Visualizing wind flow at H. J. Andrews Long Term Ecological Research Forest

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1 Introduction

One of the common obstacles many scientists face is the inability to see or observe the system which they study. If, for example, the system occurs on a small spatial scale (as in physical chemistry and biochemistry), visual observations cannot be made without the assistance of a microscope, or even more specialized machinery. If, on the other hand, the system occurs on a very large spatial scale (as in meteorology), visual observations can only be made on one portion of the system at a given time, and the whole must be pieced together.

Increasingly, the solution to these observation problems has been to use computers to visualize these systems, allowing scientists to zoom in on and visualize spatially microscopic systems, or else zoom out of and visualize at once the entirety of a spatially macroscopic system.

Computational fluid dynamics is the branch of fluid dynamics which models, simulates, and visualizes the movements of fluids (such air) as they interact with various surfaces (such as the earth's surface). Modeling air flow and wind flow over topography is one such application of fluid dynamics.

The goal of this project is to create a wind visualization tool in WebGL, a javascript API used for rendering plug-in-free, browser-based graphics. The project will be developed tangentially to the VISTAS Research Group based out of Evergreen State College and Oregon State University and in support of the Oregon State University-based VALCEX (Valley Circulation Experiment) project.

2 Background

The VISTAS (VISualization of Terrestrial-Aquatic Systems) Research Group formed as a collective effort between scientists based out of Evergreen State College and Oregon State University [12] . It is a 4-year project devoted to developing visualization software for large-scale ecological phenomena and problems which are both spatially and time-dependent.

There are currently three software projects associated with the group: VISTAS, VELMA and Envision. Computer scientists on the project have indicated that they need to research the visualization of such an invisible fluid as wind over a mountainous topography. More specifically, they require a prototype visualization which may be eventually incorporated into the existing VISTAS software of the dynamic behavior of wind as it moves across the topography of the H. J. Andrews Long Term Ecological Research Site located in the Cascades, east of Eugene, OR.

These visualizations will be based on profiles of wind speed, direction, and other meteorological parameters collected at H. J. Andrews between March 13, 2011 and June 23, 2011 as part of the Valley Circulation Experiment. Digital elevation models (DEMs) are freely available from the existing VISTAS software will be used to model valley topography.

2.1 VALCEX

The purpose of VALCEX is to better understand the nature of valley-scale airflow and diurnal weak-wind transport [13]. It serves as a preliminary study to the Advanced Resolution Canopy Flow Observations (ARCFLO) project, which looks more specifically at airflow through plant canopies [1].

The field of micrometeorology is primarily concerned with smaller-scale meteorological phenomena, specifically those which occur within the lowest atmospheric layer called the Atmospheric Boundary Layer (ABL). The primary defining characteristic of the ABL is that wind dynamics within this layer are influenced by the Earth's topography, as well as time-dependent temperature changes in the Earth's surface [13]. In mountainous terrain, solar radiation can lead to differential heating of South-facing slopes. This results in a local, low-pressure anomaly which in turn can lead to a response in near-surface air flows. On clear nights, radiative cooling of Earth's surface can cause low air temperatures and increased air density. In combination with sloped terrain, this may lead to gravity-driven density currents in the absence of significant synoptic forcing.

These weak-wind flows transport moisture, heat, gases and potential contaminants between forests and connected valleys[11]. Although weak-wind transport is a known phenomenon, it is also poorly understood. Animations and visualizations of data collected in the ABL at H. J. Andrews would allow VALCEX scientists to see these time-dependent changes in the air column extending from the Earth's surface to several hundreds of meters aloft. The use of point data shown on a DEM will also provide visual confirmations of connected valley wind flow patterns between the two data collection stations at Primet and McRae.

2.2 Data and Experiment Setup

Data collected at H. J. Andrews comes from systems installed at two locations in connected valleys, Primet and McRae. The figures below show their installation locations in relation to the valleys and each other [13]:

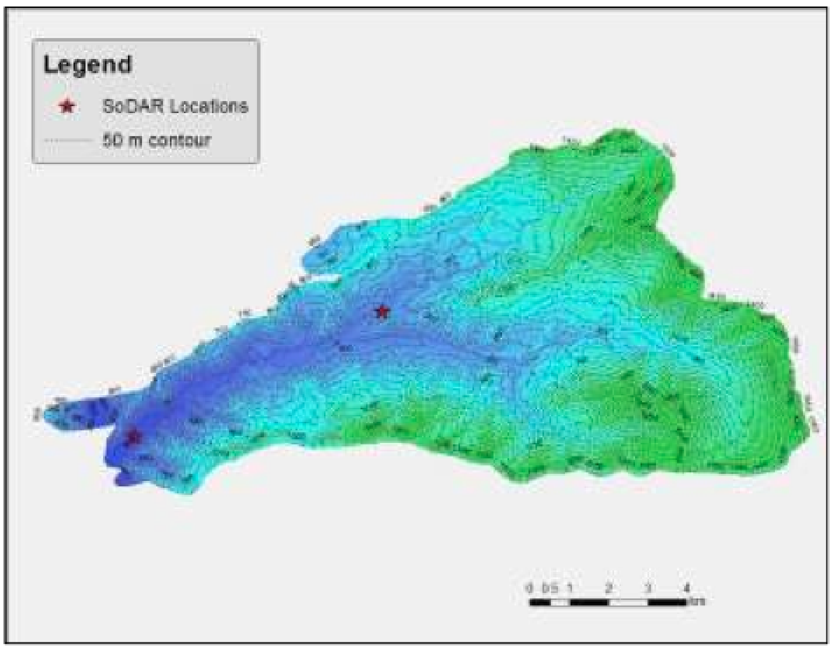

Figure 1: SoDAR Installation Locations at HJA

Each system consists of two instruments: one Sound Detection and Ranging (SoDAR) array and one sonic anemometer. SoDAR works by emitting an acoustical pulse and uses a proprietary software provided by the manufacturer METEK to analyze the return signal to calculate wind speed and direction, and atmospheric turbulence and reflectivity.

For VALCEX, SoDAR measurements were taken every 8 seconds between an elevation of 15 meters and 395 meters at 10 meter intervals, and then averaged to 5 minute and hourly intervals [13]. The sonic anemometers measured wind speed, direction, turbulence and temperature, and averaged to 5 minute and hourly intervals. Sample output from the SoDAR (called a Sodargram) is shown below [13]:

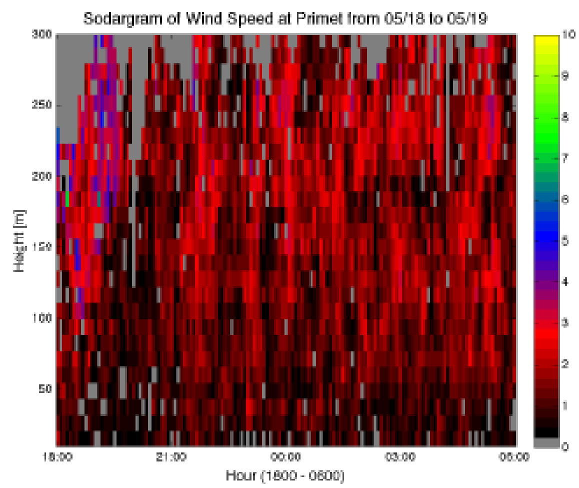

Figure 2: Sodargram showing wind speed

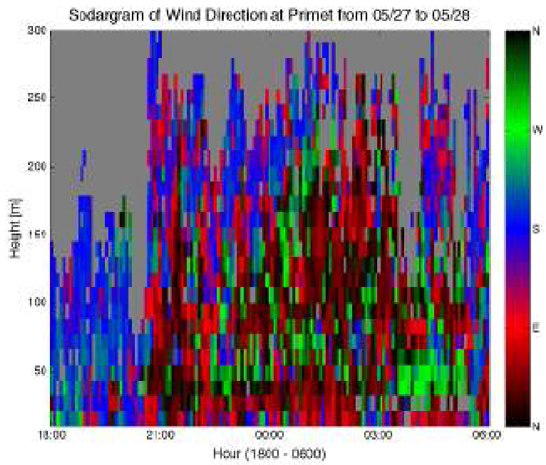

Figure 3: Sodargram showing wind direction

As evidenced in figures 3 and 4, Sodargrams are graphical depictions of raw data. As such, they are difficult to read, and require large amounts time to be spent learning to see patterns in the data. One such example in figure 4 shows to the "characteristic" appearance of the aforementioned valley jet behavior, where wind speeds at the lowest and highest elevations are slower than wind speeds at the mid-range elevation:

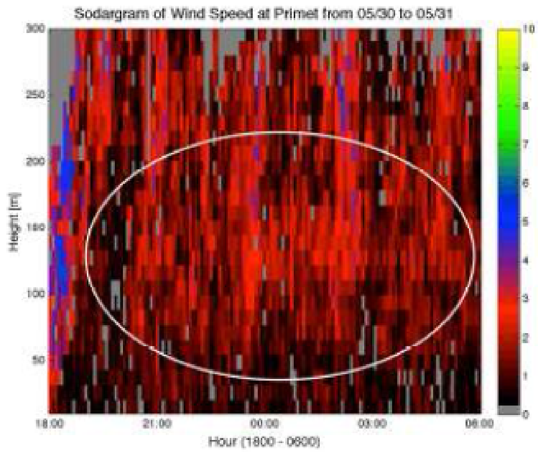

Figure 4: Sodargram showing valley jet classification

Although the current Sodargram output is difficult to read, the data can be manipulated and visualized in such a way that is easier to interpret at a glance, and therefore more informative.

3 State of the Art

3.1 Topography

While visualizations of wind data are important and informative to the project, the primary goal of this project is to develop a tool for visualizing wind as it moves over the valley topography at H. J. Andrews. Such a tool is important because it will allow VALCEX meteorologists and ecologists to see patterns in wind movement, which they would not otherwise be able to do. In order to create this tool, I will need to model the topography of H. J. Andrews as accurately as possible.

The best and most common practice for computationally modeling the topography of of a real-world terrain is to use a Digital Elevation Model, or DEM [10]. Such models are commonly used in hydrology and related fields to model fluid flows over topography [5]. DEMs of H. J. Andrews are already available and being used in the VISTAS software.

3.2 Fluid Flows

Visualizations of wind patterns and fluid movements typically rely on what are called vector fields or flow fields to depict the movement of fluids through and area[7]. Vector field representation of wind flow is useful because it allows for the observation of specific wind patterns.

Vector fields can be generated using real data sets, or else can be constructed if a model for the flow field exists [8]. In the case of this project, the vector fields will be created using point data provided by VALCEX.

4 WebGL

WebGL "is a cross-platform, royalty-free web standard for a low-level 3D graphics API based on OpenGL ES 2.0" which interfaces primarily with the HTML 5 canvas element [3]. Because it is plug-in free, it is readily accessible. Moreover, it is compatible with Javascript and supported in all five major browsers: Firefox, Chrome, Safari, Opera, and Internet Explorer.

The motivation for using WebGL for this project is partly its browser-based functionality. As the project is being developed for a group located elsewhere (namely Corvallis, OR and Olympia, WA), this browser-based functionality will allow the project to be developed remotely while collaborators will have live access to see updates and changes to the project, and therefore give relevant and frequent feedback.

Additional motivation for using WebGL stems from my previous experience using OpenGL is CS445: Computer Graphics, implementing an OpenGL ES application on the mobile platform in CS391 (Independent Study). This project will give me an opportunity to learn WebGL, thereby broadening my knowledge and understanding of computer graphics.

4.1 Limitations

WebGL is a useful tool for developing web-based, 3-D graphics, however it is somewhat limited by the inability to address more than 65536 vertices in a single draw call (each index uses 16-bits for each data point) [4]. As this project will require the use of a Digital Elevation Model (DEM), it will be necessary to overcome this limitation. This can be done by decreasing the level of detail, or by dividing the entire mesh into smaller meshes, which are then rendered using multiple draw calls [2].

Another limitation to WebGL is that while it is support across desktop platforms and browsers, support for mobile devices may be lacking, depending upon the device [6]. However, since mobile development is not a specific concern of this project, this issue will only be addressed if it becomes necessary, or if additional time is available towards the end of the project.

5 Implementation Goals

The goal for this project is to produce a wind visualization tool in WebGL that may later be integrated into the current VISTAS software, which consists of a C++, OpenGL implementation and a prototype, WebGL implementation [9]. Implementation goals for the project are prioritized into 4 tiers.

5.1 Tier I

The minimum goal for this project is to create a visualization of wind speed(u) and wind direction(ϕ) with respect to time and height on a DEM of H. J. Andrews LTER. Time will represented through the use of animation, while height will be displayed visually on the y-axis (on an xyz plane).

5.2 Tier II

Once all of the minimum project goals have been met, the next step will be to add visualizations for two additional parameters, the vertical velocity variance(σ_w) and the atmospheric reflectivity (R_3).

5.3 Tier III

The next implementation level will add parameters for spatial gradients $\frac{du}{dz}$ and $\frac{d\phi}{dz}$ and for temporal gradients $\frac{du}{dt}$ and $\frac{d\phi}{dt}$ where z corresponds to measurement height and t corresponds to measurement time. Additionally, at this implementation level, visualization elements for topographical surface temperatures may be added using color as an additional dimension.

5.4 Tier IV

The final implementation level will introduce increased user control over the visualization output. The user will be able to emphasize, de-emphasize, add, or remove visualization parameters as desired. Additionally, this implementation level will ideally include some amount of data pre-processing so that certain phenomena (i.e. station couping) can be highlighted in the visualization in real-time.

References

[1] Biomicrometeorology Group at OSU. Arcflo. Online, 2013.

[2] DiBenedetto, M., Corsini, M., and Scopigno, R. Spidergl: A graphics library for 3d web applications. *Remote Sensing and Spatial Information Sciences 38* (2011).

[3] Khronos WebGL Working Group. Webgl - opengl es 2.0 for the web. Online, 2013.

[4] McMullen, T. H., and Hawick, K. A. Procedural generation of terrain within highly customizable javascript graphics utilities for webgl. In *Proc. 10th Int. Conf. o Modeling, Simulation and Visualization Methods* (July 2013), no. CSTN-219, WorldComp.

[5] Nemes, C., and Munteanu, F. Potential solar irradiance assessment based on a digital elevation model. *Advances in Electrical and Computer Engineering 11* (2011), 89.

[6] Noguera, J. M., and Jimenez, J. R. Visualization of very large 3d volumes on mobile devices and webgl. *Journal of WSCG* (2013).

[7] Pobitzer, A., Peikert, R., Fuchs, R., Schindler, B., Kuhn, A., Theisel, H., Matkovic, K., and Hauser, H. On the way towards topology based visualization of unsteady flow – state of the art. *Eurographics 2010, STAR Reports* (2010), 137–154.

[8] Pobitzer, A., Peikert, R., Fuchs, R., Schindler, B., Kuhn, A., Theisel, H., Matkovic, K., and Hauser, H. The state of the art in topology-based visualization of unsteady flow. *Computer Graphics Forum 30* (2011), 1789–1811.

[9] Ratanasangputh, V. Vistas webgl. Online, 2013.

[10] Shingare, P. P., and Kale, S. S. Review on digital elevation model. *International Journal of Modern Engineering Research 3* (2013), 2412–2418.

[11] Thomas, C. K., Kennedy, A. M., Selker, J. S., Moretti, A., Schroth, M. H., Smoot, A. R., Tufillaro, N. B., and Zeeman, M. J. High-resolution fibre-optic temperature sensing: A new tool to study the two-dimensional structure of atmospheric surface-layer flow. *Boundary-Layer Meterology* (2011).

[12] VISTAS Group at Evergreen. Vistas blog. Online, 2013.

[13] Walley, J. Valley circulation experiment: Using inductive analysis to classify wind flow in the h. j. andrews long term ecological research forest. Master's thesis, Oregon State University, 2013.