

Synoptic Meteorology I: Meteorological Data and an Introduction to Synoptic Analysis

For Further Reading

Chapter 12 of *Midlatitude Synoptic Meteorology* by G. Lackmann discusses principles of isoplething and meteorological data analysis. Chapter 2, Sections 3-2 and 3-3, and Appendix E of *Weather Analysis* by D. Djurić provide useful information regarding observations, synoptic analysis, and surface meteorological data encoding and decoding, respectively. Federal Meteorological Handbook No. 1 provides extensive information concerning how surface meteorological observations are obtained and encoded. Federal Meteorological Handbook No. 2 provides extensive information concerning the international-standard SYNOP surface observation encoding protocol. Federal Meteorological Handbook No. 3 provides extensive information concerning how upper air meteorological observations are obtained and encoded.

Types of Meteorological Observations

There exist three primary types of meteorological observations:

- **Visual**, or observations made by the eyes of human observers.
- **Direct**, or observations made by instruments located where the observation is taken.
- **Indirect**, or observations of atmospheric properties at one location made by an instrument situated at another location.

Indirect, or *remotely sensed*, observations can be further broken down into **actively** and **passively** sensed observations. Active sensing occurs when the observing instrument emits a signal (e.g., a radio wave or radiation) and derives meteorological information from the echo that it receives in return. Passive sensing occurs when the observing instrument does not send out a signal; instead, meteorological information is derived from an echo that the instrument receives from another emitter (e.g., the Earth).

Surface Observations

A number of surface, or near-surface, meteorological properties are routinely observed. The most important properties that are observed include:

- **Surface pressure.** Measured by barometers and then converted to *sea-level pressure* by adding the pressure of the air between the surface and sea level to the surface pressure.
- **Surface temperature.** Measured by thermometers located about 1.5-2 m above ground in white-painted shelters, with the shelter typically sited in an open, grass-covered field.
- **Wind speed and direction.** Measured by anemometers and wind vanes, respectively, located 10 m above ground, above most ground-based obstructions.

- **Moisture.** Dew point is measured by measuring changes in laser beam reflection off of a mirror that occur when the mirror is cooled to the dew point.
- **Precipitation.** Rain and the liquid equivalent of frozen precipitation are measured using a heated tipping bucket rain gauge. Snowfall is measured on white-painted snow boards.
- **Visibility.** Visibility is typically estimated using active remote sensing, though such estimates can be augmented by visual observation by human observers.
- **Cloud type, altitude, and coverage.** Cloud type and coverage are determined visually by human observers. The altitude of cloud bases is determined by active remote sensing.
- **Meteorological phenomena.** The presence of sensible weather, such as precipitation type, precipitation intensity, and the like, is assessed by human observers.

Other meteorological properties, such as pressure tendency and relative humidity, can be derived from one or more of the above properties. Most surface observations are collected by automated surface weather stations. The most common such station is known as ASOS, or Automated Surface Observing System. Other such stations include AWOS (Automated Weather Observing System) and AWSS (Automated Weather Sensor System). ASOS stations are typically better-calibrated, better-maintained, and more accurate than their AWOS and AWSS counterparts.

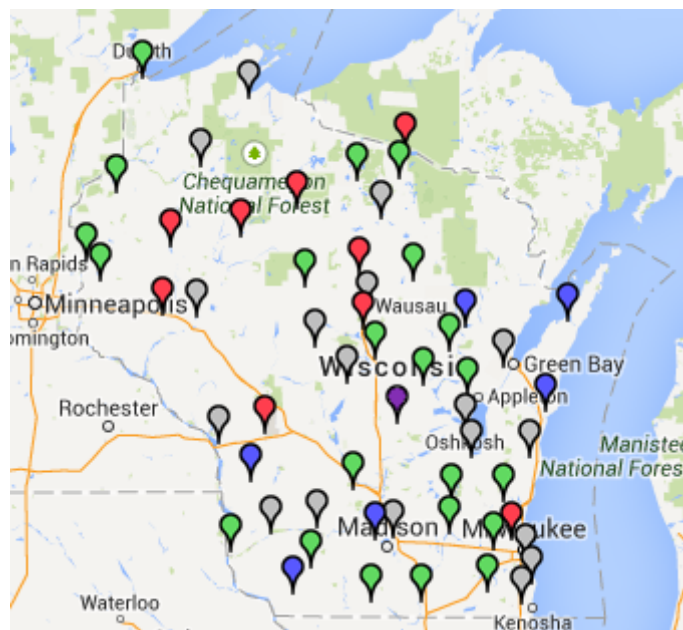


Figure 1. Locations of Federal Aviation Administration surface weather observation stations in Wisconsin, current as of summer 2014. The different colored pins denote differences in the instruments installed at each station, with grey pins denoting ASOS stations. Note the lesser density of stations in west-central and northern Wisconsin as compared to southern and eastern Wisconsin. Image obtained from the Federal Aviation Administration.

Surface observations are typically collected at regular intervals of as frequent as every 1-2 min. However, surface observations are only routinely transmitted every 1 h unless the local weather conditions are rapidly changing (e.g., a thunderstorm, cold frontal passage, or onset/termination of precipitation). In such cases, surface observations are transmitted as often as the weather conditions warrant.

Surface observations are collected over an irregularly spaced network of stations, with stations typically sited at airports. The average spacing between stations can and often does vary within a state, between states, and between countries. This spacing tends to be smaller in developed countries, particularly in the middle latitudes, and larger over water, near the poles, and in developing countries. Fig. 1 depicts the Federal Aviation Administration network of surface observing stations in Wisconsin.

Upper Air Observations

Similar to surface observations, a number of meteorological properties above the surface are routinely and directly observed. These observations are known as *upper air* observations, referring to their location above the surface. Most such observations are found within the troposphere, or below about 15 km above sea level, and are collected utilizing *radiosondes*, *rawinsondes*, *dropsondes*, or by aircraft utilizing an instrument package known as *ACARS*.

Of these, rawinsondes are the most commonly encountered observation platform. Rawinsondes are meteorological instrument packages tethered to balloons that measure meteorological properties such as pressure, temperature, relative humidity, and wind speed and direction. Other properties, such as geopotential height, can be derived from these fields. Rawinsondes are released from surface-based observing stations and relay upper air meteorological data back to the surface using radio transmitters.

Radiosondes are similar to rawinsondes, except lacking the ability to measure wind speed and direction. Dropsondes are also similar to rawinsondes, except they are released from airborne platforms, are attached to a parachute rather than a balloon, and fall to the ground rather than rise away from it. By contrast, ACARS are fixed to an aircraft and transmit data to the ground via satellite. They are particularly useful for measuring atmospheric properties over open waters.

Upper air data are reported on a set of mandatory (or standard) isobaric surfaces as well as at pressure levels where a significant change occurs in the observed temperature, relative humidity, or wind profiles. The mandatory isobaric surfaces on which upper air observations are reported are 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, and 10 hPa. Observations terminate at the altitude at which the balloon carrying the instrument package pops.

In contrast to surface observations, upper air observations are routinely taken only every 12 h at times coordinated across the globe, 0000 UTC and 1200 UTC, where UTC refers to *Universal*

multiple elevation angles above the horizon, typically between 0.5° and 19° . The functional viewable range of a Doppler radar is between 100 km and 200 km from the radar, and there are presently 155 Doppler radar sites located across the United States and its territories.

Precipitation intensity can be inferred by the amount of wave energy returned to the Doppler radar; more energy implies heavier precipitation. Precipitation location can be inferred by the amount of time it takes for the wave energy to be returned to the radar as well as from which direction it is returned to the radar. Precipitation type can be inferred utilizing what is known as *dual polarization* radar. Wind speed and direction (with respect to the radar) can be inferred using the Doppler effect, where the change in frequency of the radio waves sent out versus returned to the radar enables for these properties to be inferred.

Satellite imagers are passive remote sensors; they measure radiation energy emitted and/or reflected by the Earth and its atmosphere at specific wavelengths. This information can then be converted into usable meteorological information, particularly the presence, thickness, and altitude of clouds. There exist multiple wavelengths over which satellite imagers sense, with the three most prevalent being the *visible*, *infrared*, and *water vapor* (a special class of infrared) wavelengths. We will discuss each in more detail shortly.

There exist two types of satellites that are used for meteorological observation:

- **Geostationary.** These satellites are located approximately 36,000 km above the Earth's surface. They remain in a fixed location, above the Equator and at a specific longitude, and provide satellite imagery primarily over the tropics and middle latitudes. Imagery are available every 30 min to 3 h for any given location.
- **Polar-orbiting.** These satellites rotate around the Earth at altitudes of 700 to 1,000 km above the Earth's surface. A polar-orbiting satellite thus passes over a given location only twice per day. Polar-orbiting satellites provide imagery at all latitudes, often with a higher spatial resolution than geostationary satellites.

Satellites measure radiation emitted and/or reflected by the Earth and its atmosphere over specific wavelength bands. In the visible, this is between $0.52\text{--}0.72\ \mu\text{m}$. In the infrared, this is between $10.2\text{--}11.2\ \mu\text{m}$, or within what is known as the “atmospheric window.” Finally, in the water vapor portion of the infrared spectrum, this is between $6.47\text{--}7.02\ \mu\text{m}$.

Visible satellite imagery is derived from the amount of sunlight that is *reflected* by the Earth, whether by clouds or the Earth's surface, back to outer space. As a result, visible satellite imagery is only available during the local daytime hours. Visible satellite imagery is good for distinguishing the amount of water or ice present within a cloud. Whiter, brighter colors denote clouds with greater amounts of water or ice. Dark colors typically denote the Earth's surface.

Infrared satellite imagery is derived from the amount of radiation *emitted* by the Earth, whether by clouds or by the Earth's surface, to outer space within the atmospheric window. Through the Stefan-Boltzmann Law, the measured amount of emitted radiation can be used to estimate the temperature of the phenomenon that is emitting the radiation. Since temperature typically decreases with increasing height above sea level within the troposphere, this allows us to estimate cloud height at a given location. Colder temperatures correspond to higher cloud tops.

Together, visible and satellite imagery enable us to infer cloud type, as illustrated by Fig. 3.

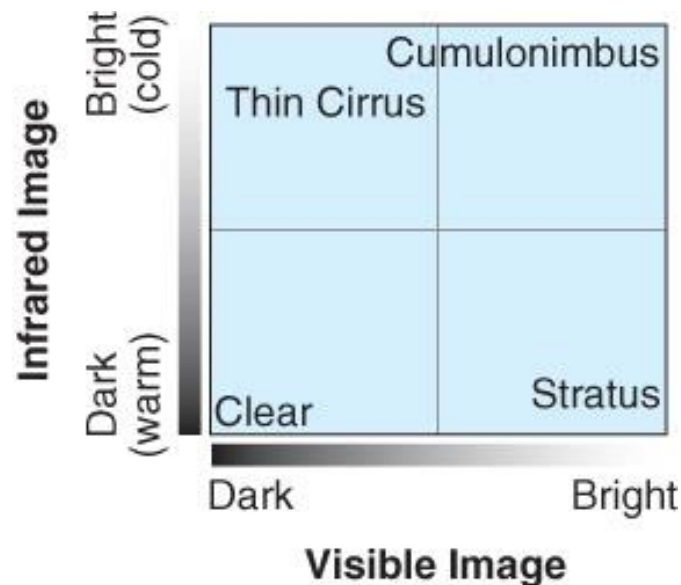


Figure 3. Illustration of cloud type inferences based upon a cloud's appearance in visible and infrared satellite imagery. Figure obtained from *Meteorology: Understanding the Atmosphere* (4th Ed.) by S. Ackerman and J. Knox, their Fig. 5-16.

A representative example in which this information can be applied to infer cloud types is provided in Fig. 4. The visible image indicates extensive broken clouds in the ArkLaTex region, where the longwave infrared image indicates warm cloud-top temperatures. These attributes allow us to infer that stratocumulus clouds dominate this area. Further east, the visible image indicates a contiguous bright-white region in south-central Mississippi collocated with reds and oranges (indicating cold cloud-top temperatures) on the longwave infrared image. These attributes allow us to infer that cumulonimbus clouds (or thunderstorms) dominate this area. Isolated regions of clear skies along the northern edge of each image in northern Arkansas and Tennessee appear as dark grey in both the visible and longwave infrared images. Finally, milkier white clouds in the visible image across eastern Alabama (and several other areas) collocated with greens and blues (indicating moderately cold cloud-top temperatures) indicate that cirrus clouds dominate this area.

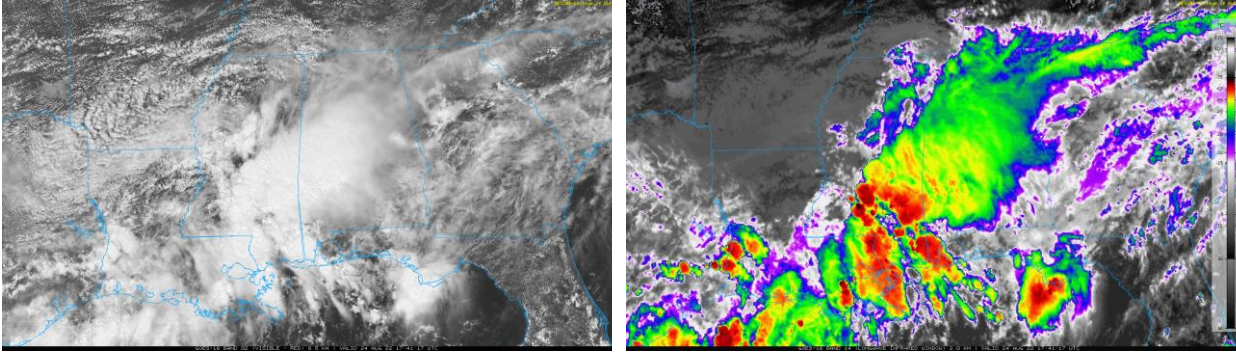


Figure 4. GOES-16 (left) visible and (right) longwave infrared satellite images on 24 August 2022 at 1741 UTC over the southeastern United States. Colors in the right panel correspond to brightness temperature, a measure of the cloud-top temperature. Images obtained from College of DuPage.

Water vapor satellite imagery is derived from the *emission* of radiation by water vapor molecules present within the middle to upper troposphere. It is obtained at wavelengths of roughly $6.47\text{ }\mu\text{m}$ to $7.02\text{ }\mu\text{m}$, as this is the wavelength band in which the peak emission of radiation by water vapor is found. Areas of clouds and greater moisture content, even if cloud-free, appear brighter in water vapor satellite imagery, whereas drier areas appear in darker colors. Water vapor satellite imagery is useful for diagnosing moist processes in the middle to upper troposphere that are important to cyclone formation and intensification.

These are not the only wavelength bands over which geostationary or polar-orbiting satellites sense radiation. For example, there are instruments on polar-orbiting satellites that sense at microwave wavelengths that can identify precipitation features beneath cloud canopies. Likewise, the recently launched GOES-16 and GOES-17 satellites (among other geostationary satellites) are capable of sensing over a wide set of wavelengths across the visible and infrared portions of the spectrum. In addition, information from one band can be combined with that from one or more other bands to obtain what are known as “difference” products, each of which have their own respective strengths. A series of quick guides corresponding to the sixteen primary wavelength bands on GOES-16/17 and several “difference” products is available from the [UW-Madison Cooperative Institute for Meteorological Satellite Studies](https://www.wisc.edu/meteorology/).

Representativeness of Observations

All instruments are associated with some amount of observational error, even if the instrument is in good working order. Typical magnitudes of observational error are 0.5 to 1 m s^{-1} for wind speed, 0.25°C for temperature, 3% for relative humidity, 0.5 hPa for pressure, and 5 m for geopotential height for both surface and upper air observations. Indirect observation instruments such as radars and satellites are also associated with observational error, the magnitudes of which vary between individual instruments. It should be noted that observational errors are typically small compared

to the magnitudes of the observed meteorological elements and, as a result, observational error typically does not compromise our ability to analyze and interpret data.

There exist situations, however, where one or more observations, whether taken at the surface or aloft, are not representative of the prevailing meteorological conditions at that location. Plausible reasons for why this might be the case for include:

- Improper siting of the observation instrument (e.g., a bank thermometer).
- The observation instrument has failed and/or has lost its proper calibration.
- The observation collected is correct but is representative of local rather than synoptic-scale meteorological conditions and variability.

We must take care to properly identify and discard observations that fit into the first or second of the above criteria. We must also take care to properly identify but not discard observations that fit into the third of the above criteria. How can we do this? We can do so by considering how observations at that station compare to those at surrounding stations at other times.

We can also do so by considering how observations at that station align with theory. In other words, based upon our knowledge of how the atmosphere works (e.g., force balances, structures of specific meteorological phenomena, local climatology, etc.), is the observation likely to be correct or in error? Over the course of this semester, we seek to develop your knowledge of meteorological theory so that you will be well-equipped to judge an observation's representativeness. When in doubt, however, we must always assume that the observation is correct; we cannot simply discount an observation that we don't like without good reasoning.

Surface Observations: The METAR Code

The United States standard means of encoding and reporting surface weather conditions at a given location and time is known as the *aviation routine weather report*, or *METAR*, code. Weather observations that you see on television, on weather charts, hear pilots mention while flying, and elsewhere are all derived by interpreting METAR code. Below, a generic example METAR observation is provided:

METAR KKKK DDGGggZ AUTO/COR dddffGggKT vvSM ww NNNhhh TT/DD Apppp
RMK (remarks)

Working from left to right, the METAR provides the following surface weather information:

- **METAR.** This identifies the text as a METAR observation.
- **KKKK.** This is replaced by a unique four-letter identifier that denotes the location of the observation. In the United States, the first letter is K. For example, the observation station at General Mitchell Airport here in Milwaukee is KMKE.

- **DDGGggZ**. This denotes the time of the observation. DD is replaced by the two-digit date of the month, while GGgg is replaced by the four-digit time. The Z denotes Zulu time, which is equivalent to UTC, and thus observations are not reported in local time.
- **AUTO/COR**. This denotes whether the observation is an automated (AUTO) or manually corrected (COR) observation.
- **dddffGggKT**. This indicates the wind direction (ddd, where 000 = from the north, 090 = from the east, 180 = from the south, and 270 = from the west), wind speed (ff), and, if present, wind gust (Ggg, where gg is the gust speed). The ending KT denotes that the wind and gust speed are in kt.
- **vvSM**. This indicates the current surface visibility (vv) in units of statute miles (SM). The maximum reported visibility is typically 10SM.
- **ww**. This denotes the sensible weather present at a given location, if any. There are a series of two-letter qualifiers for intensity, proximity, and/or description that are followed by one or more two-letter identifiers for current weather phenomena. Fig. 5 provides a full listing. If the phenomenon began and/or ended after the last observation, the identifiers may be followed by B##/E## groups to indicate the minute(s) of the hour at which the phenomena began or ended. For instance, a thunderstorm that began at :14 after the hour and ended at :31 after the hour would be encoded as TSB14E31. It is possible for multiple phenomena to be identified in a single report; e.g., RA BR indicates rain concurrent with fog.
- **NNNhhh**. This denotes cloud coverage (NNN, which could be CLR, FEW, SCT, BKN, or OVC depending upon coverage) and height (hhh, in hundreds of feet above the surface). Overcast skies 10,000 feet above the surface would be coded as OVC100. Generally, the maximum value of hhh will be 250 for a cloud deck at 25,000 feet above the surface. Note that the presence of an overcast cloud deck will obscure any clouds that may reside above it, such that any such clouds would not be reported in the METAR report.
- **TT/DD**. This indicates the two-digit surface temperature (TT) and dew point (DD), separated by a /, with both values in °C.
- **Apppp**. This indicates the current altimeter (A), or sea-level pressure, reading (pppp, in inches of mercury multiplied by 100). A sea-level pressure of 29.92" Hg would be encoded as A2992.
- **RMK (remarks)**. A series of remarks, whether automated or manual, plain-language or encoded, is often appended to the end of a METAR statement. The most common are as follows:
 - **A01/A02**. Denotes whether the observing station has a precipitation discriminator (A02) or not (A01).
 - **SLP####**. Indicates the sea-level pressure (SLP) reading in hPa multiplied by 10. For sea-level pressure less than 1000 hPa, the leading 9 is dropped; for sea-level pressure greater than or equal to 1000 hPa, the leading 10 is dropped. A sea-level pressure of 1013.2 hPa would be reported as SLP132.

- **Ttttdddd**. Denotes the surface temperature and dew point, both in °C, multiplied by 10. The first 't' and 'd' in each sequence are replaced by 0 if the reading is above 0°C and replaced by 1 if the reading is below 0°C. A temperature of 24.2°C and dew point of 18.1°C would be encoded as T02420181.
- **P#####/6#####**. Denotes the accumulated precipitation in the last hour (P#####) or in the last 3- or 6-h (6#####) in hundredths of inches.
- **1#####/2#####**. Indicates the maximum (1#####) and minimum (2#####) temperature over the last six hours in °C multiplied by 10. The first # of each is always zero if the temperature is positive and is always zero if the temperature is negative.
- **4#####**. Indicates the maximum (first four #) and minimum temperature (last four #) over the last 24 h in °C multiplied by ten. The first # of each is always zero if the temperature is positive and is always zero if the temperature is negative.
- **5#####**. Indicates the 3-h pressure tendency. The first # is the nature of the pressure change (right column of Fig. 8a, where the top row = 0, next row = 1, etc.) and the last three # is the pressure change in hPa multiplied by 10.

There exist many other remarks, and not every possible element of a METAR statement is listed above. Chapter 12 of the Federal Meteorological Handbook No. 1 provides full details regarding all possible elements of a METAR statement. Real-time METAR observations, including a list of possible stations, may be obtained from the National Center for Atmospheric Research's Real-Time Weather Data page at <http://weather.ral.ucar.edu/surface/>.

Table 12-2. Notations for Reporting Present Weather¹

QUALIFIER		WEATHER PHENOMENA		
INTENSITY OR PROXIMITY 1	DESCRIPTOR 2	PRECIPITATION 3	OBSCURATION 4	OTHER 5
- Light	MI Shallow	DZ Drizzle	BR Mist	PO Well-Developed Dust/Sand Whirls
Moderate ²	PR Partial	RA Rain	FG Fog	SQ Squalls
+ Heavy	BC Patches	SN Snow	FU Smoke	FC Funnel Cloud Tornado Waterspout ⁴
VC In the Vicinity ³	DR Low Drifting	SG Snow Grains	VA Volcanic Ash	SS Sandstorm
	BL Blowing	IC Ice Crystals	DU Widespread Dust	DS Duststorm
	SH Shower(s)	PL Ice Pellets	SA Sand	
	TS Thunderstorm	GR Hail	HZ Haze	
	FZ Freezing	GS Small Hail and/or Snow Pellets	PY Spray	
		UP Unknown Precipitation		

1. The weather groups shall be constructed by considering columns 1 to 5 in the table above in sequence, i.e., intensity, followed by description, followed by weather phenomena, e.g., heavy rain shower(s) is coded as +SHRA.
2. To denote moderate intensity no entry or symbol is used.
3. See paragraph 8.4.1.a (2), 8.5, and 8.5.1 for vicinity definitions.
4. Tornadoes and waterspouts shall be coded as +FC.

Figure 5. Allowable two-letter qualifiers and weather phenomena for the **ww** group in a METAR report. Figure obtained from the Federal Meteorological Handbook No. 1, Table 12-2.

Below, a sample METAR observation from Milwaukee (KMKE) is given. Following the example, the METAR observation is decoded.

KMKE 311552Z 03009KT 10SM FEW015 SCT180 23/18 A3006 RMK AO2 SLP175 T02330178

In this example, at Milwaukee (KMKE) on the 31st of the month at 1552 UTC (10:52 am CDT or 9:52 am CST), the wind is from just east of due north (030°) at 9 kt. The visibility is 10 statute miles. Few clouds are present at 1,500 ft above the surface, while scattered clouds are present 18,000 ft above the surface. The 2-m temperature is 23.3°C (73.94°F) and 2-m dew point temperature is 17.8°C (64.0°F). Sea-level pressure is 30.06" Hg, or 1017.5 hPa. The observing station has a precipitation discriminator.

Observation Depiction: The Station Model

To visualize the weather conditions over a given area, we construct synoptic charts containing information from multiple stations' worth of observations. This requires us to convey the decoded observations in a concise yet easily visualized format. The standard means by which this is done is through what is known as the *station model*. Generically speaking, the station model consists of a circle, drawn on the map at the location of the observation, with a variety of information arranged around it in specific locations.

The *surface station model* typically contains the same meteorological elements that appear in the METAR observation for that station, including cloud cover, temperature, dew point temperature, wind direction and speed, current weather, sea-level pressure, pressure tendency, 6-h precipitation, and low, middle, and high cloud types. Fig. 6 depicts the generic surface station model.

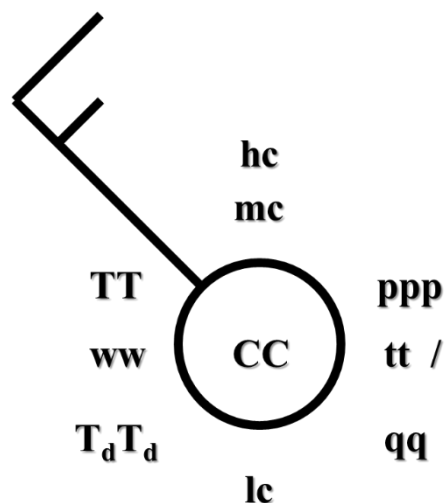


Figure 6. The surface station model. Please refer to the text for further details. Adapted from *Weather Analysis* by D. Djurić, their Fig. E-1.

Specific elements of the surface station model in Fig. 6 include:

- **CC.** Cloud cover, as represented by the degree to which the circle is filled, per Fig. 8a.
- **TT.** Temperature, in °F (United States) or °C (elsewhere).
- **ww.** Current weather conditions, as depicted by one of the symbols contained in Fig. 9.
- **T_dT_a.** Dew point temperature, in °F (United States) or °C (elsewhere).
- **ppp.** Sea-level pressure, in hPa, following the same convention as SLP in METAR code.
- **tt.** Three-hour sea-level pressure tendency, in tenths of hPa.
- **/.** Graphical indicator of 3-h sea-level pressure tendency. See Fig. 8a.
- **qq.** Six-hour accumulated precipitation, in inches.
- **Wind direction.** Represented by the line drawn out from the circle in the direction that the wind is coming from.
- **Wind speed.** Represented by the barbs or flags drawn out from the wind direction flag. One half-barb: 2.5 m s⁻¹ or 5 kt, one full barb: 5 m s⁻¹ or 10 kt, one flag: 25 m s⁻¹ or 50 kt.
- **lc, mc, hc.** Graphical indicators for low, middle, and high cloud cover. See Fig. 8b.

Not all of the above information will be plotted on a given surface station model plot. The most-commonly encountered elements are cloud cover, temperature, dew point, current weather, sea-level pressure, and wind direction and speed.

If we encode the Milwaukee METAR example above in surface station model format, it would appear as it does in Fig. 7.

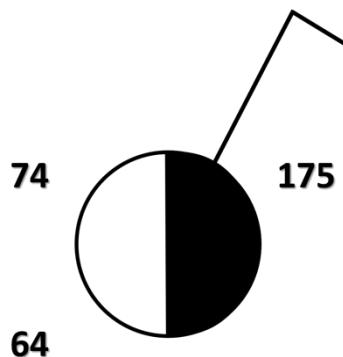






















Figure 7. Surface station model for the Milwaukee METAR observation from Page 11. Note that the wind is rounded to the nearest flag combination (9 kt → 10 kt). Not all elements of the station model appear here because this information is not present within the METAR report (cloud types, pressure tendency) or in observations (current weather, 6-h accumulated precipitation).

(a)

	
No clouds.	Rising, then falling, greater than, or the same as, 3 hours ago.
	
One-tenth or less, but not zero. One-eighth.	Rising, then steady, or rising, then rising more slowly. Now higher than 3 hours ago.
	
Two or three-tenths. Two-eighths.	Rising steadily, or unsteadily. Now higher than 3 hours ago.
	
Four-tenths. Three-eighths.	Falling or steady, then rising; or rising, then rising more quickly. Now higher than 3 hours ago.
	
Five-tenths. Four-eighths.	Steady, same as 3 hours ago.
	
Six-tenths. Five-eighths.	Falling, then rising. Now lower than, or the same as, 3 hours ago.
	
Seven or eight-tenths. Six-eighths.	Falling, then steady, or falling, then falling more slowly. Now lower than 3 hours ago.
	
Nine-tenths or more, but not ten-tenths. Seven-eighths.	Falling steadily, or unsteadily. Now lower than 3 hours ago.
	
Ten-tenths. Eight-eighths.	Steady, or rising, then falling; or falling, then falling more quickly. Now lower than 3 hours ago.
	
Sky obscured or cloud amount cannot be determined.	Not used for pressure tendency.

(b)




























	C_L	C_M	C_H
0	No Sc, St, Cu, or Cb clouds.	No Ac, As, or Ns clouds.	No Ci, Cs, or Cc clouds.
1	 Ragged Cu, other than bad weather, or Cu with little vertical development and seemingly flattened, or both.	 As, the greatest part of which is semi-transparent through which the sun or moon may be faintly seen as through ground glass.	 Filaments, strands or hooks of Ci, not increasing.
2	 Cu of considerable development, generally towering with or without other Cu or Sc; bases at same level.	 As, the greatest part of which is sufficiently dense to hide the sun or moon, or Ns.	 Dense Ci in patches or twisted sheaves, usually not increasing or Ci with towers resembling cumuliiform tufts.
3	 Cb with tops lacking clear-cut outlines, but distinctly not cirriform or anvill-shaped; Cu, Sc, or St may be present.	 Thin Ac, mostly semi-transparent; other than crenelated or in cumuliiform tufts; cloud elements change but slowly with bases at same level.	 Ci, often anvill-shaped, derived from or associated with Cb.
4	 Sc formed by spreading out of Cu; Cu may also be present.	 Patches of semi-transparent Ac that are at one or more levels; cloud elements are continuously changing.	 Ci, hook-shaped and/or filaments, spreading over the sky and generally becoming dense as a whole.
5	 So not formed by spreading out of Cu.	 Semi-transparent Ac in bands, or Ac in one more or less continuous layer gradually spreading over sky and usually thickening as a whole; the layer may be opaque or a double sheet.	 Ci, often in converging bands, and Cs or Cc alone but increasing and growing denser as a whole; the continuous veil not exceeding 45° above the horizon.
6	 St in a more or less continuous layer and/or ragged shreds, but no Fs of bad weather.	 Ac formed by the spreading out of Cu.	 Ci, often in converging bands, and Cs, or Cs alone, but increasing and growing denser as a whole; the continuous veil not exceeding 45° above the horizon but sky not totally covered.
7	 Fs and/or Fc of bad weather (scud) usually under As and Ns.	 Double-layered Ac or an opaque layer of Ac, not increasing over the sky; or Ac coexisting with As or Ns or with both.	 Vail of Cs completely covering the sky.
8	 Cu and Sc (not formed by spreading out of Cu); base of Cu at a different level than base of Sc.	 Ac with sprouts in the form of small towers or battlements, or Ac having the appearance of cumuliiform tufts.	 Cc not increasing and not completely covering the sky.
9	 Cb having a clearly fibrous (cirriform) top, often anvill-shaped, with or without Cu, Sc, St, or scud.	 Ac generally at several layers in a chaotic sky, dense Ci is usually present.	 Cc alone, or Cc accompanied by Ci and/or Cs, but Cc is the predominant cirriform cloud.

Figure 8. (a) Sky cover shading (left column) and 3-h pressure tendency (right column). (b) Low (left column), middle (center column), and high (right column) cloud type symbols. For sky cover shading, the second and third rows are equivalent to FEW, the fourth and fifth rows are equivalent to SCT, the sixth and seventh rows are equivalent to BKN, and the next-to-last row is equivalent to OVC. Figures obtained from *Weather Analysis* by D. Djurić, their Table E-1.

0		1		2		3		4		5		6		7		8		9	
00	Cloud development NOT observed or NOT observed during past hour.	01	Clouds generally dense, but NOT observed during past hour.	02	State of the sky on the whole unchanged during past hour.	03	Clouds generally forming or visibility reduced by smoke. Visibility reduced by haze.	04	Clouds generally forming or visibility reduced by smoke. Visibility reduced by haze.	05	Clouds generally forming or visibility reduced by smoke. Visibility reduced by haze.	06	Clouds generally forming or visibility reduced by smoke. Visibility reduced by haze.	07	Cloud or sand raised by wind, at time of observation.	08	Wind developed east (or west) within past hour.	09	Quasi-storm or sand storm within sight of or at station during past hour.
10	Light fog.	11	Patches of shallow fog at station, NOT deeper than 1000 ft. at time of observation.	12	More or less continuous fog at station, NOT deeper than 1000 ft. at time of observation.	13	Lightning visible, no thunder.	14	Precipitation within sight, reaching the ground.	15	Precipitation within sight, distant from station.	16	Precipitation within sight, reaching the ground, but NOT at station.	17	Thunder heard, but no precipitation at the station.	18	Squally within sight during past hour.	19	Funnel clouds within sight during past hour.
20	During (NOT freezing and NOT thawing) rain or snow, NOT falling as showers or drizzle, but NOT at time of observation.	21	Rain (NOT freezing and NOT thawing) falling as showers or drizzle, but NOT at time of observation.	22	Rain and snow (NOT falling as showers or drizzle) at time of observation.	23	Freezing drizzle or freezing rain (NOT falling as showers or drizzle) at time of observation.	24	Showers of rain during past hour, but NOT at time of observation.	25	Showers of snow, or of rain and snow, during past hour, but NOT at time of observation.	26	Showers of hail, or of rain and hail, during past hour, but NOT at time of observation.	27	Fog during past hour, but NOT at time of observation.	28	Thunderstorm (with or without hail) during past hour, but NOT at time of observation.	29	Thunderstorm (with or without hail) during past hour, but NOT at time of observation.
30	Slight or moderate dust storm or sand storm, has decreased during past hour.	31	Slight or moderate dust storm or sand storm, has increased during past hour.	32	Slight or moderate dust storm or sand storm, has become thinner during past hour.	33	Snow dust storm or sand storm, has decreased during past hour.	34	Snow dust storm or sand storm, has increased during past hour.	35	Snow dust storm or sand storm, has become thinner during past hour.	36	Slight or moderate drifting snow, generally high.	37	Slight or moderate drifting snow, generally high.	38	Heavy drifting snow, generally high.	39	Heavy drifting snow, generally high.
40	Fog at distance at time of observation, but NOT at station during past hour.	41	Fog in patches.	42	Fog, sky descends, has become thinner during past hour.	43	Fog, sky descends, has become thicker during past hour.	44	Fog, sky descends, has become thinner during past hour.	45	Fog, sky descends, has become thicker during past hour.	46	Fog, sky descends, has become thinner during past hour.	47	Fog, sky descends, has become thicker during past hour.	48	Fog, sky descends, has become thinner during past hour.	49	Fog, sky descends, has become thicker during past hour.
50	Intermittent drizzle (NOT freezing), slight at time of observation.	51	Continuous drizzle (NOT freezing), slight at time of observation.	52	Intermittent drizzle (NOT freezing), moderate at time of observation.	53	Continuous drizzle (NOT freezing), moderate at time of observation.	54	Intermittent drizzle (NOT freezing), light at time of observation.	55	Continuous drizzle (NOT freezing), light at time of observation.	56	Intermittent drizzle (NOT freezing), heavy at time of observation.	57	Continuous drizzle (NOT freezing), heavy at time of observation.	58	Intermittent drizzle (NOT freezing), very light at time of observation.	59	Continuous drizzle (NOT freezing), very light at time of observation.
60	Intermittent rain (NOT freezing), slight at time of observation.	61	Continuous rain (NOT freezing), slight at time of observation.	62	Intermittent rain (NOT freezing), moderate at time of observation.	63	Continuous rain (NOT freezing), moderate at time of observation.	64	Intermittent rain (NOT freezing), light at time of observation.	65	Continuous rain (NOT freezing), light at time of observation.	66	Intermittent rain (NOT freezing), heavy at time of observation.	67	Continuous rain (NOT freezing), heavy at time of observation.	68	Intermittent rain (NOT freezing), very light at time of observation.	69	Continuous rain (NOT freezing), very light at time of observation.
70	Intermittent (faint) snow or rain, slight at time of observation.	71	Continuous (faint) snow or rain, slight at time of observation.	72	Intermittent (faint) snow or rain, moderate at time of observation.	73	Continuous (faint) snow or rain, moderate at time of observation.	74	Intermittent (faint) snow or rain, light at time of observation.	75	Continuous (faint) snow or rain, light at time of observation.	76	Intermittent (faint) snow or rain, heavy at time of observation.	77	Continuous (faint) snow or rain, heavy at time of observation.	78	Intermittent (faint) snow or rain, very light at time of observation.	79	Continuous (faint) snow or rain, very light at time of observation.
80	Slight rain (showers).	81	Moderate or heavy rain (showers).	82	Violent rain (showers).	83	Slight showers of rain and snow mixed.	84	Moderate or heavy showers of rain and snow mixed.	85	Slight snow (showers).	86	Moderate or heavy snow (showers).	87	Slight snow (showers).	88	Moderate or heavy snow (showers).	89	Slight snow (showers).
90	Moderate or heavy showers of hail, with or without rain or snow, at time of observation.	91	Slight rain at time of observation, thunderstorm during past hour, but NOT at time of observation.	92	Moderate or heavy rain at time of observation, thunderstorm during past hour, but NOT at time of observation.	93	Slight snow or rain and snow mixed, at time of observation.	94	Moderate or heavy snow or rain and snow mixed, at time of observation.	95	Slight or moderate hail, at time of observation.	96	Slight or moderate hail, at time of observation.	97	Slight or moderate hail, at time of observation.	98	Slight or moderate hail, at time of observation.	99	Slight or moderate hail, at time of observation.

Figure 9. Allowable symbols for the current weather element of the surface station model. Adapted from *Weather Analysis* by D. Djurić, their Table E-1.

Upper air observations can also be depicted in station model format. The number of meteorological elements comprising the station model for upper air observations is much fewer than for the surface station model, however. Furthermore, no standardized form of the upper air station model exists. Two representative examples are given in Fig. 10.

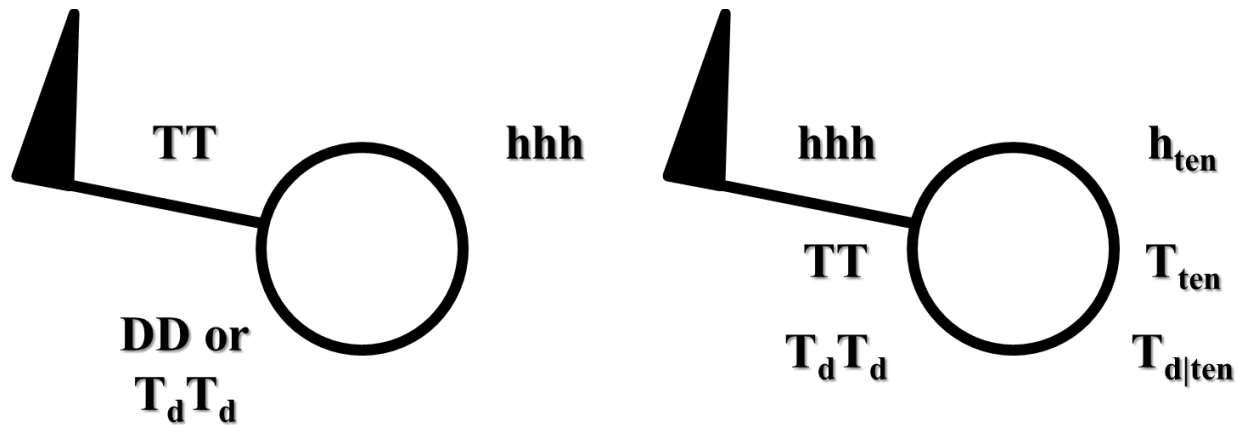


Figure 10. Two commonly encountered forms of the upper air station model. Please refer to the text for details.

Note that upper air data are typically conveyed on *isobaric surfaces*, or constant pressure surfaces. Specific elements of the upper air station model in Fig. 10 include:

- **TT.** Temperature, in $^{\circ}\text{C}$.
- **$T_d T_d$.** Dew point temperature, in $^{\circ}\text{C}$.
- **DD.** Dew point depression, calculated as $TT - T_d T_d$, in $^{\circ}\text{C}$.
- **hhh.** Geopotential height, in dam (meters * 10). If $hhh > 10,000$ m, the leading 1 may be omitted.
- **Wind direction.** Represented by the line drawn out from the circle in the direction from which the wind blows.
- **Wind speed.** Represented by the barbs or flags drawn out from the wind direction flag. One half-barb: 2.5 m s^{-1} or 5 kt, one full barb: 5 m s^{-1} or 10 kt, one flag: 25 m s^{-1} or 50 kt.
- **h_{ten} .** Twelve-hour geopotential height tendency, in dam.
- **T_{ten} .** Twelve-hour temperature tendency, in $^{\circ}\text{C}$.
- **$T_{d|ten}$.** Twelve-hour dew point temperature tendency, in $^{\circ}\text{C}$.

Note that all tendencies are computed as the present value of the variable minus its earlier value.

An Introduction to Synoptic Analysis

Overview

Typically, we are not interested in the meteorological conditions at just one surface and/or upper air observation station. Rather, we are interested in the meteorological conditions over a large spatial area from the mesoscale to the synoptic scale. As a result, we are interested in the synthesis of weather observations collected at multiple locations. Proper analysis of such data, both at the

surface and aloft, enables meteorologists to identify the four-dimensional location, structure, and evolution of meteorological phenomena such as fronts and air masses.

For this analysis, we employ a technique known as *isoplething* to the data. Isopleths connect points on a map that have the same value of the quantity being examined; this stems from the iso- prefix, which indicates “same” or “equal.” Commonly isoplethed elements include temperature, potential temperature, dew point, sea-level pressure, pressure tendency, wind speed, geopotential height, and geopotential height tendency. Isopleths of these quantities are known as isotherms, isentropes, isodrosotherms, isobars, isallobars, isotachs, isohypses, and isallohypses, respectively.

As we discussed earlier in this lecture, meteorological observations are discrete; we do not have data at every possible location. Thus, isoplething involves interpolation of the values of the quantity being examined between the observations. To do so, *we assume that meteorological fields are continuous*; i.e., if the temperature is 10°C at one point and 20°C at the nearest adjacent point, we assume that the temperature between the two points changes smoothly and uniformly between the two points.

You will often encounter features in isoplethed analyses – particularly of sea-level pressure and geopotential height – that have specific names. These include:

- **Low.** A local minimum in the field, often depicted by at least one closed isopleth.
- **High.** A local maximum in the field, often depicted by at least one closed isopleth.
- **Trough line.** A dashed line connecting points of maximum isopleth curvature, where the isopleths bend or curve around lower values of the isoplethed field.
- **Ridge line.** A jagged line connecting points of maximum isopleth curvature, where the isopleths bend or curve around higher values of the isoplethed field.
- **Trough.** The region around a trough line.
- **Ridge.** The region around a ridge line.
- **Col.** The hyperbolic point between a pair of ridges and a pair of troughs.
- **Wave.** A combination of a single trough and a single ridge.

Synoptic Analysis Guidelines

When preparing an isoplethed analysis, there are specific guidelines that should be followed. The most important of these guidelines is that isopleths should satisfy the conceptual model of the atmosphere most applicable to the isoplethed field. Examples of such conceptual models include frontal structure, geostrophic balance, and vertical structure. Our analysis should also be consistent with that at an earlier time, if such an analysis is available. We will introduce several conceptual models applicable to synoptic-scale phenomena throughout the course of this semester, and we will examine isoplething techniques for the relevant field(s) at those times.

Other guidelines that should be followed include the following:

1. Pick an appropriate interval for the isopleths. Commonly encountered values include 4 hPa for sea-level pressure, 30 m or 60 m for geopotential height, 10 kt to 20 kt for wind speed, and 2°C to 5°C for temperature and dew point. This interval should be evenly divisible into the values of your isopleths.
2. Since meteorological fields are assumed to be continuous, isopleths should not start or stop in the middle of a field, and there should not be breaks in, branches from, intersections of, or merges of the isopleths. Thus, isopleths are either closed or extend from one edge of the data to the other.
3. Isopleths should have higher values of the isoplethed field on one side of them and lower values on the other side. For instance, a 70°F isotherm should have temperature < 70°F on one side, temperature > 70°F on the other, and temperature = 70°F along the isotherm.
4. Isopleths should only reflect the level of detail allowed by the available data. Do not make up data simply because you think the isopleths should look a specific way, such as beyond coastlines where data may cease to exist.
5. Isopleths should be evenly spaced unless there is a specific reason for their spacing to vary, such as tied to a conceptual model of the atmosphere.
6. Assume that each observation is correct unless you can prove beyond a reasonable doubt that it is in error, following the guidelines under “Representativeness of Observations” above. Circle any observations that you do exclude from your analysis.
7. Your isopleth analysis should be neat, including isopleths that are both smooth and labeled at their ends. Erase all errors or preliminary markings.
8. For closed isopleths, place a “H” (for maxima) or “L” (for minima) at the center and interpolate the central value, writing it neatly in a horizontal fashion under the letter.
9. *Begin by surveying the data in its entirety.* Start your actual analysis in “easy” locations, such as where local minima and maxima are found, and proceed from there. Ensure that the above guidelines are met as you conduct and finalize your analysis.

Representative Synoptic Analyses

It can be daunting to begin a synoptic analysis; there is often a large amount of data, and it is not always immediately clear as to where to begin, or even what the final analysis should look like. In this section, we wish to consider representative surface and upper-air synoptic analyses. In addition to providing example synoptic analyses, they also help to reinforce the guidelines listed above and introduce meteorological conceptual models that we will consider later in the semester.

First, we begin with the surface. Fig. 11 illustrates the data we will use for the analysis. These conform to the surface station model in Fig. 6. For simplicity, we will analyze only temperature and sea-level pressure, even though dew point temperature and sea-level pressure observations are also available. Because there is a wide range of temperatures represented on this map – as high as the mid-70s in the central Mississippi River valley and as low as the mid-30s in the Rockies – we will use a large temperature contour interval of 5°F, choosing our specific contour levels to evenly divide by 5°F (e.g., 40°F, 45°F, etc.). We will follow the standard 4 hPa sea-level pressure standard contour interval, also choosing our specific contour levels to evenly divide by 4 hPa (e.g., 976 hPa, 980 hPa, etc.).

While each analyst is different, you may find it helpful to first identify local minima and maxima in each field. For instance, there is a distinct sea-level pressure minimum of approximately 975 hPa over south-central Minnesota. Temperature minima are found over the Rockies and southeast Canada, while a temperature maximum is found at the far bottom of the chart in western Tennessee. Drawing contours in these regions helps to establish a pattern and limit the data extent to consider for the rest of the analysis. Label your contours once you have finalized them.

Once the initial contours have been drawn, look in adjacent regions to find where the values lying between the contour you just drew and the next highest or lowest contour are located. Your next contours will be drawn on the periphery of these regions. Continue this process until the analysis is complete. Remember that the contours that you draw should only account for the data provided on the map and should be continuous. However, if an observation substantially differs from those that surround it for non-meteorological reasons (e.g., not because it is at a much different elevation, not because it is over land versus water, or not because it is experiencing precipitation instead of being dry), do not include it in your contour analysis.

The final analysis is depicted in Fig. 12. The final contours are smooth, relatively evenly spaced, and either continuous or terminate at the edge of the data. Note that the isobars have sharp kinks to them just west of the Mississippi River (along a north-northeast to south-southwest axis) and from Minnesota into central Wisconsin. These are not drawn arbitrarily, but rather to fit a specific conceptual model of the atmosphere associated with midlatitude cyclones and their associated cold and warm fronts. The fact that there are many isotherms just west of the isobar kinking along the Mississippi River is not a coincidence, either, for the same reason. In addition, note that the wind is generally directed across isobars toward low pressure. This also fits a specific conceptual model of the atmosphere, here being that of the impact of friction on the near-surface wind.

Next, we move to an upper-air chart, this at the 500 hPa isobaric surface. Fig. 13 illustrates the data we will use for the analysis. These data conform to the left-most of the two upper-air station model examples in Fig. 10, with the lower left number representing dew point temperature. For simplicity, and keeping with typical convention, we will analyze only geopotential height and wind speed, even though temperature and dew point temperature observations are available. We use a

60 m geopotential height contour interval, ensuring the specific contour levels evenly divide into 60 m, and shade wind speed at 50, 75, and 100 kt.

The same principles apply to the upper-air analysis as to the surface analysis. Start by identifying local minima and maxima in each field, then draw the associated contours. Expand outward from there, performing a manual quality check on the observations as you do so.

The final analysis for this case is depicted in Fig. 14. There are three examples of atmospheric conceptual models illustrated in this analysis. First, note that the geopotential height contours are locally parallel to the wind observations. Second, note that the spacing between the geopotential height contours is largest where the wind speed is fastest, whereas the contour spacing is smallest where the wind speed is slowest. Both insights stem from an assumption of geostrophic balance, which we will consider in more detail later in the semester. Third, note that the surface cyclone in Fig. 12 is located to the east of the 500 hPa trough axis in Fig. 14. This rearward (with respect to the synoptic-scale flow; specifically, westward) tilt with increasing height is a characteristic of a developing or mature synoptic-scale cyclone. We will consider this in more detail at the start of next semester.

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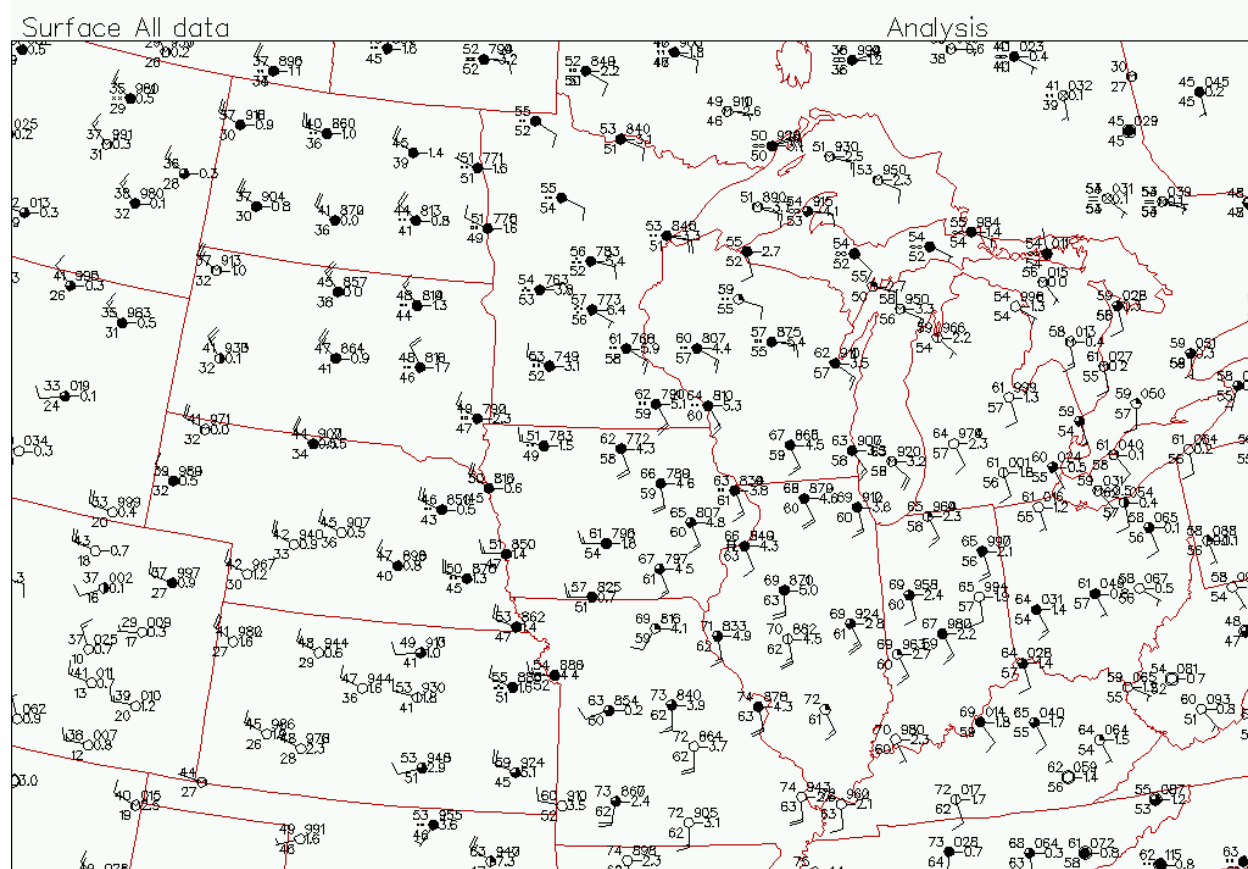


Figure 11. Surface observations, following the station model in Fig. 6, across the north-central United States.

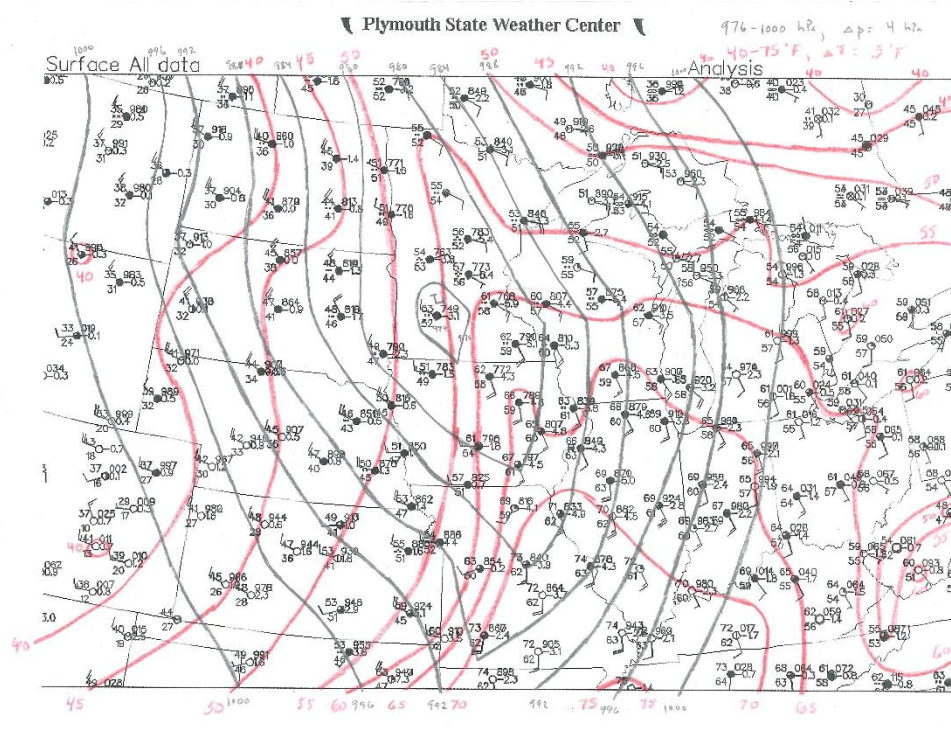


Figure 12. 2-m temperature (red contours, every 5°F) and sea-level pressure (grey contours, every 4 hPa) analysis for the data presented in Fig. 11.

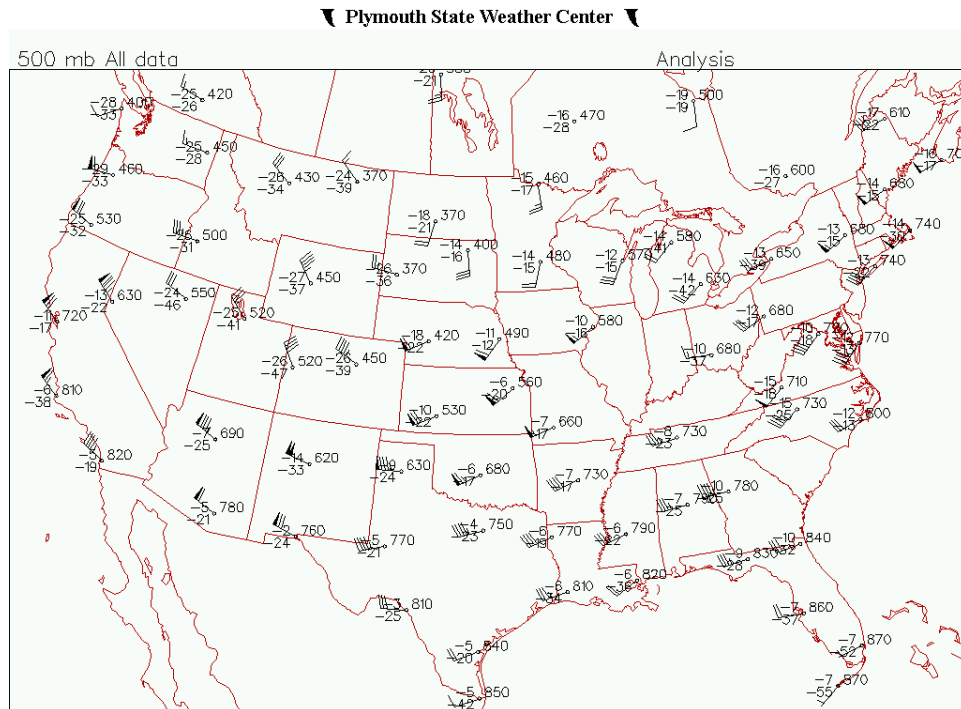


Figure 13. 500 hPa observations, following the station model in Fig. 10, across the United States.

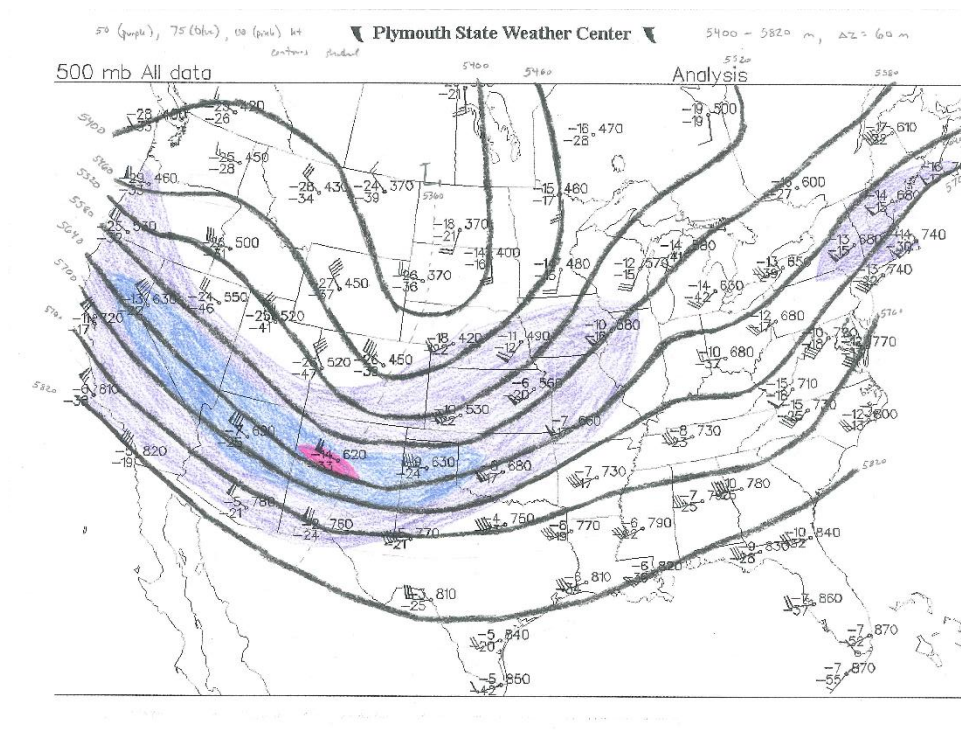


Figure 14. 500 hPa geopotential height (black contours, every 60 m) and wind speed (shaded; 50 kt = purple, 75 kt = blue, and 100 kt = pink) analysis for the data presented in Fig. 13.