Visualization of WRF Data Using VAPOR: A Georgia Weather Case Study

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Introduction

0.0 Overview

This case study is intended to provide the new user with a quick introduction to the use of VAPOR (Visualization and Analysis Platform for Research) with WRF (Weather Research Forecast model), visualizing data obtained from the advanced research WRF ARW model.

This case study is provided as a self-guided tutorial showing how to use the most important features of VAPOR on a weather dataset. The methods presented here are applicable to other datasets as well.

The results of numerical simulation are best understood when users interact directly with the data. This principle is central to the design of VAPOR. Users should be able to instantly see three-dimensional visualizations of the data as they tweak the parameters defining the visualizations. This iterative data exploration process enhances understanding of the features of interest in the data.

To ensure interactive visualization, VAPOR relies on the latest available graphics technology, i.e. graphics cards available at low cost in current personal computers. In addition, VAPOR supports interactive access to massive datasets, by allowing users to select the data resolution and region of interest to visualize.

This case study applies VAPOR to visualize a frost event (scenario) that occurred in the southeastern U.S. between April 4 and April 11, 2007. This frost event contributed to $257.5 million losses due to damages to newly emerging crops. The data are the result of a case study funded through a partnership with the U.S. Department of Agriculture-Risk Management Agency, and performed by Thara Prabhakaran and Gerrit Hoogenboom of the University of Georgia. The WRF ARW model was evaluated for frost assessment using data from the Georgia Automated Environmental Monitoring Network (AEMN) (http://www.georgiaweather.net).

Many of the capabilities of VAPOR are illustrated in the Vapor Quick Start Guide (http://www.vapor.ucar.edu/sites/default/files/docs/QuickstartGuide.pdf). You may want to work through that guide as well as this case study. The VAPOR Quick Start Guide explores turbulence data on a uniform grid. The visualization techniques performed there can also be applied to WRF data.

0.1 Update for VAPOR Version 1.5

This version of the case study has been updated to include new capabilities introduced in VAPOR since version 1.2. These include:

- Image display (discussed in section 1.3)
- Animation toolbar (discussed in section 1.6)
- User preferences (discussed in section 1.1)
- Spin animation (section 1.2)
- Color mapping of variables to isosurfaces (section 1.7)
- Support for two-dimensional variables (section 3)
- Extension of variables below/above WRF grid (section 4.2)
- Image-based flow visualization (section 4.3)

0.2 Setting up for performing this case study

Before you begin, you need to have access to a (Linux, Windows, Mac or Irix) workstation on which VAPOR has been installed. Follow the installation instructions provided on the VAPOR website (http://www.vapor.ucar.edu). When you run VAPOR, you need to be directly connected to the graphics console of the system. You cannot run VAPOR via a remote (ssh) shell, however you may be able to remotely connect to a graphics system via a remote graphics server such as VirtualGL, IBM's RVN, or HP's RGS.

You will need to prepare your execution environment before running VAPOR. For Unix and Macintosh users, there are shell scripts in the bin subdirectory of the VAPOR installation directory. You will need to initialize your shell by sourcing vapor-setup.csh (in a C shell) or vapor-setup.sh (in a Bourne shell). Remember to re-source these whenever you change your shell. Windows users need to run the VAPOR installers to set up the required paths. After VAPOR is installed, the environment variable VAPOR_SHARE will be set a directory name where are installed examples, documents and other files that will be useful.

Prior to working through this case study, you will need to download and install an example WRF dataset from

http://www.vapor.ucar.edu/page/vapor-download#Example.

The data is entitled "april_lowres", because this is a low-resolution version of the original data. The data resulted from WRF simulation by Thara Prabhakaran and Gerrit Hoogenboom at the University of Georgia, of a weather pattern occurring between April 4, 2007 and April 11, 2007. This constituted a cold front followed by persistent cold air mass over Georgia and the retrieval of the cold air mass, that was replaced by warm moist air from the south. There are 180 time steps, one time step per hour, in these datasets. In the april_lowres dataset, all 180 time steps of the data are available at the lowest refinement level (0), which is ¼ the resolution of the original data in each dimension. The april_lowres data also includes 1/10 of the time steps at refinement level 1, i.e. includes refinement level 1 data at 10 hour intervals. The original dataset was calculated at refinement level 2, on a grid with horizontal spacing 9km. We have not provided the highest refinement level because it is too big to easily download.

Note that any scientific conclusions obtained by visualizing low resolution data should be confirmed by visualizing the appropriate portions of the data at full resolution. Contact Thara Prabhakaran (thara@uga.edu) to obtain access to the original data. To see how this data was converted from the original WRF dataset, refer to the VAPOR/WRF Data and Image Preparation Guide (available at http://www.vapor.ucar.edu/page/wrf-support).

0.3 Using sample sessions in this case study

If you encounter problems following all the steps in this case study, or if you just want to jump to a specific example visualization, you can quickly advance to any of the tasks below. For all of the illustrations in this case study, there is a VAPOR session file named “WRFFigureA.B.vss”, that can be used to initialize VAPOR into the same state as was used to generate Figure ‘A.B’ below. The session files are available for download from the VAPOR download page (https://www.vapor.ucar.edu/page/vapor-download#Example). These are also installed in the VAPOR examples directory, which is the subdirectory $(VAPOR_SHARE)/examples/ in the VAPOR installation. To make use of a session file, say for figure “A.B” (A and B being integers), perform the following:

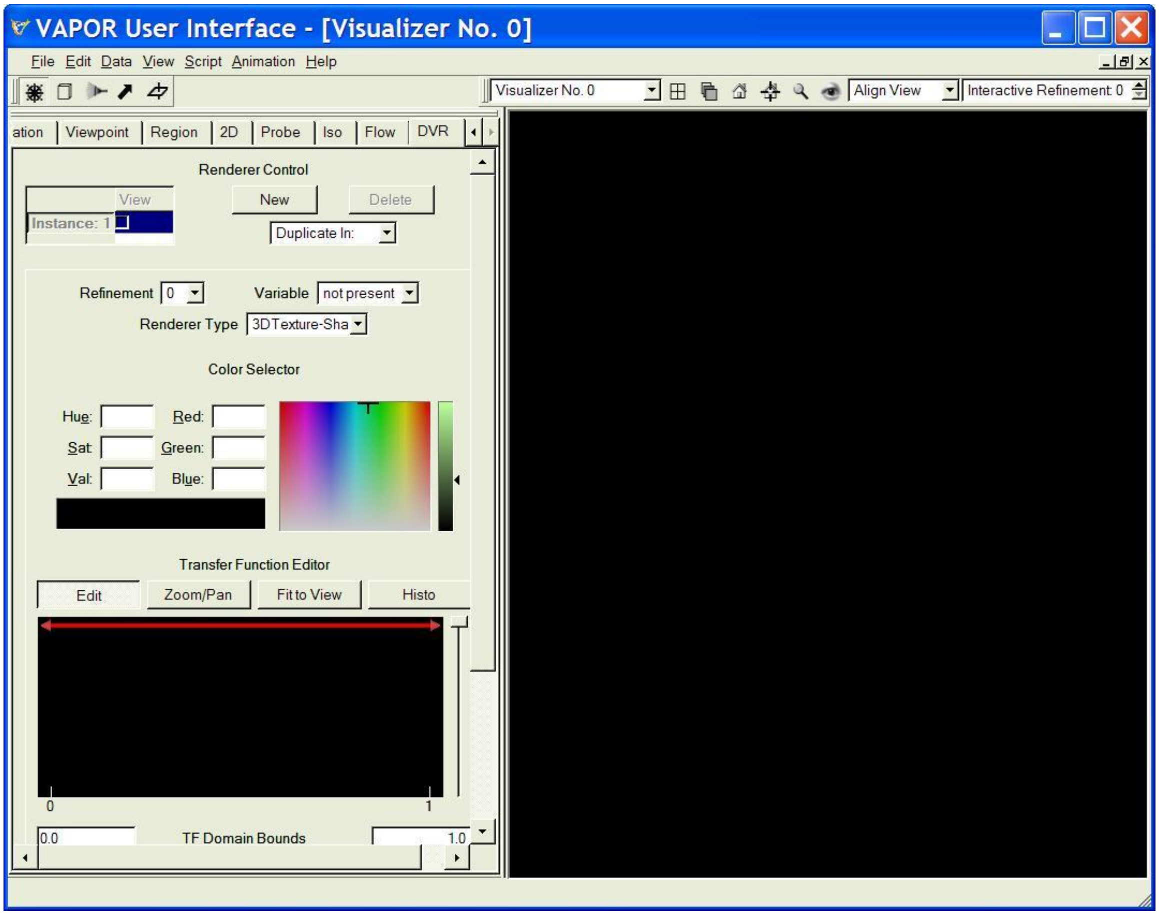
1. From the VAPOR File menu, click on Open Session and select the desired session file “WRFFigureA.B.vss” in this document.
2. From the VAPOR Data menu, click on: Load Data into current Session and select the metadata (vdf file) associated with that figure (april_lowres.vdf).
3. Click on the various renderer tab(s) used in the illustration (DVR, Flow, Iso, 2D, Image, or Probe). For each tab, under the heading Renderer Control, click the check-box for each renderer instance that that is used in the figure.
4. If the illustration includes an image, such as a terrain image, you may need to respecify the file path where the image is located on your system. In the image tab, click the button “Select Image File” and then select the appropriate image file.
5. If there is a mouse mode that is used in the illustration, (e.g. “Region Select”, “Navigation”, “Data Probe”, “Rake” or “2D”) you should select the appropriate mode by clicking on one of the mode select buttons below the VAPOR main menu bar.

You should see a similar image on your screen as is shown in figure “A.B” in this document.

Section 1: Visualizing a Cold Air Mass with Isosurfaces

1.0 Launching VAPOR

From the command line issue the command “vaporgui”. (In Windows or Mac, you can double-click on the “vaporgui” icon on the desktop, or type “vaporgui” from a console window.) You should see a screen like the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Renderer Control
View
Instance: 1
New
Delete
Duplicate In:
Color Selector
Hue:
Red:
Sat:
Green:
Val:
Blue:
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
0
1
TF Domain Bounds

Refinement 0

Variable not present

Renderer Type 3DTexture-Sha

0.0

1.0

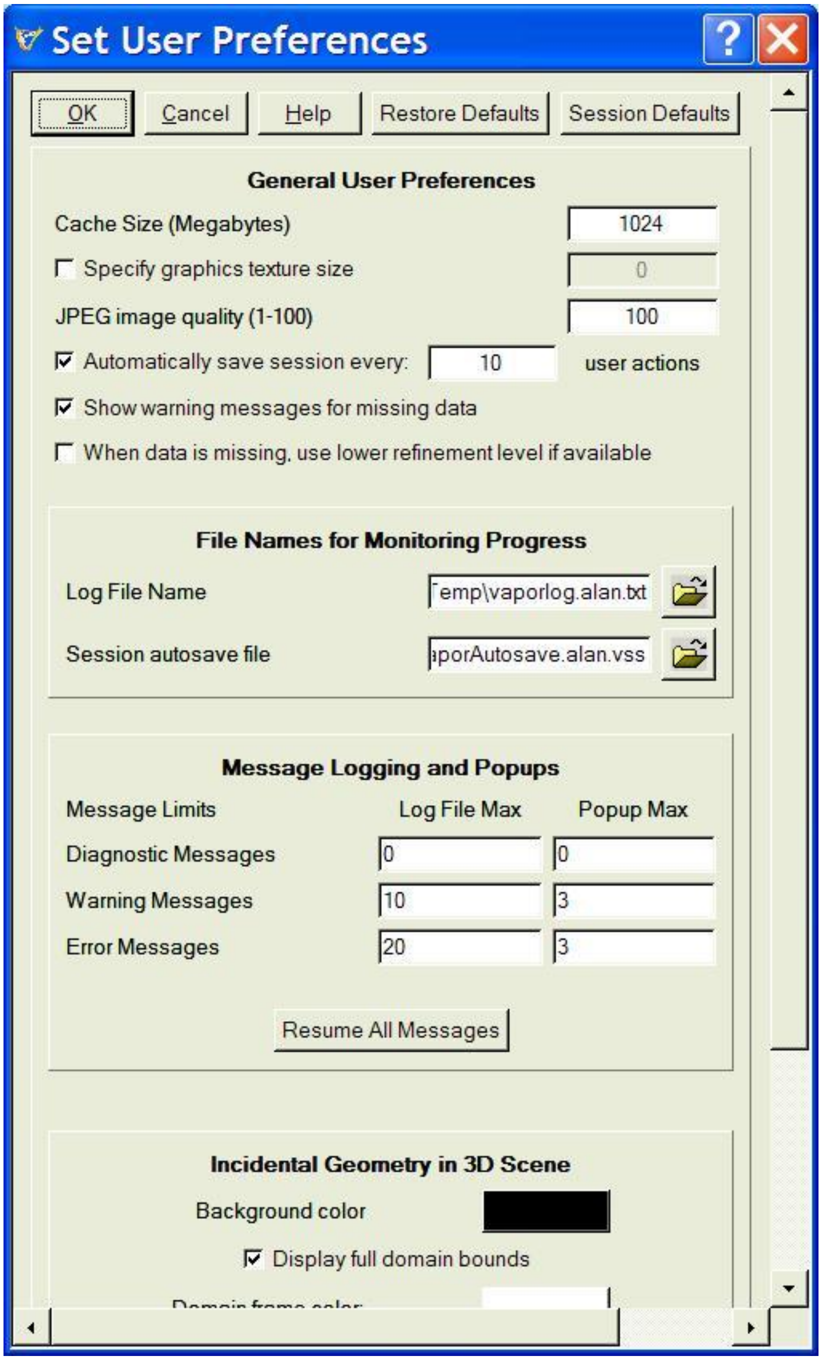
Figure 1.1: Initial VAPOR GUI window

The right side of this screen (mostly black) is the “visualizer window”, where the 3D graphics images are displayed. The left side of the screen has a set of tabs across the top, labeled View, Animation, Region, 2D, Image, Probe, Iso, Flow, and DVR. In this section we shall show how to use the Image panel, Iso (isosurface) panel and the DVR panel (this stands for “direct volume rendering”, referring to the fact that this panel controls the direct conversion of data to a volumetric representation.)

1.1 User preference settings

Before loading a data set, it is useful to set up your user preferences, which are settings that apply just to your individual system and usage requirements. Most of the defaults will work fine; however, one important preference that you may want to change is the data cache size. You will get the best performance from VAPOR if the cache size is about equal to the physical memory available to you on the computer you are using. To set this preference, click on Edit→Edit User Preferences, and you will see the user preferences panel shown in figure 1.2. Set the Cache Size (Megabytes) to a value appropriate to the computer you are using.

Another preference setting that will be useful is to allow VAPOR to use lower resolution data when the higher resolution is not available. This setting is particularly useful with the april_lowres dataset, because the available refinement level depends on the time step you are viewing. The higher level is only available at time steps that are multiples of 10. So, check the box labeled "When data is missing, use lower refinement level if available". After making these settings, click "OK", and then save the preferences to its default location (usually the $HOME directory), so that these settings will be available the next time you run VAPOR from the system you are using. These settings are not affected by loading session files.



General User Preferences

Cache Size (Megabytes): 1024

☐ Specify graphics texture size: 0

JPEG image quality (1-100): 100

☑ Automatically save session every: 10 user actions

☑ Show warning messages for missing data

☐ When data is missing, use lower refinement level if available

File Names for Monitoring Progress

Log File Name: emp\vaporlog.alan.txt

Session autosave file: porAutosave.alan.vss

Message Logging and Popups

Message Limits	Log File Max	Popup Max
Diagnostic Messages	0	0
Warning Messages	10	3
Error Messages	20	3

Incidental Geometry in 3D Scene

Background color: ■

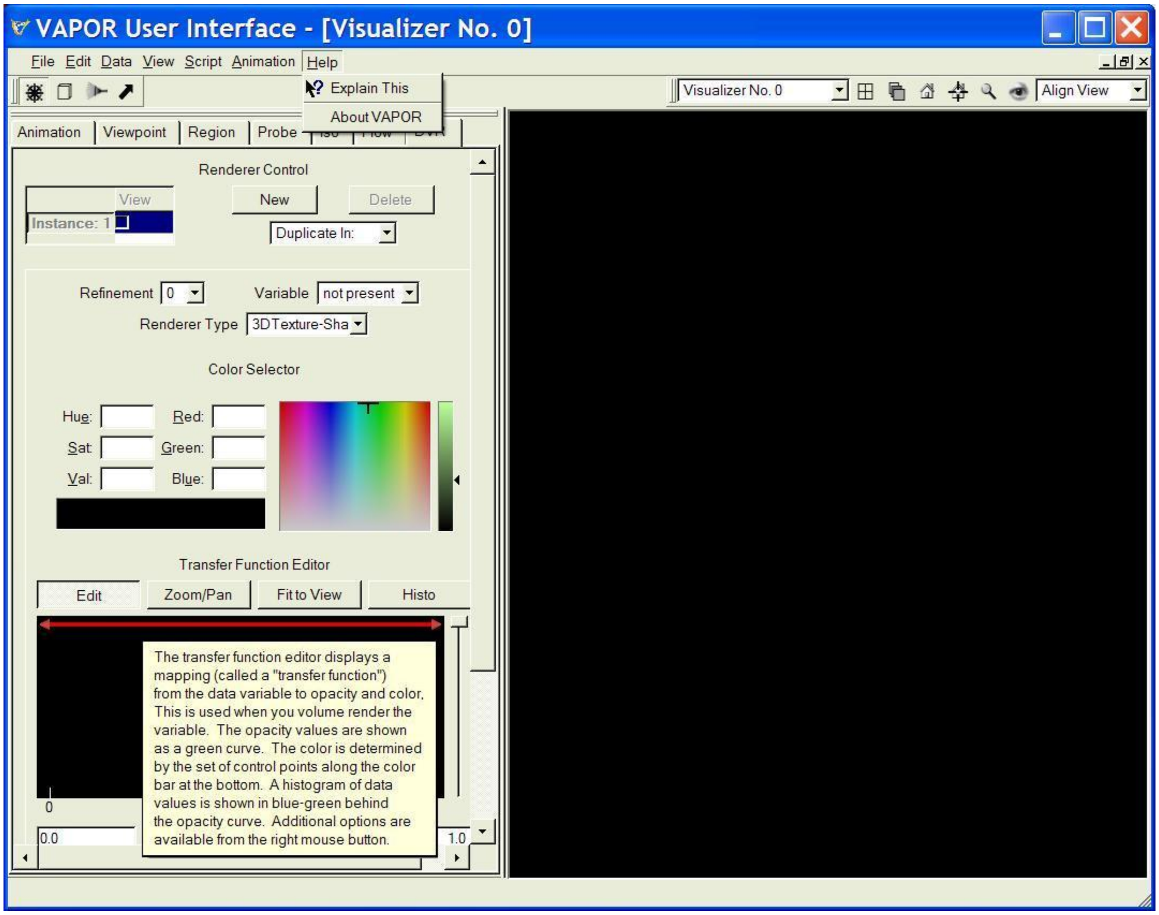
☑ Display full domain bounds

Domain frame color:

Figure 1.2: User Preferences Panel

1.2 Some useful help features

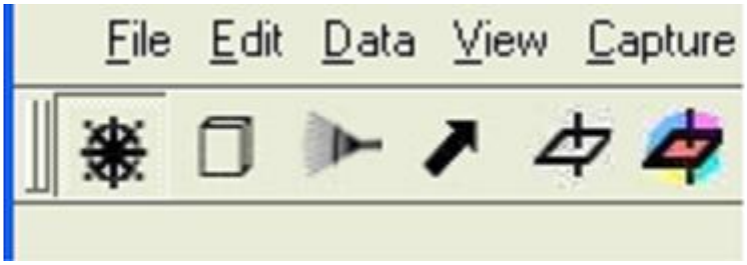
Tooltips and context-sensitive help. You can quickly answer questions about things you see in the VAPOR user interface, using either “tool-tips” or “context-sensitive-help”. If you hold the mouse over a button, text-box or other widget for a few seconds, a *tool-tip* will appear, giving a one-sentence explanation of the widget. If you need a deeper technical explanation, click on the Help menu at the top of the screen, then click on the menu item labeled “? Explain This”. Then click on the item you are curious about. A yellow *context-sensitive help* box will appear such as shown below:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Explain This
About VAPOR
Visualizer No. 0
Align View
Animation Viewpoint Region Probe
Renderer Control
View
New
Delete
Instance: 1
Duplicate In:
Refinement 0
Variable not present
Renderer Type 3DTexture-Sha
Color Selector
Hue:
Sat:
Val:
Red:
Green:
Blue:
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
0
0.0
1.0

The transfer function editor displays a mapping (called a "transfer function") from the data variable to opacity and color. This is used when you volume render the variable. The opacity values are shown as a green curve. The color is determined by the set of control points along the color bar at the bottom. A histogram of data values is shown in blue-green behind the opacity curve. Additional options are available from the right mouse button.

Figure 1.3: Context-Sensitive Help

Mouse Modes. To assist you in accessing visual features in the 3D scene, VAPOR has six mouse mode buttons above the tabs at the top-left of the window:

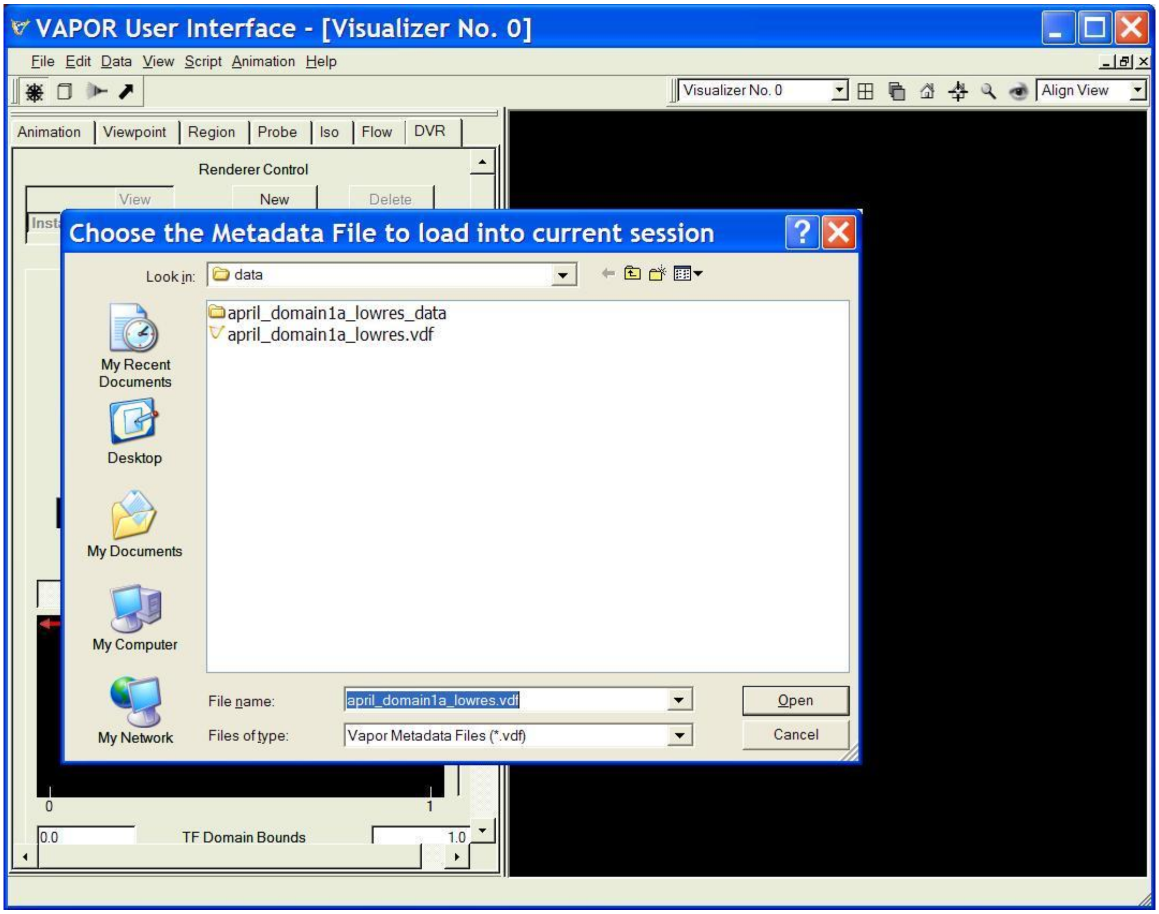

File Edit Data View Capture

Clicking on these buttons enables you to manipulate the size and location of a shape being visualized in the scene. From left to right, these buttons are associated with the following manipulation modes:

1. *Navigation mode*, used to rotate, zoom and translate the viewer position in the scene. Spin animation is also available in navigation mode. (Note: mouse-based navigation is also available in the other modes as well, provided the mouse is not depressed over one of the box handles in the scene).
2. *Region mode*, used to manipulate the box-shaped region which is used for volume rendering, isosurfaces, and flow integration.
3. *Rake mode*, used to specify a “rake” box, controlling the position of flow seed points.
4. *Probe/contour mode*, used to control the location and size of the probe/contour plane tool.
5. *2D mode*, used to position a plane of two-dimensional data in the scene.
6. *Image mode,* used to control the location and size of an image placed in the scene.

1.3 Specifying a volume dataset and a terrain image

Click the Data menu (at the top of the screen) and you will see a list of various commands that can be applied to datasets. Click “Load a Dataset into current session”. (You can alternatively load a dataset into default session, at this point). You will see a file selection dialog, asking you to “Choose the metadata file to load into current session”:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Animation
Viewpoint
Region
Probe
Iso
Flow
DVR
Renderer Control
View
New
Delete
Choose the Metadata File to load into current session
My Recent Documents
Desktop
My Documents
My Computer
My Network
Open
Cancel
0
1
TF Domain Bounds

Look in: data

april_domain1a_lowres_data
april_domain1a_lowres.vdf

File name: april_domain1a_lowres.vdf

Files of type: Vapor Metadata Files (*.vdf)

0.0

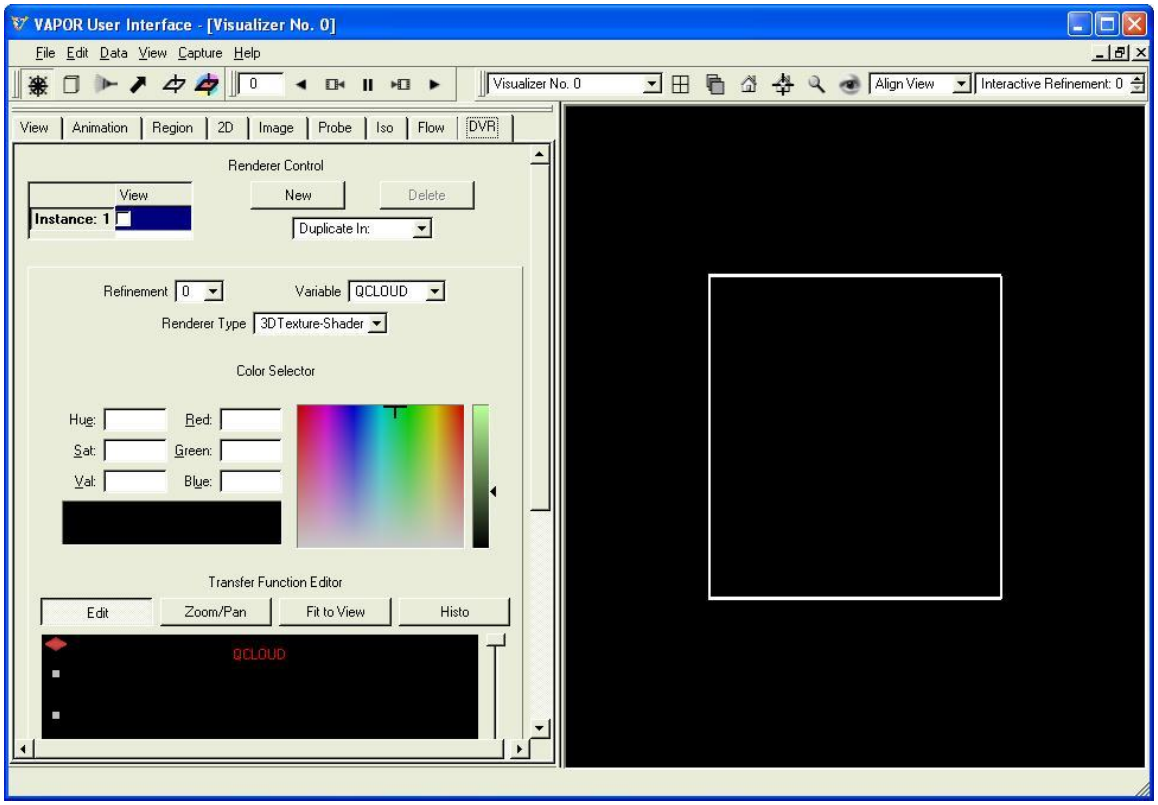
1.0

Figure 1.4: Loading a metadata file

This file selection dialog enables you to read a file of type ".vdf", which stands for "Vapor Data Format". These are *Meta*data files, not *data* files: .vdf files contain descriptions of data. Typically the referenced data is in many different files.

Choose the file "april_lowres.vdf" and click "Open". This is a time-varying WRF data set. It contains a vector field consisting of the three components (U, V, W) of the wind velocity, as well as perturbation potential temperature (T), water vapor mixing ratio (QVAPOR), cloud water mixing ratio (QCLOUD) and an auxiliary variable (ELEVATION) indicating height in meters above sea level found from (PH+PHB)/9.81; where PH and PHB are perturbation and base state geopotential height. There are also a few two-dimensional variables, such as HGT (height above sea level), TC (temperature at ground level), T2 (temperature at 2 m), TD (dew point temperature at ground level), U10 and V10 (wind at 10m), SLP (sea level pressure), and TH2 (temperature at 2m above terrain). The variables HGT, T2, U10, V10, and TH2 result from the WRF-ARW simulation, and the other 2D variables (SLP, TD, TC) were derived using NCL and added to this Vapor dataset. Instructions for including derived variables are given in the VAPOR/WRF Data and Image Preparation Guide document.

You will see a white rectangle in the visualize window as the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Capture Help
Visualizer No. 0
Align View
Interactive Refinement: 0
View Animation Region 2D Image Probe Iso Flow DVR
Renderer Control
View
Instance: 1
New
Delete
Duplicate In:
Color Selector
Hue:
Sat:
Val:
Red:
Green:
Blue:
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
QCLOUD

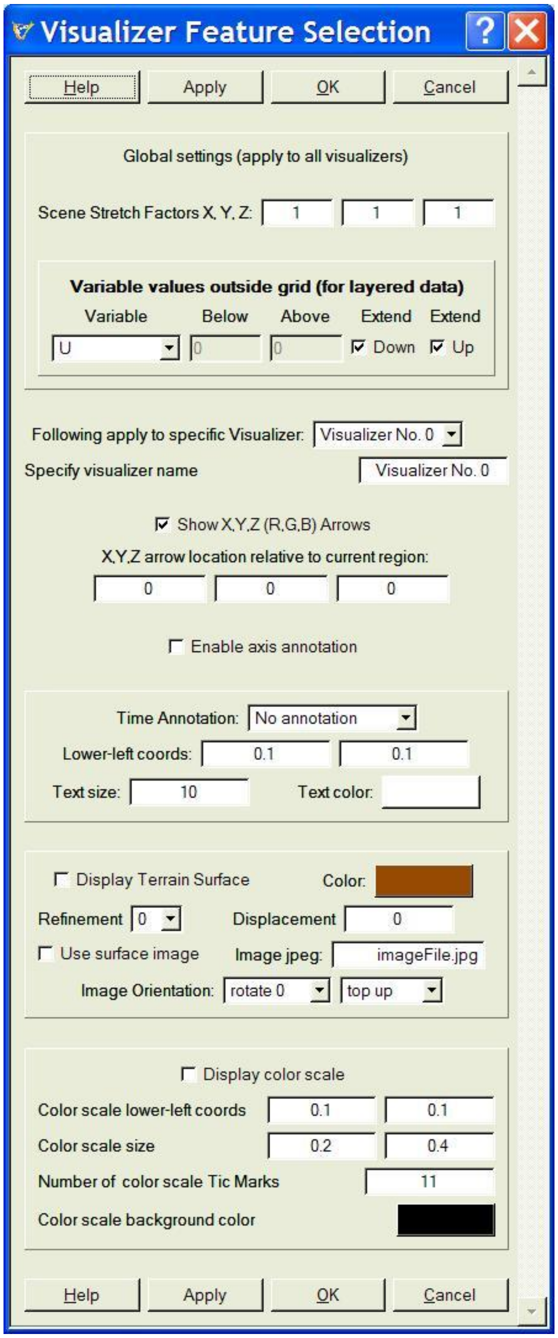
Refinement 0

Variable QCLOUD

Renderer Type 3DTexture-Shader

Figure 1.5: Bounds of april_lowres data

The rectangle is actually the top view of a slab shaped region enclosing the data. This data volume is very flat, about 1000 km in each of the two horizontal dimensions, and about 1.6 km high. In order to effectively visualize this data we need to stretch this volume in the vertical direction, exaggerating the height. Click on Edit → Edit Visualizer Features. You will see following panel:



Global settings (apply to all visualizers)

Scene Stretch Factors X, Y, Z: 1 1 1

Variable values outside grid (for layered data)

Variable	Below	Above	Extend	Extend
U	0	0	☑ Down	☑ Up

Following apply to specific Visualizer: Visualizer No. 0

Specify visualizer name: Visualizer No. 0

☑ Show X,Y,Z (R,G,B) Arrows

X,Y,Z arrow location relative to current region: 0 0 0

☐ Enable axis annotation

Time Annotation: No annotation

Lower-left coords: 0.1 0.1

Text size: 10 Text color:

☐ Display Terrain Surface Color:

Refinement 0 Displacement 0

☐ Use surface image Image jpeg: imageFile.jpg

Image Orientation: rotate 0 top up

☐ Display color scale

Color scale lower-left coords 0.1 0.1

Color scale size 0.2 0.4

Number of color scale Tic Marks 11

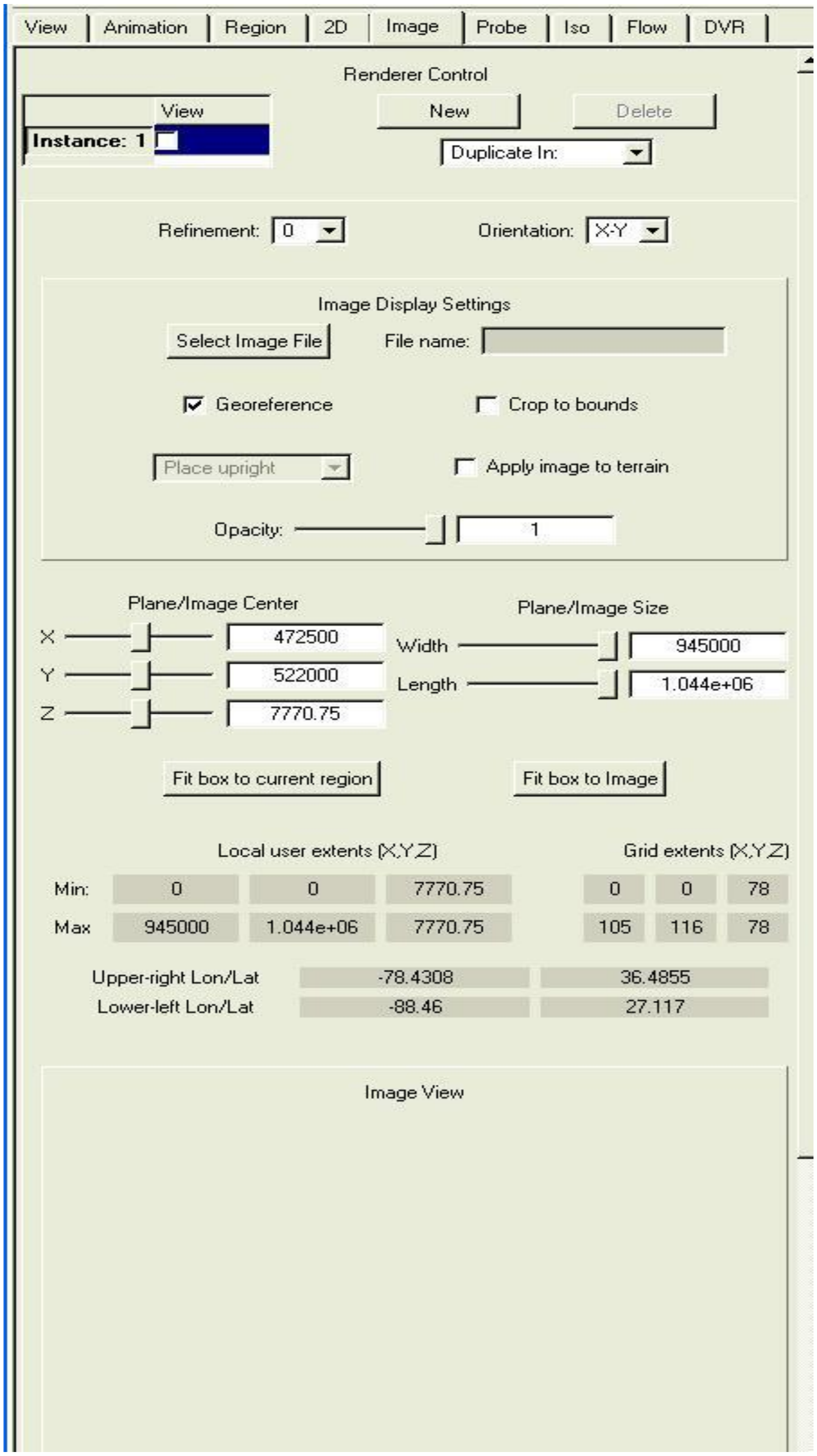
Color scale background color

Figure 1.6: Visualizer Feature Selection panel

This panel allows setting various properties of the visualizers. Note the three text boxes labeled "Scene Stretch Factors X, Y, Z:". Set the third (Z) stretch factor to 100. Click "Apply" and you will see that the data volume has stretched vertically.

There are a number of other capabilities controlled by the visualizer features panel that you may find useful; for example providing coordinate axis annotation and time annotation. The visualizer feature panel also supports display of the terrain surface. However, it is best to use Image tab for viewing images on the terrain; which we shall describe next.

Click on the Image tab to see the following panel:


View
Animation
Region
2D
Image
Probe
Iso
Flow
DVR
Renderer Control
View
New
Delete
Duplicate In:
Image Display Settings
Select Image File
Fit box to current region
Fit box to Image
Image View

Instance: 1 ☐

Refinement: 0

Orientation: X-Y

File name:

☑ Georeference

☐ Crop to bounds

Place upright

☐ Apply image to terrain

Opacity: 1

Plane/Image Center

X 472500

Y 522000

Z 7770.75

Plane/Image Size

Width 945000

Length 1.044e+06

	Local user extents (X,Y,Z)			Grid extents (X,Y,Z)		
Min:	0	0	7770.75	0	0	78
Max	945000	1.044e+06	7770.75	105	116	78

Upper-right Lon/Lat	-78.4308	36.4855
Lower-left Lon/Lat	-88.46	27.117

Figure 1.7: Image panel (top)

We shall use the image panel to place a satellite image of Georgia in this scene.

Click on the button labeled Select Image File and select the file "georgia_satview.tif" which is located in the same directory as the april_lowres.vdf file you loaded previously. This image is a geoTiff file (geo-referenced tiff file), an image with additional information that enables it to be positioned correctly in world coordinates. Instructions for obtaining such images are provided in the VAPOR/WRF Data and Image Preparation Guide . This image was enhanced with the political boundaries of Georgia and the location of Atlanta by Thara Prabharan. Check the box "Apply image to terrain" in the Image panel. Then, near the top of the image panel, check the checkbox next to "Instance:1" to enable display of the image. You should see the following in the visualizer:

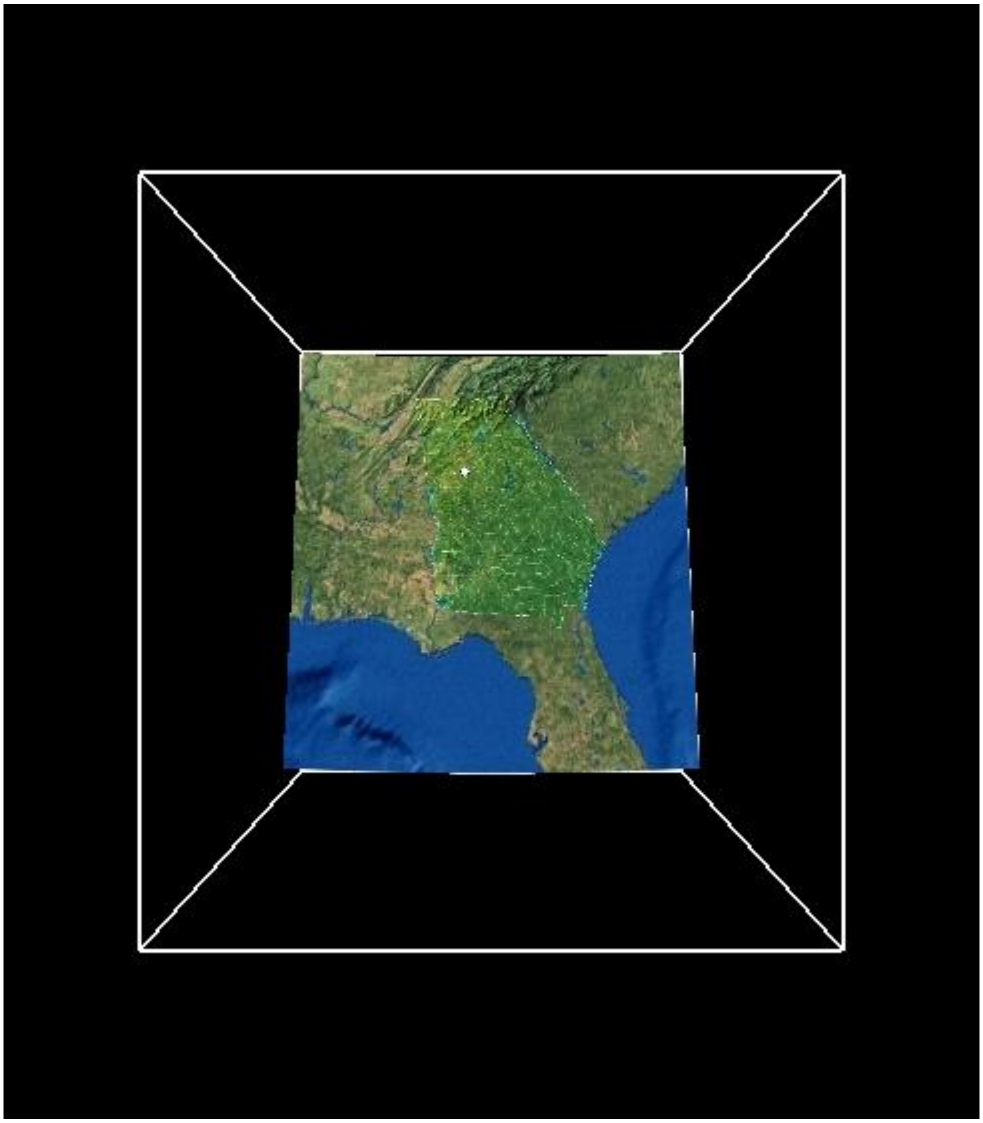
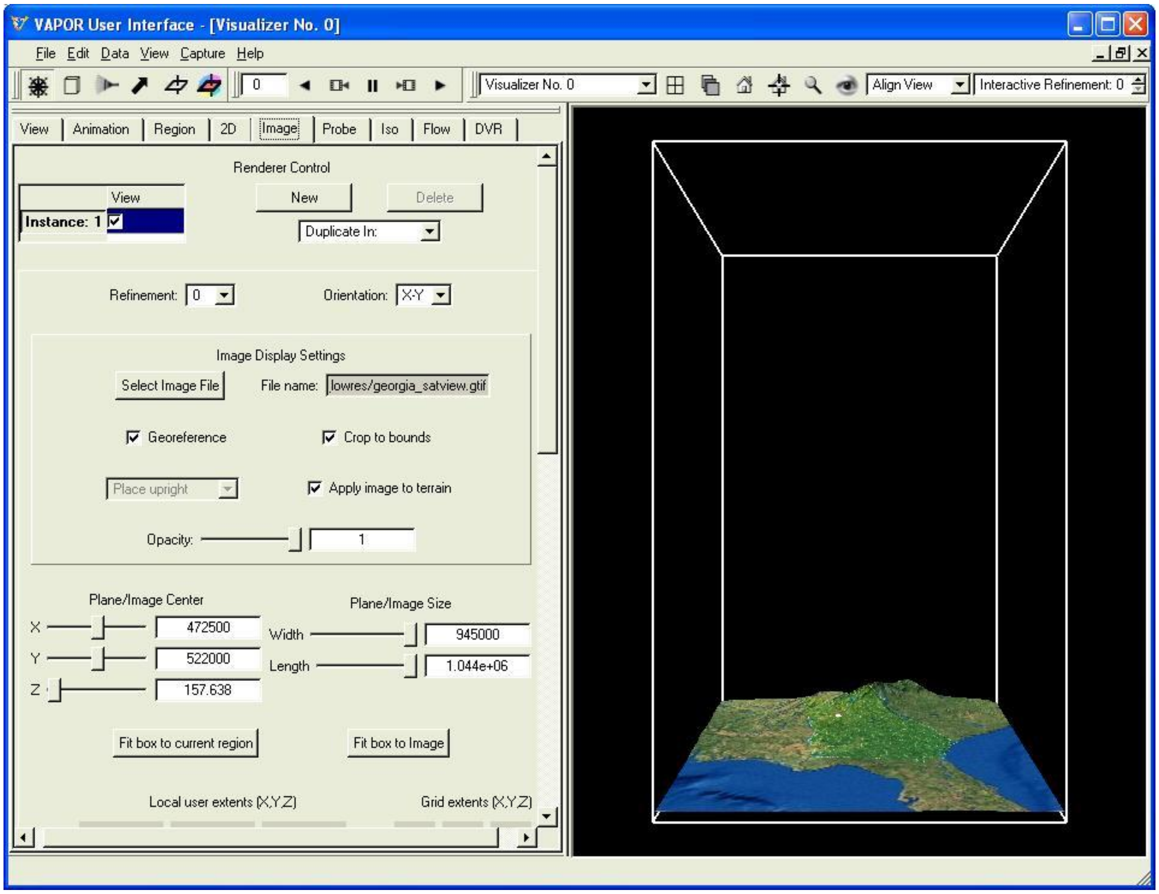


Figure 1.8: View of terrain from above

The coloring of the surface is based on a satellite image of the region, with additional lines added to indicate boundaries of counties in Georgia. There is a white dot at the location of Atlanta. Note that this image is not exactly square, for it extends beyond the WRF domain along the south-west and south-east boundaries. This is because the satellite image uses a latitude/longitude rectangle, whereas the WRF domain is a rectangle in the Lambert conformal conic map projection. You can crop the image to the WRF domain by checking the "Crop to bounds" checkbox in the Image panel.

Click and drag your left mouse in the right window and you will rotate the image you are viewing. Note that if you release the left mouse button while you are still rotating then the scene will continue to spin. You can stop the spinning by clicking in the scene. This spin animation only occurs in navigation mode; i.e. only when the navigation wheel at the upper left-hand corner of the window is depressed.

When you click and drag the right mouse button vertically, you zoom into or out of the scene. If you click and drag the middle mouse button, you translate the image vertically or horizontally. Now drag the mouse upward in the scene so you can view the region from the south, and the mountain range in northern Georgia will stand out. (Note that the scene has been exaggerated vertically by a factor of 100). Set your viewpoint so you are looking approximately from the south to the north. Then, select "Nearest Axis" from the "Align View" combo box, at the top right of the VAPOR window. You see the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Capture Help
Visualizer No. 0
Align View
Interactive Refinement: 0
View Animation Region 2D Image Probe Iso Flow DVR
Renderer Control
View
New
Delete
Duplicate In:
Image Display Settings
Select Image File
Fit box to current region
Fit box to Image
Local user extents (X,Y,Z)
Grid extents (X,Y,Z)

Instance: 1 ☑

Refinement: 0

Orientation: X-Y

File name: lowres/georgia_satview.gtif

☑ Georeference

☑ Crop to bounds

Place upright

☑ Apply image to terrain

Opacity: 1

Plane/Image Center

X 472500

Y 522000

Z 157.638

Plane/Image Size

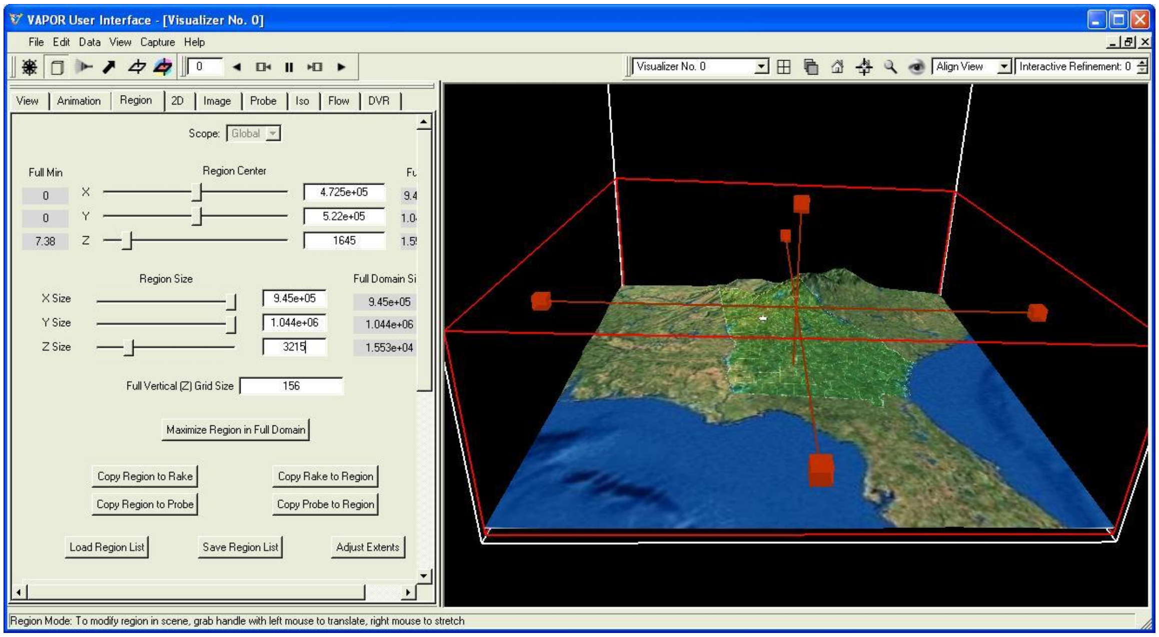
Width 945000

Length 1.044e+06

Figure 1.9: Vertically stretched region above Georgia, from the south

This figure shows the full domain with a vertical extent of 16 km. We are mostly interested in the weather near the terrain surface, so we shall restrict our attention to the bottom 1/10th of the volume. Click on the cube symbol near the top left of your screen, on the button identified in its tool-tip as Region Select Mode. You will see that the volume in the scene becomes enclosed by red lines, with cube-shaped handles on each side. These handles can be used to manipulate the bounds of the region that we visualize. If you ‘grab’ a handle by clicking on it with the left mouse, you can slide the whole region in the direction of the handle. If you ‘grab’ and slide with the right mouse button, you will slide only the side of the region closest to the handle. You are initially prevented from sliding with the left mouse button because the region is the entire domain and you cannot move the region bounds outside of the full data domain.

Click with the right mouse button on the handle at the top of the cube. The handle will change color to yellow. Drag it downward until the red box is about 1/10 of the full height of the original domain, (about 3200 m). Then release the mouse. Note that you can also read the height of the region in the Region panel, specified as the “Z-size”. To get a closer view, click on the magnifying-glass near the upper right corner of the window. Navigate in the scene using the left and right mouse buttons to get a good view of Georgia from the south. You will see something like the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Capture Help
Visualizer No. 0
Align View
Interactive Refinement: 0
View
Animation
Region
2D
Image
Probe
Iso
Flow
DVR
Region Center
Region Size
Full Domain Si
Maximize Region in Full Domain
Copy Region to Rake
Copy Rake to Region
Copy Region to Probe
Copy Probe to Region
Load Region List
Save Region List
Adjust Extents

Scope: Global

Full Min		Region Center
0	X	4.725e+05
0	Y	5.22e+05
7.38	Z	1645

	Region Size	Full Domain Si
X Size	9.45e+05	9.45e+05
Y Size	1.044e+06	1.044e+06
Z Size	3215	1.553e+04

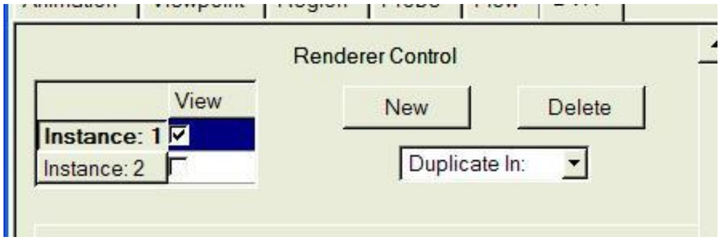
Full Vertical (Z) Grid Size: 156

Region Mode: To modify region in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 1.10: View of selected region near the ground with box handles

1.4 VAPOR Renderers and Renderer Control

The “Instance:1” checkbox that you used to enable rendering of the terrain image is a device that you will see in many other tabs. DVR, Flow, Iso, 2D, Image, and Probe tabs control the rendering of images in the visualizers. Each of these tabs has a Renderer Control section near the top, appearing as follows:


Renderer Control
View
New
Delete
Duplicate In:

Instance: 1 ☑
Instance: 2 ☐

Figure 1.11: Renderer Control

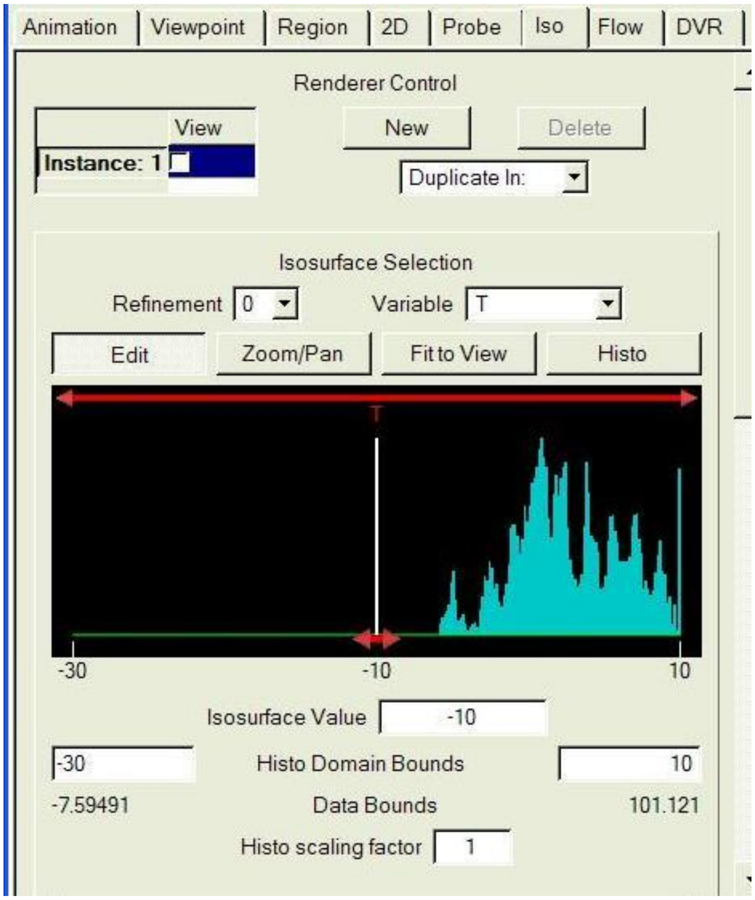
Using the Renderer Control, you can control any number of renderers in the current visualizer, after you have loaded a dataset. The different renderers are identified as “Instance: 1”, “Instance: 2”, etc. When you click in the check-box, the specified renderer is *enabled*; i.e. the renderer will start drawing in the current visualizer. One of the renderers is *active*, in the sense that the parameters displayed in the current tab, below the Renderer Control, apply to that renderer. The active renderer instance is indicated by boldface text on “Instance: N” button, and it appears depressed relative to adjacent instance buttons.   When there are multiple instances, you can change the active renderer by clicking on the

Instance: button. Additional renderers can be created by using the "New" button or the "Duplicate In" selector. The "Duplicate In" selector constructs a duplicate of the renderer in the current visualizer, or in any other visualizer window (when multiple visualizers are available). Multiple Flow, Iso, Image, 2D, and Probe renderers can be enabled at the same time in the same visualizer. However, only one DVR renderer can be enabled at one time, because of limitations in hardware support for volume rendering.

1.5 Constructing an isosurface of the temperature

Click on the Iso tab to specify the parameters of an isosurface. In order to construct an isosurface of T, it is useful to first check the values of the variable T in the current region. From the "Variable" selector, pick the variable T. Note the black rectangle in the Iso tab: This is the histogram window (see figure 1.12), where histograms of the iso variable are displayed. Below the histogram window, to the left and right of the descriptor "Data Bounds" are values -7.59491 and 101.12110.

The Isosurface Value textbox indicates the value of the variable T for the displayed isosurface. Type in an Isosurface Value of -10. The data bounds below the Isosurface Selection window indicate the min and max value of the T variable at the first time step. Type the values -30 and 10 in the left and right "Histo Domain Bounds" immediately above the Data Bounds, specifying an interval of values of T that will be useful for observing the cold air mass. Press enter to set these values, then click the buttons "Fit to View" and "Histo" above the histogram window. You will see a histogram as shown below:


Animation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Renderer Control
View
New
Delete
Duplicate In:
Isosurface Selection
Edit
Zoom/Pan
Fit to View
Histo
T
-30
-10
10

Instance: 1 ☐

Refinement 0

Variable T

Isosurface Value -10

-30 Histo Domain Bounds 10

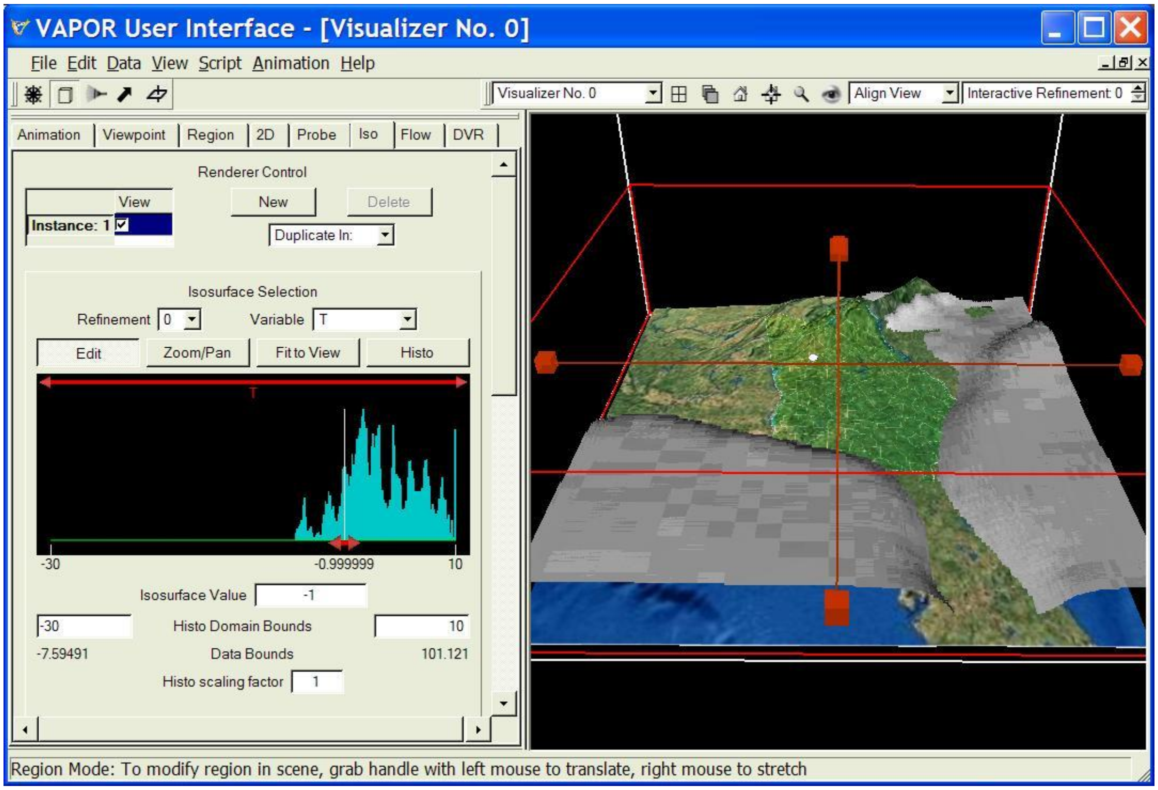
-7.59491 Data Bounds 101.121

Histo scaling factor 1

Figure 1.12: Isovalue selection window

You may note that there is a peak in the histogram at 10. This is because all values of T that are above 10 are shown at the largest value in the histogram.

Near the top-left of the Iso tab, under the heading "Renderer Control" there is a check-box, identified as "Instance 1:" Click in this check-box to enable an isosurface rendering. You will not see an isosurface because, as indicated in the histogram, all the values of T are greater than -10. Type in the value -1 as the Isosurface value (below the histogram window). You can also set the isosurface value by grabbing the isovalue slider (the red double-arrow at the bottom of the histogram) with the left mouse, and sliding it to about -1. You will then see the following isosurface of the variable T:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement: 0
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Renderer Control
View
New
Delete
Duplicate In:
Isosurface Selection
Edit
Zoom/Pan
Fit to View
Histo
T
-30
-0.999999
10

Instance: 1 ☑

Refinement 0

Variable T

Isosurface Value -1

Histo Domain Bounds -30 10

Data Bounds -7.59491 101.121

Histo scaling factor 1

Region Mode: To modify region in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 1.13: Isosurface rendering with T = -1

[Note: On some systems with older or less capable graphics cards you may experience problems with isosurface rendering. If so, bypass the remainder of this section. You can instead visualize the cold air mass using the DVR renderer. Instructions for rendering T with the DVR are given at the end of Section 2.]

Grab the slider at the bottom of the histogram window and slide it to the right or left, to get an idea of how the isosurfaces vary with T.

1.6 Animating the isosurface

Time steps and animation can be controlled in the Animation tab, or by using the animation toolbar. The animation toolbar, at the top of the VAPOR main window, provides a set of VCR controls and a text window as follows:

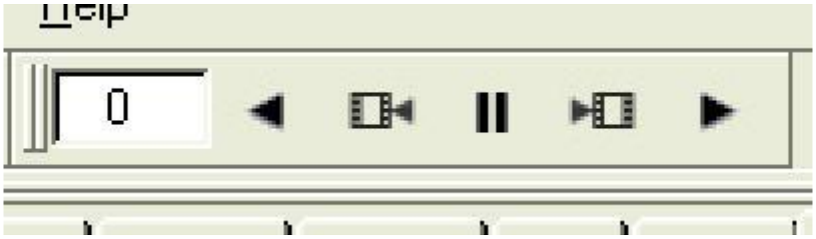


Figure 1.14: the Animation Toolbar

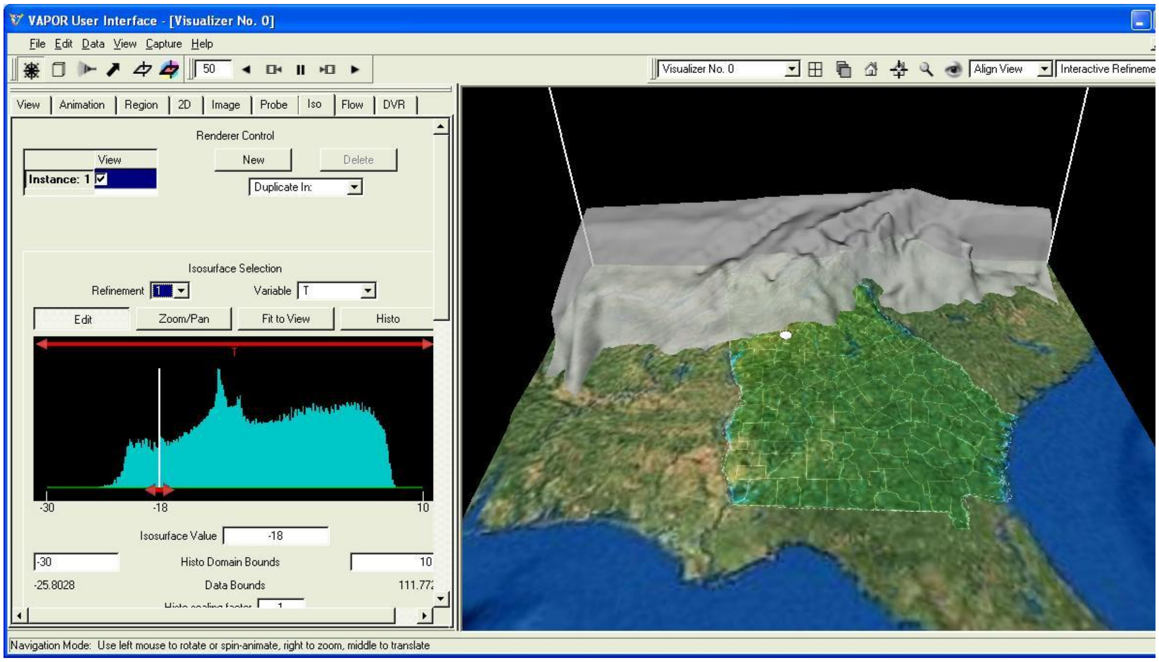
The animation toolbar controls the time-stepping in the current active visualizer window. It contains the most useful functions of the Animation tab.

Select an isovalue of about -18, and then click on the Animation tab. Click the right-pointing triangle (►) to play forward in time. You will see that, starting at about frame 25, the cold air mass advances over the mountains at night, then recedes during the day, then advances and recedes several more times, indicating diurnal changes.

You may note that the isosurface is somewhat rough. There are several things that can be done to improve the visual quality:

- Change the Bits per voxel (at the bottom of the Iso panel) to 16. This will make the surface appear much smoother.
- Reduce the Constant Opacity to a value of 0.9, so that you can see the terrain under the isosurface. The opacity is set in a text box on the right side of the bottom "Isosurface Appearance" section of the isosurface panel.
- In the Region panel, increase the "Full Vertical (Z) Grid Size" to 400. This will result in a more accurate interpolation of the data near the terrain boundary.
- Change the Refinement level to 1 (using the selector near the top of the isosurface panel, resulting in more accurate isosurfacing). This will improve the visualization of those time step values that are divisible by 10. Because of the earlier setting in the preferences panel in section 1.1, when you try to visualize other timesteps at refinement level 1, VAPOR will automatically revert to refinement level 0, because refinement level 1 is not available. If you did not set the user preferences, then whenever you look at times not divisible by 10, you will see a message indicating that the data for T is not available at the requested refinement level.

The above changes may make the rendering slower, so you may want to postpone such changes until you are ready to produce your final images. The following illustrates the isosurface at time step 50, after making the above changes:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Capture Help
50
Visualizer No. 0
Align View
Interactive Refineme
View Animation Region 2D Image Probe Iso Flow DVR
Renderer Control
View
Instance: 1 ☑
New
Delete
Duplicate In:
Isosurface Selection
Edit
Zoom/Pan
Fit to View
Histo
T
-30
-18
10

Refinement 1

Variable T

Isosurface Value -18

Histo Domain Bounds -30 10

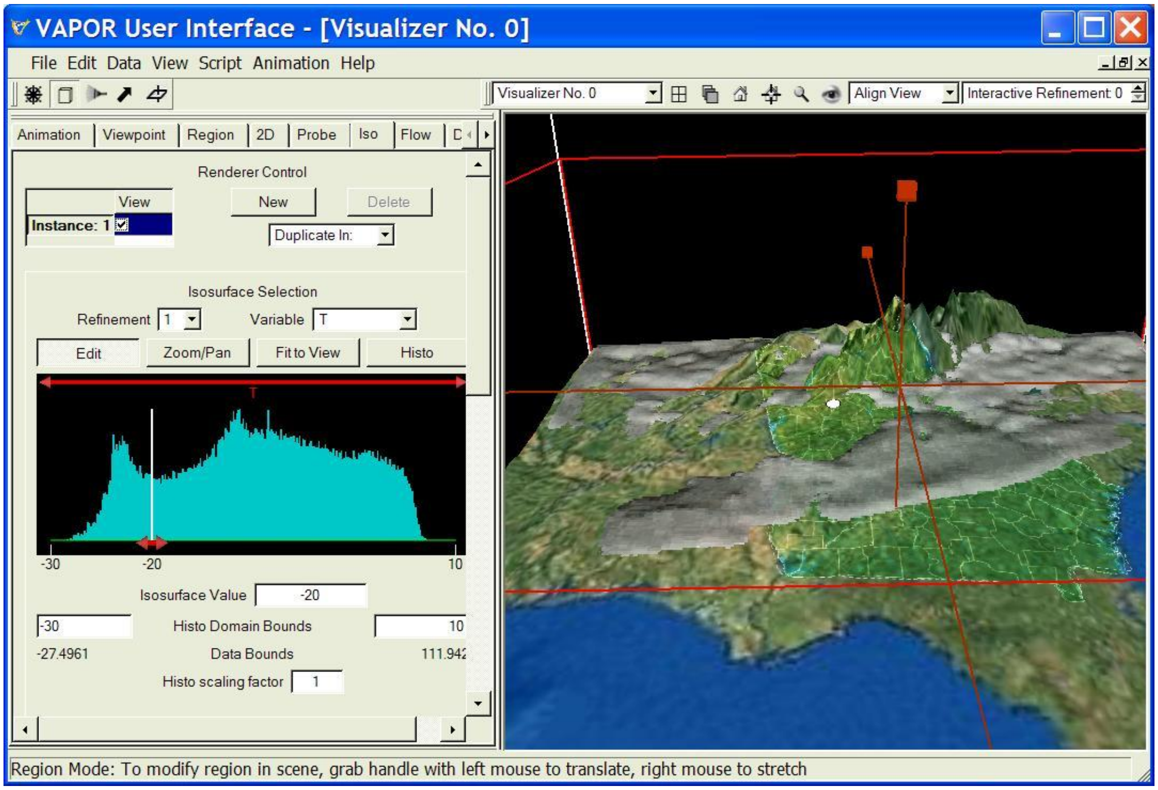
Data Bounds -25.8028 111.77

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 1.16: Isosurface of T = -18 at time step 50

Some features of the approaching and receding cold air mass can be easily seen by animating the isosurface. For example, observe the isosurface between time steps 140 and 155. You will observe that as the air mass recedes, the cold air "pools" in the valleys. You may also note that the vicinity of Atlanta is relatively warmer than the surrounding areas.

To take a closer look, stop the animation at time step 150. On the Iso panel, set the Refinement level to 1, and set the iso value to -20. From the Image panel, set the refinement level to 1. By dragging with the right mouse, zoom into the scene to see an image like figure 1.16 below:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Align View
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
Renderer Control
View
New
Delete
Duplicate In:
Isosurface Selection
Edit
Zoom/Pan
Fit to View
Histo
T
-30
-20
10

Visualizer No. 0

Interactive Refinement: 0

Instance: 1 ☑

Refinement: 1

Variable: T

Isosurface Value: -20

Histo Domain Bounds: -30 10

Data Bounds: -27.4961 111.94

Histo scaling factor: 1

Region Mode: To modify region in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 1.16: Pooling of cold air at time step 150

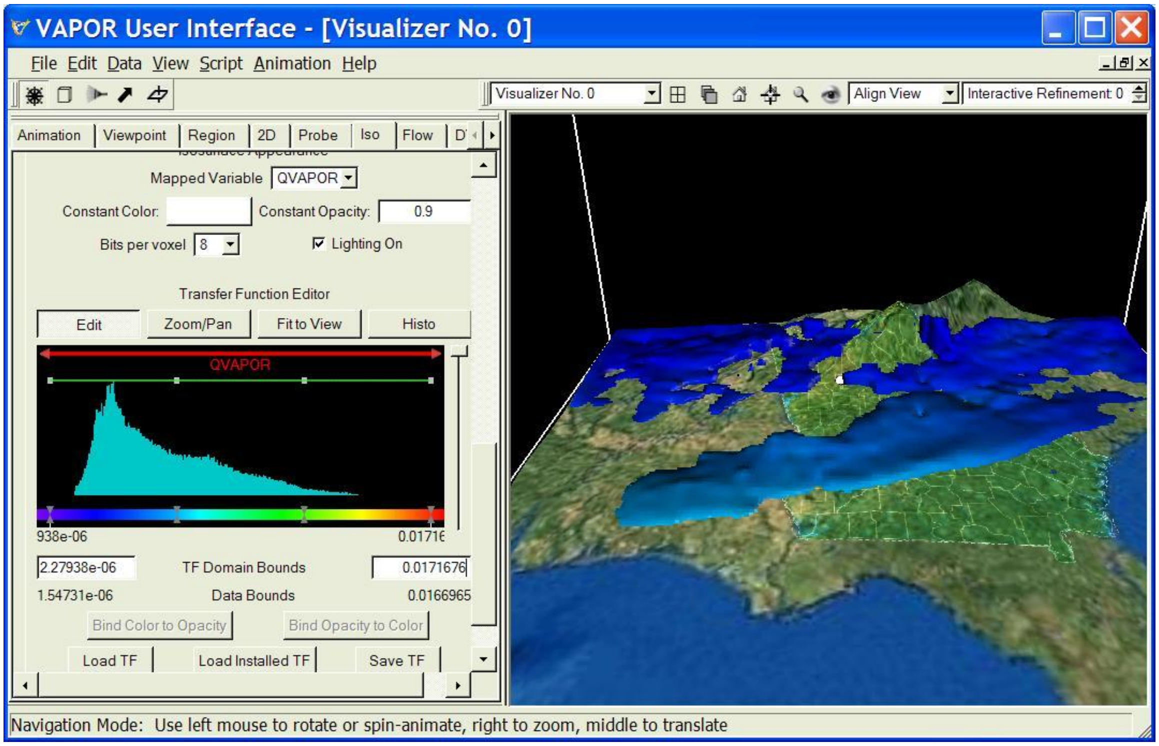
1.7: Mapping color and opacity onto an isosurface

A feature of VAPOR, introduced in version1.3, is the capability to color an isosurface based on the values of another variable. We shall illustrate this capability by coloring the isosurface of T based on the values of the variable QVAPOR.

Disable the isosurface rendering by un-checking the “Instance: 1” checkbox. Scroll down to the bottom of the Iso panel. In the section labeled “Isosurface Appearance”, using the “Mapped Variable” selector, pick the variable “QVAPOR”. There is also a section labeled “Transfer Function Editor” in which the variable “QVAPOR” is now identified in red text. The transfer function determines is a mapping of QVAPOR to color and opacity that will be applied to the isosurface.

We shall alter the color mapping, reversing the direction of the color scale so that larger values of the variable are associated with red, smaller values with blue-violet. Click on the button “Load Installed TF” and then select the file “reversedOpaque.vtf” and click “Open”. Note that the opacity mapping (by default) is the constant 1, indicated by the horizontal green line across the top of the transfer function window. Click on the “Histo” button above the transfer function mapping window to show a histogram of the values of QVAPOR in the current region.

Now scroll up to the top of the Iso tab and enable the isosurface by checking the “Instance: 1” checkbox. You will see that the isosurface is colored mostly blue and blue-violet indicating the values of QVAPOR on the isosurface are mostly in the range (0, 0.006), as follows:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
QVAPOR
938e-06
0.01716
Bind Color to Opacity
Bind Opacity to Color
Load TF
Load Installed TF
Save TF

Mapped Variable QVAPOR

Constant Color: Constant Opacity: 0.9

Bits per voxel 8 ☑ Lighting On

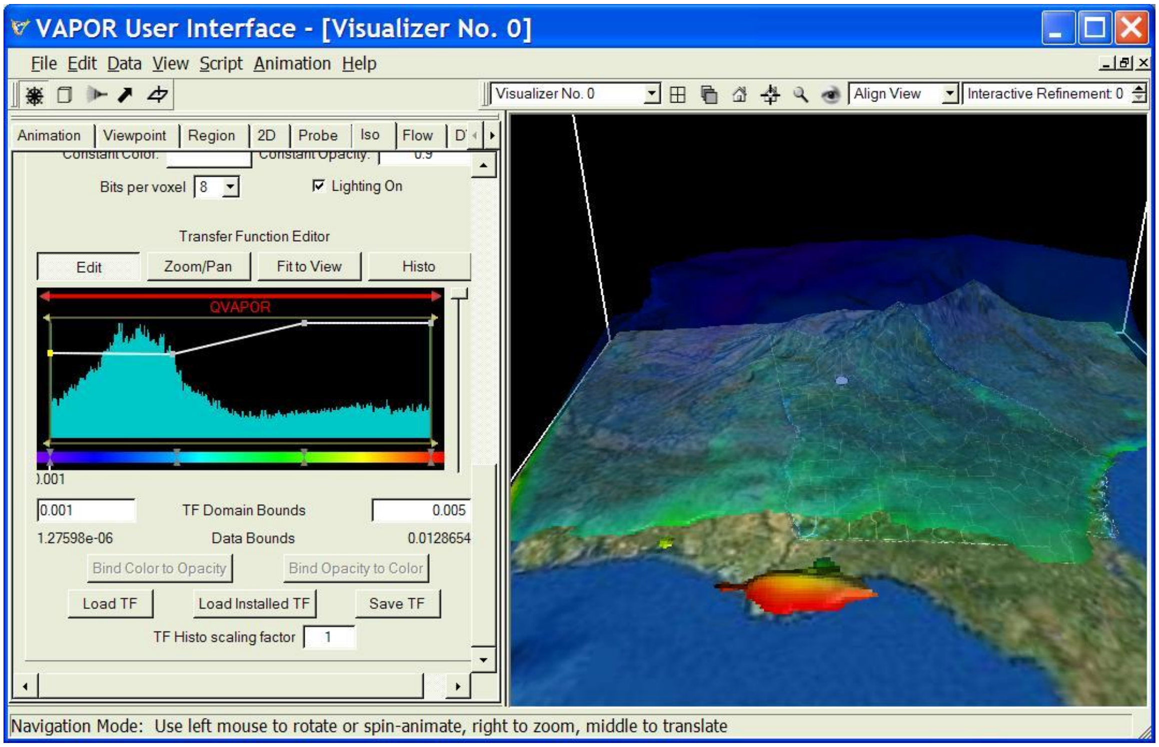
2.27938e-06 TF Domain Bounds 0.0171676

1.54731e-06 Data Bounds 0.0166965

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 1.17: Isosurface of T colored according to values of QVAPOR

Next we modify the transfer function to provide a more interesting mapping, using both transparency and color mapping. On the Animation tab, set the current time step to 130. Returning to the transfer function editor at the bottom of the Iso tab, click on the Histo button to see the values of QVAPOR in the current region at time step 130. Below the histogram window, type in the values 0.001 and 0.005 as the left and right TF Domain Bounds, then click “Fit to View” and “Histo” to see a histogram based on the new domain you set. To de-emphasize the lower values of QVAPOR, click on each of the two leftmost points on the green line across the top of the transfer function window, and drag them about ¼ of the way downward (as shown below). This will cause the corresponding values of the QVAPOR variable to map to smaller opacities, making the isosurface partially transparent at lower values of QVAPOR. The resulting image is shown below, emphasizing the part of the isosurface where QVAPOR is largest:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Align View
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
D
Constant Color:
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
QVAPOR
).001
Bind Color to Opacity
Bind Opacity to Color
Load TF
Load Installed TF
Save TF

Visualizer No. 0

Interactive Refinement: 0

Constant Opacity: 0.9

Bits per voxel 8

☑ Lighting On

TF Domain Bounds: 0.001 0.005

Data Bounds: 1.27598e-06 0.0128654

TF Histo scaling factor 1

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 1.18: Color and opacity mapped to emphasize features on isosurface at time step 130

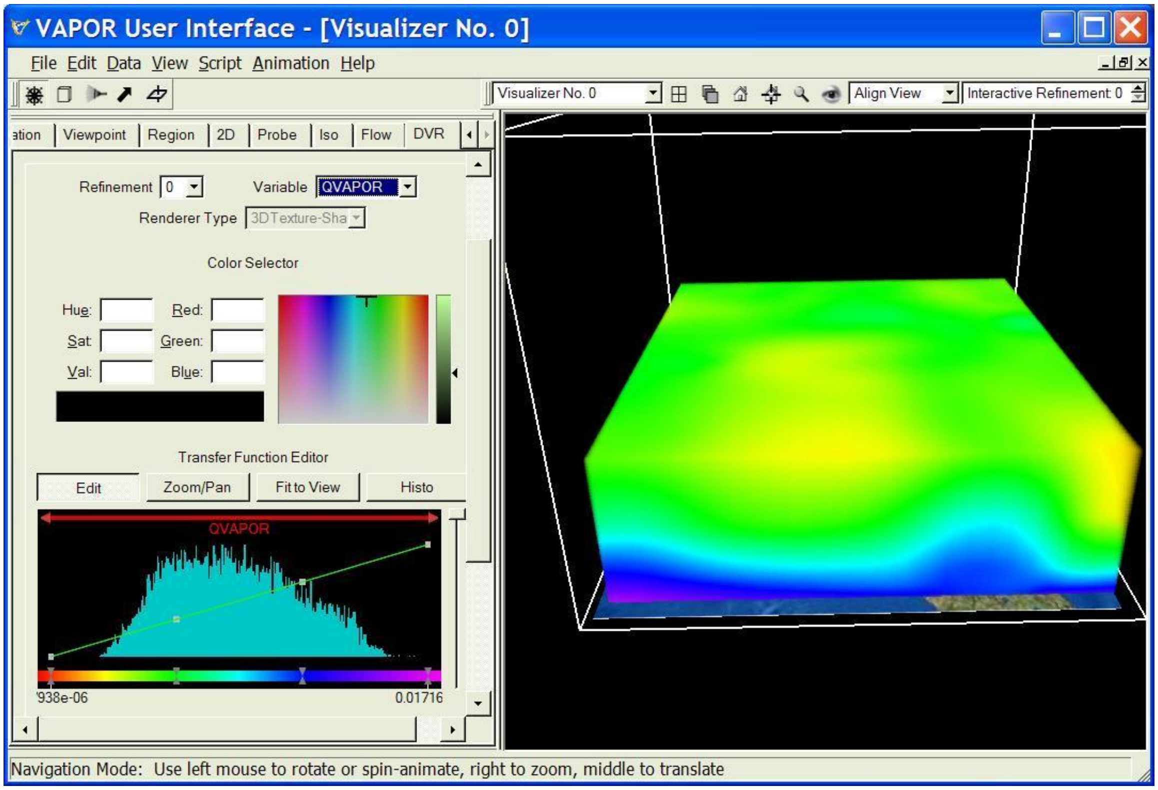
You may find it interesting to animate this isosurface between time steps 130 and 150, to see the evolution of the cold air with higher QVAPOR values, or to experiment with different mappings of color and opacity. Before proceeding to the next section, disable the color mapping of QVAPOR by setting the Mapped Variable back to “constant”.

Section 2: Volume Rendering of QVAPOR and T

2.0 Setting up for volume rendering

We shall next do a volume rendering of the “QVAPOR” variable. This is useful for visualizing the cold front that precedes the advance of the cold air mass. This volume rendering can also be used to see the presence of moist air, moving northward from the Gulf of Mexico when the cold air retreats. We shall rely on the setup that we prepared in Section 1. If you are beginning at this point, you can load the session file for figure 1.17 and load the dataset and satellite image as in section 1.3. Enable the terrain image by checking the “Instance:1” checkbox in the Image panel. Proceed as follows:

Make sure the isosurface is disabled, by un-checking the checkbox in the instance selector at the top-left of the Iso tab. On the animation tab, set the current timestep to 0. Then, click on the DVR tab. On the upper-right side of the DVR tab there is a “Variable” selector. Select the variable “QVAPOR” from the list. Near the top-left of the DVR tab, check the first renderer instance, identified as “Instance 1:” to enable a volume rendering. Click on the magnifying glass (near the upper right corner of the window) to view the current region of data. You will see the following:



VAPOR User Interface - [Visualizer No. 0]

Visualizer No. 0

Interactive Refinement 0

Refinement 0

Variable QVAPOR

Renderer Type 3DTexture-Sha

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

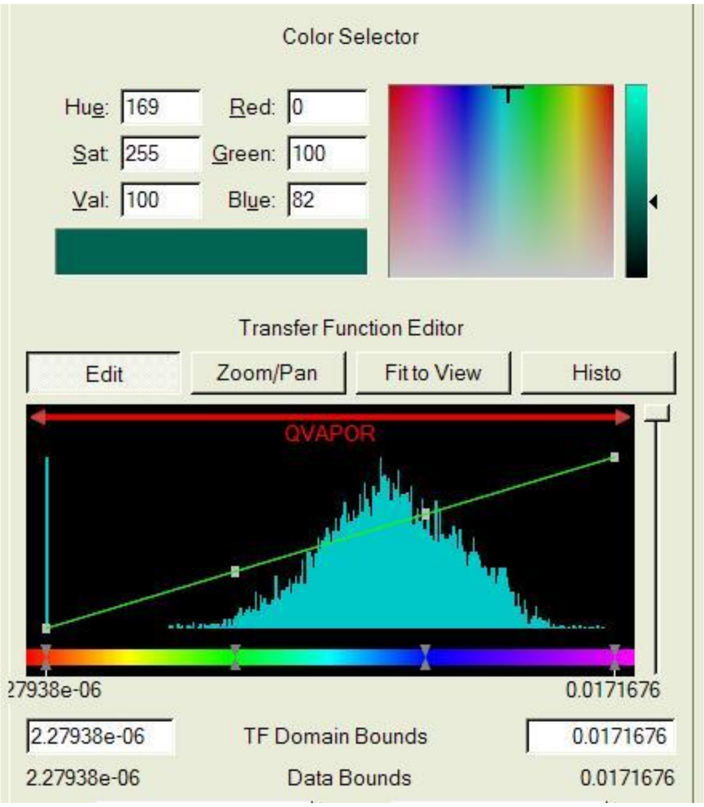
File
Edit
Data
View
Script
Animation
Help
Align View
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Color Selector
Hue:
Sat:
Val:
Red:
Green:
Blue:
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
QVAPOR
938e-06
0.01716

Figure 2.1: Volume rendering of QVAPOR

The image on the right is a 3D volume rendering of the variable ‘QVAPOR’ from the data set. The colors are based on a default color mapping, showing the variations of the QVAPOR variable from its lowest value (red) to the highest value (violet).

2.1 Designing a transfer function

The appearance (i.e. color and transparency) of the volume rendering is controlled by the Transfer Function Editor in the middle of the DVR panel, as shown below:



Hue: 169
Red: 0
Sat: 255
Green: 100
Val: 100
Blue: 82

2.27938e-06 TF Domain Bounds 0.0171676
2.27938e-06 Data Bounds 0.0171676

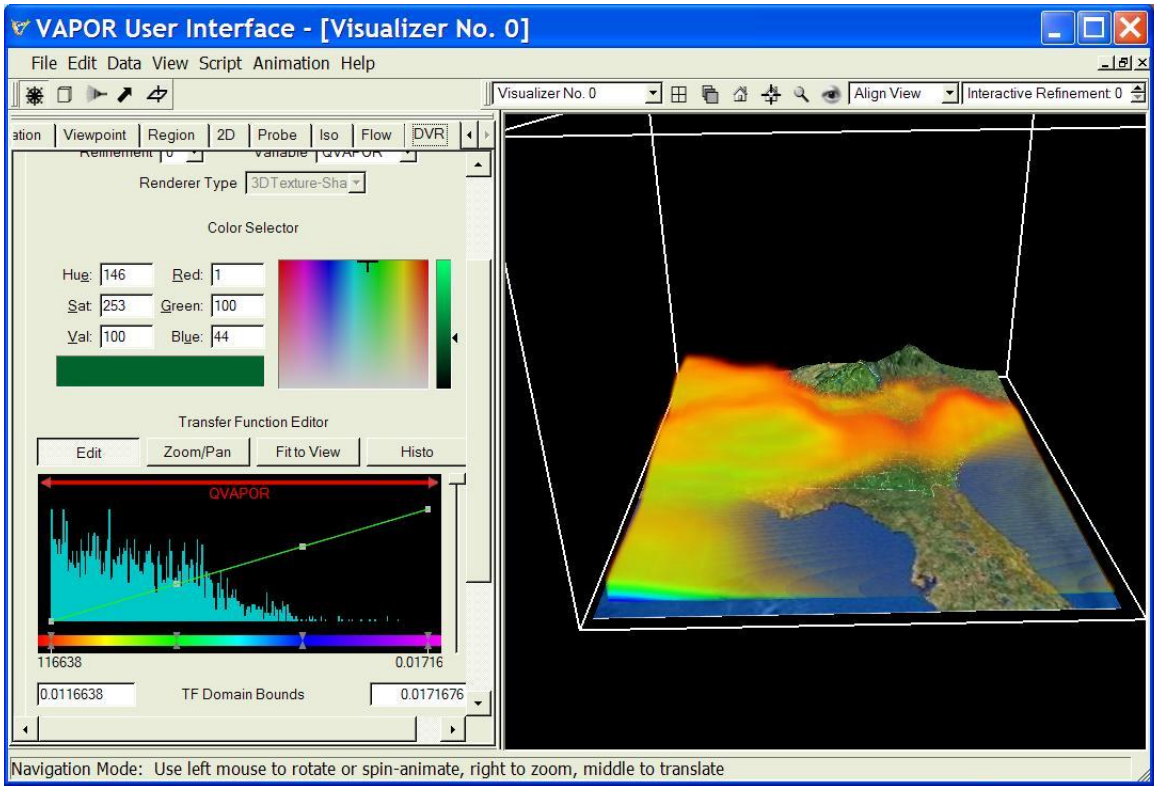
Figure 2.2: The VAPOR Transfer Function Editor

The transfer function enables visualization of important values of a variable, by making the volume opaque at the important values and transparent elsewhere. It also can be used to visualize the placement of different values of a variable by assigning various colors to these values.

We shall edit the transfer function to highlight the larger values of the QVAPOR variable, so we can see more clearly the motion of moist air. In the center of the transfer function editor window there is a blue-green histogram, indicating the values of the variable ‘QVAPOR’. You can make values of the variable less prominent by making them more transparent, and different non-transparent values can be distinguished by applying different colors to them.

The transfer function editor enables you to define a mapping from data values (in this case, values of the variable “QVAPOR”) to both color and opacity. The color is controlled by a horizontal bar of colors at the bottom of the editor. Opacity is controlled by the green line in the center region. You initially will see four color control points (grey triangle pairs) on the color bar, and four opacity control points (grey squares) on a diagonal green line. Colors and opacity in the scene are interpolated between the control points.

We must make some changes in the domain of the transfer function, to focus our attention on larger values of QVAPOR. Note that the domain is initially set to (2.279e-06, 0.0172). This is the range of the variable QVAPOR at the first time step. Grab the left end of the red arrow at the top of the transfer function window, and slide it to the right, about 2/3 of the way across the TF window, Then, above the histogram window click on the button “Fit to View” and on the “Histo” button. The editor should appear as follows:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Color Selector
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
QVAPOR
116638
0.01716

Visualizer No. 0

Align View

Interactive Refinement: 0

Renderer Type: 3DTexture-Sha

Hue: 146
Sat: 253
Val: 100
Red: 1
Green: 100
Blue: 44

TF Domain Bounds: 0.0116638 0.0171676

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 2.3: Transfer Function Editor with higher QVAPOR values mapped to increased opacity.

Next we make some changes in the opacity curve, to show some important values of the variable ‘QVAPOR’. We are interested in the higher values of QVAPOR, as they indicate presence of water vapor. To show these values we make the opacity lower for smaller values of QVAPOR. We will make the opacity curve in the transfer function editor look like the curve you see in Figure 2.4 below.

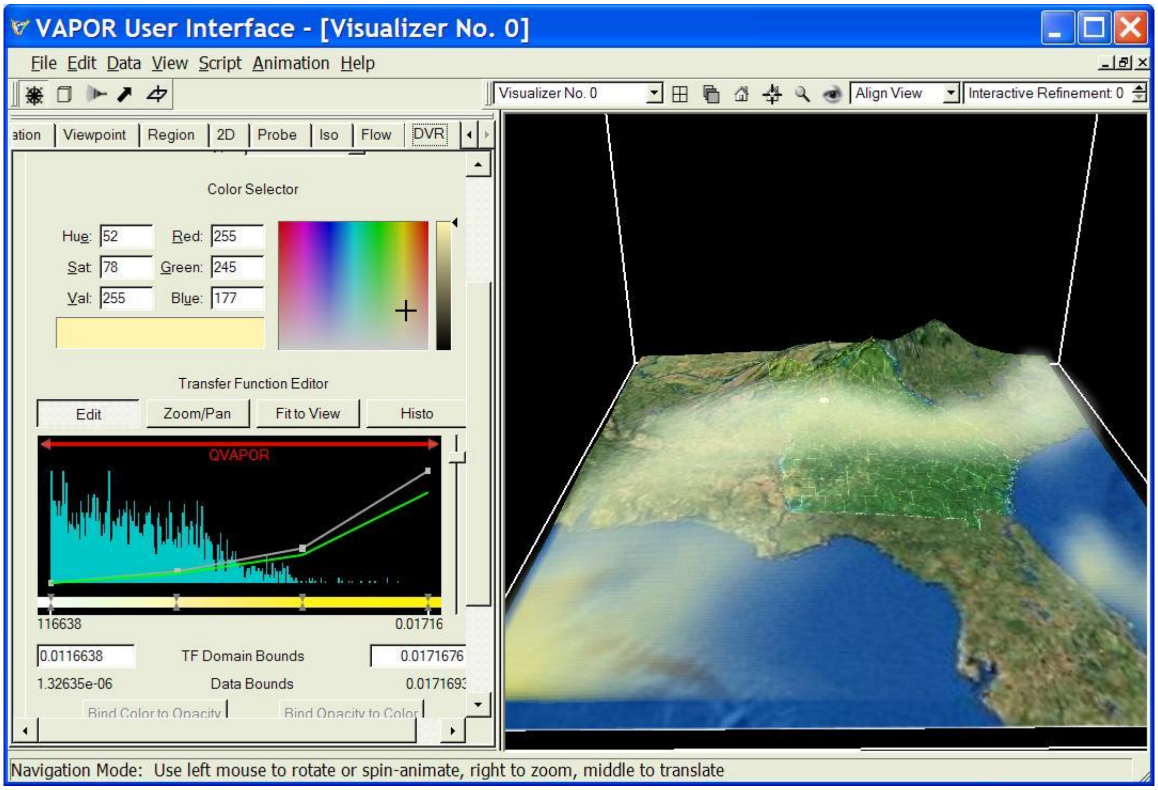
You move control points by clicking on them with the left mouse button and dragging them to their new locations. You create new control points by clicking with the right mouse at the desired location, and then selecting "New Opacity Control Point" from the menu of choices.

First select the second opacity control point from the left, and drag it down almost to the bottom of the opacity graph, setting the opacity to about 0.10. Drag the third opacity control point from the left downward to an opacity of about 0.30. (You can see the current opacity value by holding the mouse over the point, and you can set the value by clicking the right mouse button over the control point.) Leave the fourth (rightmost) opacity control point alone, so that values of QVAPOR greater than or equal to 0.017 will always be opaque If you make mistakes, you can undo (or redo) your latest changes by selecting "Edit" from the main menu, and clicking to undo (or redo) the specified actions. Note that you can also adjust the overall opacity with the vertical slider to the right of the opacity window.

It will also improve the visualization to change the colors. A yellow color can be used to indicate increased moisture. With the right mouse button, click on the left color control point (at the left end of the color bar). Select the "Edit control point" option. From the menu that results, select white, for example choose (R,G,B) to be (255,255,255). Assign colors to other control points using increasing levels of yellow, such as shown below. (You can also select colors by selecting the color control point and then picking a color in the color selector above the transfer function editor).

Animate the scene from frames 10 to 40. Note that a band of moist air moves from north to south across Georgia. These are the cloud bands ahead of the cold front we are looking for. Adjust the slider on the right of the transfer function editor window up and down, to make the moist air transparent enough to see it the terrain.

Zoom into the scene by dragging the mouse upward in the scene with the right mouse button depressed. Your transfer function and visualizer should look about like the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Color Selector
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
QVAPOR
116638
0.01716
Bind Color to Opacity
Bind Opacity to Color

Hue: 52 Red: 255
Sat: 78 Green: 245
Val: 255 Blue: 177

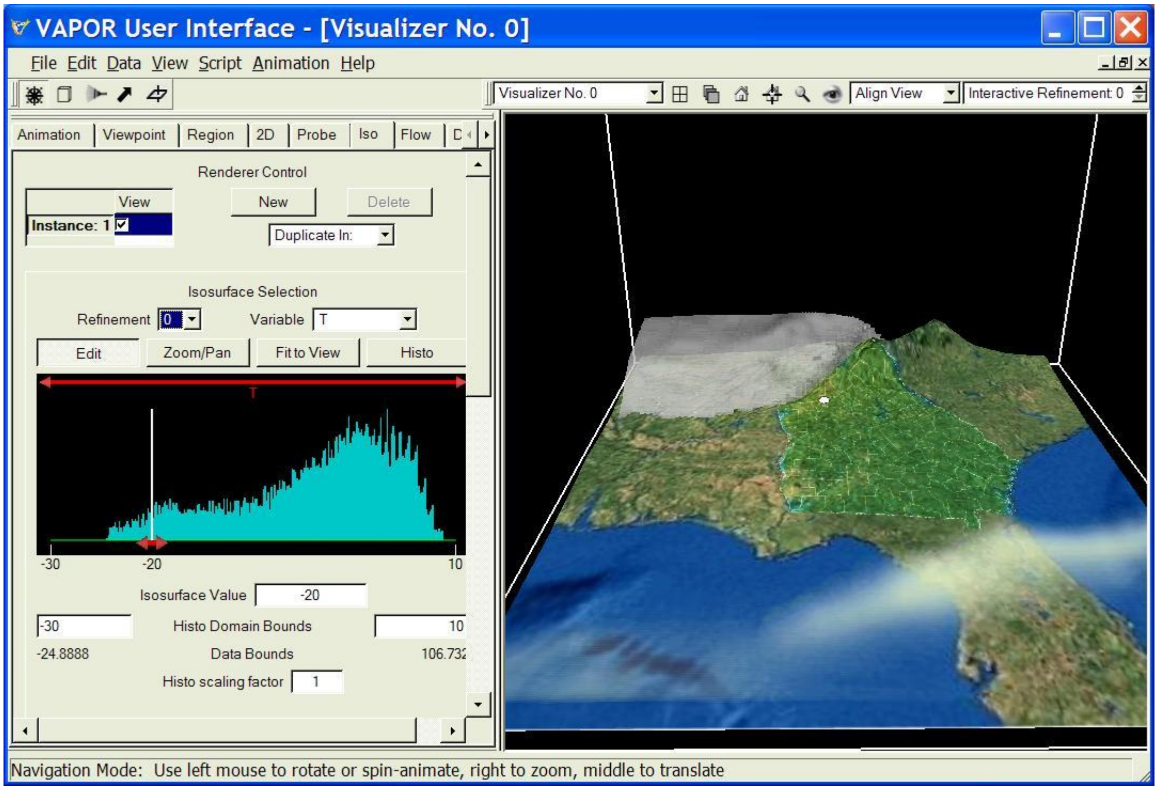
0.0116638 TF Domain Bounds 0.0171676
1.32635e-06 Data Bounds 0.017169

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 2.4: DVR of QVAPOR with edited colors and opacities
in the Transfer Function at time step 10.

2.2 Animating the humidity and temperature

To track the motion of the cold front, use the animation toolbar. Click the right-pointing triangle (►) button to play forward in time. If it plays too fast, reduce the Max Frames/Second value. You will see the cold front pass in the first 40 time steps. Later, starting at frames 140 or so, moist air returns from the south as the cold air dissipates. Click on the Iso tab, and enable the isosurface rendering that we created in Section 1. You can see how the advancing cold air mass follows the cold front, and recedes later. The following image (Figure 2.5) shows this animation at time step 31, when the cold and dry air mass flows over Georgia and the moist air is located farther south, gradually disappearing from the domain.


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
Renderer Control
View
New
Delete
Duplicate In:
Isosurface Selection
Edit
Zoom/Pan
Fit to View
Histo
T
-30
-20
10

Visualizer No. 0

Align View

Interactive Refinement: 0

Instance: 1 ☑

Refinement 0

Variable T

Isosurface Value -20

Histo Domain Bounds -30 10

Data Bounds -24.8888 106.732

Histo scaling factor 1

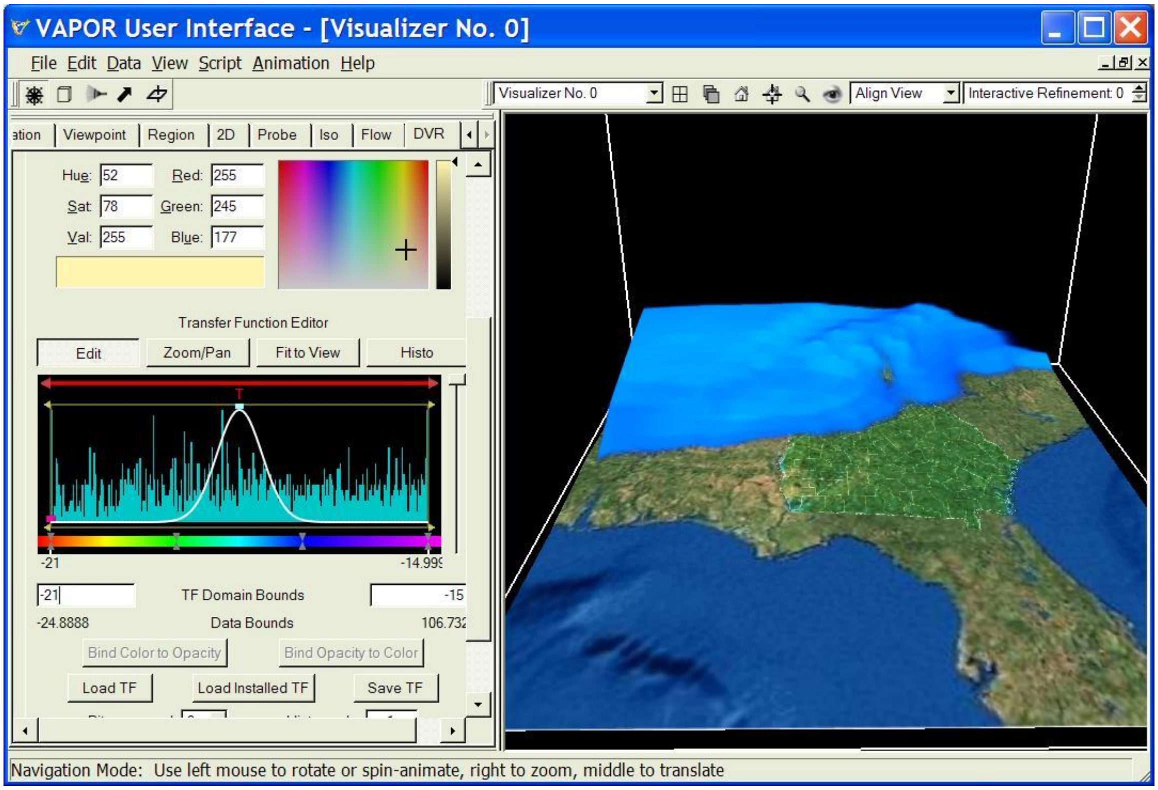
Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 2.5: At time step 31 the cold front, identified by a volume-rendered band of moist air, is followed by the cold air mass.

2.3 Other volume visualizations

Other variables in this WRF dataset, such as QCLOUD or T can be understood using volume visualization. For example, the cold air mass that we tracked (in Section 1) using an isosurface, can also be seen using a volume visualization. Disable the isosurface rendering, by un-checking the “Instance:1” checkbox in the Iso panel. From the DVR panel, change the selected variable from QVAPOR to T. In the animation toolbar, set the current time step to 31, where we know the cold air advance will be visible.

Recall that we found the isosurface T = -18 to be useful in tracking the cold air mass. We can use the transfer function editor to construct an opacity mapping, using a Gaussian curve centered at -18. Click with the right mouse button over any of the opacity control points in the transfer function editor. You will see a menu of choices of actions that can be applied at that control point. Select “Delete Opacity Widget”. Then, click again with the right mouse button in the middle of the opacity edit region. Select “New Opacity Widget → Gaussian”. You will see a gaussian curve filling the opacity region. Type in -21 and -15 as the left and right TF Domain Bounds, and then click on “Fit To View”, to center the Gaussian curve in the opacity window. Click with the left mouse button on the Gaussian curve, to select it. You will see a red square on the left end of the Gaussian curve, and a green square in the middle. These are handles that can be used to modify the curve. Slide the red square down, narrowing the Gaussian curve, to obtain a curve that is concentrated mostly in the center third of the opacity region, as shown below:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
ation Viewpoint Region 2D Probe Iso Flow DVR
Transfer Function Editor
Edit Zoom/Pan Fit to View Histo
T
-21
-14.99
Bind Color to Opacity
Bind Opacity to Color
Load TF
Load Installed TF
Save TF

Visualizer No. 0

Align View

Interactive Refinement 0

Hue: 52 Red: 255

Sat: 78 Green: 245

Val: 255 Blue: 177

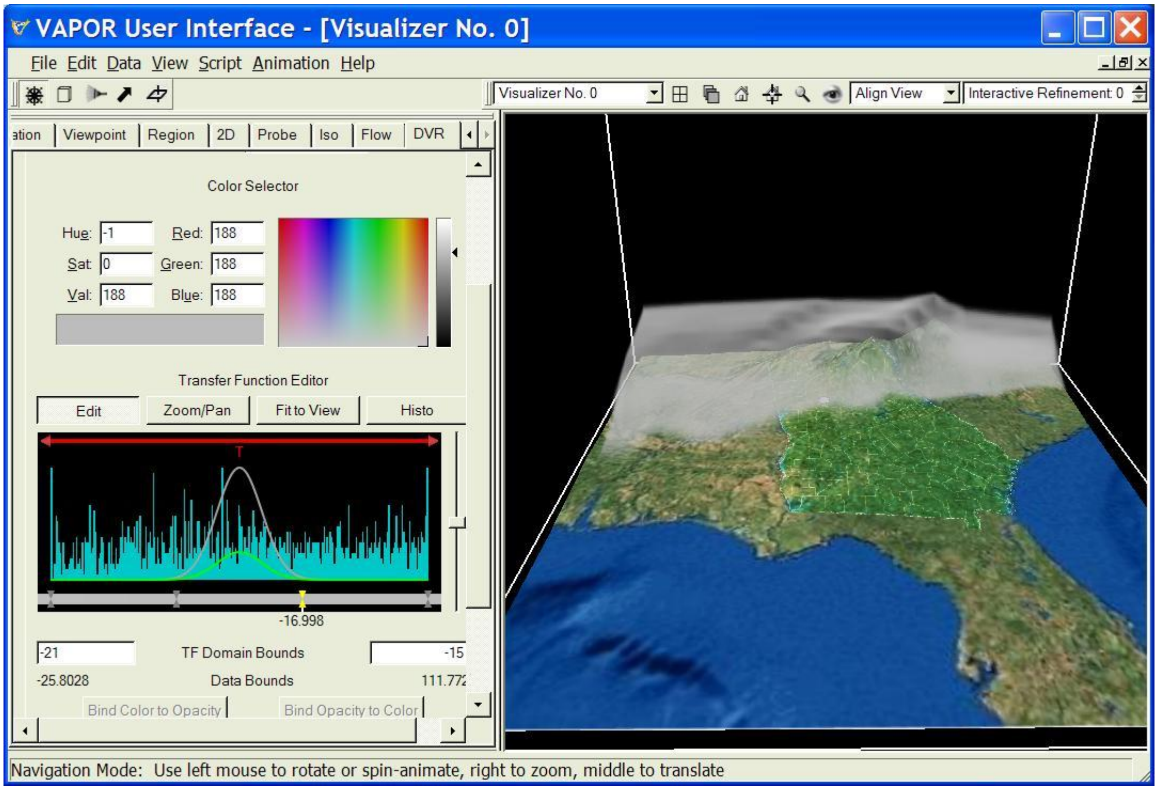
-21 TF Domain Bounds -15

-24.8888 Data Bounds 106.732

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 2.6: Using a Gaussian curve to define a transfer function for T, with opacity concentrated at T = -18.

Using the Color Selector above the Transfer Function Editor, make all four color control points a light grey (e.g. R = G = B = 195). Grab the opacity control slider on the right side of the opacity edit window and pull it about 1/3 of the way down. You should see an image similar to the isosurface we saw before. Compare figure 1.16 to the resulting volume rendering at timestep 50:


VAPOR User Interface - [Visualizer No. 0]
File
Edit
Data
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Script
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Help
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Color Selector
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
T
Bind Color to Opacity
Bind Opacity to Color

Visualizer No. 0

Align View

Interactive Refinement: 0

Hue: -1

Sat: 0

Val: 188

Red: 188

Green: 188

Blue: 188

-16.998

TF Domain Bounds: -21, -15

Data Bounds: -25.8028, 111.77

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 2.7: Volume rendering of T at time step 50,
with grey colors and reduced opacity.

We leave it as an exercise for the user to construct a volume rendering of QCLOUD that illustrates the development and motion of clouds in this dataset.

Section 3: Visualizing Two-dimensional Variables

3.0: Two-dimensional Data

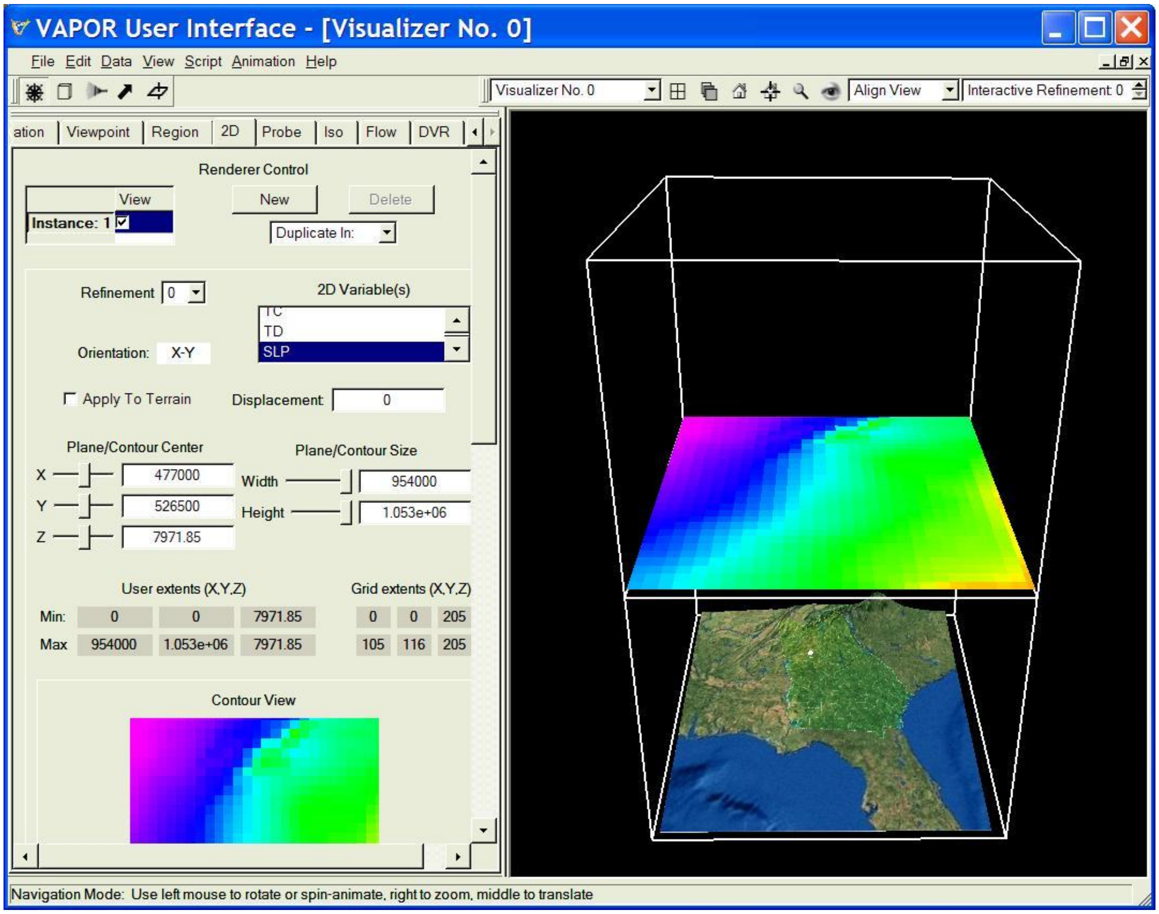
VAPOR includes the capability of visualizing two-dimensional variables. They must be horizontally oriented (a function of the X and Y coordinates in the scene). These can be displayed on a horizontal plane or can be applied to the terrain in the scene. In this section we provide a brief introduction to this capability.

The april_lowres dataset includes several two-dimensional variables. Five of them were output by the WRF-ARW simulation: HGT (height above sea level), T2 (temperature at 2 meters), TH2 (potential temperature at 2 m), and U10 and V10 (wind at 10m). There are also three variables that were calculated using NCL scripts (see http://www.mmm.ucar.edu/wrf/OnLineTutorial/Graphics/NCL/index.html). These derived variables include SLP (sea level pressure), TD (dew point temperature at ground level), and TC (temperature at ground level). Variables that are calculated in NCL can be added to a VAPOR VDC using methods described in the VAPOR/WRF Data and Image Preparation Guide.

3.1 Selecting and displaying a two-dimensional variable.

We shall show how to combine the SLP and TC variables with the isosurfaces and volume rendering created in sections 1 and 2. We continue with the session settings from section 2.3. If you are resuming at this point, then load the session file “wrfFigure2.7.vss”, load the april_lowres dataset, then load and enable the terrain image as in section 1.3. Make sure that the animation panel is set to display time step 50, and the Iso renderer is disabled.

Click on the “2D” tab. In the variable selection box, identified by the text “Select 2D variable(s) mapped to color and transparency”, you will see a list of 2D variables that are in this dataset. Scroll down to see the “SLP” variable name and select it by clicking with the left mouse button. Then enable the 2D visualizer by checking “Instance: 1” at the top of the 2D panel. The 2D image in the scene may not be immediately visible because by default it is a square in the center of the data. Click the eye icon at the top right of the vapor window (above the visualizer) to see the full scene. You should see the following in VAPOR:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Renderer Control
View
New
Delete
Duplicate In:
Contour View

Instance: 1 ☑

Refinement 0

2D Variable(s)
TC
TD
SLP

Orientation: X-Y

☐ Apply To Terrain

Displacement 0

Plane/Contour Center
X 477000
Y 526500
Z 7971.85

Plane/Contour Size
Width 954000
Height 1.053e+06

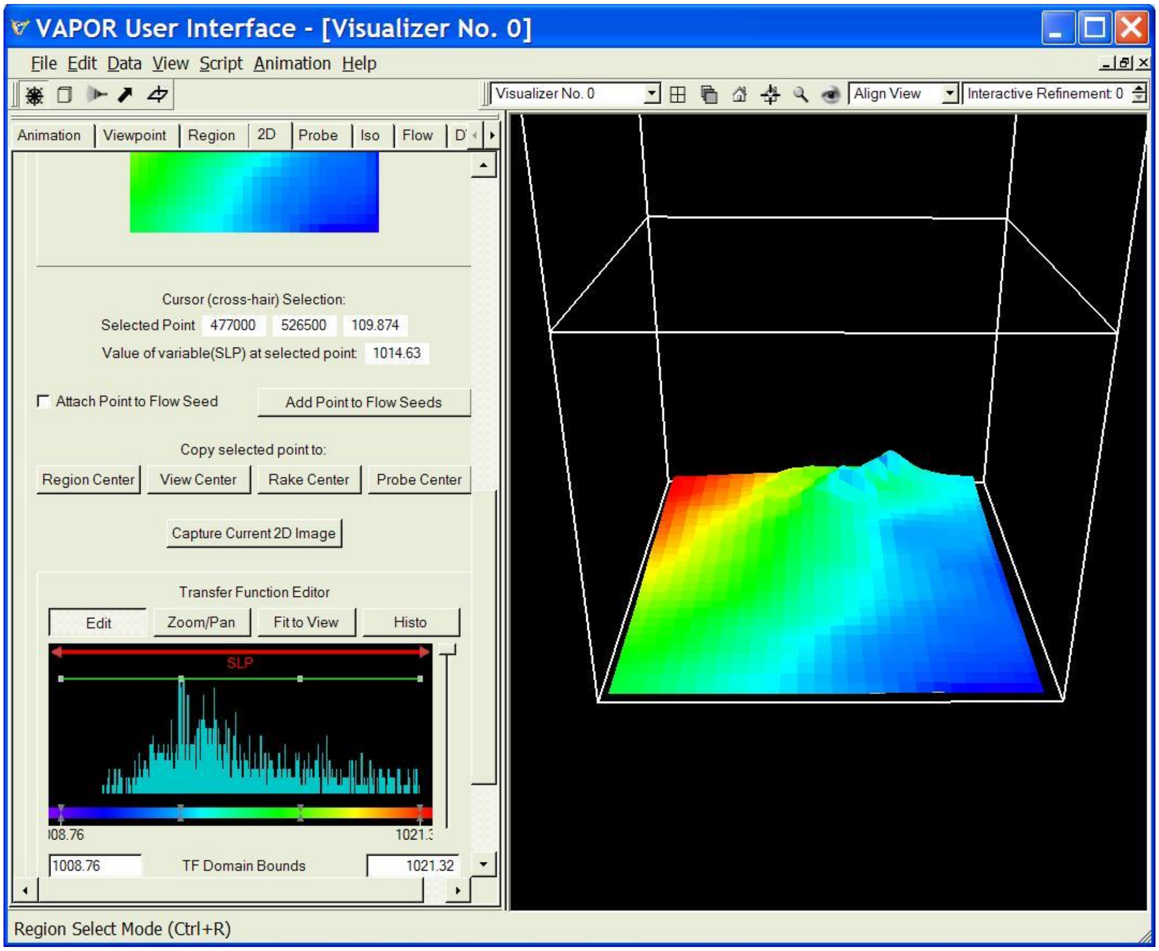
	User extents (X,Y,Z)			Grid extents (X,Y,Z)		
Min:	0	0	7971.85	0	0	205
Max	954000	1.053e+06	7971.85	105	116	205

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 3.1: Default 2D visualization of SLP

To provide a more useful visualization of this 2D variable we shall use this variable to color the terrain surface, and specify a color map that is more intuitive. Below the 2D variable list, check the box labeled “Apply color and opacity to terrain surface”. This will move the 2D image to match the terrain surface elevations. Specify the value 120 as the “Z” coordinate of the Plane/Contour Center in the 2D tab. This will make the 2D surface slightly higher than the satellite image in the Image tab. You should also set the Refinement level to 1, so that this surface uses the same refinement level as the terrain image.

Scroll down to the bottom of the 2D tab where a transfer function editor is provided. We shall reverse the colors in this mapping because it is more intuitive for large values to be associated with red. Click on the button labeled “Load Installed TF”. In the file selection dialog that pops up, select the file “reversedOpaque.vtf”, and click “Open”. The resulting transfer function has constant full opacity, with the color mapping reversed, so that small values of SLP are mapped to blue-violet and large values are mapped to red. Click on the magnifying glass icon at the upper right of the window to zoom into the scene, and you will see the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Align View
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
D
Attach Point to Flow Seed
Add Point to Flow Seeds
Copy selected point to:
Region Center
View Center
Rake Center
Probe Center
Capture Current 2D Image
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
SLP
)08.76
1021.3

Visualizer No. 0

Interactive Refinement: 0

Cursor (cross-hair) Selection:

Selected Point 477000 526500 109.874

Value of variable(SLP) at selected point: 1014.63

1008.76 TF Domain Bounds 1021.32

Region Select Mode (Ctrl+R)

Figure 3.2: SLP values mapped to terrain using reversed color map

We can combine this image of SLP with other visualizations that will show how sea level pressure evolves relative to QVAPOR and T. First, grab the slider on right side of the transfer function editor on the 2D tab, and pull it about halfway down (for an opacity value of 0.5).

Next, click on the Iso tab and enable the isosurface rendering of T. Click on the DVR tab and enable the volume rendering of QVAPOR. Click on the play button in the animation toolbar. Figure 3.3 below shows this visualization at time step 30, with all three rendered variables clearly visible over the terrain image. You will see how the advance of cold air is associated with a high pressure (large values of SLP), and later the decreased pressure is associated with the increased QVAPOR at the end of the sequence.

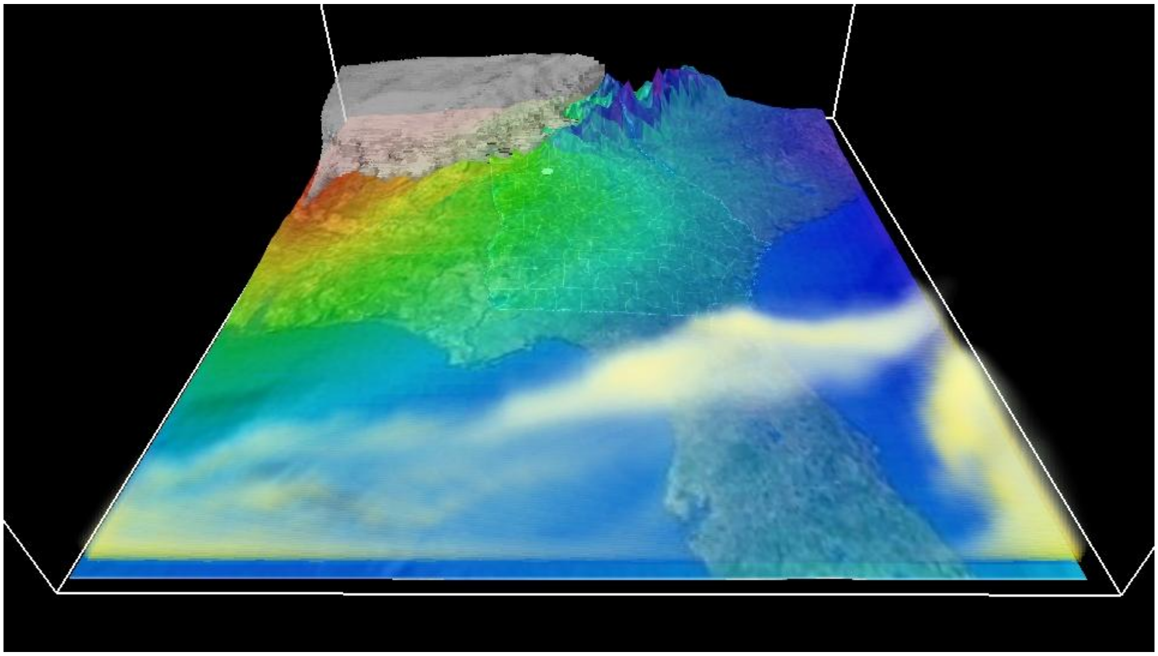


Figure 3.3: Combined 2D rendering of SLP
with 3D volume rendering of QVAPOR and Isosurface of T at timestep 30.

Section 4: Steady flow visualization

4.0 Getting started with flow integration

In this section we shall construct flow visualizations based on the same WRF dataset that we used the previous sections. VAPOR visualizes flow by performing a numerical integration of a vector field in a volume of data. The integration starts at user-specified starting points, called "seed points", and tracks the successive positions in the volume that result from the integration. The successive positions can be visualized with various geometric entities.

We can continue from the session we established in section 2.2. If you are starting at this point, load the session from figure 2.7, reload the april_lowres.vdf dataset and enable the satellite image in the Image panel. Disable the isosurface renderer and the DVR, and set the current timestep in the Animation tab to 0.

4.1 Constructing random streamlines in the wind field

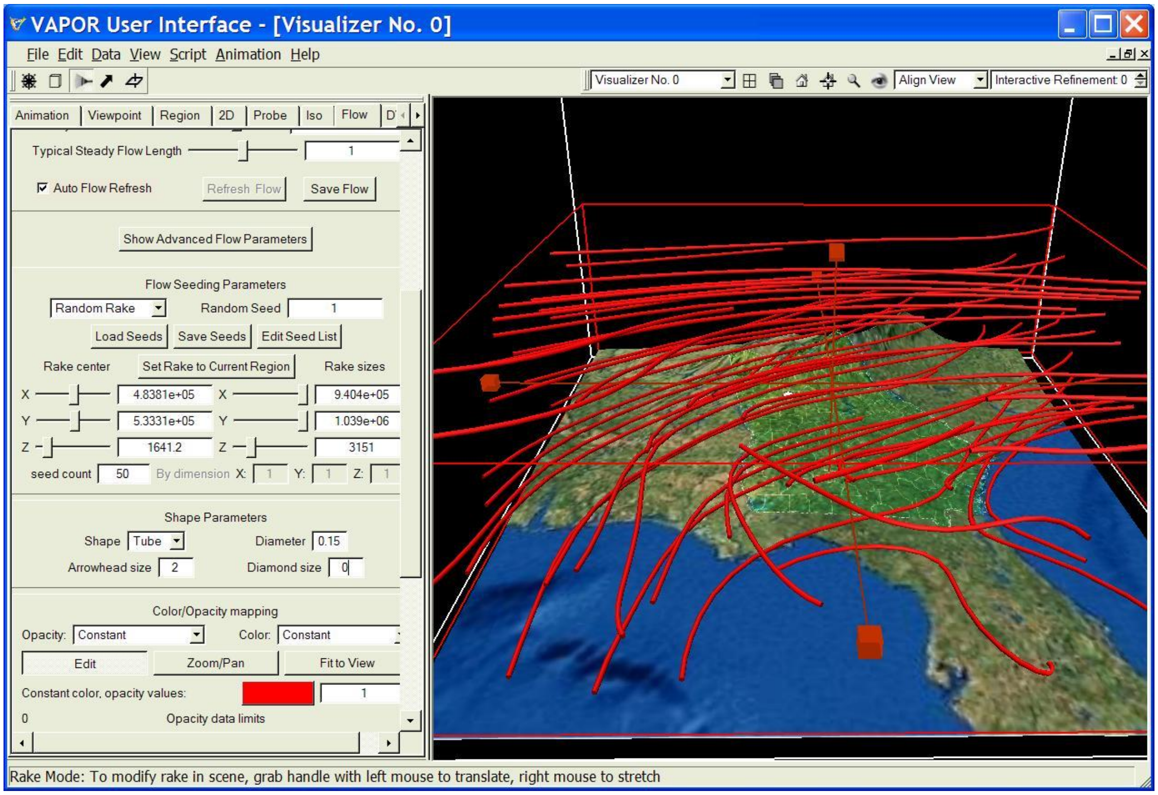
Click on the Flow tab. Before we can design an interesting flow visualization, we need to establish some basic parameters. First, we must specify three variables that define the vector field that will be visualized. The wind is defined by the three components (U,V,W), so set the X, Y, and Z-coordinate selectors (labeled as steady field) to U,V,W. Note that by default, the flow type is *steady.* By steady we mean that the vector field does not change during the flow integration. The successive positions of a flow line in a steady flow depend only on the coordinates along the flow line, not on the elapsed time. You could also have selected the flow Type to be unsteady or Field Line Advection. One can also select whether the flow integration goes forward, backward, or in both directions from the seed points. By default it is set to bidirectional.

Second, we establish the seed points for the flow, i.e. the points that will be used to start the flow integration. Look at the section entitled "Flow seeding parameters". Note that the seed points are initially set to use a "Random Rake". This means that the seed points are randomly generated within the bounds of the box-shaped region defined by the "Rake center" and "Rake sizes". Click on the button "Set Rake to Current Region". (Recall that our current region is a slab at the bottom of the data volume. If a seed point is not inside the current region, there will be no flow line generated.) Set the "seed count" to 50, so that we will see 50 flow lines resulting from the random seed points. This will give us a coarse idea of the wind flow, although more accurate seed placement will be needed for detailed understanding of the flow. If you would like to see the location of the rake, click on the rake icon at the top of the screen (above the tabs) and there will appear a red box with handles describing the location of the rake.

Check the “Instance:1” checkbox at the top of the Flow tab, to enable flow rendering. You will see 50 randomly placed thick red tubes passing through the volume.

You probably also saw a warning message indicating that the flow variables (U,V,W) are not zero at the bottom of the data. This can have the undesirable effect of causing wind to appear to flow through and below the terrain. To fix this issue, click on Edit→Edit Visualizer Features. Near the top of the Visualizer Features panel is a frame labeled “Variable values outside grid (for layered data)”. This is illustrated in Figure 1.6. Select the variable “U”, uncheck the checkbox labeled “Extend Down”, and specify the value of 0 in the box labeled “Below”. Do the same for the variables “V” and “W”. Now the wind field will be always equal to zero below the terrain. Click “OK”.

Returning to the Flow panel, to make the lines thinner, scroll down to the “Shape Parameters” section of the Flow tab and set the diameter to 0.15. Below the diameter, set the “Diamond size” parameter to 0. This controls the size of a diamond shape that shows up where the wind velocity is zero. Your flow lines will look as follows:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement: 0
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
Refresh Flow
Save Flow
Show Advanced Flow Parameters
Load Seeds
Save Seeds
Edit Seed List
Set Rake to Current Region
Edit
Zoom/Pan
Fit to View

Typical Steady Flow Length: 1

☑ Auto Flow Refresh

Flow Seeding Parameters

Random Rake; Random Seed: 1

Rake center: X 4.8381e+05, Y 5.3331e+05, Z 1641.2

Rake sizes: X 9.404e+05, Y 1.039e+06, Z 3151

seed count: 50; By dimension X: 1, Y: 1, Z: 1

Shape Parameters

Shape: Tube; Diameter: 0.15

Arrowhead size: 2; Diamond size: 0

Color/Opacity mapping

Opacity: Constant; Color: Constant

Constant color, opacity values: 🟥 1

0 Opacity data limits

Rake Mode: To modify rake in scene, grab handle with left mouse to translate, right mouse to stretch

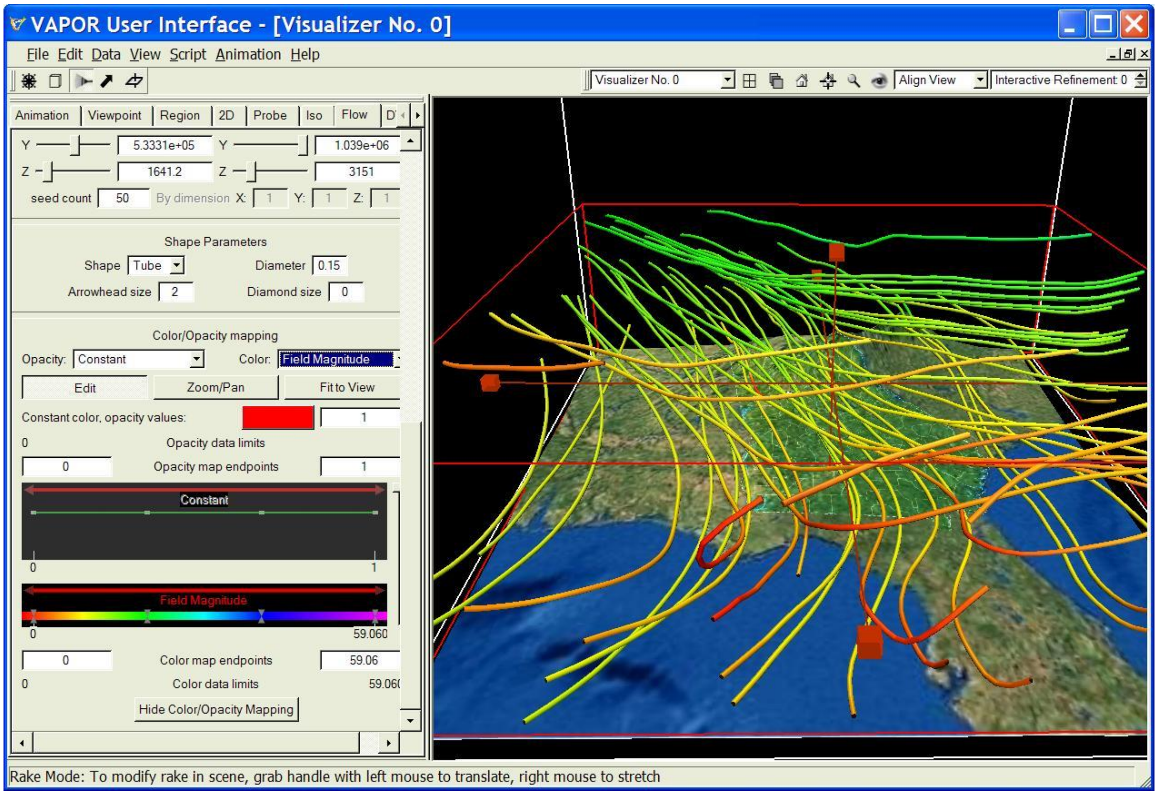
Figure 4.1: Streamlines from 50 random seed points

We can choose how long or short we want the flow lines to be, and how smooth they should appear. Slide the Steady Line Smoothness slider to the right to a value of about 200, and set the Typical Steady Flow Length to about 2.

These values are based on the average magnitude of the field, and will result in flow lines that are of length about 2 times the volume diameter, and having up to 400 sample points along their length.

The streamlines are by default a constant red color. To give an indication of how strongly the wind is blowing, we can color them according to the wind speed. In the bottom section of the Flow panel, entitled "Color/Opacity mapping", next to the text "Color:", select "Field Magnitude". The mapping from field magnitude to color uses the default color mapping at the bottom of the panel, mapping the magnitude range (0,59) to the rainbow of colors from red through green to purple.

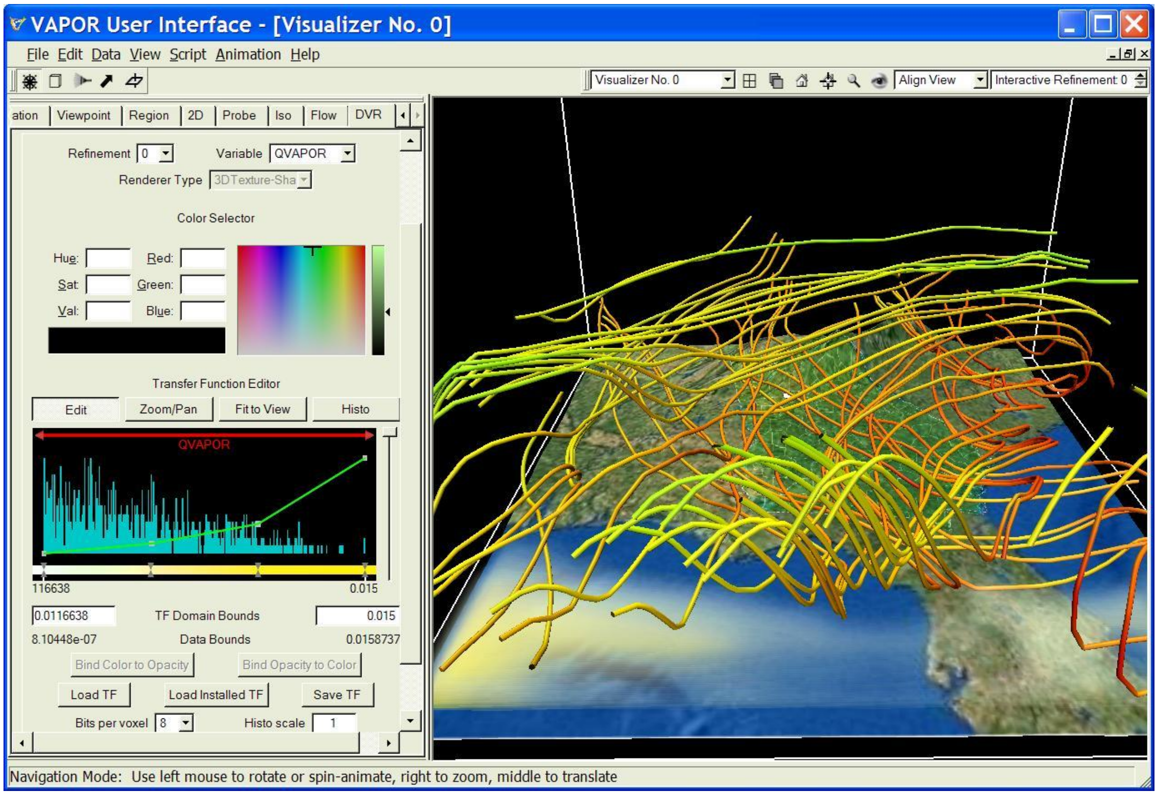
To see how the streamlines vary in time, use the animation toolbar to play forward in time. The same 50 random seed points are repeatedly used to produce a changing set of 3D streamlines at each time step. Note that the wind tends to be stronger at higher elevations, and to show much more directional variation near the ground. The following shows the streamlines at time step 35. Note that the wind direction at this time varies from south-north near the ground to east-west at higher elevations, although we cannot yet see which direction the wind flows along these curves.


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement: 0
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
Shape Parameters
Color/Opacity mapping
Edit
Zoom/Pan
Fit to View
Constant
Field Magnitude
0
1
0
59.060
Hide Color/Opacity Mapping

Y 5.3331e+05 Y 1.039e+06
Z 1641.2 Z 3151
seed count 50 By dimension X: 1 Y: 1 Z: 1
Shape: Tube Diameter: 0.15
Arrowhead size: 2 Diamond size: 0
Opacity: Constant Color: Field Magnitude
Constant color, opacity values: 1
Opacity data limits: 0
Opacity map endpoints: 0 1
Color map endpoints: 0 59.06
Color data limits: 0 59.060
Rake Mode: To modify rake in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 4.2: Streamlines colored by wind speed at time step 35

It is also interesting to see how the wind direction varies with the changes in water vapor. Click on the DVR tab and enable the QVAPOR rendering (that we created in section 2). Note as you play the animation how the increase in QVAPOR is associated with variation in the streamlines, resulting in more significant up/down drafts, and significant changes between lower and upper wind direction. Time step 165 of this animation is illustrated in figure 4.3 below. We have accentuated the QVAPOR variable by setting the right mapping bound of the DVR transfer function to 0.015.


VAPOR User Interface - [Visualizer No. 0]

Refinement 0
Variable QVAPOR
Renderer Type 3DTexture-Sha
TF Domain Bounds 0.0116638 0.015
Data Bounds 8.10448e-07 0.0158737
Bits per voxel 8
Histo scale 1
Interactive Refinement: 0

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

File
Edit
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Script
Animation
Help
Visualizer No. 0
Align View
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Color Selector
Hue:
Sat:
Val:
Red:
Green:
Blue:
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
QVAPOR
116638
0.015
Bind Color to Opacity
Bind Opacity to Color
Load TF
Load Installed TF
Save TF

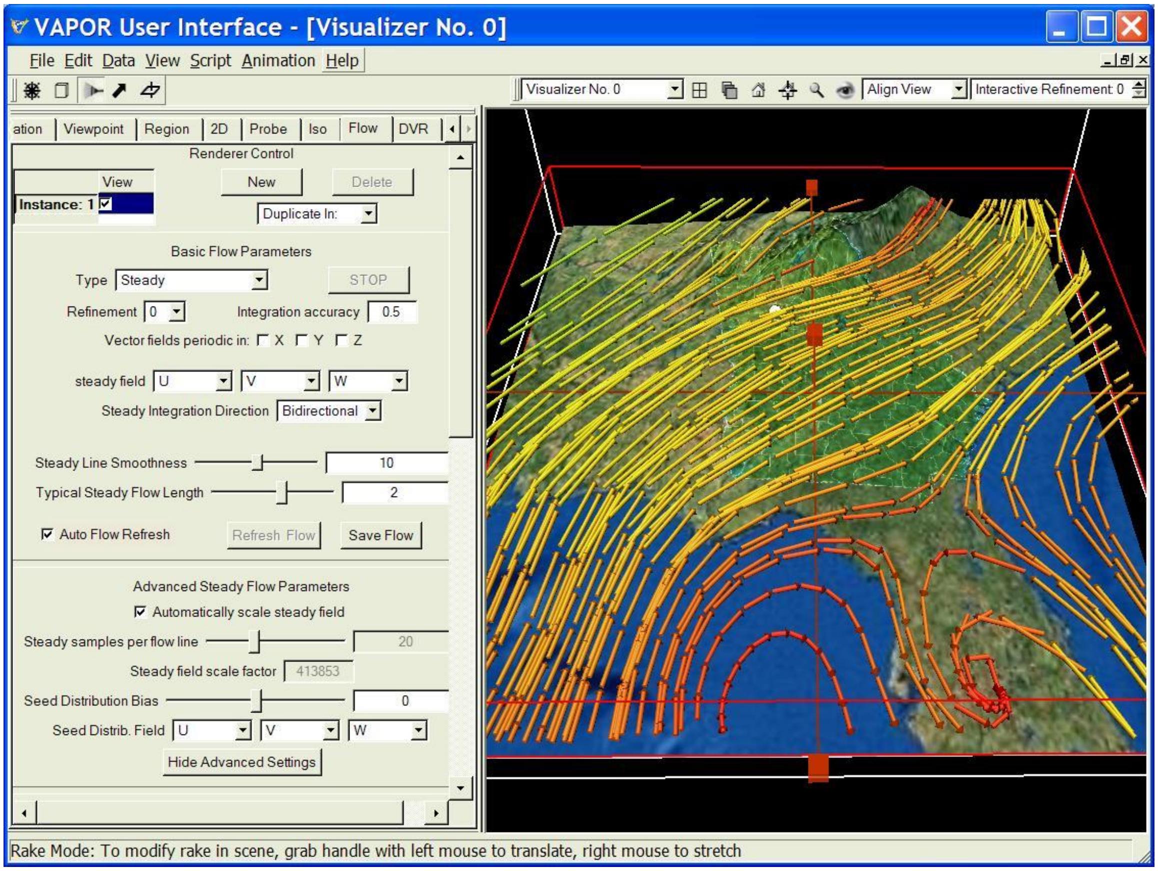
Figure 4.3: Increasing wind convection coincides with a moving ridge of increased values of QVAPOR.

Before continuing, save the current session, as we shall need it later. Click on File→Save Session As , and save the session under the name ConvectiveWind.vss. Disable the DVR before proceeding.

4.2: Visualizing and animating wind direction with velocity arrows

We next visualize the wind direction by using regularly placed seed points (this is called a Nonrandom Rake). We shall construct an 8 by 8 array of seed points, placed in a rectangle slightly above the ground. Set the time step back to 0 (using the animation toolbar). Return to the Flow tab and scroll down to the Flow Seeding Parameters. Select “Nonrandom Rake” (instead of “Random Rake”). At the bottom of the Flow Seeding Parameters, next to “By dimension X:…” type in values 8, 8, and 1 into the three textboxes, and press the <enter> key. This will result in a regularly spaced array of seed points, of sizes (in the x, y, and z-directions) 8x8x1, centered within the bounds of the current rake (which is also the current region). Scroll down to the Shape Parameters section. Change the Shape (currently set at "Tube") to "Arrow". In the Basic Flow Parameters, change the Steady Line Smoothness to 10. Each streamline is now represented by a sequence of arrows pointing in direction of the wind, each arrow about 1/10th of the scene diameter.

In order to position the wind arrows near the ground, click on the rake icon button near the upper left corner, above the tabs (unless it is already depressed). You will see a red box with handles that indicates the extents of the rake. Grab the top handle of the rake with the right mouse button, and slide it down to where the top of the box is about as high as the tops of the mountains at the northern end of the scene. The "z" component of the rake size in the flow tab should be about 1000. The flow arrows are now close to the ground, similar to the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Align View
ation Viewpoint Region 2D Probe Iso Flow DVR
Renderer Control
View
New
Delete
Duplicate In:
Basic Flow Parameters
STOP
Refresh Flow
Save Flow
Advanced Steady Flow Parameters
Hide Advanced Settings

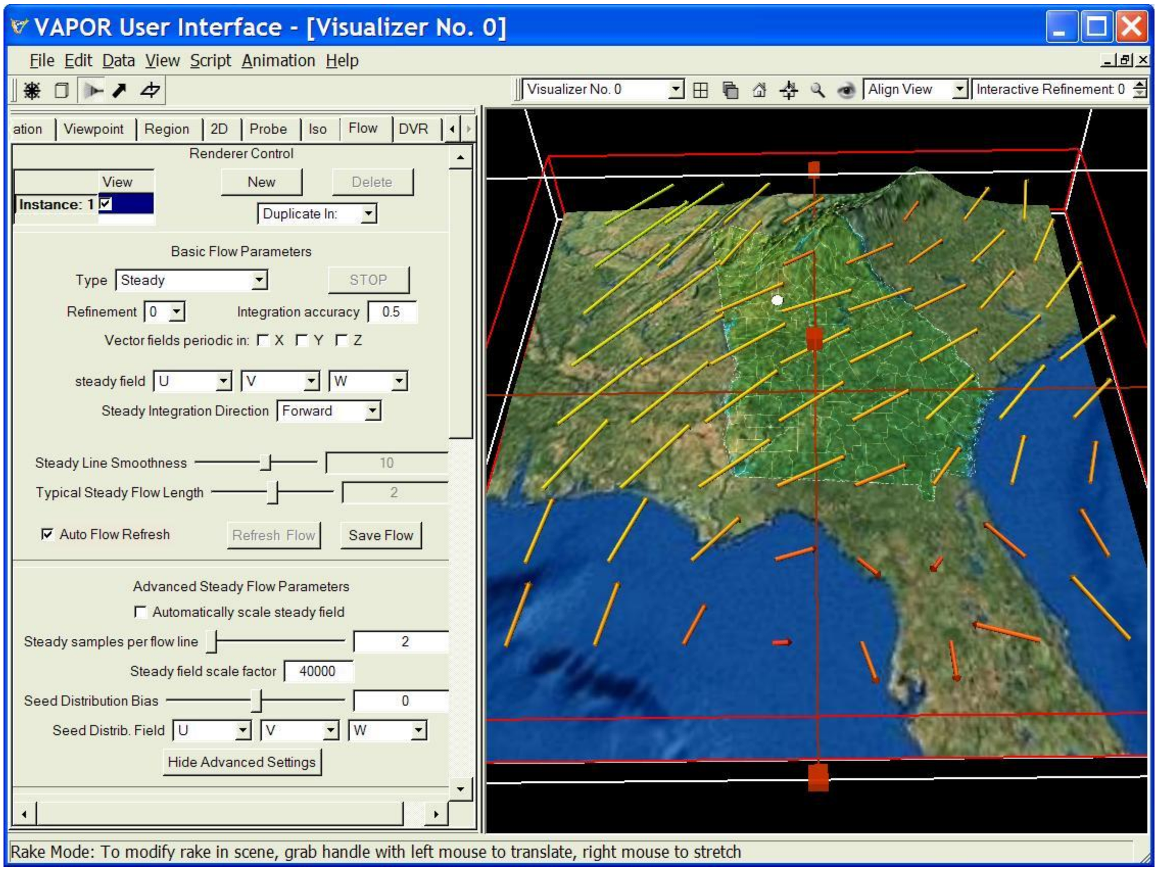
Visualizer No. 0
Interactive Refinement 0
Instance: 1 ☑
Type Steady
Refinement 0
Integration accuracy 0.5
Vector fields periodic in: ☐ X ☐ Y ☐ Z
steady field U V W
Steady Integration Direction Bidirectional
Steady Line Smoothness 10
Typical Steady Flow Length 2
☑ Auto Flow Refresh
☑ Automatically scale steady field
Steady samples per flow line 20
Steady field scale factor 413853
Seed Distribution Bias 0
Seed Distrib. Field U V W

Rake Mode: To modify rake in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 4.4: Streamlines represented by arrows shown inside rake box.

Next we change the settings to use arrows as a simple indicator of wind direction at each seed point, rather than drawing streamlines. This requires disabling the automatic calculation of flow length so that we can use a single arrow at each seed point. In the Basic Flow Parameters, set the Steady

Integration Direction to “forward”. In the flow panel, below the Basic Flow Parameters, click the button “Show Advanced Flow Parameters”. Un-check the checkbox labeled “Automatically scale steady field”. Set the Steady samples per flow line to the minimum (2), and change the Steady field scale factor to about 40000. You will see an 8x8 array of arrows pointing in the wind direction, of length proportional to the wind speed, like the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
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Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Renderer Control
View
New
Delete
Duplicate In:
Basic Flow Parameters
STOP
Refresh Flow
Save Flow
Advanced Steady Flow Parameters
Hide Advanced Settings

Instance: 1 ☑

Type Steady

Refinement 0

Integration accuracy 0.5

Vector fields periodic in: ☐ X ☐ Y ☐ Z

steady field U V W

Steady Integration Direction Forward

Steady Line Smoothness 10

Typical Steady Flow Length 2

☑ Auto Flow Refresh

☐ Automatically scale steady field

Steady samples per flow line 2

Steady field scale factor 40000

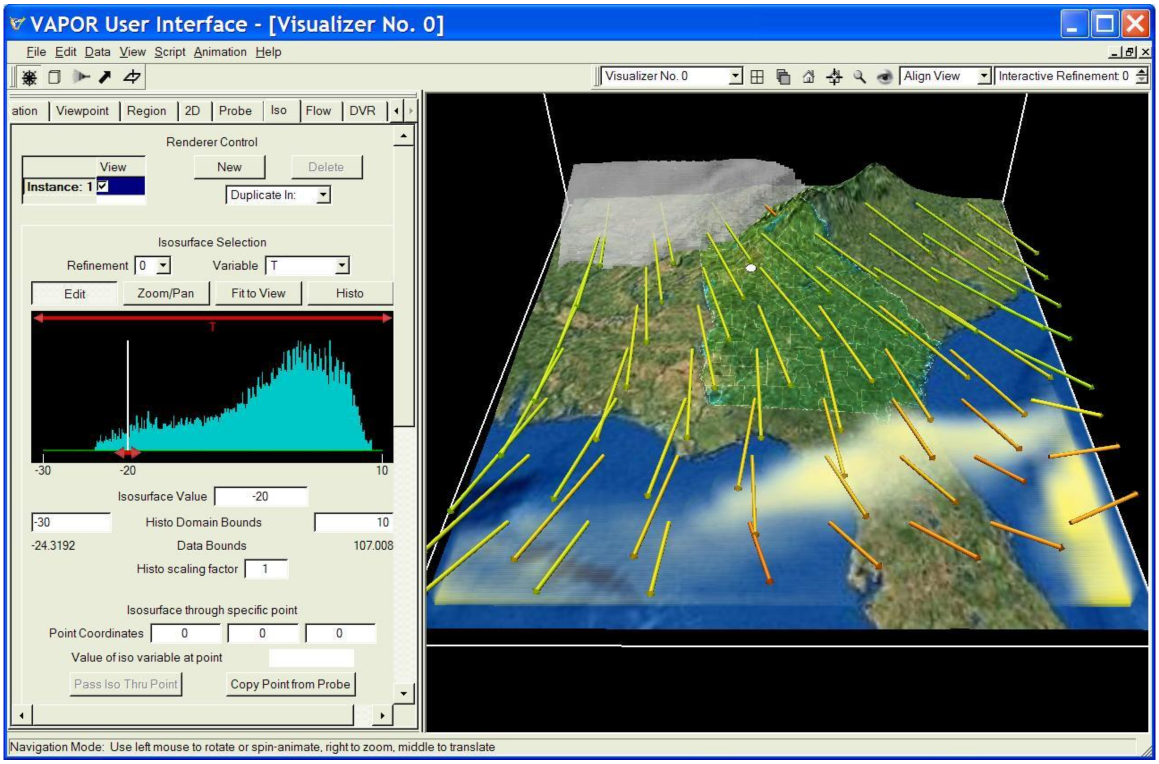
Seed Distribution Bias 0

Seed Distrib. Field U V W

Rake Mode: To modify rake in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 4.5: Wind vectors at time step 0

To restrict the wind arrows to the horizontal plane, change the third component of the steady field from “W” to “0”. Next we shall combine the flow visualization with the DVR and Iso rendering that we prepared before. Enable the DVR of QVAPOR and the Iso renderer of T (these were constructed in sections 2 and 4). To eliminate the rake box, click on the navigation wheel at the upper left corner of the window. Using the animation toolbar, play forward from time step 0. You will note that the wind direction changes abruptly from westbound to southbound with the passage of the cold front. The direction then oscillates on a daily basis until the arrival of the moist air from the south. Figure 4.6 illustrates the change of wind direction during the passage of the cold front at timestep 30:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
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Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Renderer Control
View
New
Delete
Duplicate In:
Isosurface Selection
Edit
Zoom/Pan
Fit to View
Histo
T
-30
-20
10
Isosurface through specific point
Pass Iso Thru Point
Copy Point from Probe

Interactive Refinement 0

Instance: 1 ☑

Refinement 0

Variable T

Isosurface Value -20

Histo Domain Bounds -30 10

Data Bounds -24.3192 107.008

Histo scaling factor 1

Point Coordinates 0 0 0

Value of iso variable at point

Navigation Mode: Use left mouse to rotate or spin-animate, right to zoom, middle to translate

Figure 4.6: Combined visualization of wind arrows with QVAPOR and T at time step 30

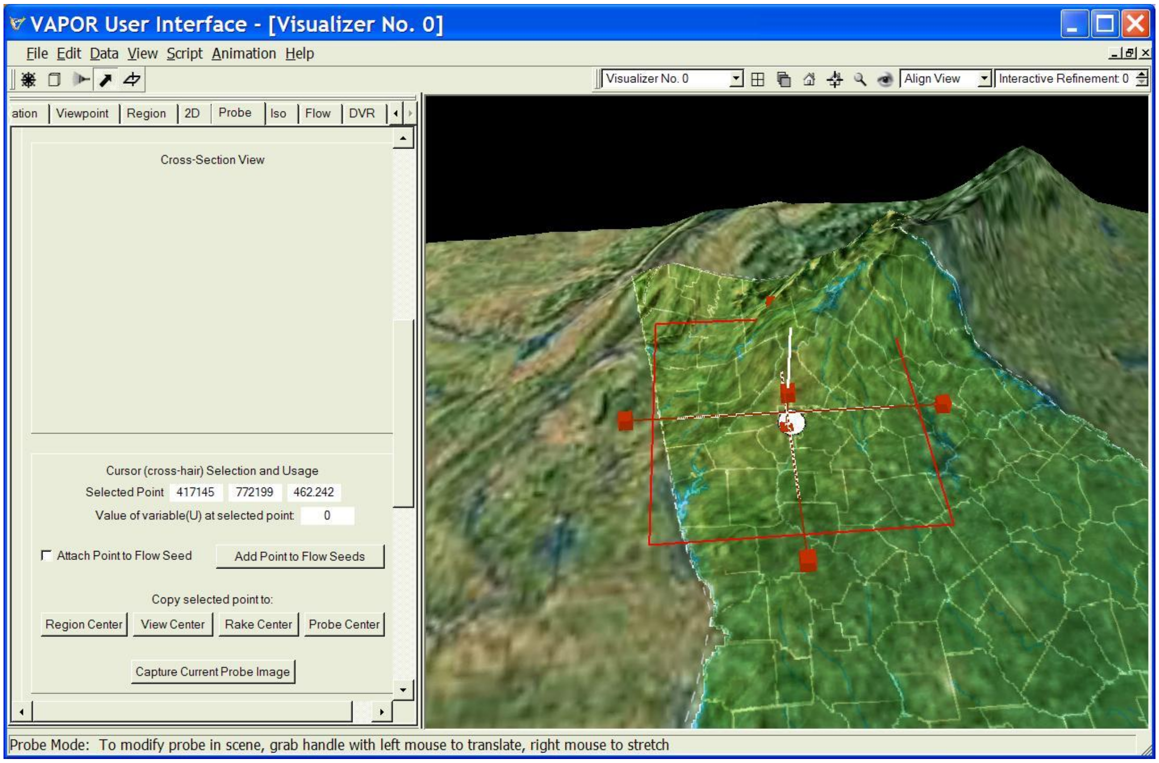
Next we show how to save this animation sequence as a set of jpeg files, so that they can be posted on the Web or combined into an animation sequence. Before producing these image files, we shall make a few changes to enhance the animation:

Click Edit→Edit Visualizer Features to launch the Visualizer Features Panel as in figure 1.6. Next to Time Annotation, select "Date/time stamp", so that the date and time will be displayed in each frame. Then click OK. From the animation toolbar, set the current time step to 0. From the main menu, click "Capture" and then select "Begin Image Capture Sequence in visualizer 0". From the file selection dialog that pops up, select a directory and a file name where the resulting jpeg files will be saved. Then, from the animation toolbar, play forward to the end of the sequence. After the sequence is complete, from the Capture menu, click on "End Image Capture Sequence in Visualizer 0". You will see that a series of jpeg files has been saved. These may be converted to Quicktime® or Window Media Player® files using software that you can purchase or obtain from the Web.

Note: When an image capture sequence is very time-consuming, you may find it necessary to disable the screen saver on your computer, because the screen saver could interfere with the image capturing.

Next, we show how to position the wind arrows to visualize the local flow near Atlanta. Retain the flow settings from above, including the use of the nonrandom rake, with single arrows at each seed point as established by the settings we made in the Advanced Steady Flow Parameters.

It will be easiest if we first use the Probe to make Atlanta the center of our viewpoint. Disable the Iso, the Flow, and the DVR renderers. Click on the bold upward-pointing arrow near the upper-left corner of the VAPOR window (its tooltip is "Data Probe Mode"). Zoom out of the scene (drag downward with the right mouse in the scene) until you see a red rectangle with red handles above the middle of Georgia; or click on the eye icon above the visualizer window to see the full volume with the probe in the middle of it . Grabbing the top handle of the probe manipulator with the left mouse, slide the probe down near the ground, and then, using the handles on the edges of the Probe, center it near Atlanta (the white spot on the terrain). To position the Probe near Atlanta you may find it necessary to zoom in and rotate the scene as you reposition the Probe, until you get it where you want it. When the Probe is centered slightly over Atlanta, then, on the Probe tab, scroll down below the "Cross-Section View" portion and click the button labeled "Use selected point to center: View". This button is located below the Cross-Section View in the Probe tab. This will make the cross-hairs of the probe become the center of your view. After you zoom in close to Atlanta, your view should look like the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Cross-Section View
Cursor (cross-hair) Selection and Usage
Attach Point to Flow Seed
Add Point to Flow Seeds
Copy selected point to:
Region Center
View Center
Rake Center
Probe Center
Capture Current Probe Image

Selected Point 417145 772199 462.242

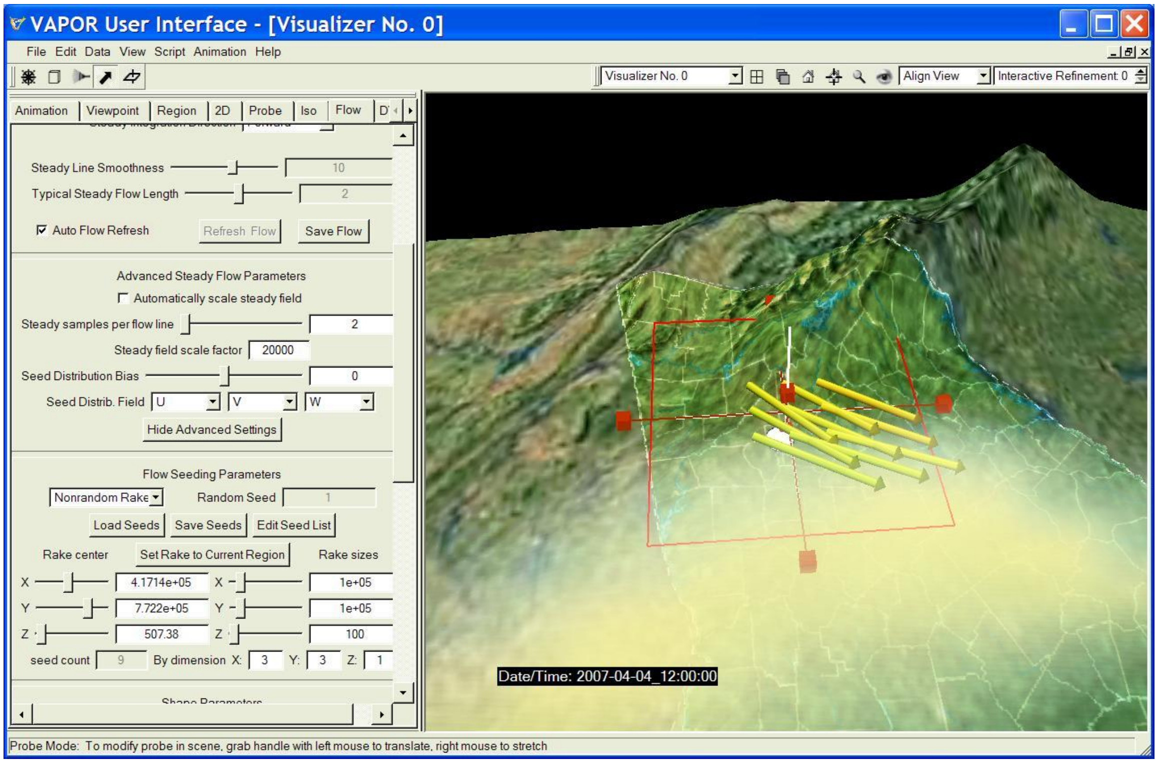
Value of variable(U) at selected point 0

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 4.7: Probe centered at Atlanta

Now that the view is centered on Atlanta, we can easily position the flow rake near Atlanta. On the probe panel click the button "Use selected point to center:... Rake". Then, from the Flow panel, adjust the rake size, using the sliders in the Flow Seeding Parameters. Adjust the X and Y size to about 100000 (100 km) and adjust the Z size to about 100m. Also reduce the "Seed Count by Dimension" values to 3x3x1. In the Advanced Steady Flow Parameters, reduce the Steady field scale factor to 20000, to make the arrows half as long.

Enable the Flow, to display the wind arrows. Enable the volume rendering of QVAPOR to see how the wind in Atlanta changes as the front passes through. Figure 4.8 illustrates the wind arrows near Atlanta at time step 12, just as the cold front is passing.


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
Refresh Flow
Save Flow
Advanced Steady Flow Parameters
Hide Advanced Settings
Flow Seeding Parameters
Load Seeds
Save Seeds
Edit Seed List
Set Rake to Current Region
Rake center
Rake sizes

Steady Line Smoothness 10
Typical Steady Flow Length 2
☑ Auto Flow Refresh
☐ Automatically scale steady field
Steady samples per flow line 2
Steady field scale factor 20000
Seed Distribution Bias 0
Seed Distrib. Field U V W
Nonrandom Rake
Random Seed 1
Rake center X 4.1714e+05, Y 7.722e+05, Z 507.38
Rake sizes X 1e+05, Y 1e+05, Z 100
seed count 9 By dimension X: 3 Y: 3 Z: 1
Date/Time: 2007-04-04_12:00:00
Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 4.8: Wind vectors near Atlanta at time step 12 with volume render of QVAPOR

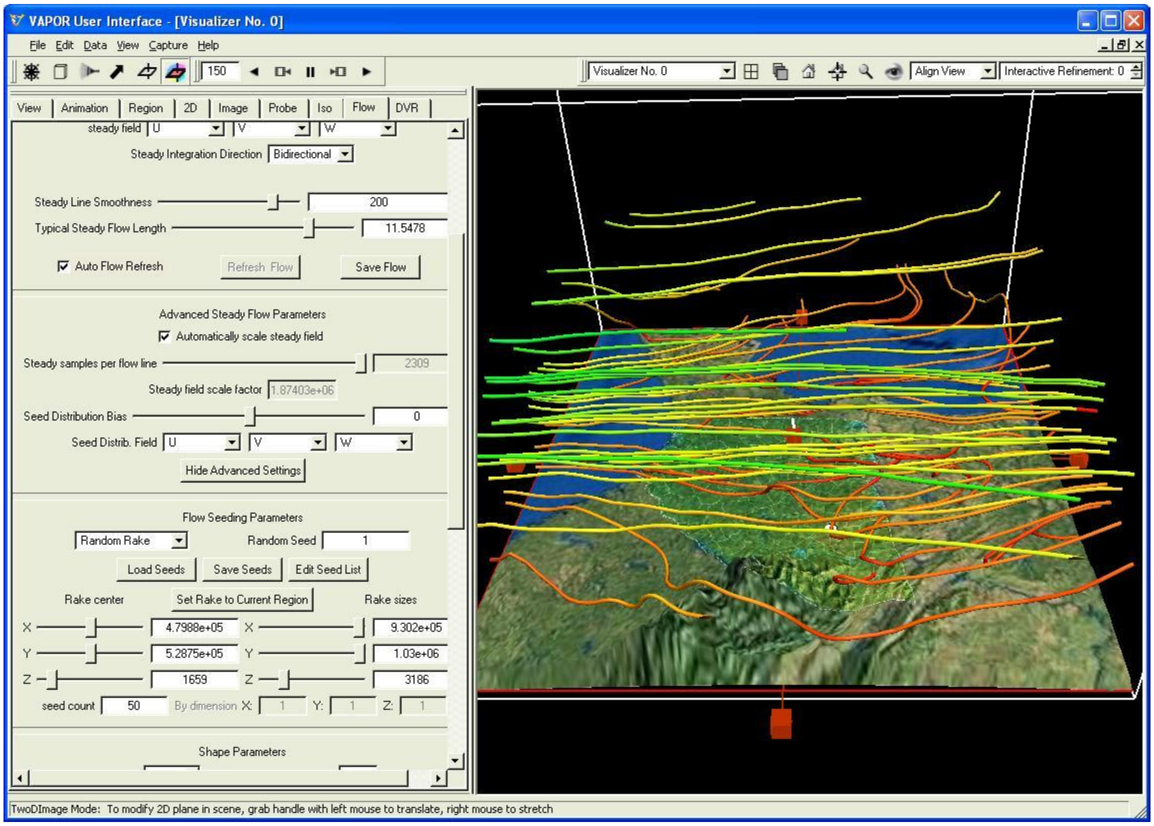
Save the current session as "AtlantaArrows.vss" before continuing. We shall return to this session in a later section.

4.3: Using the Probe to visualize wind near the mountains

In this section we use the Probe tool to visualize the wind patterns that occur near the mountains north of Atlanta. The Probe combines a number of useful functions. For example, as we saw in section 4.2, the Probe is useful for obtaining precise coordinates for specific features in the visualization and for repositioning the viewpoint and the rake. The Probe can also be used to create planar contour plots of any 3D variable in the scene. The Probe has two other important capabilities for investigating flow fields. In this section we shall first use the Probe to create animated images of flow motion, to get a better sense of how the mountains affect the flow. We shall then use the probe to insert flow seeds using the images in the probe for spatial reference.

To return to the visualization of section 4.1, from the File menu, load the session file we saved at the end of section 4.1 (ConvectiveWind.vss) or, if you did not save that session, you can load the file WRFFigure4.3.vss from the vapor examples directory. From the Data menu, load the april_lowres.vdf. Load and enable the satellite image from the Image panel. Enable the flow by checking the "Instance: 1" checkbox.

We next position the probe above the mountains north of Georgia where the wind flow patterns are affected by the mountains. Set the time step (in the animation toolbar) to 150. Rotate the scene around (dragging with the left mouse button) so that you are looking southward from a position north of Georgia. You will note that a few of the streamlines are following the terrain over the mountains, as in the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Capture Help
Visualizer No. 0
Align View
Interactive Refinement: 0
View Animation Region 2D Image Probe Iso Flow DVR
Refresh Flow
Save Flow
Advanced Steady Flow Parameters
Hide Advanced Settings
Flow Seeding Parameters
Load Seeds
Save Seeds
Edit Seed List
Set Rake to Current Region
Shape Parameters

150

steady field U V W

Steady Integration Direction Bidirectional

Steady Line Smoothness 200

Typical Steady Flow Length 11.5478

☑ Auto Flow Refresh

☑ Automatically scale steady field

Steady samples per flow line 2309

Steady field scale factor 1.87403e+06

Seed Distribution Bias 0

Seed Distrib. Field U V W

Random Rake Random Seed 1

Rake center X 4.7988e+05 Y 5.2875e+05 Z 1659

Rake sizes X 9.302e+05 Y 1.03e+06 Z 3186

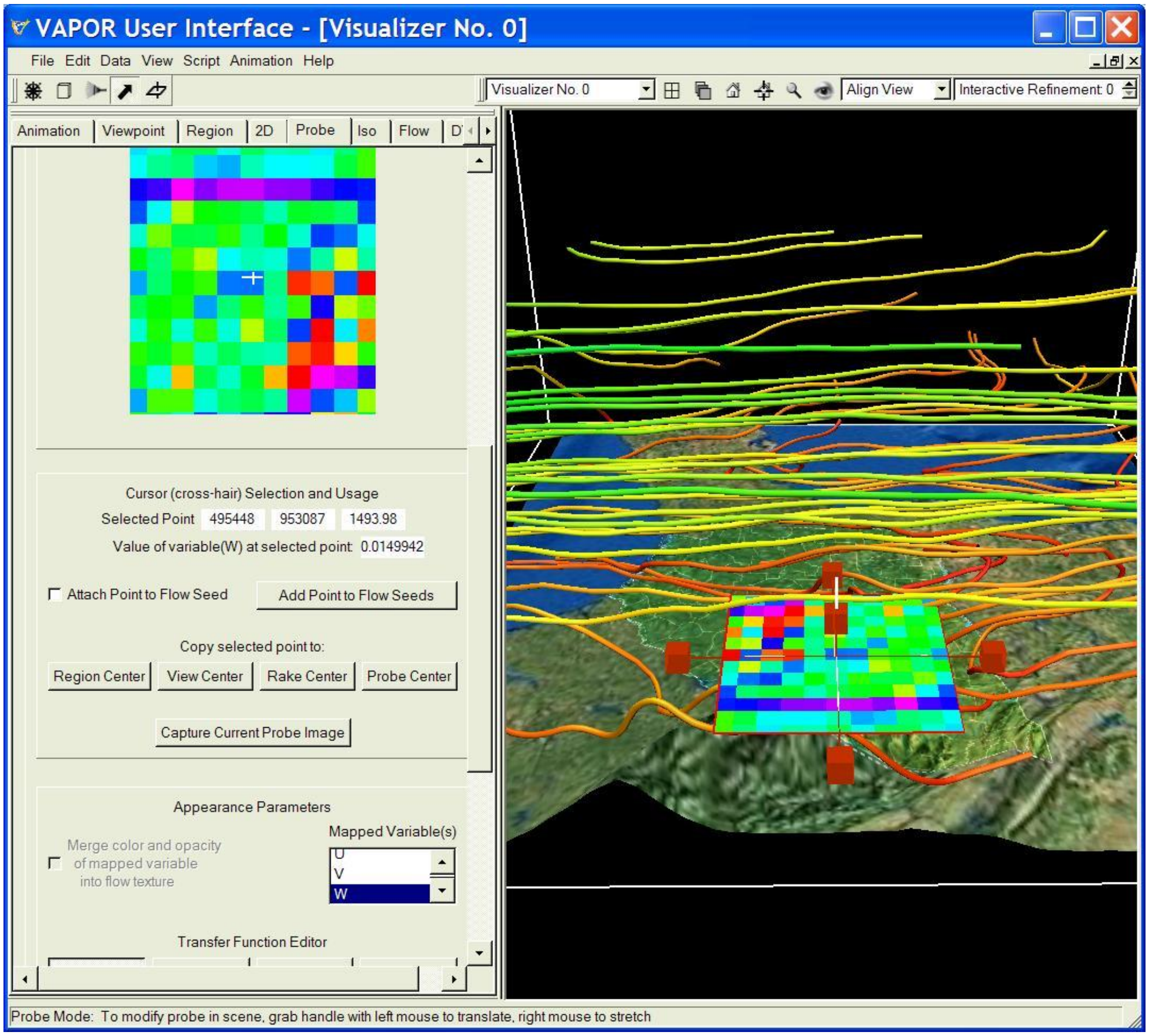
seed count 50 By dimension X: 1 Y: 1 Z: 1

TwoDImage Mode: To modify 2D plane in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 4.9: Streamlines over the mountains north of Georgia at time step 150

Click on the probe (upward pointing thick arrow) icon above the tabs near the top of the VAPOR window, if that button is not already pressed. Zoom out, by dragging downward in the scene with the right mouse button, until you see the probe outline. By clicking and dragging with the left mouse button on the red handles on the probe, slide it to the north end of the scene right above the mountains.

In the Probe tab, check the “Instance: 1” checkbox to enable the first probe instance, and set the Refinement level to 1. Then scroll down to the bottom of the Probe tab, and, above the Transfer Function Editor, select the Mapped Variable “W”. You will see a coarse image of the W variable in the probe in the scene, similar to the following:



VAPOR User Interface - [Visualizer No. 0]

Visualizer No. 0

Align View

Interactive Refinement 0

Cursor (cross-hair) Selection and Usage

Selected Point 495448 953087 1493.98

Value of variable(W) at selected point: 0.0149942

☐ Attach Point to Flow Seed

Appearance Parameters

☐ Merge color and opacity of mapped variable into flow texture

Mapped Variable(s): U, V, W (W selected)

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

File
Edit
Data
View
Script
Animation
Help
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
D
Add Point to Flow Seeds
Copy selected point to:
Region Center
View Center
Rake Center
Probe Center
Capture Current Probe Image
Transfer Function Editor

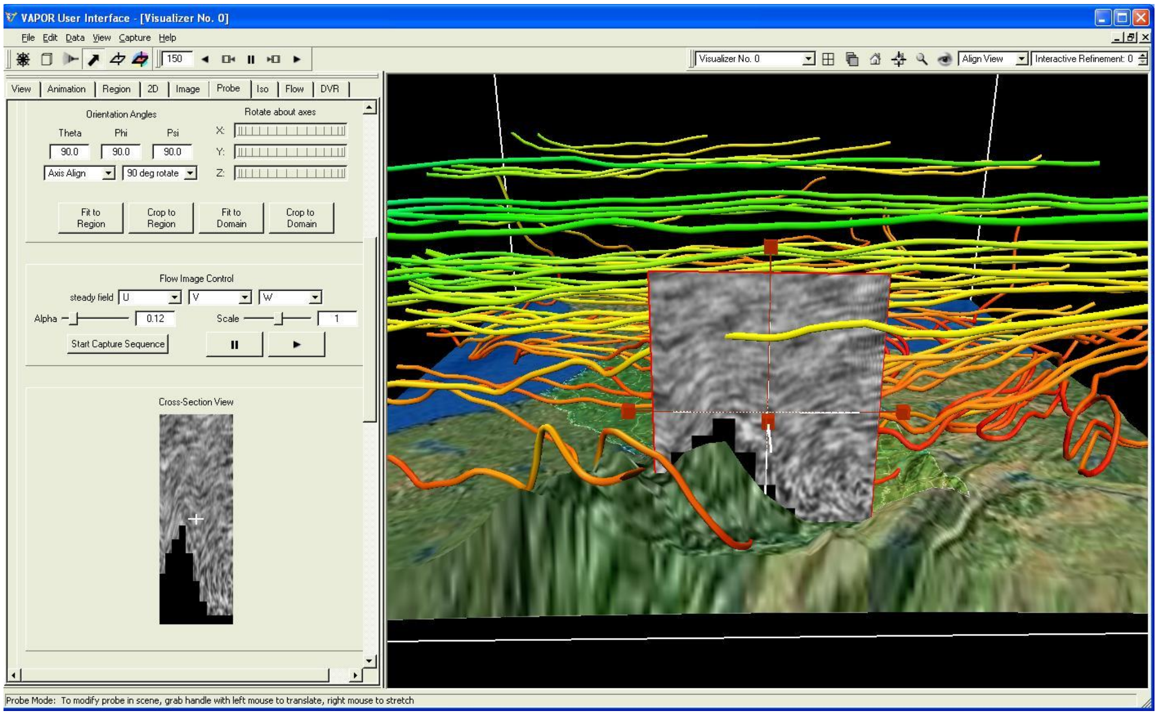
Figure 4.10: Probe of W in wind flow near mountains

In order to be consistent between the various renderers in the scene, set the refinement level in the Flow panel to 1, and, in the Image panel, set the refinement level of the terrain image to 1.

We would like the probe to be vertically oriented so as to see the vertical wind motion. In the probe tab, at the bottom of the top section entitled “Probe Position and Size” there is a selector displaying the text “90 degree rotate”.

These controls can be seen in Figure 4.11 below. From that rotation selector, choose “+X” to rotate the probe 90 degrees about the positive X axis. You will see that the probe is now very tall (the scene vertical stretch causes this effect). Then click the button “Crop to Region”, below the rotation selector, to make it shorter. You will note that the image of the probe in the probe tab is as seen from the south side. Rotate it 180 degrees about the vertical axis by twice choosing “+Z” from the rotation selector. To facilitate navigating around the probe, click the button (below the probe image) labeled “Use selected point to center: View”, making the probe center the center of your view.

At the top of the probe tab, under the text “Probe Type” select “Flow Image”. In the section of the Probe entitled “Flow Image Control” set the steady field variables to U, V, and W. The image in the probe will become a black-and-white representation of flowing particles as in the following:


VAPOR User Interface - [Visualizer No. 0]
File
Edit
Data
View
Capture
Help
Visualizer No. 0
Align View
Interactive Refinement: 0
View
Animation
Region
2D
Image
Probe
Iso
Flow
DVR
Orientation Angles
Rotate about axes
X:
Y:
Z:
Fit to Region
Crop to Region
Fit to Domain
Crop to Domain
Flow Image Control
Start Capture Sequence
Cross-Section View

150

Theta 90.0
Phi 90.0
Psi 90.0
Axis Align
90 deg rotate

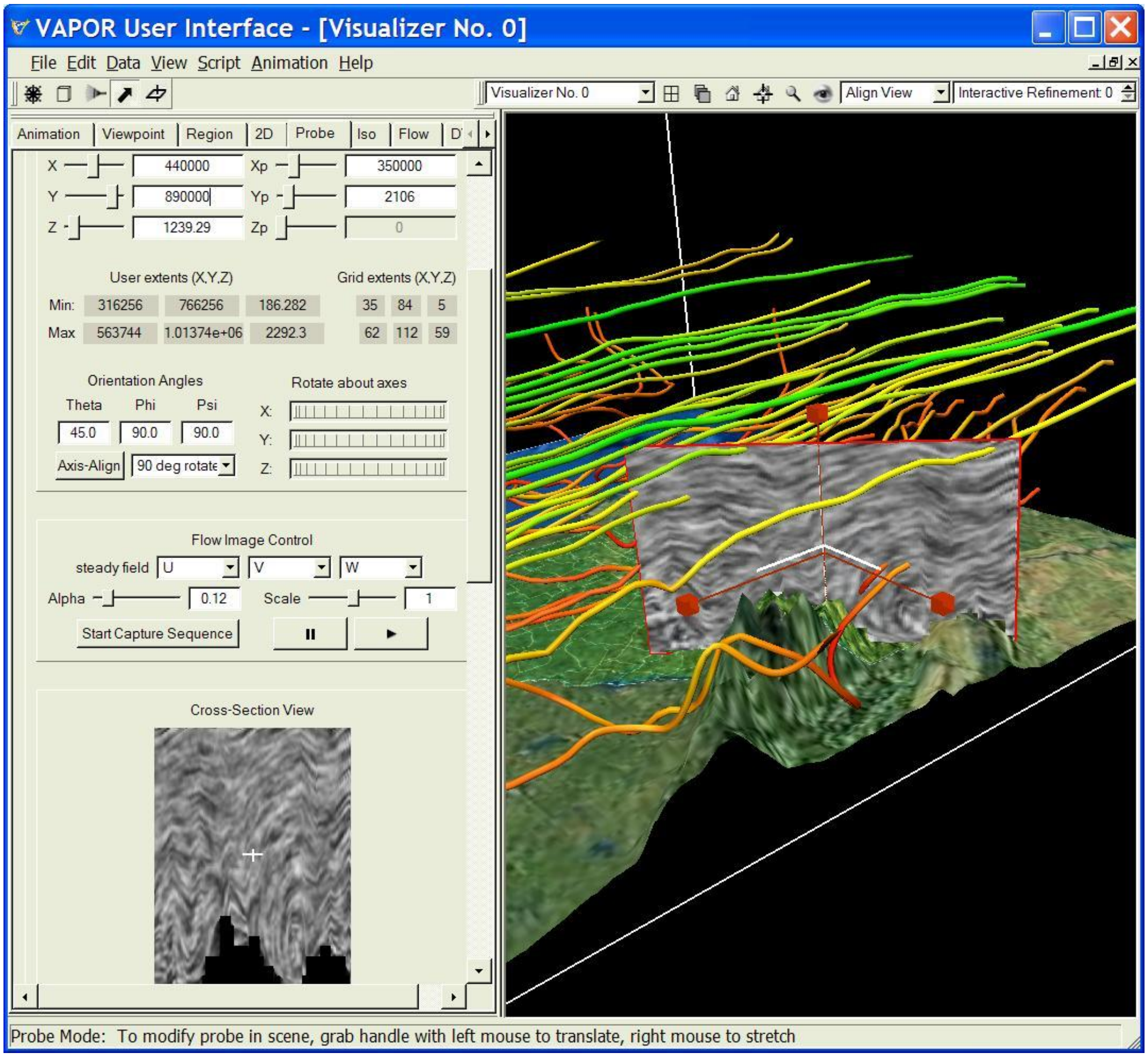
steady field U V W
Alpha 0.12
Scale 1

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 4.11: Flow Image over the mountains

Note that in figure 4.11 the probe in the scene intersects the terrain, so that lower portions of the probe in the tab are black. Also, the aspect ratio of the probe in the tab is adjusted to make the pixels in that image square. This can make the probe in the scene appear stretched relative to the probe in the tab. The flow image in the probe is best understood by animating it. In the “Flow Image Control” section of the Probe Tab, above the Cross Section View, click on the play (►) button, so see the flow motion represented as moving particles. You will see that the wind is flowing over the mountains from west to east. This is a flow visualization technique known as “Image Based Flow Visualization” or IBFV, invented by Jarke Van Wijk (*Proc. Siggraph 2002*). Basically it works by advecting a noise pattern in the flow, and blending in the result of multiple advections over time. The flow motion is projected into the plane of the probe. You can tune the flow images by tweaking the Scale and Alpha sliders in the Flow Image Control, and the flow images can be captured as a sequence of jpeg files by pressing the “Start Image Capture” button.

To better visualize the flow over the mountains, increase the width of the probe to about 350km (e.g use the Probe/Contour Xp Size slider in the probe tab). Then use the Z: thumbwheel (under the text “Rotate about axes” to orient the probe to go from north-west to south-east. Move your viewpoint and reposition the probe to where you have a good view of the wind over the mountains as in the following:



VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
Animation Viewpoint Region 2D Probe Iso Flow D
Orientation Angles
Rotate about axes
X:
Y:
Z:
Axis-Align
90 deg rotate
Start Capture Sequence
Cross-Section View

X 440000 Xp 350000
Y 890000 Yp 2106
Z 1239.29 Zp 0

	User extents (X,Y,Z)			Grid extents (X,Y,Z)		
Min:	316256	766256	186.282	35	84	5
Max	563744	1.01374e+06	2292.3	62	112	59

Theta 45.0 Phi 90.0 Psi 90.0

Flow Image Control
steady field U V W
Alpha 0.12 Scale 1

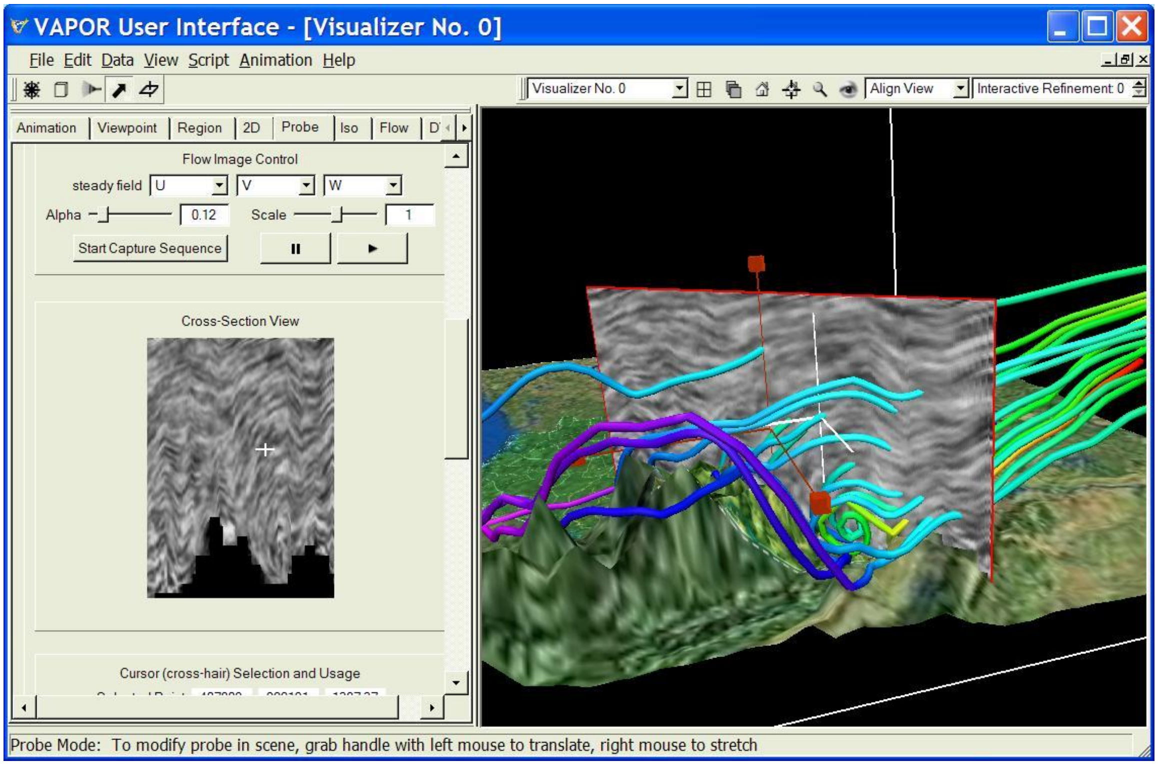
Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 4.12: IBFV of wind flow over the mountains

In the above image, the probe is centered at X = 440000, Y = 890000, and is oriented with theta = 45 degrees.

Next we use the probe to position flow seed points. In the flow panel, under Flow Seeding Parameters, select “List of Seeds” replacing “Random Rake”. Dismiss the error messages about the lack of seeds at the current time step. You will notice that the streamlines have disappeared because there are no seeds in the current seed list. Select the probe tab and scroll down where you can see the options below the Cross-Section View. Check the check box entitled "Attach Point to Flow Seed". You will see a streamline originating at the position of the cross-hairs in the probe. By moving the cursor around the probe image you can position flow seeds and see the resulting streamlines. Each time you find a streamline of interest, click the button "Add Point to Flow Seeds". Repeat this until you have added enough seeds to get an understanding of the wind flow in this region.

At the bottom of the flow panel in the section "Color/Opacity mapping", select the color mapping to be "Position along Flow", so that streamline color indicates the wind direction, going from red to violet as in the following:



VAPOR User Interface - [Visualizer No. 0]

Visualizer No. 0

Align View

Interactive Refinement 0

Flow Image Control

steady field U V W

Alpha 0.12

Scale 1

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

File
Edit
Data
View
Script
Animation
Help
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
Start Capture Sequence
Cross-Section View
Cursor (cross-hair) Selection and Usage

Figure 4.13: Streamlines inserted in the flow by selecting seed points in the IBFV image in the Probe

Observe that at higher elevations the wind flows over the mountains from west to east; however, nearer the terrain, streamlines may be trapped in the valleys and sometimes emerge from the mountains in a southerly direction.

Section 5: Unsteady Flow Visualization (particle trajectories)

Unsteady flow visualization can be used to track the motion of wind currents over time, or to see particle trajectories. As in Section 4, specifying the flow requires establishing a set of seed points; however, with unsteady flow, the seed points at one time step determine the flow positions at subsequent time steps. Each seed point is moved by integrating the flow field for one time step, resulting in a new point at the next time step.

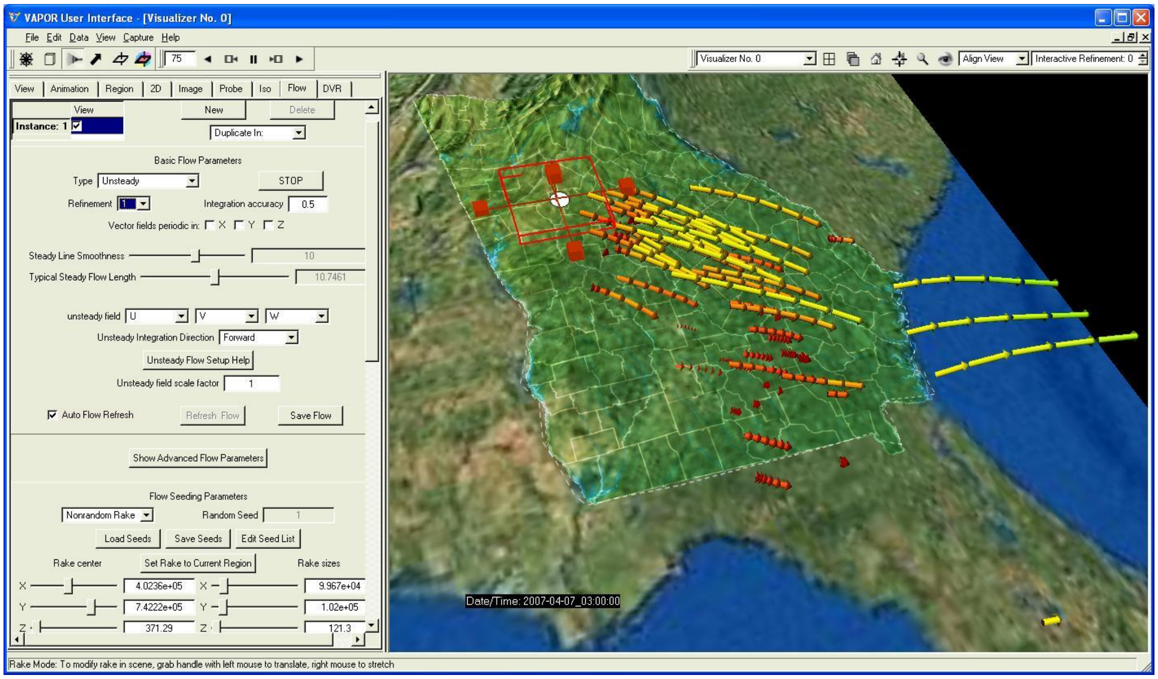
In this section we use the rake as well as the Probe tool to specify seeds, providing a precise way of controlling the seed point placement.

5.1 Tracking the motion of particles released near Atlanta

We continue with the setup used for figure 4.8 at the end of section 4.2. (Load the session "AtlantaArrows.vss" or WrfFigure.4.8.vss , load the april_lowres.vdf data, and load and enable the satellite image in the Image panel.). Set the current time step to 12. Click on the Flow tab, and set the Type to "Unsteady". Set the unsteady field variables to U, V, and W. Set the Unsteady Integration Direction to "Forward". (Note: the Unsteady field scale factor should be set to "1", since the correct scaling factors were derived from the WRF output files when the Vapor data was constructed.) Then enable the flow. It will take few seconds to integrate the flow, because U, V, and W for all 180 time steps need to be read from disk.

When the integration is complete, you will see that the 9 seed points have resulted in 9 path lines, describing the trajectories that would be taken by 9 particles released near Atlanta at time step 0. To animate the motion of these particles, scroll down (in the Flow panel) to the "timestep display interval min, max" values at the bottom of the Shape Parameters. Set these values to -3 and 3. This means that at each time step *t* you will see the sequence of particle positions from time steps *t-3* to *t+3*. You can animate this motion by clicking on the play button in the animation toolbar.

To see the continuing motion of particles that are repeatedly released near Atlanta, set the "Seed time start, end, increment" values at the bottom of the Flow Seeding parameters. These specify the first and last time step that seeds are released, and the increment between subsequent seed release times. Set these to 0, 170, and 10, so that seed particles will be released every 10 hours. This setup is useful for tracking the motion of pollutants released at Atlanta. You will note that the particle paths generally stay close to the ground until they reach the ocean. The following image illustrates these paths at time step 75, showing that particles released at times 70, 60, and 50 are near the ground, while the seed particles released at time step 40 have reached the ocean and are moving upward:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Capture Help
Visualizer No. 0
Align View
Interactive Refinement: 0
View
Animation
Region
2D
Image
Probe
Iso
Flow
DVR
View
New
Delete
Duplicate In:
Basic Flow Parameters
STOP
Unsteady Flow Setup Help
Refresh Flow
Save Flow
Show Advanced Flow Parameters
Flow Seeding Parameters
Load Seeds
Save Seeds
Edit Seed List
Rake center
Set Rake to Current Region
Rake sizes
Date/Time: 2007-04-07_03:00:00

Time step: 75

Instance: 1 ☑

Type: Unsteady

Refinement: 1

Integration accuracy: 0.5

Vector fields periodic in: ☐ X ☐ Y ☐ Z

Steady Line Smoothness: 10

Typical Steady Flow Length: 10.7461

unsteady field: U, V, W

Unsteady Integration Direction: Forward

Unsteady field scale factor: 1

☑ Auto Flow Refresh

Nonrandom Rake

Random Seed: 1

Rake center: X 4.0236e+05, Y 7.4222e+05, Z 371.29

Rake sizes: X 9.967e+04, Y 1.02e+05, Z 121.3

Rake Mode: To modify rake in scene, grab handle with left mouse to translate, right mouse to stretch

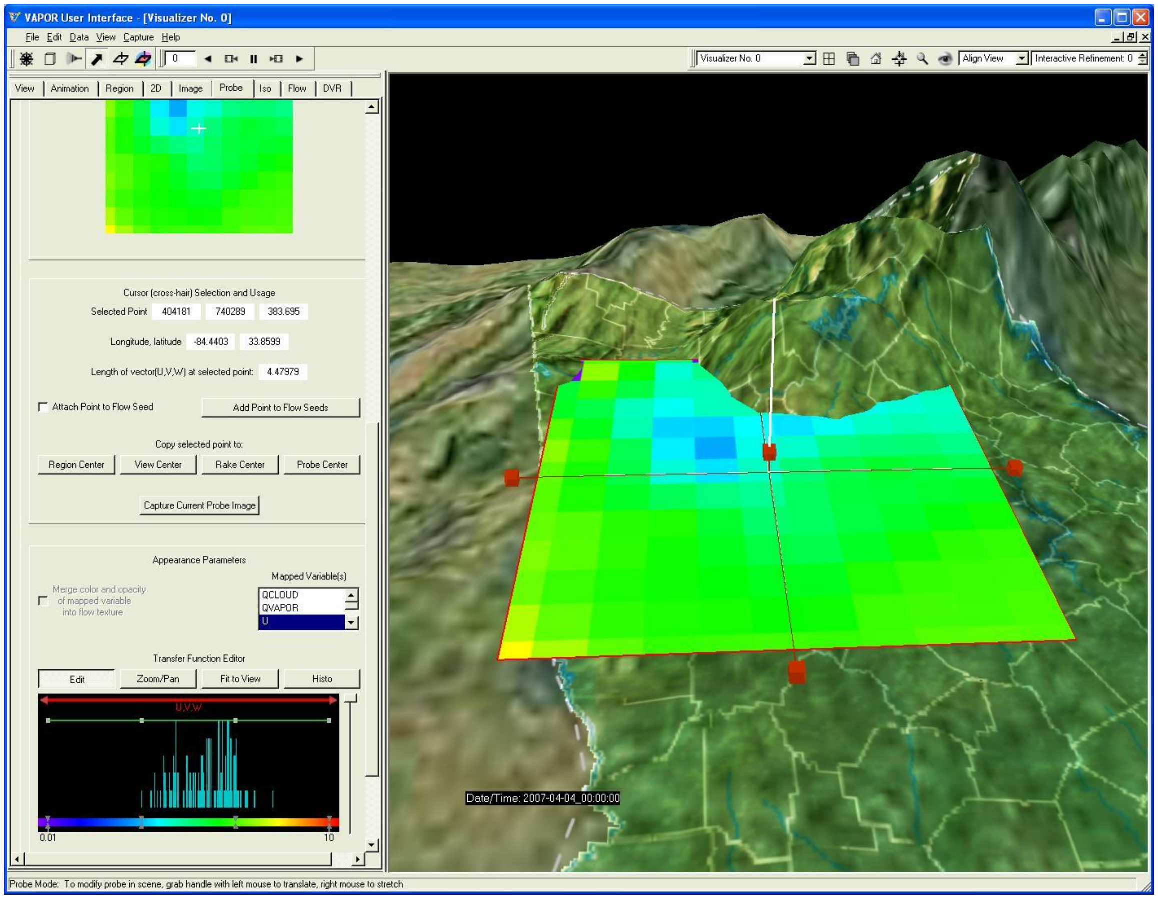
Figure 5.1: Particles released at Atlanta reaching the ocean at time step 75

5.2: Placing flow seeds with the Probe

In order to see the motion of particles released in the mountains north of Atlanta, we place individual seed points manually, using the Probe. Continuing with the setup from Figure 5.1, disable the Flow, and click on the probe arrow near the upper left-hand corner of the VAPOR window. The probe should still be positioned near Atlanta; if not, follow the directions in section 4.2, preceding figure 4.7, to position the probe. In the lower part ("Appearance Parameters" section) of the Probe panel is a "Mapped Variables" selection box. Hold the "Ctrl" key while you select the three variables U, V, and W. (Multiple variable selection results in the norm of the vector of the variables being color-mapped in the probe.) This will enable us to see the magnitude of the wind velocity in the cross-section image in the probe. Set the current time step to 0.

Now check the "Instance: 1" checkbox to enable the probe. You will see a horizontal rectangle near Atlanta, colored according to the wind velocity. It is fairly coarse because we are using the lowest resolution data. Set the Refinement level of the Probe to 1 to see a more accurate indication of wind speed in the Probe.

In the Probe panel there is a Transfer Function Editor like the one in the DVR panel. This one is controlling the mapping from wind velocity to color and opacity. In order to map larger values of velocity to red, click on the button "Load Installed TF" and select the transfer function "reversedOpaque.vtf". Set the TF Domain Bounds to 0.01 and 10 and press "enter". (We set the minimum larger than 0 so as to avoid zeroes contributing to the histogram.) Then click "Fit to View" and "Histo" to see a histogram of the values of the wind speed in the probe. This is illustrated in Figure 5.2:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Capture Help
View
Animation
Region
2D
Image
Probe
Iso
Flow
DVR
Attach Point to Flow Seed
Add Point to Flow Seeds
Copy selected point to:
Region Center
View Center
Rake Center
Probe Center
Capture Current Probe Image
Appearance Parameters
Merge color and opacity of mapped variable into flow texture
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
U,V,W
0.01
10
Visualizer No. 0
Align View
Interactive Refinement: 0
Date/Time: 2007-04-04_00:00:00

Cursor (cross-hair) Selection and Usage

Selected Point 404181 740289 383.695

Longitude, latitude -84.4403 33.8599

Length of vector(U,V,W) at selected point: 4.47979

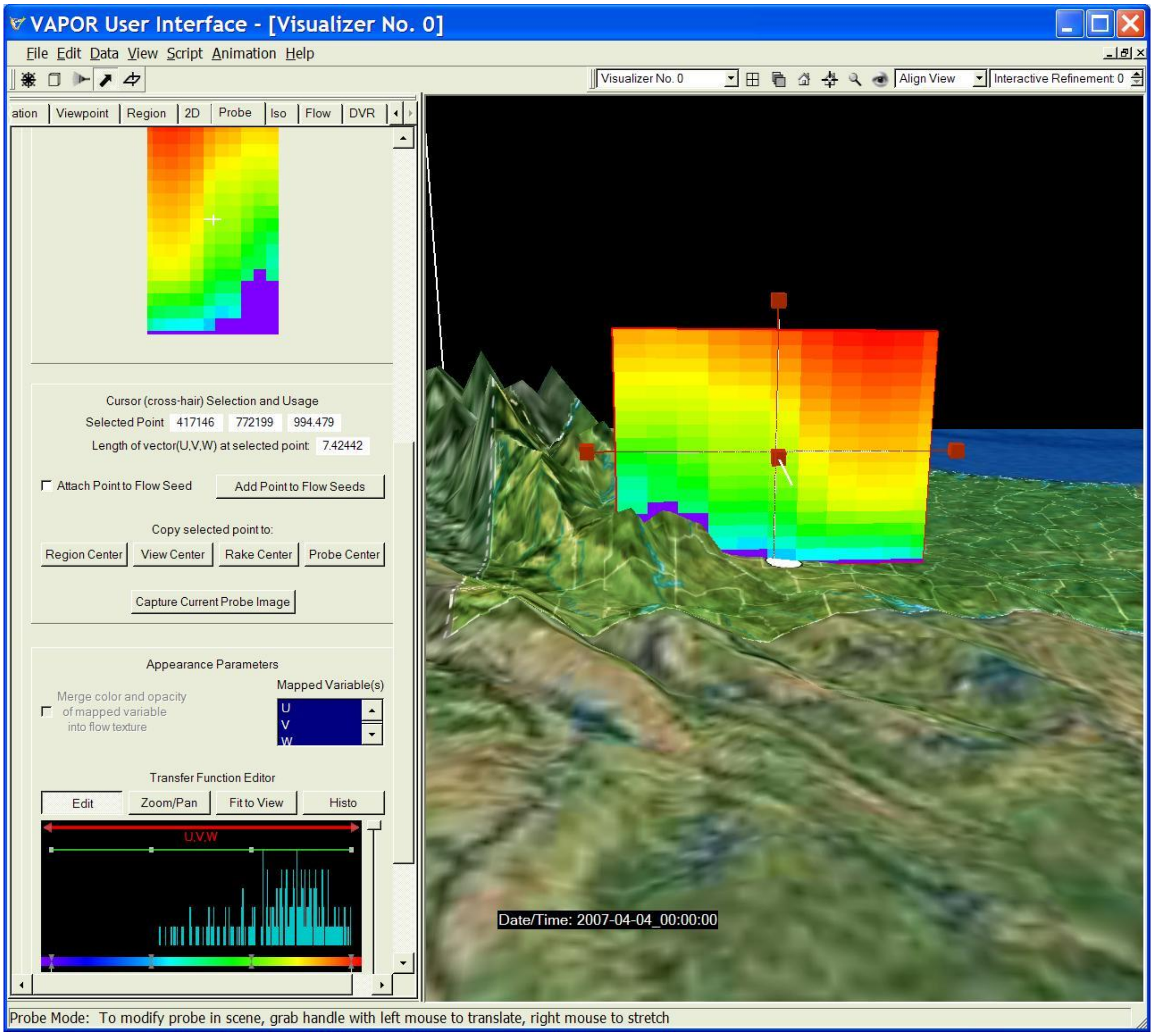
Mapped Variable(s): QCLOUD, QVAPOR, U (selected)

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 5.2: Data probe above Atlanta at time step 0.

Note that the portion of the probe below the ground is colored violet; this is because U, V, and W were set to be 0 below the lowest level of the WRF grid in section 4.1, and the probe color mapping assigns the color violet to the value 0.

We must orient the probe vertically to see a cross-section of wind speed near the ground level. Note that the Probe Orientation Angles are currently set to zero, indicating that the (x,y,z) coordinates in the probe are along the same axes as in the scene. The probe orientation controls are shown in figure 4.11. Below the Orientation Angles there is a selector with the text "90 deg rotate", which provides a convenient way of rotating the probe by 90 degrees. Click on the selector, and select "- Y" to rotate the probe so it points up and down. Then select "+ X" from the same selector so that the bottom of the probe image is downward in the scene. (Note: phi is the rotation of the probe from the vertical (z) axis, theta is a rotation about the z-axis, and psi specifies a rotation of the probe about its center axis prior to its insertion in the scene. You could rotate the probe by setting these angles, but it’s easier to use the rotation selector.) Click on the “Crop to Region” button to shorten the probe. Navigate in the scene so that you are looking eastward at the probe from the west side. Grab the top handle of the probe with the right mouse button and drag it down to make the probe image approximately square, as in the following image:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
ation Viewpoint Region 2D Probe Iso Flow DVR
Cursor (cross-hair) Selection and Usage
Attach Point to Flow Seed
Add Point to Flow Seeds
Copy selected point to:
Region Center
View Center
Rake Center
Probe Center
Capture Current Probe Image
Appearance Parameters
Merge color and opacity of mapped variable into flow texture
Mapped Variable(s)
U
V
W
Transfer Function Editor
Edit
Zoom/Pan
Fit to View
Histo
U,V,W

Selected Point 417146 772199 994.479

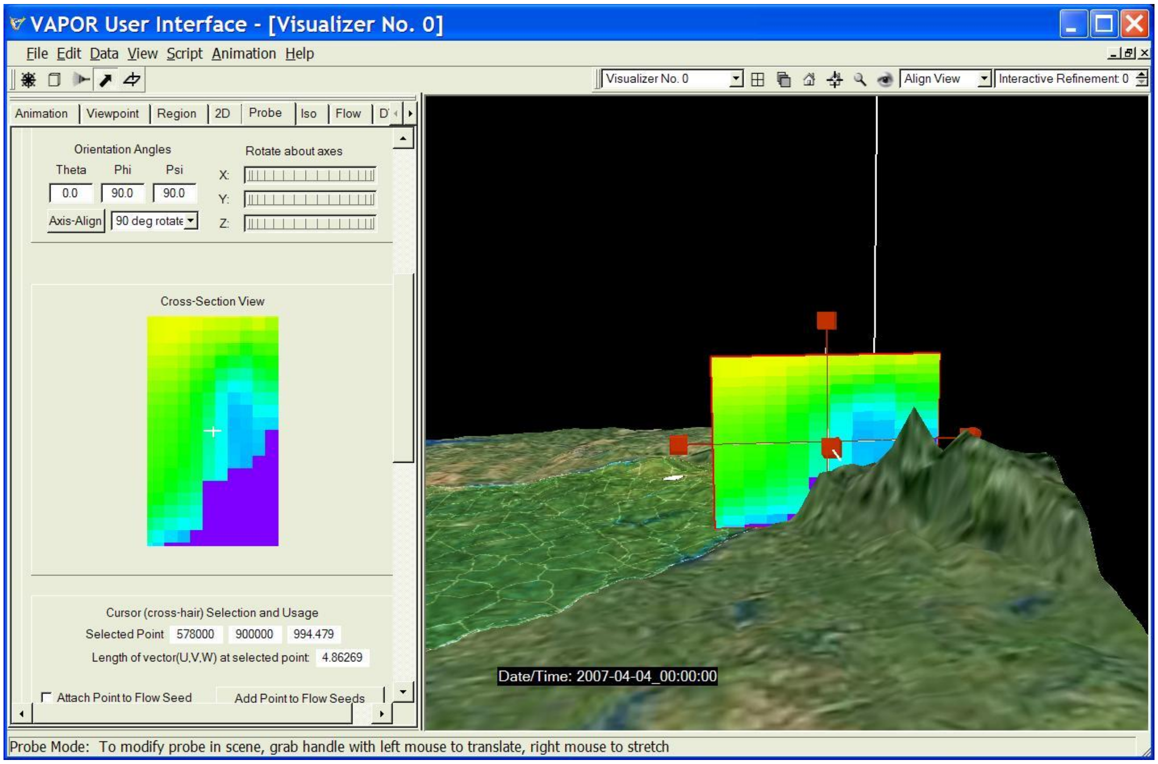
Length of vector(U,V,W) at selected point 7.42442

Date/Time: 2007-04-04_00:00:00

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 5.3: Vertically oriented probe above Atlanta.

To position the probe further north and east of Atlanta, first re-center the view on the probe by clicking the button on the probe tab, below the Cross Section View, labeled: “Use selected point to center: View”. Then drag the handles on the probe with the left mouse button to position the probe in the mountain range north-east of Atlanta. (You can alternatively just set the probe center coordinates at about (578000, 900000, 1000). Navigate your viewpoint around to the east side of the probe, as in the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
Animation
Viewpoint
Region
2D
Probe
Iso
Flow
Orientation Angles
Rotate about axes
X:
Y:
Z:
Axis-Align
90 deg rotate
Cross-Section View
Cursor (cross-hair) Selection and Usage
Add Point to Flow Seeds

Theta 0.0 Phi 90.0 Psi 90.0

Selected Point 578000 900000 994.479

Length of vector(U,V,W) at selected point 4.86269

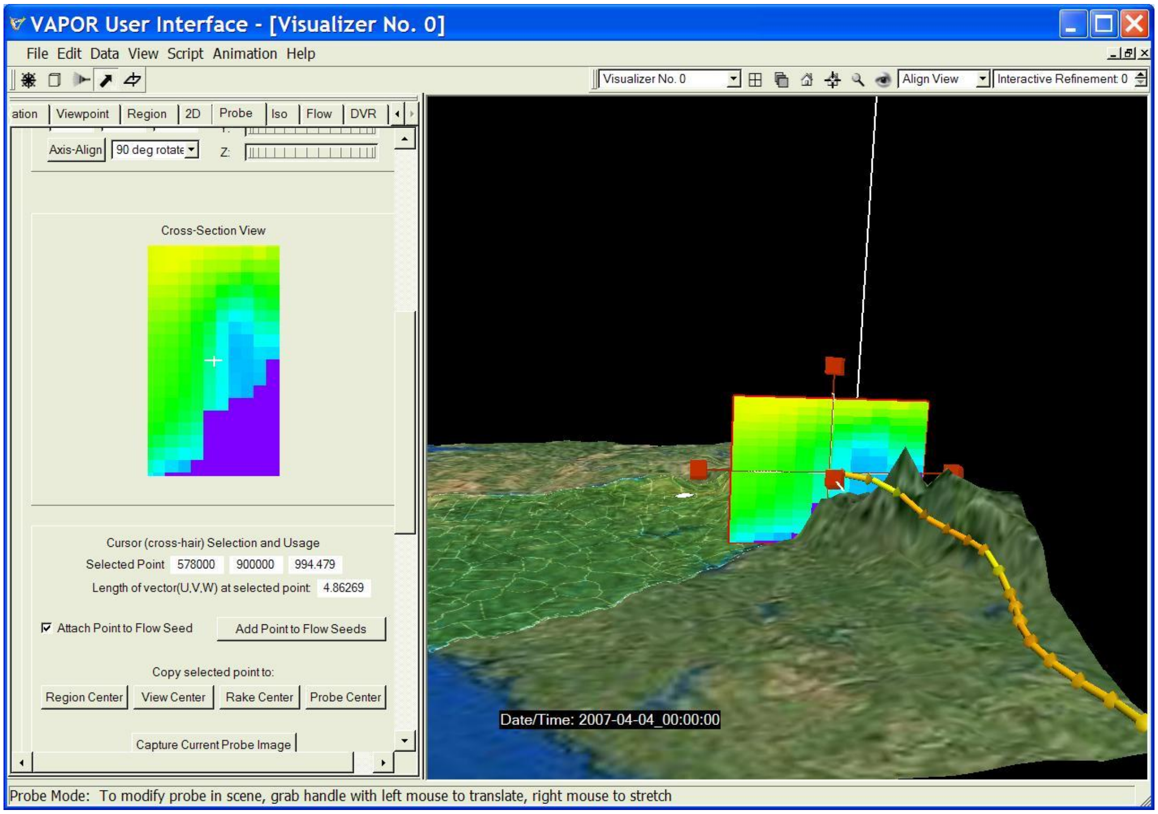
☐ Attach Point to Flow Seed

Date/Time: 2007-04-04_00:00:00

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 5.4: Probe placed in mountains northeast of Atlanta

We next use the probe to specify a set of flow seed points near the mountains. Click on the Flow tab. In the Flow panel, in the Flow Seeding Parameters, select "List of Seeds" instead of "Nonrandom Rake". In the flow Shape Parameters, set the "timestep display interval min, max" to -100 and 100 With this setting we shall see 100 time steps of the path lines, forward and backward, relative to the current time step resulting from the seed points we insert. Check the "Instance:1" checkbox to enable the flow integration. Since no seeds have been specified, you will not see any flow lines. Click on the Probe tab, and check the check-box "Attach Point to Flow Seed" which is located below the Cross-Section View. You will need to dismiss a couple of warning popup messages, indicating that all the flow lines have exited the current region. You will see be a series of flow arrows that start at the position of the cursor and move to the east from the probe. Zoom out, to get a good view of the path line as in the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Axis-Align
90 deg rotate
Z:
Cross-Section View
Cursor (cross-hair) Selection and Usage
Add Point to Flow Seeds
Copy selected point to:
Region Center
View Center
Rake Center
Probe Center
Capture Current Probe Image

Selected Point 578000 900000 994.479

Length of vector(U,V,W) at selected point: 4.86269

☑ Attach Point to Flow Seed

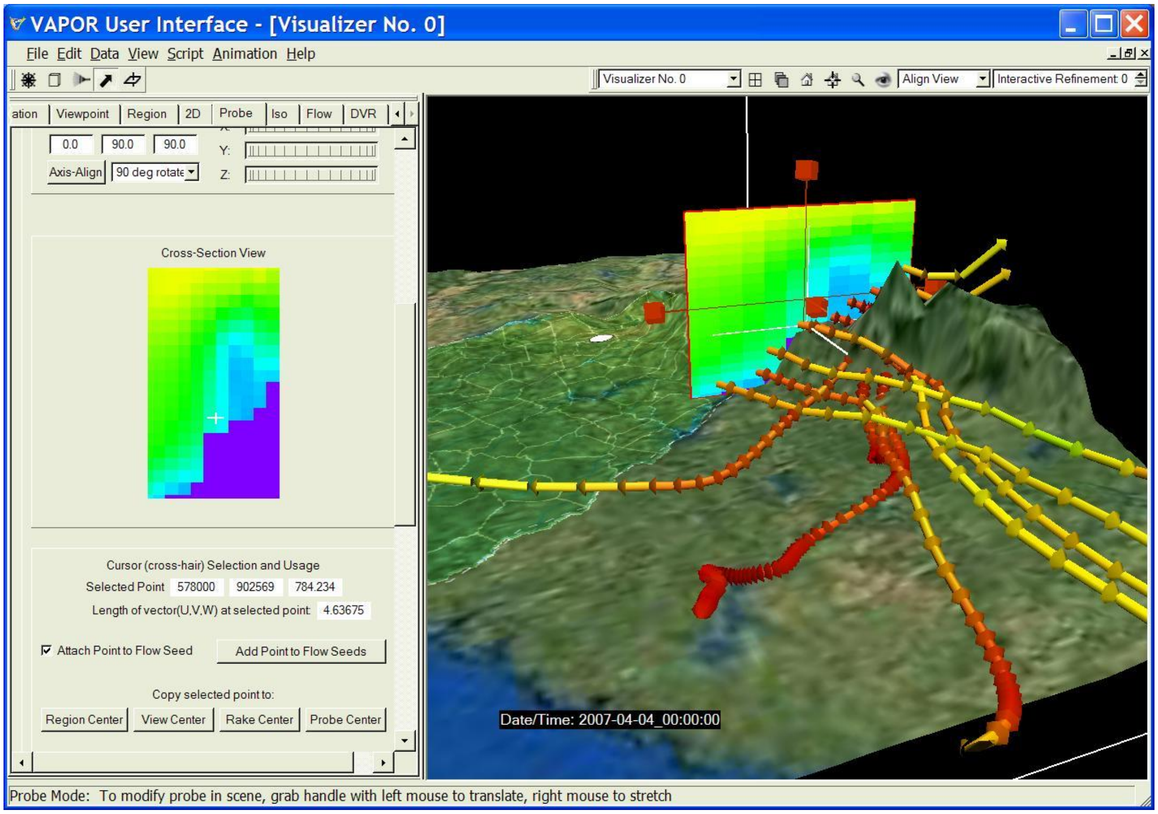
Date/Time: 2007-04-04_00:00:00

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 5.5: Trajectory (path line) resulting from seed point in the probe.

Using the left mouse button, click at various positions in the cross-section image in the Probe tab. You will see the resulting path lines. If the point you pick is under the ground, the path will go nowhere. Note that some of the path lines appear to intersect the ground. This is because, in order to save data access time, the flow integration is using Refinement level 0 of the wind field; however the probe and the terrain rendering we are using are at Refinement level 1. More accuracy could be obtained by using the full accuracy (refinement level 2) of the original data.

Select a few seed points near the terrain surface. Each time you find a seed point of interest, click on the button “Add point to flow seeds”. After you have added 8-10 seeds, you can clearly see how the particles follow the terrain to the east of the probe, as in the following:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement 0
ation
Viewpoint
Region
2D
Probe
Iso
Flow
DVR
Y:
Z:
Axis-Align
90 deg rotate
Cross-Section View
Add Point to Flow Seeds
Copy selected point to:
Region Center
View Center
Rake Center
Probe Center

0.0 90.0 90.0

Cursor (cross-hair) Selection and Usage

Selected Point 578000 902569 784.234

Length of vector(U,V,W) at selected point 4.63675

☑ Attach Point to Flow Seed

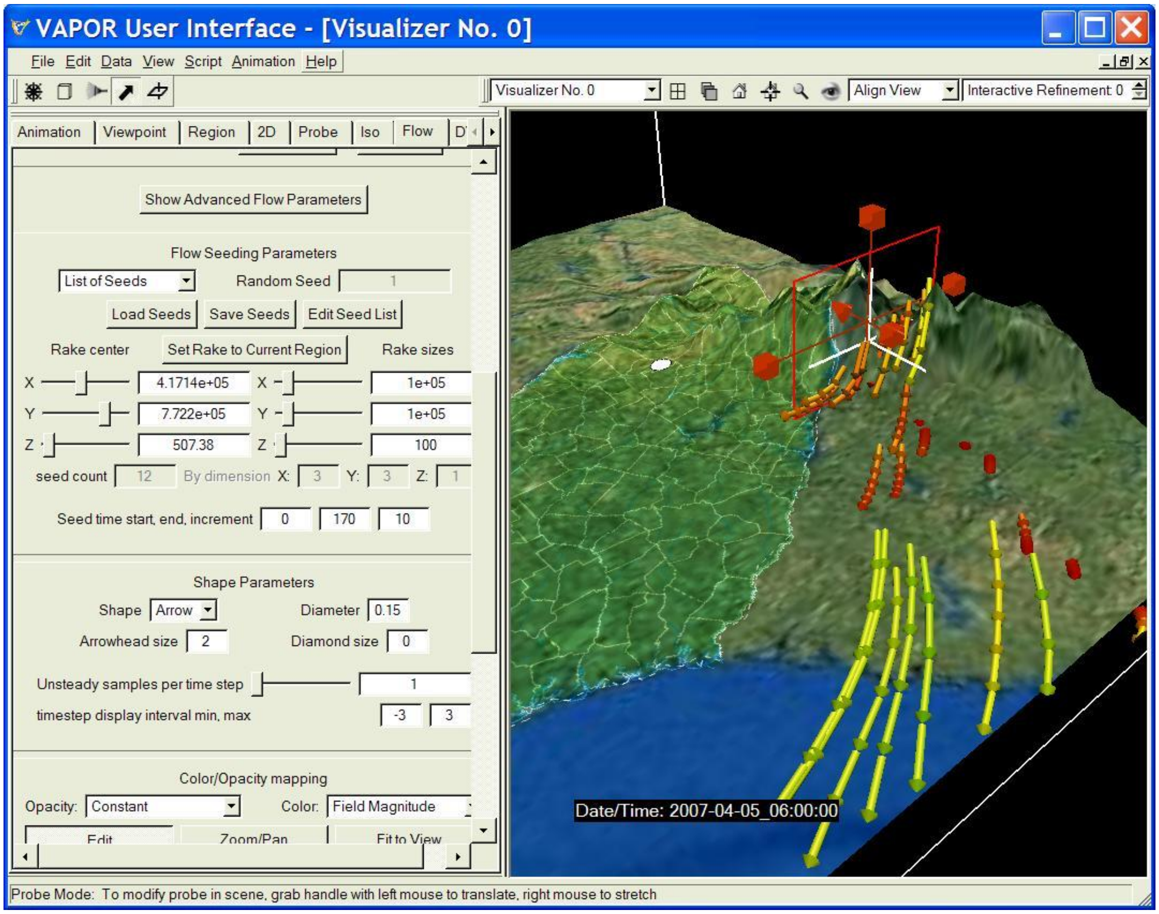
Date/Time: 2007-04-04_00:00:00

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 5.6: Trajectories (i.e. path lines) of particles released near the mountains.

To animate these particle trajectories, it is useful to set up the flow settings similar to the previous settings of unsteady flow near Atlanta. Rather than just having the particles released at one time step, we would like to see the result of releasing particles every 10 time steps. Disable the Probe and the Flow tabs. In the Flow tab, in the section entitled "Shape Parameters", set the "timestep display interval min, max" to -3 and +3. In the Flow Seeding Parameters click on the button "Edit Seed List". You will see that all of the flow seed points are set to have time step 0. For each seed point in the list, double-click in the time step cell, and replace the 0 with an asterisk "*", indicating that the seed can be inserted at any time step. Make sure that the Seed time start, end, increment (at the bottom of the Flow Seeding Parameters) are still set to 0, 170, 10. Click OK to accept the new values in the list.

Now enable the flow rendering. From the animation toolbar, play forward. You will see the paths followed by particles placed every 10 time steps near the mountains. The following shows this animation at time step 30:


VAPOR User Interface - [Visualizer No. 0]
File Edit Data View Script Animation Help
Visualizer No. 0
Align View
Interactive Refinement: 0
Animation Viewpoint Region 2D Probe Iso Flow
Show Advanced Flow Parameters
Load Seeds Save Seeds Edit Seed List
Set Rake to Current Region
Edit Zoom/Pan Fit to View

Flow Seeding Parameters
List of Seeds
Random Seed: 1
Rake center: X 4.1714e+05, Y 7.722e+05, Z 507.38
Rake sizes: X 1e+05, Y 1e+05, Z 100
seed count: 12
By dimension X: 3 Y: 3 Z: 1
Seed time start, end, increment: 0 170 10

Shape Parameters
Shape: Arrow
Diameter: 0.15
Arrowhead size: 2
Diamond size: 0
Unsteady samples per time step: 1
timestep display interval min, max: -3 3

Color/Opacity mapping
Opacity: Constant
Color: Field Magnitude

Date/Time: 2007-04-05_06:00:00

Probe Mode: To modify probe in scene, grab handle with left mouse to translate, right mouse to stretch

Figure 5.7: Trajectories of particles emitted every ten hours from the probe positioned in the mountains, viewed at time step 30.

A full animation of this sequence, calculated at full resolution and including rendering of T and QVAPOR, can be viewed at: http://www.vapor.ucar.edu/sites/default/files/gallery/movies/unsteadyAnim.mov

Appendix: How VAPOR deals with WRF data

(The following section is for people who wonder about how VAPOR deals with WRF data grids. You can bypass this section on first reading.) WRF datasets contain a number of variables defined on a non-Cartesian 3D grid. VAPOR uses the 3D variables defined above the ground (i.e., it ignores soil_layers), and it also uses the floating point 2D variables that are oriented horizontally. The grid is regularly spaced in X and Y, but the vertical (Z) dimension can be nonuniform.

When a WRF dataset is converted to a VAPOR VDC (see the VAPOR/WRF Data and Image Preparation Guide), these 3D and 2D variables in the WRF dataset are saved in the VAPOR data format in wavelet form. This format does not increase the size of the data but does enable rapid access to sub regions or lower resolution versions of the data. Included in the VAPOR data is an additional variable called “ELEVATION” which is equal to (PHB+PH)/g, i.e.

is equal to the elevation above sea level at each point in the WRF grid. At conversion time, additional derived variables, such as normalized pressure, can optionally be calculated.

At visualization time, when a VAPOR user first accesses a variable in the data, the wavelet coefficients are converted to Cartesian gridded data in a two-step process: First a wavelet reconstruction of the WRF-gridded region is performed, then that data is interpolated to the Cartesian grid, utilizing the ELEVATION data to define the interpolation. The vertical spacing of the Cartesian grid is determined by the value of “Full Vertical (Z) Grid Height” specified in the Region panel. The reconstruction and interpolation results are cached to minimize data read time.

The variables in a WRF dataset may be specified in the WRF grid on cell centers or on face centers (i.e. on an unstaggered or staggered grid). VAPOR uses only the cell-centered grid, so all variables on unstaggered grids are averaged to the cell-centered grid when the data is converted.

The vertical resolution of the Cartesian grid that is used for visualization is controlled by the VAPOR user (in the Region tab). By default, the full resolution grid has height equal to four times the number of vertical layers in the WRF grid. A higher vertical resolution is appropriate when examining regions, such as near the terrain surface, where the WRF layers are more closely spaced. When users visualize low resolution versions of the data (by specifying a refinement level in a visualizer), the vertical resolution is reduced by the same power-of-two factor as is the horizontal resolution.

When constructed using VAPOR data conversion utilities, the default VAPOR grid extends vertically from the bottom of the lowest layer of the WRF grid to the bottom of the highest layer of the WRF grid. (These extents are calculated by averaging (PHB + PH)/g, since PH and PHB are specified on a vertically staggered grid). As a result there can be points in the VAPOR grid that are outside (below or above) the WRF grid. By default, all variables in the data have their bottom and top values extended from the bottom and top of the VAPOR Cartesian grid; however users can specify any other value for these in the Visualizer Features panel. Different vertical extents for the grid can also be specified by the wrfvdfcreate utility.

Typical WRF grids extend much further in the horizontal dimensions than in the vertical. A WRF grid may have a horizontal size of thousands of kilometers, while the vertical dimension is often on the order of a kilometer. When visualizing such 3D data in its native scale, users would not be able to see vertical features of the data. VAPOR allows the users to stretch the data (using the Visualizer Features panel), exaggerating the vertical scale. This stretching only affects how the data appears to the user; it does not modify the data values or affect the flow integration.

The bottom level of the data can be displayed in VAPOR as a terrain surface (using the HGT variable to specify terrain elevation), and users may supply an image (as a tiff image specified in the Image panel) that will be applied to that surface. Two-dimensional variables can also be mapped to the terrain. Note that the terrain surface will not always coincide precisely with the lowest values of variables in the data, due to user-specified approximations used in displaying the data. To obtain the closest match to the terrain surface, the variables and the terrain must be visualized at highest resolution, and the vertical grid height must be great enough to ensure the vertical grid spacing is finer than the vertical spacing at the lowest level of the WRF grid.