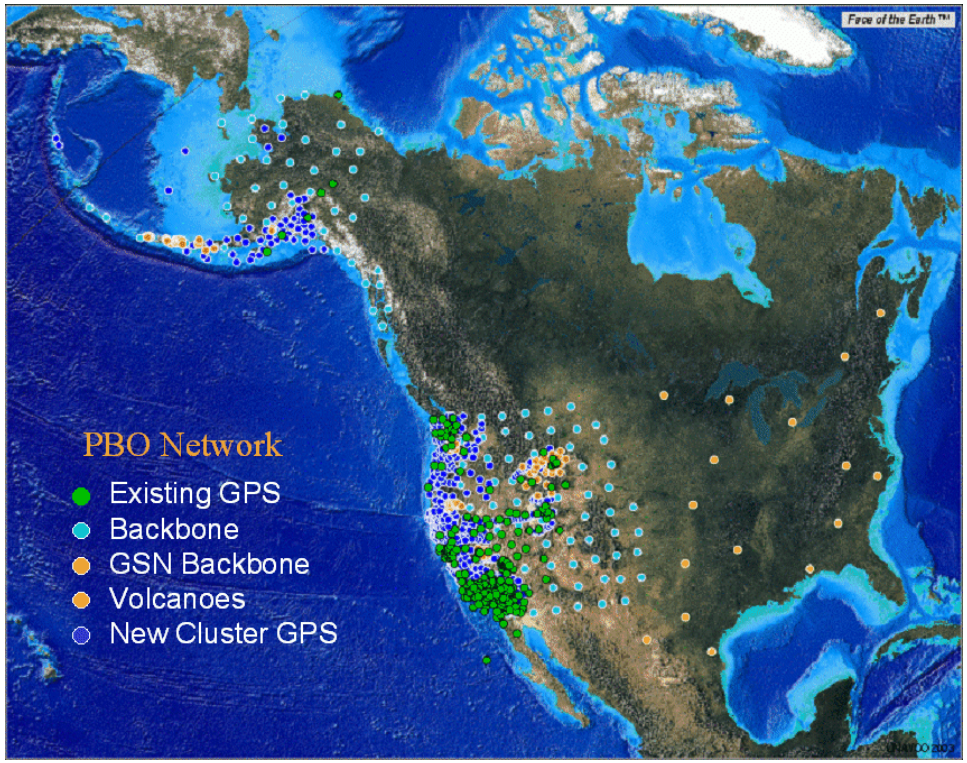


An Integrated EarthScope … leading to new scientific discoveries!

EarthScope Instrumentation

EarthScope GPS and Strainmeter Instrumentation

891 new CGPS stations
226 existing CGPS stations
100 SGPS receivers
143 BSM stations
5 LSM stations



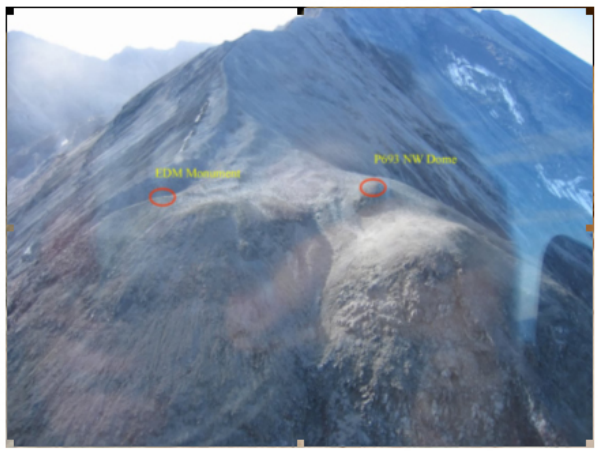
EarthScope Mt. St. Hellens Emergency Response

5 New continuous GPS Stations are being installed in October.

UNAVCO PBO

GPS Station Reconnaissance Report

UNAVCO, INC.
PLATE BOUNDARY OBSERVATORY



Site Name: P693 NW Dome, Mt. St. Helens, Washington
Recon Number: P693

Submitted By: Peter Gray

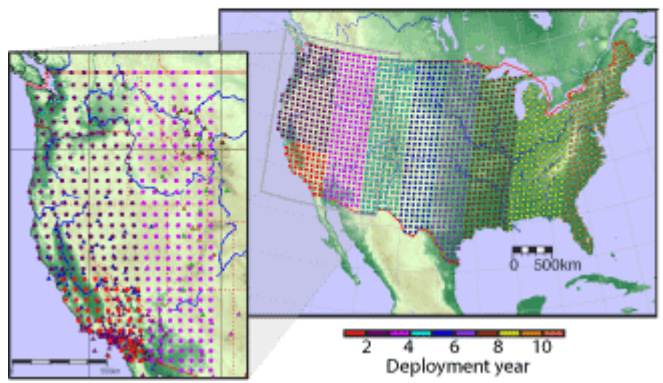
Organization: UNAVCO, PBO – PNW Region

Date of Reconnaissance: Aug. 5, 2004

10/1/20041 Reconnaissance Form v1.1

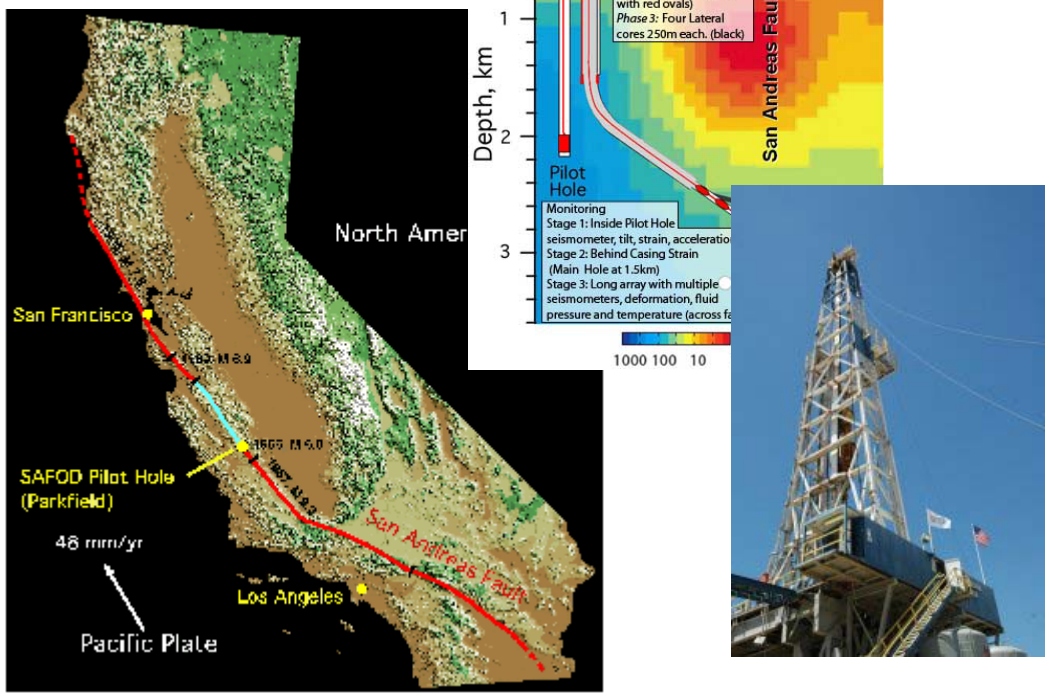
EarthScope Transportable and Fixed Seismic Instrumentation

- 400 Instrument Broadband Transportable Array (~2000 locations)
- 39 permanent stations (16 with GPS)
- Instrument Flexible array (200 Broadband, 200 short-period, 2000 high-frequency)
- Magneto-telluric field systems (40)



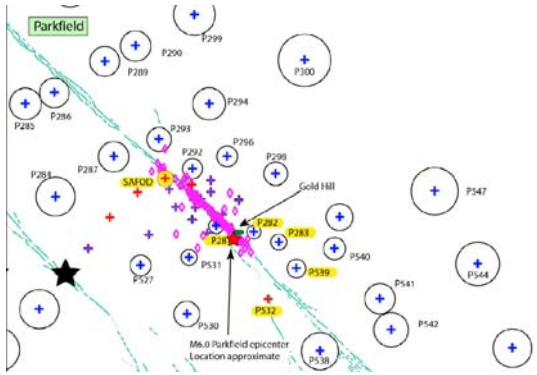
EarthScope San Andreas Fault Observatory at Depth (SAFOD)

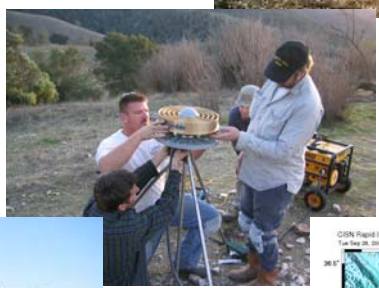
- seismic (bore hole and near field)
- down bore hole pressure, temperature, stress and strain
- directly sampled fault zone materials (rock and fluids)

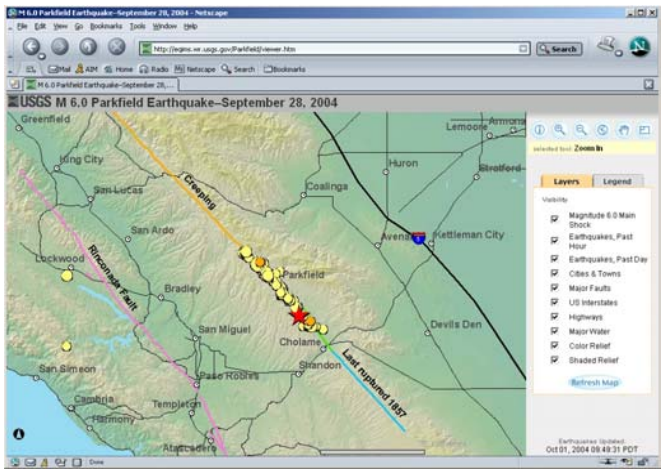


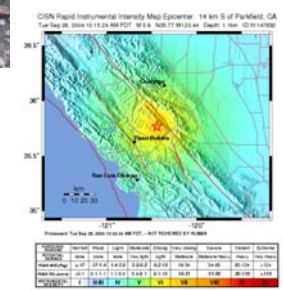
Parkfield Magnitude 6.0 Earthquake 28 Sept 2004

- GPS Response includes installation of 5 PBO permanent GPS sites and reoccupation of numerous campaign monuments
- USGS ArcIMS earthquake map (below)

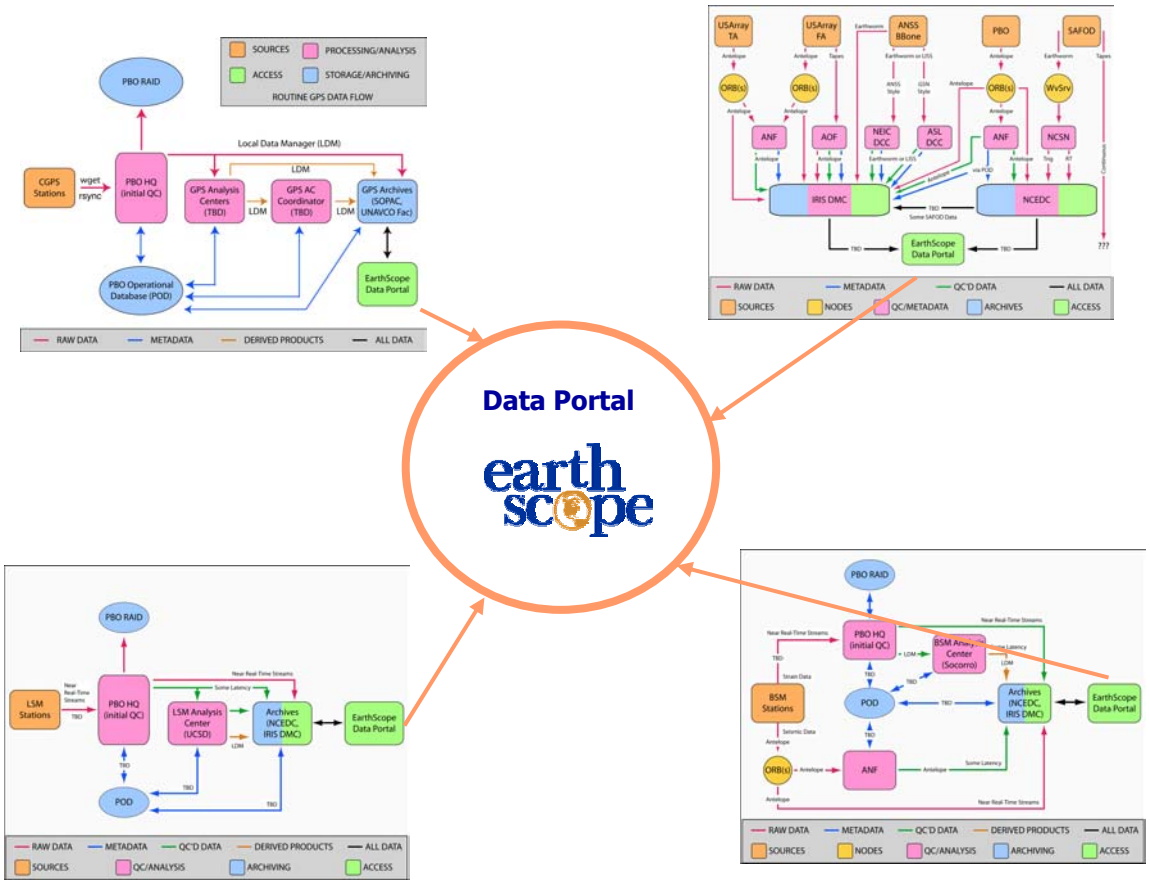








EarthScope Data Portal
system for data, metadata, and derived products



Figures from Greg Anderson, see EarthScope data plans for details

EarthScope Information Technology – A critical component needed to make EarthScope accessible to scientists, educators and the public

Providing:

- Reliable and open access to data and products
- Rapid data access
- Handle and store large volumes of data
- Complex 4-D datasets
- Long-term security
- Integration into analysis, modeling and visualization

"EarthScope Data Products for Science and Education"

- Raw data
- Derived products
- Interpretive products
- Knowledge products
- Educational products

Sample EarthScope PBO Data and Products

GPS

Raw data and metadata

- Permanent Station and Campaign Raw Data
- Station Metadata

Derived Products

- Velocity Vectors
- Coordinate Time Series
- Co-seismic Offsets

Borehole and Laser Strain

Raw data and metadata

- Strain and Seismic Waveforms

Geologic Data

- Geochronology
- Aerial Imagery (ALSM, Photos)

Knowledge Products

- GPS-Derived Strain Rates
- Deformation Models spanning seismic to Geologic time scales

Sample EarthScope USArray Data and Products

Seismic Data

- Traveling Array and Flexible Array Station Waveform Data
- Station, Event Metadata

Derived Products

- Earthquake locations, arrival times, focal mechanisms, source time functions, cross-correlated phases, shear-wave splitting measurements, and normal modes

Knowledge Products

- 3 and 4-dimensional models of the Earths interior including tomographic images of P and S velocity, Poisson Ratio, attenuation and anisotropy

EarthScope - the instrument facility - is about the data

Cumulative Data from the Plate Boundary Observatory

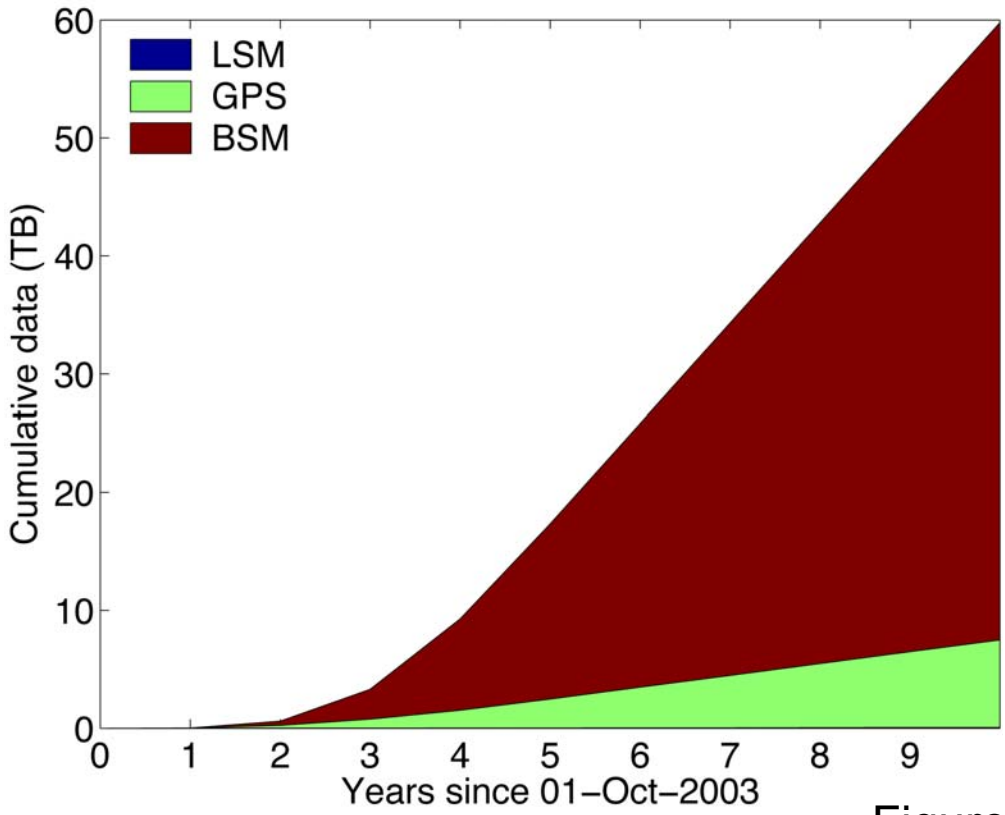
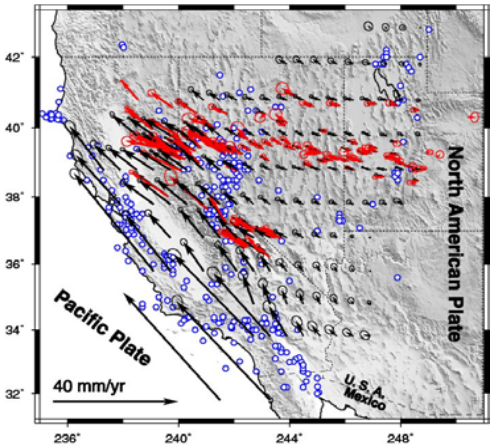
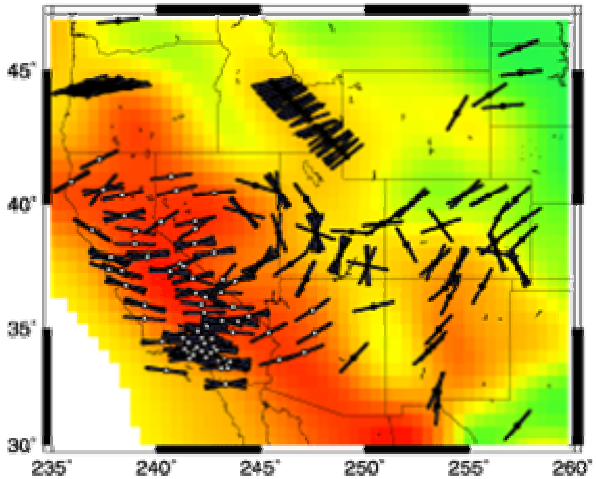


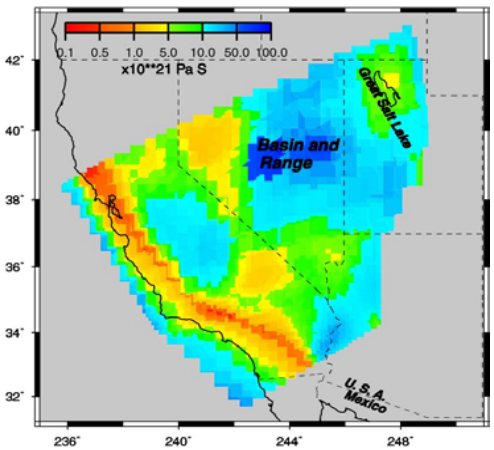
Figure from Greg Anderson

Earthscope - the project - is about putting it together to make new scientific discoveries!



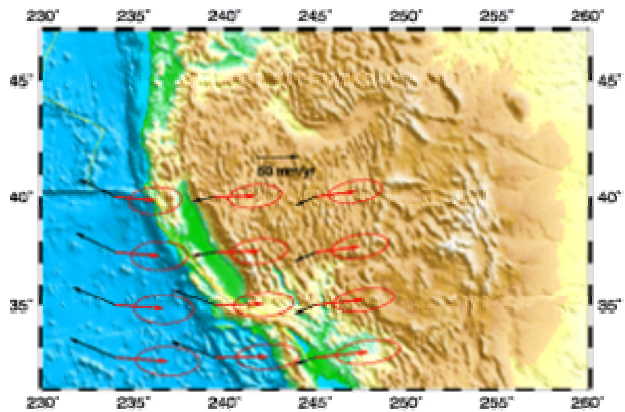
Left: Inverting for lithospheric viscosity through a force-balance model of surface deformation





(*Flesch et al., 2000*)

Right: Inverting for mantle flow velocity by adding mantle deformation from seismic anisotropy.

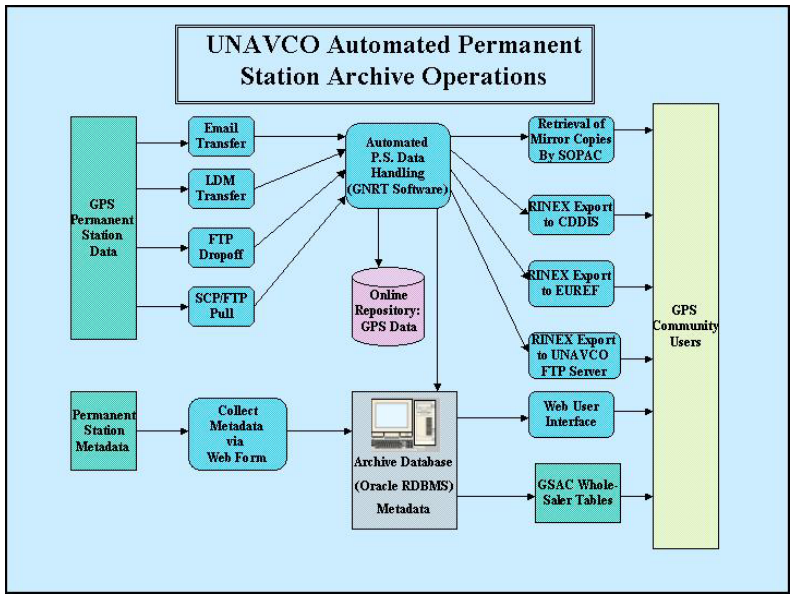


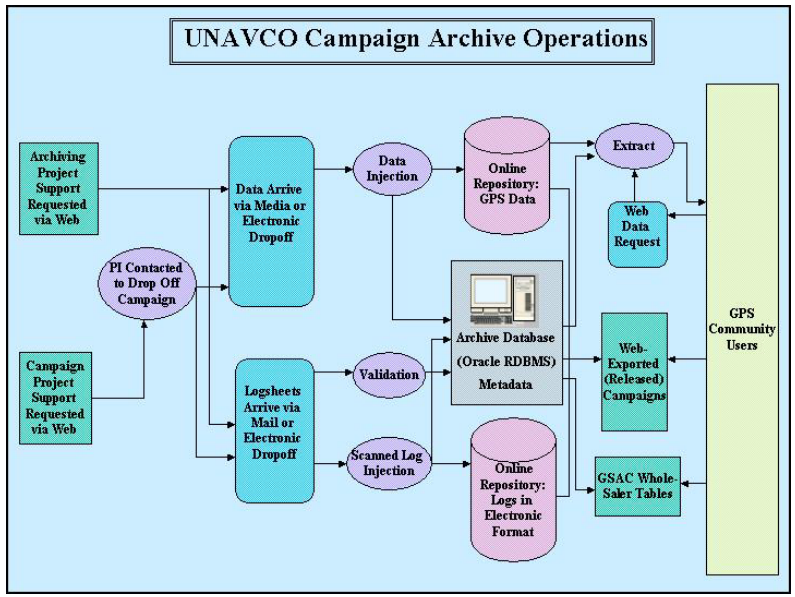
(Silver and Holt, 2001)

Academic Research Geophysical Data Access

e.g. UNAVCO and GPS Seamless Archives
IRIS
and
Numerous other geological and geophysical databases from academic consortia and individual investigators

UNAVCO Archive





Automated data delivery systems or web access from the UNAVCO website. More recently the GPS Seamless Archive Centers (GSAC) for raw GPS data discovery and retrieval beyond the confines of the website. Separate access to GPS velocity and strain archives via web pages and map tools. The IT challenge is to integrate these data and derived products into a broader cyberinfrastructure such as GEON and EarthScope.

GPS Seamless Archive (GSAC)

The GSAC helps you locate GPS data files which are archived at different GPS Data Archive Centers from a single user interface.

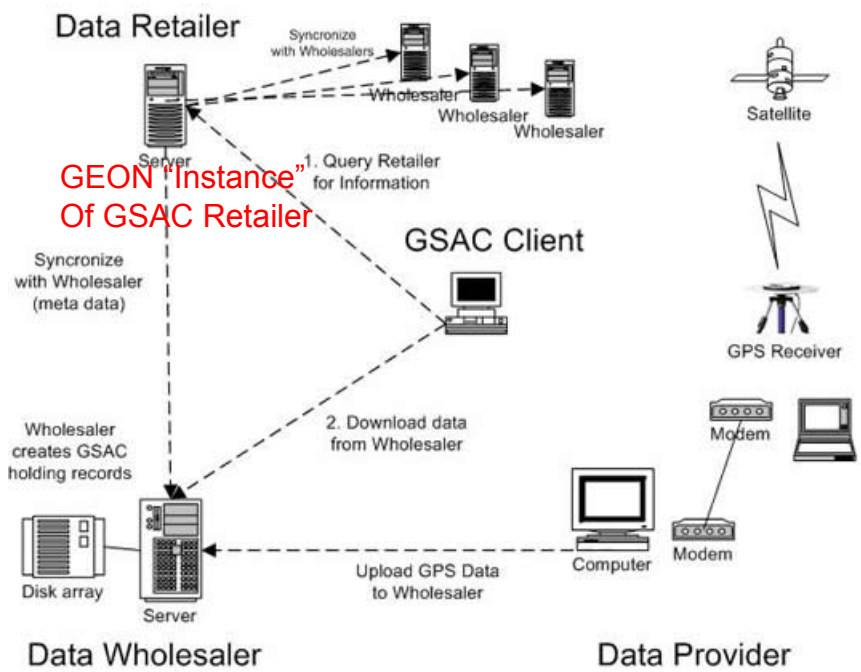
GSAC Clients:

1. The GSAC Wizard is a web-based client.
2. The GSAC command-line client.

GSAC Retailer:

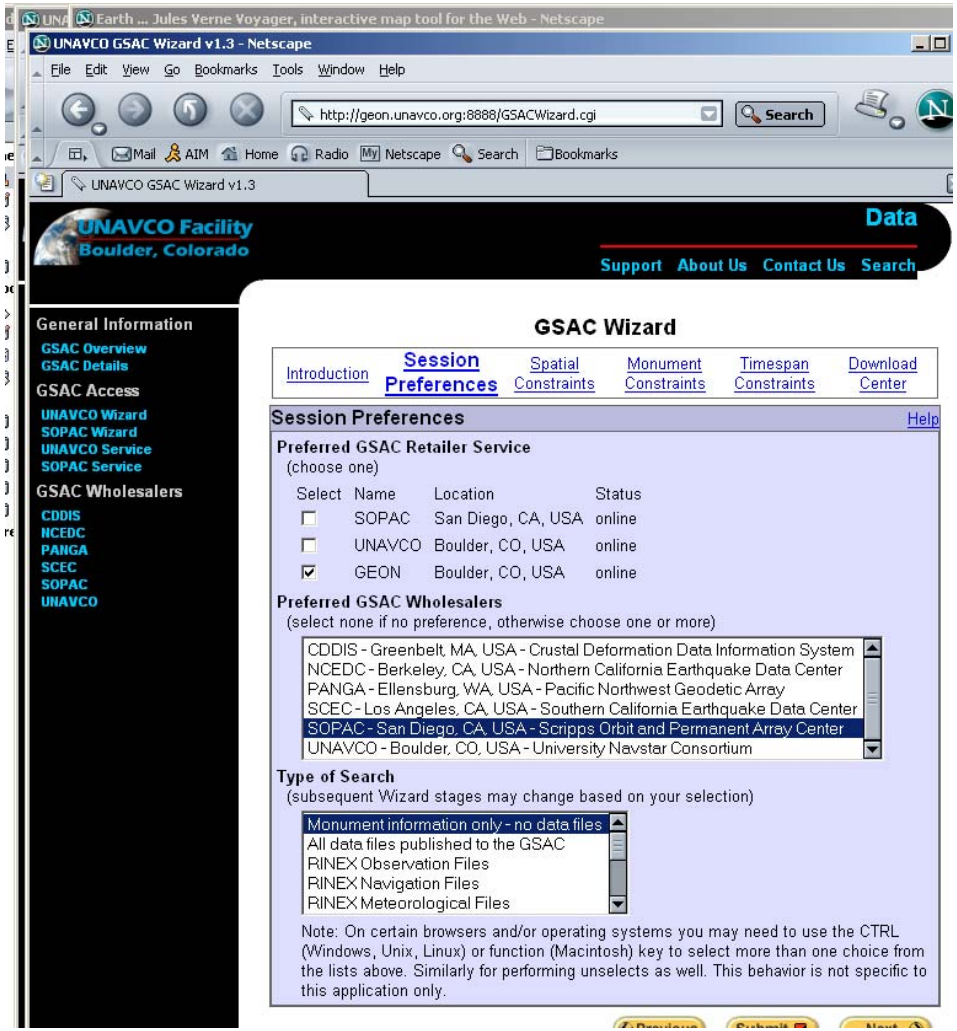
1. Gathers metadata and file locations from wholesalers
2. Organizes data into a POSTSQL relational database (same as GEON)
3. Provides services to GSAC Clients

The GSAC will be the primary means of GPS raw data and data product discovery and access for EarthScope

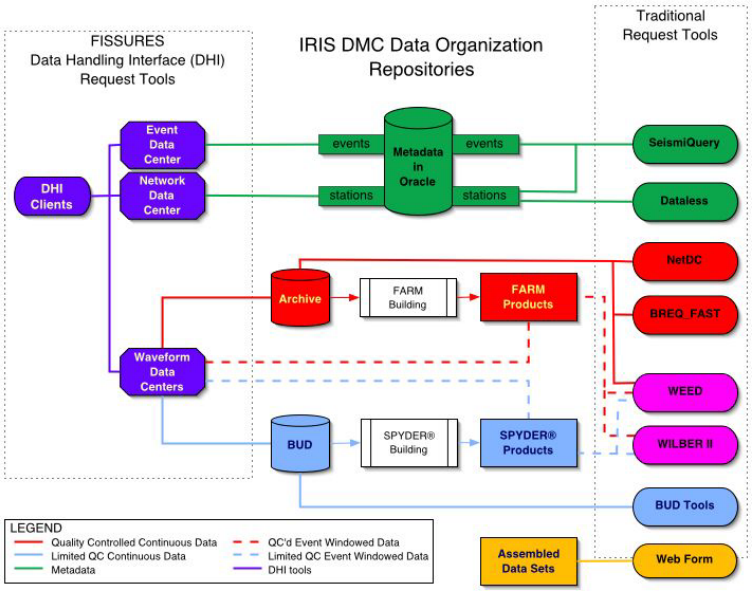


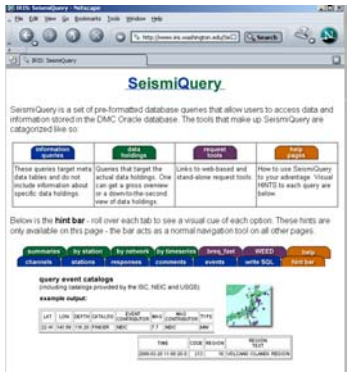
GSAC developed by Scripps and UNAVCO

GSAC Retailer “Wizard”

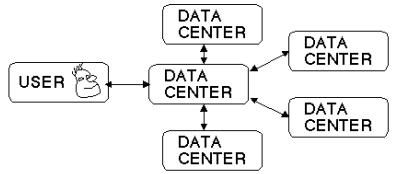


IRIS Seismic and Strain Data Retrieval

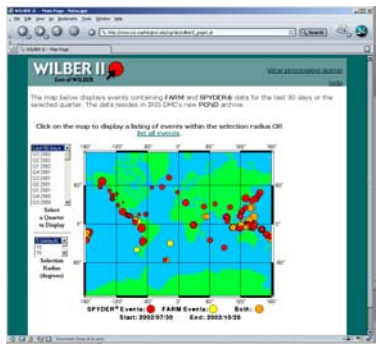




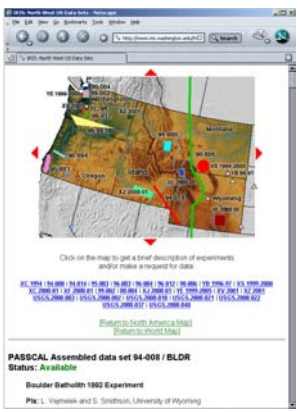
SeismiQuery Interface:
Meta-data queries



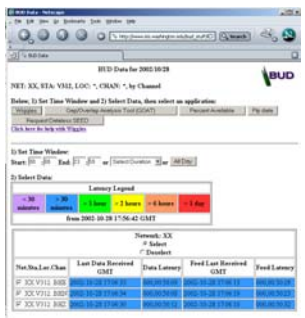
Networked Data Centers:
Email and Ftp



WILBER II Interface:
Quality-Checked, Near-real-time and historic waveform data retrieval



Requests for Assembled Data From the Flexible array



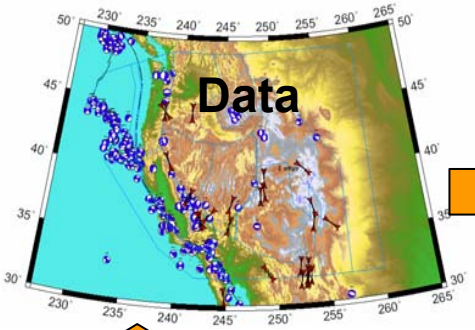
BUD Interface:
IRIS Near-real-time system

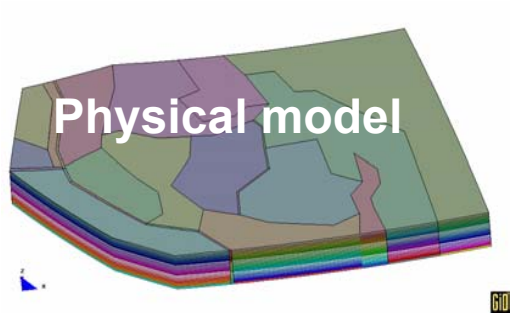
UNAVCO Facility

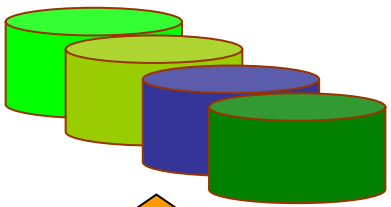
GEON Information Technology Research Project

A cyberinfrastructure project to combine IT with Geoscience knowledge

GEON: GEOsciences Network







Portal (login, myGEON)

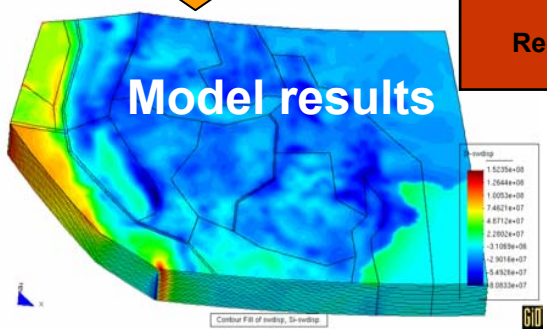
Registration | GEONsearch | GEONworkbench (Community Modeling Environment)

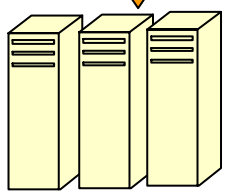
Registration Services | Data Integration Services | Indexing Services | Workflow Services | Visualization & Mapping Services

Core Grid Services
Authentication, monitoring, scheduling, catalog, data transfer, Replication, collection management, databases

Physical Grid
RedHat Linux, ROCKS, Internet, I2, OptIPuter (planned)

Modeling Environment





HPCC

GEON: GEOsciences Network

EarthScope provides the connectivity of knowledge from surface geology, through the lithosphere into the deeper mantle …. Krishna Sinha, GEON PI

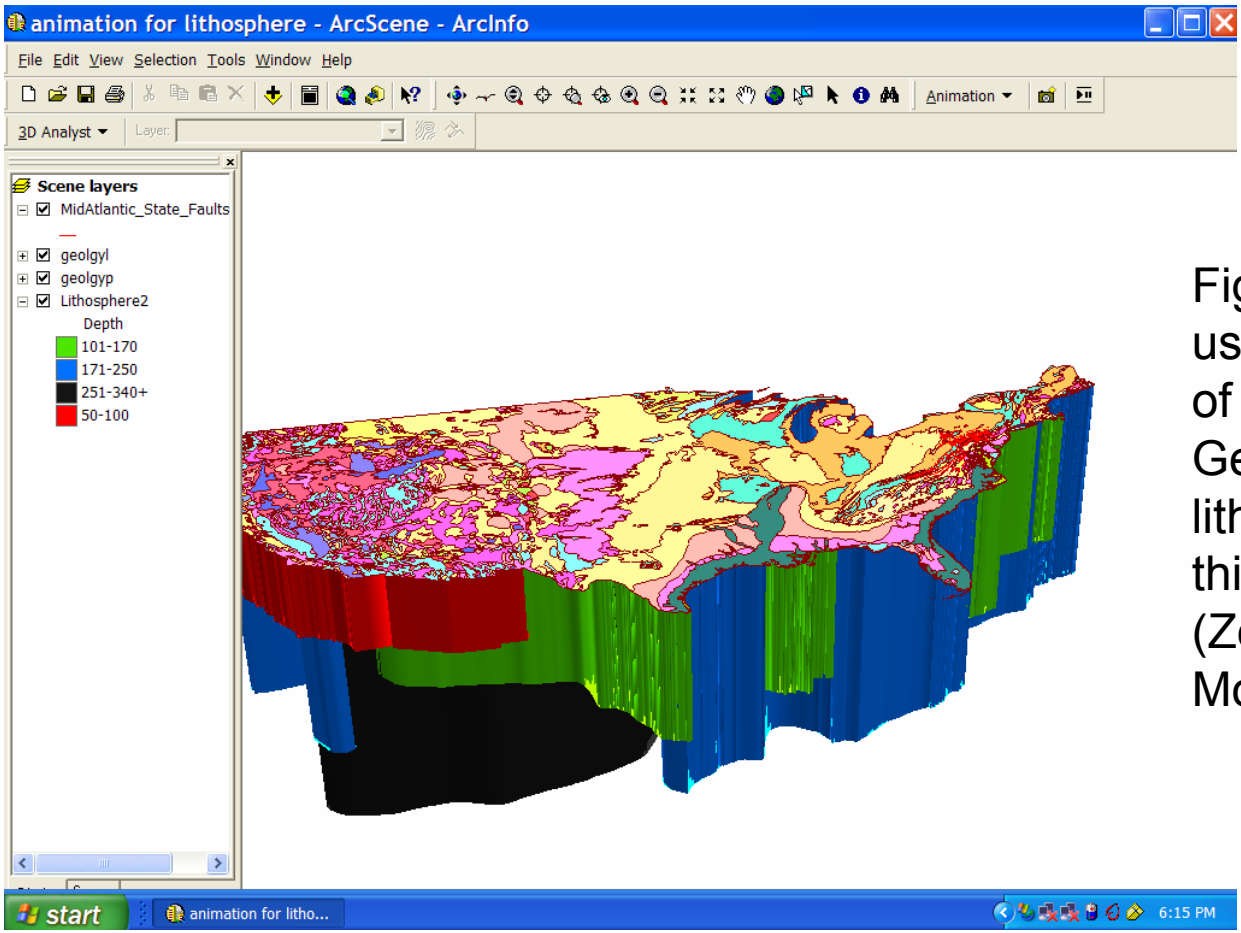


Figure made using ArcScene of USGS Geologic map, lithosphere thicknesses (Zoback and Moony, 2003)

GEON Project Scope

- Develop a distributed, services-based system that enables geoscientists to publish, share, integrate, analyze, and visualize their data, ontologies, tools, workflows, applications, and models

- Conduct integrated scientific studies on targets of opportunities in the test beds, in concert with geosciences community

GEON Project Activities

- GEON will
  - develop services for data integration and model integration, and associated model execution and visualization
  - Mid-Atlantic test bed will focus on tectonothermal, paleogeographic, and biotic history from the late-Proterozoic to mid-Paleozoic
  - Rockies test bed will focus on integration of data with dynamic models, to better understand deformation history
  - develop the most comprehensive regional datasets in test bed areas

Current GEON participant institutions

NSF Supported

- Arizona State University
- Bryn Mawr College
- Penn State University
- Rice University
- San Diego State University
- San Diego Supercomputer Center / University of California, San Diego
- University of Arizona
- University of Idaho
- University of Missouri, Columbia
- University of Texas at El Paso
- University of Utah
- Virginia Tech
- UNAVCO, Inc.
- Digital Library for Earth System Education (DLESE)

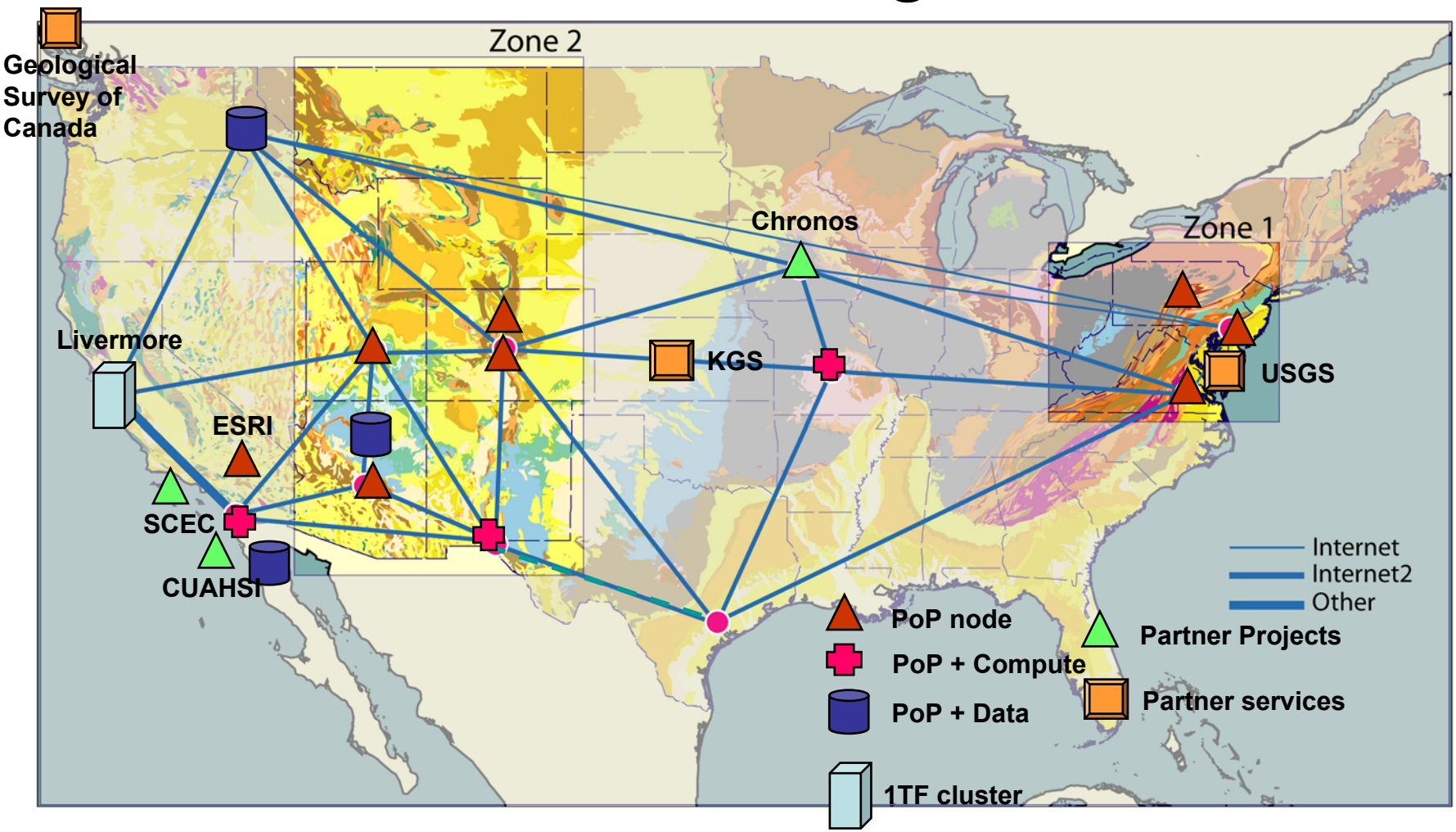
Partners

- California Institute for Telecommunications and Information Technology (Cal-(IT)^2)
- Chronos
- CUAHSI
- ESRI
- Geological Survey of Canada
- Georeference Online
- IBM
- Kansas Geological Survey
- Lawrence Livermore National Laboratory
- U.S. Geological Survey (USGS)
- HP
- Other Affiliates
- Southern California Earthquake Center (SCEC), EarthScope, IRIS, NASA

IT Approach

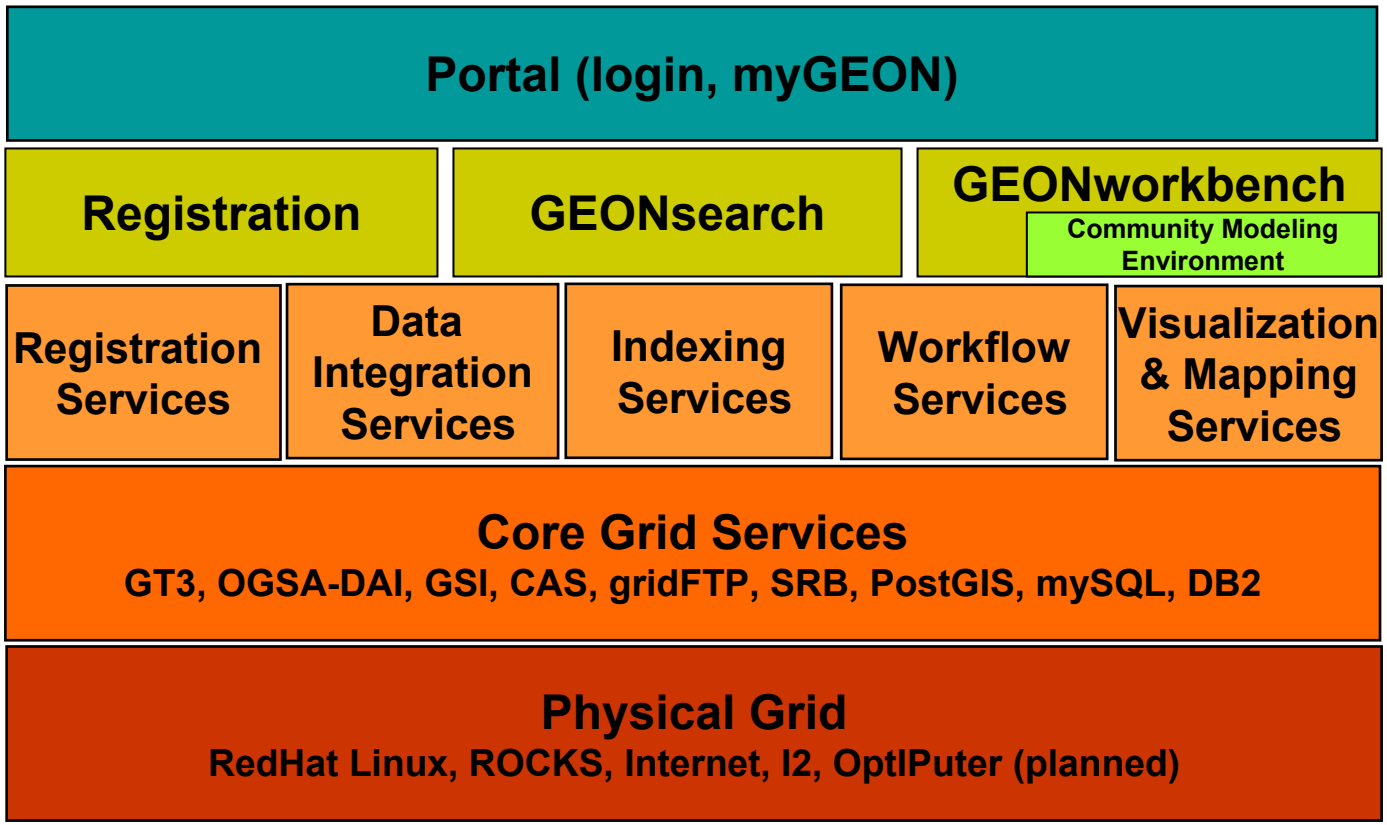
- Develop *cyberinfrastructure* to support the "day-to-day" conduct of science (*e-science*)
  - Based on a Web/Grid services-based distributed environment
- Work closely with geoscientists to help create data sharing frameworks, best practices, and useful and usable capabilities and tools
- The "two-tier" approach
  - Use best practices, including commercial tools,
  - while developing advanced technology in open source, and doing CS research
- Leverage from other intersecting projects

The GEONgrid



- Grid Systems and Portal – Dr. Karan Bhatia, SDSC

GEONgrid Software Layers



GEON Database Projects

GEON PIs:

- Geologic maps (Mid-Atlantic, multiple scales; detailed)
- Geochemical analyses of igneous rocks
- Map of all faults in the mid-Atlantic testbed
- Geologic maps with metamorphic information (Mid-Atlantic)
- Data sets of P-T time
- Sedimentary and Paleontological databases (Global)
- ASTER webservices
- USGS (DEM, 30m, 1/3, 1/9), direct access; equivalent hydrologically-corrected versions, imagery (W. US)
- Physical properties of rocks (General)
- Gravity data (Continental US)
- Magnetic data (Continental US)
- Lithospheric structure models (W. US)
- Regional-scale (1:1,000,000) geology and geophysical data sets from Cornell
- Reconciled geologic maps of a portion of the Northern Rocky Mountains
- Tectonic map of the same region, also DEM, gravity, magnetic, etc.)
- GPS data products, global strain rate
- Updated seismicity data for Colorado region
- Extensive Yellowstone Geologic and geophysical database
- Reference model of the western U. S. (preliminary)
- CRONOS chronostratigraphic database

Partners:

- NATCARB webservice link
- CA Baja
  - geochronological database
  - Reconcile CA and Baja geologic maps
  - SRTM data
- NASA Goddard link
  - paleomagnetic data set, archeomagnetic data set, magnetic field models, imagery
  - New DEMs from ICESAT (LIDAR) (Global Scale), SRTM, LIDAR
- Geological Survey of Canada
  - Geologic Data
- ESRI
  - Grid service wrappers for ArcWeb Services
  - Ability to publish GEON "products" using ArcWeb Services
- CUAHSI
  - Hydrological Data
- Purdue
  - Realtime – remote sensing data, national soil database
- IRIS
  - Wave forms via Synseis, event data

GEON Cyberinfrastructure …

More than just about the data, GEON is about going from simple Queries to complex Questions

(a peek under the hood)

A query example: Use SQL to ask a database to show you all white wines from California with a vintage 2003.

A question: "Tell me what wines I should buy to serve with each course of the following menu. And, by the way, I don't like Sauternes." … from W3C

This requires two databases (e.g. food and wine) and and prescribed relationships between them that are defined for computers as Ontologies

Ontology

- **Q. What is an ontology? (from W3C)**
- A. Although the concept of ontology has been around for a very long time in philosophy, in recent years it has become identified with computers as a machine readable vocabulary that is specified with enough precision to allow differing terms to be precisely related.
- More precisely, from the OWL Requirements Document:
- An ontology defines the terms used to describe and represent an area of knowledge. Ontologies are used by people, databases, and applications that need to share domain information (a domain is just a specific subject area or area of knowledge, like medicine, tool manufacturing, real estate, automobile repair, financial management, *food, wine* etc.). Ontologies include computer-usable definitions of basic concepts in the domain and the relationships among them [...]. They encode knowledge in a domain and also knowledge that spans domains. In this way, they make that knowledge reusable.

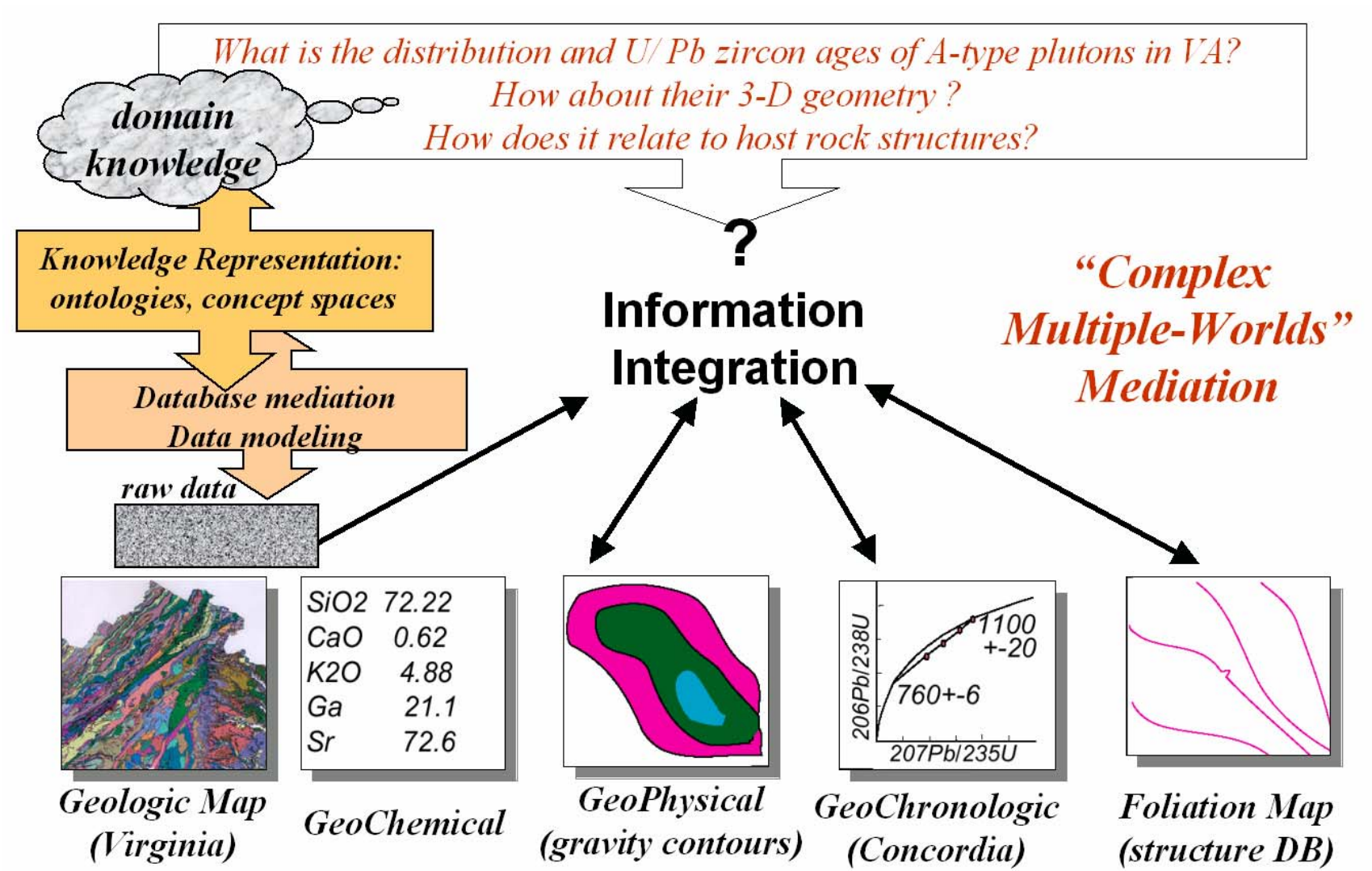
- GEON uses OWL the Web Ontology Language (w3C)
- OWL is designed for use by applications that need to process the content of information instead of just presenting information to humans. OWL facilitates greater machine interpretability of Web content than is supported by XML, RDF, by providing additional vocabulary along with a formal semantics.
- Code looks like:
- rdfs:Class rdf:ID="**WINE**">
- <rdfs:subClassOf rdf:resource="#POTABLE-LIQUID"/>
- <rdfs:subClassOf> <daml:Restriction> <daml:onProperty rdf:resource="#MAKER"/> <daml:minCardinality> 1 </daml:minCardinality> </daml:Restriction> </rdfs:subClassOf>
- rdfs:Class rdf:ID="**MEAL-COURSE**"> <rdfs:subClassOf rdf:resource="#CONSUMABLE-THING"/> <rdfs:subClassOf> <daml:Restriction> <daml:onProperty rdf:resource="#FOOD"/>

Current GEON Ontology Efforts

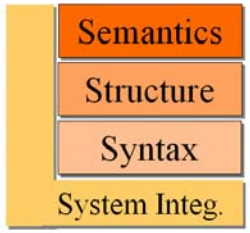
- Formal ontology of plutons
- Taxonomy for textures and shapes of plutons
- Informal ontology for processes as they effect igneous rocks
- Metamorphic ontology
- Preliminary ontology for structural geology

- Ontologies are being developed through a series of workshops. There will also be resources at the GEON Portal to allow for submission of new ontologies and toolkits to help develop them.

The Problem: Scientific Data Integration
or: *… from Questions to Queries …*



Information Integration Challenges: *S⁴ Heterogeneities*



- **Systems** Integration
  - platforms, devices, data & service distribution, APIs, protocols, …

  ➔ **Grid middleware technologies**

  + e.g. single sign-on, platform independence, transparent use of remote resources, …
- **Syntax & Structure**
  - heterogeneous data formats (*one for each tool* ...)
  - heterogeneous data models (*RDBs, ORDBs, OODBs, XMLDBs, flat files, …*)
  - heterogeneous schemas (*one for each DB* ...)

  ➔ **Database mediation technologies**

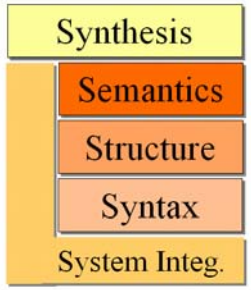
  + XML-based data exchange, integrated views, transparent query rewriting, …
- **Semantics**
  - fuzzy metadata, terminology, "hidden" semantics, implicit assumptions, …

  ➔ **Knowledge representation & semantic mediation technologies**

  + "smart" data discovery & integration

  + e.g. ask about ***X*** ('**mafic**'); find data about ***Y*** ('**diorite**'); be happy anyways!

Information Integration Challenges: *S^5 Heterogeneities*



- ***S*ynthesis** of analysis pipelines, integrated apps & data products, …
  - How to make use of these wonderful things & put them together to solve a scientist's problem?

➔ **Scientific Problem Solving Environments**

➔ **GEON Portal and Workbench ("scientist's view")**

+ ontology-enhanced data registration, discovery, manipulation

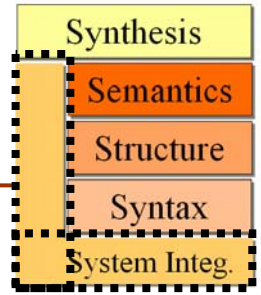
+ creation and registration of new data products from existing ones, …

➔ **GEON Scientific Workflow System ("engineer's view")**

+ for designing, re-engineering, deploying analysis pipelines and scientific workflows; ***a tool to make new tools …***

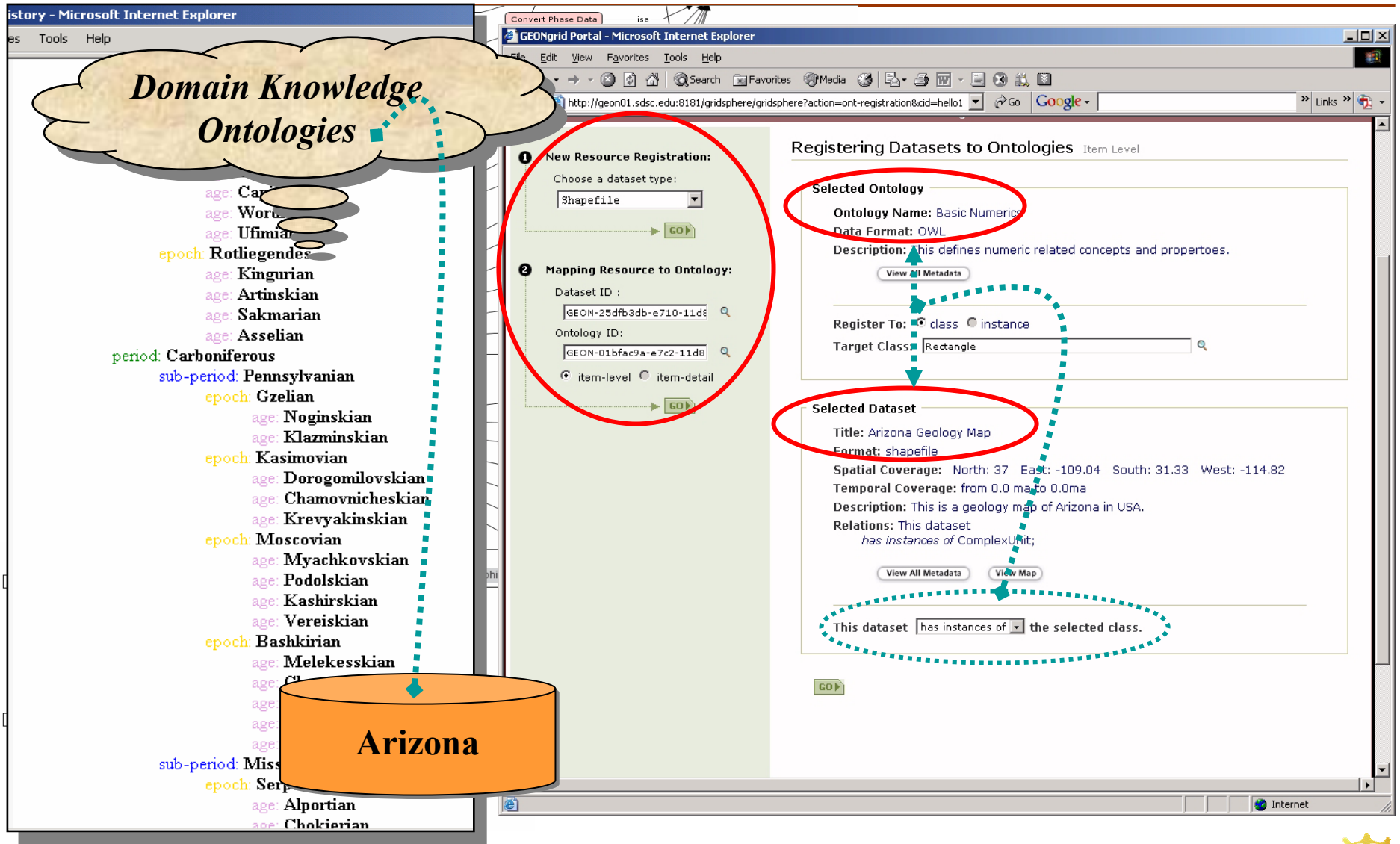
+ e.g., creation of new datasets from existing ones, dataset registration,…

A Prerequisite: Resource Registration

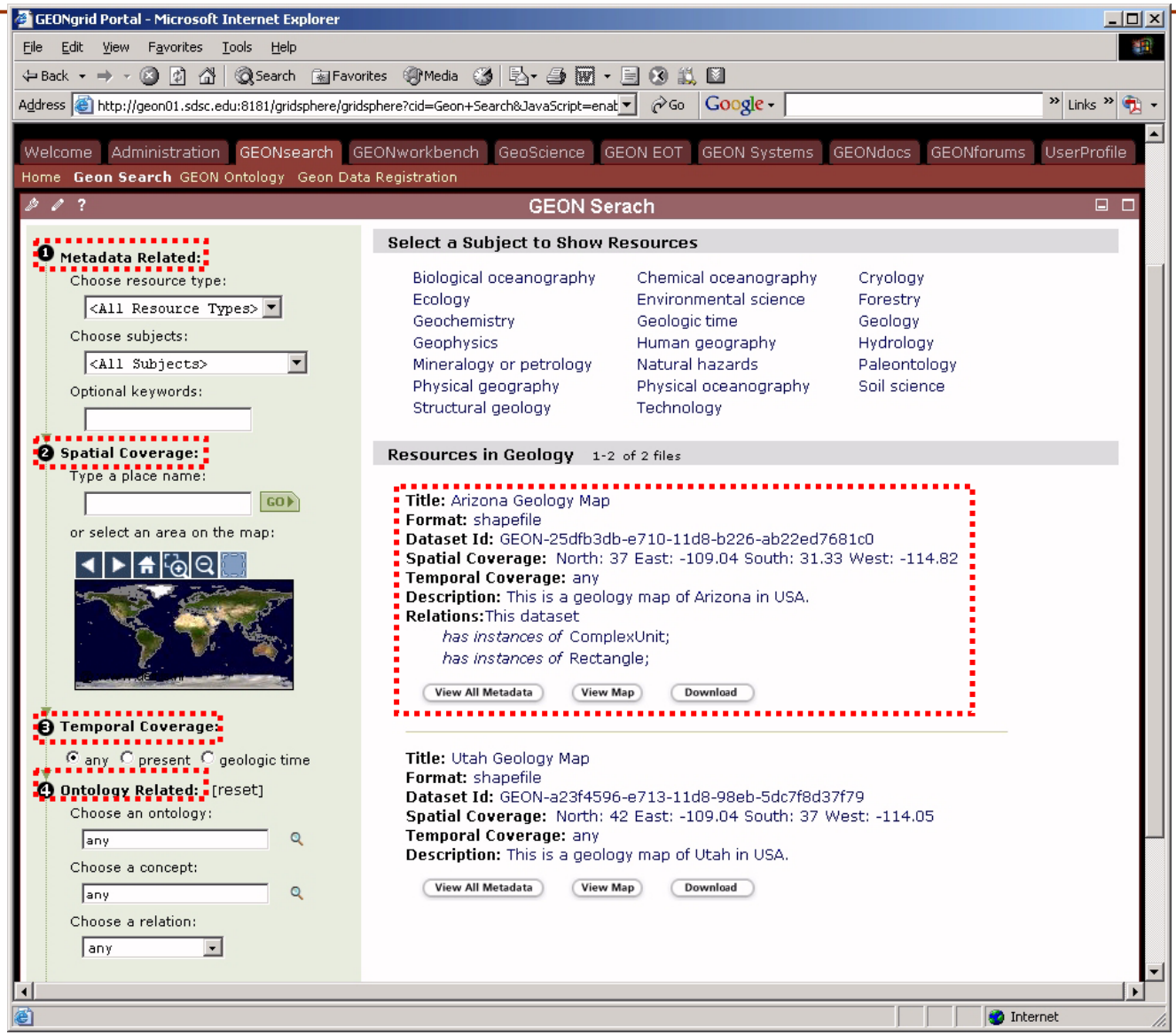


- **(1) Register ontologies**
  - geologic age; rock classifications (GSC, BGS), seismology; …
- **(2) Register Dataset** (myShapeFiles.zip)
- **(3) Perform Item-level dataset registration** (1⇔2)
  - ADN metadata; other controlled vocabularies & ontologies (e.g. geologic age timescale (USGS), SWEET (NASA), …)
- **Use ontology-based query UI / application at GEON Portal**
  - e.g. query by **geologic age** and **chemical composition**

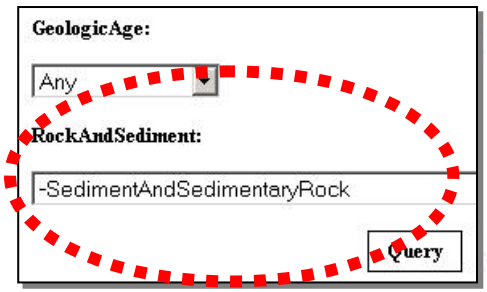
Dataset to Ontology Registration (Item-level)

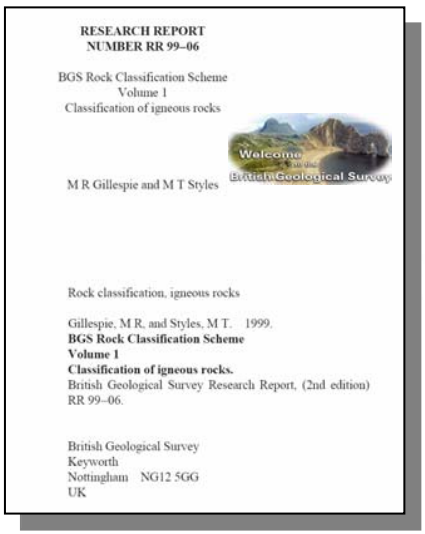


GEON Search: Concept-based Querying



Sedimentary Rocks: BGS Ontology




RESEARCH REPORT
NUMBER RR 99–06

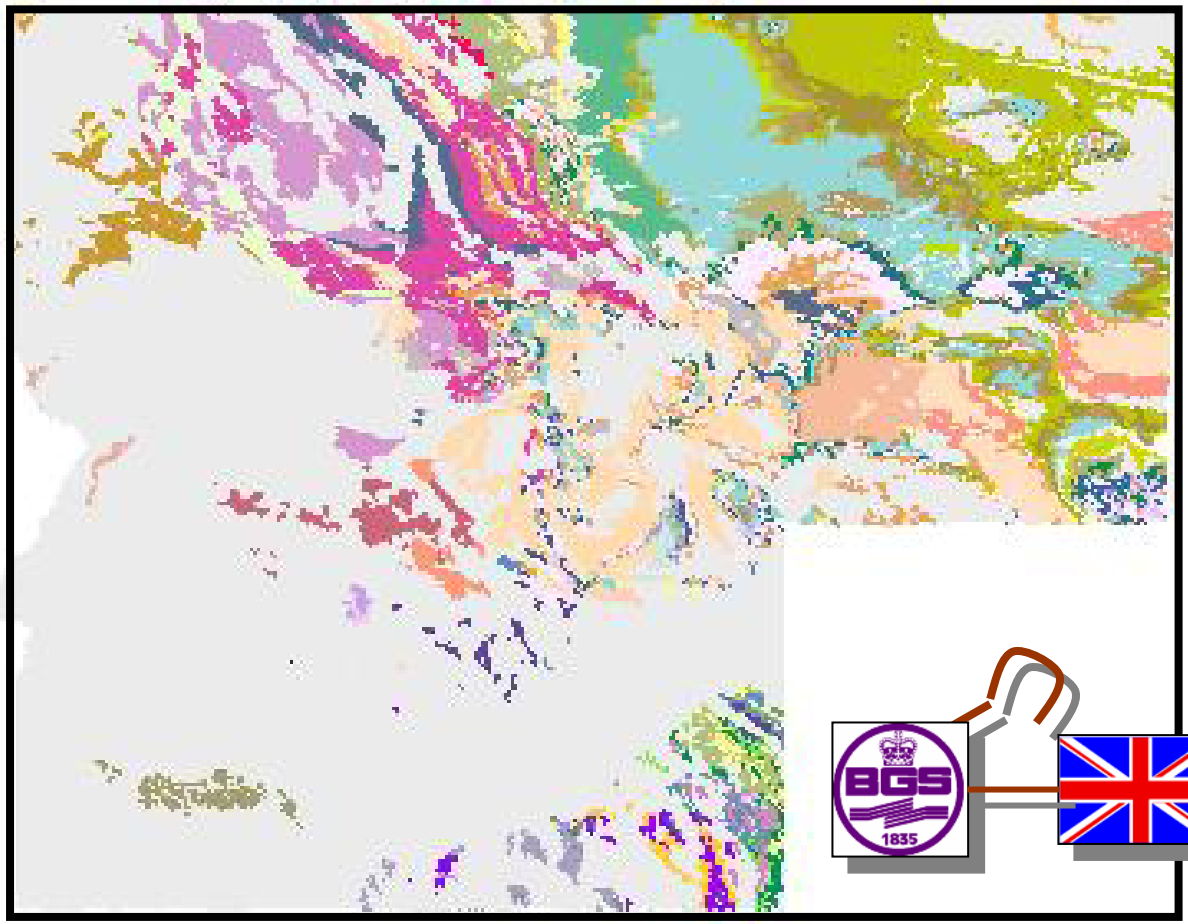
BGS Rock Classification Scheme
Volume 1
Classification of igneous rocks

M R Gillespie and M T Styles

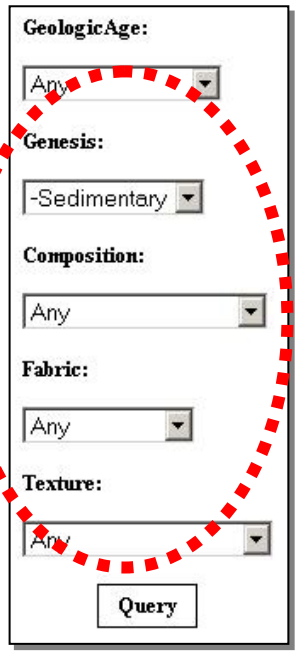
Rock classification, igneous rocks

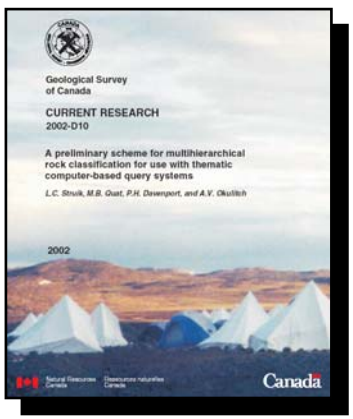
Gillespie, M R, and Styles, M T. 1999.
BGS Rock Classification Scheme
Volume 1
Classification of igneous rocks.
British Geological Survey Research Report, (2nd edition) RR 99–06.

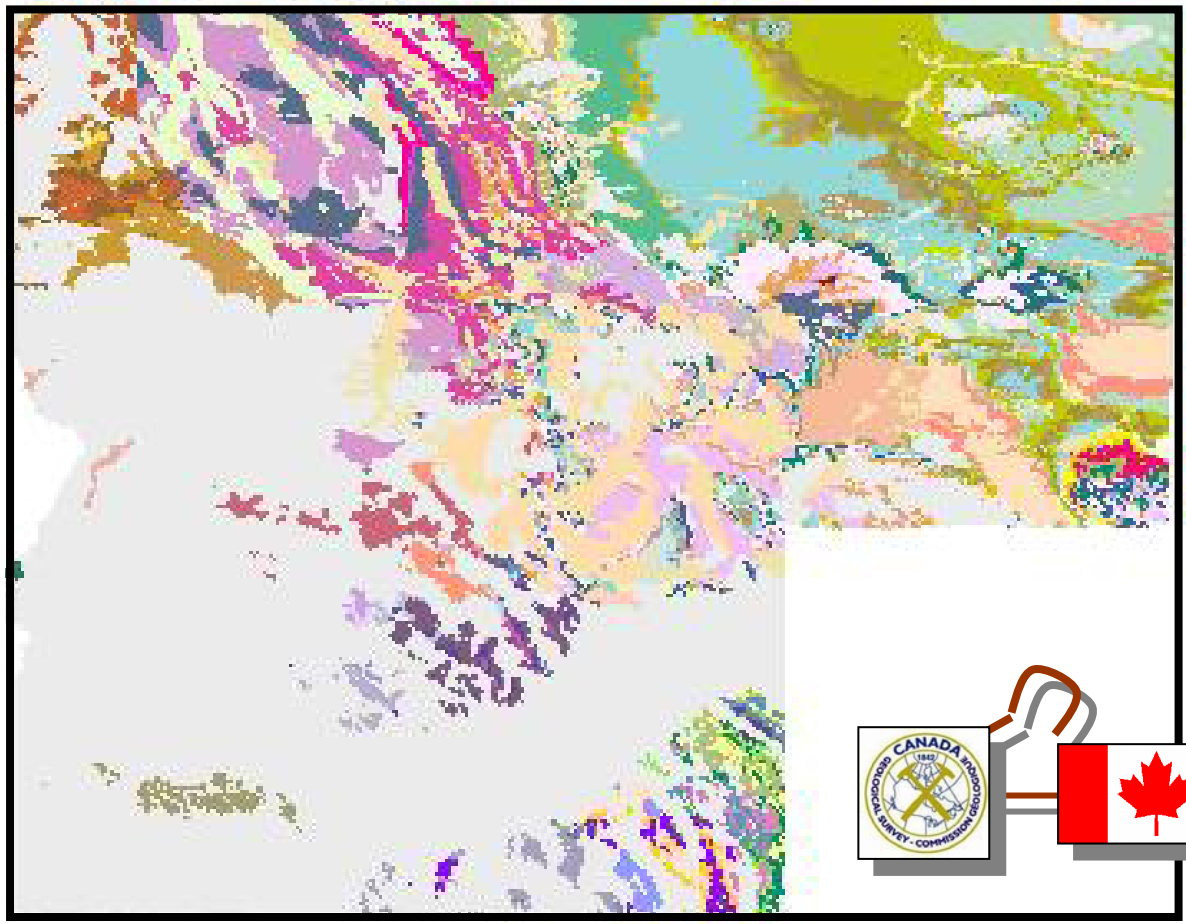
British Geological Survey
Keyworth
Nottingham NG12 5GG
UK



Sedimentary Rocks: GSC Ontology







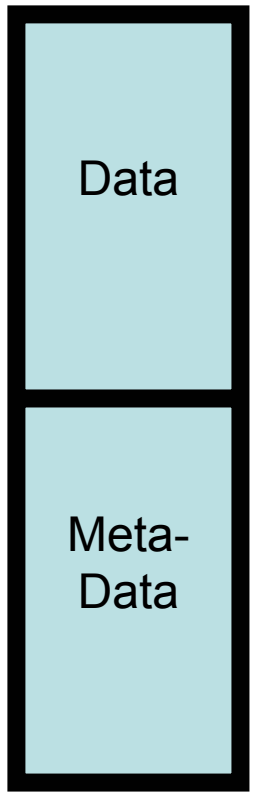
GEON Portal…

A UNAVCO example of a one approach to go from data to visualization (3-D)

UNAVCO/GEON PoP

Access to UNAVCO/GEON resources provided via the GEONgrid Portal

UNAVCO Data Access Methods



UNAVCO/GEON
PoP

Current Access
Methods:

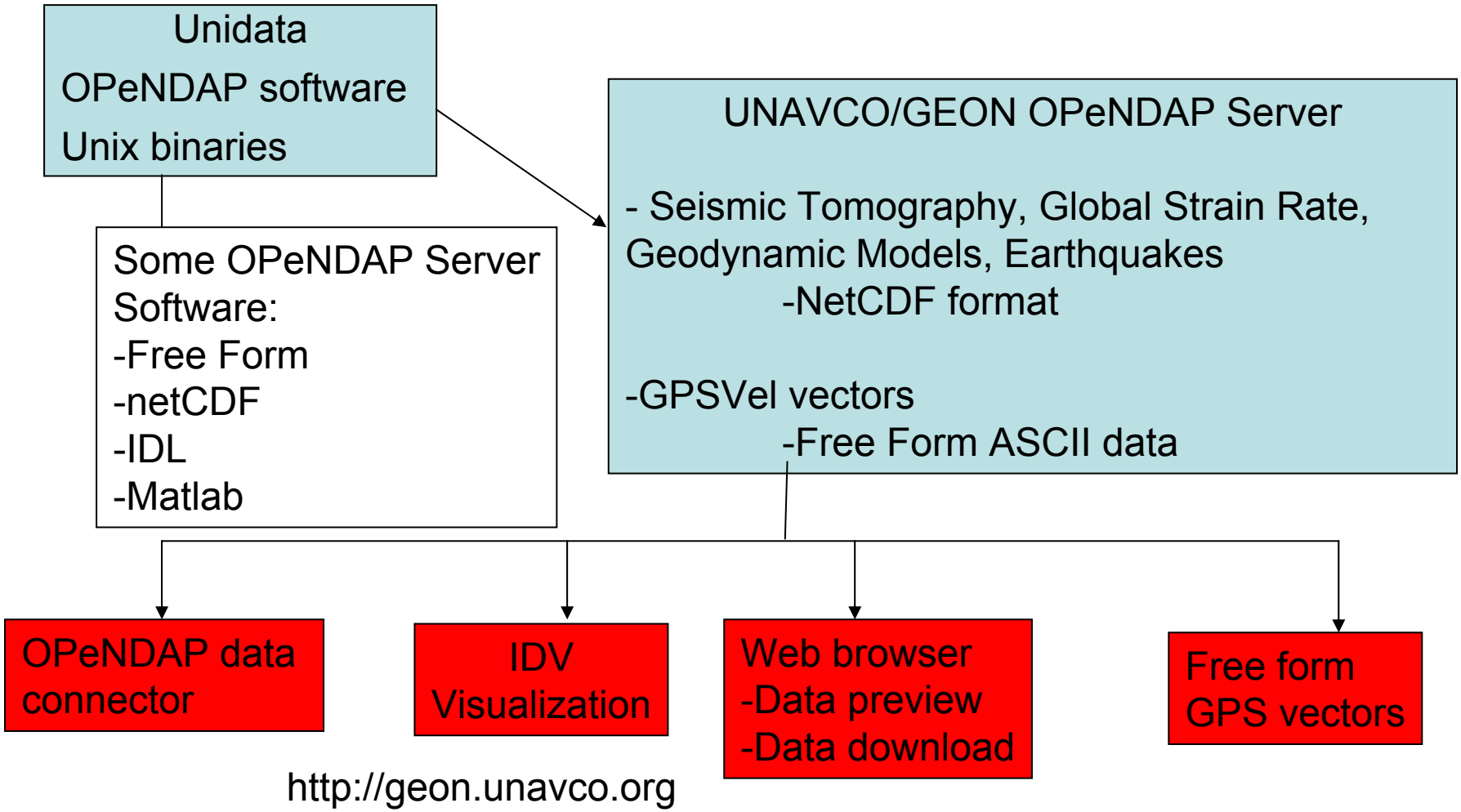
http and ftp (e.g. GPS Seamless Archive, GSAC, webpages)

OPeNDAP (e.g. IDV 3D Visualization)

Under consideration:

ODBC/JDBC
SRB
Arcxml
Gridftp
GML
SCP

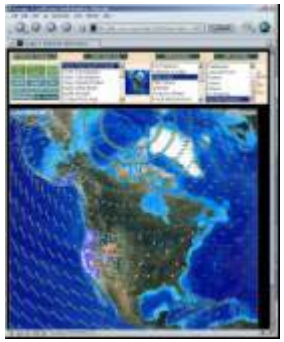
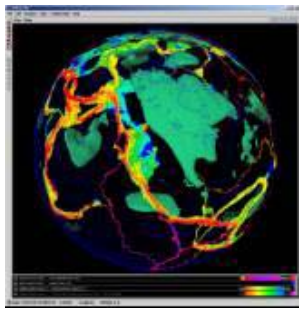
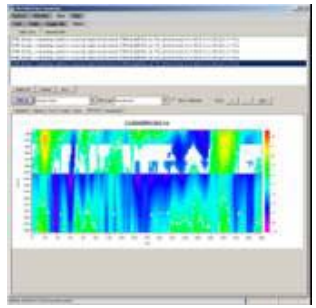
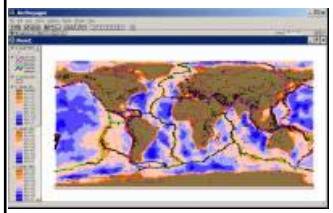
UNAVCO/GEON
OPeNDAP Server



http://geon.unavco.org

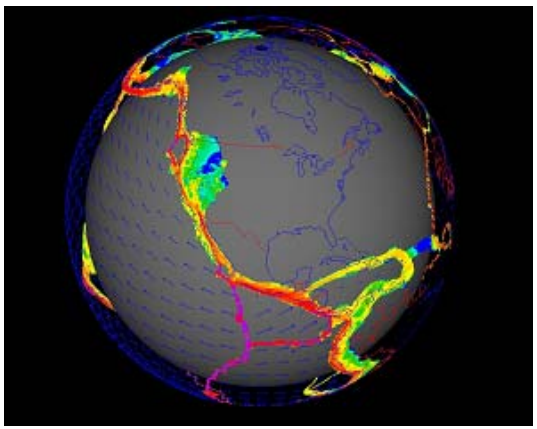
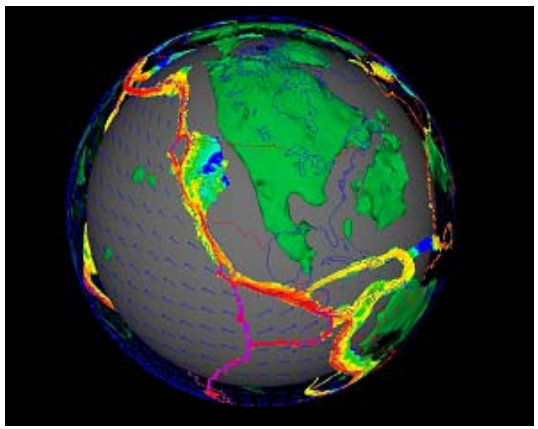
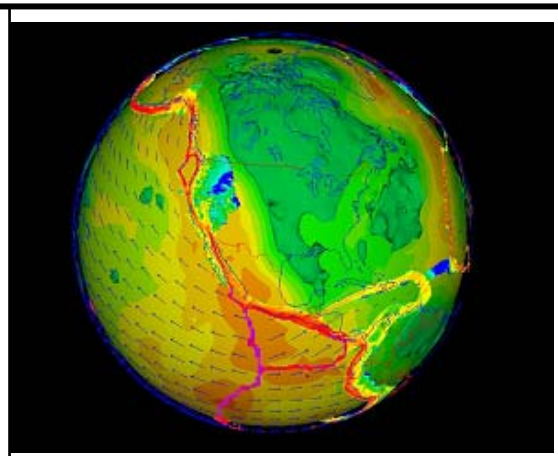
Data Visualization

Same data or model => many uses …but currently
same data + graduate students => fewer uses!

				
Jules Verne Voyager Java Applet -> GMT Server Versions: Voyage to Earth Voyage to the Solar System Global Strain Rate Map (GSRM, Kreemer, et. al. 2003).	**Jules Verne Voyager, Jr.** **EarthScope Voyager, Jr.** Javascript ->data server Shown are the velocities from the GSRM and planned EarthScope sites.	**Interactive Data Viewer (IDV)** **Global and Map versions** Java Application -> OPeNDAP Server Shown are S-wave anomaly isosurfaces of Ritzwoller, et. al. 2002 and the GSRM strain rates using the Global IDV.	**OPeNDAP Data Connector** C application -> OPeNDAP Server Shown is the S-wave velocity model converted to netCDF files.	**ArcVoyager, ArcMap** ESRI Application DLESE/GEON, with UNAVCO contributions, is building an education module for the Earth Exploration Toolbook

IDV Visualization

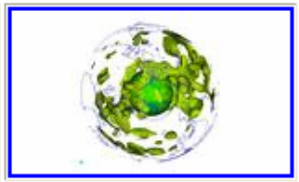
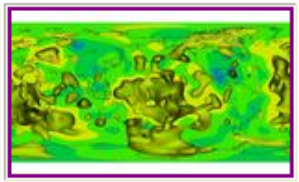
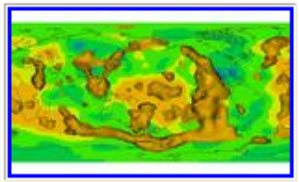
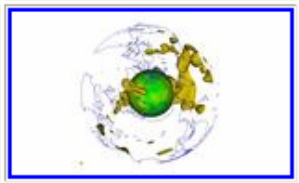
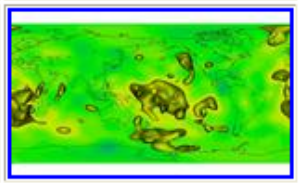
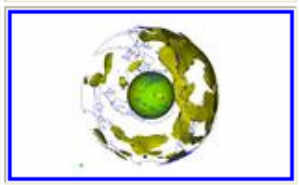
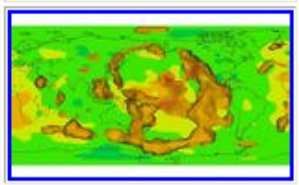
An example of an end-to-end solution: data/models -> NetCDF -> OPeNDAP server -> Visualization & Collaboration (developed by UNIDATA using U. of Wisc. VISAD)

		
Color contours of the second invariant of the strain rate tensor (blue to red show low to high strain rate). Blue arrows indicate global plate motion from with respect to the North American Plate. Results are from the UNAVCO-supported Global Strain Rate Map (GSRM) project (Kreemer, et al. 2003).	Isosurfaces of 5% positive S-wave anomalies (green surfaces) in the upper mantle from a global tomographic model of Ritzwoller, et. al. 2002. The higher velocity regions are typically associated with colder denser regions underlying continental interiors such as the Canadian shield.	All data from the above figures shown together with a color contour surface of the S-wave anomalies at 100 km depth. The IDV has powerful capabilities to show integrated views of volume and surface data. There is a clear correlation between areas of high strain rate and low S-wave velocities in the upper mantle under W. North America and the east Pacific rise

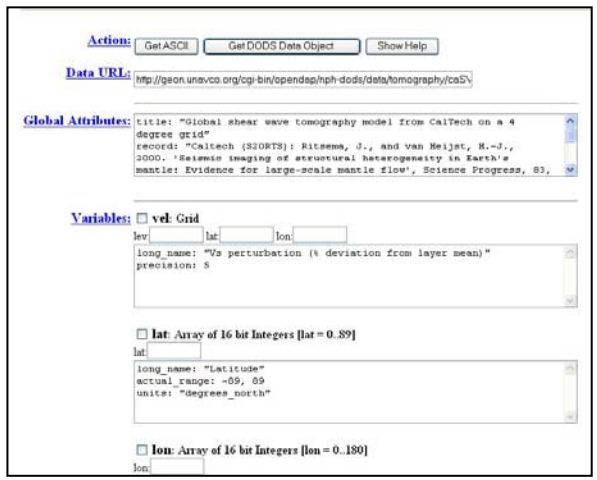
Data Visualization

Example: Mantle Tomography with IDV

Example data on UNAVCO/GEON node and IDV xml configuration files simplify getting started with the IDV

Data	Globe Picture	Globe IDV File	Map Picture	Map IDV File
BK 2 Degree		IDV File		IDV File
BK 4 Degree		IDV File		IDV File
CA 2 Degree		IDV File		IDV File
CA 4 Degree		IDV File		IDV File

Metadata embedded in NetCDF file is returned from the OPenDAP Server in response to URI



IDV Visualization

Mantle Geodynamics: Convection with geologic plate motions over 120 m.a.

Purpose: "resolving multiple scale (both temporal and spatial) physics in mantle convection and lithospheric deformation"

scale: "whole mantle with plates"

resolution: "~40-50 -km, spherical geometry"

method: "Numerical (finite element)"

material_properties: "temperature and depth dependent viscosity (linear, no elasticity)"

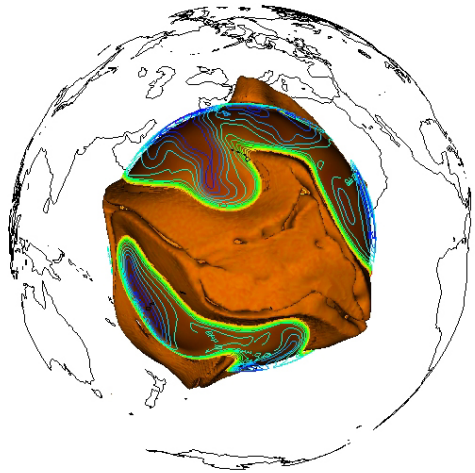
code: "CitcomS [Zhong, Zuber, Moresi and Gurnis, 2000], 5000 time steps, over 4 million nodes!"

output: "normalized thermal and composition structure of the mantle from convection"

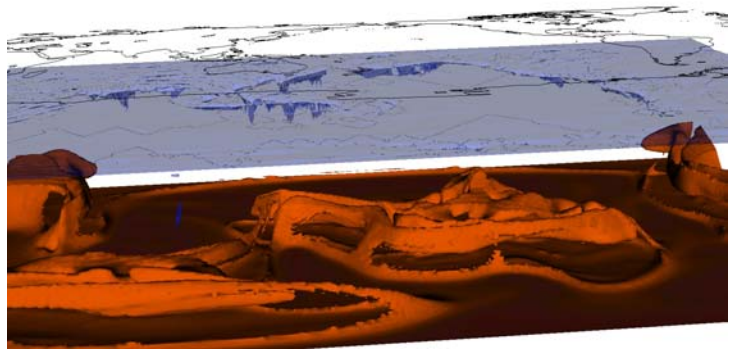
credits: "McNamara and Zhong (2004) - Allen McNamara and Shijie Zhong"

location: "Department of Physics at University of Colorado at Boulder, Campus box 390 Boulder Co, 80309-0390 USA"

website: "http://anquetil.colorado.edu/szhong"



Mantle Temperature

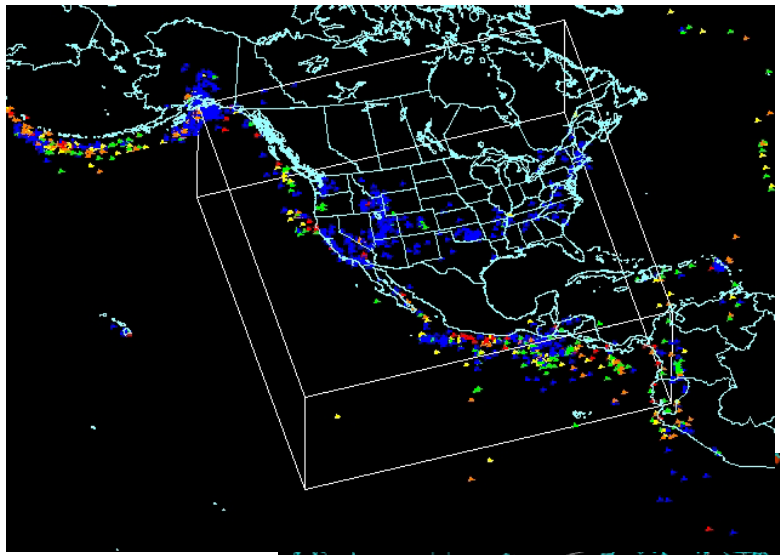


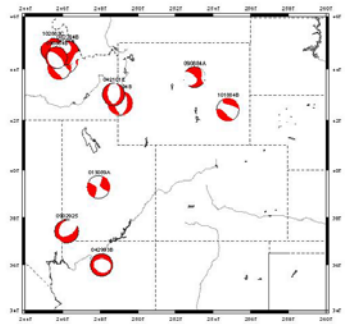
IDV Visualization
UNAVCO/GEON Enhancements to UNIDATA's Java Code

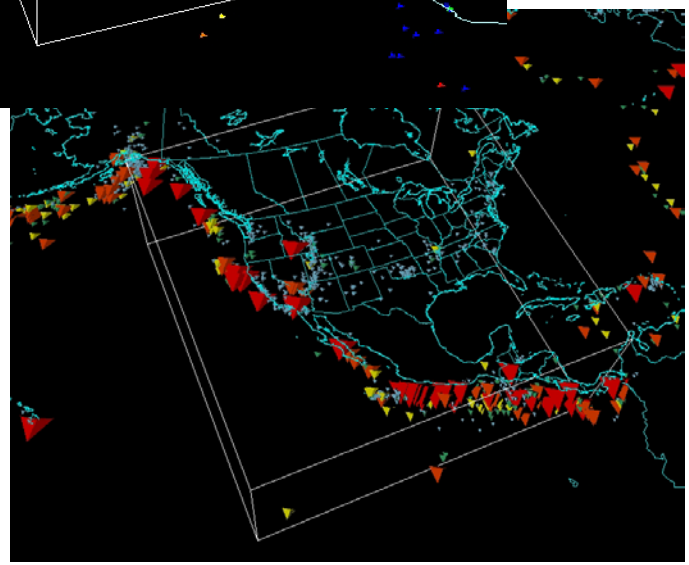
UNAVCO is adding new features to UNIDAT's IDV

(Dr. Stuart Wier, under contract to UNAVCO)

- •Earthquakes (done)
- •GPS vectors with error ellipses
- •Earthquake focal mechanisms
- •Customize interface for earth science users



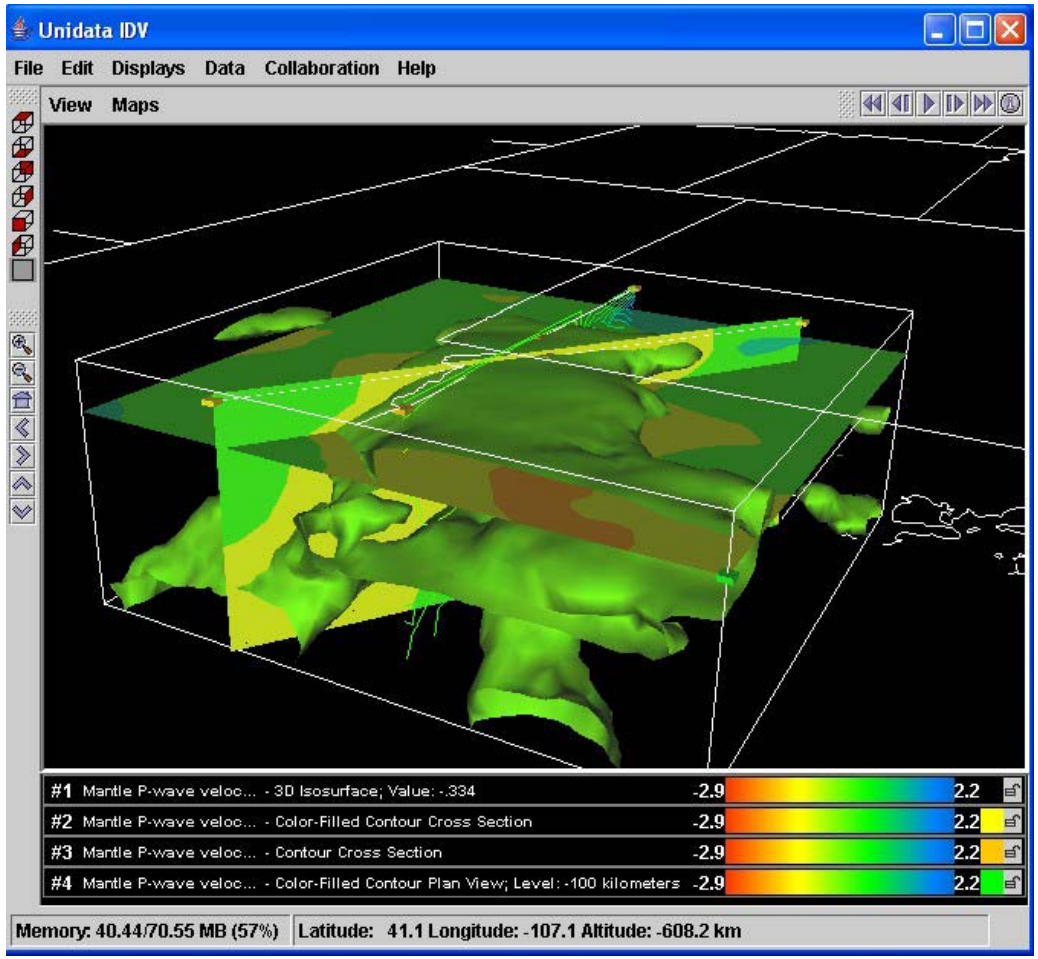




The IDV Interactive Dataviewer developed by Unidata using U. of Wisc. VisAD java platform

Shear wave topography of the Yellowstone plateau. The IDV allows the user to make cross-sections, probe the data, and to make 3-D isosurfaces of constant velocity anomaly.

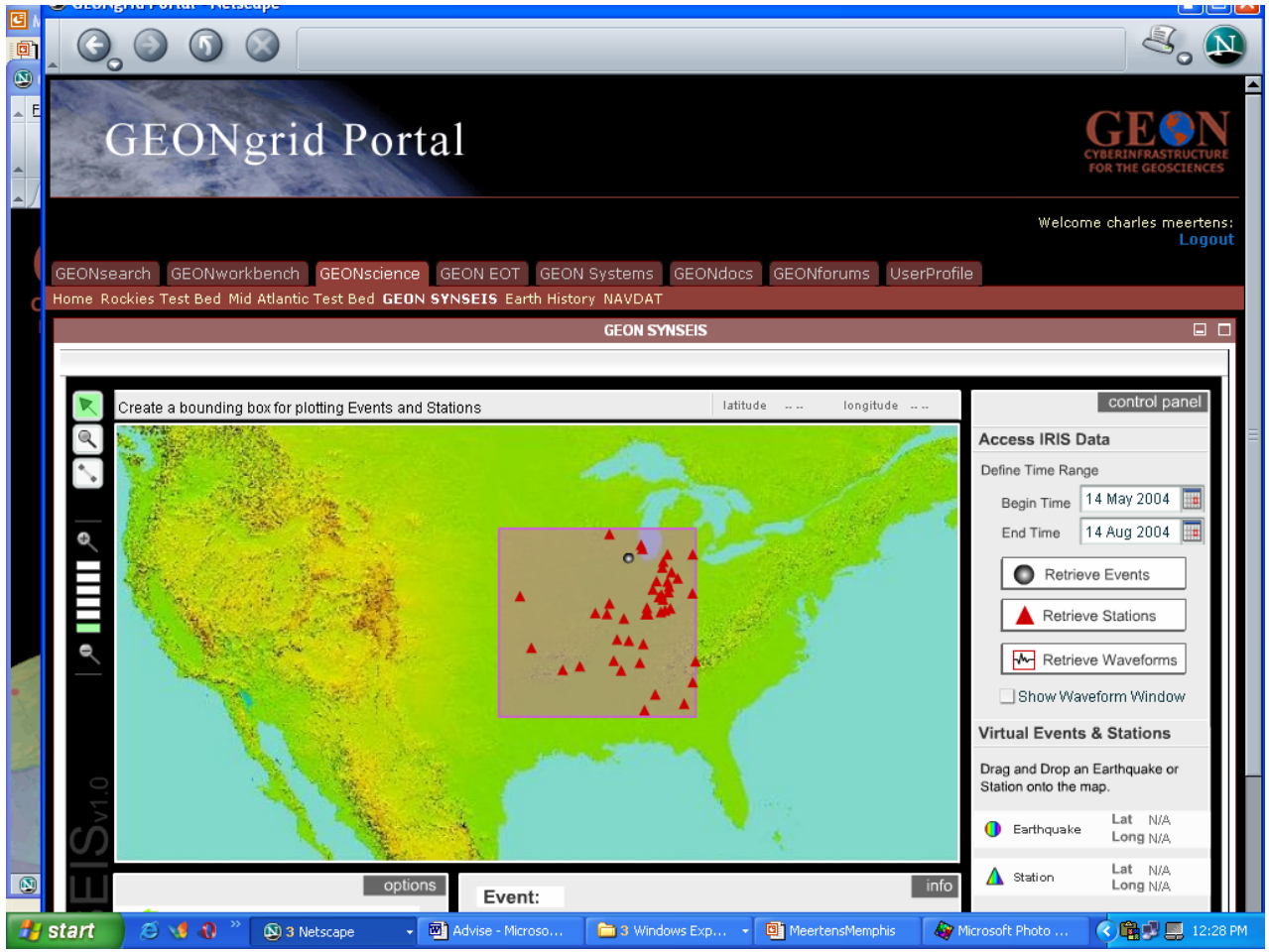
From M. Jordan and R. Smith, U. of Utah – new research, 2004



GEON Portal - SYNSEIS

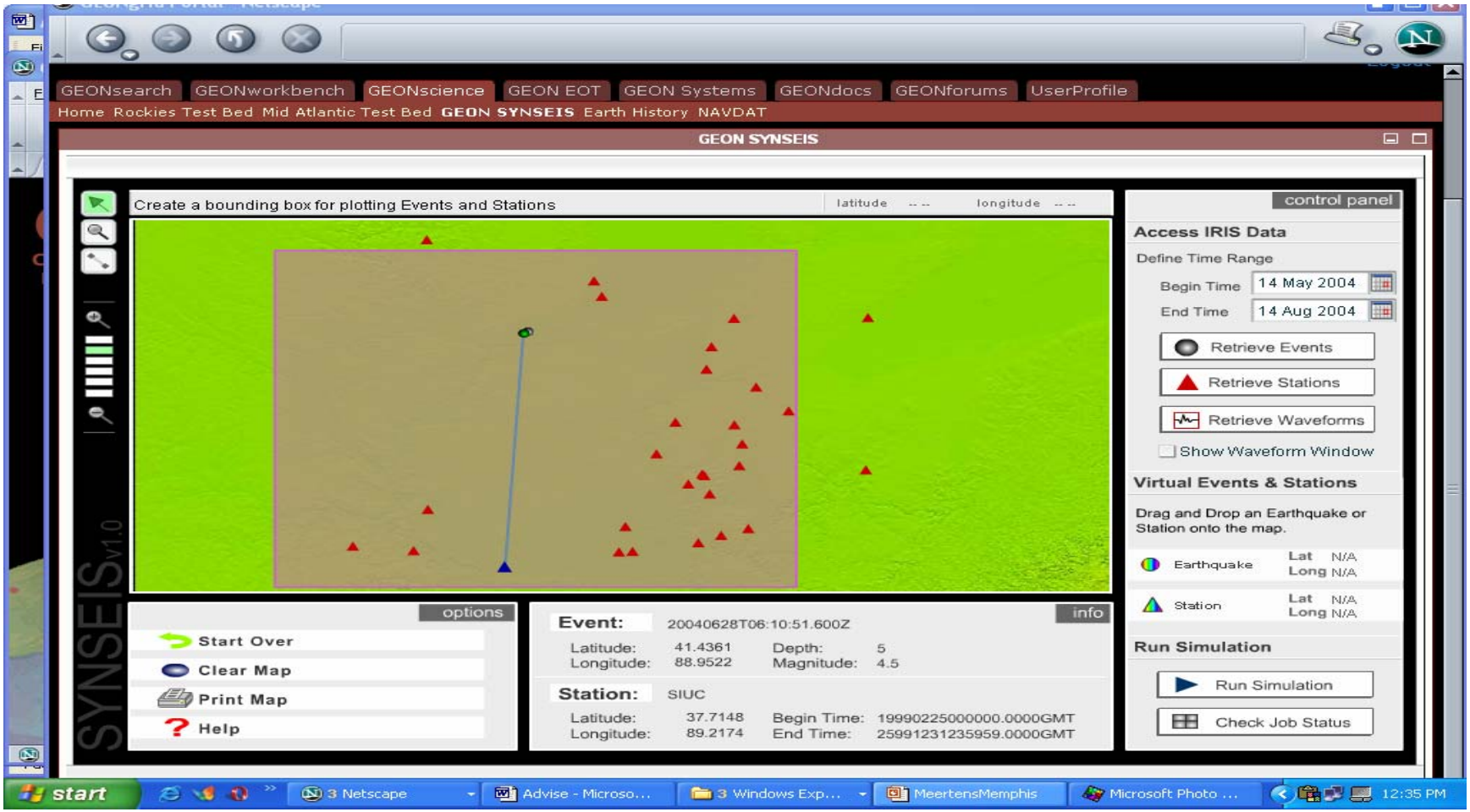
An example of an integrated computational tool using distributed Grid resources.

GEON Synseis Example
Log into Geon Portal and select region (shown is Mid Continent)

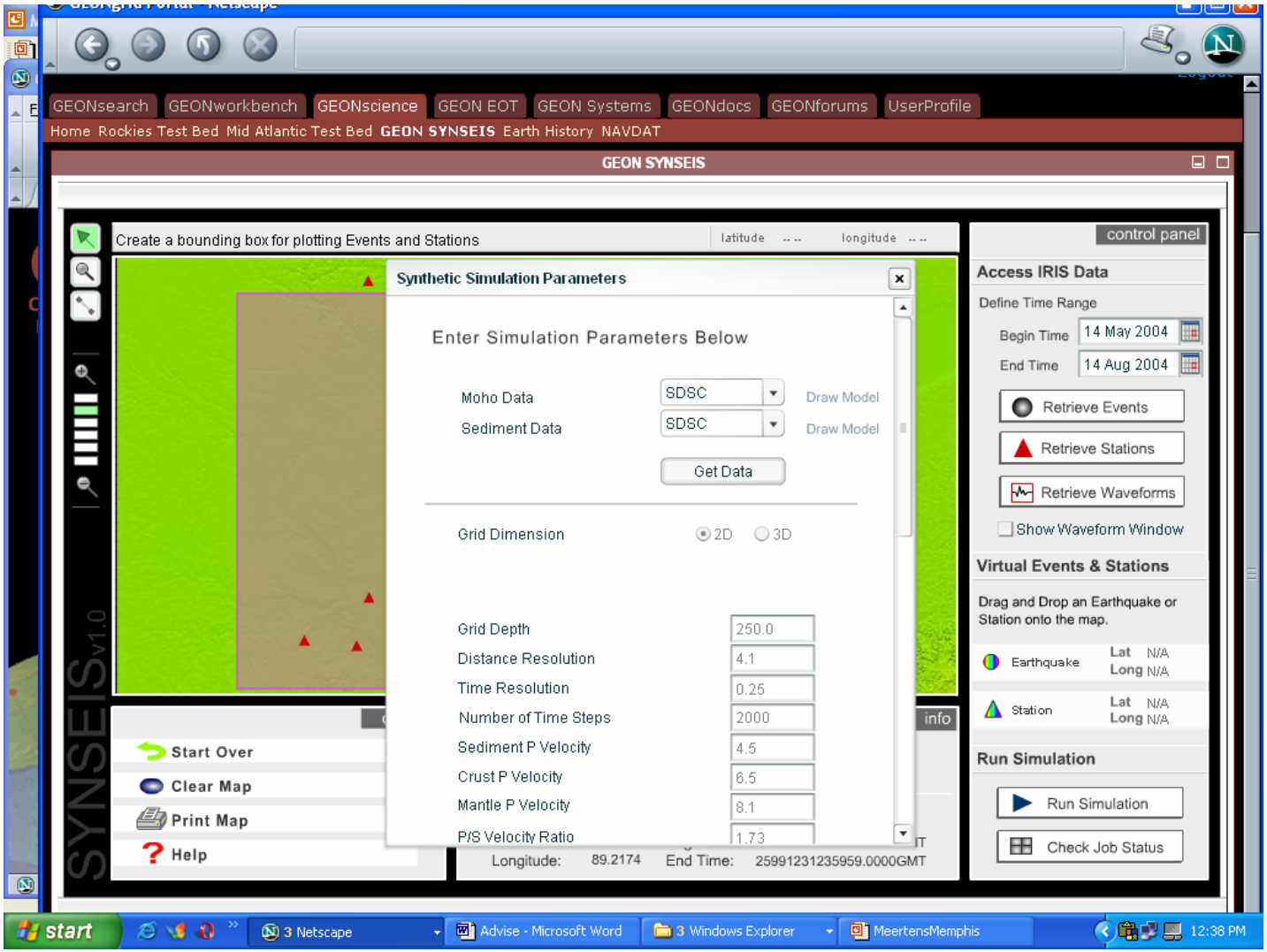


Synseis effort headed by Dogan Seber

Select time window, then specific earthquake and station pair
(Example from June, 2004)



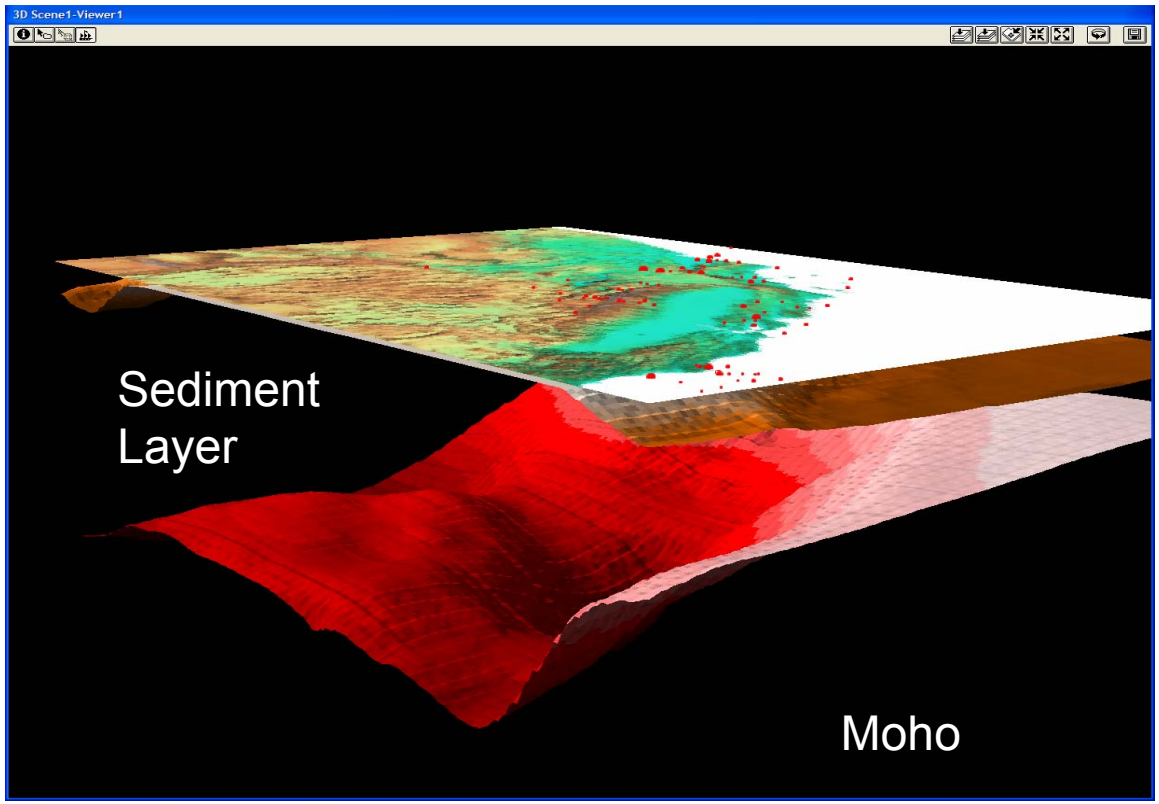
Select crustal velocity model



Velocity Model For Selected Region From ArcIMS webservice

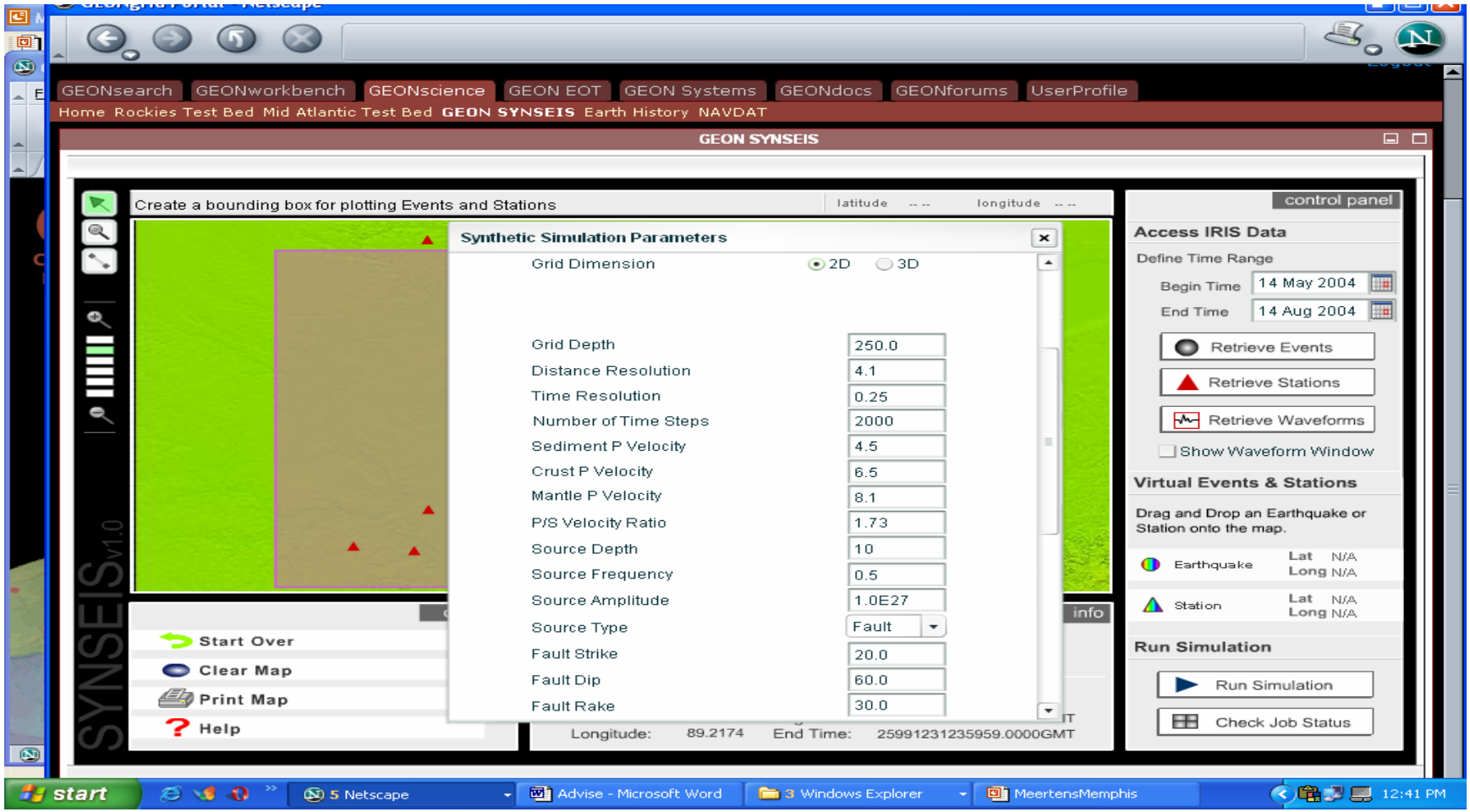
Synseis

Region-specific structure Model from GEON ArcIMS webservice

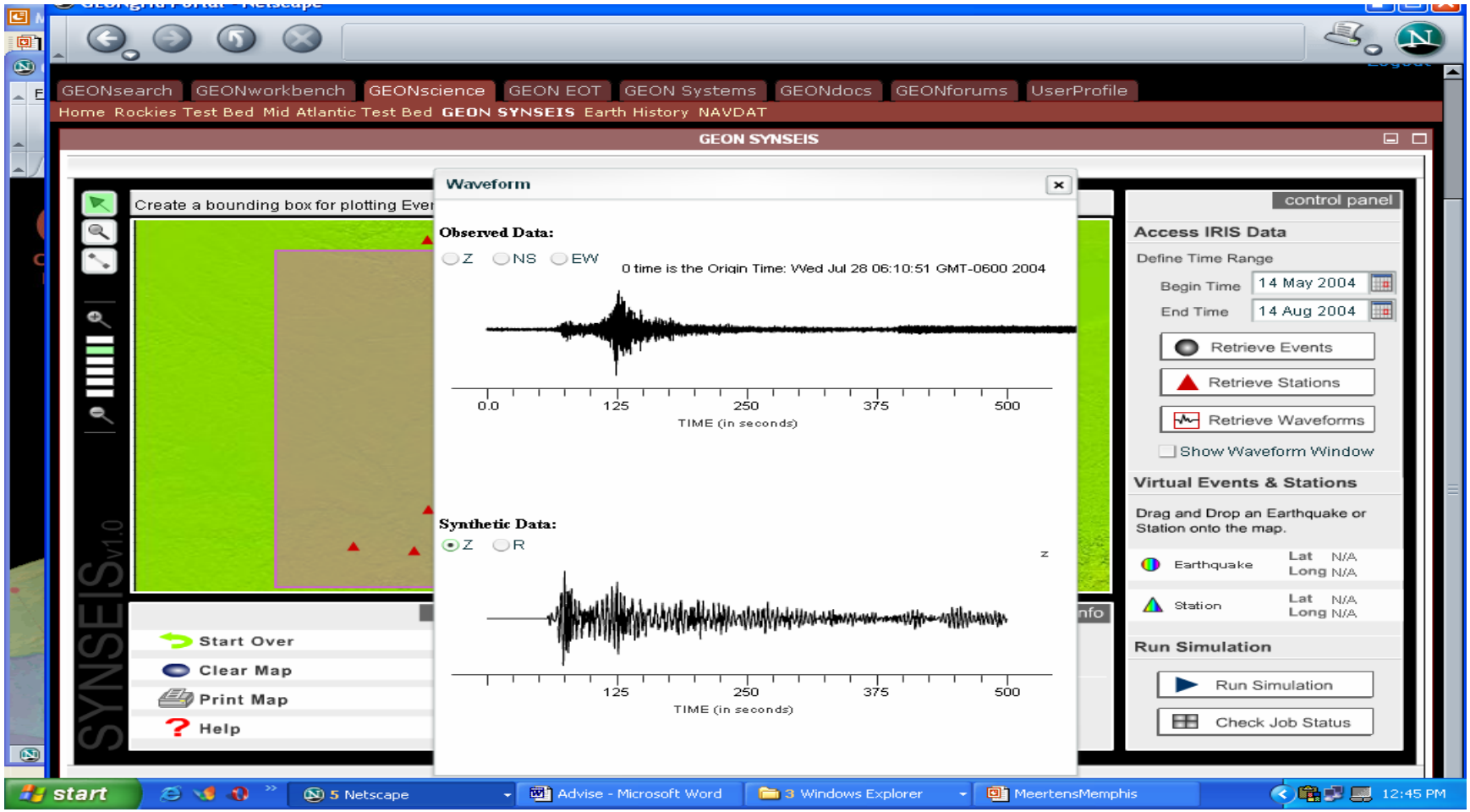


Slide from Dogan Seber, SDSC

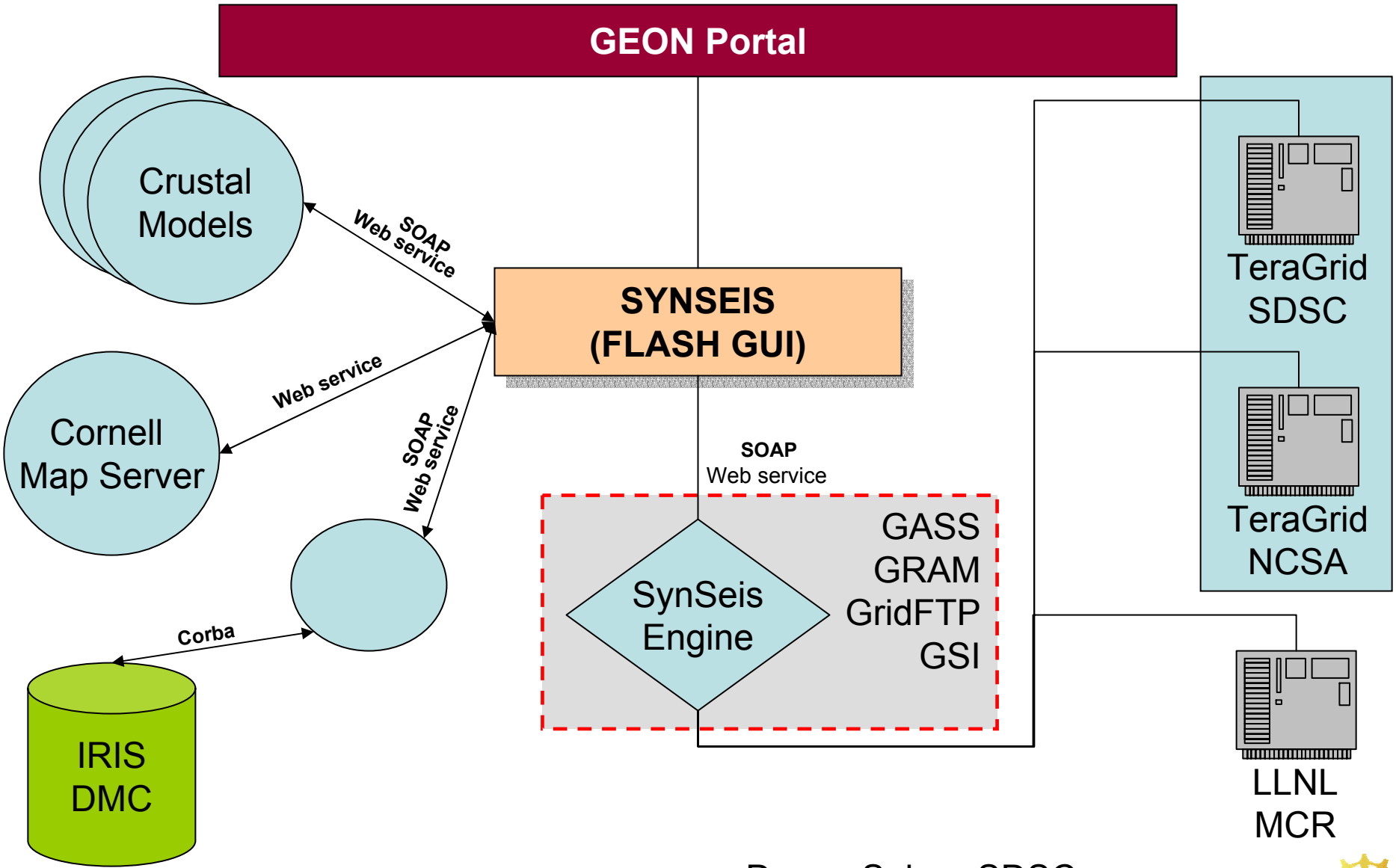
Enter simulation parameters, select supercomputer, run job



Compare IRIS waveform with synthetic waveform



SYNSEIS Architecture



Dogan Seber, SDSC

GEON Portal Development- Finite Element Models

Another example of an integrated computational tool using distributed Grid resources and new flexible numerical problem solving methods.

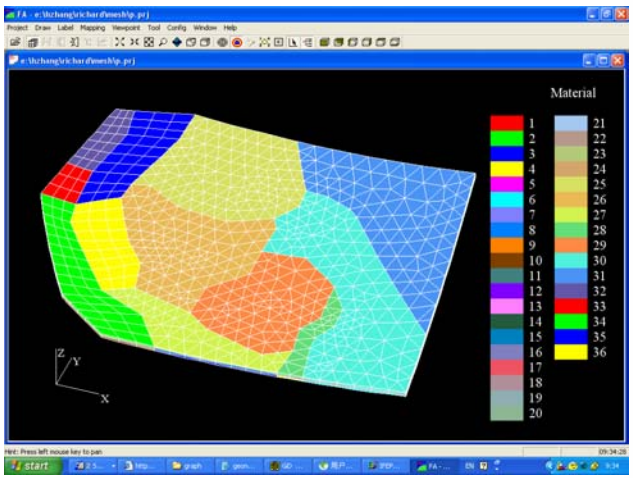
4D simulation of continental deformation in the western US

Mian Liu, Huai Zhang & Youqing Yang

University of Missouri-Columbia
San Diego Supercomputer

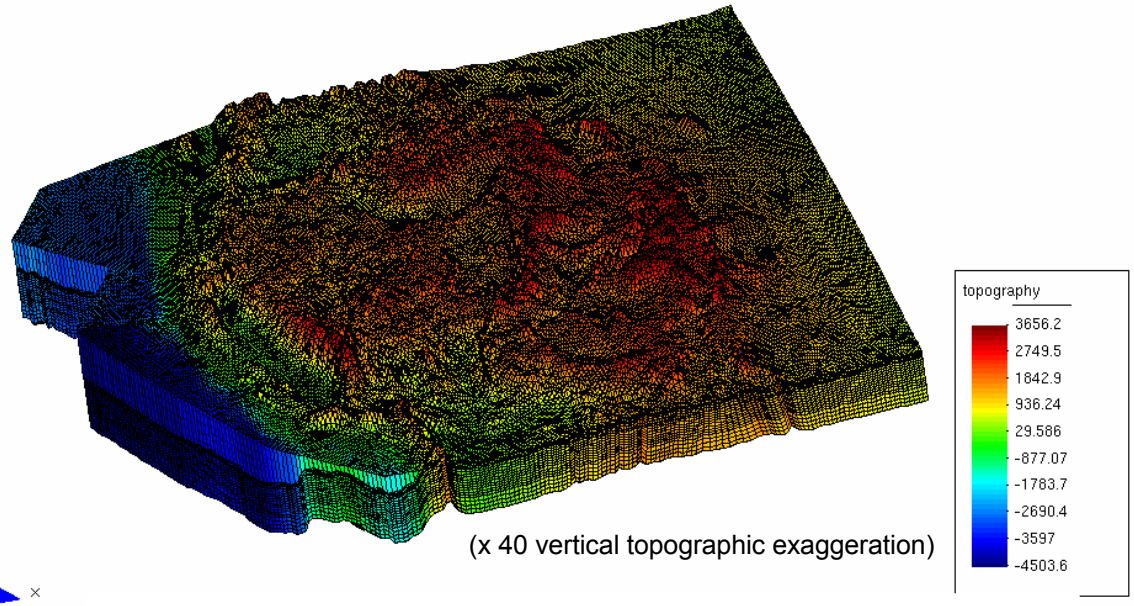
The Power of GEON Cluster Nodes

Original model (single CPU)



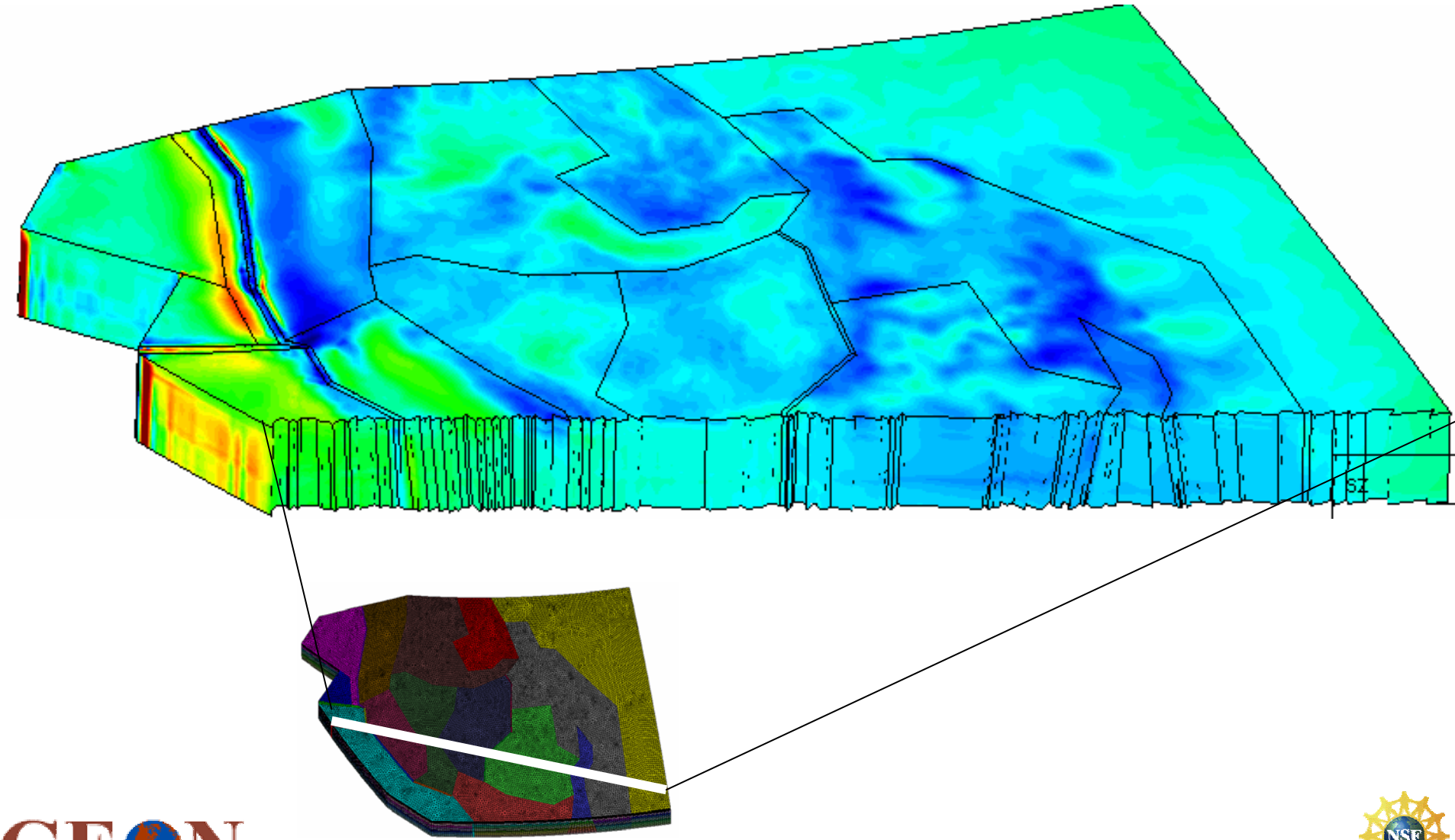
- Less than 3000 elements
- Three layers in R-direction
- 2 min for per time step

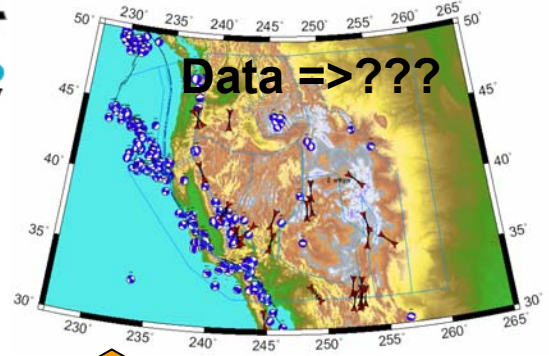
Current model (2-nodes, 4CPUs)

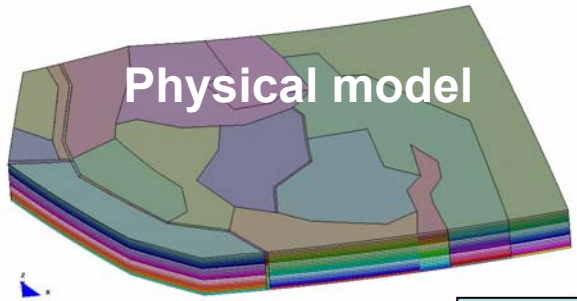


- More than 800,000 unstructured elements
- Major Faults and more deformation zones
- Subduction of Juan de Fuca slab
- 21 layers in R-direction
- 15 min per time step

The model now allows simulation of large scale continental deformation with unprecedented detail







PDEs

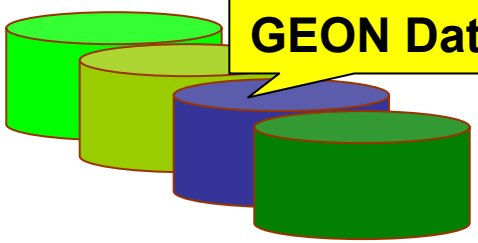
$$\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} + \frac{\partial \sigma_{xz}}{\partial z} + f_x = 0$$

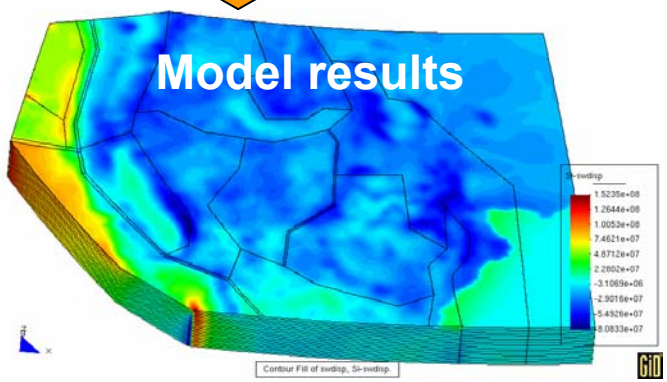
$$\frac{\partial \sigma_{xy}}{\partial x} + \frac{\partial \sigma_{yy}}{\partial y} + \frac{\partial \sigma_{yz}}{\partial z} + f_y = 0$$

$$\frac{\partial \sigma_{xz}}{\partial x} + \frac{\partial \sigma_{yz}}{\partial y} + \frac{\partial \sigma_{zz}}{\partial z} + f_z = 0$$

FEM Modeling Language

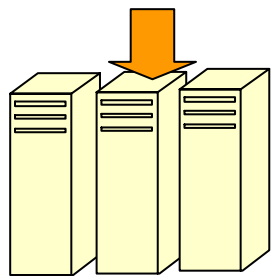
```
func
funa=+[u/x]
 ……
funf=+[u/y]+[v/x]

 ……
dist
=+[funa;funa]*d(1,1)+[funa;funb]*d(1,2)+[funa;func]*d(1,3)
+[funb;funa]*d(2,1)+[funb;funb]*d(2,2)+[funb;func]*d(2,3)
+[func;funa]*d(3,1)+[func;funb]*d(3,2)+[func;func]*d(3,3)
+[fund;fund]*d(4,4)+[fune;fune]*d(5,5)+[funf;funf]*d(6,6)

load = +[u]*fu+[v]*fv+[w]*fw-[funa]*f(1)-[funb]*f(2)-[func]*f(3)
-[fund]*f(4)-[fune]*f(5)-[funf]*f(6)
```





Automatic source code generator

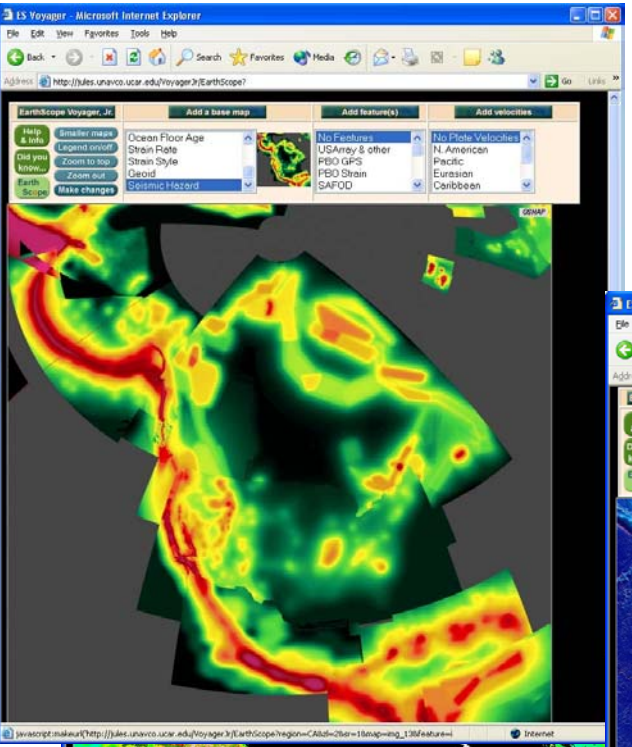
Complete source code

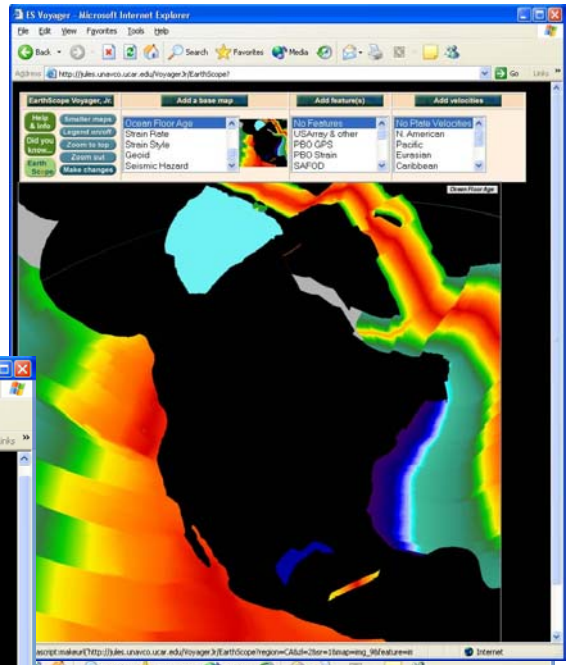


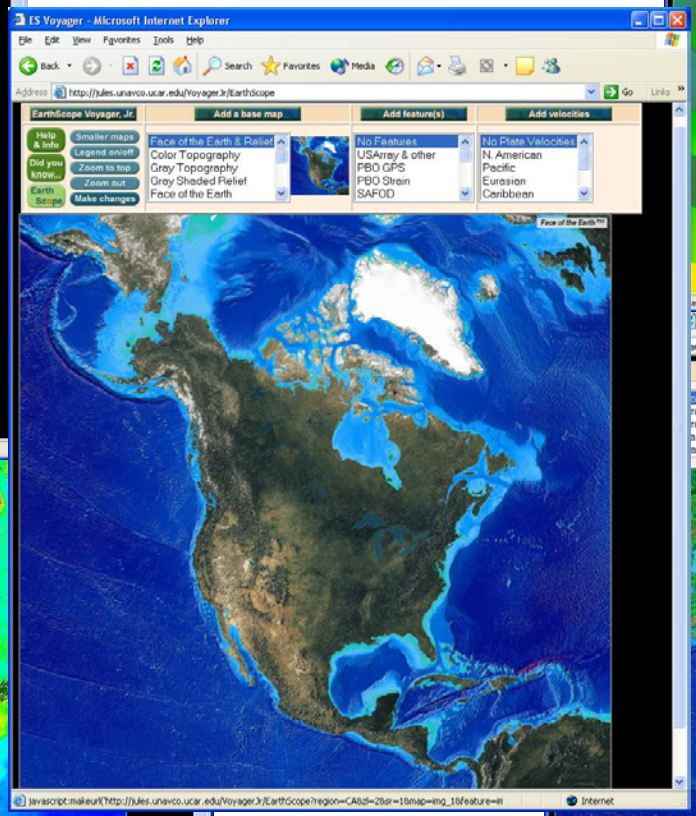
UNAVCO Facility

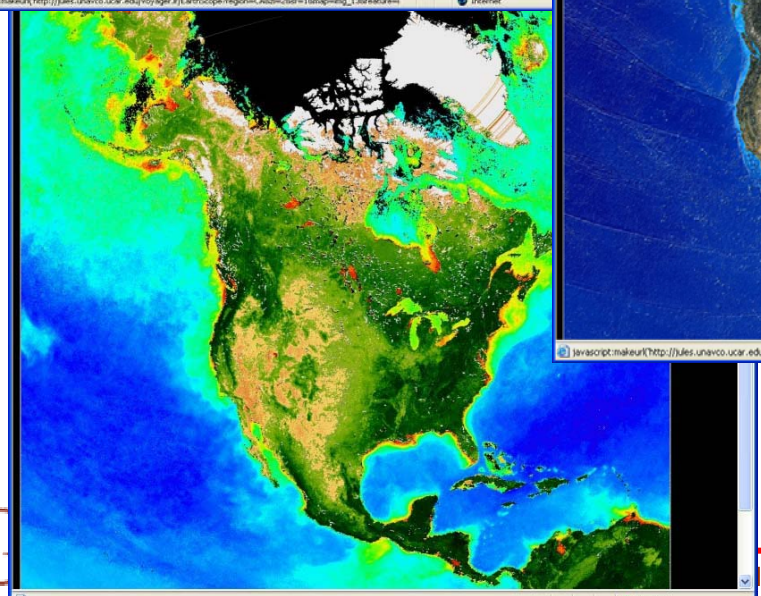
EarthScope

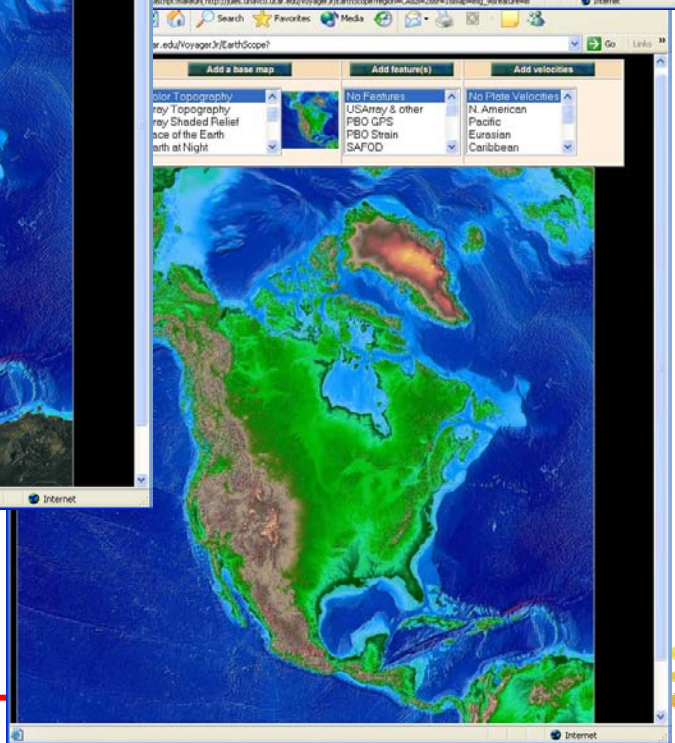
Voyager











E GEOSCIENCES

NSF

Conclusions

Efforts to create an integrated cyberinfrastructure for the earth sciences face enormous challenges due to the heterogeneous nature of the data, the sheer volume of data , computational requirements, and cultural issues …

But efforts like GEON and EarthScope can be "centripetal" forces that will bring the community together to help solve complex science, IT and Education problems.