Interactive 3D Visualization Techniques using VAPOR

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Tutorial Overview

Purpose : Understand how to incorporate interactive 3D visualization into understanding of simulation results

Utilizing **VAPOR** (A visualization and analysis package developed at NCAR):

On completion: You will be able to:

- Convert data for VAPOR visualization
- Use multiresolution for interactive navigation in massive datasets.
- Edit transfer functions to identify important features in volume rendering of data
- Construct flow visualizations using streamlines and image-based flow.
- Place flow seed points based on features in data.

Supporting software and data

- Installed on Longhorn
  - VAPOR 2.0.2
  - Raw data at: /scratch/01380/anorton/8spot3dRaw
  - Sample Vapor datasets at /scratch/01380/anorton
- On the web:

  Vapor website is http://www.vapor.ucar.edu where you can get:
  - Installers
  - Documentation and Tutorials
  - Example data
  - Image Gallery

VAPOR project overview

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- **VAPOR** is the **V**isualization and **A**nalysis **P**latform for **O**ceanic, atmospheric and solar **R**esearch
- **Goal**: Enable scientists to *interactively* analyze and visualize turbulence datasets resulting from numerical simulation
  - Initially supported uniformly gridded turbulence data
  - Expanded to support WRF-ARW and AMR data
- VAPOR is a collaboration between scientists and computer scientists:
  - A steering committee of scientists helps prioritize capabilities
  - Applying current visualization research to advance earth science research
- VAPOR is funded by NSF, relies on research efforts at NCAR, UC Davis, and Ohio State University
- VAPOR is free, open source, many resources available at http://www.vapor.ucar.edu

Tutorial Outline

- Data preparation process (command-line tools)
- Set up a visualization session in VAPOR of a hydrodynamics data set.
- Render an isosurface, navigate in the 3D scene
- *Volume rendering*: Identify and analyze vortices
  - Build a *Transfer Function* (color/opacity map)
- *Flow integration*
  - *Streamlines:* track fluid motion
- *Derived variables:* Use Python to derive new variables
  - Use derived variable visualization to position flow seeds
- Visualize a large dataset using VAPOR's *multi-resolution (wavelet)* representation
  - Navigate through an MHD dataset, identifying a roll-up of a current sheet
  - Position magnetic field lines associated with the current roll

Preparing data for VAPOR visualization

Two command-line utilities needed before you visualize your data; *this conversion has already been done for this tutorial*

- **`vdfcreate [options] vaporfile.vdf`**
  - Constructs a metadata file that describes the dataset
  - Options include:
    - -dimension XDIMxYDIMxZDIM (grid sizes)
    - -extents minx:miny:minz:maxx:maxy:maxz (user coordinate extents)
    - -vars3d a:b:c:d …. (names of 3d variables)
    - -numts N (number of time-steps)
    - -level L (number of multiresolution refinement levels)
  - Writes a metadata file “vaporfile.vdf” describing the entire Vapor Data Collection to be created from the data
- **`raw2vdf [options] vaporfile.vdf rawfile`**
  - Converts one timestep of one variable into the VAPOR VDC

To save time, the data used in this tutorial has already been converted, available at /scratch/01380/anorton/

Data preparation exercise

This exercise shows how to prepare to run VAPOR. Then we illustrate the use of `vdfcreate` and `raw2vdf`.

- `vdfcreate` will create a vapor metadata file (file of type .vdf) that describes your dataset.
- `raw2vdf` is used to convert raw data files into the VAPOR multiresolution data format.
- `ncdf2vdf` (not used here) can be used to convert NetCDF data files

Open a shell on Longhorn in your VNC session.

In that shell issue the command:

```
module add vapor
```

Data preparation exercise

To use `vdfcreate` and `raw2vdf`:

Change directory to your $SCRATCH directory

Create a vapor metadata file ‘`vaporfile.vdf`’ with following command (all in one line):

```
vdfcreate -dimension 512x512x255
     -extents 0:0:0:1:1:0.5
     -vars3d ru:rv:rw:ro
     -numts 30
     -level 3
     vapordata.vdf
```

Convert the raw files from the directory /scratch/01380/anorton/8spot3dRaw/ into your VAPOR data collection with the command:

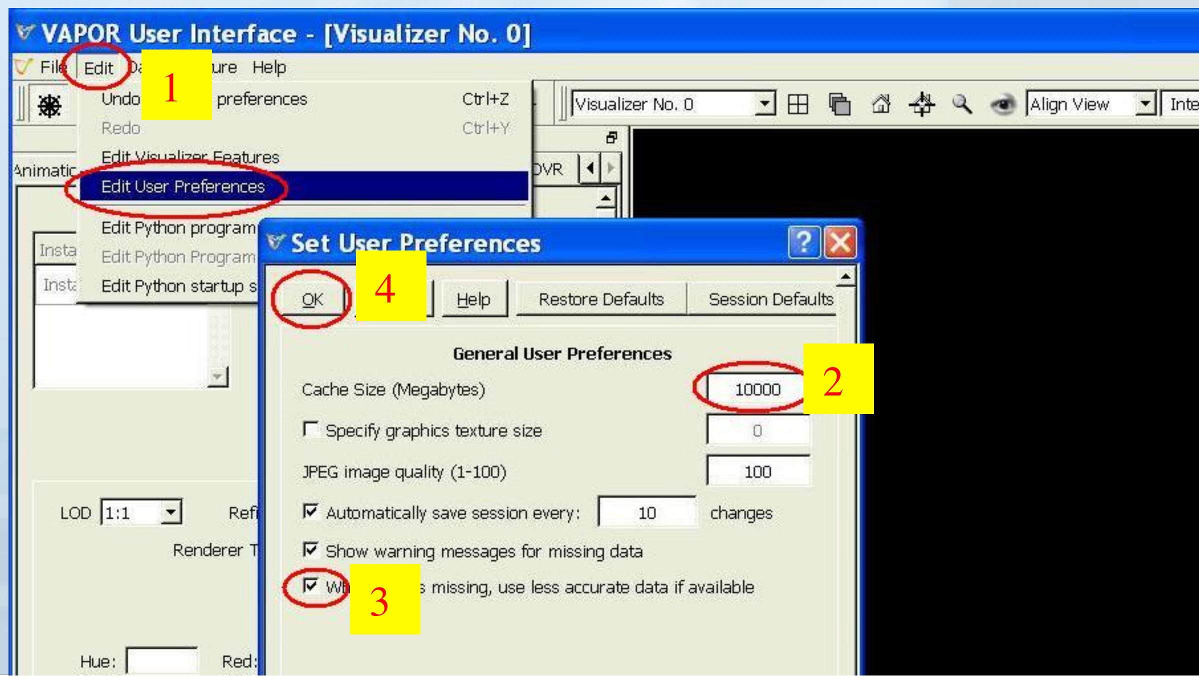
`raw2vdf -varname` ***`ru`*** **`-ts 0 vapordata.vdf wrfout* /scratch/01380/anorton/8spot3dRaw/`*****`ru`*****`.0.raw`**

Then reissue this command with ***ru*** replaced by ***rv***, ***rw***, and ***ro***

Set-up to visualize a dataset

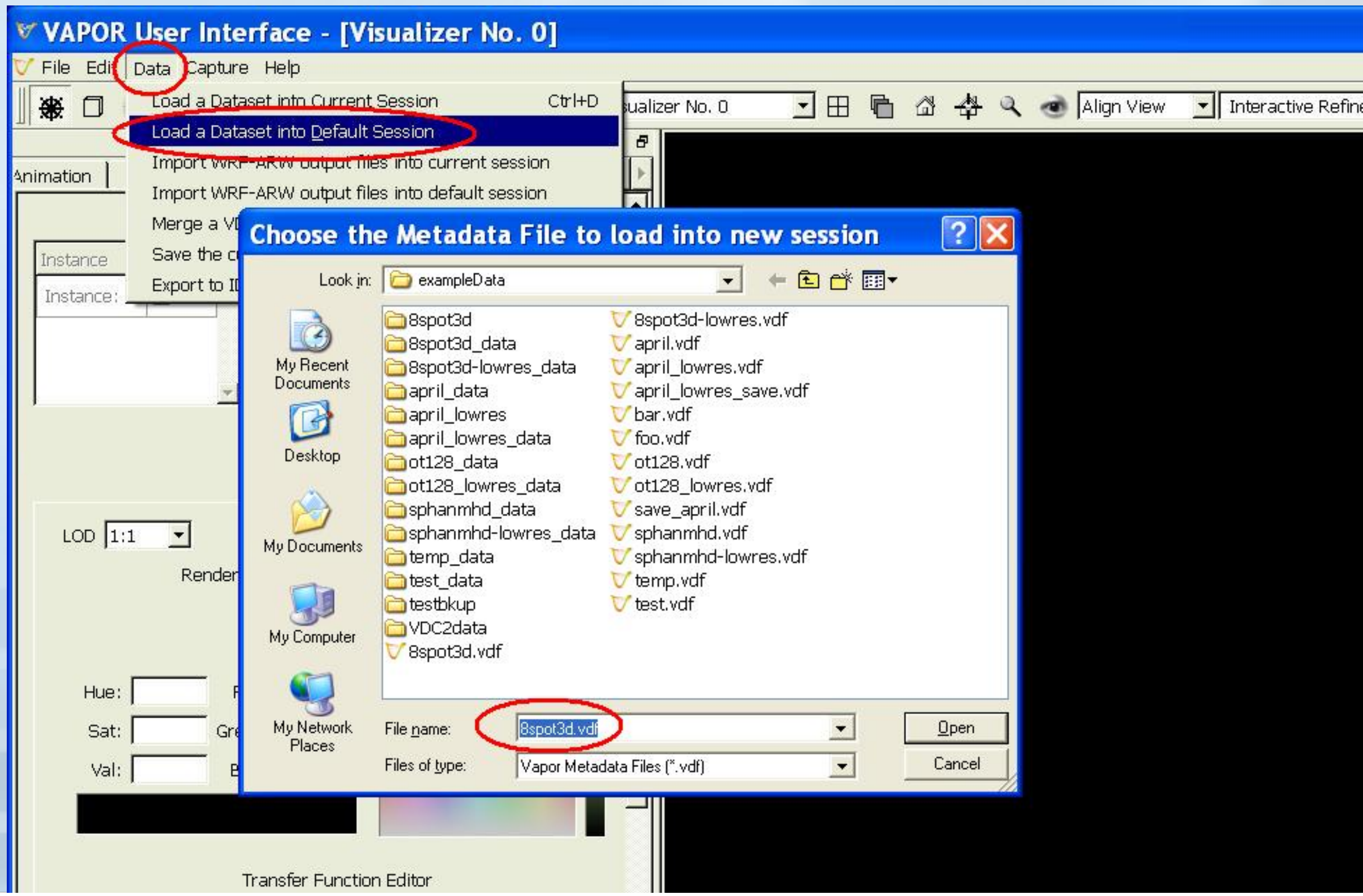
- Use a command shell wherein '**`module add vapor`**' was issued
- Launch VAPOR user interface with

  `vglrun vaporgui`
- Set up preferences from Edit menu:
  1. Edit➔Edit User Preferences
  2. Set cache size to 10000 MB
  3. Check "When data is missing, use lower refinement if available"
  4. click "OK", save preferences to default location



Load a vapor dataset (.vdf file)

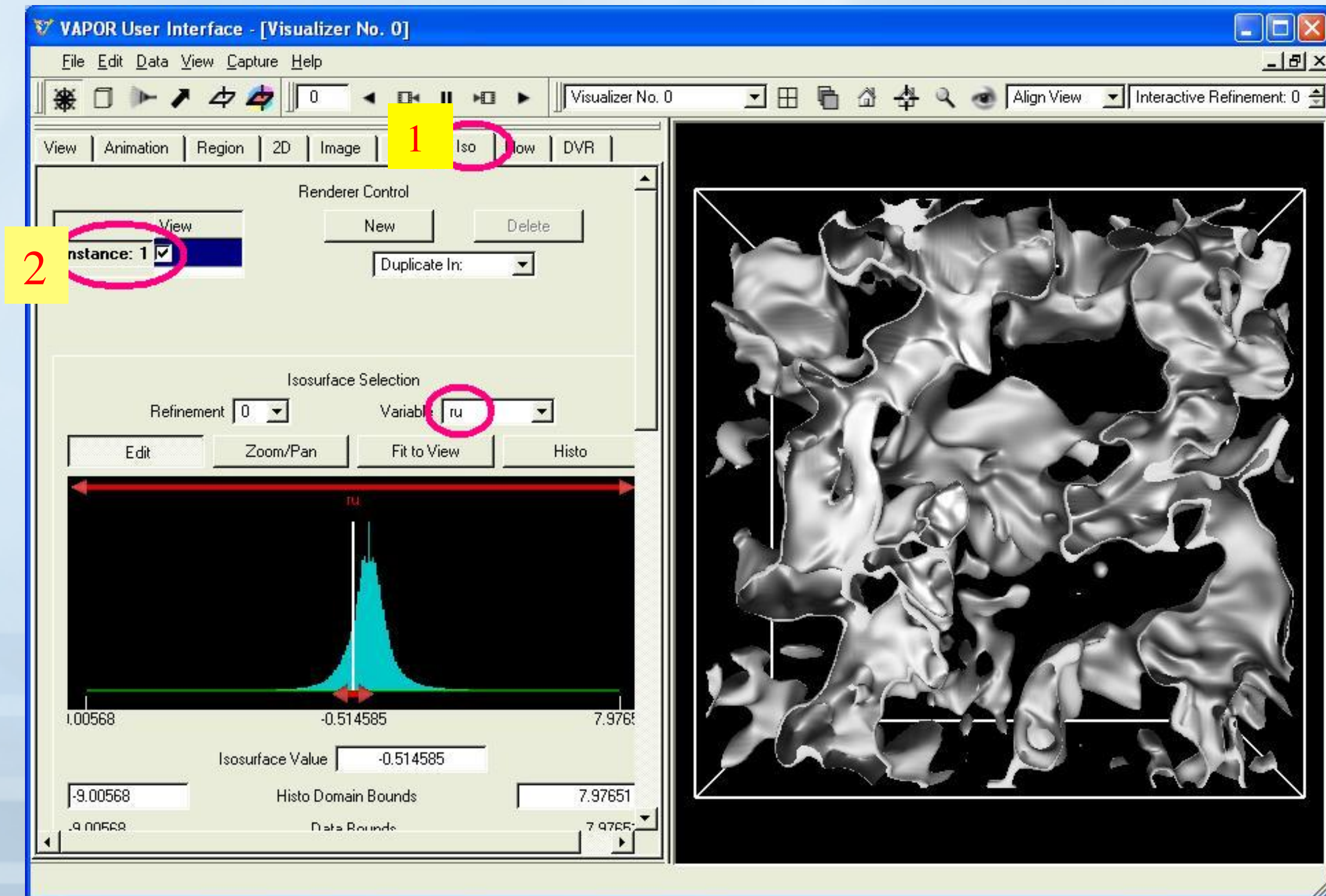
- From Data menu:
  - Load a Dataset into Default Session:
- select 8spot3d.vdf from /scratch/01380/anorton/



Render an isosurface

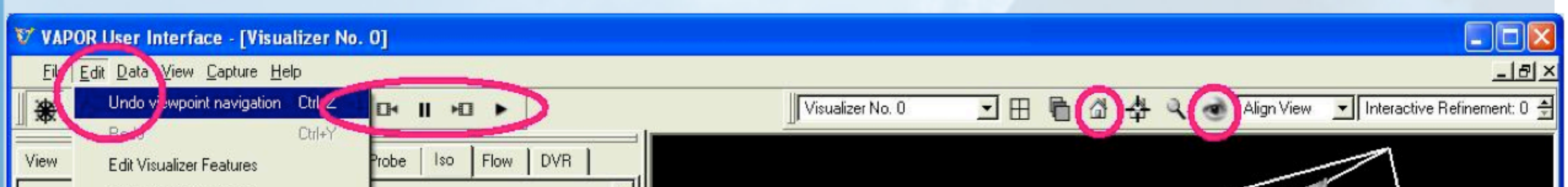
You are now prepared to visualize the dataset.

1. Click Iso tab;
2. Check the “Instance:1” checkbox to enable rendering of an isosurface of ru.

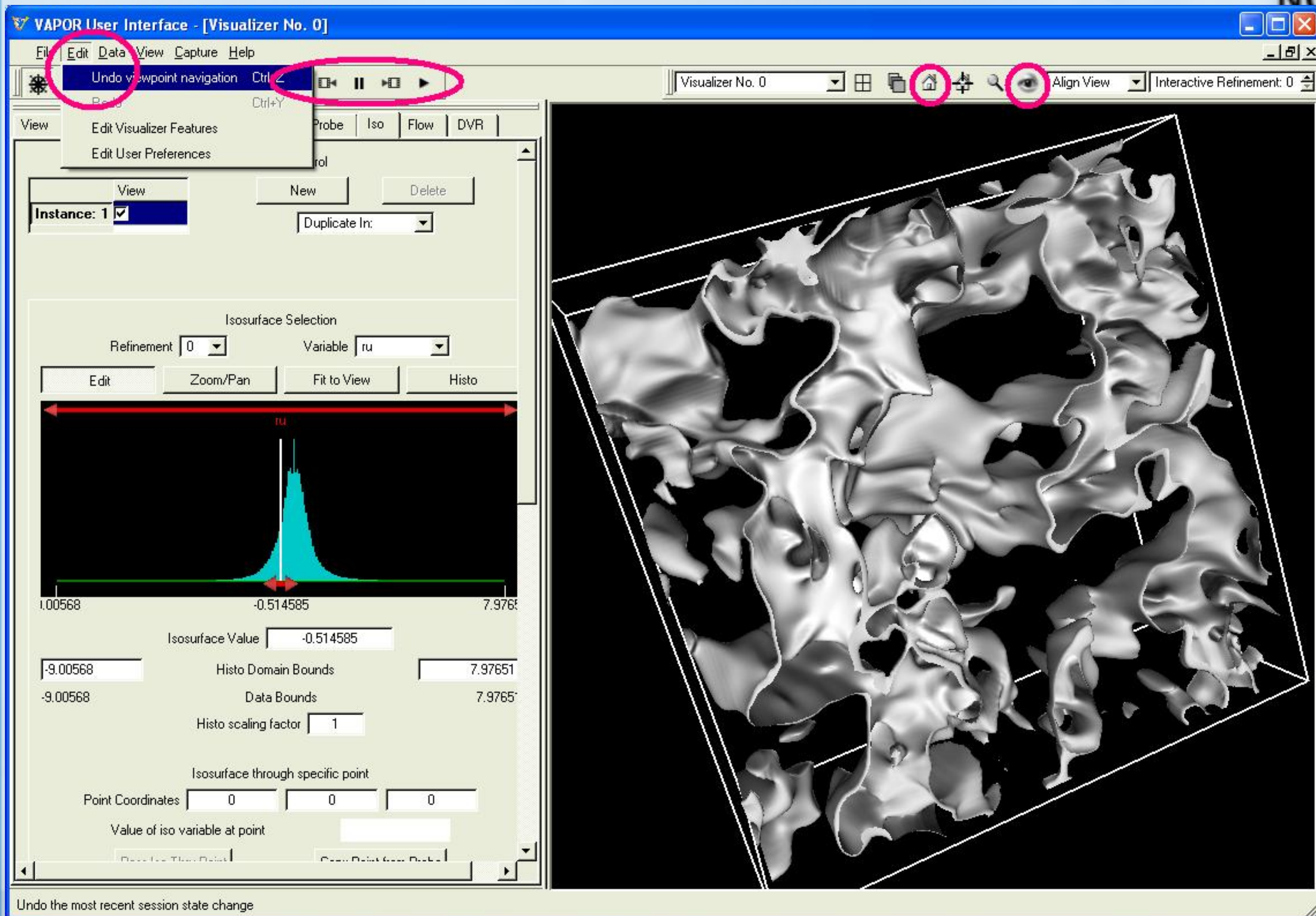


Ways to Navigate in the 3D Scene

- To navigate: rotate, zoom, translate by dragging in the scene with left, right and middle mouse buttons respectively.
- Click “Home” icon ( ) to return to starting viewpoint
- Click “Eye” icon ( ) to see full domain
- Use Edit→Undo if you make a mistake
- Use the VCR controls at the top left of the window to animate through time



Navigation with an isosurface of *ru*



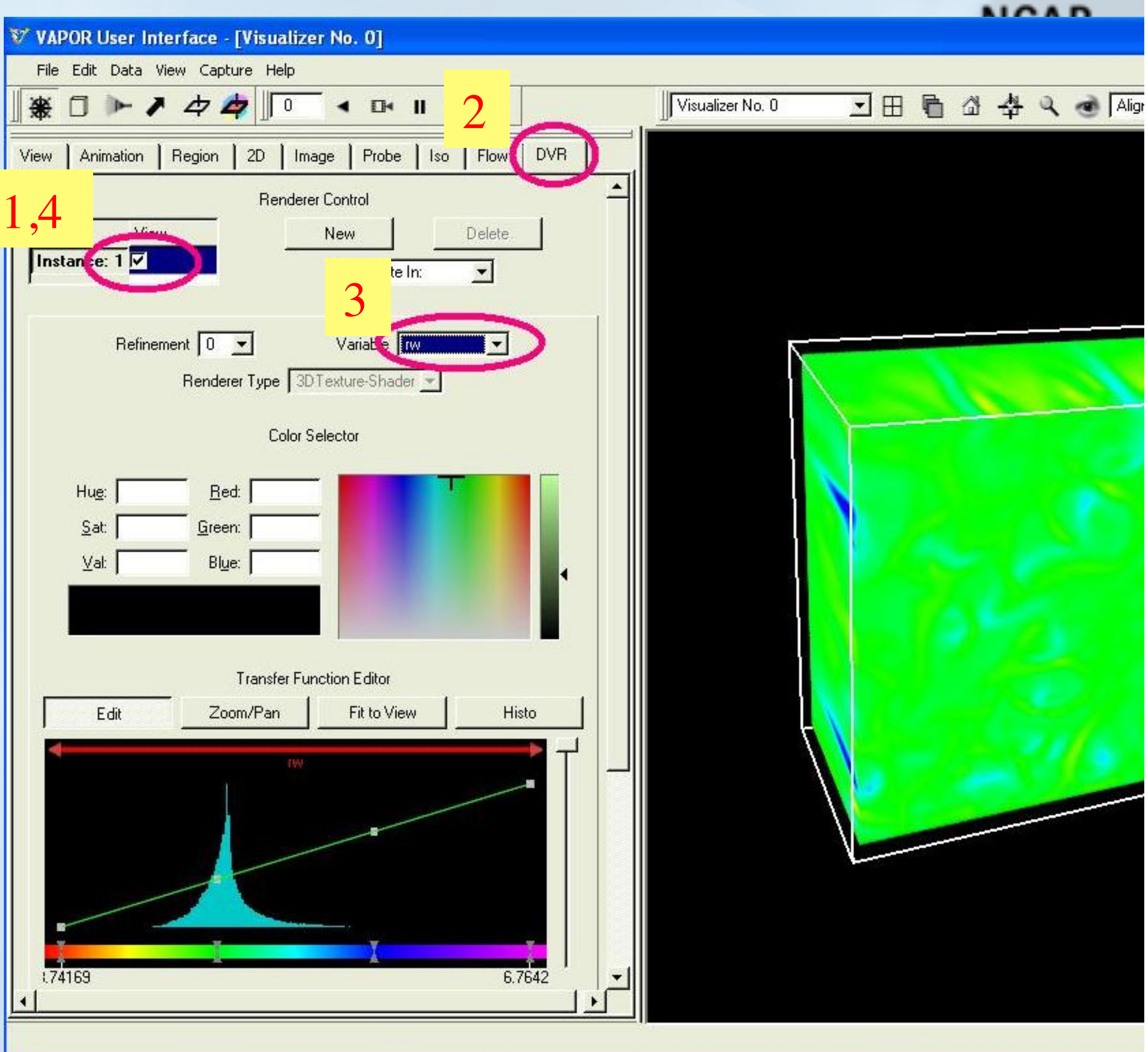
Volume Visualization of vertical momentum (rw)

1. Disable the isosurface (un-check the Instance: 1 checkbox)

2. Select DVR panel (direct volume rendering)

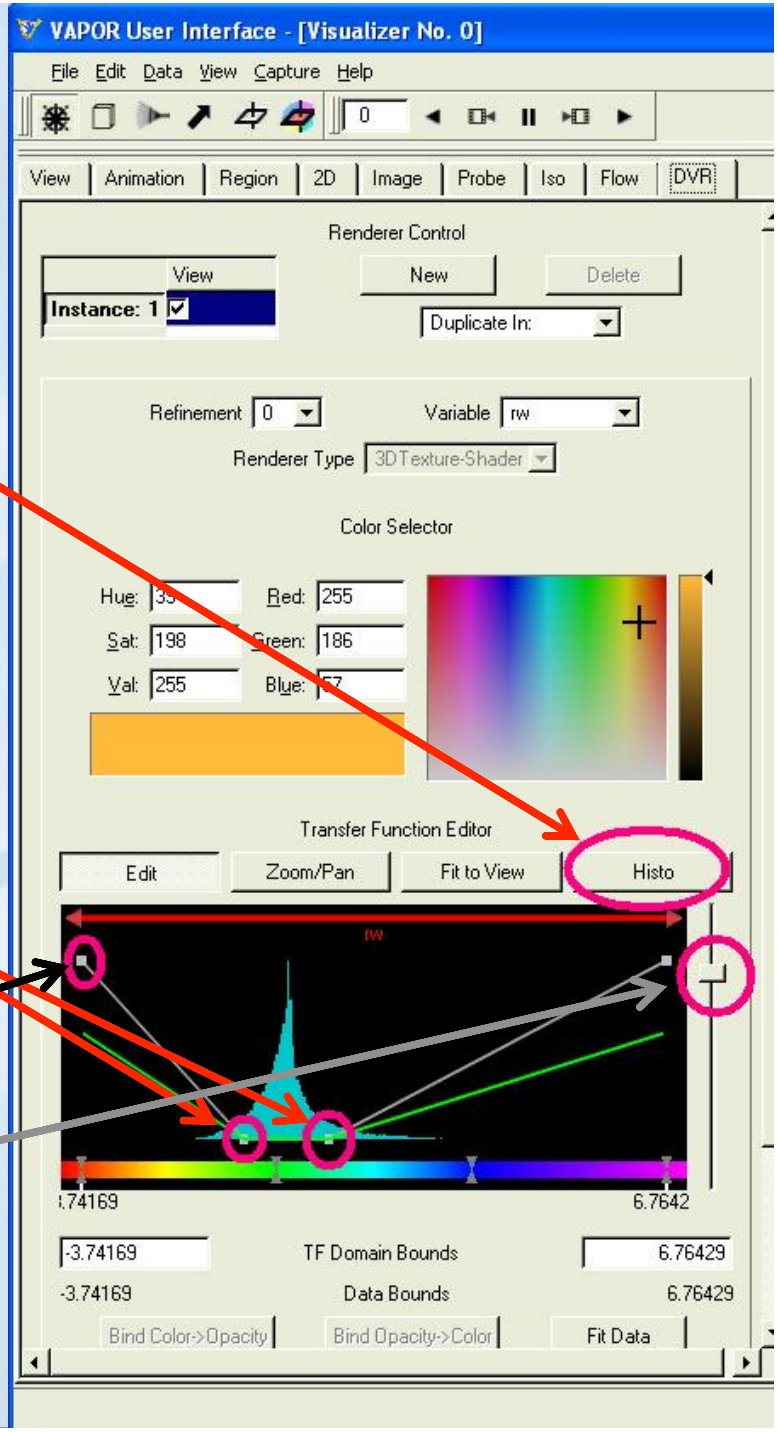
3. Select variable "rw" (vertical momentum)

4. Check "Instance:1" to enable volume rendering



Volume Visualization: Edit Transfer function (1)

- Click "Histo" to see histogram of data values of rw at current timestep
- Objective: Show the largest and smallest values of rw, hide the intermediate values
- To edit transparency:
  - Drag two opacity control points to position on left and right sides of histogram peak, move down to set to opacity 0
  - Make opacity=1 at largest and smallest values of rw.
- Control overall transparency with the vertical slider on the right



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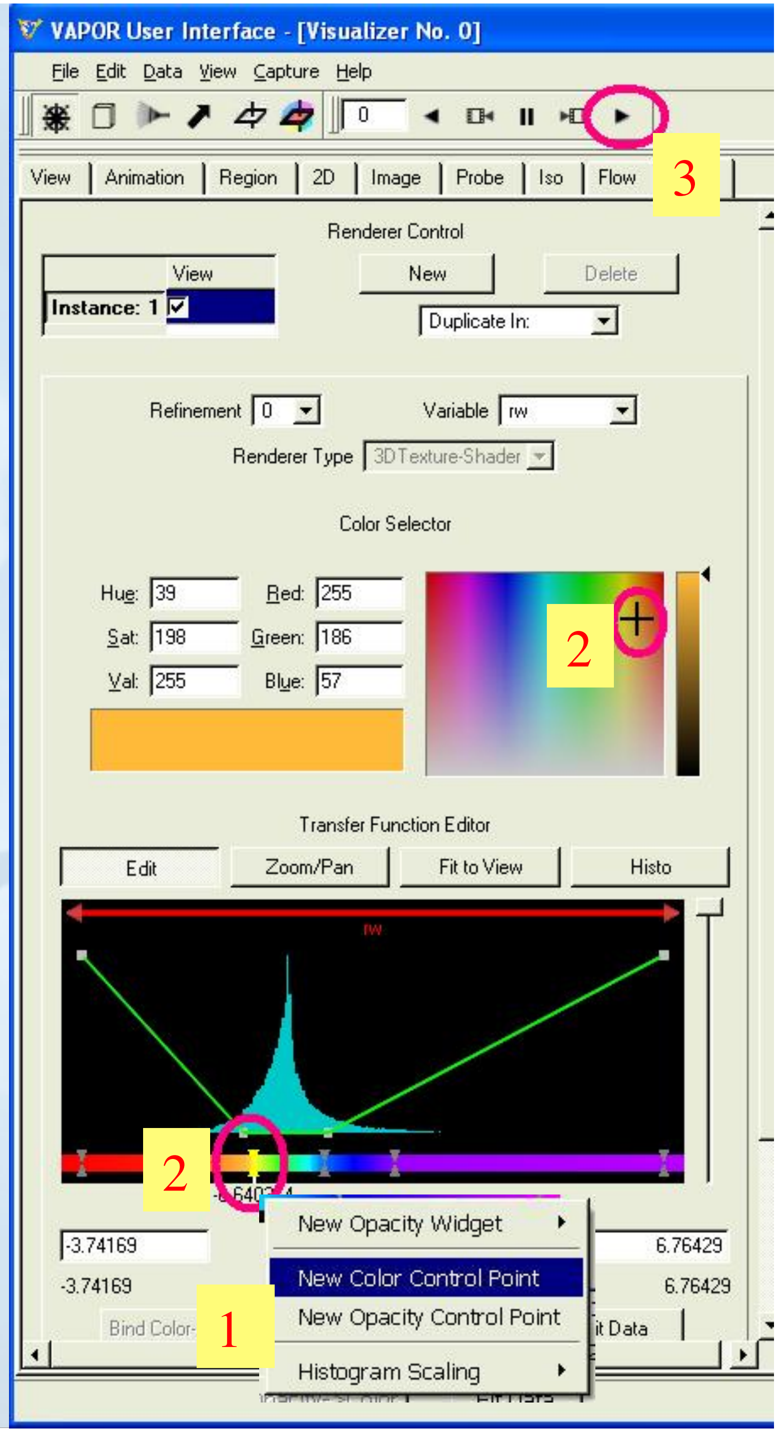
Volume Visualization: Edit Transfer function (2)

1. Add or delete control points with right mouse menu over transfer function editor.
2. To edit the color, select a color control point and then click on the desired value in the color selector.
   - Make the color blue to violet for upward motion (rw>0)
   - Make the color orange to red for downward motion (rw<0)
3. Click the play button "►" to animate the fluid motion



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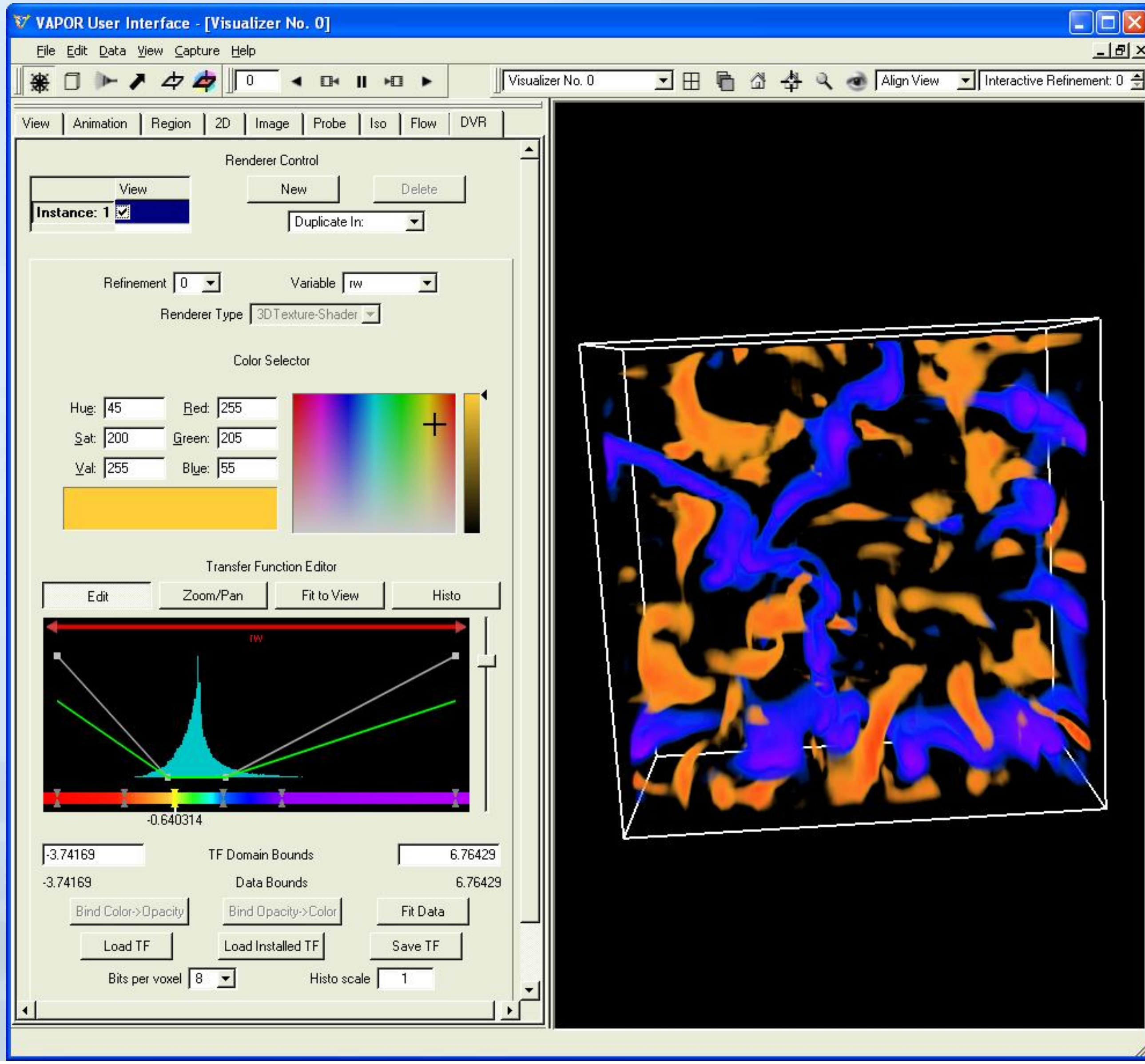
Using a transfer function to identify upward and downward fluid motion



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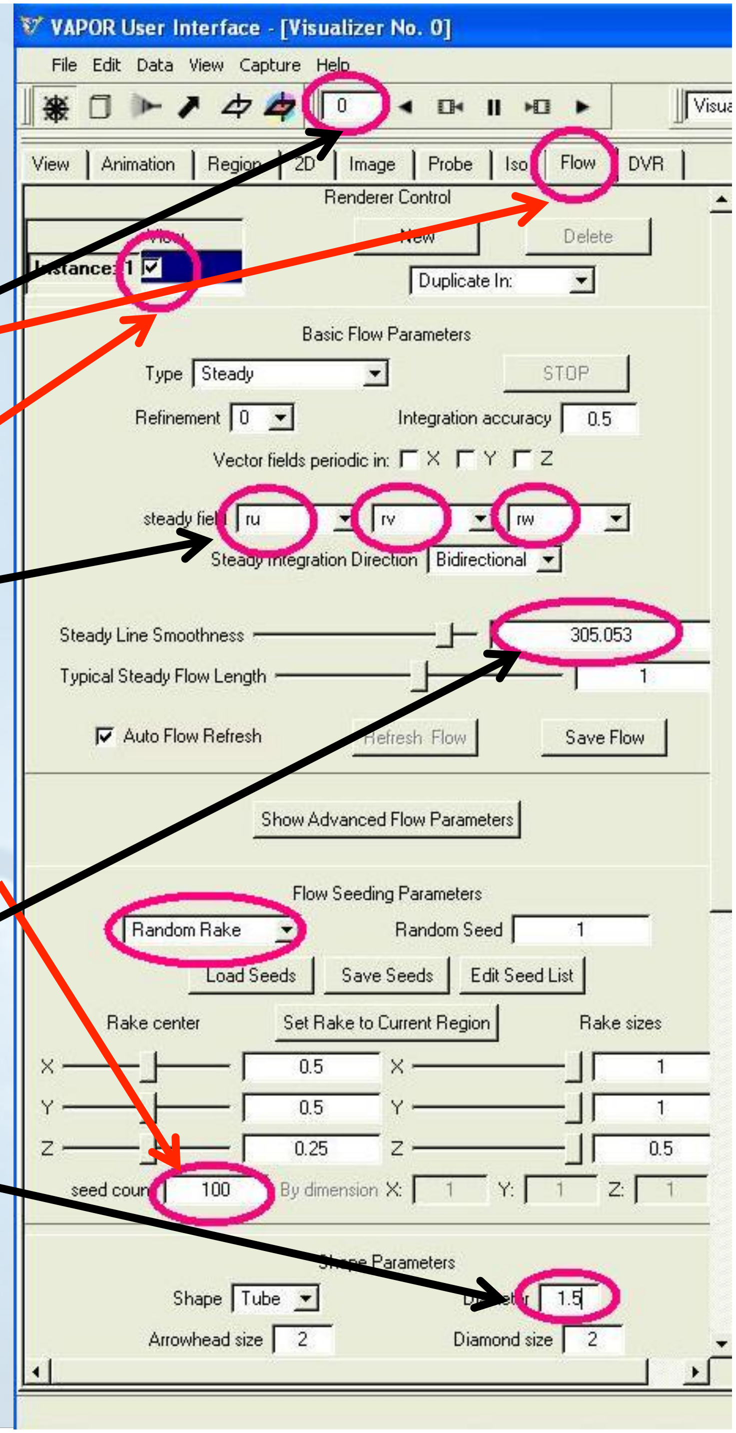
VAPOR Visualization & Analysis Platform

Flow Visualization Overview

- Vapor can display streamlines (***steady*** flow, constant time) and pathlines (***unsteady*** flow, showing particle paths over time)
- Flow can be illustrated in cross-section using the ***flow image*** capability in the Probe tab.
- Streamlines and path lines are established by ***seed points*** (starting points for flow integration)
- Seed points can be:
  - ***Random***: Randomly placed within a range of x, y, and z values, or
  - ***Nonrandom***: Evenly spaced in x, y, and z dimensions, or
  - ***Seed List***: Explicitly placed in the scene
- Vapor ***Rake*** tool is provided to specify a box for random or evenly spaced (nonrandom) seeds (looks like: )
- VAPOR ***Probe*** tool () can be used to position flow seed points.

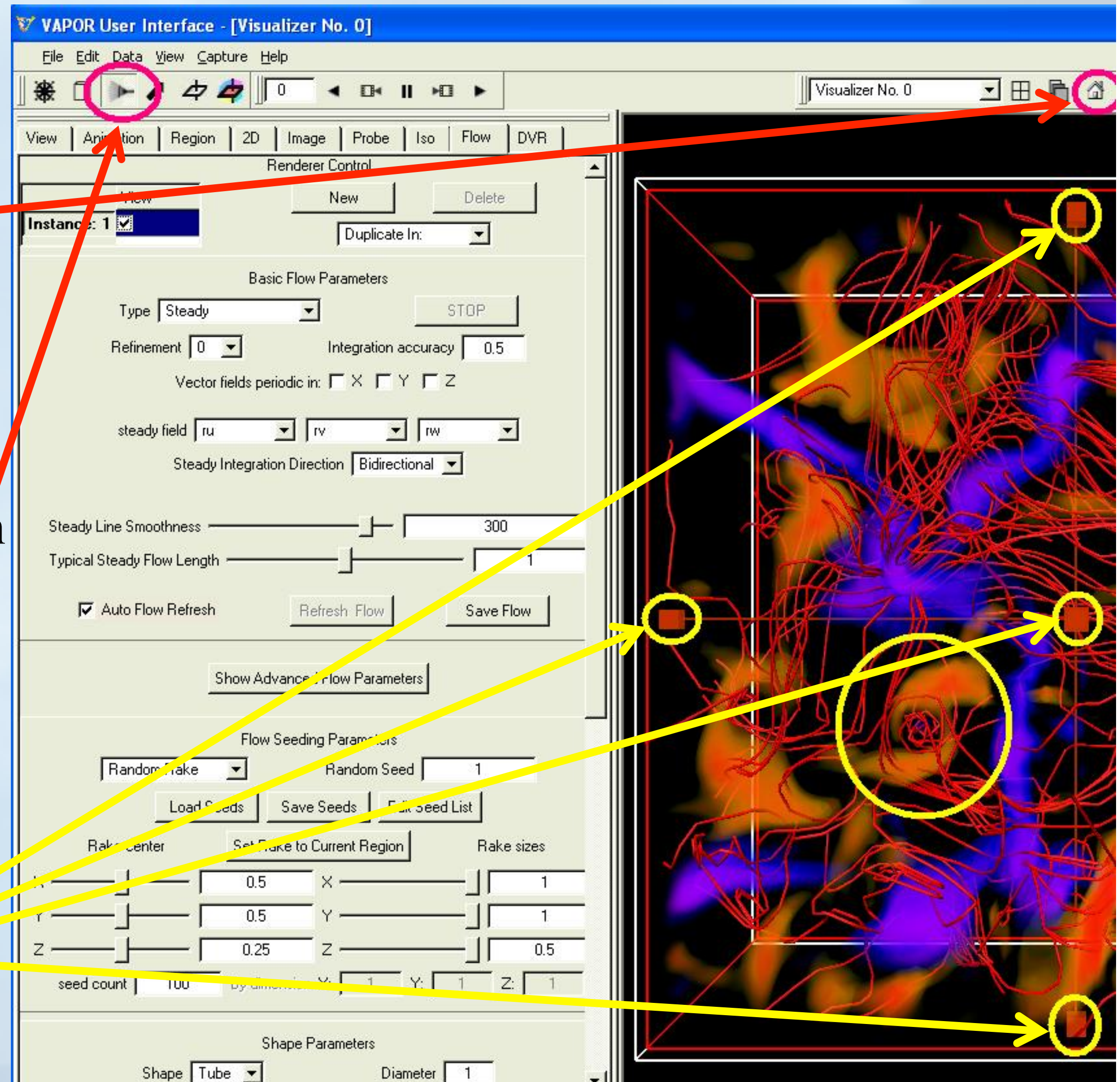
Random streamlines using the Rake

- Disable DVR (un-check Instance:1 box)
- Click on Flow tab
- Set time step to 0
- In flow tab, select ru, rv, rw as steady field variables.
- Check “Instance: 1” to enable steady flow (streamlines).
- Specify seed count 100 (random) for steady flow
- Adjust smoothness (~300) and diameter (~1.5)



Position seed points with the rake

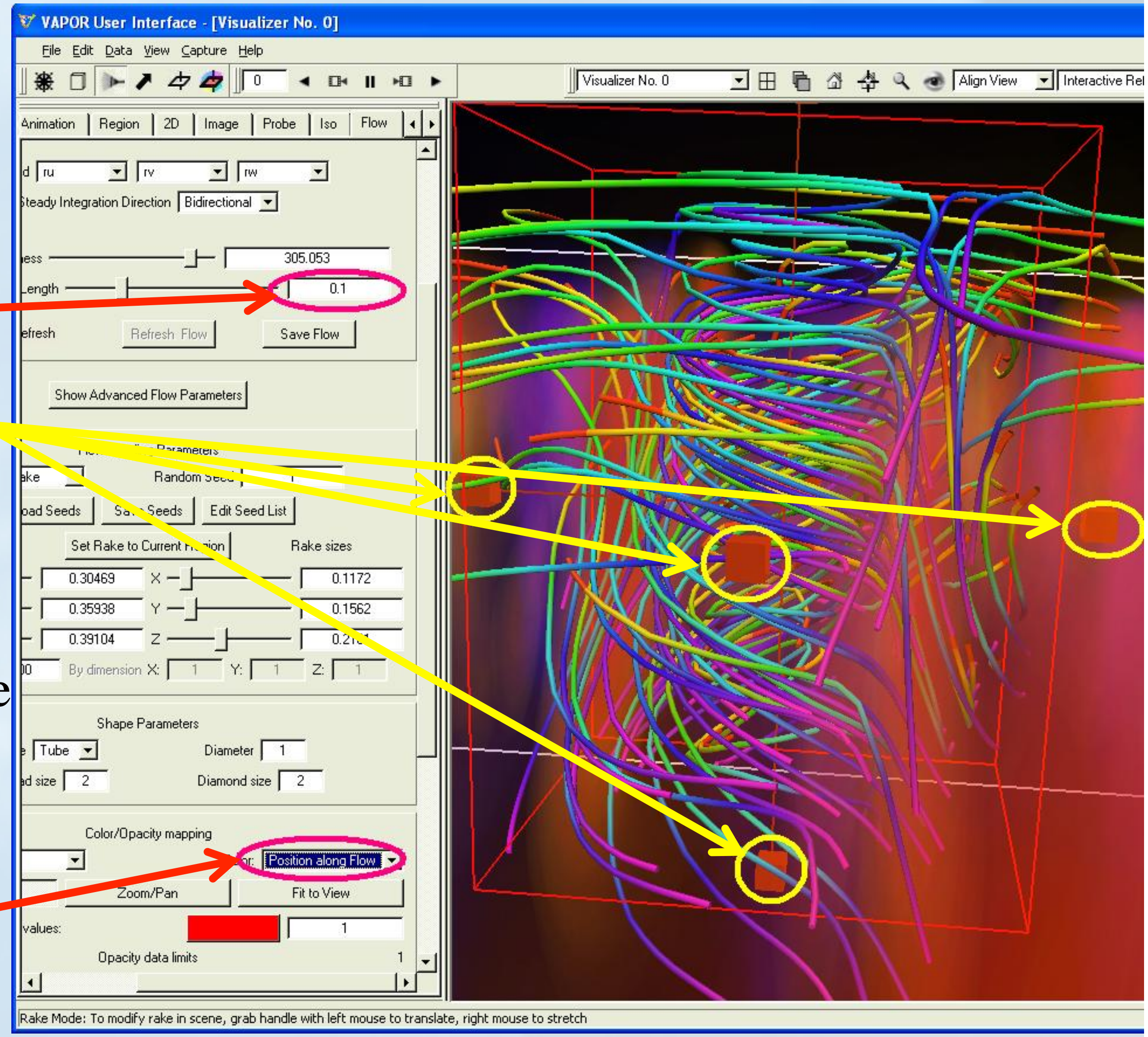
- Enable the DVR again (check Instance:1 in DVR panel)
- View it from the bottom (home viewpoint).
  Note that there appears to be a vortex in the lower-left quarter of the volume. We shall concentrate the streamlines in that region to visualize the vortex.
- Click on rake button ( ) at top left, above the tabs . Note that the red rake-box has red cube-handles on each face.



Isolating a vortex with the rake

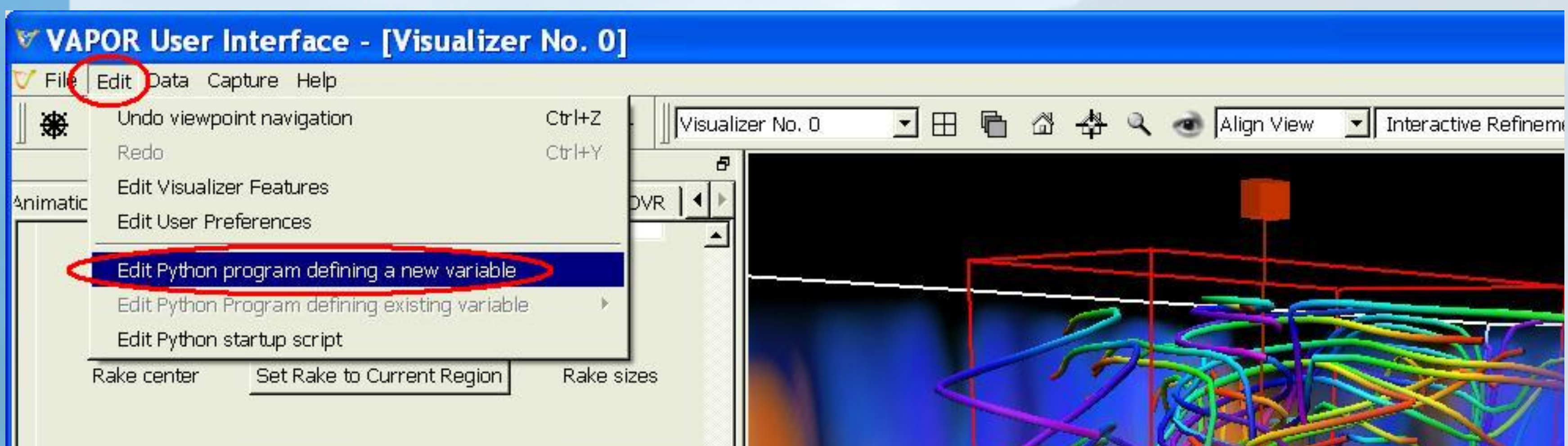
We will position the rake in the region around the apparent vortex:

- Set “Steady flow length” to 0.1 (shorten the streamlines)
- Grab the red handles of the rake box with the right mouse, drag them inward to enclose the vortex
- Rotate the scene so that you can shorten the rake in its vertical dimension.
- Color flow lines according to “Position along flow”
- Zoom in closer to the rake



Use Python to derive a new variable

- We next use vorticity to analyze the vortex we found.
- We shall create a derived variable, "vortmag" representing the magnitude of vorticity.
- The vorticity magnitude provides another way of identifying a vortex in the data.
- From Edit menu, select "Edit Python program defining a new variable". This will launch the Python editor.

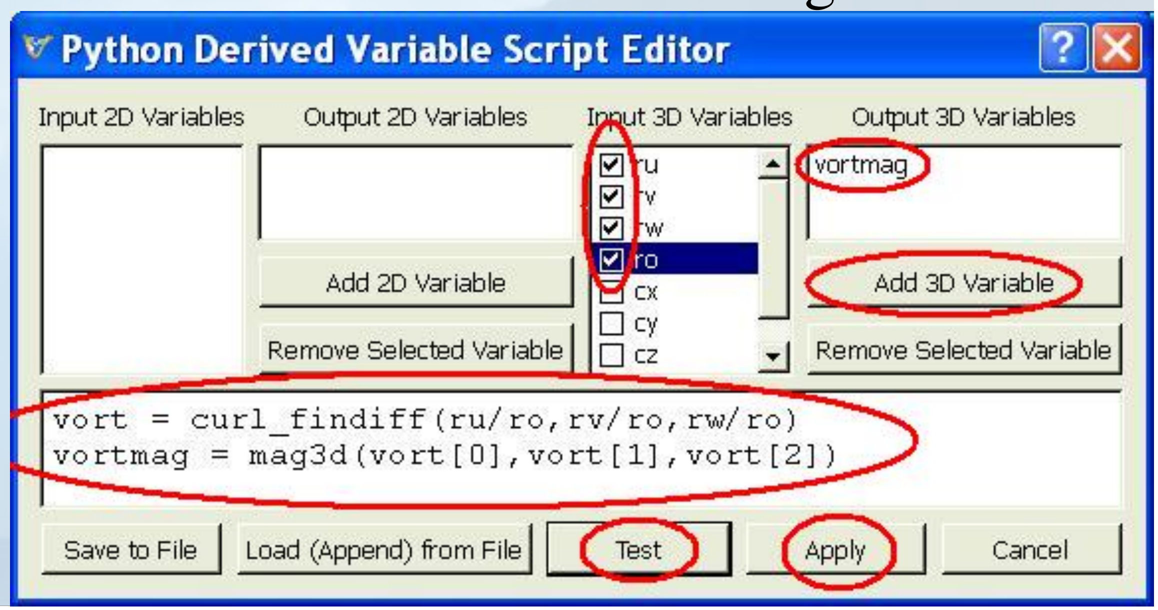


Use Python to derive a new variable

- In the Python Editor, check ru, rv, rw, and ro as Input 3D Variables.
- Click “Add 3D Variable” and specify “vortmag”
- Type in the following 2-line python script:

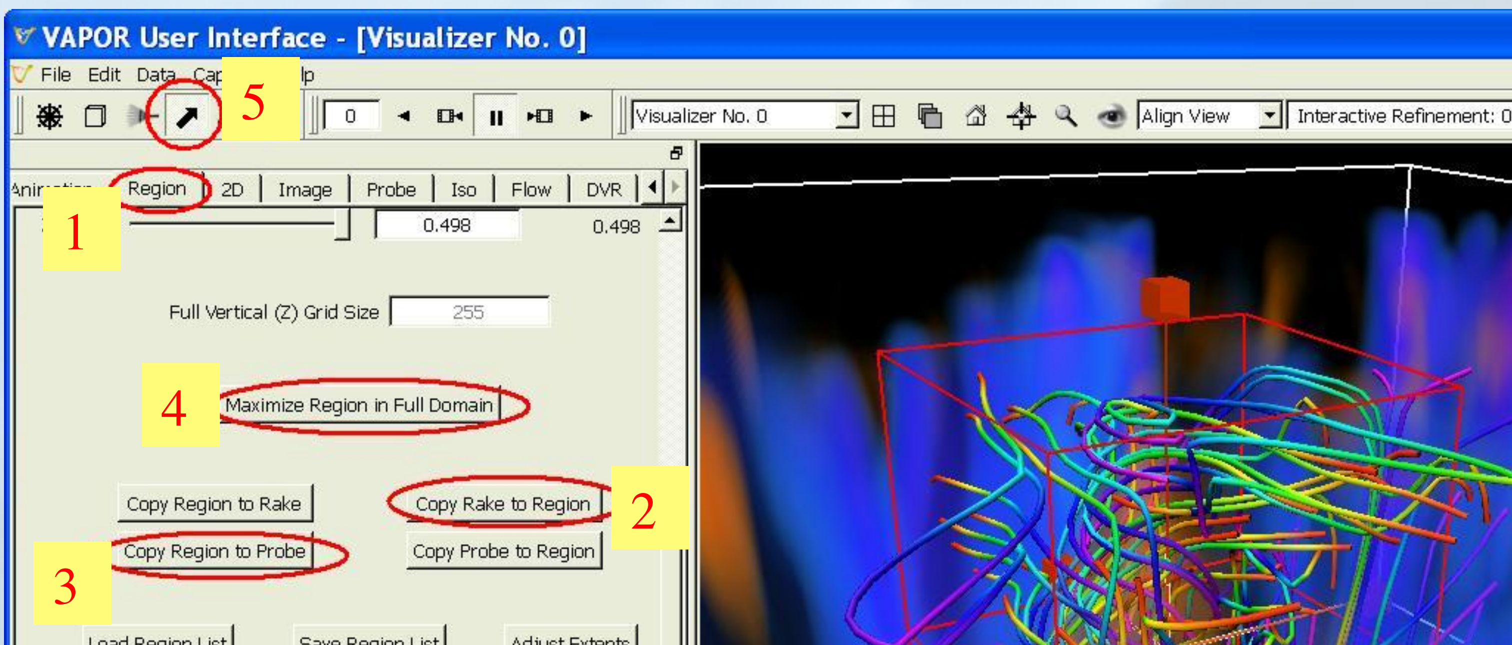
  vort = curl_findiff(ru/ro, rv/ro, rw/ro)

  vortmag = mag3d(vort[0],vort[1],vort[2])
- Click “Test” and make sure there are no error messages
- Click “Apply”



Position the Probe in the middle of the rake

1. Click on the Region tab.
2. In the Region tab, click "Copy Rake to Region"
3. Then click "Copy Region to Probe"
4. Then click "Maximize Region in Full Domain", returning the region to the original (full) extents.
5. Click on the Probe icon ( ) to show the Probe location



Use the Probe to visualize vorticity magnitude

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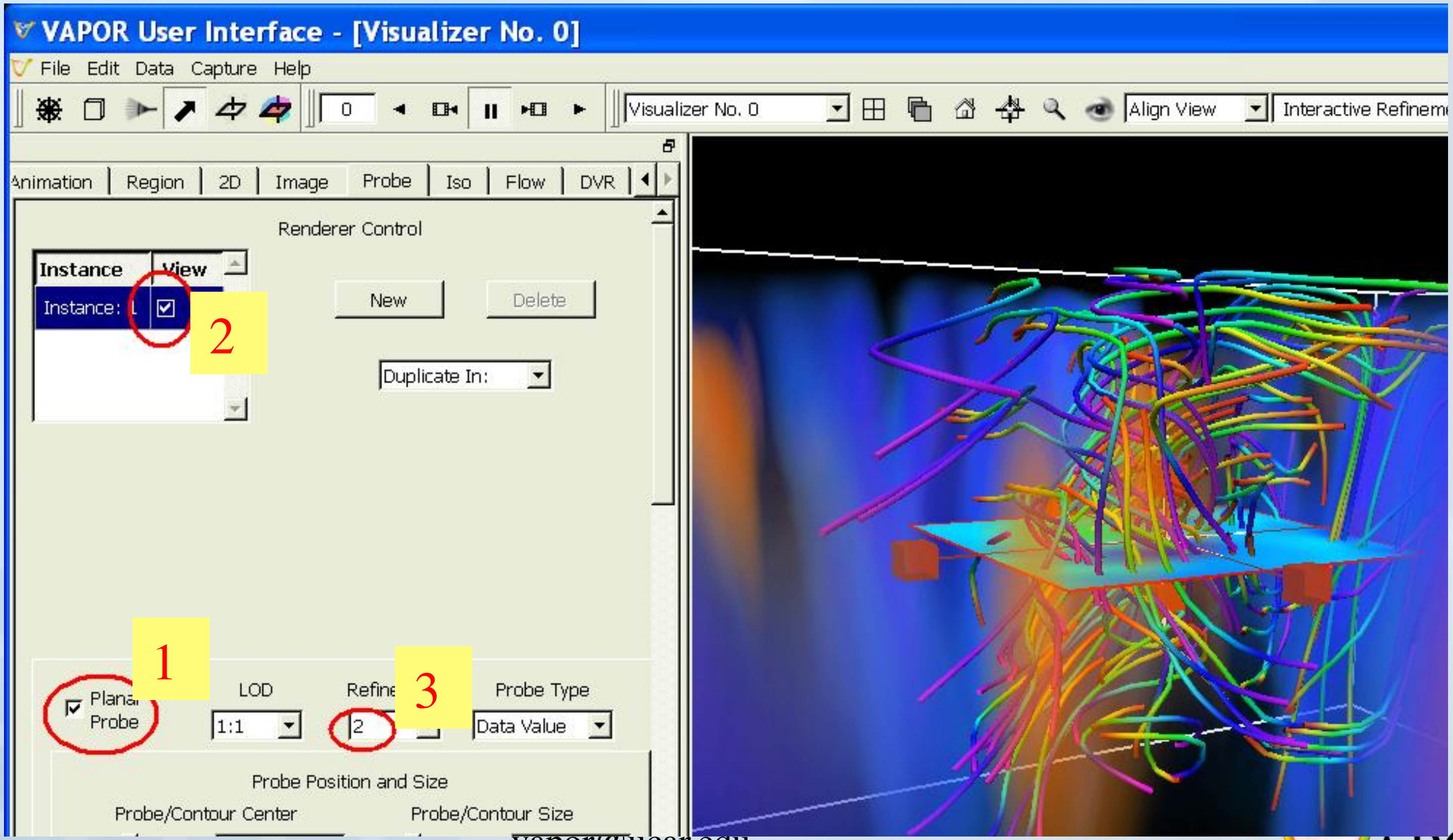
1. In the Probe tab, check the checkbox "planar probe" to make it just a 2D probe.
2. Check the "Instance:1" checkbox to enable the probe.
3. Set the probe refinement level to 2.



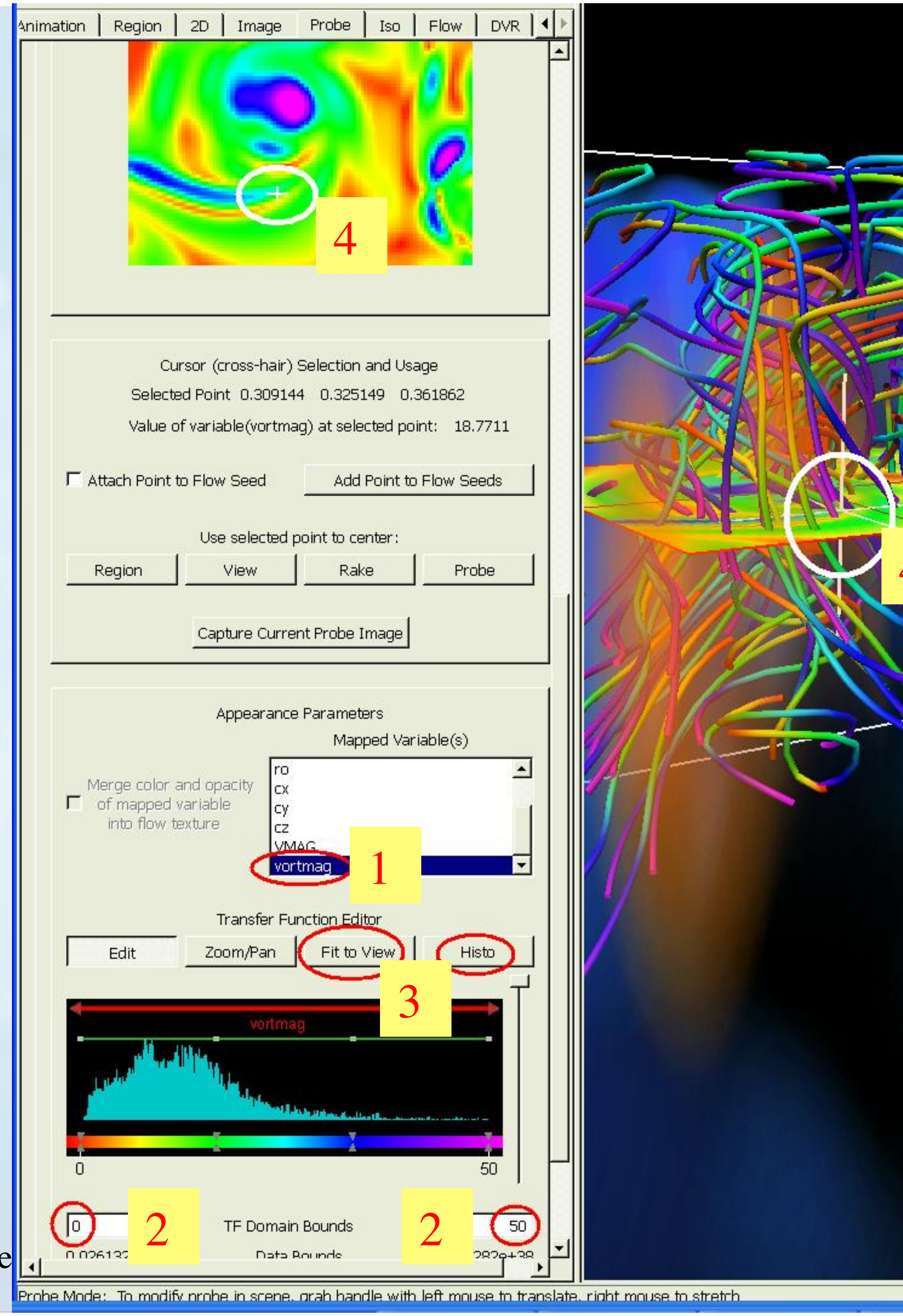
Visualize vorticity magnitude (2)

1. Scroll to the bottom of the Probe tab, select the variable “vortmag”

2. Below the transfer function, set the TF bounds to 0 and 50.

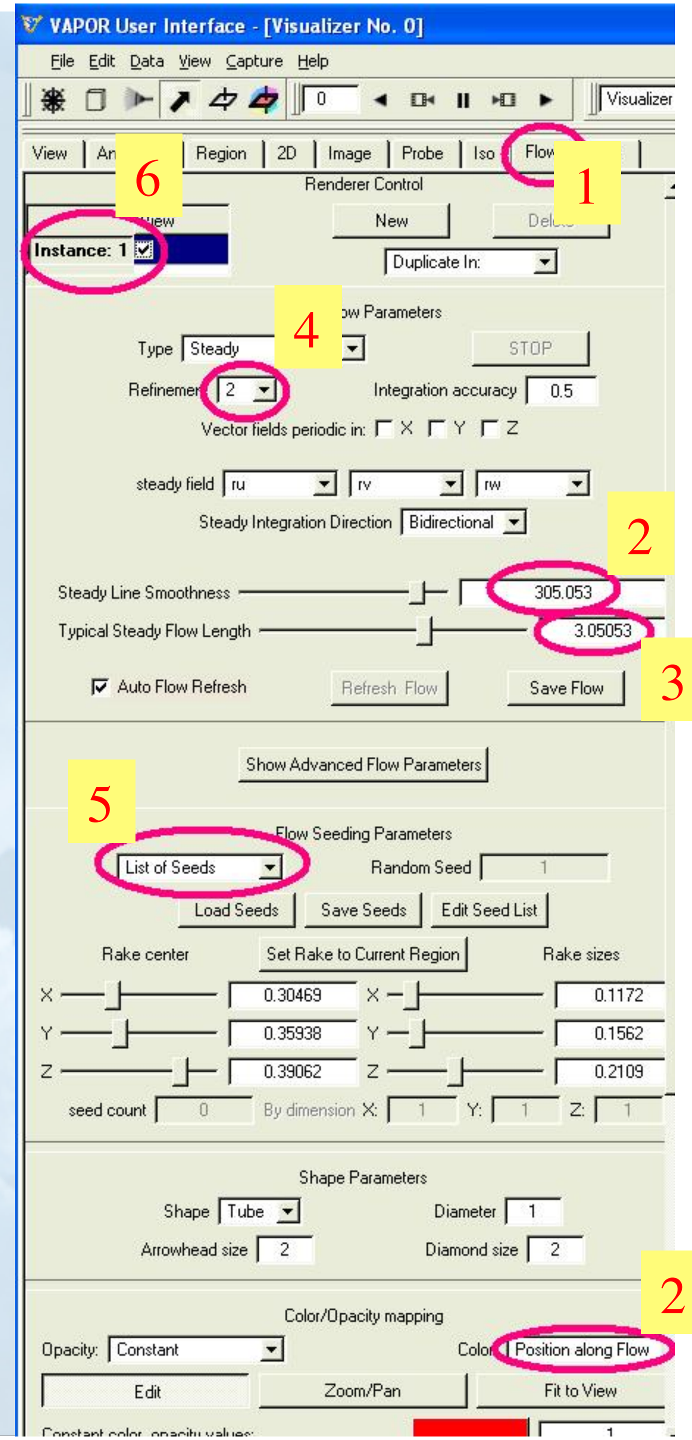
3. Click “Fit to View” and “ Histo” to get a histogram of values of vortmag.

4. Click in the probe image, note how the <u>2D probe cursor</u> controls the <u>3D cursor</u> in the scene



Using the probe to specify flow seed points (1)

1. Click on the Flow tab
2. Set the flow tab with the same settings as before (smoothness = 300, color=position along flow)
3. Set Typical Steady Flow Length = 3
4. Set refinement level to 2
5. On the flow tab, under “flow seeding parameters”, select “List of Seeds” instead of “Random Rake”.
6. Check “Instance:1” to enable the flow. Ignore the warning messages (there are no seeds in the list).



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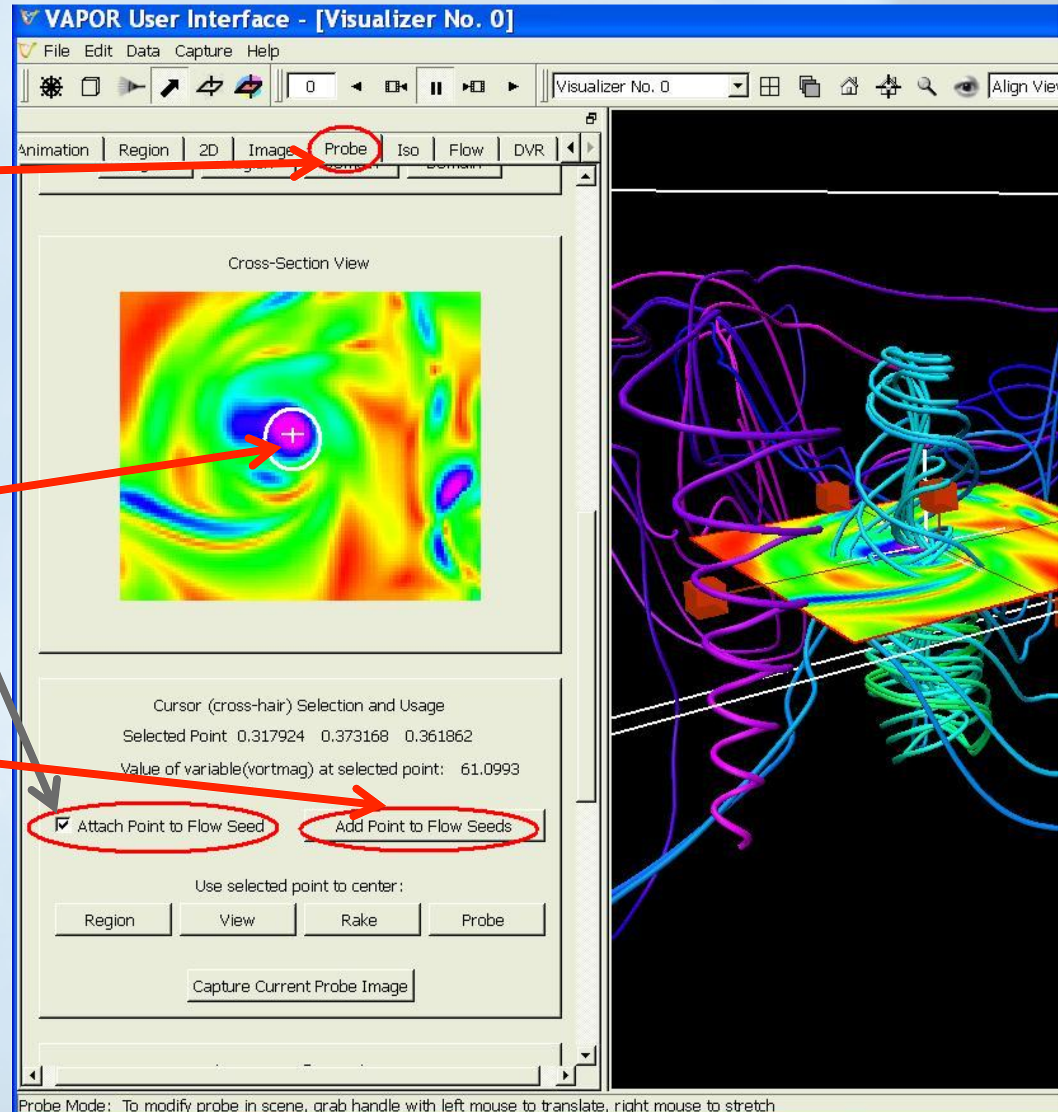
Using the probe to specify flow seed points (2)

- Click on the DVR tab. Disable the DVR.
- Click on the Probe tab
- Below the Cross-section view, click on “Attach point to flow seed”
- Click cursor in image, see various resulting streamlines
- Click “Add point to Flow Seeds” for several points near the vortex center (where the color is purple)



A large, interesting MHD dataset

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- Based on results of P. Mininni, A. Pouquet, D. Montgomery: MHD simulation at high Reynolds Number. Found that current sheets can evolve to tubular structures ("current roll").
- Grid size 1536^3. Time steps infrequently saved. Sample data for one time step (105) is on Longhorn at /scratch/01380/anorton/rnd1536.vdf
- Interesting structures are hard to find, requires interactive browsing of large data volume
- VAPOR multi-resolution approach facilitates browsing in large data, identifying novel structures.

Set up for volume visualization of current magnitude

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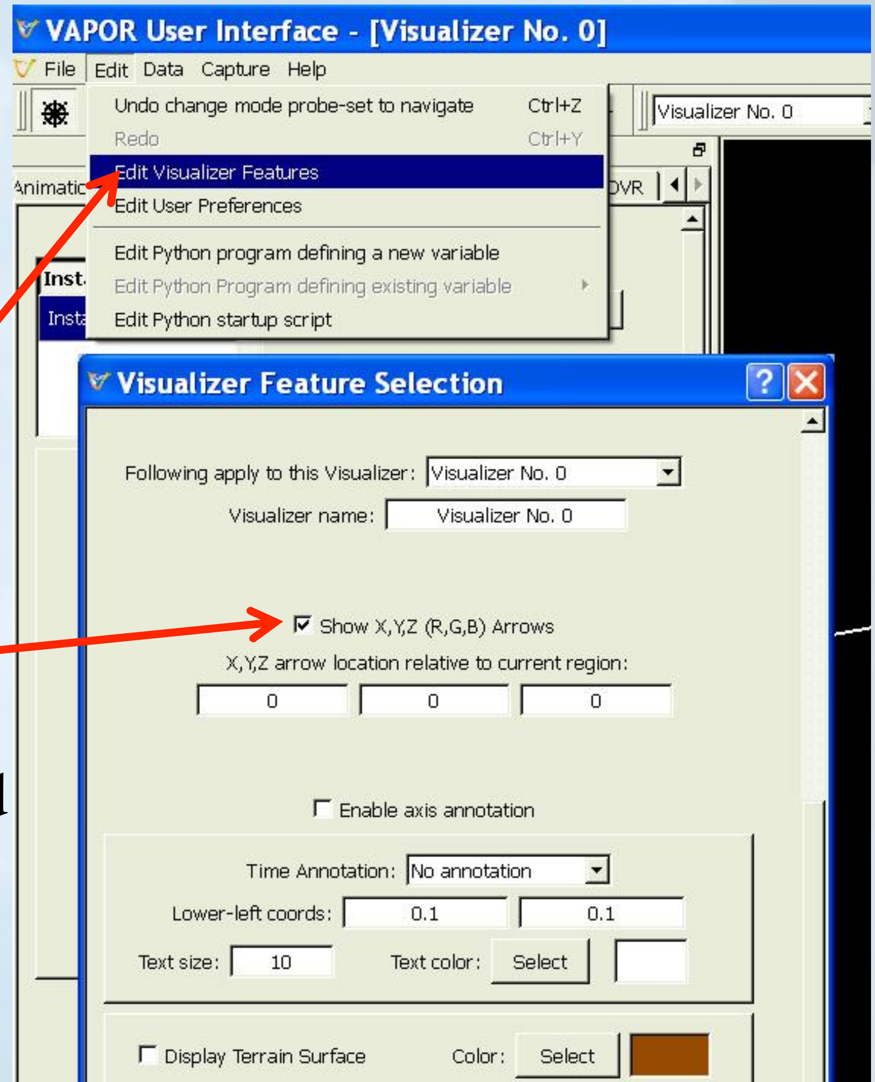
- From your vnc window on Longhorn, issue:
  - **module add vapor**
  - **vglrun vaporgui**
- **Edit → Edit Visualizer Features** to launch visualizer features panel:
  - check "**Show X,Y,Z (R,G,B) Arrows**"; then click "**OK**"
- **Data → Load Data** then load scratch/01380/anorton/rnd1536.vdf



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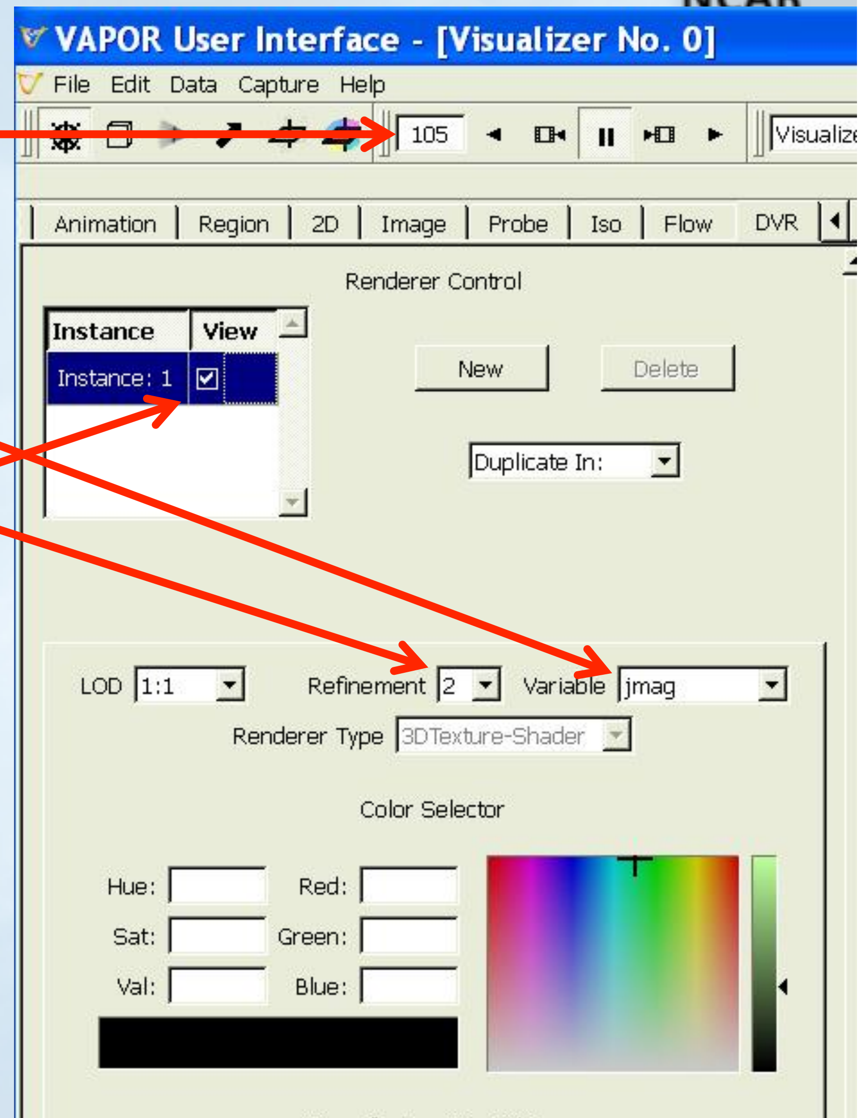
VAPOR Visualization & Analysis Platform

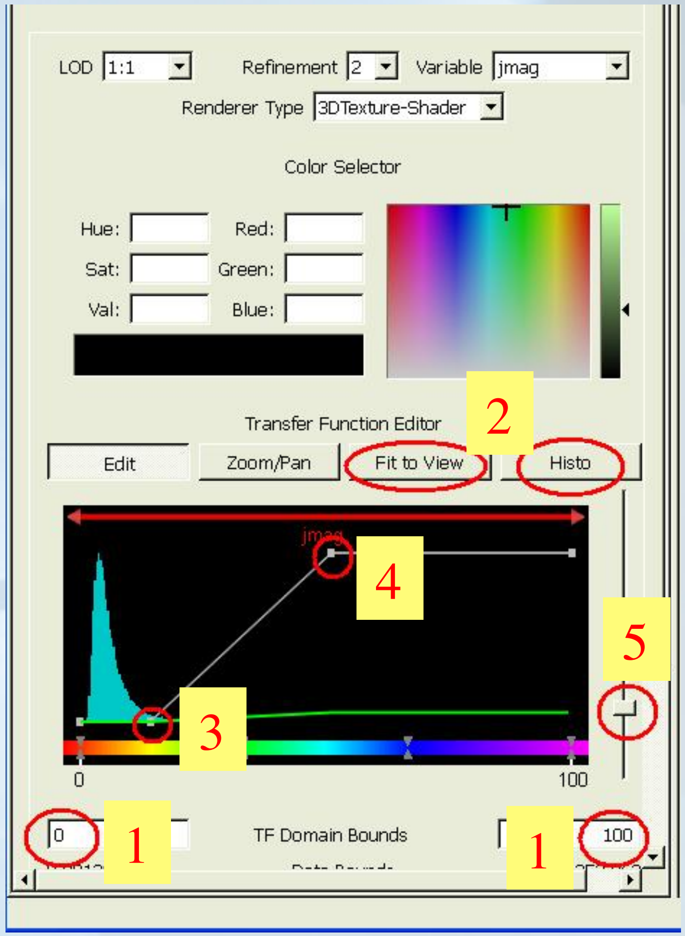
Set up for volume visualization of current magnitude

- Set timestep = 105
- Click DVR panel:
  - Set variable = jmag (current magnitude)
  - Set refinement level 2
  - Enable (check Instance:1 checkbox)



Edit transfer function of current magnitude

- Setup transfer function for jmag, to clearly display the current sheets:
  1. Set TF Domain Bounds to 0, 100
  2. Click “Histo” and “Fit to View” buttons
  3. Drag 2nd opacity control point down to the bottom (opacity 0) at data value about 15
  4. Drag 3rd opacity control point upward (opacity 1) at data value ~50
  5. Slide opacity slider to about 1/5 of the way up, to make current sheets fairly translucent.



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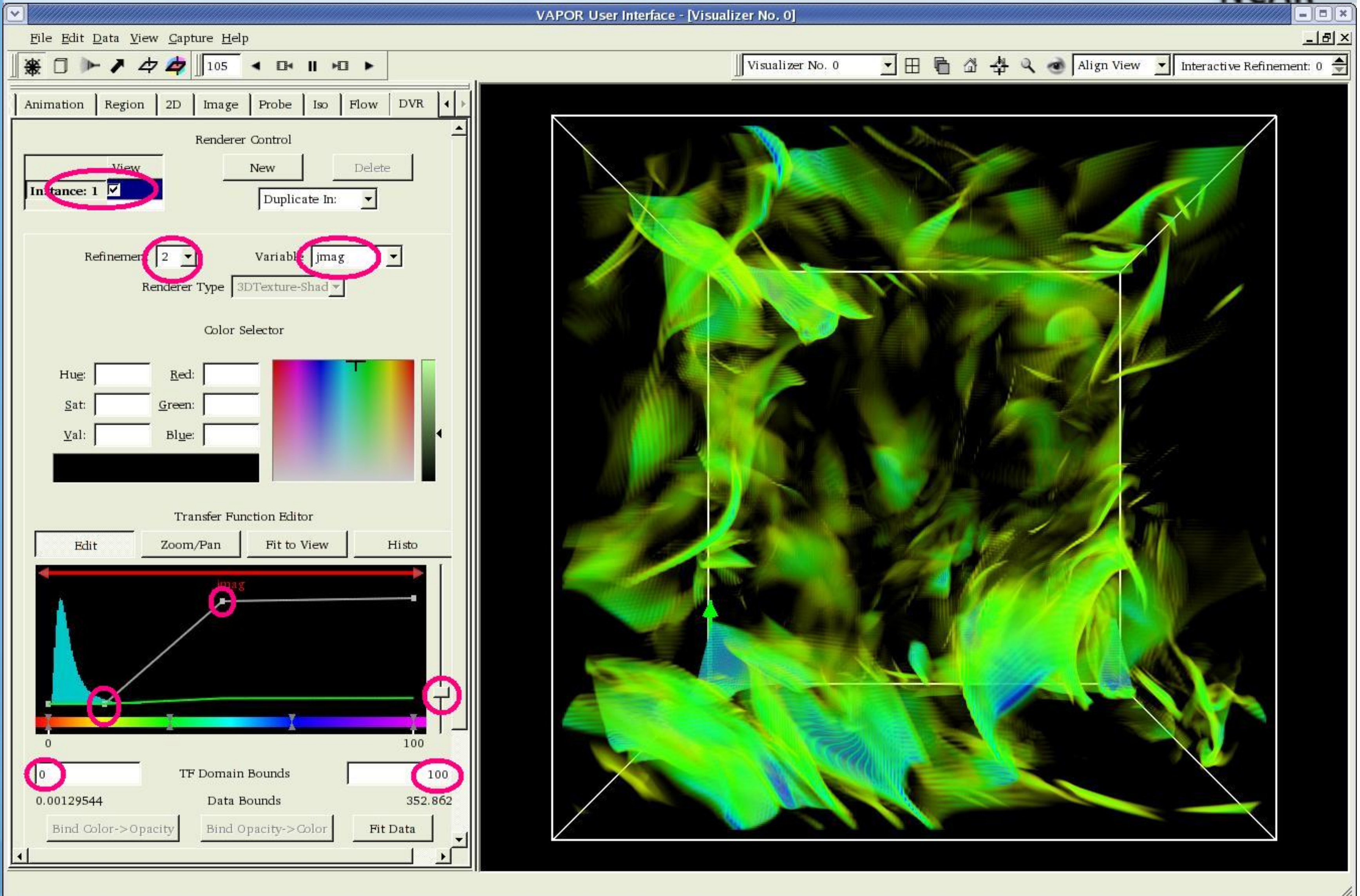
Transfer function highlights current sheets



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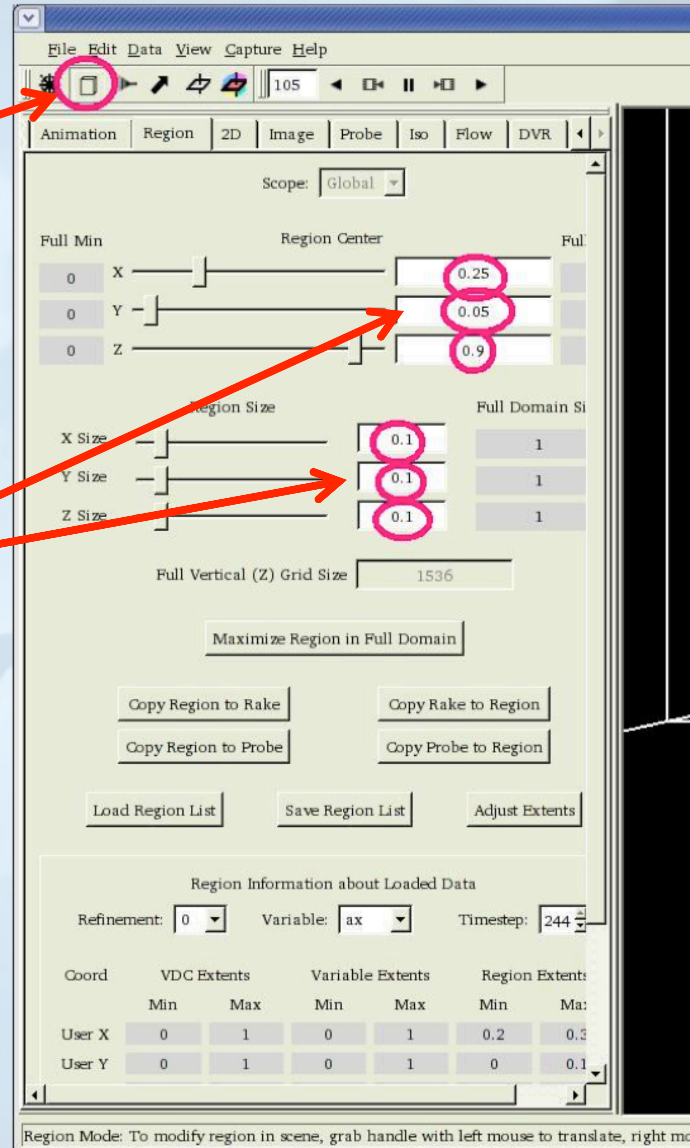
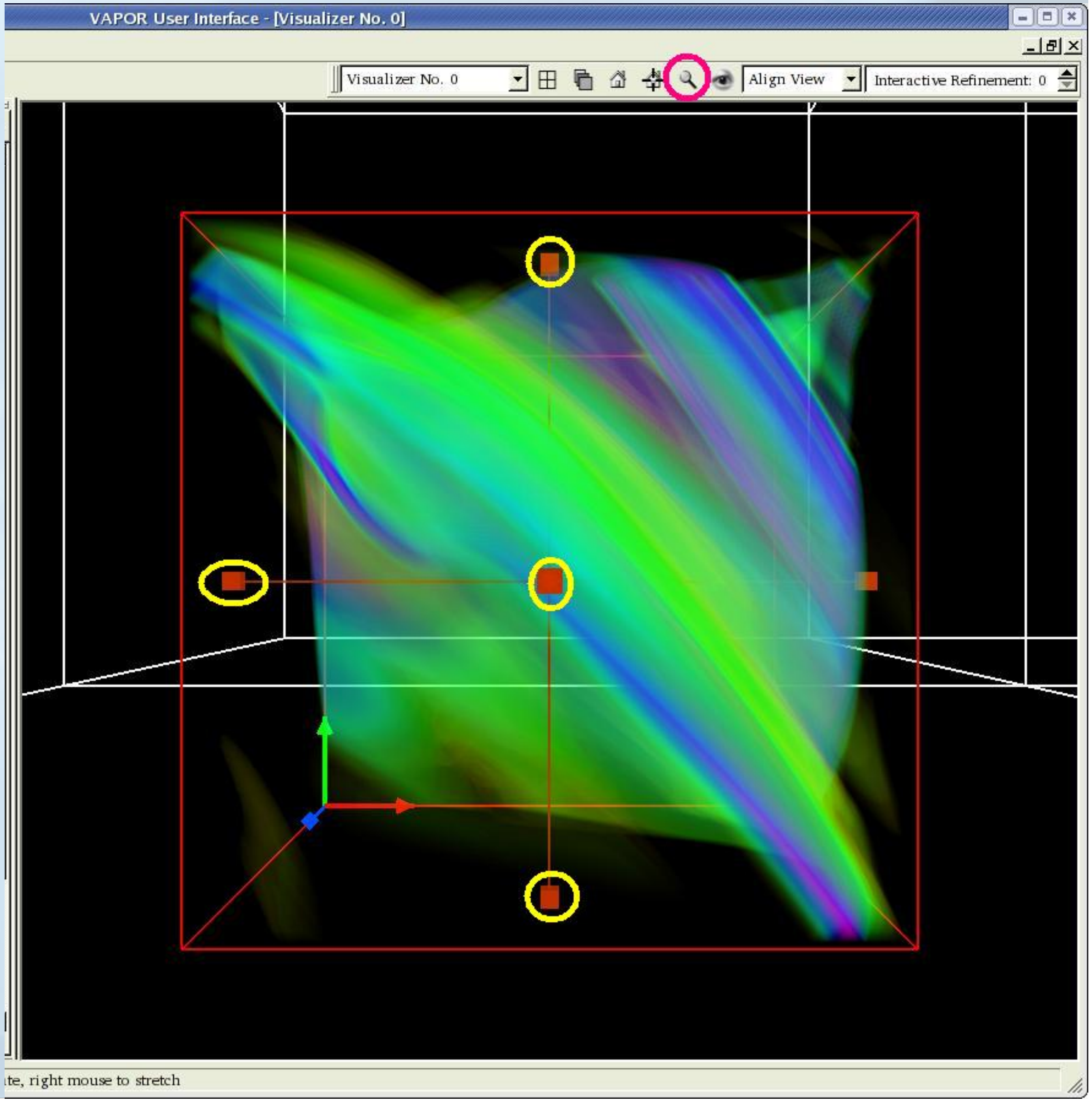
Focus on small subregion to allow interactive visualization at full resolution

- Enable region mode ( )
  - Note the complex structure at bottom (large z, small y)
- Grab region handles to make a box of diameter ~ 0.1, centered near x=0.25, y=0.1, z=0.9
  - Or just type these values into the Region panel



Focus on small subregion to allow interactive visualization at full resolution

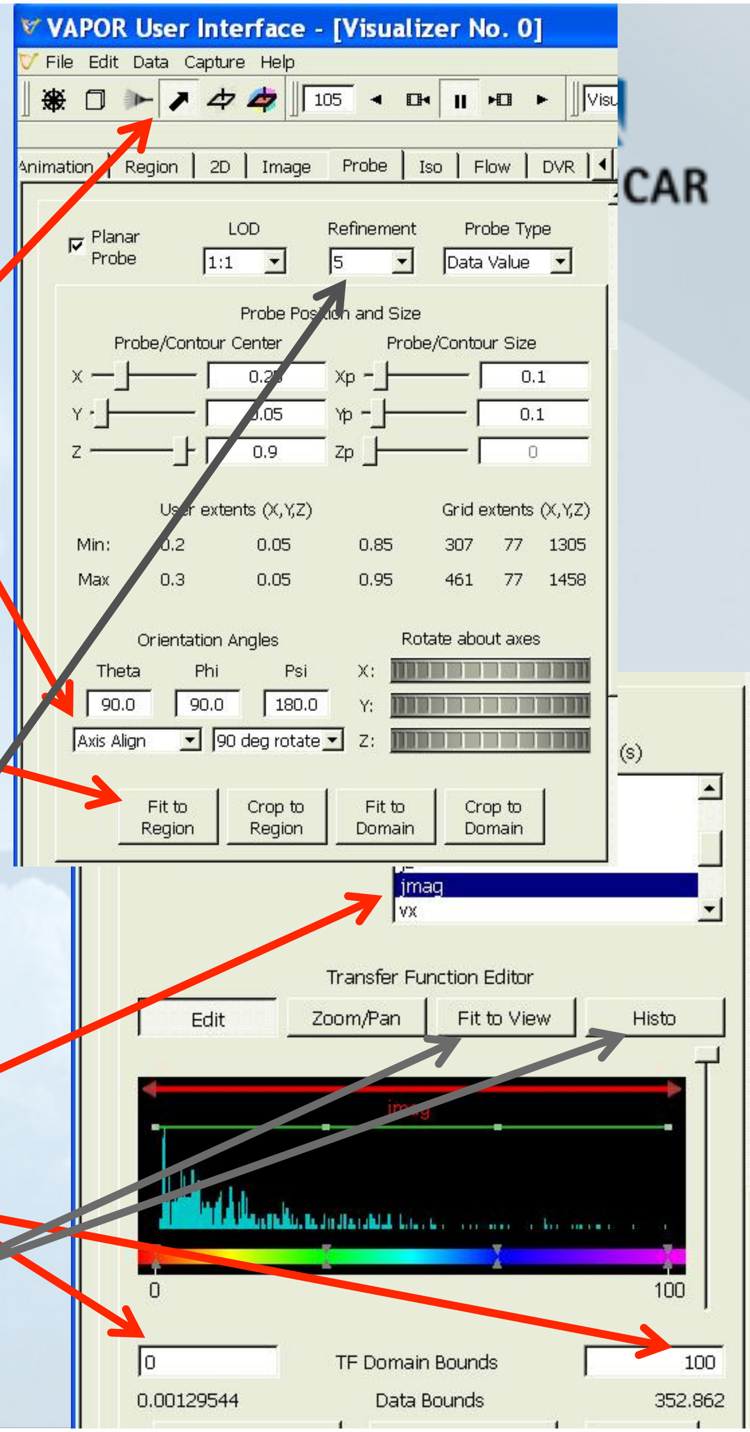
- Click on magnifying glass icon () to center view on new region
- Set refinement level to 5 to see data at full resolution
- Rotate around to see the current roll



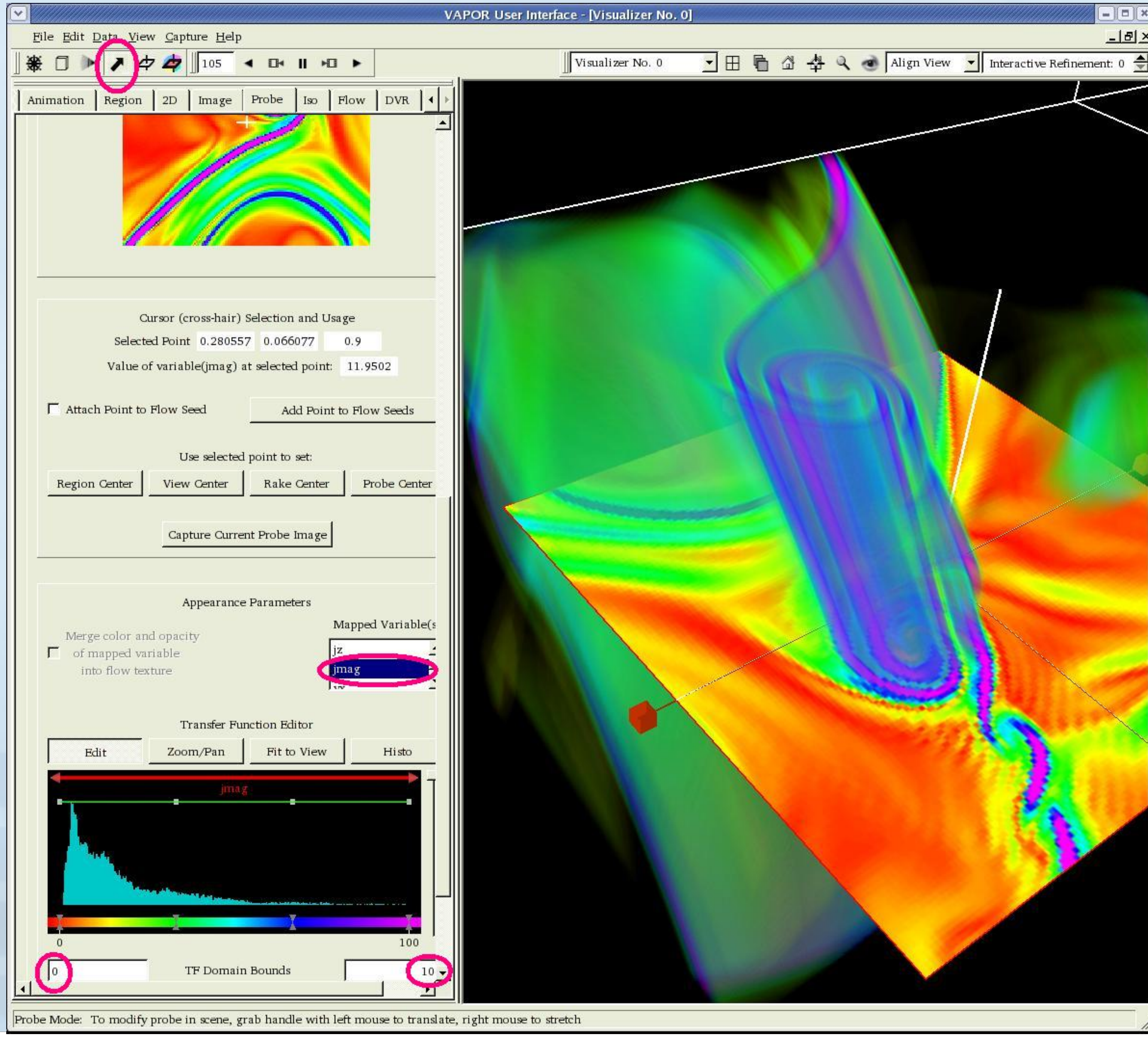
Set data probe to view cross-section of current roll

- Enable Probe mode (click ↗)
- In Probe tab, click "Axis Align" and select "+Y" to make probe orthogonal to current roll
- Click "Fit to Region", then slide probe down to middle of region (Y = 0.1)
- Set Probe refinement level 5
- Scroll down in Probe panel,

  Set "Mapped Variable" = jmag
- Set TF domain bounds 0, 100; then click "Histo" and "Fit to View"

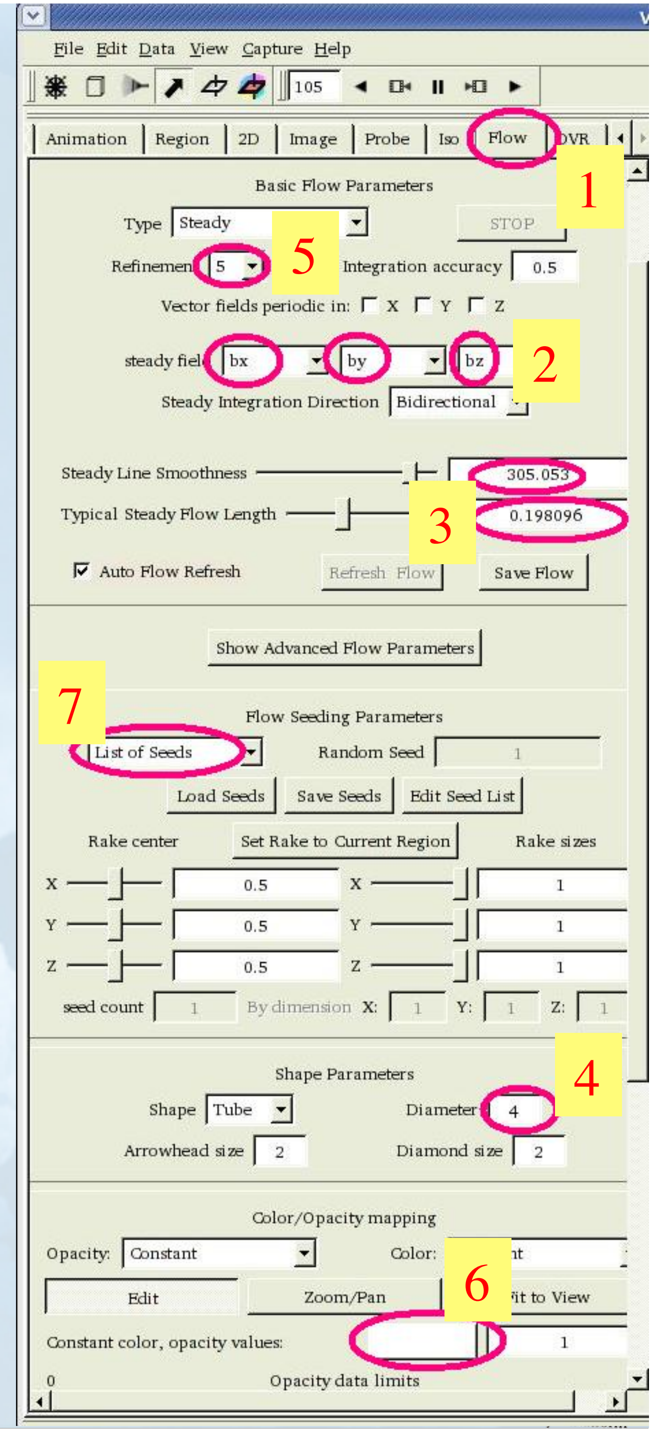


Current roll in probe



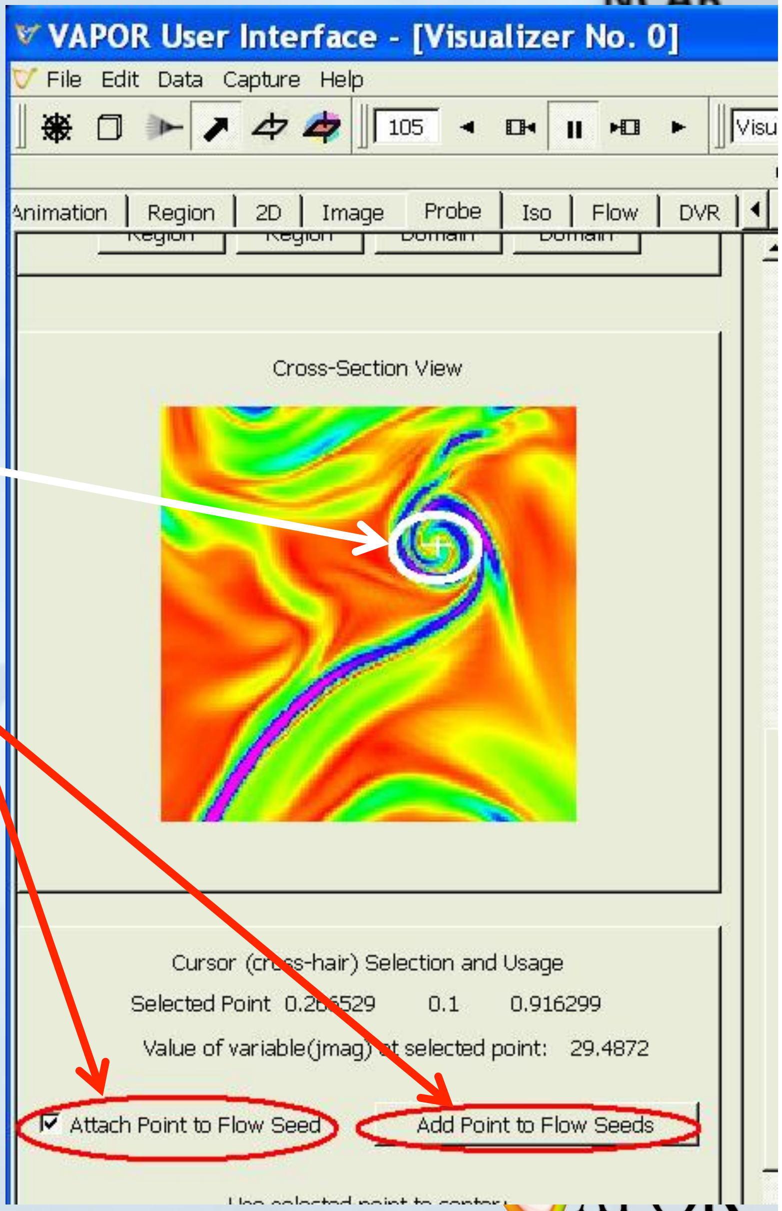
Set up flow to observe magnetic field lines

1. Click on Flow tab
2. Set variables bx, by, bz
3. Set smoothness 300, length = 0.2
4. Set diameter 4
5. Set refinement level 5
6. Set color white
7. Set “List of Seeds”
8. Enable (check “Instance:1” at top of flow tab), ignore error messages

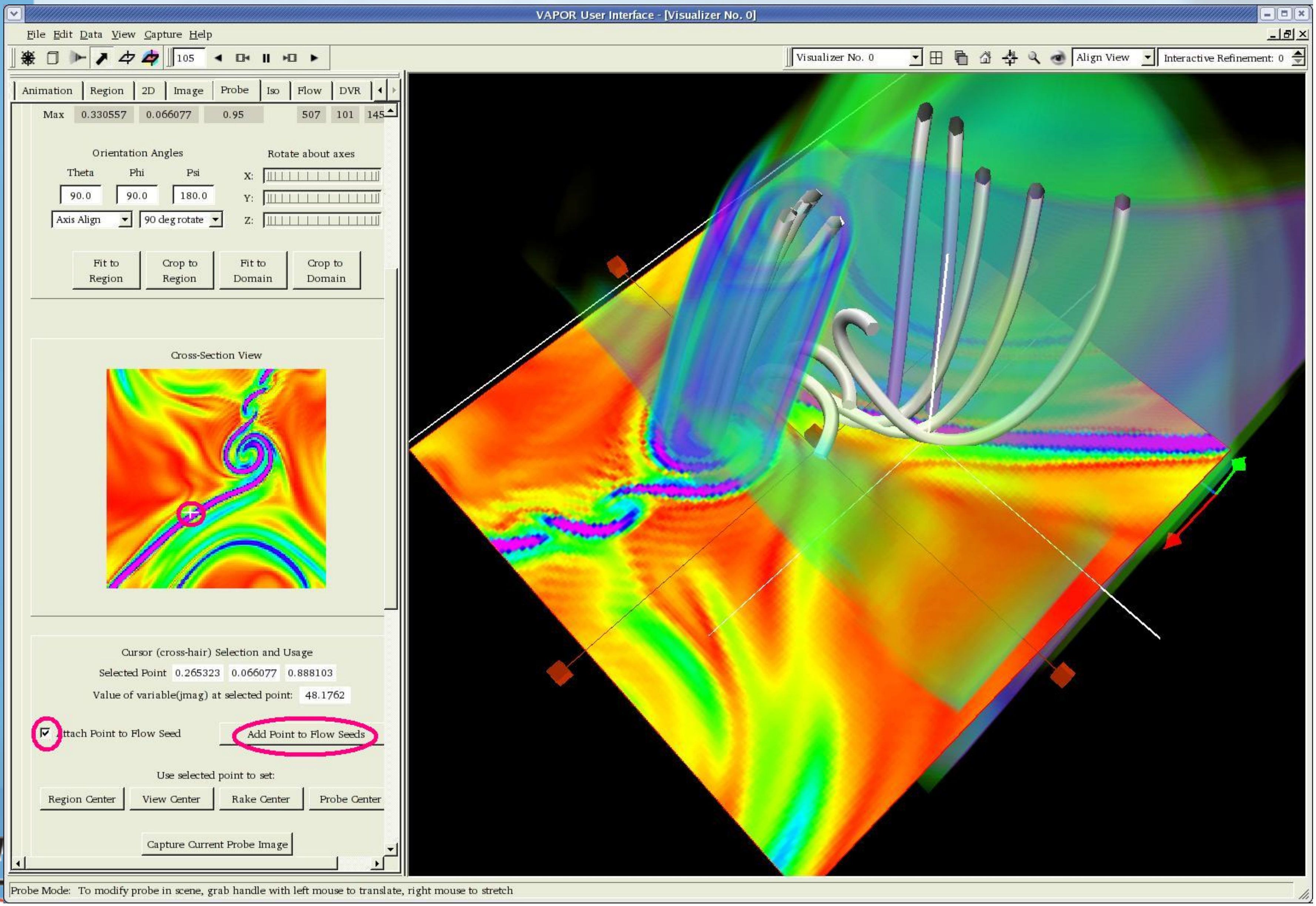


Insert magnetic field lines near current roll

- Click on Probe tab
- Click “Attach Point to flow Seed”
- Place cursor in core of current roll, click “Add Point to Flow Seeds”
  - Note that field lines follow the core of the roll
- Insert seeds on either side of current sheet. Note change of magnetic field as it crosses current sheet.



Magnetic field lines placed nearby current roll



Other useful capabilities of VAPOR

Some features we haven’t shown you

(more at http://www.vapor.ucar.edu/):

- Visualization of WRF output
- Support for compressed data
- Calculate derived variables in IDL or NCL
- Visualization of 2D variables
  - 2-dimensional variables can be visualized in the scene alongside the 3D variables, and can be applied as terrain images
- Insert images into scene
  - Can be applied to terrain surface, or geo-referenced
- More flow visualization
  - Image-based flow, to animate flow motion in a surface
  - Particle traces can be visualized and animated.
  - Field line advection can be used to track field lines moving over time
- Animation capture
  - A sequence of images can be captured to jpeg files, for making a movie

VAPOR plans

We are preparing a new release for later this year

Some features under consideration:

- 3D geometric model rendering
- Wind barbs
- Improved Python support
- Extensibility support: users can add their own renderers.
- Inclusion of standard earth-based geo-referenced images.
- Improved usability of probe and flow panels
- Enhanced Web-based documentation

Where to go from here

To visualize the output of your simulation:

- Install VAPOR on your (Windows/Linux/Mac) computer (Instructions at http://www.vapor.ucar.edu/)
- Convert your data to VAPOR using command-line utilities
- Additional tutorials and user guides are available at http://www.vapor.ucar.edu/
- VAPOR WRF tutorial is at http://vis.ucar.edu/~alan/wrf2011/tutorial
- E-mail vapor@ucar.edu with questions, suggestions, bugs.
- Let us know if you have additional needs – That's how we select and prioritize new features!

VAPOR Availability

- Version 2.0.2 software is available
- Runs on Linux, Windows, Mac
- System requirements:
  - a modern (nVidia or ATI) graphics card (available for about $200)
  - ~1GB of memory
- Supported in NCAR visualization/analysis systems
- Software dependencies:
  - IDL® http://www.ittvis.com/ (only for interactive analysis)
- Contact: vapor@ucar.edu
- Executables, documentation available (free!) at http://www.vapor.ucar.edu/

Thanks!

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Acknowledgements

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  - Nic Brummell - UCSC
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  - Pablo Mininni, NCAR, IMAGe
  - Aake Nordlund, University of Copenhagen
  - Helene Politano - Observatoire de la Cote d'Azur
  - Yannick Ponty - Observatoire de la Cote d'Azur
  - Annick Pouquet - NCAR, ESSL
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