Visualization and Analysis of WRF-ARW output using VAPOR

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VAPOR (Visualization and Analysis Platform for atmospheric, Oceanic and solar Research) is an NSF-funded project at NCAR to enable scientists to interactively visualize and analyze the results of turbulence simulation. VAPOR provides interactive performance on Windows, Mac OS X, Linux, and Irix, requiring about a Gigabyte of memory and a recent graphics card. VAPOR exploits the new features of the current generation of inexpensive PC graphics cards, enabling interactive 3D visualization of massive volume data, even on laptops.

VAPOR has been customized to support WRF-ARW data. Two command-line tools are provided (wrfvdfcreate and wrf2vdf) to directly convert WRF-ARW data to the VAPOR format. Additional variables (e.g. wind speed, temperature, vertical vorticity) can optionally be derived during the conversion.

WRF-ARW data and valuable technical discussions provided by: Thara Prabhakaran and Gerrit Hoogenboom of the University of Georgia, Atlanta, GA (Cold front in Georgia simulation), and Yongsheng Chen of NCAR, Boulder, CO (Hurricane simulation).

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VAPOR software is available free at http://www.vapor.ucar.edu/. Contact vapor@ucar.edu

VAPOR utilizes WRF-ARW time stamps, terrain elevation, variables and staggered/unstaggered coordinate mappings. Images can be applied to the terrain surface for geo-referenced terrain features. The grid can be stretched for improved identification of vertical features. Vertical interpolation accuracy is user-specified to enable close examination of features near the terrain surface.

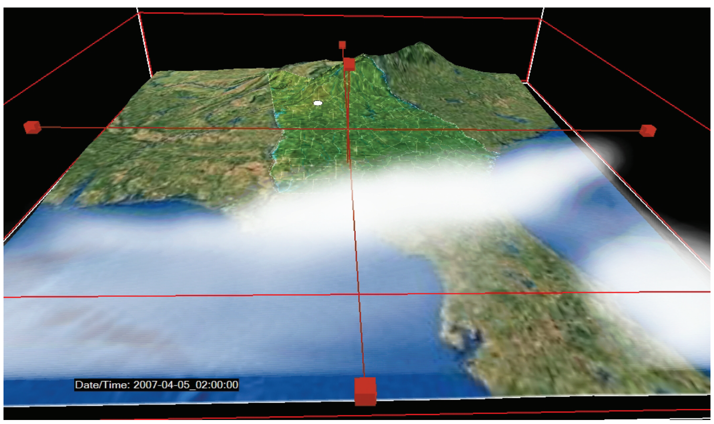

Figure 1: Satellite image is applied to terrain of vertically-stretched region to provide geo-reference information. White dot indicates location of Atlanta, Georgia. Region has been stretched vertically by a factor of 100, then slab near terrain surface (identified with red box outline) has been selected for closer examination. White volume indicates increased values of QVAPOR associated with advance of cold front.

Volume Rendering: VAPOR utilizes recent advances in GPU (Graphics Processing Unit) technology for direct volume rendering. The color/opacity editor, designed in collaboration with turbulence researchers, allows the color and opacity to be controlled by sliding control points, resulting in immediate visual feedback. Improved accuracy and realism can be obtained by use of shading and the use of 16-bit graphics data.

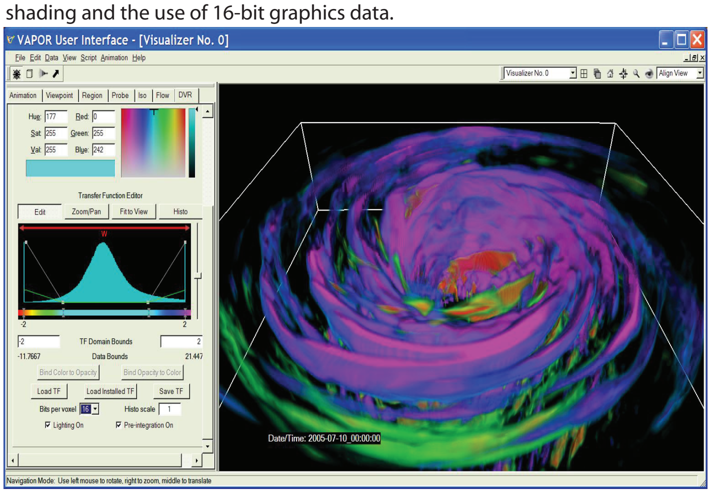

Figure 2: Volume rendering of W in hurricane simulation using a color/opacity mapping to emphasize updrafts and downdrafts.

Isosurfaces: VAPOR calculates isosurfaces on-the-fly in the graphics processor, allowing the user to interactively select the variable, iso-value and other parameters. Users can define a color/opacity mapping of any variable in the data, to interactively determine the color and opacity of the isosurface. Any number of isosurfaces can be visualized in the same scene.

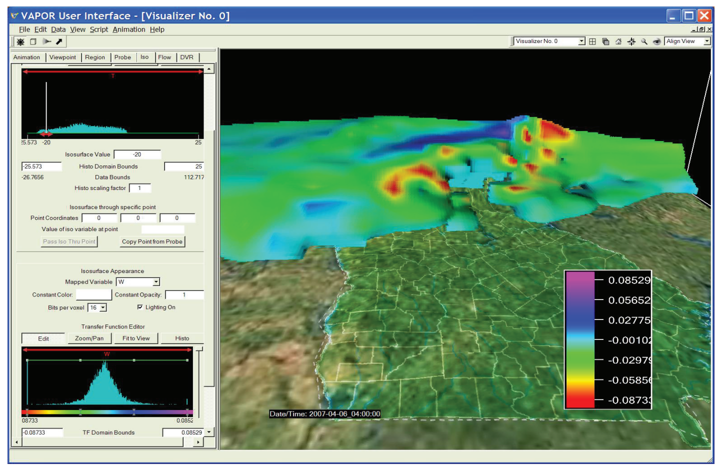

Figure 3: Isosurface of T, color specified by mapping of values of W (vertical wind velocity) at isosurface.

Flow integration: VAPOR supports steady and unsteady flow integration (for streamlines and particle traces). Wind vector arrows can also be specified. Flow seed points can be interactively positioned randomly or on a uniform grid using a rake. Seed points can also be manually specified or calculated externally. Users can determine the color and opacity of flow lines by mapping other variables in the dataset. Shape, diameter, smoothness, etc. are easily and interactively specified.

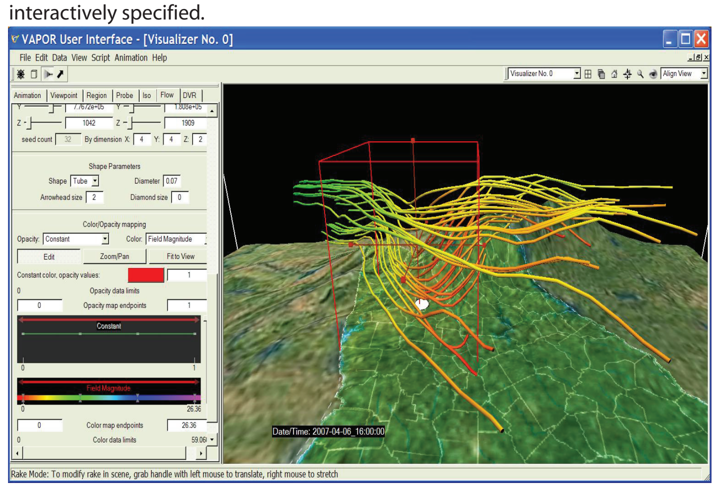

Figure 4: Streamlines resulting from positioning rake over Atlanta are colored by wind speed. Dependence of wind direction on elevation is shown by positioning of upper and lower levels of regularly spaced seed points.

Particle traces: Unsteady flow integration in VAPOR enables visualization and animation of particle trajectories. Users can position rake or individual seeds to track motion of individual particles for duration of simulation. Velocity can also be integrated backwards in time to determine wind sources.

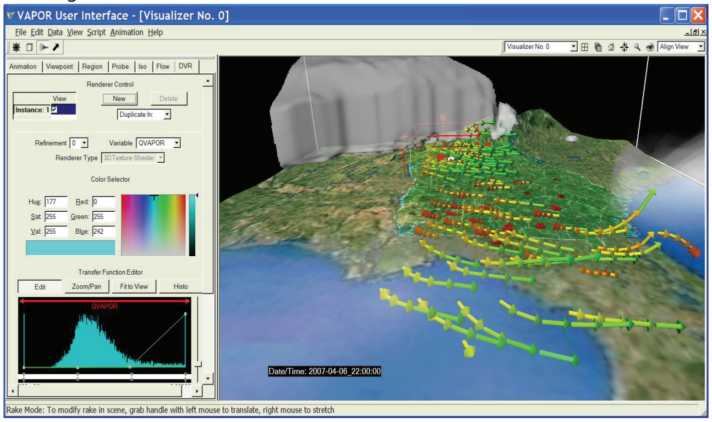

Figure 5: Particle traces resulting from rake near terrain around Atlanta show dispersion of pollutants in advance of approaching cold front. Particles are released every 10 hours. Path of each particle is shown as sequence of arrows, each arrow indicating the distance traveled in one hour. Image combines isosurface and volume rendering with particle traces.

Region-of-interest and resolution control: Very large (e.g. Terabyte) datasets can be interactively visualized in VAPOR. The underlying multi-resolution data representation in VAPOR is wavelet-based, permitting immediate loading of data at user-specified resolution and spatial extent. Users specify the desired refinement level to maintain interactive data access rate. Large data sets can be interactively browsed at lowered resolution (using any of VAPOR's visualization or flow integration capabilities). When full resolution is required, users can specify a smaller region of interest and zoom in for closer examination.

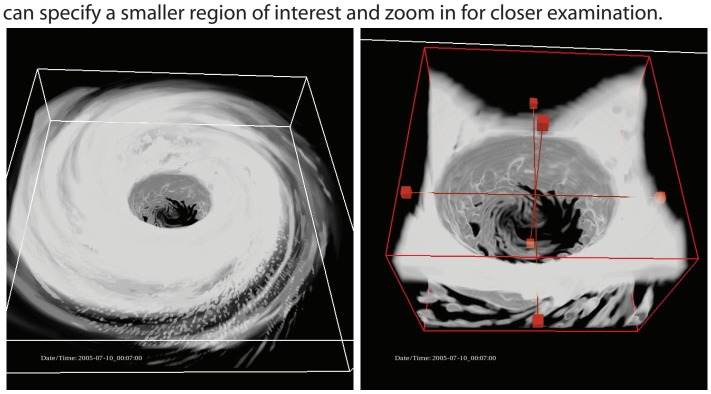

Figure 6: Details of QCLOUD variable in the eye of a hurricane are visualized by selecting a region of interest with VAPOR's region manipulator. The smaller region can be interactively displayed at full resolution.

In-scene manipulators: For interactive browsing of features in volume datasets, VAPOR provides various in-scene data manipulators. Region-of-interest, flow rake, and data probe have handles that can be interactively dragged in the scene, to move or stretch to desired position. The data probe/contour plane tool can also be manually rotated to any desired orientation.

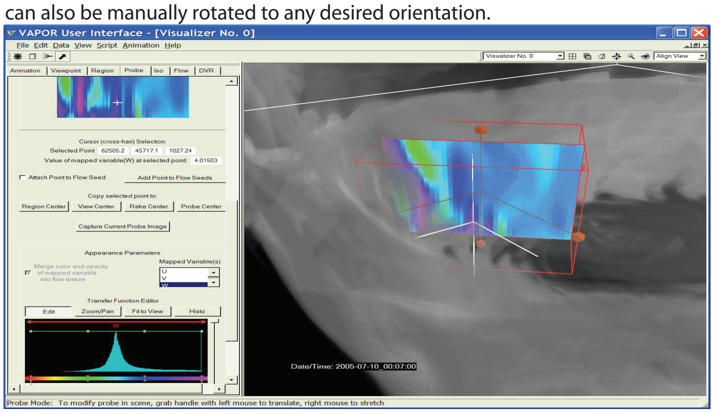

Figure 7: The probe manipulator is positioned at edge of hurricane eye-wall, rotated to desired orientation. Volume rendering of QCLOUD is used for spatial context. Cursor is manually positioned in probe based on values of vertical component of wind. Histogram indicates distribution of values in full 3D box defined by probe.

Seed placement with data probe: The data probe/contour plane tool is useful for explicit placement of flow seeds. The VAPOR probe includes a contour plane image that can be used as reference for 3D cursor positioning. Color/opacity mapping is used to map variable values into the contour plane image in the probe. Users can interactively visualize the resulting streamlines as the seed point is moved.

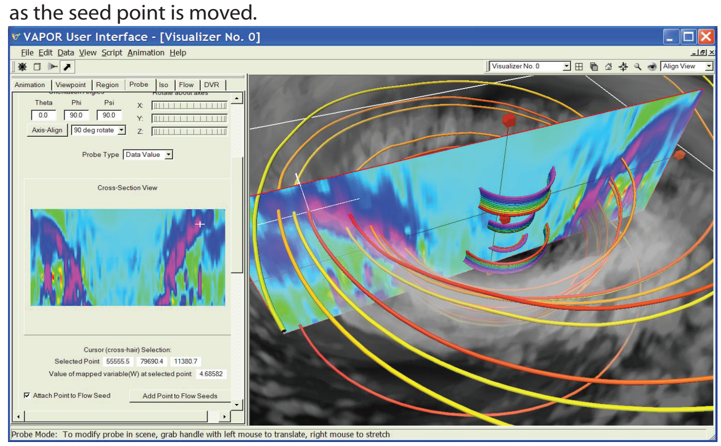

Figure 8: Streamlines in hurricane are specified by using contour plot of W in probe as reference for flow seed positioning. Probe illustrates internal structure of hurricane. Streamlines in interior of eye trace nearly circular orbits. Maximal values of W form upward opening cone. When W is large, streamlines rotate upward and outward. Near earth surface, streamlines rotate inward into eye.

Image based flow visualization: Details of wind flow can be easily seen using the Image Based Flow Visualization (IBFV) function of the probe. This feature provides animated images showing flow direction and speed in an arbitrary plane. The IBFV images are produced by advecting a random spot noise pattern in steady flow, alpha-blending the resulting images over repeated advections. Animated sequences can be seen in real-time or captured to file. This feature can be used to identify vortices and other patterns in wind flow.

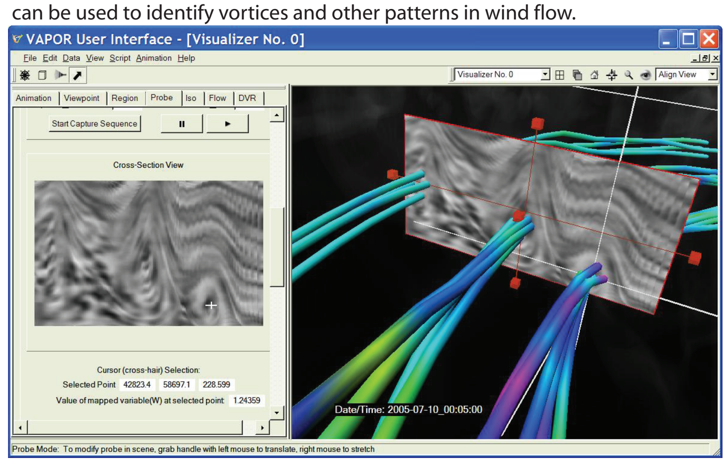

Figure 9: Image based flow visualization is used to identify vortices in wind flow near the earth surface at the eye wall. The animated images provide a clear indication of flow patterns along the planar slice specified by the data probe. Multiple seeds inserted around vortex result in twisting bundle of streamlines.

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