Interactive Analysis and Visualization of Massive Turbulence Datasets

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Outline

- VAPOR Project overview
- VAPOR capabilities
  - Designed to support scientific understanding, by interactive visualization and analysis of massive data
- New features of VAPOR
- Interactive demonstration (on laptop):
  - Spherical rendering
  - Isosurfaces
  - Shear-driven turbulence and convection in seawater mixing
  - Magneto-hydrodynamics in a multi-terabyte dataset
  - Animation of magnetic layer instability (Solar MHD)
- Future Directions (J. Clyne)

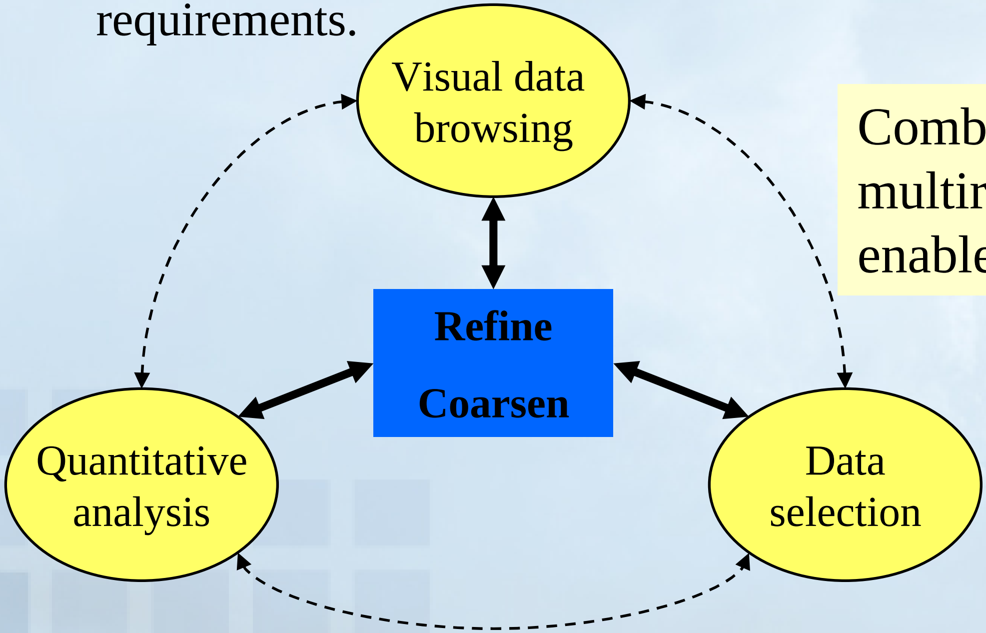
VAPOR project overview

- **Problem**: The scientific value of Terascale and Petascale computations is reduced if we can't analyze and visualize the results quickly.
- **Goal**: Enable scientists to *interactively* analyze and visualize massive datasets (Terabytes now, Petabytes next)
- **VAPOR** is the **V**isualization and **A**nalysis **P**latform for **O**ceanic, atmospheric and solar **R**esearch
- **VAPOR** is a collaboration between developers and scientists, applying the latest visualization research to advance earth science research

VAPOR Technical Approach

Key components

1. Multiresolution data representation, enables interactive access:
    - Entire dataset available at lowered resolution
    - Regions of interest available at full resolution
2. Integrate visualization and analysis, interactively steering analysis while reducing data handling
3. Domain specific application focus: numerically simulated turbulence
4. Usability enhanced via a desktop application derived from scientific requirements.



Combination of visualization with multiresolution data representation enables interactive discovery

Capabilities of VAPOR

Provided in an interactive user interface, exploiting modern graphics cards

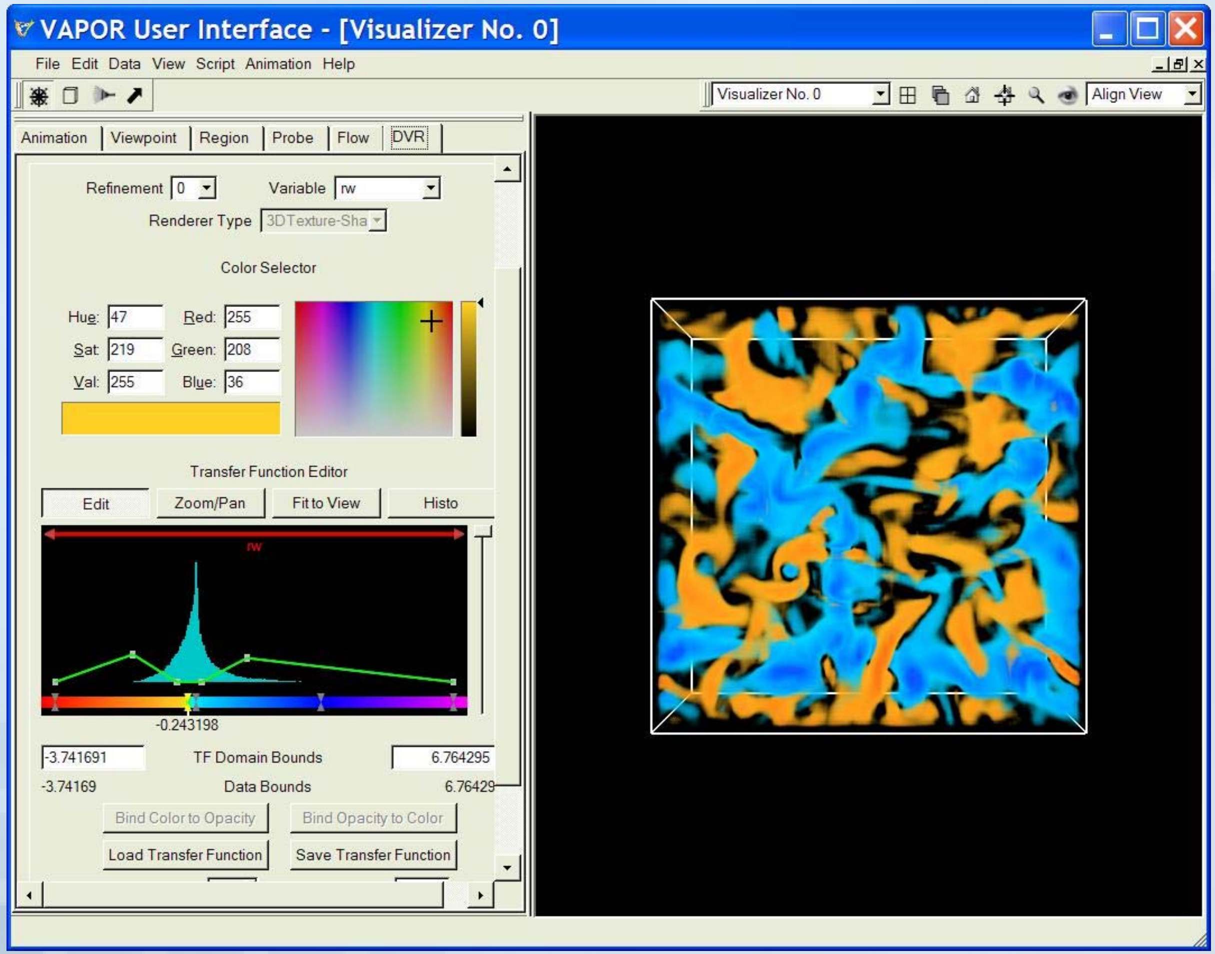
- Volume rendering
- Interactive control of region size and data resolution
- Tight bidirectional integration with IDL® for analysis
- Flow integration
- Data probing and contour planes
- Animation of time-varying data

New Features:

- Isosurfaces
- Spherical grid rendering
- Terrain-following (WRF) grids

Capabilities of VAPOR: Feature identification

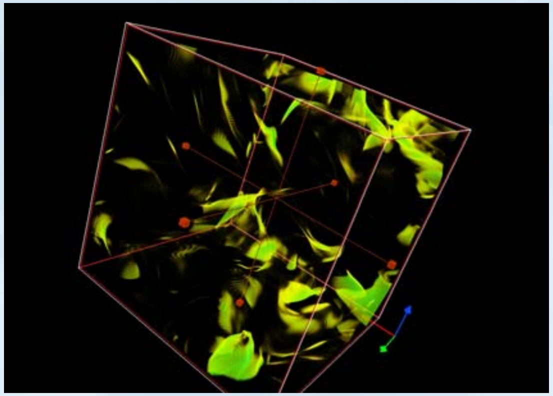
- Interactive color/transparency mapping (transfer function editing) to exhibit features of interest

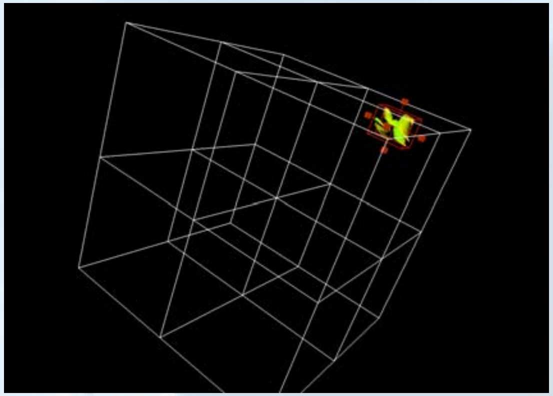


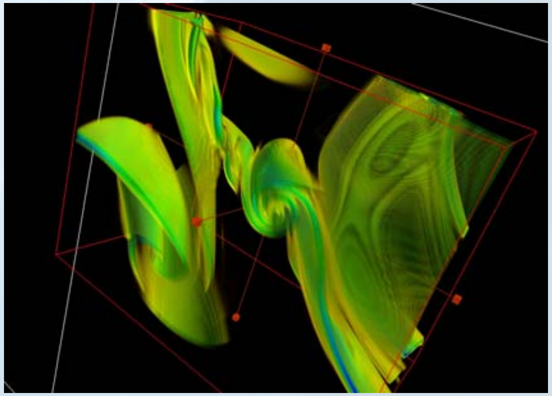
Data courtesy of Mark Rast

Capabilities of VAPOR: Data browsing

- Volume data browsing with region-of-interest and resolution control
  - View large regions at lowered resolution
  - Select regions of interest
  - Zoom-in for high-resolution view







Data courtesy of Pablo Mininni

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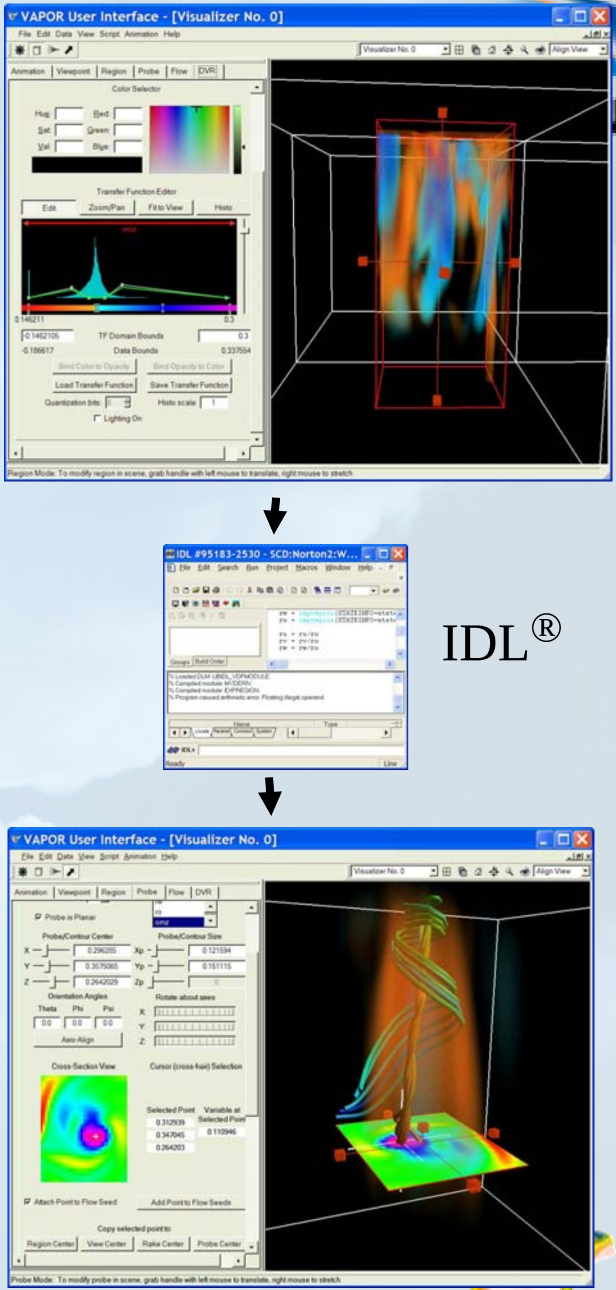
Capabilities of VAPOR: Data analysis

- VAPOR interacts with IDL® to calculate and visualize derived quantities in region-of-interest
  - Immediate analysis applied to data identified in visualization
  - Immediate visualization of derived quantities calculated in IDL
    - Identify region of interest
    - Export to IDL session, calculate derived variables
    - Import result into visualization



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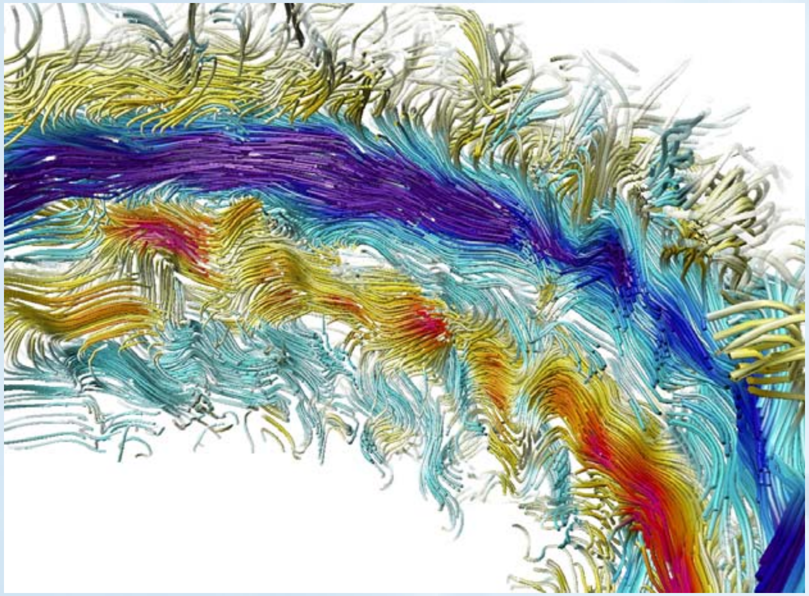
Capabilities of VAPOR: Flow integration

- Steady flow integration is used to visualize field lines



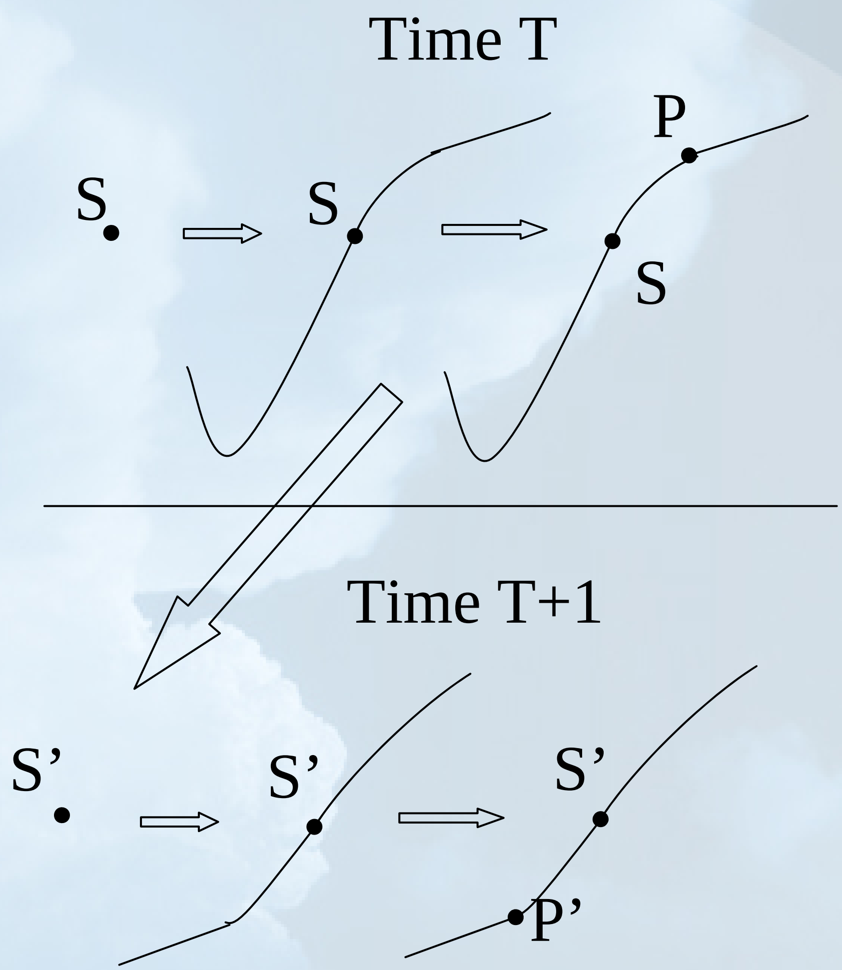
(image courtesy of B. P. Brown)

- Unsteady flow is used to track particles in velocity field
  - (animation of hydrodynamic convection)

Capabilities of VAPOR: Field line advection

- Combines steady and unsteady flow integration to animate field lines in a time-varying velocity field
- Algorithm proposed by Aake Nordlund
- Animation of Magnetic Reconstruction

(Data courtesy of Pablo Mininni)



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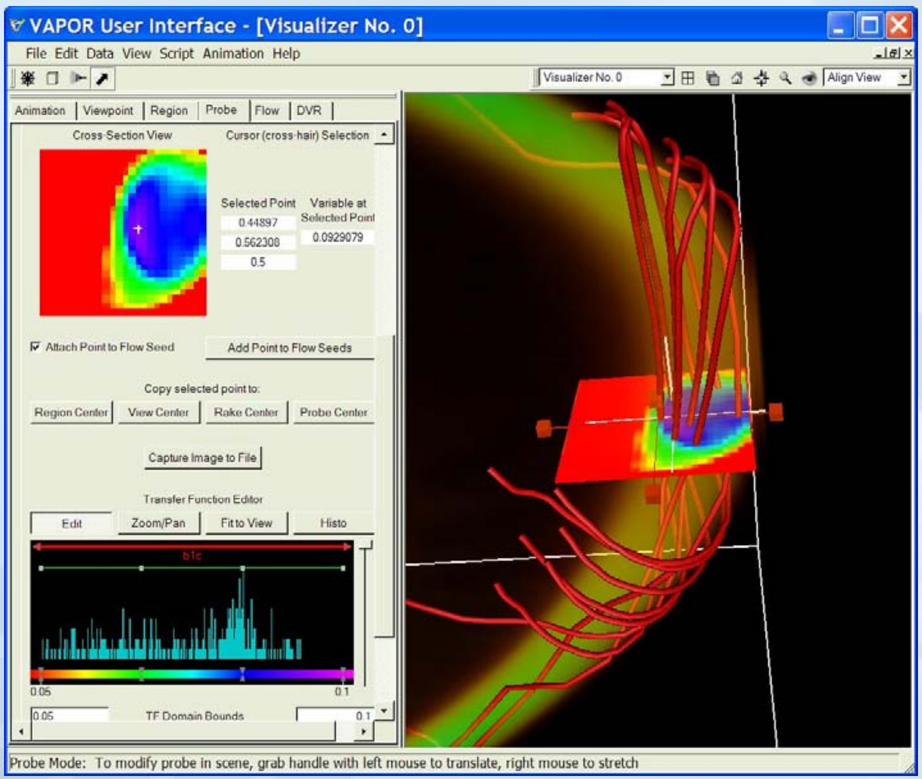
Capabilities of VAPOR: Data probe tool

- Displays contour planes
- Allows interactive interrogation of data values
- Enables interactive seed placement for flow integration.



Data courtesy of Yuhong Fan

New Features of Vapor 1.2

Plan to release this month:

- Isosurfaces
  - Interactively constructed and rendered on GPU
- WRF (Weather Research and Forecasting Model)
  - Support for non-Cartesian (terrain-following) grids
- Improved volume rendering quality
  - 16-bit support
  - Pre-integration
- Prototype spherical volume renderer

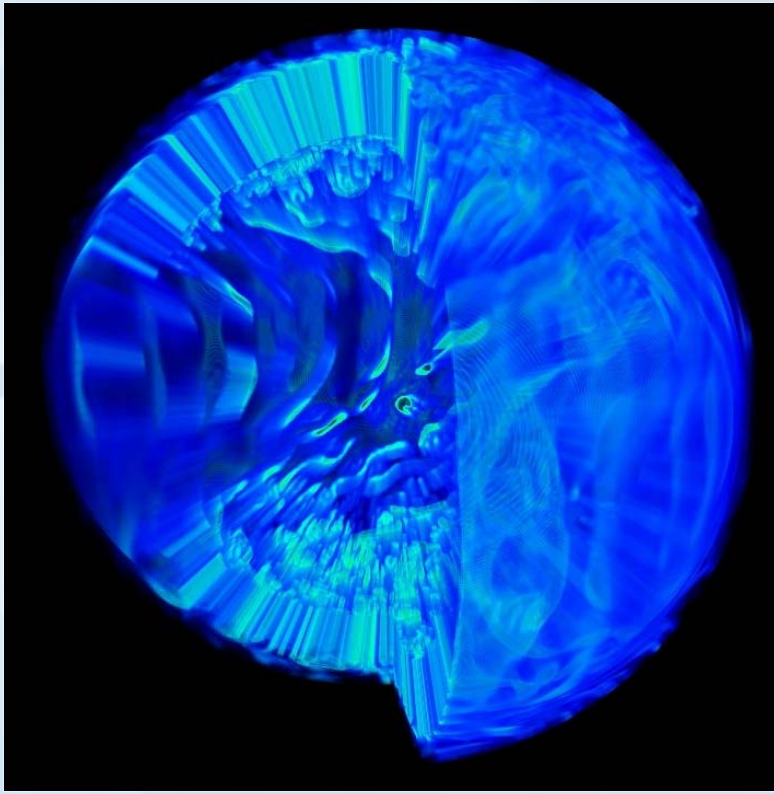
Spherical rendering application

- Simulation of deep convection in convection zones of solar-like stars

- Grid geometry is a spherical shell, covering all latitudes and longitudes and spans a depth of 0.72-0.96 solar radii

- Non-uniform grid spacing in latitude and radial axes

(Data courtesy of Ben Brown, CU)



Spherical shell data

- Poorly suited for re-sampling onto an isotropic grid

Native dimensions: 512x256x97

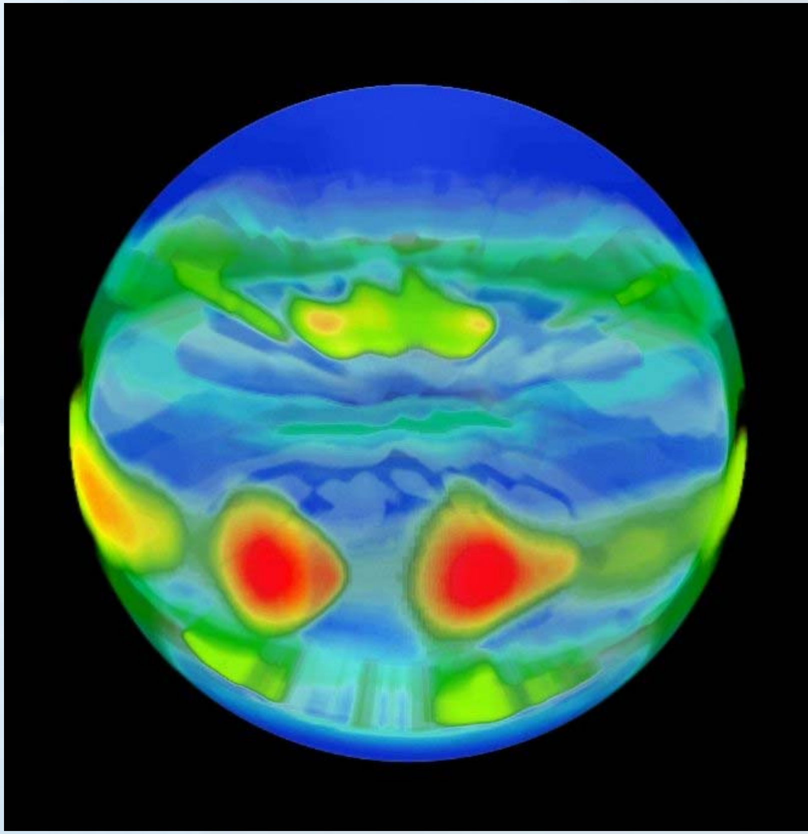
(longitude, latitude, radius).

Native size: 48.5 MB

Re-sampled dimensions:

1075x645x645

Re-sampled size: 1.7 GB



Procedurally Modeled Grid Geometry

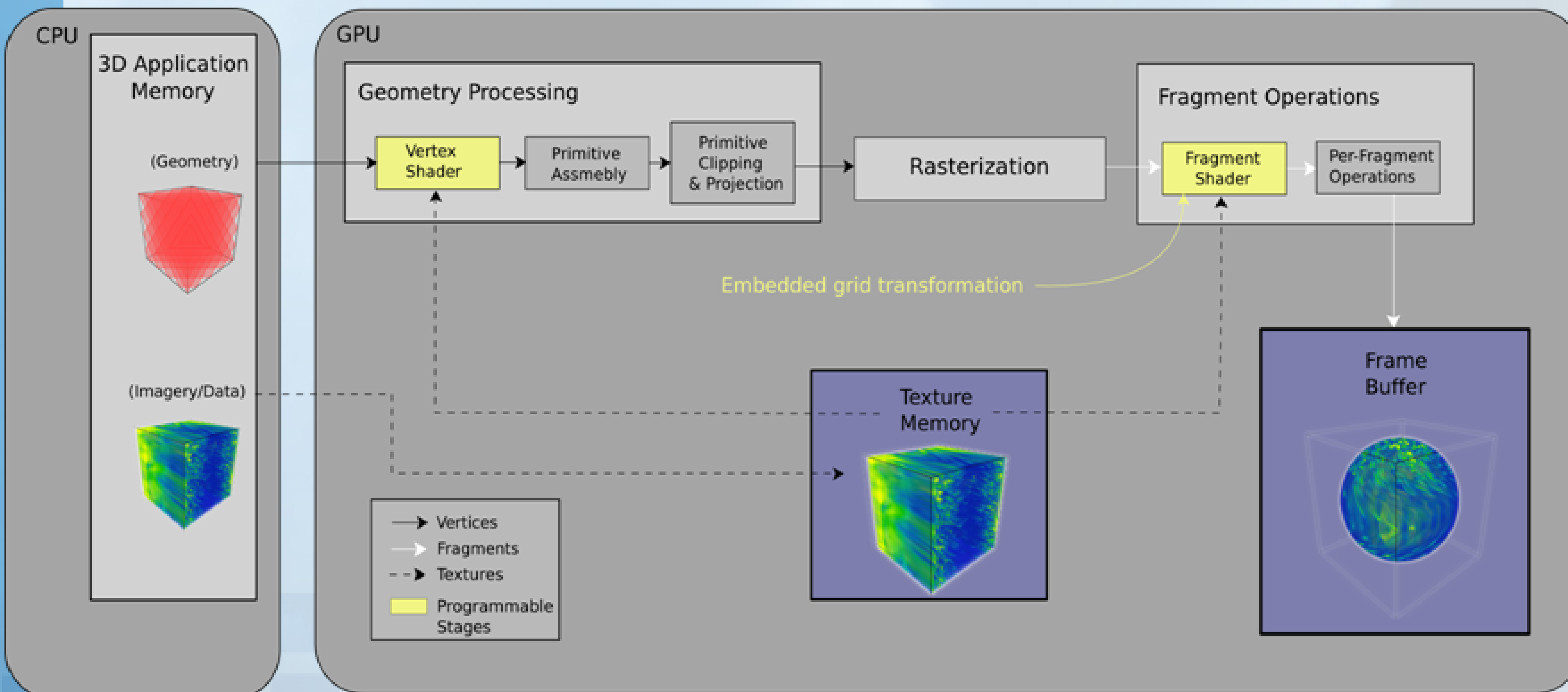
Work of Kenny Gruchalla, CU

$$\rho = \sqrt{(x^2 + y^2 + z^2)}$$

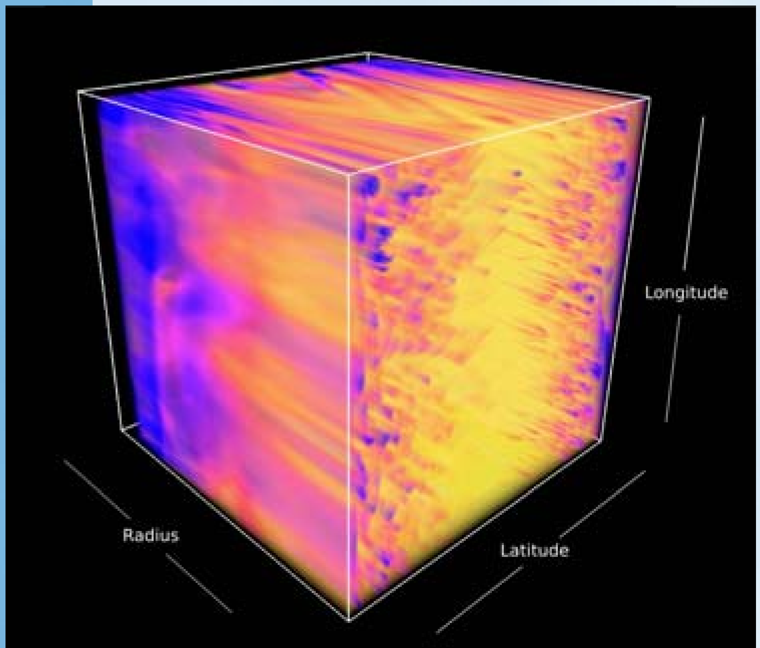
$$\theta = \arccos\left(\frac{z}{\sqrt{(x^2 + y^2 + z^2)}}\right)$$

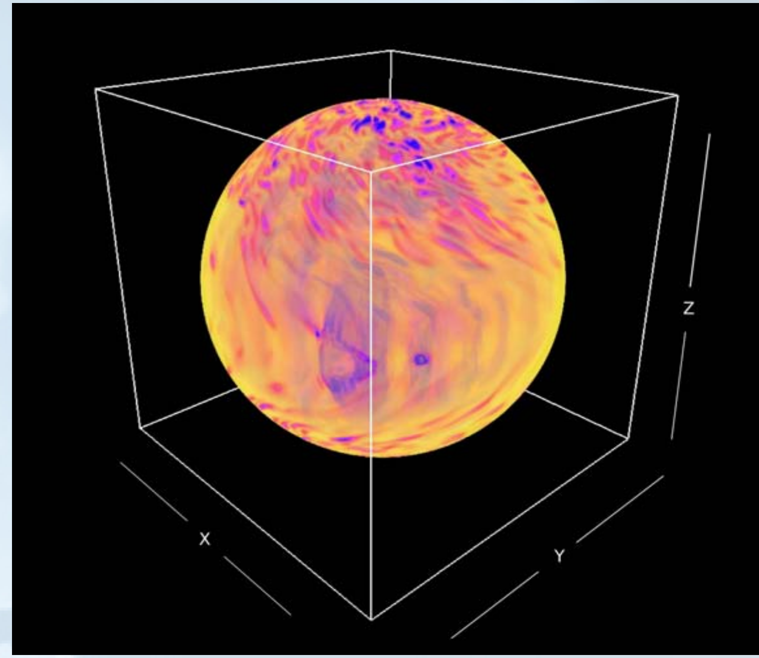
$$\phi = \arctan\left(\frac{y}{x}\right)$$

Spherical transform performed in fragment shader



Spherical Volume Rendering





Good News:

+ >Thirty-fold decrease in memory and storage demands
+ No re-sampling artifacts

Not so Good News:

- Non-interactive frame rates (on a GeForce FX6800)

  128x64x24 < 6fps

  512x256x97 < 2fps

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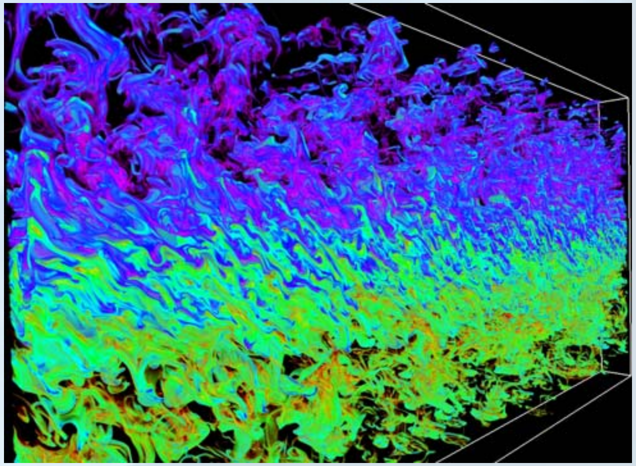
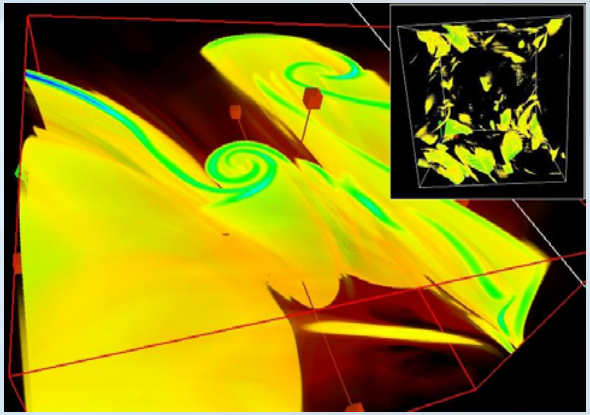
VAPOR demo (using a laptop)

Illustrates new rendering capabilities, plus interactive terascale visualization

- Isosurface rendering
- Spherical rendering
- Mixing in seawater caused by turbulence and convection (Bill Smyth, Satoshi Kimura)
- A ‘current roll’ in a multi-terabyte MHD dataset (Pablo Mininni)
- Animation of magnetic layer instability in solar MHD simulation (Nic Brummel, Geoff Vasil)





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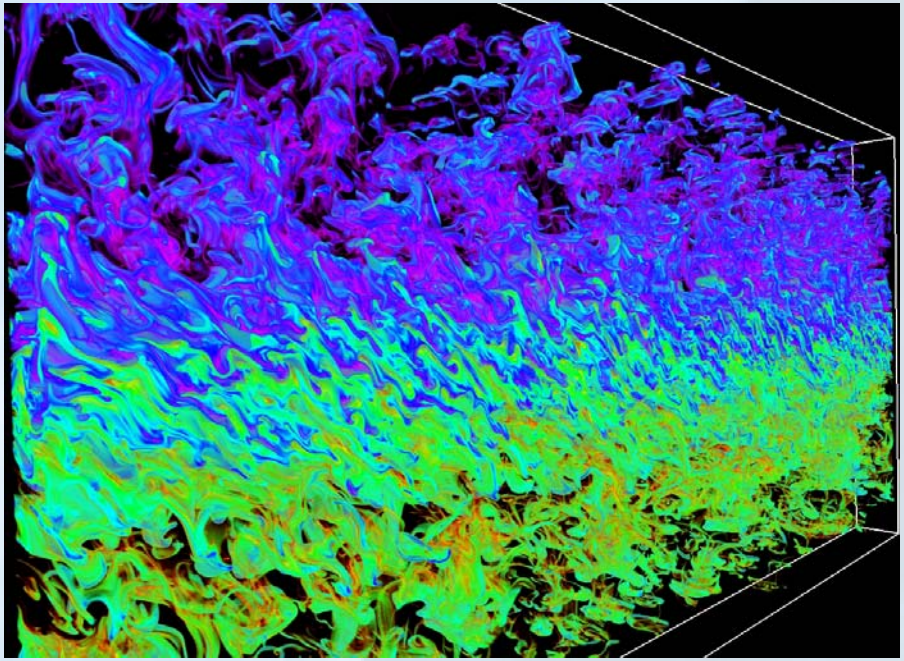
Mixing in seawater
Resulting from turbulence and convection

NCAR

(Bill Smyth, Satoshi Kimura, Oregon St. Univ.)

- 3000x6000x140 simulation performed in 2007 (BTS program)
- Double-diffusive convective instability resulting from simulation of moving layer of lower density (fresh) water mixing with higher density (salt) water
- First direct simulation of turbulence with salinity in seawater
- Animation produced using VAPOR

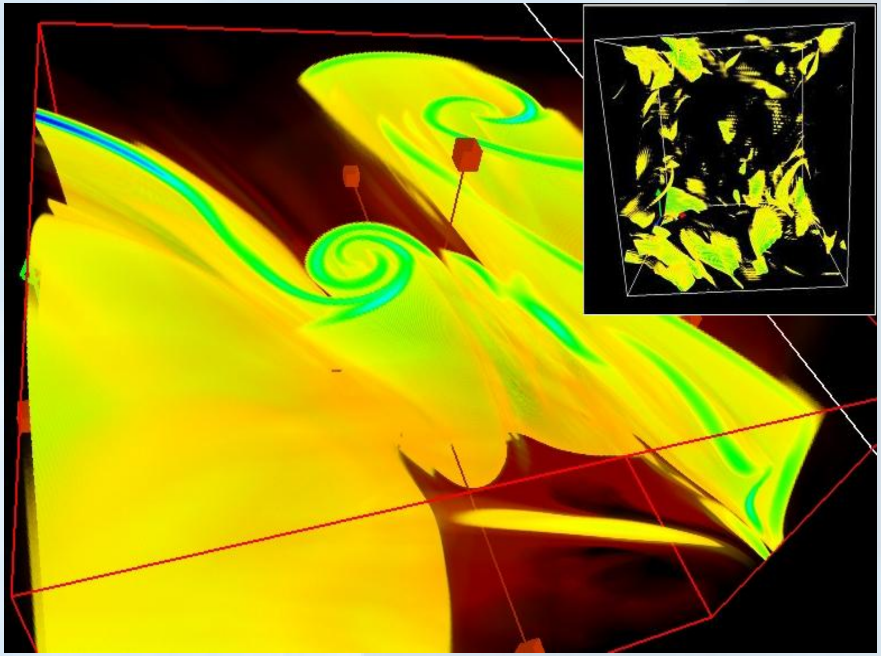


Small scale structures in MHD turbulence with high Reynolds number

NCAR

(Pablo Mininni, NCAR)

- 1536x1536x1536 volume, 16 variables (216 GB per timestep)
- Scientific goal: understand MHD flow dynamics at high resolution and high Reynolds no.
- Analysis and visualization performed with VAPOR and IDL
- Resulted in discovery of intertwining current sheets (“current rolls”)



Simulation of Solar MHD

(Nic Brummell, Geoff Vasil, Lab for Computational Dynamics, Univ. of Colo.)

- Methodology: Finite-difference in vertical, periodic pseudo-spectral in horizontal; time-step full MHD PDEs.
- Machinery: parallel supercomputers (e.g. Datastar: IBM SP @ SDSC)
- Resolution: order of $512^3 - 1024^3$
- Animated in VAPOR (can now be performed over Teragrid)

Movie of magnetic layer creation and instability

(G. Vasil, N. Brummel, U. of CO)

VAPOR Availability

- Version 1.1 software released in March 2007
- Version 1.2 available soon (October 2007?)
- Runs on Linux, Irix, Windows, Mac
- System requirements:
  - a modern (nVidia or ATI) graphics card (available for about $200)
  - ~1GB of memory
- Software dependencies
  - IDL® http://www.ittvis.com/ (only for interactive analysis)
- Executables, documentation available (free!) at http://www.vapor.ucar.edu/
- Contact: vapor@ucar.edu
- Source code, feature requests, etc. at http://sourceforge.net/projects/vapor

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