MEA 443 Synoptic Weather Analysis and Forecasting
Fall 2009, Lackmann
A General Approach to Weather Forecasting

This document includes information on several aspects of weather forecasting, beginning with general philosophy and ending with specific tips for forecasting different meteorological parameters.

Outline

I. Philosophical Considerations

A. The National Weather Service NDFD and the Human Element in Weather Forecasting

The manner in which weather forecasts are made by the National Weather Service (NWS) took a radical change in September, 2003, when the National Digital Forecast Database (NDFD) system was officially implemented. You may have read the article by C. Mass of the University of Washington expressing some concerns with this new forecasting methodology. Although many of these concerns have been or are being addressed, Professor Mass and many others note that the future role of humans in weather forecasting will be very different from that in the past.

If humans are to remain a viable element in the forecast process, they must do one of a number of things to prove that their presence is worthwhile. One such item is “adding value” to numerical forecast output. In order to accomplish this, forecasters must be able to distinguish situations in which they CAN add value from those in which they cannot. If the model forecast is turning out to be extremely accurate, then it would be a waste of time for humans to try and improve upon it. However in other situations, the model forecasts are not reliable. How can forecasters recognize and anticipate such situations? This requires that the forecasters ***know how the models work, and understand the limitations in NWP modeling.***

Other human elements could include improved communication of NWP output to emergency managers and decision makers, exclusive focus on the very short-term forecast, and communication of uncertainty to users. The issue of humans in the forecast process is currently being debated, and you should know that there are some who feel that there is no future for humans in weather forecasting. In fact, I know several NWS employees who feel that NDFD is the first step toward automating the forecast process. Personally, I am of the opinion that humans will remain an important component of the forecast process for at least another 10-20 years, but eventually the models will be sufficiently accurate that humans will be able to add little value in terms of deterministic forecast accuracy. Thus, it would serve future forecasters well to diversify skills and stay abreast of changes in the science of weather forecasting.

In general, there is no question that numerical weather prediction (NWP) models have improved our ability to accurately predict the weather. Several published studies demonstrate that the average errors in various forecast parameters have decreased with time, and that forecasts demonstrate statistical skill out to longer lead times than ever before, in large part due to improvements in the models. However, as mentioned above, it is my opinion that we are still 10-20 years away from the point where the human element in weather forecasting is unnecessary. A skilled human forecaster can still consistently outperform even the best numerical forecast model when it comes to specific parameters at a specific location (e.g., the high temperature at RDU airport tomorrow), especially in high-impact weather situations. There are several specific ways in which humans add value beyond what the NWP models alone can provide:

1.) Humans can logically anticipate, based on meteorological understanding of atmospheric processes, how given weather conditions will evolve with time.
2.) Humans can anticipate biases (over many forecasts or situations) in numerical models, and apply "corrections" for systematic errors.
3.) Experienced human forecasters can apply observations to evaluate short-term model forecasts, and recognize when the models are "going wrong". Through the combination of conceptual models, observations, and meteorological understanding, humans can recognize unrealistic model output when they see it, and subjectively correct the forecast.
4.) Humans can assimilate observational data, conceptual models of atmospheric systems, and numerical forecast output and generate a verbal forecast that describes the "weather" that a given location will experience.
5.) Humans are able to interpret observational data to formulate accurate short-term forecasts of severe local storms more effectively than automated techniques. Our "on-the-fly" pattern-recognition skills have yet to be reproduced by computers.

Finally, I should represent a viewpoint held my many in our field: over-reliance on NWP models can lead to "meteorological cancer", meaning that the forecaster or researcher treats the model as a "black box" and stops thinking about physical processes in the real atmosphere. We will take measures to protect ourselves from this phenomenon yet we will utilize model output as one element in our forecast process.

For an interesting discussion on this, see the recent article by Lance Bosart in the journal *Weather and Forecasting* (June 2003 issue).

B. The Attributes of a Good Forecaster

See http://www.flame.org/~cdoswell/forecasting/Forecaster_Qualities.html for an extended discussion by Dr. Chuck Doswell on this topic. The following is an excerpt from this web page.

Traits of good forecasters:

Decisiveness: A forecaster has to be able to make decisions, often in the face of inadequate information, and within the deadlines that typically are imposed on him/her.

Deals well with pressure: The responsibility of forecasting, perhaps in situations that literally involve people's lives and property, under the constraint that those decisions have to be timely to be of value creates considerable stress on the responsible forecaster. Decisions have to be made under these circumstances that will have serious consequences.

Visualization/conceptualization skills: Meteorological data are inherently 4-dimensional. They evolve with time in 3 space dimensions. A good forecaster must be able to visualize this 4-d structure to be able to grasp the existing relationships and to be able to anticipate the evolution of that structure.

Passionate for meteorology: Every good forecaster shares a passion for the job. This means that the forecaster is excited about the weather and stimulated by the challenge of forecasting.

Continuous learner: The passion for the subject necessitates a career-long commitment to continuous learning about the atmosphere. Every experience is a learning experience, and there is no avenue of learning that a good forecaster will willingly exclude in trying to become a better forecaster.

People skills: A successful forecaster must be able interact with other people successfully. This means that s/he will be a leader when called upon to do so, as well as a follower when the situation requires it. S/he must deal effectively not only with other forecasters well, but also with the variety of users that are the customers for his/her forecast products.

Organized/multitasking: In the complex, volatile world that constitutes the forecaster's environment, the successful forecaster must be able to carry out multiple tasks simultaneously. This means that prioritizing the multiplicity of tasks is needed. It takes considerable organizational skills to be able to handle the complexities of real-world forecasting.

Able to deal with failure: Given the reality of weather forecasting, failure is inevitable.. The successful forecaster must avoid the extreme reactions to the inevitable forecast failures: (a) giving up and becoming unconcerned about forecast failures, or (b) letting the frustrations and criticisms associated with forecast failures become disheartening. ***A good forecaster accepts failure but is never satisfied with it.***

Situational awareness: A successful forecaster never loses situational awareness. Even when the weather is fair and the situation is apparently boring, the successful forecaster remains aware and therefore is less vulnerable to surprise weather events.

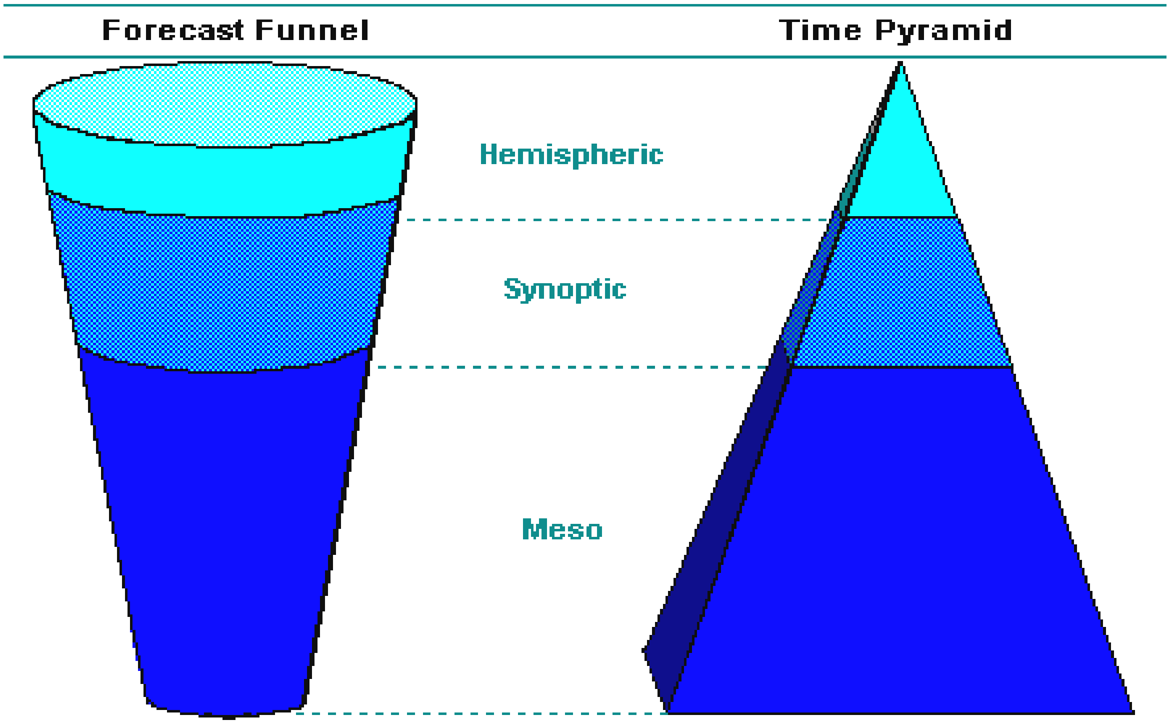
Communication skills: The successful forecaster is an effective communicator, to other forecasters and to forecast users, in terms of verbal, graphical, and textual communications tools.

Flexibility: A good forecaster is able to adapt effectively to constantly changing situations,. Although experience can suggest ways to deal with particular situations, every weather situation is unique and good forecasters can cope with unanticipated changes and still get the job done effectively.

Physical capability to do shift work: Not everyone is able to adapt well to the shiftwork that is typical of most forecaster positions. Only those who can do so without substantial impairment of their general abilities will ever become successful forecasters.

C. The Snellman Funnel Approach to Forecasting

One of the great forecasters of all time was the late Len Snellman, who devised a systematic approach to organizing forecast information by scale. This approach has become known as the "Snellman Funnel", and can be summarized by the diagram below:



1. Hemispheric Questions

When beginning a forecast shift, it is imperative to set the stage by examining the long wave pattern and asking:

What is the hemispheric pattern and what effect will it have on my forecast?

In other words, what is my hemispheric scale *problem of the day*?
In order to determine the above, one should ask

- What is the pattern of the westerlies?
- How is the pattern evolving?

2. Synoptic Questions

The important synoptic level questions to ask are probably many of the same ones you find yourself asking each time you work a shift. The most important question to ask in making a good forecast is:

What is the problem of the day?
In order to answer this question at the synoptic level, other questions must be asked:

- What and where are the weather-producing features?
- How well do the numerical models represent these features?
- How are they going to evolve?

3. Mesoscale Questions

The primary question at the mesoscale level is:

How does the mesoscale affect my problem of the day?

In order to determine if precipitation is in the local forecast, the forecaster must ask two questions:

- What is the direction and magnitude of the vertical motion?
- Is the local airmass going to be wet or dry?

Finally, it is important to fill in the details of the forecast by asking:

How extreme or benign will the weather in my forecast area be?

D. Basic Forecasting Strategies

1.) ***Persistence Forecast***

Perhaps the simplest forecasting strategy is a prediction that future conditions will be identical to present conditions. This strategy can be applied on seasonal as well as short-term time scales, but is generally not very accurate and should be used with caution. In general, persistence is less accurate with increasing forecast lead time. The following is an example:

Your forecast area is under the influence of a summertime maritime tropical air mass with weak gradients of temperature and moisture in the surrounding regions. The jet stream is well removed from the area, and you do not expect any significant change in air mass properties in the near future. The current dew-point temperature is 65°F, and haze and shallow fair-weather cumulus have dominated the past several days. At night, clear skies with patchy fog have been the rule, with a low temperature of 63°F each of the past two nights. Even the best statistical (MOS) guidance will have a hard time beating a persistence forecast in this situation; a forecast minimum temperature of 63°F should be excellent. The following day's high temperature, as well as fog and cloud cover forecasts could also be determined by this method.

2.) ***Climatological Forecast***

Another simple forecast technique is to forecast climatological conditions for a given station and date. Like persistence, this method works best when storm tracks are far away and seasonal weather prevails. For example:

In Los Angeles during the month of July, it rains roughly one out of 90 days. A precipitation forecast of no rain (based on climatology) would be correct about 99% of the time. Summertime in central Florida is characterized by hot, humid weather with afternoon showers and thundershowers set off by convergence of sea-breeze boundaries. A general forecast of hot and humid with afternoon and early evening thunderstorms would be correct much of the time.

3.) ***Analog Forecast***

Another approach is to identify a reasonably similar weather pattern in the past and base the current forecast on the sequence of events that occurred at that time. This strategy is of limited use because it is difficult to find past events that are sufficiently similar for many situations; no two weather patterns are exactly alike! Also, unless computer algorithms are used, it is time consuming to search past databases for similar examples.

4.) *Consensus Forecast*

Due to statistical behavior, it is often true that the average of many different forecasts is superior to any of the individual forecasts. This is the philosophy behind the NCEP "ensemble" forecasting, which we will discuss in more detail soon. Individual forecasters can also practice this strategy by averaging together different MOS, NWS, and other forecast sources. A new technique, pioneered by researchers at Florida State, is the so-called "superensemble". In this technique, past performance is weighted in to the consensus process. Rather than a linear average of the different component forecasts, the consensus forecast is computed from a *weighted* average of input forecasts.

5.) *Synoptic-Dynamic-Numerical Forecast*

The previously mentioned techniques are seldom used in isolation. Actually, modern forecasters incorporate elements from all of these areas into their forecasts, in addition to synoptic interpretation of the meteorological situation, and guidance from numerical weather prediction models. This is the technique that we will strive to perfect in this course. Remain cognizant of techniques 1-4, as each offers something unique.

II. A Basic Forecast Process

In this section I will outline a more specific forecast process developed within the context of the Snellman funnel and other arguments outlined above.

A.) Observations: Past and Current Weather

The first step in the forecast process involves examination of the recent past and current state of the atmosphere. *The importance of observations in the forecast process cannot be overemphasized.* If a forecaster simply jumps to the numerical forecast model output without regard to observations or recent history, it is difficult for them to assess the quality of the forecast because they lack context. If a forecaster undertakes a careful examination of the current weather, he or she can make a much more effective judgment regarding the quality of a computer forecast.

The following is a suggested "checklist" with which to start your forecast process. There is no single "correct" forecast procedure- you will need to experiment and come up with one that works best for you; also, the elements are situation-dependent.

1.) When forecasting for a specific location, you should always collect some background information. What is the climatological average high and low temperature? What are the records? What about precipitation? Most of this information can be obtained via the web. Also examine recent conditions, for example, what was the high temperature on the previous day? What has changed between yesterday and today?

After the background information is obtained, a common technique is to apply the "Snellman funnel" as discussed in section I.

2.) Examine the hemispheric 500-mb geopotential height (hereafter simply “height”) and sea-level pressure for the past day or two. Do you anticipate any weather disturbances approaching the forecast area? If so, is the system's intensity changing with time? You should make sure to examine the most recent analysis possible, and always remember to check the dates carefully! Zoom in on the area of interest and reduce contour intervals after the initial large-scale inspection.

3.) View the hemispheric GOES IR or VIS satellite loop. Relate cloud patterns to any weather systems you noticed in 1). If you cannot do this easily, consider what other mechanisms may be leading to the rising air needed for clouds and precipitation. Examples include orographic lifting, instability, upper jet streaks that were not visible on the 500-mb map, and local circulations near coastlines or lakes. Try to distinguish cloud patterns associated with cyclones and fronts from those due to other phenomena. For example, distinguish deep, precipitating clouds from low stratus.

4.) Extend your analysis to the national NEXRAD radar loop for the past few hours. If you are making a short-term forecast, you may be able to extrapolate the movement of a precipitation feature to pinpoint the time of arrival for precipitation in your forecast area.

5.) Upper-air data and raw surface observations can be very useful to consider. If convection is a forecast concern, then it is wise to examine several soundings from the area of interest, along with high-resolution radar and satellite data, and surface reports. The altitude of temperature inversions, cloud layers, and vertical wind profile are all important to note.

6.) Stop and think about how what you've just seen may affect your forecast. For example, if your forecast includes an overnight low temperature for that night, and a thick cloud shield is moving in, it would lead to a warmer value than would otherwise be anticipated. If the clouds are expected to persist, it could have a negative impact on the following day's maximum temperature. Likewise, think about how precipitation can affect temperatures.

7.) Now, consider local, smaller-scale influences that might modify conditions around your specific forecast site. Some examples include up- or down-slope wind flow, land-sea breezes, or urban heat island effects.

At the end of this part, you should have some idea of what the main “forecast problem of the day” is, for example, which weather system or systems are going to be affecting your forecast area, and what the cloud and precipitation patterns will be like around your forecast site. Try to utilize “conceptual models” of weather systems and envision the type of day it will be, and how the forecast will unfold. **Write down a preliminary verbal forecast, including temperature and precipitation data, before examination of model output.**

B. Model output and forecast conditions

It is dangerous to become overly reliant on computer model output for your forecasts. However, models are here to stay, and we will be spending considerable time later in the semester learning the details of each of the operational models. The most important thing to keep in mind at this point is that the models are only there to help guide your forecast; they should not be trusted without justification! It takes courage and strong knowledge of atmospheric processes to go against model forecasts, especially when all the models agree, but sometimes it is necessary (for example, this was the case on 24 January 2000).

1.) Comparison of recent model forecasts with observations.

There are several things forecasters can do to increase the chances of picking the "right" model. Verify previous runs of the forecast models. Determine how each one performed, which was best, which were wrong and why (if possible). How can we do this? Overlay model analyses on old forecasts (sea-level pressure and 500 mb height, for example). Overlay model forecasts on raw surface observations, or satellite and radar imagery. Identify errors, and think about why they might have occurred. Often in these situations, if a given model is handling a particular weather system better than the others, it is best to stick with that model!

2.) Evaluation of the latest short term model forecasts and analyses using observations.

You have several choices of models to use as guidance in your forecast. A brief listing of these models is provided in the following pages, but for now we will first discuss how to use them in general terms.

Examine the latest model forecasts (from 12 UTC this morning) and see how they are shaping up so far. The 6-hour forecasts from these models were valid at 18 UTC (2:00 p.m. daylight time, 1:00 p.m. standard time). Overlay the 18Z-satellite image, model 6-hour forecasts, and surface observations to determine if the strength and location of key features is being handled correctly by each model in the short-term forecast. For example, if a cyclone is forecasted to move across the U.S., see how well the short-term forecast of central pressure compares to raw surface observations. Then, check the model precipitation forecast against the 18Z radar mosaic. Note differences between forecast and observation, and try to determine the degree to which the models have a handle on things!

3.) Examination of model output

The previous exercises should help you assign various levels of confidence to various models. Often, the Eta model will be the model of choice. It is a good idea to limit yourself to a specific set of forecast graphics, otherwise you will be looking at data all day! This set can be situation-specific. For example, you will want to consider stability information more carefully in a potentially convective situation relative to others. A suggested set of graphics might include

- a.) sea-level pressure with surface potential temperature superimposed,
- b.) sea-level pressure with 6-hourly precipitation superimposed,
- c.) sea-level pressure with 500-mb height superimposed,
- d.) 500-mb height with vorticity superimposed,
- e.) 850-mb height with temperature superimposed,
- f.) Q-vector diagnostics,
- g.) 700-mb height with mixing ratio or other humidity variables superimposed,
- h.) 250-mb heights with isotachs superimposed,
- i.) CAPE, CIN, and other stability parameters,
- j.) Model forecast soundings for specific locations
- k.) Finally, check the model output statistics (MOS) and compare the values to your forecast. If there are major discrepancies try to determine why.

Now, finalize your forecast. Think carefully about the time window you are forecasting for, and what might happen within that time frame. Enter your forecast in the WxChallenge web page.

4.) The operational models

Below is a listing of the current operational models and a few brief facts about each one. We will go into more detail on this later in the semester. Forecast output from all of the following can be obtained via GARP or links on the MEA 443 web page.

i.) The Global Forecast System (GFS) model runs on a global domain; note that it used to be called the Aviation (AVN) model, and also the Medium-Range Forecast (MRF) model, but they have changed the name to GFS now. The GFS is run out to 15 days 4 times per day. This is a state-of-the-art global model that has fairly coarse resolution (effectively about 40-km grid spacing). The resolution is degraded after 5 days to save computer time. This model is quite reliable; for example it often does very well with cutoff low pressure in the southwestern U.S. The GFS is a "spectral" model, meaning that it integrates the governing equations using different techniques than "grid point" models. More on this later. Note that we received the output from these (and other) models on several different grids, not all of which are global. But, these different outputs are all coming from the same model runs!

ii.) The North American Mesoscale (NAM) model is a form of the Weather Research and Forecasting (WRF) model, also known as the nonhydrostatic mesoscale model (NMM). This model has the best physics, in that it accounts for several important physical processes that the other models do not account for. The NAM has the highest resolution of the operational models, with a current grid spacing of 12 km with 60 vertical levels. The highest resolution grids we receive, however, are the 20-km grid spacing "215" grid. It is the "state-of-the-art" model at this time, the best NCEP currently has to offer. We get three version of the NAM output, the "211 grid", which is fairly coarse (80 km), the "212 grid", which has 40 km grid spacing, and the "215 grid", which only includes surface parameters but has 20 km grid spacing. The NAM is run four times a day, and is now run out to 84 hours (3.5 days), but we do not receive all the output.

iii.) The Rapid-Update Cycle model (RUC)- this model is primarily used for short-term severe weather forecasting, and is only run out 12 hours at most. However, it is run 24 times a day! It has excellent physics, but we won't use it much due to the limited 12-hr window. This model produces an analysis every hour, which is very useful for monitoring the quality of other model runs.

iv.) The Navy NOGAPS model- also a global spectral model with rather coarse resolution. Excellent for oceanic regions. We now receive these grids via the LDM (see GARP).

v.) The Canadian GEM model- also a global spectral model, with effectively 90-km grid spacing and excellent physics and numerics. We also receive this model via the LDM.

vi.) The UKMET model- from the United Kingdom met office- also global with intermediate resolution, see the output in GARP.

vii.) The European Center for Medium-Range Weather Forecasting Model (ECMWF)- this is probably the best model in the world, especially for extended range forecasting. Also a global spectral model, and also available in GARP.

viii.) Ensembles. This is not actually a model, but a modeling strategy. An ensemble forecast involves making multiple model runs for the same forecast period, but with slight differences introduced into the initial conditions or model physics. It has been demonstrated that the *ensemble mean* (the average of all of these multiple runs) is a more skillful forecast than any of the individual members of the ensemble. Also, the degree of spread between the ensemble members is a measure of predictability—if the members all provide completely different solutions for the 72-hour forecast, we should have little confidence in the extended forecasts for that particular situation. Currently, ensembles are available for a variety of models, including the GFS, Canadian GEM, ECMWF and others. A new technique, dubbed the "super-ensemble" by developers at FSU, is essentially a weighted ensemble mean that provides outstanding forecast skill and holds great promise for the future.

See http://www.cdc.noaa.gov/map/images/ens/ens.html for these forecasts, or follow the link from the MEA 443 class web page.

III. Forecasting Specific Parameters

A. Temperature:

One must consider ***cloud cover***, ***precipitation,*** time of day, ***thickness, model-forecasted boundary-layer temperatures, temperature advection, vertical air motion (e.g., downslope vs. upslope flow)*** the relative location of high and low pressure systems, and climatology in their temperature forecast.

a.) Be aware of recent past and current conditions!
b.) Climatological conditions are due to a number of factors:
- i.) latitude and geographical location
- ii.) Surface character, snow cover, vegetation, & soil moisture are important!
- iii.) Topography and associated adiabatic warming/cooling
- iv.) Urbanization - urban heat island can be significant.

c.) *Maximum Temperature:*
- i.) With clear skies & weak thermal advection, and sufficient buoyant or mechanical mixing, bring the temperature down dry adiabatically from the top of the mixed layer (winter ~900 mb, summer ~800 mb) to the *surface* pressure to get a good estimate of the high temperature. With high- or mid-level clouds, subtract 3-6°F. During peak solar heating, especially with a dry surface, add 1-2°F degrees for superadiabatic conditions near the surface.
- ii.) Wind direction and speed are critical. With nearby topography, wind direction dictates adiabatic modifications. Strong winds favor a deeper mixed layer, and warming. Light winds in winter mean reduced mixing and cool weather, while light winds in summer can result in superadiabatic conditions and warming. Nocturnal inversions may not mix out with light winds or clouds.
- iii.) Precipitation - due to evaporative cooling in conjunction with cloud cover, precipitation can significantly reduce the maximum temperature (and affect minimum temperature via the “wet-bulb effect”).

d.) *Minimum Temperature:*
- i.) Cloud cover is a primary consideration. Downward IR flux can prevent the formation of a nocturnal inversion, and keep minimum temperatures much higher than they would otherwise be.
- ii.) Given no air mass change and clear, calm conditions, the afternoon dew point is often a good lower bound on the minimum temperature, especially when the dew point is above 50°F. With the formation of dew or frost, the minimum temperature can fall below the dew point value, but latent heat release will offset the cooling to some extent.
- iii.) Wind speed: In general, the stronger the wind the warmer the low temperature as mixing is enhanced. The exception would be with strong cold-air advection.

iv.) *Wet-bulb effect:* With the onset of precipitation and little or no temperature advection, the wet-bulb temperature is a good estimate of what the temperature will be once precipitation begins.

v.) *Local effects:* Pay attention to the orientation between the synoptic wind direction and local topography. Drainage flows can cause cool air to collect in some valley stations, and downslope warming/upslope cooling can be important. Urban heat island can warm local temperatures 3-8°F.

B. Precipitation:

a.) Probability of precipitation (POP):

Know forcing mechanisms for ascent and be able to identify them.
Determine if these mechanism are currently causing precipitation.
Determine if sufficient moisture will be present to generate precipitation in the forecast area. Consider

i.) Relative humidity and dew point temperatures
ii.) Proximity to moisture sources (e.g., Gulf of Mexico)
iii.) Potential for water vapor transport (WV imagery, model output)
iv.) Precipitable water
v.) Static stability (for assessing convective potential)

Precipitable water correlates well with amount, given ascent.
Mean layer relative humidity correlates with probability.
Carefully compare model output of QPF before using it as guidance in a forecast.

b.) Quantitative precipitation forecast (QPF): The same general considerations as in a.) apply, but pay special attention to iii.) through v.). Also, consider the speed of movement of forcing mechanisms. A fast-moving cold front versus a slow-moving stationary front with frontal waves and convection will produce dramatically different results!

Later on in the semester, we will spend time talking about additional forecasting techniques, including winter weather.

C. Forecasting wind speed and direction

The challenge of predicting wind speed and direction is exacerbated by local effects, and winds are sensitive to local effects on scales from the site of the instrument itself to local orography. Standard ASOS wind measurements include the sustained wind, which is a 2-minute average that is constructed from the mean of 24 5-second wind averages, and the 5-second wind gust. Currently, ASOS winds are measured by a cup anemometer at the 10-m level, although at some sites the sensor is located slightly below this level.

In predicting the sustained wind speed, one must consider many physical processes, including:

1.) What is the overall pressure gradient in the region? The geostrophic wind speed will overestimate the winds, but can provide a good starting point for the maximum winds.

2.) To what extent will vertical mixing in the planetary boundary layer bring higher wind speeds to the surface? This requires consideration of stability and the depth of the mixed layer.

3.) Are there local orographic influences that could result in channeling or down-gradient accelerations, such as during a gap wind event?

4.) What are local surface characteristics? If there is an upstream fetch of water (lake or ocean), expect greater wind speeds.

5.) For rapidly changing synoptic conditions, isallobaric wind effects can be important.

6.) Will convective storms be in the vicinity? If organized convection occurs, it can produce very strong winds. The environmental moisture profile can factor in here, and if dry air is present in the vicinity, the possibility of strong outflow increases. This gets into the realm of mesoscale convective systems, and is beyond the scope of this course.