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Ecohydrology: Relationships and Processes Driving Fluctuations in Streamflow in Watershed 2 of the H.J. Andrews Experimental Forest

Historically, it is only relatively recently that the importance of maintaining the health of watersheds has entered the mainstream public awareness in the Pacific Northwest. Understanding the relationships between ecology and hydrology of watersheds enables scientists to better predict the consequences of forest management polices, and allows lawmakers and forest management to adapt and respond to changing environmental and socio-economic conditions. For this study, we attempted two types of analysis, a water balance and visualization of air temperature, on data collected at H.J. Andrews Experimental Forest in the western Cascades. Although the Andrews has been collecting meteorological data in and near a site known as Watershed 2 (WS2) for a number of years, such analyses of this data have not been done prior to this study.

Introduction:

Water balance: To understand what is happening in WS2, a water balance was created. According to Dunne and Leopold (1978), a water balance is the balance between incoming water from precipitation and snowmelt and outflow of water by evapotranspiration (ET), groundwater recharge, and stream flow. To find ET in WS2, the Penman-Monteith equation was used, which uses climactic variable in estimating evapotranspiration.

Visualization: While many parameters are factored into understanding the inputs and outputs to watershed systems, air temperature has been included mainly as a 1 dimensional data point. By analyzing air temperature data collected at multiple points, it may be possible to develop a more detailed picture of how air temperature behaves in space above the watershed. While this is not a research question, analyzing the air temperature at multiple points may provide results that will provoke questions for further research, or provide material useful for other types of analysis, such as models of the watershed.

Data

Waterbudget: Soil moisture and transpiration data were obtained from Georgianne Moore's Ph D dissertation. Data was collected from August 2000- June 2002. Climactic variables such as temperature and global radiation were collected and recorded by the PRIMET meteorological station, relative humidity and precipitation were collected and recorded by CS2MET, snowmelt data was collected and recorded by H15MET, and discharge data was collected and recorded by the gauge station in WS2. All of the data climactic and discharge data were obtained from the H.J. Andrews Database

Visualization: Air temperature is recorded at 15 minute intervals at 4 points vertically (450, 350, 250, 150 cm) on PRIMET, a meteorological station near Watershed 2. This data is made available through the H.J. Andrews Data website. Trial visualizations were made of data from late summer 2000, chosen mainly because of the proximity to the date range used for the water budget. Other data also included are solar radiation and wind speed (also from PRIMET) and precipitation from CS2MET all at hourly resolution. All data was loaded into a MySQL database in order to simplify the creation of the necessary datasets.

Methods

Water balance: The water balance was created to find the cumulative storage of WS2 in water year 2001. The formula used to see the storage subtracted all of the outputs from the inputs: Storage = S[t-1] + P - Q + SM - ET; where S[t-1] is the storage from the previous day; P is precipitation, Q is discharge, SM is snow melt, and ET is evapotranspiration.

ET was calculated using the Penman-Moneith equation, which used the formula:

$$ET(Wm^{-2}) = \frac{[(\Delta * irad) + (\frac{\rho * cp * VPD)}{r_{aM}})]}{\Delta + \gamma(1 + \frac{r_c}{r_{aM}})}$$

where Δ is slope of the saturation vapor pressure temperature curve, irad is incoming net solar radiation, ρ is the density of air, cp is specific heat of air, VPD is vapor pressure deficit, r_{aM} is aerodynamic resistance, γ is psychrometer constant, r_c is canopy resistance (Unsworth 2007). Because wind speed and humidity data was not readily available for WS2, the parameters r_c and r_{aM} were used from a similar Penman-Monteith study done in the H.J.Andrews Experimental forest done by Cody Hale.

Visualization: Two types of visual analysis were attempted in regard to the air temperature data. We began with parallel coordinates visualization; for this type of visualization, only vertical axes are used, one for each parameter to be visualized, and then a series of line segments known as a polyline is drawn across all axes to show the connection between related data points. In this case, each air temperature gauge was represented by an axis that represented temperature (e.g. from 0 to 40 deg. celsius); thus there were four vertical axes plus one to display time (from 0 to 23 hours). If the temperatures at the four gauges at midnight were, for example, 5.6, 5.4, 5.4, 5.3, then a line segment was drawn from the first axis (the time axis) at 0 to the second axis (the first temperature gauge) at 5.6; the polyline then continued to the 3rd axis at 5.4, and so on, ending at 5.3 on the fifth axis.

The program for this visualization reads in a data file that is for the most part simply generated via a query to the database; at this point it is necessary to manually write the header for the data file, including the number of axes, the range of data values for each axis, the labels for each axis, and the number of data rows. After the data is read, OpenGL is used to draw the axes, polylines, and labels.

A common problem with most visualization techniques is that they do not tend to scale well: as the amount of data is increased, intelligibility is increasingly limited. One method of dealing with this is known as binning. In this case, binning was accomplished very simply by viewing each possible pair of lines between two axes as a bin and counting the number of occurrences in each bin. The bins with the highest frequency were drawn with full values for color saturation and value, whereas lines of lesser frequency were drawn at correspondingly lesser values for color saturation and value; the purpose behind this technique is to allow the viewer to spot important trends and patterns more easily. Although we had anticipated having to smooth the data by removing extreme outliers, initial plotting of the data suggested that such filtering was unnecessary.

The second type of visualization involved representing the data as a 3D shape. The data can be thought of as 3-dimensional: time, temperature, and height. As the data represents only a few discrete points spatially and therefore was fairly limited, it was necessary to interpolate between data points. From initial tests with plotting the data, it did not seem necessary to filter the data to remove outliers, and in addition, the similarity of the data points suggested that a linear interpolation would be an appropriate place to begin.

As software for displaying 3D shapes from .PLY files was provided for this project, it was only necessary to convert the data into the PLY format. A .PLY file begins with a header that contains information such as the number of vertices and the number of faces; following the header is a list of all vertices defined by their x, y, and z coordinates, and then each face is defined with a list of vertices identified by their indices in the list. The program written to do this conversion reads a tab-spaced data file generated from the database and calculates and outputs the vertices and then the faces necessary to draw the 3D shape. For the test shapes accomplished during the EISI program, just under 20000 vertices and 40000 faces were defined for each ply file.

Results

Water balance:

The depth of water storage accumulated to 1756.5 mm of water in the 64 ha watershed by the end of the water year 2001. From October to early June the storage increases, however from mid April through the end of September the storage appears to plateau (Fig 1).

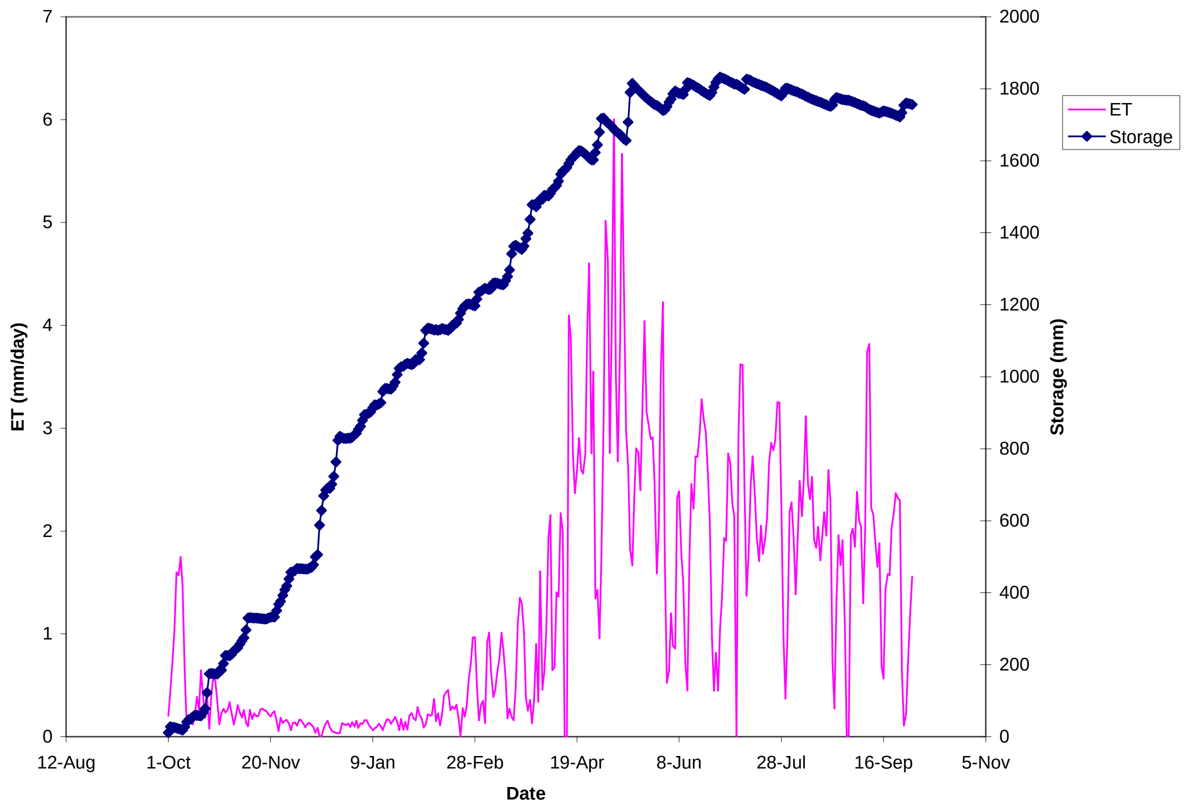

Figure 1: ET and storage of water in WS2 during water year 2001

Visualization: To a certain extent, the analysis of the data for the period of August and September 2000 seemed to confirm expected behavior: the air closest to the ground is the most affected by surface temperature and presumably solar radiation (Figures 2-6).

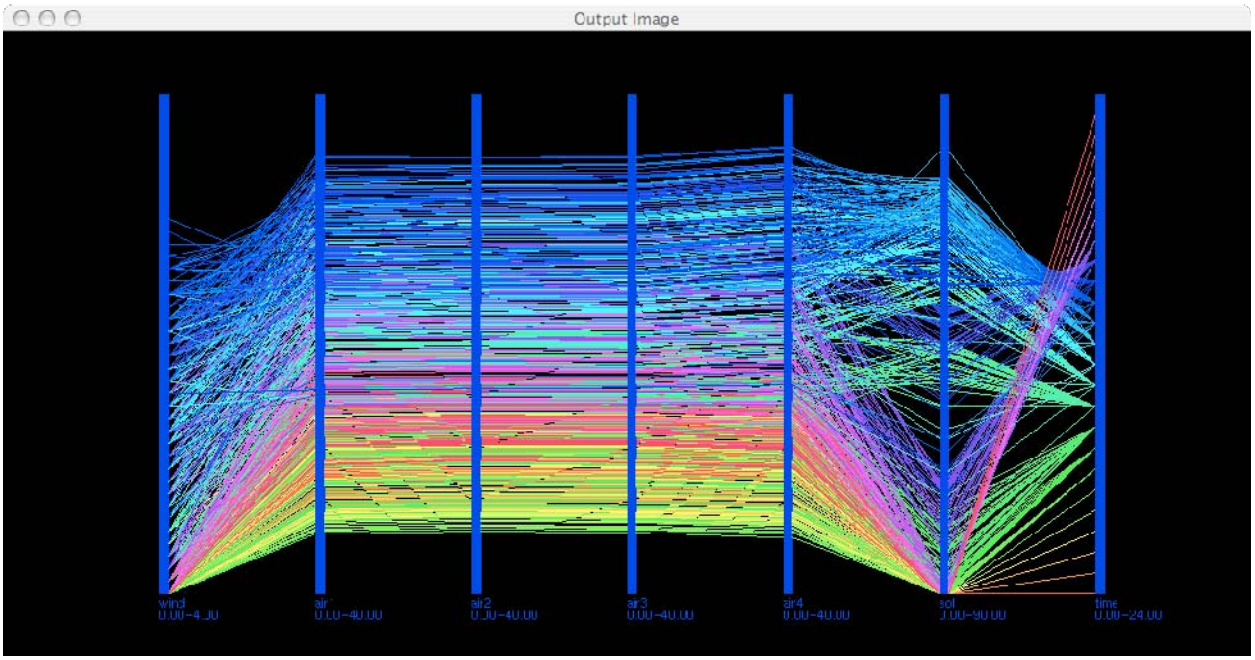

Figure 2: Air Temperature at PRIMET in August 2000

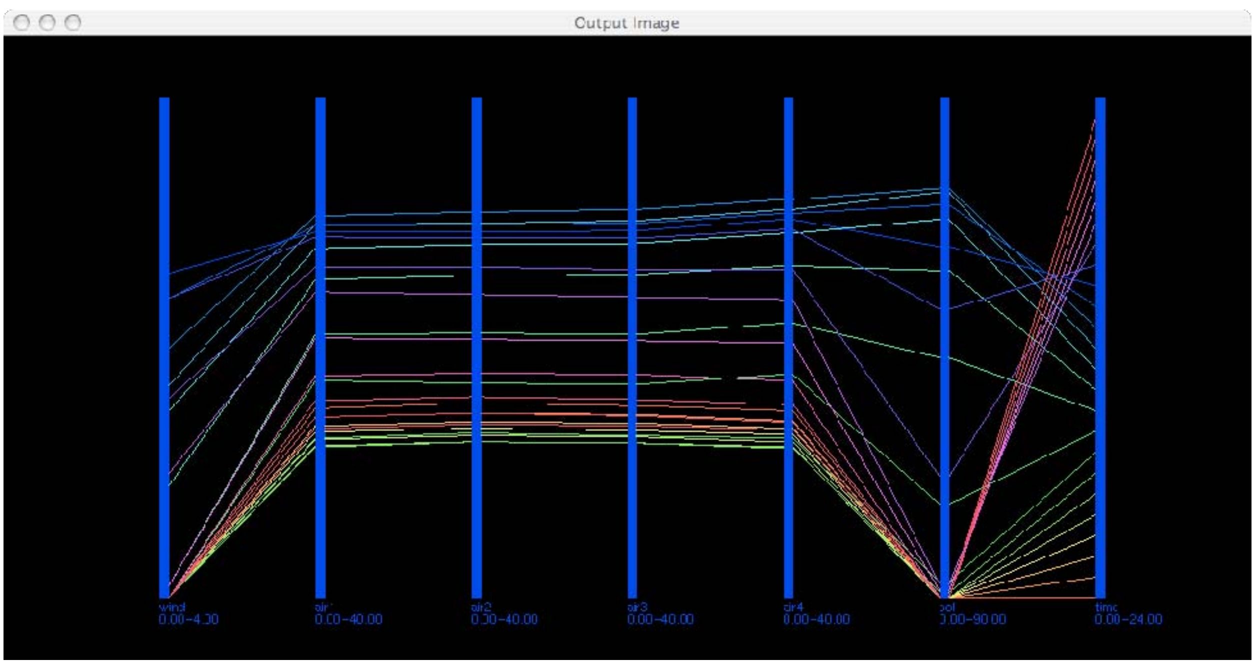

Figure 3: Air Temperature at PRIMET on 8/1/2000

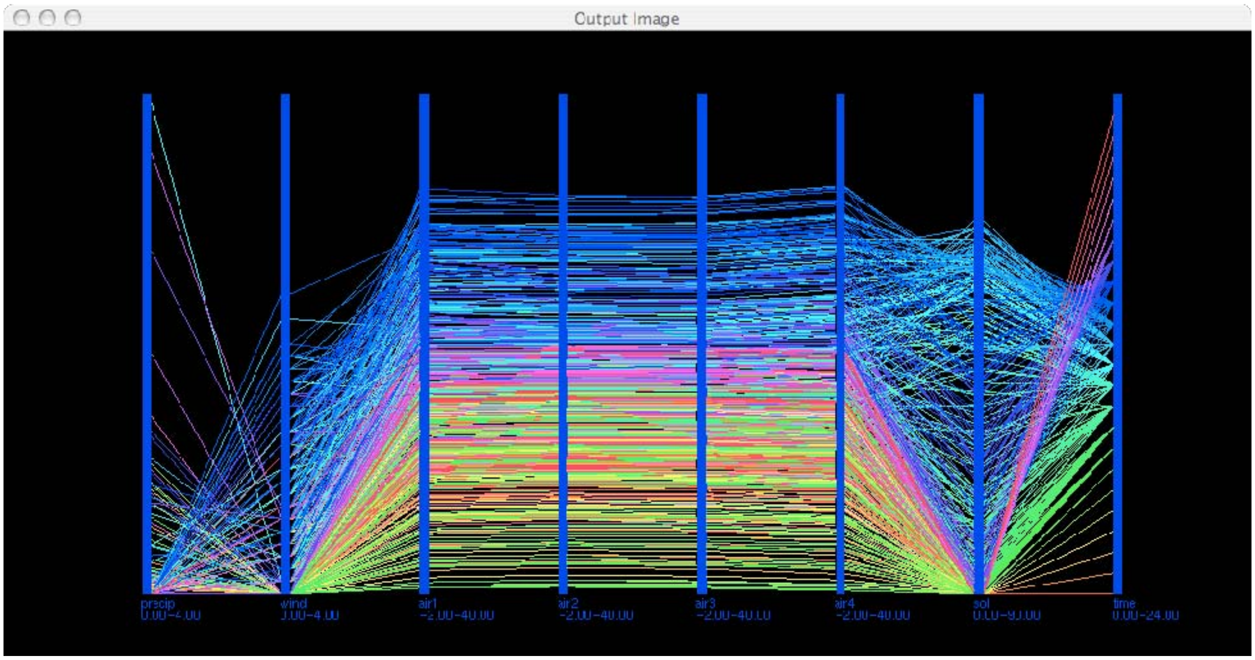

Figure 4: Air Temperature at PRIMET in September 2000

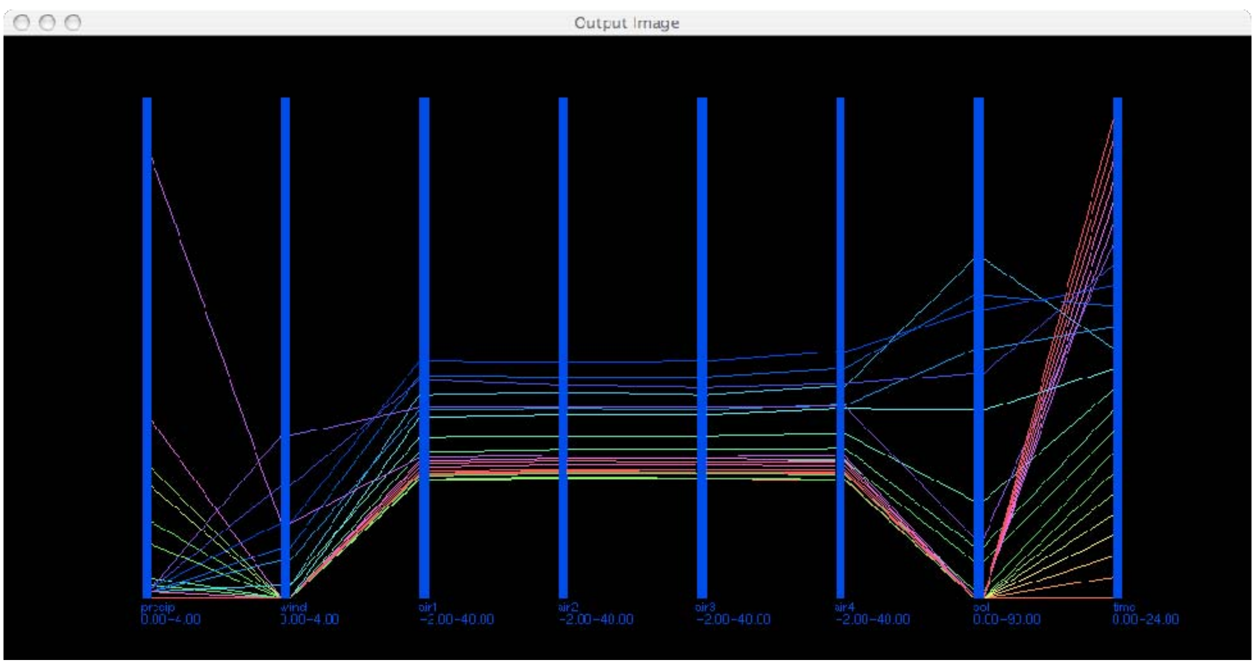

Figure 5: Air Temperature at PRIMET on 9/3/2000

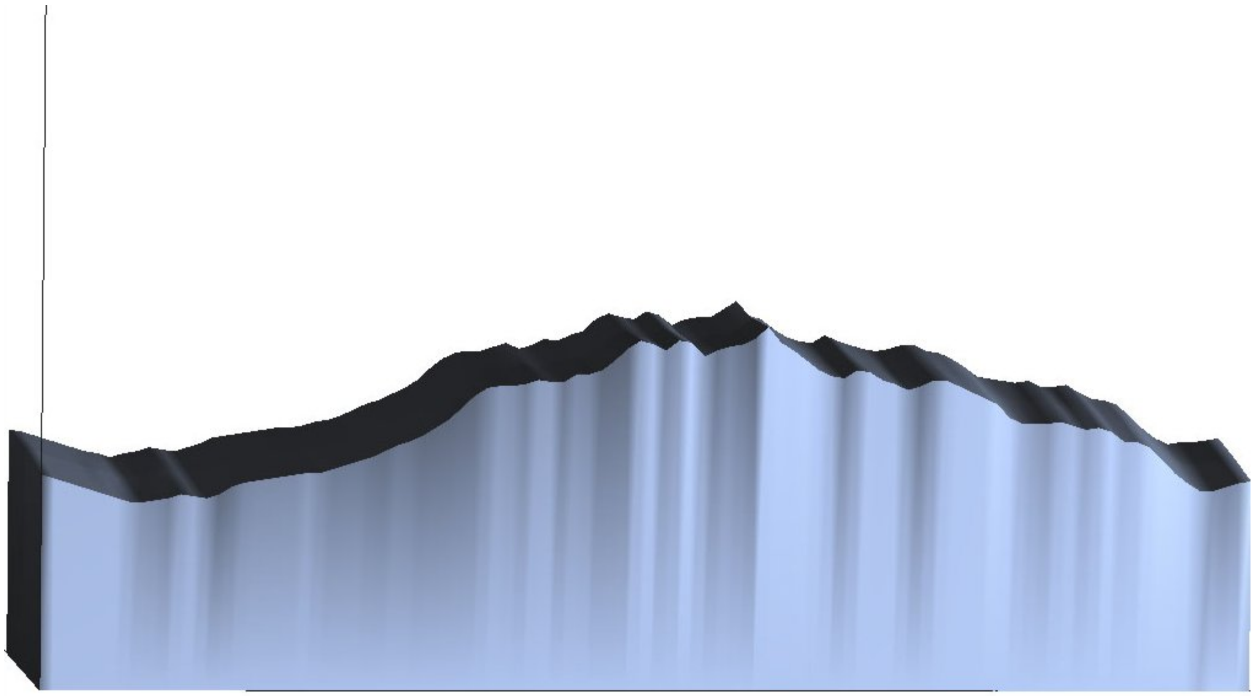

Figure 6: Air Temperature at PRIMET on 8/31/2000

Overall, the temperature of the air between 450 and 250 cm appears to be fairly "stable" in that the air throughout that vertical space tends to be very close in temperature even in changing conditions such as wind and precipitation.

Discussion

Water balance: The plateau of storage may be because the ET also plateaus at the same growing time. This is also the dry season for the western Cascades, where soil moisture decreases and water is less available for trees to transpire. The ET estimation from the Penman-Monteith equation seems to correlate with the transpiration data showing the plateau, even though the transpiration data came from sap-flow meter sensors in the watershed, whereas the ET data was derived from climactic variables collected at meteorological stations.

Possible sources of error when using the Penman-Monteith may be due to the sensor or instrumental error. A second source of error includes meteorological data that are available, but not immediately at the site (Hupet & Vanclooster 2001). This is especially evident as I used most of the data from CS2MET, a met station within Watershed 2, or PRIMET, a meterological station within 0.75 km with similar elevation. Ideally, all of the climactic variables would have been collected at the same metereological station within WS2, so that changes in ET can be easily understood with each climactic variable.

The Penman-Monteith equation is sensitive to the changing climatic variables. Several different studies have examined the sensitivity to climactic data, although with different outcomes. Vanclooster et al. (2001) found that solar radiation and windspeed variables most impacted the ET data, whereas Long et al (2006) found that relative humidity and radiation data to be the most sensitive climactic variable. A sensitivity analysis of the Penman-Montieth equation would be informative if resources were available.

Visualization: While the parallel coordinates visualization was fairly straightforward to realize, interpretation of the results requires a good deal of initial effort. Depending on the experience of the viewer, the number of dimensions represented, and level of complexity arising from the graph's layout, the graph as a whole tends not to provide an immediate grasp of the behavior of the data; instead, successive, individual segments on a given polyline or axis must be studied. Intelligibility however, may be increased by experimentation with the layout of axes and the selection of data.

In the case of this visualization, the point at which intelligibility was affected by the amount of data occurred fairly quickly: a month's worth of data at an hourly resolution was difficult to read. Binning was not very helpful in this situation in that the data tends to be spread out across the range of possible values. A more sophisticated binning process could use a clustering technique, and this may still prove to be helpful in comparing data across different seasons.

The 3d shape provides a more intuitive access to the data because it relies on a familiar visual analogy which allows viewers to be fairly efficient at processing information. While from a visual standpoint, this type of visualization would seem to handle large data sets well, a practical issue concerns the ability of the hardware to handle shapes with large numbers of faces. Time constraints did not permit experimentation with visualizing larger data sets, thus the usefulness of this technique for scaling up is left for future work.

Conclusions

The two types of visualization provide very different views of the data which potentially are useful in bringing different insights. The parallel coordinates visualization is useful not only for grasping the behavior of air across the 4 vertical points, but also for showing the relationships between air temperature and other factors. The 3D shape, on the other hand, provides a more intuitive grasp of the behavior of the air spatially and over the diel cycle.

The analysis discussed here of Andrews data is at a very early stage, and it was not possible to combine the results from the water balance and visualization analyses. Analysis of air temperature data that is measured at greater resolution in regard to time, vertical, and horizontal space will make it possible to explore in greater depth the relationship between air temperature and transpiration in the watershed, and hopefully inform water balance analysis as well as other analyses and models of watersheds.

References:

Dunne and Leopold. 1978. Water in Environmental Planning. W.H. Freeman an Company, New York.

Hupet, F., M. Vanclooster. 2001. Effect of the sampling frequency of meteorological variables on the estimation of the reference evapotranspiration. *Journal of Hydrology* 243: 192-204.

Long, L., X. Chong-yu, C. Deliang, S. Halldin, Y. D. Chen. 2006. Sensitivity of the Penman-Montwith reference evapotranspiration to key climactic variables in the Changjiang (Yangtze River) basin. *Journal of hydrology* 329: 620-629.

Moore, G. (2003). Drivers of variability in transpiration and implications for stream flow in forests of western Oregon (Doctoral dissertation, University of Oregon, 2003).

Novotny, M, H. Hauser. 2006. Outlier Preserving Foucs+Context Visualization in Parallel Coordinates. IEEE Transactions on Visualization and Computer Graphics. 12: 893-900.

Unsworth, M., personal communication, fall 2007, interactions of vegetation and atmosphere (ATS 564). Oregon State University.