

# Weather Observation and Analysis

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## Course Notes

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## Chapter 4. CREATING A HAND ANALYSIS

### 1. Introduction

An analysis is a depiction of the state of the atmosphere as determined from observations.

Within this definition lie the secrets of creating a good subjective analysis.

Why learn how to create a handmade analysis? Aside from the fact that you may need that skill someday, the most important reason is that it teaches you how the atmosphere fits together, how to take snapshots of pieces of the atmosphere and assemble them in your mind to form a coherent whole. Creating a good hand analysis requires that you understand both the observations and the atmosphere.

### 4.2 Observations

The most important word in this definition is the word “observations”. There are infinite possibilities for an analysis, depending on the person (or computer algorithm) performing the analysis and the purposes of the analysis itself. There is no single “right” analysis. But the easiest way to produce a flat-out wrong analysis is to miss an observation. An analysis could be gorgeous and sophisticated, but if it doesn’t agree appropriately with the observations, it’s worthless.

So, the analyst's first responsibility is to consider all the available data, or at least as much as can be considered in the available time. This is not as hard as it sounds. In the course of drawing the analysis, you will cover the map with lines and will necessarily look at most of the data in the process. Three tips: First, when confronted with a map with nothing but data on it, take a good hard look and get a sense of the basic patterns in the data. Second, when you are drawing contours, look beyond the data on either side of the contour and make sure that you're considering all the data in the area. Third, when you think you have finished, scan the map and make sure all the data fits.

You will find that when you first see the map with data, it's a big jumble of numbers. When you finish the analysis and scan it for the last time, you will see all the patterns in the data, and most of it will make sense! In fact, that's the most important reason to do an analysis in the first place: to discover what the data is telling you, and to understand what's really going on in the atmosphere.

### 4.3 Types of Analysis Errors

Individual teachers of hand analysis may have a different list or a different ranking, but in my opinion there are seven different types of errors that can be made on an analysis. In order of severity, with the worst first, they are:

1. *Analysis unclear.* Whatever your analysis, right or wrong, it has to be clear enough for someone to read it. Known mistakes should be cleanly erased, and labels should be clearly written and placed with sufficient frequency. The amount of expected clarity depends on the amount of time available to perfect the analysis, but in all cases it must be possible to determine what the analyst had in mind.

2. *Impossible analysis.* It is quite possible to create an analysis depiction that is utterly and physically impossible. One example of an impossible analysis feature is two contours, with a different value on each contour, crossing each other. There are others, some of which will be discussed below.

3. *Disagrees with the data.* Some disagreement with the data is OK in the interest of smoothness or ignoring obvious data errors, as will be seen below, but other times an analysis will clearly disagree with the data because the analyst didn't notice the data. An analyst should learn to read all the available data whenever possible.

4. *Disagrees with indirect data.* Some meteorological fields contain information about other fields. For example, pressure and wind

fields are closely related. Ignoring the information from all available fields on a surface map is a serious error.

5. *Elements missing.* The lack of a contour, perhaps because of not noticing an observation in the corner of the map, is an error of omission that is almost as serious as placing a contour in the wrong place.

6. *Wrong smoothness.* The concept of smoothness in an analysis will be discussed below. Frequently this error is one of agreeing too closely with the data.

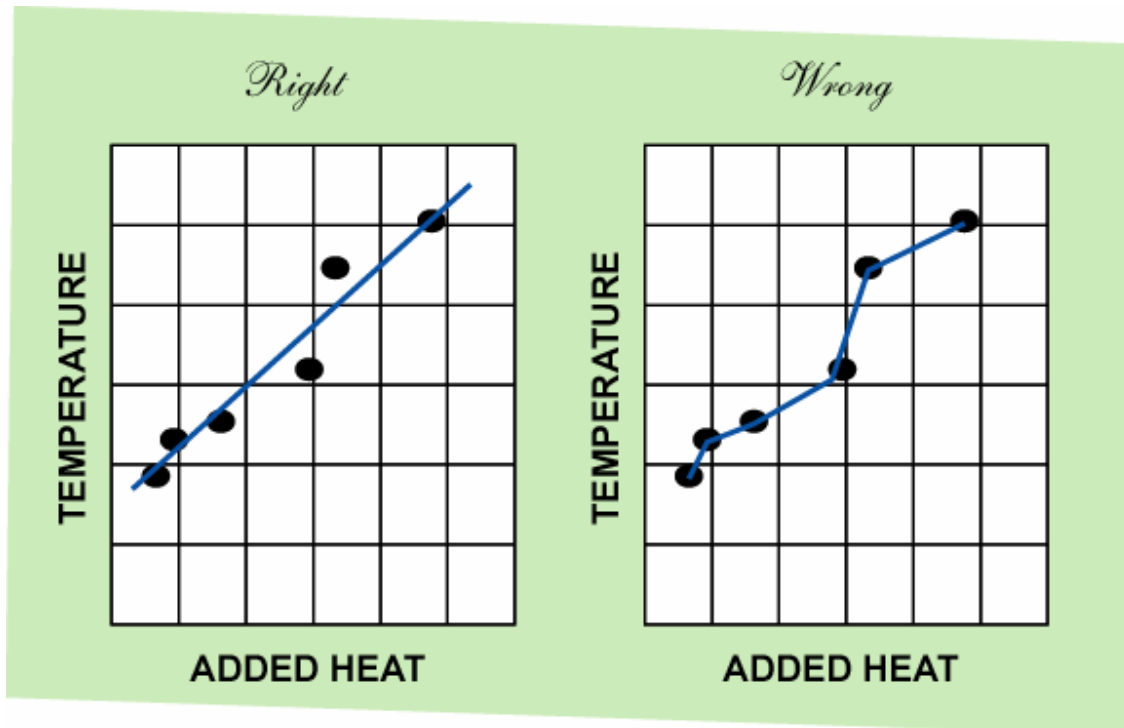
7. *Wrong application of conceptual model.* Much of the art of analysis is recognizing weather features based on limited amounts of data. If you fail to recognize a feature or put it in the wrong place, your analysis of that feature is next to worthless.

#### **4.4 Determination**

The act of creating an analysis is not merely a graphical exercise. The analysis represents the analyst's best judgment about what lies between the observations, and in particular which characteristics of the atmosphere between the observations deserve to be depicted in the analysis. If the analysis were simply an alternate view of the data, it wouldn't be worth drawing. Its value lies in the information that the analyst adds to the map while creating the analysis.

The idea that there are judgments to be made, and not simply single correct solutions to be divined, is often difficult for the novice analysis to grasp. Even more difficult is the concept that the best possible analysis does NOT coincide precisely with the data. This is not to say that the analyst ignores some of the data, but rather that the good analyst understands that the data itself is inherently imprecise and doesn't pretend otherwise.

The situation is similar to the scientist conducting an experiment and seeking to determine the relationship, say, between the amount of heat added to a beaker of water and the temperature of that water. This scientist understands, or at least expects, that the relationship is linear, as long as the water doesn't get hot enough to boil, and wants to determine the proportionality constant, the heat capacity. So heat is applied, measurements are taken, and the measured temperatures are plotted on a graph as a function of the integrated amount of heat. The data tends to lie along a line, but with some scatter. The scientist determines the best-fitting straight line, perhaps through linear regression, and the resulting line is the best possible estimate, given the data, of the relationship between the added heat and the resulting temperature.



What just happened? The scientist did not complete the graph by simply connecting the dots. The better approach was to recognize that the measurements of temperature were inherently imprecise. Maybe the thermometer was in a warm part of the beaker during one measurement and in a cooler part of the beaker during another. Maybe a hot bubble of rising water passed across the thermometer at the time the measurement was taken. Maybe the thermometer itself was imprecise or erratic. In any case, the scientist had to see past those errors to discern the underlying pattern, and the resulting best-fit line is not wrong because it doesn't pass through every dot on the graph. In a real sense, it's RIGHT because it doesn't pass through every dot on the graph.

But, you may say, what if measurements of temperature in the beaker were all perfectly correct and representative? Our scientist may have missed a real, interesting phenomenon by his or her compulsion to fit a straight line to the data! True enough, I say. To fit the straight line, the scientist must have some awareness of how large the errors in the data ought to be. If the scatter from a straight line does not consist of random errors of appropriate magnitude, then a straight line isn't the right analysis.

Consider, now, measurements of temperature at surface weather stations. The same types of errors in the beaker are found in the atmosphere. Some observing sites are in locations that are often warmer or colder than most of their surroundings. Such a site is said to be unrepresentative, and an analysis that intends to represent the typical

conditions in the surroundings shouldn't deviate to include an unrepresentative point measurement. Similarly, sometimes the weather at a particular spot happens to be unusual. A good example of that would be an isolated thunderstorm that nails a weather station. That station will be cold and cloudy, but that single observation may be the only one for dozens of miles. Unless that thunderstorm has significance on a larger scale, it shouldn't intrude in the analysis of the larger-scale temperature pattern. Finally, some measurements are just plain wrong. If an analyst assumes that the measurements are correct, the analysis becomes wrong.

The meteorological analyst must know how large the representativeness, siting, and instrument errors ought to be. Apparent disagreements between the analysis and the observations that are small enough to be within the "noise level" of the data are perfectly acceptable and in fact desirable if they lead to a simpler, cleaner analysis. If a data point's value is far from what the analyst expects, the analyst should, at least, attempt to determine why it is so different. What is the source of error? Or does the analysis have the wrong expectation?

#### **4.5 State of the Atmosphere**

Subjective analysis would be really hard if all we were analyzing were a bunch of numbers distributed on a map. Indeed, the first few analyses you perform, the data WILL all seem like just a bunch of numbers. You have my sympathies, but fear not, you will outgrow this state. Soon, if not already, you will know enough about the atmosphere to recognize that the data are evidence of recognizable weather patterns present in the atmosphere.

That's good news, for it greatly reduces the number of possible analyses that might be consistent with the data. (It reduces it from a large infinity to a small infinity.) Whatever analysis you produce has to be something that the atmosphere is capable of producing, too. If the pattern you analyze can't happen, then it must be wrong.

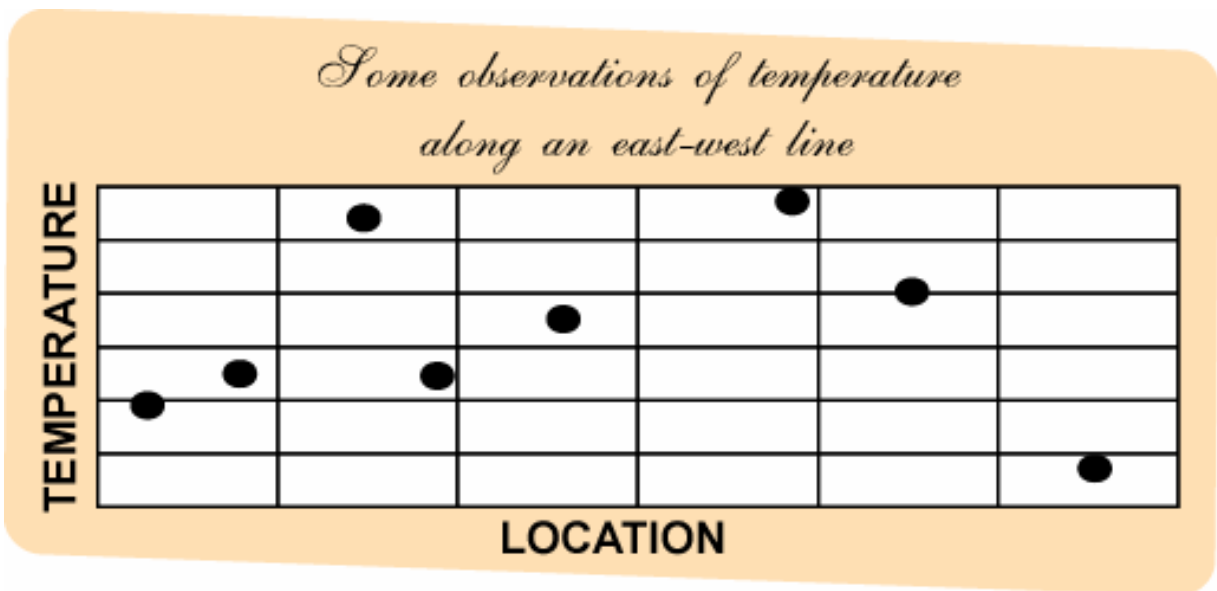
Beyond the impossible analyses are the unlikely analyses. With multiple ways of analyzing the data, some of these possible atmospheric states are much more likely to happen than others. Since you don't have data at every single point (and the data wouldn't be perfectly correct even if it did exist everywhere), you have to decide which possible atmospheric state seems to make the most sense, given the data that's available, within the constraints of what the analysis is allowed to show.

An analysis isn't supposed to show everything. After all, each tiny bit of air has its own temperature, which is slightly different than the next

tiny bit of air, and by the time you've gone a hundred yards, you've spanned a wealth of variability. A good rule of thumb is that a synoptic or mesoscale analysis is supposed to show structures down to the scale represented by the typical observation spacing, but no farther. If data is especially sparse, the analysis should still attempt to represent structures that might be present on the scale of a couple hundred kilometers or so.

Fronts are special cases. They are long, but thin. For the purposes of the analysis, it's the long dimension that matters. It's okay to draw a very detailed temperature pattern along a front, as long as that pattern stretches a considerable distance along the front.

If an analysis depends on what atmospheric states are possible, and what the analysis is allowed to show, it follows that the same data might lead to different "best" analyses in different circumstances. Let's look at some examples of this. Suppose we have a string of temperature measurements along an east-west line. Suppose those measurements, if plotted on a graph, look like the figure shown here.

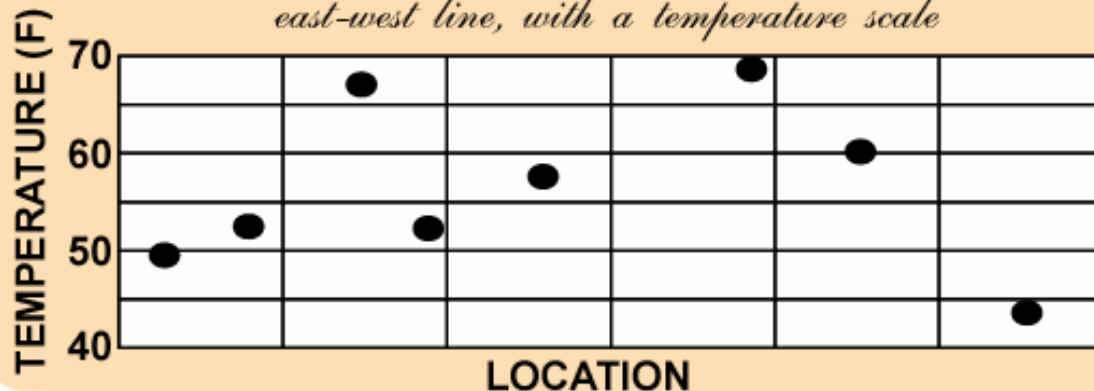


What's the proper analysis? What's the "real" value of temperature between those data points? What line or curve traces the "true" temperature? To tell, we need to know the relative accuracy of the data points and the horizontal scale of variation that should be resolved.

Let's worry about the accuracy first. Suppose we were to add a temperature scale to the left side of the diagram.

Now one might say: "Look at those rather large variations in temperature, ranging from the low 50s to near 70. Those temperature

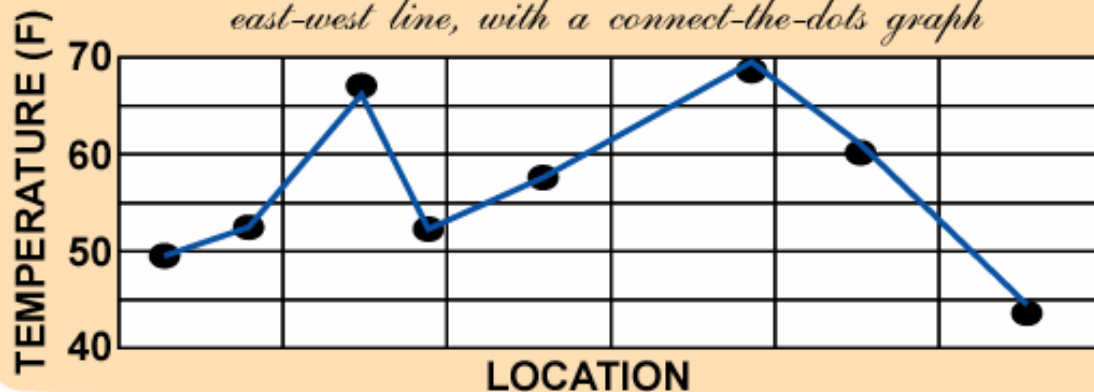
*Some observations of temperature along an east-west line, with a temperature scale*



variations are pretty big, they must be real. I'll draw the analysis so as to be consistent with all the data."

What does such an analysis look like? Is it this:

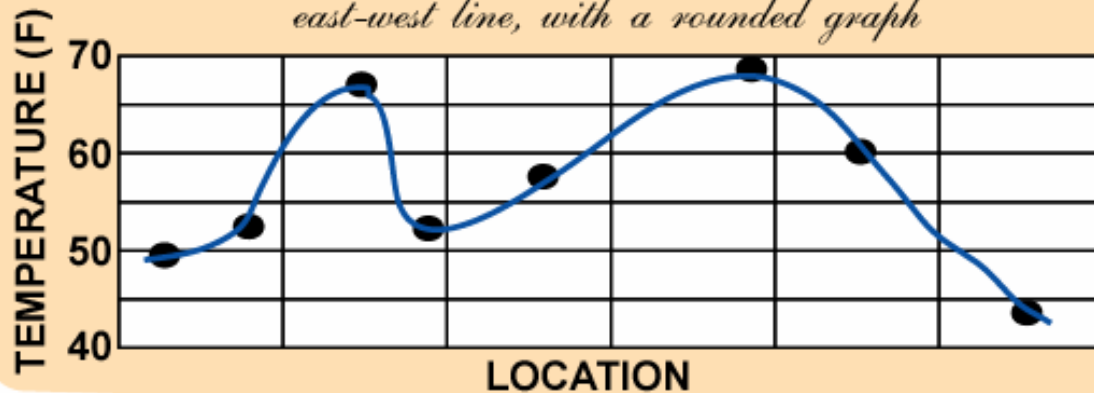
*Some observations of temperature along an east-west line, with a connect-the-dots graph*



Or the one on the next page?

Both of those analyses go through every data point. And if every data point is accurate, linear interpolation between the data points (as in the first alternative) would be the best way of estimating the value of temperature at any arbitrary location between observations. But estimating temperature is not the whole story. The analysis must represent a realizable, likely distribution of the real temperatures. How likely is it that the horizontal partial derivative of temperature (on this graph, the

*Some observations of temperature along an east-west line, with a rounded graph*

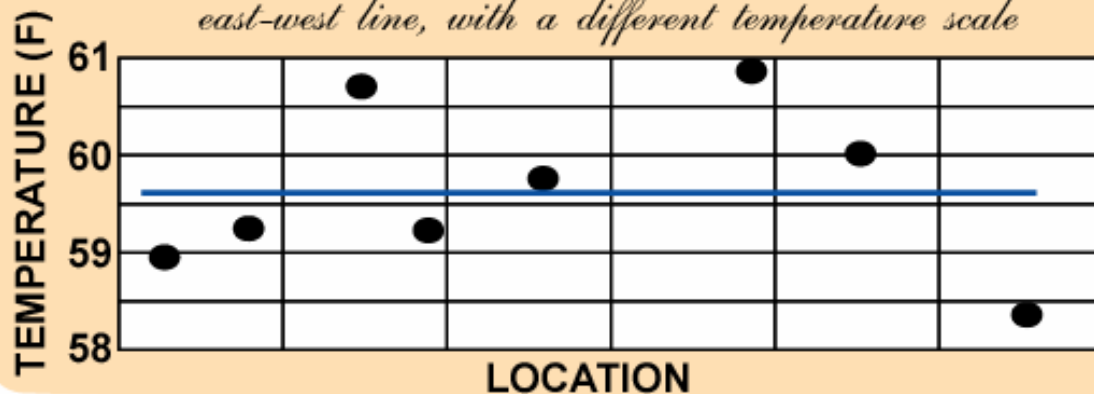


slope) is constant between stations and suddenly jumps to a new value at each station? What atmospheric process would cause the temperature to reach pointy peaks and troughs rather than varying smoothly with position? If you think about it, you will realize that the second graph is a possible, realistic, distribution of temperature and the first graph is a highly implausible one. So, as a meteorological analysis, #2 is the winner.

As a general rule, unless you have a good reason for analyzing discontinuities such as in #1, don't do it.

What if we had a different temperature scale?

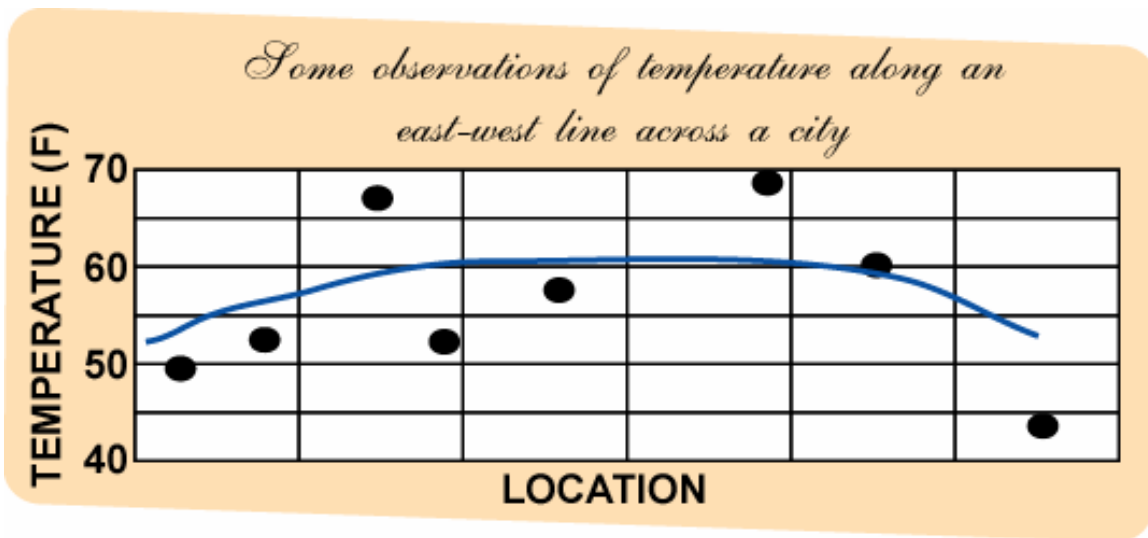
*Some observations of temperature along an east-west line, with a different temperature scale*



In this particular case, the temperature variations are so small that they are well within the range of uncertainty of a typical temperature measurement. This means that the apparent warm spots and cold spots can't be trusted, and the best analysis is simply a straight line.

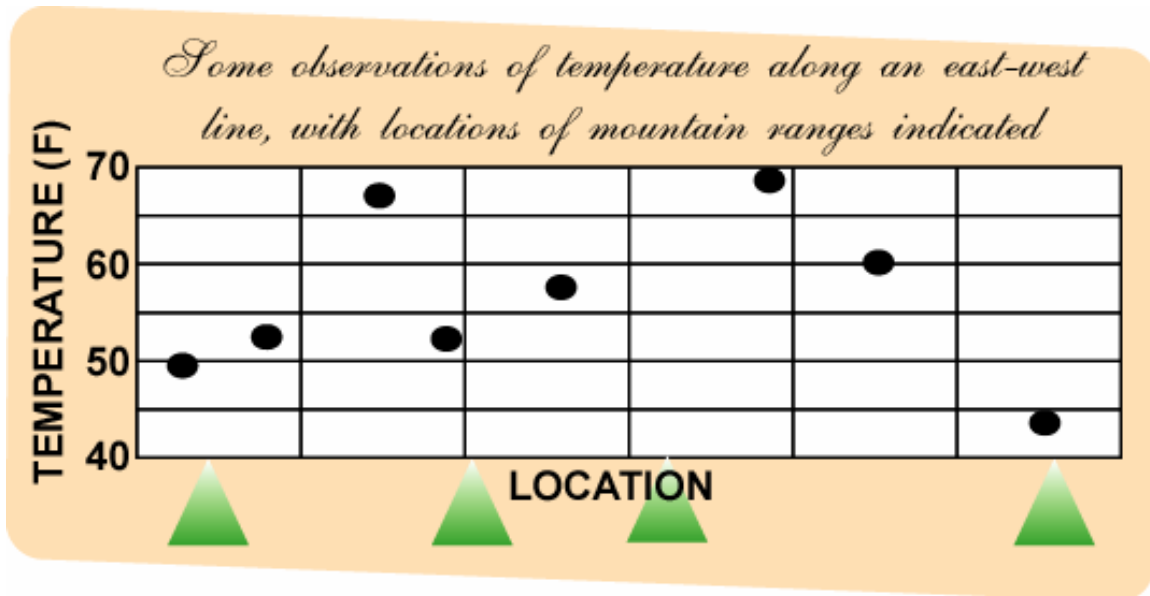
The cutoff between a real temperature difference and one likely to be due to random errors depends on the field being analyzed. For temperature, METAR measurements should be deemed to be accurate to within about a degree. Atmospheric pressure can be off by as much as a millibar, and wind direction can easily be off by twenty degrees or so, more if winds are light and there is a lot of local terrain in the way.

We've seen the extreme cases regarding the relative amplitudes of the observed variability and the observation error. Now consider the issue of spatial variations and what should be represented on an analysis. Suppose we consider the following distribution of temperatures again, but suppose further that they represent temperatures across a city. I suppose if one wanted to analyze the comparative temperatures of parking lots and green areas, one could infer a very detailed analysis on the basis of this small sampling of data. Presumably the parking lots would be the warmer areas. But if the analysis is of the entire state of Texas, such a level of detail is unreasonable. Instead, the small collection of observations should be sort of lumped together into a general pattern. Such an analysis is indicated by the graph below:



Suppose we have the opposite problem, which is unfortunately quite common: not enough data. If the data is very sparse, you must use all the extra information and knowledge at your disposal to infer what's happening between stations. For example, suppose the data represents temperatures across an idealized version of the western United States.

Having good geographical knowledge (you need it in meteorology, for this and a thousand other reasons), you know that changes in elevation can have big impacts on temperature, and that the major mountain ranges are located as shown on the next figure.



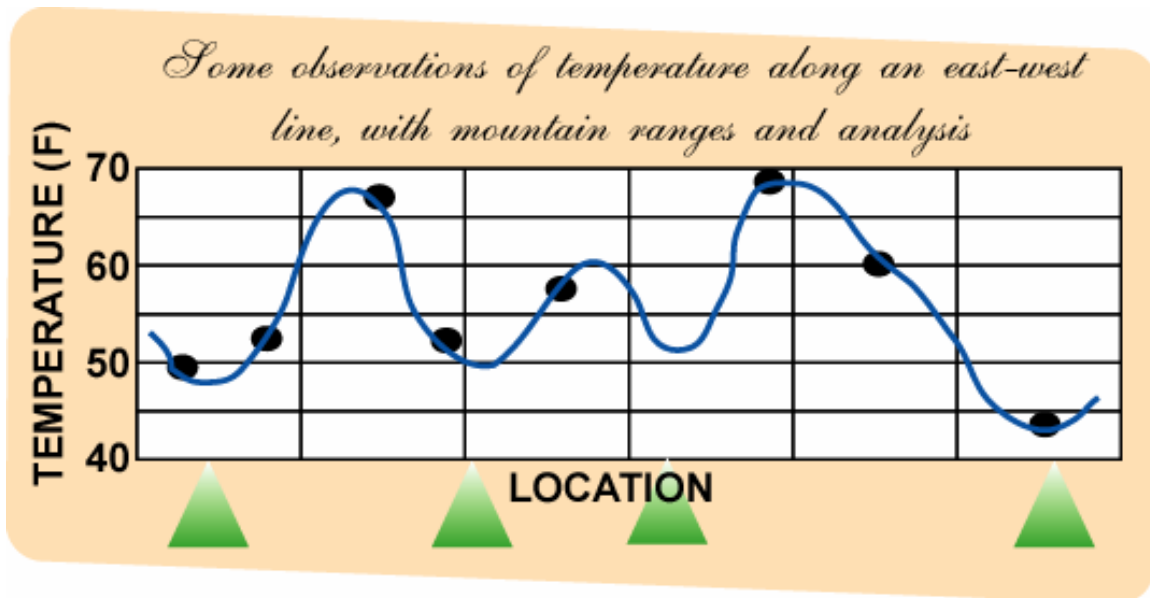
Notice that the cooler temperatures tend to be associated with the mountain ranges. This makes sense if you know that temperature tends to decrease with elevation. Thus, there's a pattern in the data, and that pattern has a sound physical basis, so we can make use of that pattern in our analysis to help out between stations.

Three of the mountain ranges have temperature data points associated with them, but the fourth (second from the right) does not. Based on the pattern we observe elsewhere, we infer that there ought to be cool temperatures along that mountain range. Furthermore, the other gaps in the data are not along mountain ranges, so temperatures should be relatively warm there.

My analysis is shown in the next figure. See how the same data points can yield many different analyses, each of which is correct under certain circumstances? The key factors to consider are the accuracy of the data, the scales of variability that the analysis needs to depict, and, if there are data gaps, an understanding of what's probably going on where there is no data.

Ultimately, your analysis is meant to be of benefit and value both to yourself and to others. For yourself, part of the benefit comes in the construction of the analysis and the resulting unavoidable need to study the data and make sense of it. For others, the analysis is fundamentally a

communications device. It is therefore important that the analysis convey the (correct) information in a visually straightforward and clear manner.



#### 4.6 Contour Spacing and Gradients

It has often been said that a good analysis looks like a work of art. Unless time is an overriding factor, the analysis should show as much neatness and attention to detail as possible. Indeed, neatness will be one of the measures by which your analyses will be graded.

That said, I should warn you that, for the purposes of these analyses, cubism is not an appropriate style of art to emulate. The data points are discrete and isolated, but the analysis must be the opposite: smooth and flowing. Remember that you are not just analyzing the values of some scalar field such as temperature. Your analysis also depicts the magnitude of the horizontal variations of that scalar field. You have seen in the previous chapter that, when the wind blows, proper knowledge horizontal variations are fundamentally important for predicting the evolution of the weather.

The overriding stylistic rule in drawing contours is to pay attention to the contour spacing. Do not put corners or sharp curves in your contours unless it's specifically called for in the data or by the weather phenomenon being analyzed, and do not be so careless in your analysis that contours come close to touching for no apparent reason. Just as the scalar field (such as temperature) should be assumed to vary smoothly across the map unless the data and weather dictate otherwise, so the

contour spacing should also vary smoothly across the map. Appropriate smoothness is a difficult technique to learn, but it is so important that it will be the second of the three factors by which your analysis will be graded.


Cmaps are, among all possible ways of displaying two-dimensional information, the best and easiest type of map for estimating spatial derivatives. Visually, they give an immediate sense of the strength and direction of derivatives. Quantitatively, it is possible at selected points to make precise (as accurate as the analysis itself) computations of spatial derivatives.

We'll start with quantitative methods, then move on to the quicker, qualitative ones.

Recall the technique in Chapter 3 for computing a horizontal derivative from a contour map: picking two points on either side of the point of interest, estimating the value of the field at those points, subtracting one value from the other, and dividing the difference by the distance between the points. It works. But there's a much easier way.

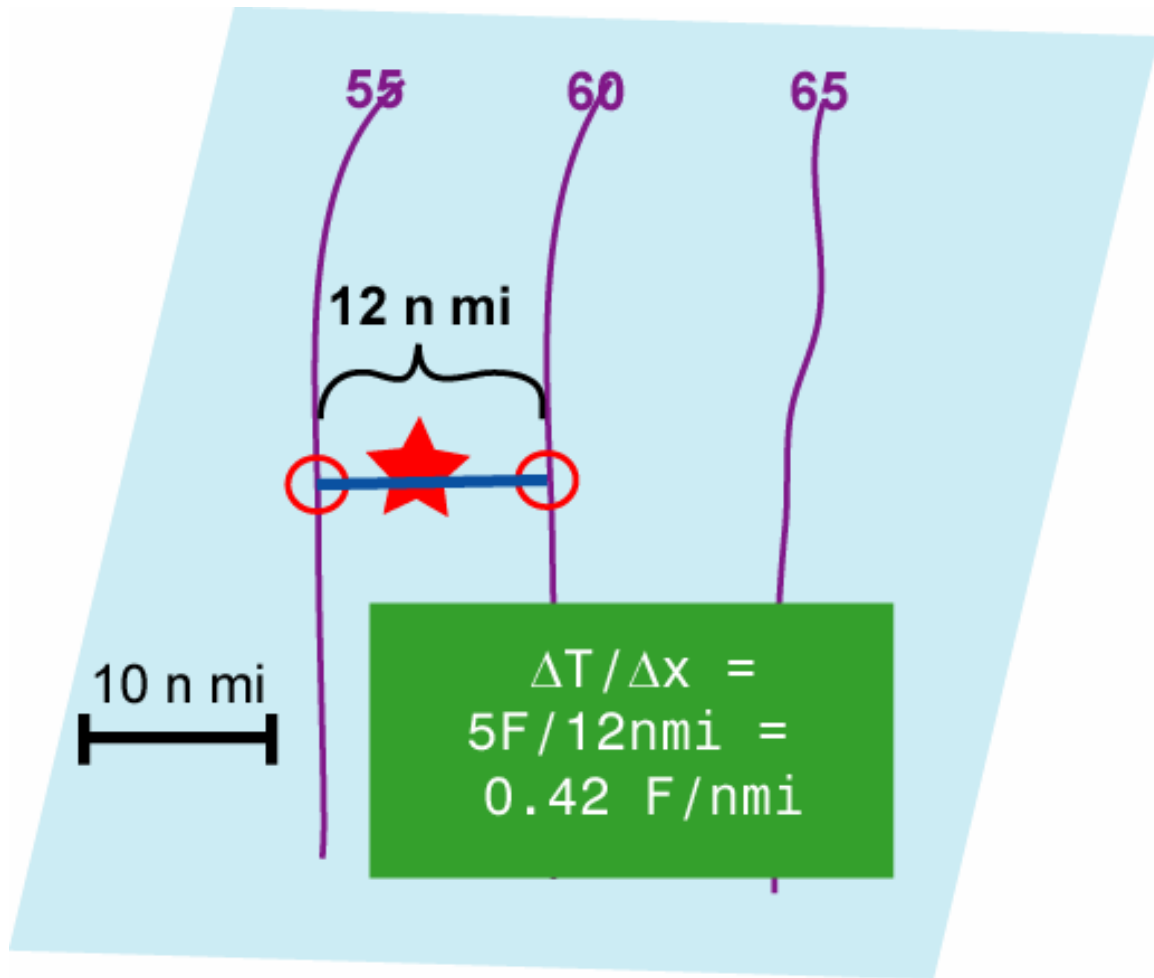
The derivative of temperature with respect to  $x$  is the change in temperature over some distance in  $x$  divided by that distance, with the distance interval taken as small as possible. On a map with isotherms, the isotherms themselves define intervals of temperature. If the isotherms are five degrees apart, each time you cross another isotherm the temperature has changed five degrees.

Here's how you can use that information to estimate a derivative. Draw your line through your point of interest, parallel to  $x$ . Now go both ways along the line from your point and find where the first isotherms cross the line. Then, estimate the distance between those crossing points. The difference in temperature between those two isotherms, divided by the distance between them, is the average derivative of temperature with respect to  $x$  over that interval.

This technique is similar to the earlier one, but instead of choosing a fixed distance  and estimating the temperature change, you find a known temperature change and estimate the distance. It amounts to the same thing. It's simpler (and more accurate) because instead of having to estimate two temperatures, you only need to estimate one distance.

The quantitative technique suggests what the qualitative method would be. The closer together the isotherms (as long as they are not all the same isotherm), the more rapidly temperature changes with distance and the larger the derivative. If the isotherms cross your  $x$  line at points that

are far apart, the denominator in your derivative computation would be very big and the derivative itself must be small.



In the real world, you don't generally care about how quickly temperature changes in the  $x$  direction alone; you care about the  $y$  direction too. Or, more likely, you would care about which direction temperature changes most rapidly, and exactly how rapidly it changes in that direction.

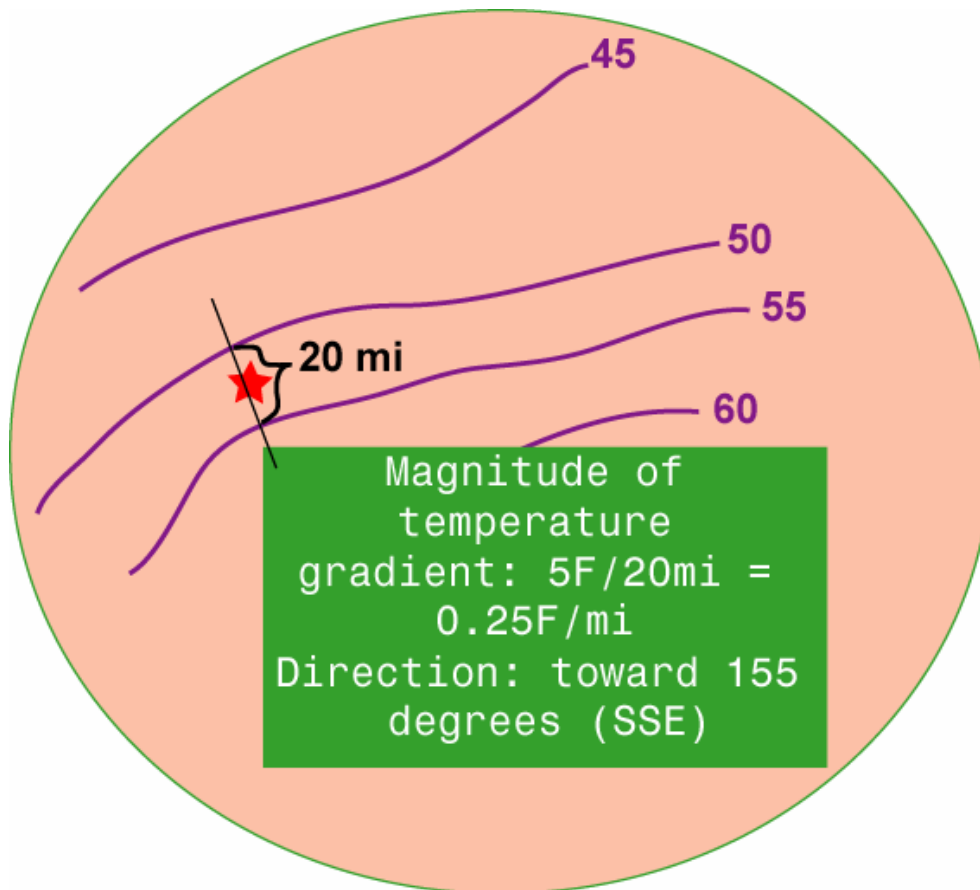
Hmm, the magnitude of change, and the direction in which that change occurs. A magnitude and a direction. Sounds a lot like a vector, doesn't it?

The name of this vector is the *gradient*. The direction of the gradient vector is the direction in which the quantity in question increases most rapidly. The magnitude of the gradient is the derivative of that quantity in that direction.

As with all vectors, the gradient vector can be expressed as components. Those components are simply the partial derivatives with respect to  $x$  and  $y$ . We've done a lot with partial derivatives in Chapter 3 already. Here we see that two of them are the components of the gradient vector. So if you know how to compute a spatial derivative or two, you know how to compute a gradient.


Mathematically, the gradient of temperature is written as  $\nabla T$ . The upside-down delta is called the gradient operator and the whole expression is read as "grad T". Since we have three spatial dimensions, the gradient vector is technically a three-dimensional vector. But for most of this class, we will concern ourselves only with the two-dimensional vector composed of the  $x$  and  $y$  components of the gradient. So that there's no ambiguity, these notes will use the subscript "2" to identify the gradient as two-dimensional only:  $\nabla_2 T$ .

With the two gradient components, one could use trigonometry to compute a magnitude and direction. But if you're going to estimate the gradient from a weather map, you may as well do it the easy way.



On a weather map with contours, the direction of the gradient is everywhere perpendicular to the contours themselves, pointing in the direction of higher contour values. The magnitude of the gradient is everywhere equal to the spacing between the contours divided into the contour interval.

That's even simpler than derivatives!

To see why this works, imagine a gradient vector. Orient your cartesian coordinate system so that one axis is in the direction of the gradient. Now think about the ponents of that vector in that coordinate system. The component along that axis is equal to the whole magnitude, while the component along the other axis, being perpendicular to the vector, is exactly zero. This zero is the derivative of the quantity in question along that direction. And if the value of that quantity doesn't change along that direction, that direction must be parallel to the contours there. (Remember, the contours are lines along which the value of that quantity doesn't change.) And so the gradient must be perpendicular to the contours.

The relationship between contours and gradients is so fundamental, so organic to the depiction with contours, that it's easier to eyeball the gradient of a quantity than it is to eyeball that quantity itself. Think about it: if you want to know where that quantity is largest, you have to scan the map, read some contour labels, and find the high spot. If you want to know where the gradient is largest, you just look for where the contour lines are closest together, as long as they're different lines. After all, if a 60 degree isotherm is close to another 60 degree isotherm, the gradient between those isotherms must average out to zero. It's only where the contours show rapidly changing values that the gradient is largest.

In calculus, you'll work with gradients a lot. But you may never deal with them in the context of contour maps. In meteorology, contour maps are how we see gradients. As we will continue to see, gradients are fundamentally important to our understanding of how the atmosphere behaves and evolves.

So now, think about your responsibility when doing an analysis, drawing your own contour map. You're not just drawing isopleths, you're creating a graphical representation of the gradients. That's why you must always be conscious of the orientation and especially the space between the contours. This also calls to mind another reason for drawing smooth contours: if the contours are erratic, and one contour doesn't look anything like the next one, it is impossible for someone to look at the space between the contours and infer the magnitude and direction of the gradient. It sounds wrong, but a smooth map actually provides more information than

a jagged map because it clearly shows both the quantity being analyzed and its gradients.

#### 4.7 Creating Your Depiction

To get a good, artistic analysis, you should learn to follow a basic procedure. The procedure I recommend is as follows:

1. *Identify yourself.* Write your name and the current date in the lower right corner of the map.

2. *Examine the map.* Spend a few seconds examining the map to get a sense of the overall pattern and to decide where to start the analysis. Once you learn frontal analysis, you will use this step to sketch in the initial positions of your fronts.

3. *Start simple.* Select a portion of the map where you think it will be easy to place contours. For height or pressure, this would be a place where the winds are relatively strong or uniform. For other scalar fields, find an area where the gradient is large. Regions of light winds or nearly uniform fields are tricky; save them for later.

4. *Select your contours and contour interval.* Some fields, such as height, have standard contour intervals at each level. For most others, you are on your own. For temperature, for example, every 2, 5, or 10 degrees might make sense, depending on the situation. You should pick an interval that lets you draw enough lines to show the structure of the field throughout the map. As for the specific contour values, the hard and fast rule is that every contour value should be evenly divisible by the contour interval. So, for example, if you are analyzing every 10 degrees, a 50 degree contour is okay but a 54 degree contour is not.

5. *Draw lightly.* Your initial contours should be drawn very lightly in graphite pencil, and be constantly refined for smoothness. Sketch in a few labels as you go so that you don't confuse contours. When you have all the contours where you want them, add permanent, dark contour labels (enough so that each line can be identified without hiring a detective) and then retrace the contours darkly and smoothly. If you have drawn your initial contours lightly enough, it will not be necessary to erase them, but go back and clean up any sloppy squiggles.

6. *Draw with lower values to the left.* As you get more proficient in your analysis technique, you can ignore this rule, but it's very important for beginners! Remember that each contour is representing not only the values of a scalar but also its gradient. If the gradient is directed toward one side of the contour at one point, it can't suddenly switch to the other

side. The way to ensure that your gradients are consistent is to draw with lower values to the left. (It will become obvious why left is preferred when you begin analyzing pressure and heights.) To do this, start a contour on the edge of the map or somewhere in the middle, and draw so that the lower values are to the left of the direction of motion of the pencil. If you have to stop the contour for some reason, mark the end that you finished with, so that you can pick it up again from there. Always go in the same direction, sort of like combing or brushing your hair.

7. *Draw alternating contours.* Once you have your first contour drawn, do not then draw the contour right next to it if the gradients are strong. Instead, pick the second contour away, or the fourth, and fill in the remaining contours later. This technique has two benefits: it lets you see what the overall pattern will look like at an early stage, and it makes it easier to determine the proper contour spacing. You will find that if you already have the 60 and 70 degree contours, the 65 degree contour will be a piece of cake.

8. *Visualize the field.* Think of the contours you draw as contours on a topographic map, and visualize the resulting terrain. If you can do this successfully, you will avoid impossible or pathological analyses.

9. *Erase.* As you add contours, you will discover that your first few contours probably aren't in the right place. Do not hesitate to erase parts of them and adjust their position. To continue the art analogy, the analysis is like a sculpture that only reveals its true shape after every square inch of rock has been refined.

10. *Add intermediate contours.* If there's a large gap between contours over a portion of the map, such that it's pretty much impossible to eyeball the gradient there, you need to add one or more intermediate contours. Intermediate contours are distinguished from primary contours by making them dashed rather than solid lines. The intermediate contour should be a value halfway between the primary contours, or halfway beyond if the intermediate contour is to be the last contour within a high or low. In exceptional circumstances, you can add intermediate contours between the intermediate contours, at  $\frac{1}{4}$  the primary contour interval.

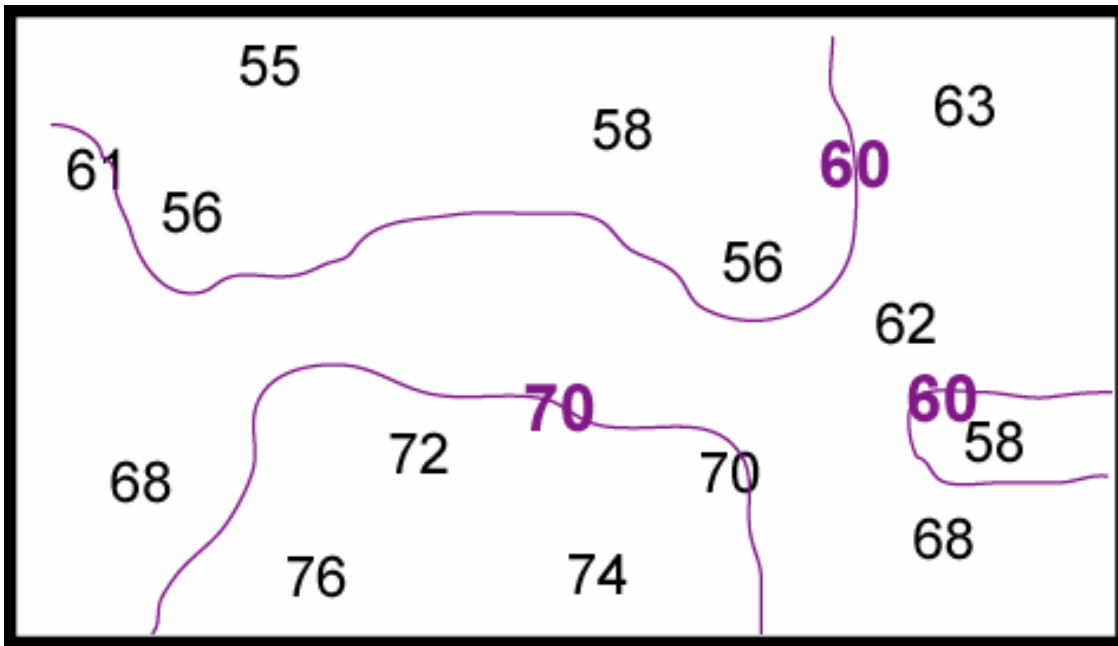
11. *Label.* In addition to adding contour labels (step 5 above), you must also label the extrema, that is, maxima and minima. (Pet peeve: please remember that the singular is maximum or minimum, and the plural is maxima or minima.) The conventional labels are H and L for highs and lows of pressure or height, W and K for extrema of temperature (they stand for the German words for warm and cold), and X and N for maXima and miNima of everything else. Beneath the extremum label, write the analyzed extreme value of the field and underline it. The extreme value

will generally be close to but not necessarily equal to the highest or lowest data point in the area.

12. *Reexamine the map.* Take one more look at the analysis to make sure the information is presented clearly and that there are no impossible or confusing contours.

#### 4.8 Common Errors

We conclude this chapter with examples of common errors and tips on how to avoid them.



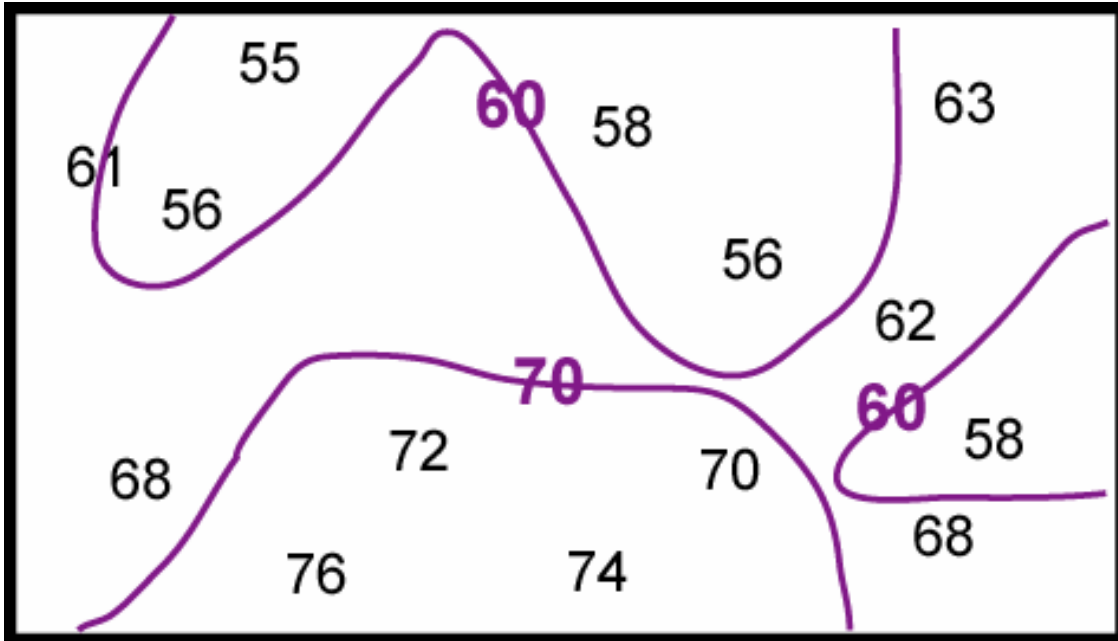
*Error #1: Unsmooth contours.*

In this analysis, the contour lines are jagged and don't give any sense of a coherent pattern. There is no attempt to depict the temperature gradients properly, and so the analysis adds nothing to the data that's already there.

An example is the hump in the middle of the 60 degree contour in the center of the map. There's no reason for the contour to extend farthest north there. If the analyst really believed that the temperature was a bit warm in the center of the map, that information should have been conveyed in the 70 degree contour too. Instead, the 70 degree contour shows no hint of this bump.

The 60 degree contour on the right seems to have been perfunctorily drawn to "pick off" the 58 degree observation, without any

consideration of what structure the below-60 air might have. A thin strip magically oriented normal to the edge of the map is an unlikely pattern.

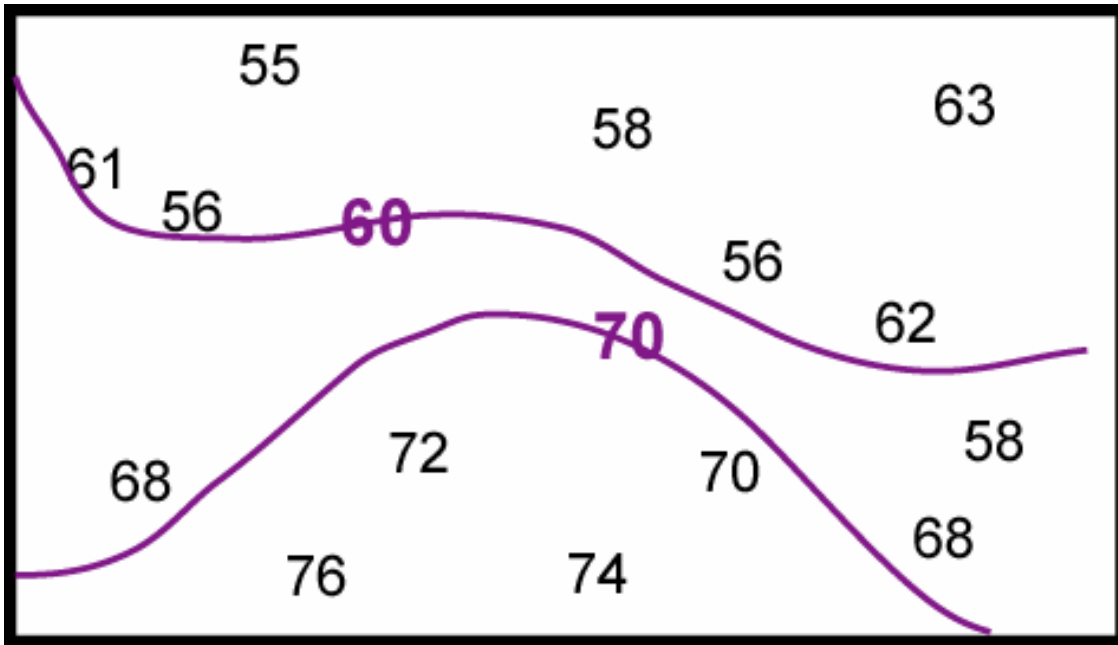


*Error #2: Unsmooth gradients*

The next map is the result of an analyst who has a very steady hand and can draw nice, smooth contours. Unfortunately, the analysis hasn't taken as much care with the spacing between contours. The contours get close together and far apart without any direct support in the underlying data. It's as though the analyst has what I call "data phobia": the contours seem to have been drawn as far as possible from the data. There's no physical reason that the real-atmosphere "contours" should know where the stations are and avoid them, so this analysis is wrong. Avoiding stations with contours almost always results in gradients which are erratic and way too strong.

*Error #3: Impossible contours*

The impossible analysis above has a lot going for it. The contours are nice and smooth, but still consistent with the data. They have the same general shape, so it's easy to perceive an overall temperature pattern. Over on the left edge, the analyst has not forced the 60 degree contour between the 61 and 56 observations. Those observations are so close together compared to the rest of the data, it's a good idea to do what was done here and treat that observation as a collective 58 or 58 with a hint that the temperature increases to the west.

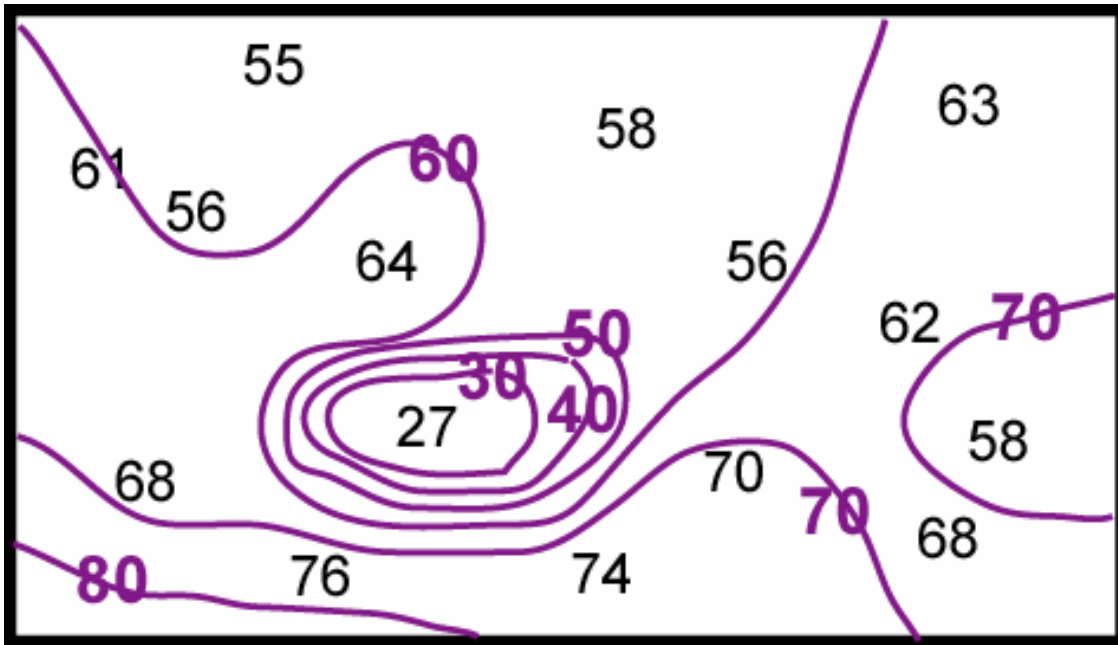


On the right hand side of the map is where the analyst has gotten into trouble. A novice analyst might see nothing wrong with this analysis: at first glance, the 60 degree isotherm fits nicely between temperatures in the 50s and temperatures in the 60s. But look more closely: as you follow the contour across the map from left to right, part of the time cooler temperatures are on its left, and part of the time they are on its right. This is impossible.

Another indication of trouble is that a few station pairs, such as the 56 and 62 on the right-hand side, ought to have a 60 degree contour running between them but don't. Both these problems are caused by the analyst in effect forgetting which way is "up": which side of the contour has cooler temperatures, and which side has warmer. They can't switch in the middle. The previous two analysis, while they had their problems, at least were possible.

#### *Error #4: Gullibility*

This analysis might be a good interpretation of the data, if the data were all correct. But one data point is clearly an outlier. It turns out that the 27 is a typographical error from the 72 that appeared on the other maps. The analyst, though, has believed the 27, even though it doesn't make any sense given the surrounding data. Data or observations which the analysis believes are erroneous should be marked through with an "X" on the analysis so that it is clear that the analyst has considered and disregarded the data.



Another difficult matter is the 80 degree contour along the southern edge of the map. There's no data to directly support the temperature being greater than 80 degrees there, but it's sort of consistent with the surrounding temperature gradient. Contours near the edge of the map are a judgment call. If you have a good, justifiable reason for extrapolating a contour to the edge of the map or putting a new one there, go ahead. But extending a contour just to fill up the map is not a sufficiently good reason. Better a blank section than a completely wrong section.

#### 4.9 Conclusion

Learning to analyze well takes practice. Fortunately, becoming a good analyst is not merely an end in itself. To analyze well, you have to learn to understand data, understand how data fits together, and understand how the atmosphere works. This is best done by going directly to the data and looking at it. Looking at lots of it. In learning to draw the atmosphere, you'll learn to see the atmosphere in all its complexity and interrelationships.

#### Questions

1. Create an imaginary set of observations, then create five separate analyses, each of which is an example of errors 1, 2, 3, 5, and 6, respectively, from Section 4.2.

2. Take a segment of a topographic map and extract “observations” of height at random locations. Stop when you think you have enough observations to show the basic topographic pattern. Exchange your observations with a partner and then try analyzing them to see how much of the real topography you can infer from the observations. Finally, assess your analysis. To the extent that your analysis does not agree with the real topography, does the fault lie with the limited number of observations or with the analyst?

3. On a contour map, identify the location with the strongest gradient. Estimate the magnitude and direction of the gradient there.

4. On a contour map, identify all locations where the gradient is exactly zero, based on the analysis alone.

5. Take an existing analysis. Draw a horizontal line through it. Construct a graph of the analyzed field as a function of distance along the line. Your distance units should correspond to those of the map, and your graph should agree with the location of every contour line as it crosses your horizontal line. Discuss whether the information in the analysis is sufficient to enable you to draw a fairly precise graph.