

Atmospheric Sounding Visualization

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ABSTRACT

This paper describes AtmosView, a re-design of the visualization of atmospheric sounding data. Relationships between temperature, dewpoint, and the lifting of imaginary parcels of air are important to the determination of soaring conditions, atmospheric stability, and likelihood of severe weather. The current diagrams to display these relationships have been described as the most difficult atmospheric diagrams to read. The re-design applies well tested information visualization principles to expose data to the user previously hidden behind lines and frames. This not only improves extraction of data from individual charts, but allows for easier comparison between multiple charts. An informal evaluation of the re-design was encouraging and with some further work, a system designed around the AtmosView visualization should become usable for people with an amateur interest in these meteorological relationships.

Keywords: Information visualization, atmosphere, weather, design, colour.

1 INTRODUCTION

The advantage of applying graphical analysis to a data set is that the graphic can testify much more effectively than words or numbers alone. Graphics have been called to testify about data in every domain imaginable with varying degrees of success. The visualization of atmospheric sounding data is one domain where the graphic has not been exploited to its limit.

Meteorologists use several varieties of diagrams to visualize the changes of atmospheric properties throughout the vertical extent of the atmosphere. The charts that report the temperature as compared with the dew-point are thought by some non-experts to be the most difficult atmospheric charts to read [8]. The goal of this project was a redesign of the current visualization techniques for use by non-experts with an amateur interest in this data such as students, soaring pilots, and storm-chasers.

First, I present an introduction to this domain including current presentation formats. Second, I will describe some related work that informed my initial design ideas. Third, I present a new visualization for this data set, describe its use, and explain the design decisions that led to the end result. Last, I review the results of an informal evaluation of this new tool.

2 PRELIMINARIES

2.1 Background Information

It is important for the understanding of the domain data that a few terms are defined and explained at the outset.

2.1.1 Relative Humidity and Dew-Point

Relative humidity is the ratio of the amount of water vapour in the air to the amount of water vapour in the air at saturation. In a mixture of water vapour and air, only a certain amount of water can exist in vapour form without the mixture becoming saturated with water vapour. If the amount of water vapour in the mixture reaches

the saturation level the relative humidity is 100%. If the amount of water vapour in the mixture is at half of the saturation level, the relative humidity is 50%. The saturation level increases as temperature increases. Thus, if temperature increases, with no additional moisture added to the air, the relative humidity will decrease. If the air is instead cooled, with no change in the moisture content, the relative humidity will increase. If this cooling continues until saturation occurs, the water vapour in the air will condense into dew, fog, or clouds. The temperature at which this will occur is the *dew-point*.

2.1.2 Environmental Lapse Rate

Throughout the lower levels of the atmosphere (to a height of approximately 12km), the temperature decreases as altitude increases. On average, the rate of temperature decrease is 6°C per km. This is called the *environmental lapse rate*. The value of 6°C per km is the average environmental lapse rate and not a constant. Day-time heating and nighttime cooling affect the lowest layers of the atmosphere more than they affect higher levels. Thus, during a hot summer day, the temperature near the surface may be heated 20°C above average, while the layers above will not have been affected as much: the environmental lapse rate in the region affected by the surface heating will be greater than 6°C per km. On a cold, clear night, the opposite effect might be seen: the lowest layer of the atmosphere will be cooled more quickly than overlying layers. Taken to the extreme, it is possible, and common, that the lowest layer will cool so quickly that it becomes cooler than the air above. This is known as a temperature inversion. These examples are just two of the reasons that the environmental lapse rate might differ from the average. They also show that the environmental lapse rate isn't constant throughout the vertical extent of the atmosphere.

2.1.3 Adiabatic Lapse Rates

Atmospheric pressure decreases as altitude increases. When a parcel of air is caused to rise (by being blown up the side of a mountain, for example), it enters a region of decreased pressure, and the parcel of air expands. As a result of this expansion, its temperature decreases. When unsaturated air is lifted, it cools 9.8°C per 1000m. This is the *dry adiabatic lapse rate*. When saturated air is lifted, it cools at a variable rate somewhere between 5°C and 9°C per 1000m, depending on the moisture content. This is the *wet adiabatic lapse rate*.

2.1.4 Data Collection

The relationships between the above factors is very important in the analysis of atmospheric stability and potential for severe weather. It is important to have a sampling of the environmental lapse rate and humidity throughout a large vertical extent of the atmosphere. This sample is collected by launching a balloon with an attached sensor and transmission equipment called a radiosonde. The set of data from one balloon launch is called a *sounding*. Table 1 shows a small subset of one sounding's data.

Note that although there are eleven variables for each "raw data" point, only pressure (PRES), height (HGHT), temperature (TEMP), dew-point (DWPT), wind direction (DRCT), and wind speed (SKNT) are actually sampled. Relative humidity (RELH), mixing ratio (MIXR), and three temperature indices (THTA, THTE, THTV) are derived from the sampled variables.

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Table 1: An example of collected sounding data. [7]

PRES(hPa)	HGHT(m)	TEMP(C)	DWPT(C)	RELH(%)	MIXR(g/kg)	DRCT(deg)	SKNT(knot)	THTA(K)	THTE(K)	THTV(K)
1020.0	61	6.0	3.8	86	4.95	0	0	277.6	291.2	278.4
1000.0	224	10.0	6.9	81	6.28	15	4	283.1	300.7	284.2
997.0	249	10.2	7.1	81	6.38	17	5	283.6	301.5	284.7
990.0	305	10.0	6.8	80	6.30	20	6	284.0	301.6	284.0

This project assumed that only the first four (PRES, HGHT, TEMP, and DWPT) along with wind information were available and derived a relevant subset of the latter variables and other indices to avoid a dependency on data sources that provide all of these variables.

The next section relates these sampled variables to current diagrams and explains the visual derivation of other relevant variables using the grid-lines on the diagrams.

2.2 Current Presentation Methods

Figure 1 shows four varieties of thermodynamic diagrams that this data can be plotted on. The choice of diagram varies with country and organization, but, from each chart, the same conclusions can be made. I will use the Skew-T Log-P Chart (Skew-T diagram) for explanation and comparison.

2.3 Interpretation of the Skew-T Plot

This section serves two purposes: first, to give an idea of the set of tasks that one can accomplish using the Skew-T; second, to motivate discussion of the shortcomings of the Skew-T. For a deeper understanding of the Skew-T chart, see [3], [14], or [1]. The following discussion is based around Figure 2.

The log-scale axis on the left shows the atmospheric pressure measured in millibars. The pressure levels are associated approximately with a height above sea level; the exact relationship changes over time.

The numbers along the bottom are indexes onto the skewed temperature axis: the dark blue constant temperature lines (isotherms) running at a 45° angle from the lower left towards the upper right. The units are in degrees Celsius.

The lines described so far are all that are needed to display simply the sampled data of temperature and dew-point. For visual derivation of the other variables and estimates of severe weather, the following additional lines are included on the chart.

The purple lines running slightly more vertical than the isotherms are lines of constant mixing-ratio. These lines are used to determine the moisture content and relative humidity at a given level. The units for the mixing ratio are grams of water vapour per kilograms of dry air. Following the mixing ratio lines to the bottom of the chart, you can see the index onto these lines also written in purple.

The green lines are dry adiabat lines. The temperature of a rising parcel of unsaturated air will trace a line parallel to these dry adiabats.

The blue lines are wet adiabat lines. The temperature of a rising parcel of saturated air will trace a line parallel to these wet adiabats.

There are two data lines plotted onto this grids: the dew-point, and the temperature. The dew-point will always be found to the left of the temperature line. Often, the dew-point and temperature lines will be coloured differently, but there is no standard colouring scheme.

To further aid understanding, I will now present three examples using the Skew-T plot in Figure 2.

2.3.1 Example: Mixing Ratio at 700mb

To determine the mixing ratio at the 700mb pressure level, first find the intersection p of the 700mb line and the dew-point line (the left-most plotted data line). Interpolate between the nearest mixing ratio lines to determine the mixing ratio. In this case, the intersection p lies on the 1.0g/kg mixing ratio line: no interpolation is required and one can read directly the mixing ratio.

2.3.2 Example: Relative Humidity at 700mb

To determine the relative humidity at the 700mb level, one needs to find the mixing ratio as in the previous example and then also the saturation mixing ratio. The saturation mixing ratio is found at the intersection of the 700mb line and the temperature line. In this case, the saturation mixing ratio at the 700mb level is approximately 2.5g/kg (by visual interpolation). The ratio of the mixing ratio and the saturation mixing ratio is the relative humidity: $1.0/2.5 = 40\%$.

2.3.3 Example: Cloud base

Calculation of the cloud base in air that is being lifted from below illustrates the purpose of the adiabat lines.

1. Trace a line from the surface dew-point upward, parallel to the mixing ratio lines.
2. Trace a second line from the surface temperature upward, along a dry adiabat line.
3. Their intersection is at the level at which cloud will form if air is forced upward from the surface.

2.4 Practical Use and Shortcomings

The following is a partial list of tasks that can be accomplished through varying degrees of manual processing based on the information displayed on a Skew-T diagram.

- Determine the relative humidity at any pressure level.
- Forecast the base and tops of convective cloud.
- Make judgments about the stability or instability of the atmosphere at different pressure levels.
- Forecast the severity of thunderstorm weather.
- Forecast the type of precipitation likely to fall.

These are some tasks that any visualization of the sounding should allow. Although these are all possible using a Skew-T plot with only a few hours of training (or days if a deeper understanding of the results is also desired), there are several advantages in the use of a new visualization tool as an alternative and possibly a replacement.

In the education field, it takes some effort to expose these important relationships that are presented on the thermodynamic diagrams to students. A visualization of the data that makes it easier to discern the relationships on first sight would be a benefit to education. Presented in traditional Skew-T plots, much cognitive effort

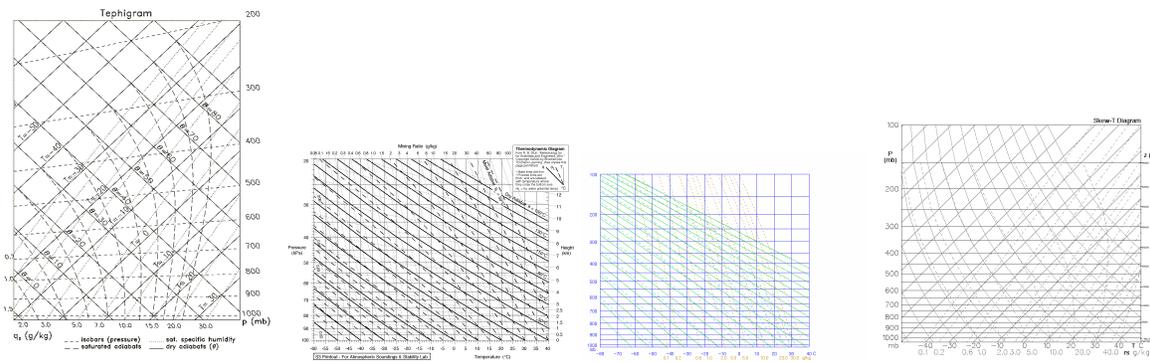


Figure 1: Thermodynamic diagrams.

is used simply to extract the relevant data, leaving little to form relationships between the data and expected weather.

It is also difficult to compare side-by-side multiple Skew-T diagrams. Again, this is due to the lack of information that pops out.

It might seem that with the increases in computing power and advancements in graphics display, that there would have already been much work towards the improvement of these diagrams, but I believe that there are reasons why improvement of these diagrams has *not* been pursued. First, the increase in computing power has been used in the meteorological community not to improve visualizations of the sounding data, but to extract forecasts and derive data, with the data from atmospheric soundings as input. That is, computers have been used to offload the task of forecasting and pattern finding from humans. Secondly, the trained specialists that use these diagrams do not claim a need for improvements to the diagrams, much like the radiologists who did not find alternatives to the grey-scale 2D slice useful. However, the Skew-T plot is still taught in introductory meteorology courses and referred to in several fields with an amateur interest in meteorology.

The data from the Skew-T is often reduced into several indices of severe weather, displayed alongside the Skew-T in the margin. (See Figure 2.) The result is that there has not been any improvement to the visualization of the original data, and the extracted indices are obscured by being adjacent to the poorly displayed data and even the noisy frame containing the data.

The Skew-T diagram is in violation of the foremost of Edward Tufte's criteria for good graphical displays: show the data [12]. The temperature and dew-point lines *are* shown, but in practice, it turns out that these are not what matters.

Furthermore, the Skew-T displays a very poor data-ink ratio. "Data graphics should draw the viewer's attention to the sense and substance of the data, not to something else." [12] On first glance, it is not clear at all that the background lines are simply part of the frame for the data and not data themselves. Tufte emphasizes the importance of the data-ink ratio so much as to suggest that "the grid should usually be muted or completely suppressed, lest it compete with the data".

These and several other violations of graphic design principles make the Skew-T a ready candidate for redesign.

There may be latent value in the complexity of the Skew-T plot however. In my use of the Skew-T, I have found that an understanding of the definition of a term helps one to remember the procedure for deriving it from the Skew-T plot, and knowing how to derived a term from the Skew-T plot reinforces the definition. The effects of eliminating this complexity are not clear.

One other benefit of the Skew-T plot along with many meteorological products is that colour is not needed. From a black and white printout, one can usually get the same information as from a colour printout. I attempted to capture this benefit in the new visualization

tool as well.

3 PREVIOUS WORK

In the 1980s, Morgan produced an alternative to the Skew-T diagram called the THETAPLOT diagram [6]. However, it followed the path paved by the Skew-T and its predecessors, and simply transformed the Skew-T diagram to allow the wet adiabat lines to be drawn as straight lines. The benefit was to allow a subset of the derived values to be more easily visually extracted.

There has been little work done other than optimization of the diagrams for specific tasks. With a lack of previous work in this domain to guide further work, I turned to oceanic visualization methods for motivation with the thought that visualization of vertical samples through the ocean should be similar to the visualization of vertical samples through the atmosphere. Haeger ([5]) investigated the visualization of vertical oceanic profiles of temperature and salinity. It turns out that in this environment, as in the atmosphere, it is not the absolute values, but the relationships between the recorded variables that give applicable insight. For example, for a certain task, it was the gradient of the temperature that was important. The visualization that best benefited this task was a direct plot of the gradient. Other derived values that were plotted included conductivity, salinity gradient, and density.

4 ATMOSVIEW VISUALIZATION

Figure 3 shows the redesign of the atmospheric sounding visualization. This redesign was informed by several sources of guidance including Tufte [12, 13, 11], Stone [9], and Ware [15]. This section will describe in detail each element in the redesign.

4.0.1 The Axes

This was the first decision made in the redesign: the horizontal axis was to show the difference between the temperature and the dew-point. This difference determines the relative humidity which is important for the forecasting of cloud. The vertical axis shows altitude, in metres, rather than log-scale pressure as in the Skew-T.

4.0.2 The Bars

The most prominent feature in this new visualization is the set of narrow horizontal bars extending from the vertical axis. The length of these bars represents the temperature-dewpoint spread, the value of which can be read from the index at the horizontal axis. The colour of these bars represents the contribution at a particular altitude to convective potential or convective inhibition. This colour is determined by interpolating within a colour scale that is divergent in hue and sequential in lightness. This choice was made from a modification to a ColorBrewer colour scheme used in a presentation by Maureen Stone (see Figure 4) [9].

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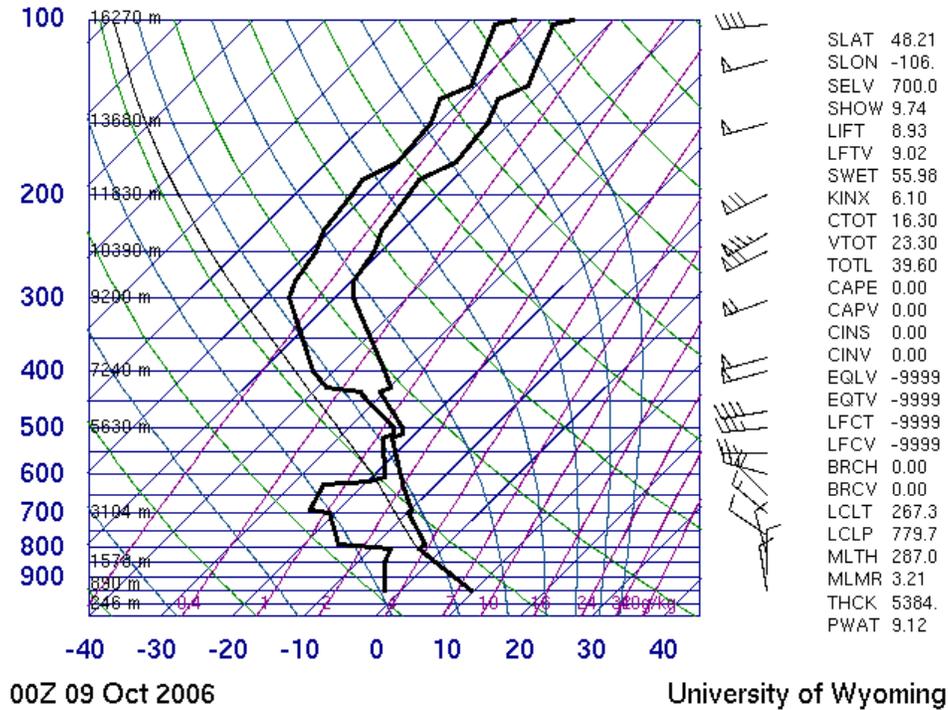


Figure 2: An example Skew-T diagram. [7]

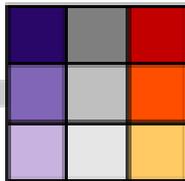


Figure 4: The diagonal is used as the colour scheme in the AtmosView visualization.

The diagonal of this colour matrix was chosen as the colour scheme for the bar colouring. The lowest value is plotted in the dark purple, the mid value in the mid grey, and the highest value in the light saffron. Using a divergent colour scheme fit this dimension well since varying magnitudes of both negative and positive values occur. The choice of embedding a sequential lightness scale within this divergent hue scheme was to allow distinction of values even if the visualization was viewed in grey-scale. This colour scheme is also colour-blind safe as checked through VisCheck [4].

The prime benefit of this colouring is that a general description of the stability of the atmosphere is immediately apparent to the viewer. Neither visual tracing, nor searching for a number in a set of indices is required as was in the Skew-T.

4.0.3 Annotations

The left margin area is used for several graphical devices and annotations aimed to clearly expose data that was previously hidden in the Skew-T. I will describe briefly what is being shown and then the method of display for each of these elements.

As air is forced to lift from below, it will cool, eventually reaching its dew-point and forming cloud. The level to which a surface

based parcel of air must be lifted for this to occur is called the *lifted condensation level* (LCL). With a certain amount of further lifting, the parcel might reach a level of the atmosphere where it is warmer than the surrounding temperature and become buoyant, no longer requiring lifting from below to continue its ascent. The altitude at which this occurs is called the *level of free convection* (LFC).

The altitude range between the LCL and the LFC is indicated by blue, downward pointing triangles alongside the vertical axis. The downward direction of the triangles is associated with resistance to vertical motion, which is the case in the atmosphere until the parcel reaches the LFC. Above the LFC, red, upward pointing triangles are used. These continue until the *equilibrium level* (EQL), the level at which the parcel becomes the same temperature as the surrounding atmosphere. This is the level where upward acceleration of the cloud will cease. Like the downward pointing triangle, the upward pointing triangle was chosen for its association with vertical motion.

At levels where the temperature-dewpoint spread equals zero, there will be cloud. However, it is very difficult to determine at a glance whether the temperature-dewpoint spread is zero, or slightly greater than zero. For this reason, at altitudes where the temperature-dewpoint spread equals zero, a blue vertical bar is placed alongside the vertical axis, between the axis and the triangles described above.

One other behaviour of the atmosphere that is displayed is convection: lifting due to heating from below. If the air at the surface is heated to a high enough temperature, it will become buoyant beginning at the surface, will rise, and eventually form cloud. The temperature to which the surface parcel must be heated for this to occur is called the *convective temperature* and the altitude that air rising in this manner will form a cloud is called the *convective condensation level* (CCL). These two values are related by small vertical and horizontal bars placed across the axes. The vertical bar placed

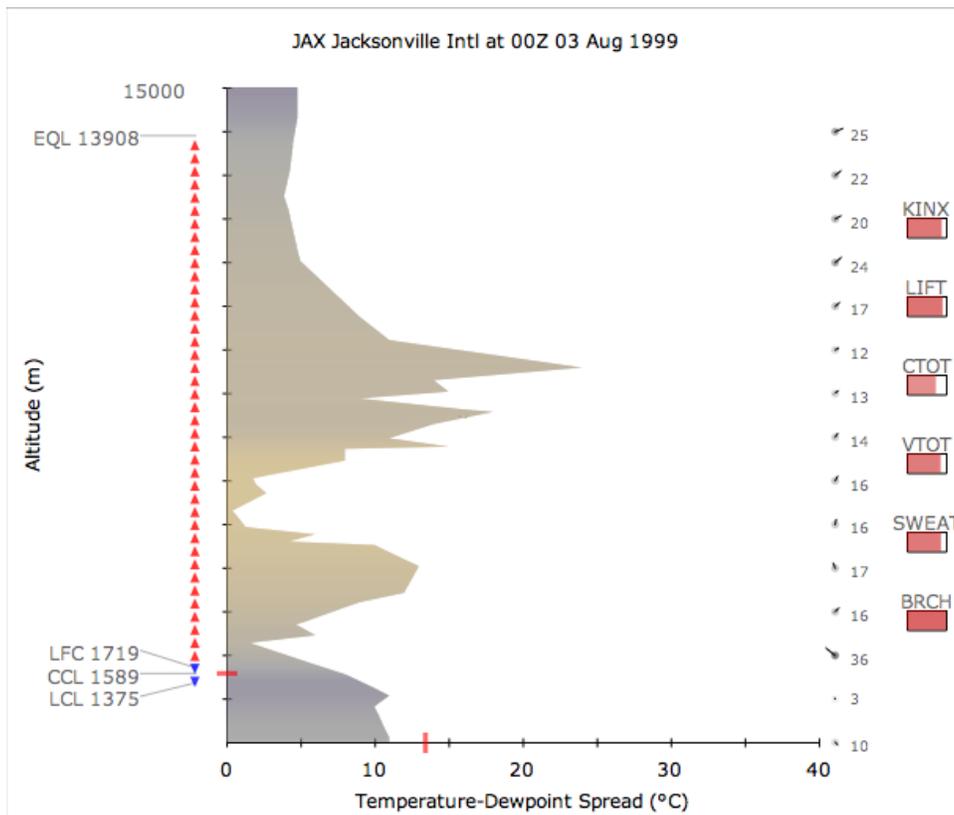


Figure 3: AtmosView display, the atmospheric sounding visualization redesign.

across the horizontal axis indicates the temperature rise required to trigger this behaviour. The horizontal bar placed across the vertical axis indicates the CCL. The bars are coloured red and are thicker and longer than the axis tick marks. This is another design element that uses colour, but does not require it.

There were several design iterations before deciding on the current labeling scheme for these significant altitudes. First, there was no labeling of the significant altitudes: only major axes ticks were labeled. It was left to the viewer to interpolate between these ticks and determine the altitudes of significance. Worse, these labels were non-data ink, and could not last. The solution was to label only the significant altitudes described above (see Figure 5). This increased the data-ink ratio in the left margin by a factor of 4.

As the significant altitudes were often close together, the labels for these altitudes had to be shifted in order to avoid overlap. This was done by shifting each label away from the median label just enough to avoid the overlap. However, through this shifting, a label might become significantly displaced from the altitude it is labeling. Association lines were needed to connect a label to the altitude it was labeling. Drawing these lines from the label directly to the vertical axis produced a very distracting interference between the lines and the margin data – the very data that the labels were meant to augment (see Figure 5).

The solution was to direct the association lines to the data they were meant to label, rather than to the non-data frame. This is shown in Figure 6. To further reduce interference effects, the labels are muted to a mid-grey shade.

4.0.4 Wind

The Skew-T plot uses a standard meteorological glyph to display the wind direction and speed as shown in Figure 7. The “feath-

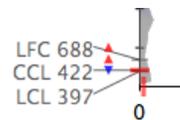


Figure 5: Labeling only the significant altitudes. Notice the interference between the association lines and the data.

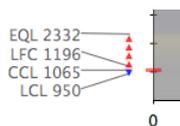


Figure 6: The association lines now point at the data rather than at the frame.

ered” end is the direction from which the wind is blowing. Like the Roman numeral system, Each triangle adds fifty knots to the wind speed, each long tick adds ten knots, and each half tick adds five knots. The only item from this glyph that visually pops out is the wind direction and even this salient feature is corrupted by the triangles and ticks which guide the eye away from the wind direction. These also increase the angular area occupied by the glyph, increasing the likelihood of overlap with an adjacent glyph of similar direction.

It has been shown that arrows are effective for the visualization of vector flow data [15], [16]. Wittenbrink, in a paper that presented glyphs for visualizing uncertainty in vector fields, displayed the magnitude of the vector by scaling the arrow glyph’s length.



Figure 7: Wind glyph used in the Skew-T. This specific glyph is showing a wind from 045° at 25 knots.



Figure 8: Interference caused by adjacent wind bars.

This type of glyph is adopted in the AtmosView visualization and is shown in Figure 9. Two factors contribute to the improvement of wind visualization in this system. First, speed is mapped both to length, a visual channel known to well represent quantity, and to the opacity of the pivot. Second, wind glyphs are not drawn at every sample point, but are interpolated and are drawn in 1000m increments. Their design alone decreases interference potential, but the increased spacing aids as well.



Figure 9: AtmosView's wind glyphs. Magnitude is mapped both to length and to the opacity of the pivot.

Positioned just to the right of each wind glyph is a muted speed label. This allows the user to delve into a finer level of detail after gathering an overall impression of the conditions.

4.0.5 Weather Indices

In the Skew-T diagram, weather indices are often listed in a margin. This does not aid the viewer in capturing a quick impression of the state of the atmosphere. As well, there is no reference as to what values are indicative of an increased potential of severe weather. In fact, for one of the indices, it is *negative* values that indicate greater likelihood of severe weather. These problems are remedied by small, framed bars for each severe weather index (Figure 10).

In this new glyph, colour and framing are used to allow the user to quickly see *and* interpret the value of the weather index. The colour is an interpolation between white and a semi-transparent deep red.



Figure 10: A glyph to display a severe weather index. Both colour and length are used to show the value.

4.1 Small Multiple View

In addition to being able to display single charts for inspection, the system allows display of small multiples of charts for comparison. This is something that is made much easier by the redesign. A good design should “encourage the eye to make comparisons” [12]. As seen in Figure 11, even between similar charts, small differences can be distinguished.

As charts are added, the small multiple display is re-arranged to give each chart an equal share of the screen space. That is, when viewing only one chart, it is given the entire panel; when viewing two charts, each is given only one half the panel. This proceeds in this manner until four charts are displayed. Adding a fifth chart simply begins a second row of charts, equal in height to the first row. Charts can be added up to a maximum of eight and can be removed by right-clicking a chart. For closer inspection of any of the small multiples, a double click will display the chart full size in the single-chart mode.

4.2 Implementation Details

I developed the AtmosView visualization and the system supporting it using Java in the Eclipse development environment. The only third-party component used was the date chooser, a nice calendar-like interface for choosing a date [10]. The current data source for the system is <http://weather.uwyo.edu/upperair/sounding.html>, which provides sounding data for hundreds of sites around the world, with some data dating to 1973. Although this site does provide many of the derived variables in text form, along with the sample data, I wanted to avoid a dependence on having these variables derived for the system. Therefore, I developed a module responsible for calculating the reported figures given only the pressure, height, temperature, and dew-point of each sample point.

5 COMPARISON OF USE

This section compares the use of the Skew-T against the AtmosView visualization for several tasks. Table 2 lists the tasks and describes their accomplishment using the Skew-T and using the Atmosview Visualization.

6 EVALUATION

To determine the usefulness of the new visualization, I performed an informal evaluation with two volunteers from a class that I had been teaching. They had just completed a unit on meteorology, but the students had not seen any form of atmospheric thermodynamic diagram. The evaluation consisted of instruction on the use of the AtmosView visualization, followed by a set of tasks for them to accomplish using the visualization. Then, they received instruction on the use of the Skew-T diagram, followed by the same set of tasks for them to accomplish using the Skew-T. The tasks included extracting information from individual charts, making comparisons between two charts, making comparisons between two miniature charts, and making comparisons between two grey-scale charts. I did not inform the students that I had created one of the designs. The students did not actually interact with the system, but were using charts taken from screen-shots of only the AtmosView display panel of the system.

This was an informal evaluation and the sample size was only two, but I can say that the results were not discouraging. There was no significant difference in performance between the two types

Table 2: Scenarios of Use.

Task	Skew-T	AtmosView
Calculate relative humidity at a given level	<ol style="list-style-type: none"> 1. From the dew-point plot at the given level, read off the mixing ratio interpolated between the mixing ratio lines. 2. From the temperature plot at the given level, read off the saturation mixing ratio lines interpolated between the mixing ratio lines. 3. Divide the mixing ratio by the saturation mixing ratio. 	The length of the bar is inverse to the relative humidity.
Find layers of potential stratus (non-rising, layer-type) cloud.	Look for places where the temperature and dew-point lines touch.	Displayed by a distinct vertical bar alongside the vertical axis.
Determine the convective condensation level.	Follow a mixing ratio line upward from the surface dew-point plot until it intersects the temperature plot.	Displayed by a the red horizontal line across the vertical axis.
Determine the lifted condensation level.	Follow a mixing ratio line upward from the surface dew-point plot until it intersects a dry adiabat line traced upward from the surface temperature plot.	Displayed directly by the lowest blue triangle in the left margin. It is labeled.
Determine regions of convective potential/inhibition.	From the lifted condensation level, trace a wet adiabat line upward. Levels at which this traced line lies to the right of the temperature plot are levels of convective potential. Levels at which this traced line lies to the left of the temperature plot are areas of convective inhibition.	Bars are light saffron in areas of convective potential; bars are deep purple in areas of convective inhibition.
Determine the wind speed and direction at a given level.	Read the wind direction from the orientation of the wind glyph. Read the wind speed by adding fifty for each triangle, ten for each fill tick, and five for each half tick.	Read the wind direction from the orientation of the wind glyph. Read the wind speed in the muted label to the right of the wind pivot.
Estimate likelihood of severe weather.	Read the values of several severe weather indexes from the margin. Recall for each of the indices what values are indicative of severe weather.	View the severe weather index bars. The more full a bar, the more that index predicts severe weather.
Determine the temperature or dew-point at any pressure level.	Read the values directly off of the skewed temperature axis.	Not possible using only the new visualization. The system that was designed does include an accessory display that allows one to directly read the temperature or dew-point from a non-skewed plot, however.

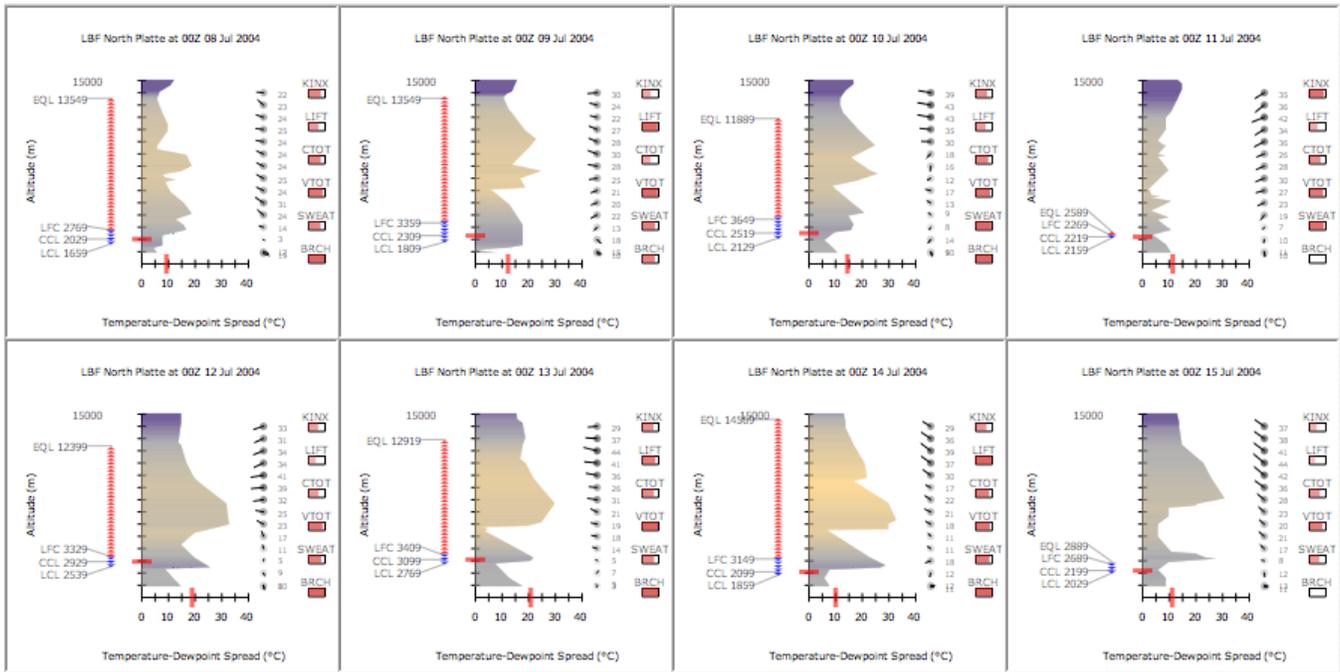


Figure 11: Small multiples encourage comparison, which is possible with this visualization. Notice the higher equilibrium level and brighter bar colour on the 14th. On that day, a tornado occurred.

of charts and the students rated the redesign quicker to use, less confusing, and just as informative as the Skew-T. Figures 12 and 13 summarize the results.

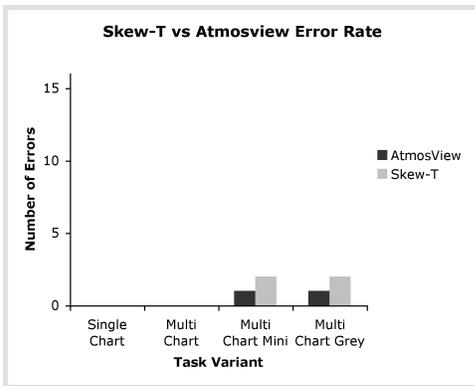


Figure 12: Number of errors committed using the charts. *Single chart* was the task of extracting data from a single chart. *Multi chart* was the task of comparing two charts. The *mini* and *grey* variations were miniature and grey-scale versions of the *multi chart* task.

7 CONCLUSION

This project shows that an information visualization informed design can result in notable improvement over previous designs. As this field continues to expand, there will be fewer and fewer domains not affected.

As for this design, there are still areas for improvement. Temperature is not displayed on the AtmosView visualization, although it is available on the accessory display in the single-chart view within this system. It does seem though, that temperature is not so important after the interesting variables have been derived, except perhaps

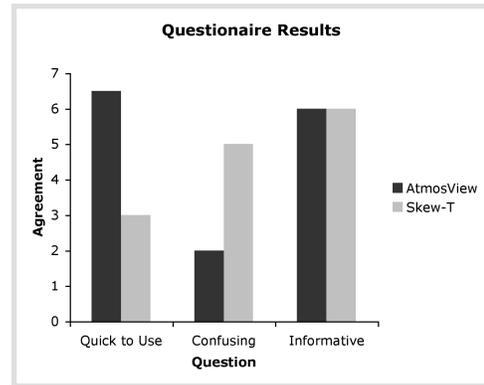


Figure 13: Subjective preference results.

to forecast the type of precipitation that may fall. In either case, if temperature could be displayed in a way that enhances rather than clutters the design, this would be desired.

Also, several people have commented on the temperature-dewpoint plot being opposite to their intuition in that as the temperature-dewpoint bars shrink to zero, the relative humidity goes to 100% and cloud will form. This might have been an oversight early in the design phase: is the temperature-dewpoint difference only important because it determines relative humidity? If the answer is yes, then it is relative humidity that should be displayed, not the temperature-dewpoint difference.

From a system viewpoint, there is still more work to be done to ensure usability. Helpful features like printing, or loading from a variety of sources will be added in the future. As well, either verification of the correctness and accuracy of the derivation module or inclusion of a third-party meteorology package is needed.

Reviewing several of Tufte's criteria for great graphical displays

best testifies to the strengths of this redesign.

Show the data. From the decision to display the temperature-dewpoint difference, to the association lines being directed at the data instead of the frame, this principle was applied throughout the redesign.

Graphics should draw the viewer's attention to the sense and substance of the data, not to something else. Removing the heavy frame did the much towards meeting this criteria, as did removing the requirement for the user to derive or find the significant derived values themselves.

Encourage the eye to make comparisons. Framing of the weather indices, and presenting very salient features to represent significant aspects of the data accomplishes this.

Reveal the data at several levels of detail, from a broad overview to the fine structure. I believe this is one of the stronger points of this redesign. One can quickly absorb a general impression of the atmospheric stability, cloud presence and potential height, severe weather potential, and approximate wind direction and speed. On closer inspection, more can be drawn from the chart: exact values for the significant altitudes and wind speeds.

This project hopefully can remove the stigma from atmospheric sounding data of having the most difficult charts to understand. That will be the ultimate evaluation of this project: will it be seen in soaring clubs, storm-chasers' vans, and students' notebooks?

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A EVALUATION DOCUMENTS

The diagrams and tasks used in the evaluation are available at: <http://www.cs.ubc.ca/sanchom/documents/Evaluation.tgz>.