

## CHAPTER 1

---

# GRAPHICAL RHETORIC

---

1

Academic science is a social institution devoted to the construction of a rational consensus of opinion over the widest possible field.

JOHN ZIMAN *An Introduction to Science Studies* (1984)

They [sc. the Royal Society] have exacted from all their members, a close, naked, natural way of speaking; positive expressions; clear senses; a native easiness; bringing all things as near the Mathematical plainness, as they can: and preferring the language of Artizans, Countrymen, and Merchants, before that, of Wits, or Scholars.

THOMAS SPRAT *The History of the Royal-Society of London, for the Improving of Natural Knowledge* (1667)

The advantages proposed by this [sc. graphical] mode of representation, are to facilitate the attainment of information, and aid the memory in retaining it: which two points form the principal business in what we call learning, or the acquisition of knowledge. Of all the senses, the eye gives the liveliest and most accurate idea of whatever is susceptible of being represented to it.

WILLIAM PLAYFAIR *The Statistical Breviary; Shewing, on a Principle Entirely New, The Resources of Every State and Kingdom in Europe* (1801)

---

1

## 1.1 Introduction

Science, as stated in the first quotation, is fundamentally a social enterprise;<sup>2</sup> so being a scientist is not only getting new results, but also communicating them to other researchers.

As with all human communication we can break this into four steps:

1. Something – an idea, result, or whatever – is a thought you have.
2. Based on this thought, you produce some kind of signal: speech, or shapes on paper or on a screen.
3. Somebody else receives these signals, through their ears or their eyes.
4. They interpret these signals to produce thoughts in their own head.

In scientific communication, as in scholarly communication in general, the goal is for the thoughts at both ends to be the same; so your aim, in Step 2, should be to produce signals that will cause Steps 3 and 4 to make someone else think about things as you do.

Scientists use three kinds of signals, some little used in other contexts:

1. Language, spoken or more usually written.
2. Equations and other mathematics.
3. Pictures, maps, diagrams, and graphs.

Because we acquire and use spoken language so easily, it is deceptively easy to believe that what you write is as clear to others as it is to you; “deceptively” because written prose can easily be tedious or obscure – sometimes so obscure that few readers can understand it. You can reduce the chance of this happening by learning techniques for clear writing,<sup>3</sup> and by revising your writings carefully: no first draft should survive unscathed. You should aim for a style that matches Sprat’s description above.

---

<sup>2</sup> There is now a large literature on “Social Studies of Science”; Ziman’s book is a good introduction.

<sup>3</sup> I recommend Joseph Williams (1990) *Style: Toward Clarity and Grace* (Univ. of Chicago Press, Chicago), as a practical guide to writing clear academic prose. G. D. Gopen and J. A. Swan (1990) The science of scientific writing, *Amer. Scient.*, **78**, 550-558 provide a summary, which shows how to improve a seismological example. This paper is available online at the *American Scientist* website,

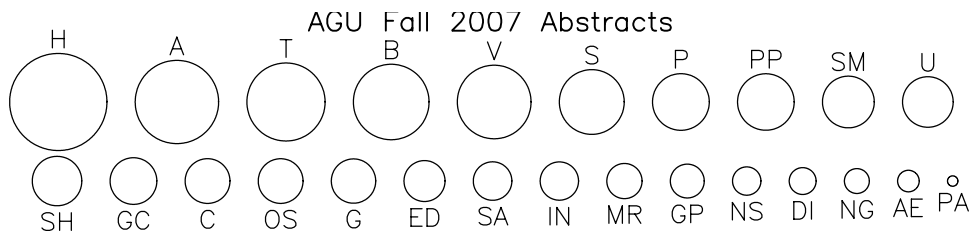


Figure 1.1:

Presenting mathematics can be easier, since mathematical notation is much more structured and much less ambiguous than natural language. But there are still choices to be made when writing mathematics. Your first choice is how detailed you need to be – remembering that what is perfectly comprehensible to some (especially you) will be too condensed for other readers. Notations also require choices. The more symbols the reader has to assimilate, the harder the mathematics is to read. Little is gained and something lost by a plethora of subscripts and superscripts; for example, once you have learned vector notation, it is easier to read  $\nabla \times \mathbf{r}$  than  $\epsilon_{ijk} \partial_j r_k$ . Similarly, it is usually a bad idea to use names for variables or subscripts, however convenient this may be in writing programs. And subscripting can make the notation easier to remember: displacements in spherical coordinates are easier if written as  $u_r$ ,  $u_\theta$ , and  $u_\phi$  rather than with arbitrary labels such as  $u$ ,  $v$  and  $w$ .

But the most difficult element of communication is pictures, particularly graphical representations of data, which were the last class of communication methods to be developed.<sup>4</sup> One reason for this late development was a prejudice (still present in some areas of scholarship) that pictures are inferior to words;<sup>5</sup> another was technological: pictures were more expensive to produce, and reproduce, than written language. Now that everything is done with bits, this cost discrepancy (color printing aside) is now gone, and there is software to make complicated graphics easy to produce. This software does not solve the problem that graphics can communicate your message well, or badly – and many popular software packages make the bad choices the easiest ones.

My aim is to set out some principles to help you produce clear and infor-

<sup>4</sup> Statistical graphics were largely invented by William Playfair, in two books published in 1786 and 1801, and only gradually came into use through the nineteenth century. A good online resource for this history is M. Friendly and D. J. Denis, “Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualization”

<sup>5</sup> Rudwick, M. J. S. (1976). The emergence of a visual language for geological science: 1760-1840, *Hist. Sci.*, **14**, 149-195.

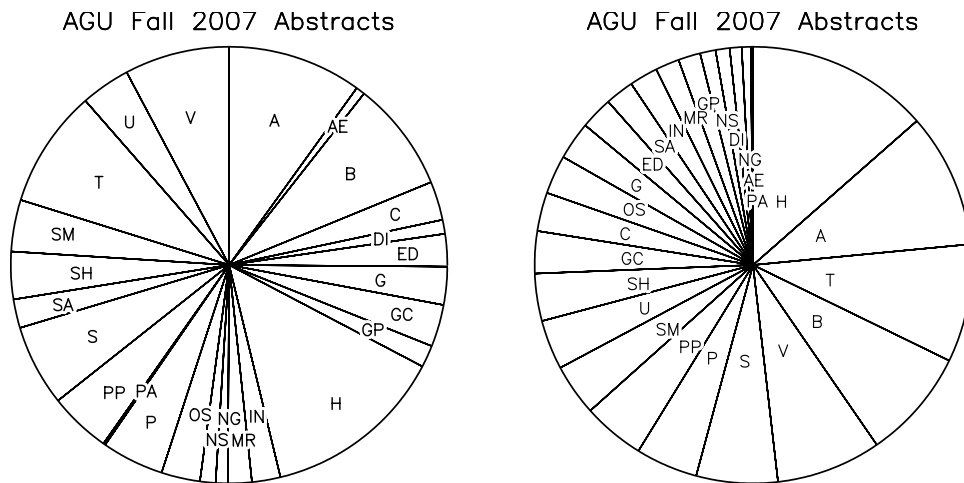


Figure 1.2:

mative graphs. Many of these principles are taken from the books by Tufte and by Cleveland, but adapted to geophysically relevant examples.

### 1.1.1 Encode Your Data Intelligently

We start with one of Playfair's inventions which is to represent the size of something (such as population) by circles with proportional areas. For our example, we look at the size of various geophysical populations, as given by the number of abstracts submitted for each section of the Fall 2007 AGU meeting. Figure 1.1 shows the data plotted using circles with areas proportional to the number of abstracts, and two-letter codes as identifiers. This certainly gives a more immediate impression of relative sizes than a table would, but it is difficult to compare areas when these are nearly the same, unless the circles are next to each other. Also, representing numbers by areas is a possible source of ambiguity; we might wonder if diameter is the variable being used instead, though it shouldn't be.<sup>6</sup>

A more compact approach uses another of Playfair's inventions, the pie chart: a staple of business and newspaper graphics, with a popularity far greater than its usefulness. The left plot in Figure 1.2 shows the pie slices arranged alphabetically; on the right, we follow Playfair (many piemakers

<sup>6</sup> Scaling two- or three-dimensional images by the relative sizes of the data, is a well-known form of graphical deception; the viewer can assume that area or volume, not length, is meant. This practice is rare in science, but you should be wary of it in popular graphics.

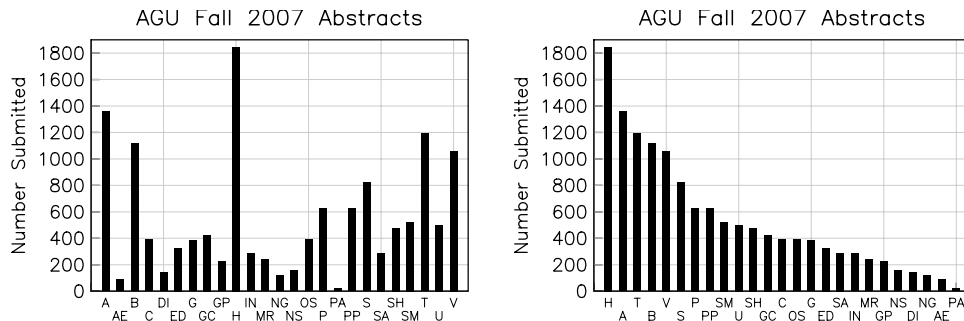


Figure 1.3:

do not) in showing the segments sorted from largest to smallest. The second version is better because it puts similarly sized segments close to each other. The pie chart is more compact than the circles, but we still cannot easily compare relative sizes: for example, it is difficult to estimate the ratio of GC to OS.

To understand the problem, and its cure, we should realize that what we try to do with this and other graphics is to **encode** something – in this case a quantity – into visual form. The question to ask of any graphical design is, what visual element does it use to mark relative sizes? Figure 1.1 used area, and the pie charts of Figure 1.2 can be viewed as using either area or angle. But our visual system is in fact not particularly good at judging if two areas, or angles, are equal, or estimating their relative sizes. To decide if a graphic is good, or not, we should ask what is the most effective encoding for what we are trying to show: in this case, relative sizes.<sup>7</sup>

Because we are not good at comparing angles, they are a poor method of encoding – a good, simple graphical rule is never to use a pie chart.<sup>8</sup> Our eyes and brain are better at judging length, either relatively or (even better) in comparing small differences. Encoding by length leads us to another venerable graphic, the bar chart, shown in two arrangements (alphabetical and numerically sorted) in Figure 1.3. Again, the numerically sorted one is better: by putting similar bars near to each other it makes comparisons between them more accurate.

Our visual system does even better in judging relative position along a line, rather than length from a base. This encoding leads to a design (invented

<sup>7</sup> Cleveland, W. S., and R. McGill (1984). Graphical perception: theory, experimentation, and application to the development of graphical methods, *J. Amer. Stat. Ass.*, **79**, 531-554.

<sup>8</sup> Except for introducing the concept of fractions in elementary school.

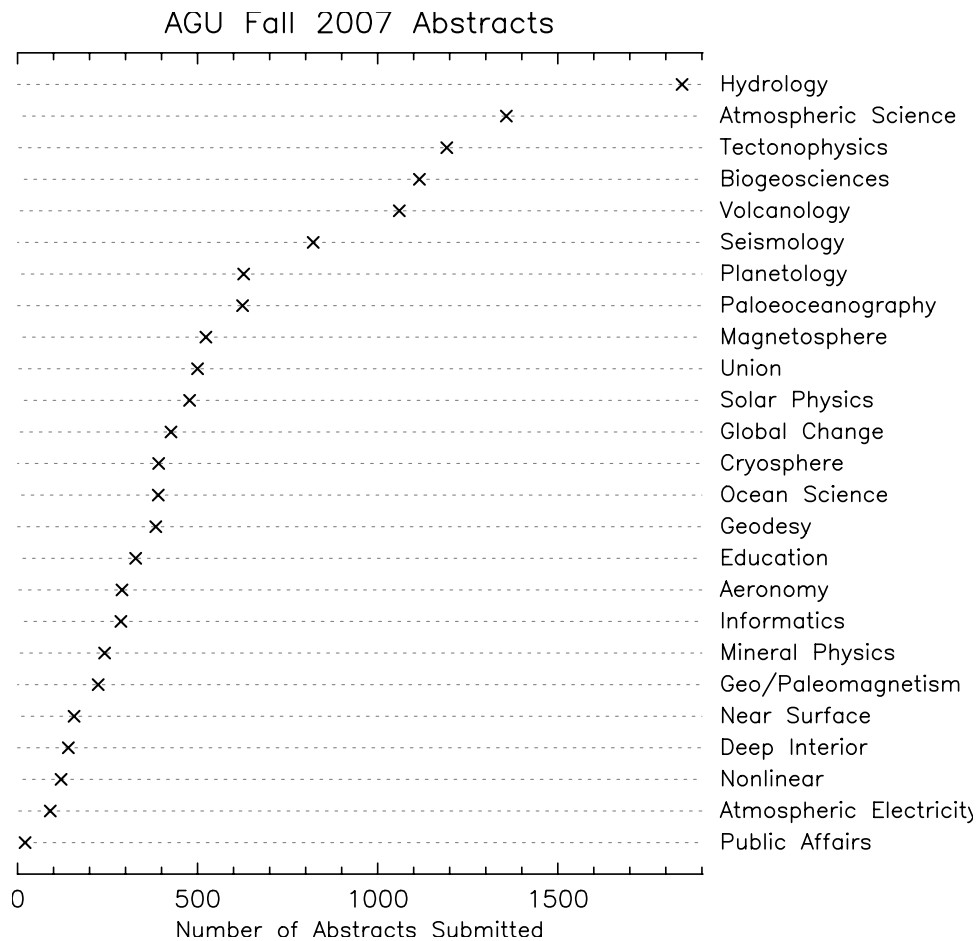


Figure 1.4:

by Cleveland) called a dot chart, in which we plot the values along a set of lines with a common scale. Since text is read horizontally, stacking these lines vertically gives space for better labels. Figure 1.4 shows a dot chart of the AGU data. Once again, plotting the data in numerically sorted order makes relative comparisons much easier than an alphabetic ordering would; and after all the alphabetic order is completely arbitrary.<sup>9</sup> The dot chart can use a log scale; and with different symbols it can show more than one type of data; though you cannot then sort them all. And it is not too difficult to recover the numbers from the chart; indeed, if you don't need to provide more

<sup>9</sup> In tables as well as figures, it is worthwhile to think about how to order your data. Never enslave yourself to names or to the alphabet.

**Table 1: Possible Encodings, Best to Worst**

- Positions along common and aligned scales.
- Positions along common but unaligned scales.
- Lengths.
- Angle, or slope of a line.
- Areas of similar figures (areas of dissimilar figures cannot be decoded with any accuracy).
- Apparent volumes of similar solids shown by 2-D pictures.
- Color (hue, saturation, or brightness).

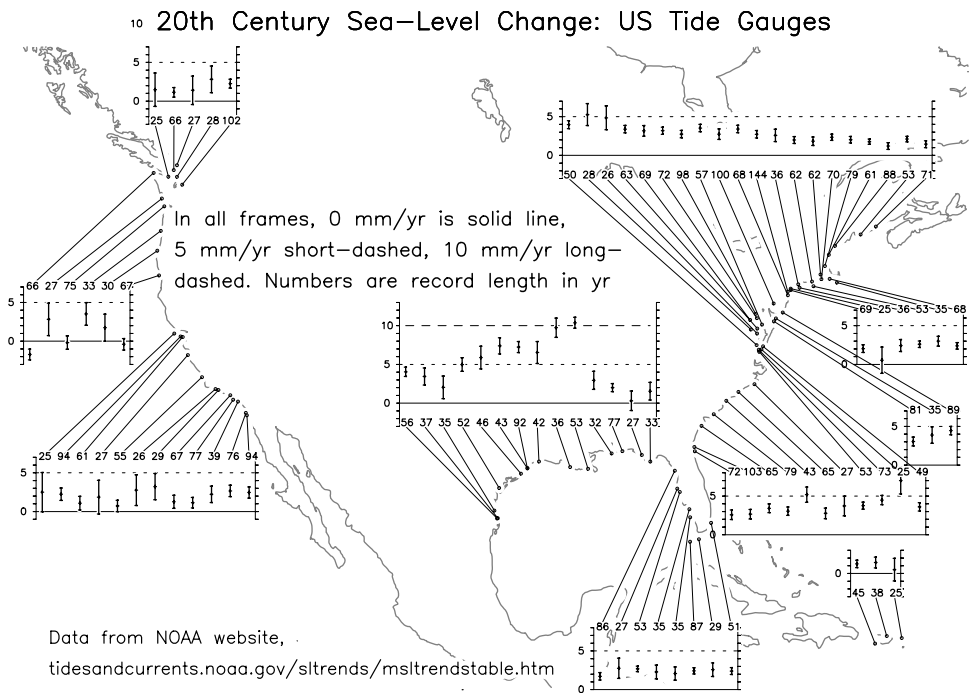


Figure 1.5:

than two decimal places, a dot chart makes a table unnecessary.

Table 1 lists the different visual encodings, ranked in the order they can be used to discriminate values. What is meant by “position along common but nonaligned scales” is shown in Figure 1.5, which illustrates (in a modified form) another of Cleveland’s inventions, the framed-rectangle plot. This plot shows scalar quantities defined at different locations. This can be done with color or a gray scale, but these are the poorest encodings of all. Bars at

each point, which encode the data as length, are an improvement; but even better is to include an identical scale with each bar, which makes it easier to judge differences for regions not close to each other. Figure 1.5 shows the rate of change of sea level at tide gauges in the lower 48 United States, plus nearby US-controlled locations; groups of values are arranged, as much as possible, to lie along common scales, with lines pointing back to the locations. As much as possible a common scale is used for each group. Two signals are evident: going south along the east coast there is an increase in the rate of sea-level rise, from the collapse of the bulge caused by glacial loading during the Ice Age. And high rates in Louisiana are from loading by the Mississippi delta. Even though the west coast is tectonically active, there is little variation in rates of sea-level change, except for a few sites close to the Cascadia subduction zone and the Mendocino triple junction.

### 1.1.2 Show What You Want To Show

These [sc. rules] require that the author shall: 12. *Say* what he is proposing to say, not merely come near it. 13. Use the right word, not its second cousin.

MARK TWAIN Fenimore Cooper's literary offenses (1895)

That a plot should show what you want it to might seem obvious, but surprisingly it is not. Perhaps because we know what we are trying to show, we do not easily realize that while something in a plot is clear to us, it may not be to someone else. So you always need to ask, "What is the message in this plot?" and "Have I made it obvious?"

Making the message obvious is especially important for plots shown in a talk: obscurity is disastrous when the plot may be visible for less than a minute. All too often, the speaker who shows such a plot<sup>10</sup> says something like, "If you imagine doing [X] to what is shown on the plot, you would see that...", a remark almost as fatuous as "I know you can't read the table, but if you could you would see that ...".<sup>10</sup>

The three plots in Figure 1.6 may seem to be a silly example, but they are wholly realistic, in that the bad versions are very common. These plots all show time series of one component of displacement for two nearby GPS

---

<sup>10</sup> Perhaps because of the low resolution of projected images, a character size that is easily readable on the page will be illegible when projected, except maybe to the people in the first few rows. Make text, whether in tables, or axis labels and numbers in graphics, twice as high as it would need to be on the page.

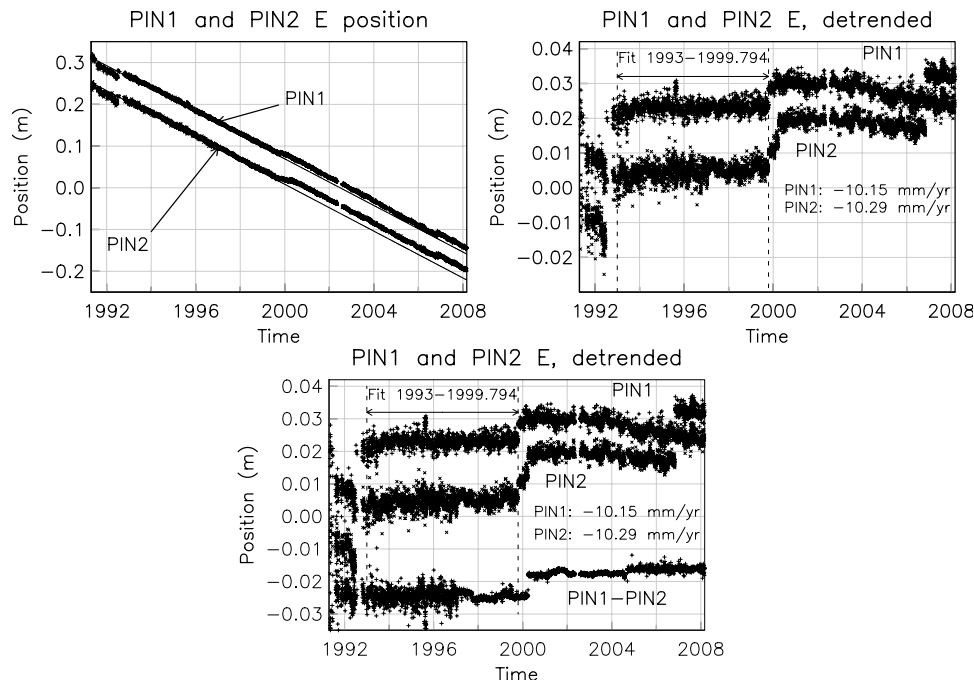


Figure 1.6:

stations. In the first plot (upper left), about all we can see is that both show a steady, and similar, decrease with time. This might be acceptable if that was the only message, but such a message would be equally well provided by two numbers giving the two rates of change.

It is easy to convey more information, say about fluctuations in the series.<sup>11</sup> To do this, we simply remove the long-term trends, which can still be included on the plot as numbers, and show the residuals; this is done in the plot on the upper right. This improved plot mostly shows something not obvious before, namely that there are motions shared by both sites. All too often we are invited to look at such plots and see that the series are similar, though not entirely, with a phrase such as “some part of the variation is common to both signals” – to which an obvious response is “Yes, that is clear, but how much?”.

Again there is a simple cure, which is to show the difference between the two, as in the bottom plot. Since the time series and the trend are also in-

<sup>11</sup> I have seen plots of just this type used to show amount of variation, usually, again, with the words “I know you can’t see this, but ...”.

cluded, this plot has all the information, while allowing us to see much more about the behavior of the two series.

This is just one example of a general rule: show whatever you are trying to draw a conclusion from. If you want to demonstrate how well a model fits some data, show the difference (the residuals), not just the model overlain on the data. If you want to show differences between data sets, or ratios of values, show these differences or ratios – *not* the two data sets individually. This approach may mean that plots take up more space, if (for example) you want to show both data sets and their differences. Such plots may seem redundant: why show (say) the ratio as well as the data? But it is better to be redundant than obscure.

Another example of showing what you want occurs when showing several time series whose sum is also important. It is then tempting, and all too common, to stack them on top of each other, adding as you go – but then the only variations that are clearly visible are those in the bottom series and those for the total; the variations in all but the bottom one become obscured. Instead, show all the series, including the sum – and if that takes several frames, so be it.

### 1.1.3 If There is a Lot of White Space, Revise

Since the purpose of a plot is to provide information about something, having large areas of white space, provides little information and often indicates bad design, Figure 1.7 shows a common reason for this: an unintelligent choice of plot limits. Many people learn that plots should always include zero, since a plot that does not can exaggerate the size of small fractional changes. Most scientists can spot and allow for this effect, and it is foolish to produce a lot of blank space just to have zero in the plot. In Figure 1.7, the left frame shows what can happen: a scale that includes two outlying points squeezes most of the data into a small area. The cure is simple: use narrower plot limits and indicate the extreme values separately.<sup>12</sup> Another possibility would be to use a log scale, though in this case even a log scale (bottom left) still leaves a lot of white space.

Three of the frames in Figure 1.7 are designed to provide information on how the time to degree has varied over the years: on average, not a lot though

---

<sup>12</sup> These are the PhD thesis of W. R. Gayman (entered 1956, PhD exam 1970, degree awarded 2000) .“Barrier formation in the Gulf of California” and the MS thesis of C. Jerde (entered 1961, MS 1981).

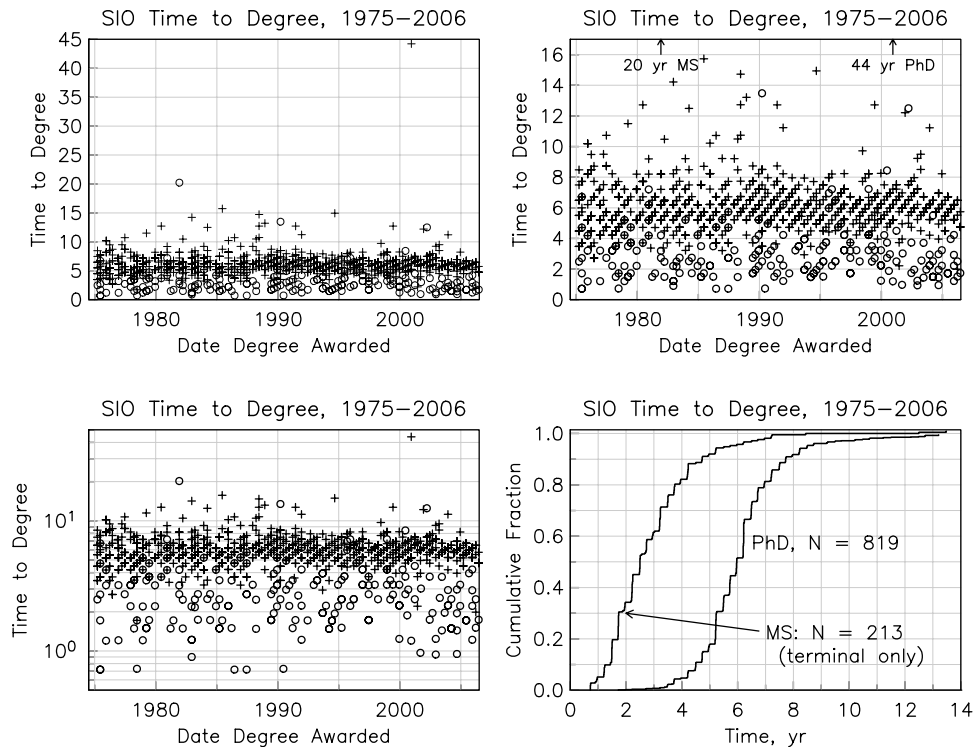


Figure 1.7:

the more recent times vary less. In keeping with the advice given the previous section, it is worthwhile to also make a different plot to answer a different question, namely “How are the times distributed?”. This can be guessed at from the time series, but is better shown directly, either as a histogram or (as here) using a cumulative distribution – which is especially appropriate because it shows the answer to the question most students would have, namely, what fraction of people take more than X years. The time series in Figure 1.7 show that the distribution of times is roughly the same from 1975 through 2006, so we can aggregate this part of the data to construct cumulative curves.

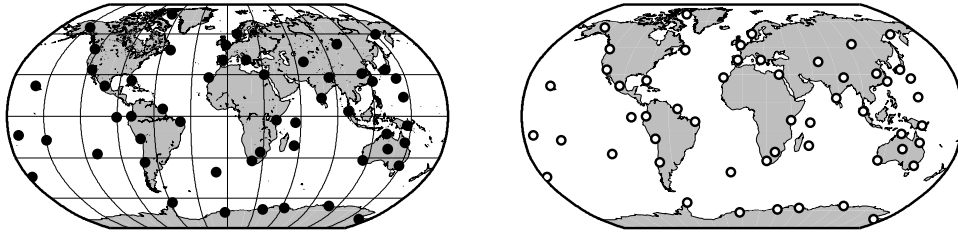


Figure 1.8:

### 1.1.4 Do Not Show What You Do Not Need To

So geographers, in Afric maps,  
With savage pictures fill their gaps,  
And o'er unhabitable downs  
Place elephants for want of towns.

Jonathan Swift (1733) *On Poetry: a Rhapsody*

14. Eschew surplusage.

Mark Twain, *op. cit.*

The viewer has to look at and evaluate everything on the plot, so you make her life easier by leaving out as much as you can, saving her the trouble of deciding that what she has seen is irrelevant. This might seem obvious, but experience shows that geophysicists, like geographers of old, often abhor graphical vacua – especially in maps. One reason is the widespread use of the GMT (Generic Mapping Tools) package, which marries many powerful capabilities to two major weaknesses: an arcane and cumbersome set of commands, and the ease with which the user can overdecorate the result. A minor example of overdecoration is the pointless striped bar that surrounds most GMT maps; a more important one is the inclusion of unnecessary geographic detail that clutters the plot, often obscuring the data of interest.

Figure 1.8 is a world map, showing the locations of GPS monitoring sites. The left plot (modeled after a figure I have seen) is an example of excess clutter: the latitude-longitude graticule is not needed, and a lot of marks inside major landmasses come from various lakes and rivers. On the right, both of these have been dropped to leave just the outline of the continents,

which is all that is needed to see where the sites are.\*<sup>13</sup> The right-hand map also uses hollow circles for the symbols. Like the thin line along the coasts (something found in good maps) this relies on the strong sensitivity of the human visual system to edges. Because of this sensitivity, the outline of any shape of a uniform shade will be enhanced by an edge that contrasts with the shades on either side.

GMT is not the the only source of overdecoration, since many commercial graphics packages, driven by the aesthetic inclinations of graphic designers to make plots “interesting”, allow (and sometimes demand) pointless elaboration: for example, showing bars on a bar chart as 3-D shaded columns. Even if a plotting package has a feature, (*especially* if that package is PowerPoint), it may well be one you should eschew.

### 1.1.5 On a Good Design, You Can See a Lot

You should not avoid complication, or a lot of information, if it really is needed; the human visual system can absorb a great deal, and you can pack a surprising amount into a well-designed plot. This is of course truer for plots in papers (or posters) than those used in talks, for two reasons. One is that the viewer has time to study the plot, while in a talk there may be only a minute. Also, printing technology can provide much higher density than all but high-resolution video screens. A typical (current) resolution for these is 640 by 480 pixels, so most figures will use about 300 by 300; this is equivalent to a printed figure about 3 inches on a side.

The second map in Figure 1.8 shows how much can be made legible in a small space. A method that makes use of this is what Tufte calls “small multiples”: instead of trying to stuff all your information into one plot, you should show different parts of it on a series of smaller and simpler plots. Figure 1.9 is an example, showing the history of different sources of information on California earthquakes from 1850 to 1890, with different symbols for how often they reported; the more often, the better. The individual figures are simple, but together provide a detailed visual history that shows, among other things, how the first Southern California real estate boom (in the 1880’s) caused many weekly newspapers to be started.

---

<sup>13</sup> For GMT users: to remove the graticule, use a large interval in the `-B` option of `pscoast`; to remove the lakes and rivers, and small islands, set `-A10000/0/1`. Use the `-Dc` option for any global map.

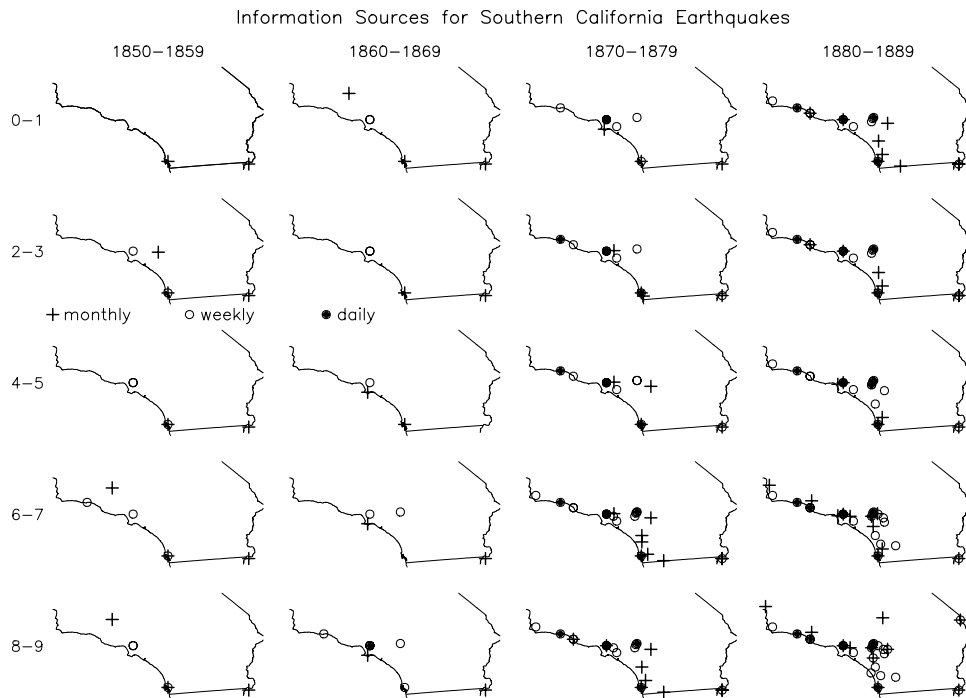


Figure 1.9:

### 1.1.6 Color: Essential, Useful, or Superfluous?

While Figure 1.9 would be perfectly adequate for a paper, it would not work well in a talk. The time needed to assimilate it can be reduced by differentiating the different information types not just by symbol shape, but also by color, as shown in Figure 1.10. Our visual system (like those of other species that eat fruits) is superb at quickly distinguishing one color from another. Until recently, displaying colors was technically challenging; now it is so easy, and the vividness of color is so tempting, that colors are often overused or abused.

There are several reasons to use color. From good to bad, they are:

1. To mimic the colors we would see if looking at an actual scene (a color photograph) or else to highlight features in a scene that we would not naturally see. Color photographs, or false-color ones, convey much more information than black and white.
2. To display densely pixelized information, such as InSAR data.

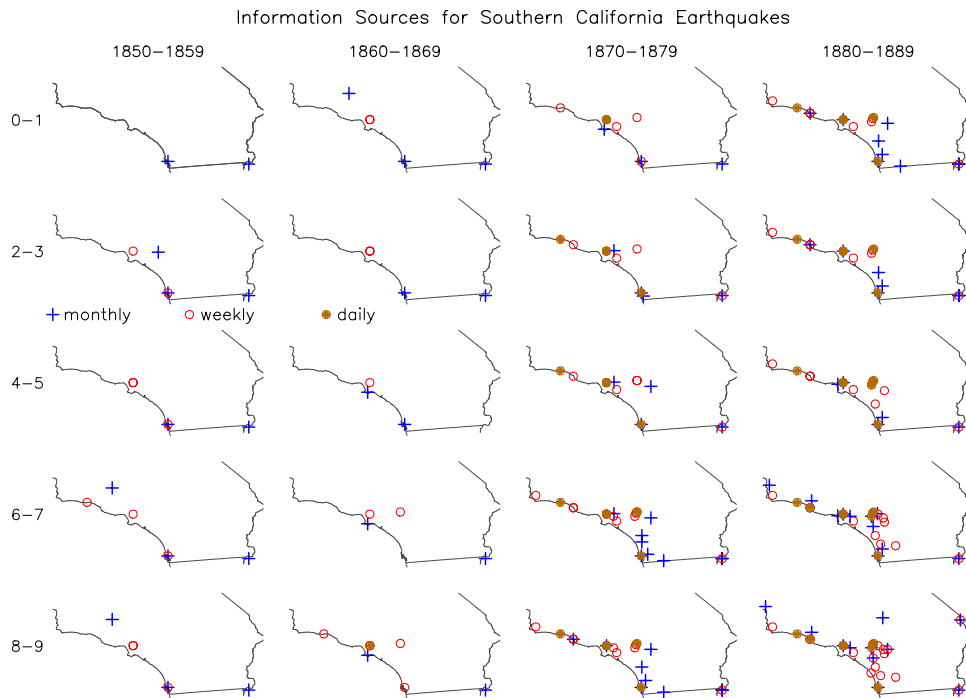


Figure 1.10:

3. To distinguish one element of a plot from another, as in Figure 1.10. Color does not automatically cure bad design: while a jumble of black lines may be incomprehensible, the same lines if colored may still be a jumble.
4. To encode, through some ordering of colors, quantitative information. This is the second most common use, and I discuss it further below.
5. To provide a nominal sense of “reality”; for example, using aerial or space photographs as a map base.
6. To provide pointless visual excitement and make the plot more “interesting”; this is common in plots influenced by graphic designers.

As noted in Section 1.1.1, colors encode values very poorly. If you are thinking of using colors to encode value, ask yourself if you really have to. One case where you may need to is showing the variation of a scalar over a two-dimensional area: the “densely pixelized” case above. Colors easily

show small-scale variation – not surprisingly, given that color variations are ubiquitous in natural scenes.

Any good map (I will venture to offer Figure 1.15, below) shows how coloring allows us to effortlessly separate different elements of a plot. But for simple plots, if you do not need color, do not use it, since it then becomes just another thing that the viewer has to decide doesn't really matter.<sup>14</sup>

But, if you have other things to show than just the value of some scalar, the colors are often *too* noticeable and obscure other data. Elaborately colored topography (easy to do in GMT) is the commonest example. You can do much better by keeping colors in the background: which is to say, pastels are good. If some large area of your plot will have the same hue, whitening it to a pastel shade will keep it from overwhelming the rest of the plot. A simple example is using a light gray grid: available but unobtrusive. The next two figures show the contrast between using bright and (some) pastel colors for a map of seismic intensity from a hypothetical earthquake; because of the variations from geology, this is the kind of spatially-varying quantity that would be difficult to contour. Figure 1.11 uses bright (saturated) colors throughout; Figure 1.12 restricts them to those which take up only a small part of the plot. Letting the background approach whiteness makes it easier to see anything overlain on it: in this case, other faults and the state highway network.

A final point about color is that you should *never* assume colors will come out just as you thought they would – at least, not unless you are willing to learn something about how colors are specified.

You should also keep in mind that a part (up to 7%) of your audience may have much less ability to distinguish colors than the rest do.<sup>15</sup> The commonest case is that red and green become indistinguishable. The best single colors to distinguish points or lines from each other are black, red, and blue.

Colors used to encode value have to be chosen carefully for the results to make sense to those with deficient color vision; in particular, the common “spectral sequence” does not work well – but then, it is almost *never* a good choice anyway.

---

<sup>14</sup> And, until journals abandon the creation of paper copies, there are good economic reasons to avoid color, which is still much more expensive to print many copies of. And the reader of your proposal may not have a color printer available.

<sup>15</sup> This is the percentage for men; the rate for women is much lower. There is some evidence that many women might have additional types of color receptors, and may therefore distinguish colors better than men do.

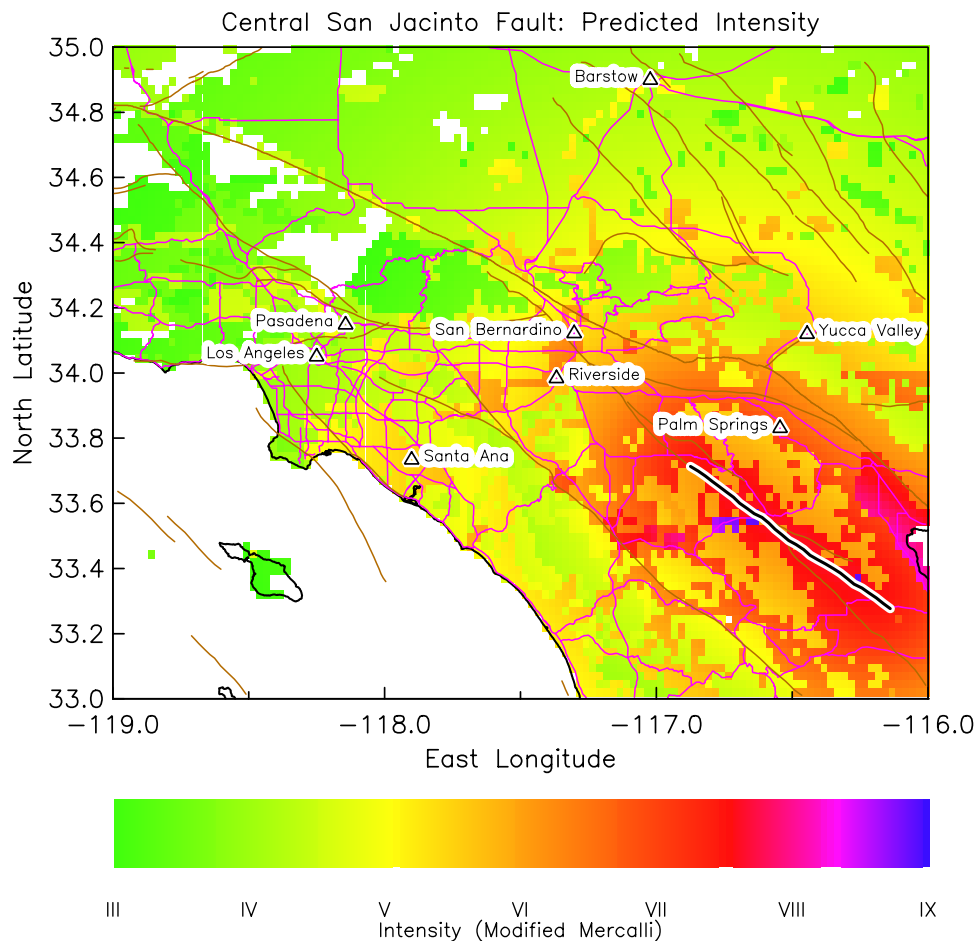


Figure 1.11:

### 1.1.7 Avoid Realism in Showing Surfaces

Although the establishment of a curved surface of this kind seems to require the three dimensions of space, we possess a notation as simple as it is expressive, by means of which it is easy to replace the constructions that we have just indicated in space by others effected on a plane surface. ... This process is altogether the same as that which is employed for painting to the eye elevation of land on topographical plans, carefully raised and traced out.

L. Lalanne (1843/45). "Graphical representation of laws with two variables"

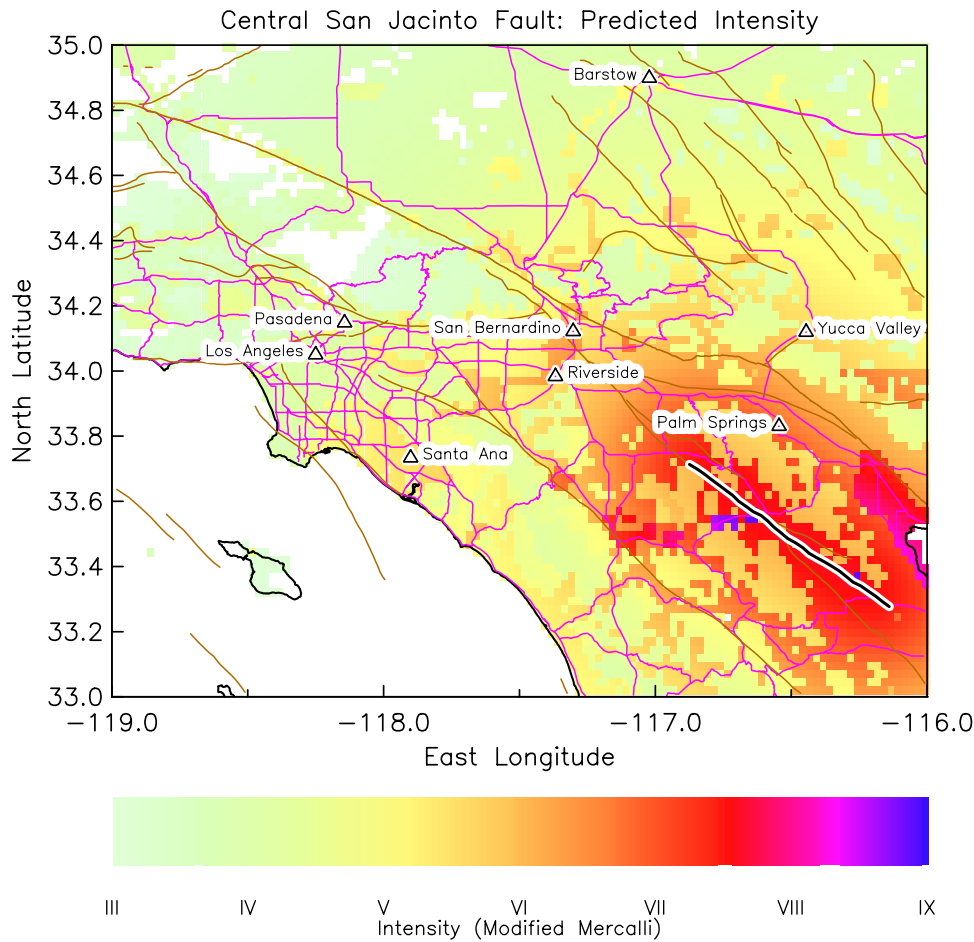


Figure 1.12:

Almost all graphics packages allow you to make perspective views of a surface, for example, one defined by a function of two variables  $f(x_1, x_2)$ ; this is often referred to as “2.5D data”. Perspective views produce an image that the visual system can easily interpret as three-dimensional, especially if the software included sophisticated rendering algorithms for simulating lighting and shading.

But though such images are easy to recognize, they cannot be interpreted quantitatively, and should be avoided in scientific use. A much better method has been available, for a long time: a contour plot. It takes practice to learn to interpret such a representation, but it is probably a safe assumption that an audience of scientists will know how to do this – especially an audience of

## Temperature at Halle

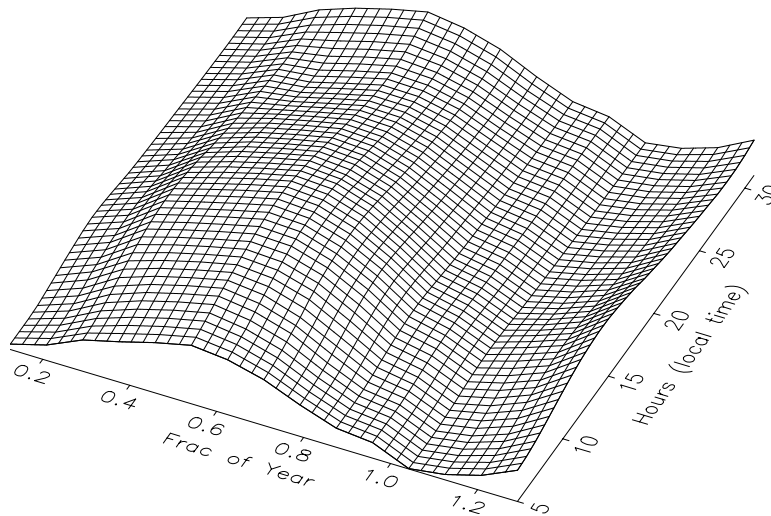


Figure 1.13:

earth scientists, who have to “read” contour maps of topography.

As an example, Figure 1.13 and Figure 1.14 show a perspective and contour representation of data that define a function of two variables, namely the mean temperature in Halle, Germany, as a function of time of day and time of year.<sup>16</sup> The original data were published in that paper, and I have used modern software to make the plots. The perspective plot immediately shows one of its defects: for any viewing position some portion of the surface will be invisible or badly foreshortened. Being able to change the viewpoint would solve this, but that is an expensive patch to a poor initial design. And not even a dynamic display can show what value of temperature corresponds to any particular pair of times.

<sup>16</sup> I pick this dataset because it was used in the first non-topographic contour plot ever made, by Leon Lalanne, as part of the paper from which I took the quotation at the head of this section. This is an Appendix to L. F. Kaemtz, C. Martin (trans.), L. Lalanne, and C. V. Walker (trans.) (1845). *A Complete Course of Meteorology, with Notes, and an Appendix, Containing the Graphic Representation of the Numerical Tables* (London: Hippolyte Baille). The original appendix is L. Lalanne (1843). *Appendice sur la representation graphique des tableaux météorologiques et des lois naturelles en général*, in the French translation of Kaemtz’ German original. For the history of contour plots and related developments, see Hankins (1999); Palsky (1996).

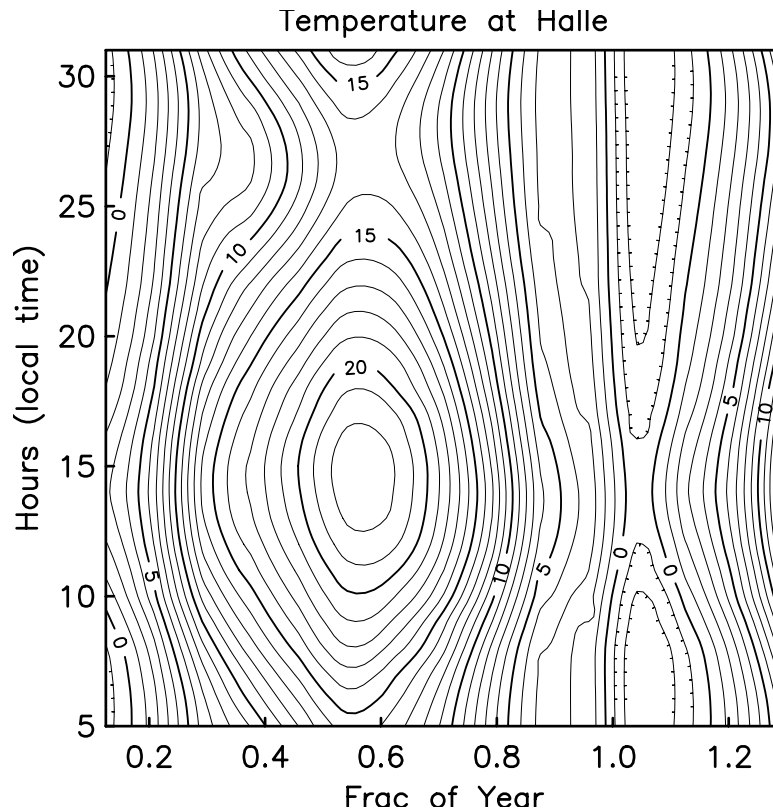


Figure 1.14:

In contrast, the contour plot shows the entire surface, makes it possible to estimate the value for any pair of times, and allows us to get a sense of, for example, the daily variation at a particular season – though in keeping with Section 1.1.2 if that is what we want to show, we should use a separate plot to do so.

But, as we noted in Section 1.1.6, a contour plot is hard to read if it shows a complicated surface, not that this makes 3D views any more useful. Since landforms can be very complicated, if you need to represent such a surface, you should investigate the techniques that cartographers use to represent surface topography (Imhof, 2007); since landforms can be very complicated.<sup>17</sup> But even topographic maps sometimes use a special symbol for “intricate topography”. Layer coloring, of which Figure 1.12 is an example, is probably

<sup>17</sup> Two websites with many useful ideas are <http://www.reliefshading.com> and <http://www.shadedrelief.com>.

## Glendale-Verdugo LSM Site

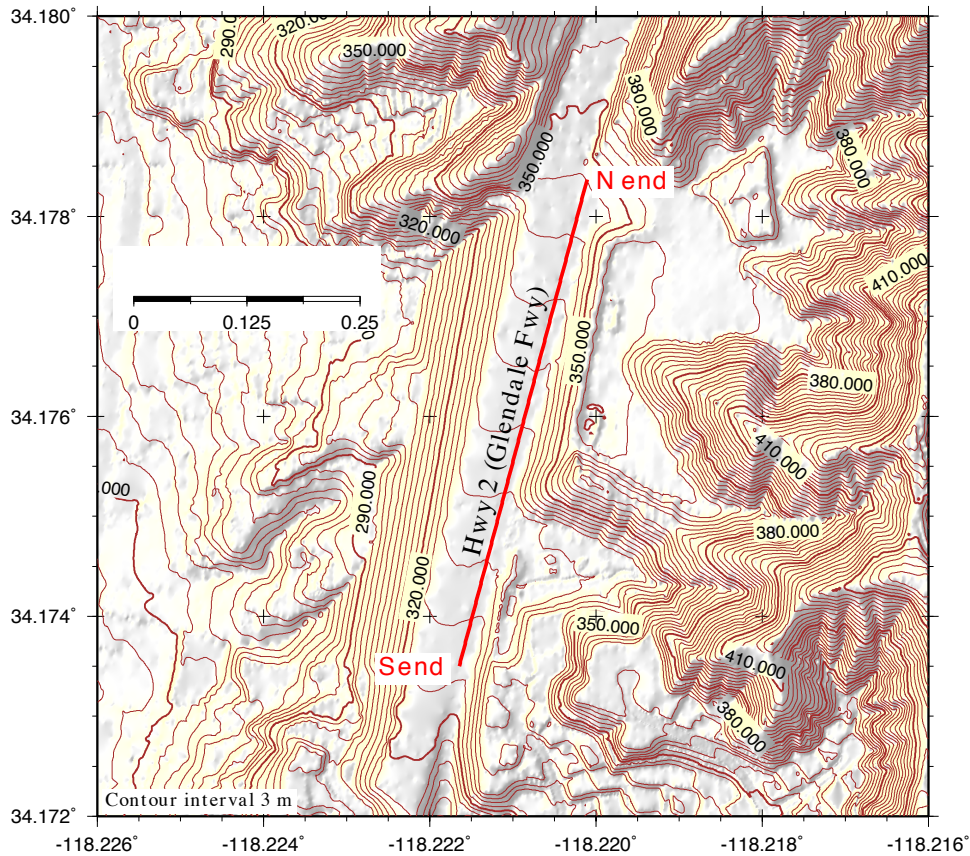


Figure 1.15:

the only method that can be used for really complex surfaces. Even though it is easy to do (especially with GMT) it should not be used for simple situations such as Figure 1.14. You should first try to make contour lines more legible by thoughtful choice of contour intervals, by using varying line thicknesses, and in extreme cases using varying colors.

It can be also be useful to combine contours with another method from cartography: applying a very light shading to show local slopes. Figure 1.15 shows this applied to some actual topography, with yellow on the “sunlit” slopes (those facing the NW) and gray on the “shaded” ones (facing SE). This range of shaded is better than the more common white-to-gray shading because the darkest gray can be paler, and any flat area is left white.

## 1.2 Conclusion

I have tried to offer some precepts for what makes for effective graphics: “effective” meaning that the viewer will get whatever message you are trying to convey. These suggestions are only useful if you start by asking, for each figure you create, what the message is, and indeed if a figure is the best way to convey this message. Often it is, but only if you are prepared to spend effort on designing it, and evaluating what visual elements to include and exclude. As with any other attempt at communication, having someone else look at it is the best way to find out how clearly a graphic makes your point. With luck, you may find that after careful design, much revision, and the use of the principles set forth here, the viewer will take one look and say “That’s obvious”; then, if your idea is as good as your graphic, you are well on your way.

---

# Bibliography

---

- Hankins, T. L. (1999), Blood, dirt, and nomograms: a particular history of graphs, *Isis*, **90**, 50–80.
- Imhof, E. (2007), *Cartographic Relief Presentation*, vol. visualization, surfaces, ESRI Press, Redlands, Calif.
- Palsky, G. (1996), *Des Chiffres et des Cartes: Naissance et Developpement de la Cartographie Quantitative Francaise au XIXe Siecle*, Ministere de l'enseignement superieur et de la recherche, Comite des travaux historiques et scientifiques, Paris.