9 WEATHER REPORTS & MAP ANALYSIS

Contents

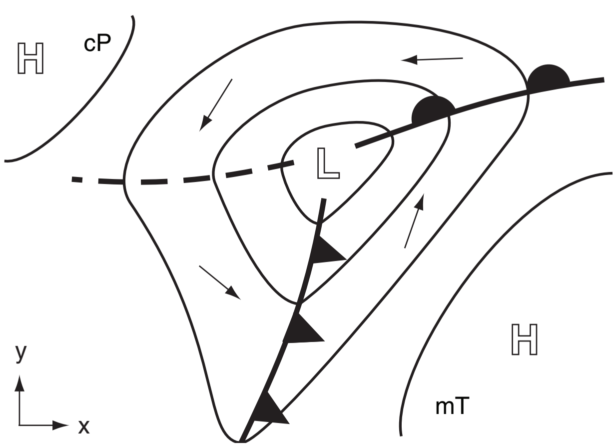


Figure 9.1
Idealized surface weather map showing high (ℍ) and low (𝕃) pressure centers, isobars (thin lines), and fronts (heavy solid lines) in the N. Hemisphere. Vectors indicate near-surface wind. Dashed line is a trough of low pressure. cP indicates a continental polar airmass; mT indicates a maritime tropical airmass.

Surface weather charts summarize weather conditions that can affect your life. Where is it raining, snowing, windy, hot or humid? More than just plots of raw weather reports, you can analyze maps to highlight key features including airmasses, centers of low- and high-pressure, and fronts (Fig. 9.1). In this chapter you will learn how to interpret weather reports, and how to analyze surface weather maps.

9.1. SEA-LEVEL PRESSURE REDUCTION

Near the bottom of the troposphere, pressure gradients are large in the vertical (order of 10 kPa km^{-1}) but small in the horizontal (order of 0.001 kPa km^{-1}). As a result, pressure differences between neighboring surface weather stations are dominated by their relative station elevations z_{stn} (m) above sea level.

However, horizontal pressure variations are important for weather forecasting, because they drive horizontal winds. To remove the dominating influence of station elevation via the vertical pressure gradient, the reported station pressure P_{stn} is extrapolated to a constant altitude such as mean sea level (MSL). Weather maps of **mean-sea-level pressure** (P_{MSL}) are frequently used to locate high- and low-pressure centers at the bottom of the atmosphere.

The extrapolation procedure is called **sea-level pressure reduction**, and is made using the hypsometric equation:

$$P_{MSL} = P_{stn} \cdot \exp\left(\frac{z_{stn}}{a \cdot \overline{T_v^*}}\right) \qquad (9.1)$$

where $a = \Re_d/|g| = 29.3$ m K^{-1}, and the average air virtual temperature $\overline{T_v}$ is in Kelvin.

A difficulty is that $\overline{T_v}$ is undefined below ground. Instead, a fictitious average virtual temperature is invented:

$$\overline{T_v^*} = 0.5 \cdot [T_v(t_o) + T_v(t_o - 12\text{ h}) + \gamma_{sa} \cdot z_{stn}] \qquad (9.2)$$

where $\gamma_{sa} = 0.0065$ K m^{-1} is the standard-atmosphere lapse rate for the troposphere, and t_o is the time of the observations at the weather station. Eq. (9.2) attempts to average out the diurnal cycle, and it also extrapolates from the station to halfway toward sea level to try to get a reasonable temperature.

Sample Application

Phoenix Arizona (elevation 346 m MSL) reports dry air with T = 36°C now and 20°C half-a-day ago. P_{stn} = 96.4 kPa now. Find P_{MSL} (kPa) at Phoenix now.

Find the Answer

Given: T(now) = 36°C, T(12 h ago) = 20°C,
z_{stn} = 346 m, P(now) = 96.4 kPa. Dry air.
Find: P_{MSL} = ? kPa

$T_v \approx T$, because air is dry. Use eq. (9.2) : $\overline{T_v^*}$ =
= 0.5·[(36°C) + (20°C) + (0.0065 K m^{-1})·(346 m)]
= 29.16·°C (+ 273.15) = 302.3 K
Use eq. (9.1):
P_{MSL} = (96.4 kPa)·exp[(346 m)/((29.3 m K^{-1})·(302.3 K))]
= (96.4 kPa)·(1.03984) = **100.24 kPa**

Check: Units OK. Physics OK. Magnitude OK.
Discus.: P_{MSL} can be significantly different from P_{stn}

Sample Application

Interpret the following METAR code:
METAR KSJT 160151Z AUTO 10010KT 10SM TS FEW060 BKN075 28/18 A2980 RMK AO2 LTG DSNT ALQDS TSB25 SLP068 T02780178

Hint: see the METAR section later in this chapter.

Find the Answer:

Weather conditions at KSJT (San Angelo, Texas, USA) observed at 0151 UTC on 16th of the current month by an automated station: Winds are from the 100° at 10 knots. Visibility is 10 statute miles or more. Weather is a thunderstorm. Clouds: few clouds at 6000 feet AGL, broken clouds at 7500 feet AGL. Temperature is 28°C and dewpoint is 18°C. Pressure (altimeter) is 29.80 inches Hg. REMARKS: Automated weather station type 2. Distant (> 10 statute miles) lightning in all quadrants. Thunderstorm began at 25 minutes past the hour. Sea-level pressure is 100.68 kPa. Temperature more precisely is 27.8°C, and dewpoint is 17.8°C.

Exposition: As you can see, codes are very concise ways of reporting the weather. Namely, the 3 lines of METAR code give the same info as the 12 lines of plain-language interpretation.

You can use online web sites to search for station IDs. More details on how to code or decode METARs are in the Federal Meteor. Handbook No. 1 (2005) and various online guides. The month and year of the observation are not included in the METAR, because the current month and year are implied.

I am a pilot and flight instructor, and when I access METARs online, I usually select the option to have the computer give me the plain-language interpretation. Many pilots find this the easiest way to use METARs. After all, it is the weather described by the code that is important, not the code itself. However, meteorologists and aviation-weather briefers who use METARs every day on the job generally memorize the codes.

9.2. METEOROLOGICAL REPORTS & OBSERVATIONS

One branch of the United Nations is the **World Meteorological Organization** (**WMO**). Weather-observation standards are set by the WMO. Also, the WMO works with most nations of the world to coordinate and synchronize weather observations. Such observations are made simultaneously at specified **Coordinated Universal Times** (**UTC**) to allow meteorologists to create a **synoptic** (snapshot) picture of the weather (see Chapter 1).

Most manual upper-air and surface synoptic observations are made at 00 and 12 UTC. Fewer countries make additional synoptic observations at 06 and 18 UTC.

9.2.1. Weather Codes

One of the great successes of the WMO is the international sharing of real-time weather data via the **Global Telecommunication System** (**GTS**). To enable this sharing, meteorologists in the world have agreed to speak the same weather language. This is accomplished by using **Universal Observation Codes** and abbreviations. Definitions of some of these codes are in:

World Meteorological Organization: 1995 (revised 2015): *Manual on Codes. International Codes Vol. 1.1 Part A - Alphanumeric Codes*. WMO-No. 306. 466 pages.

Federal Meteorological Handbook No. 1 (Sept 2005): *Surface Weather Observations and Reports*. FCM-H1-2005.

Both manuals can be found with an online search.

Sharing of real-time data across large distances became practical with the invention of the electric telegraph in the 1830s. Later developments included the teletype, phone modems, and the internet. Because weather codes in the early days were sent and received manually, they usually consisted of human-readable abbreviations and contractions.

Modern table-driven code formats (**TDCF**) are increasingly used to share data. One is **CREX** (Character form for the Representation and EXchange of data). Computer binary codes include **BUFR** (Binary Universal Form for the Representation of meteorological data) and **GRIB** (Gridded Binary).

However, there still are important sets of **alphanumeric codes** (letters & numbers) that are human writable and readable. Different alphanumeric codes exist for different types of weather observations and forecasts, as listed in Table 9-1. We will highlight one code here — the **METAR**.

Table 9-1. List of alphanumeric weather codes.

Name	Purpose
SYNOP	Report of surface observation from a fixed land station
SHIP	Report of surface observation from a sea station
SYNOP MOBIL	Report of surface observation from a mobile land station
METAR	Aviation routine weather report (with or without trend forecast)
SPECI	Aviation selected special weather report (with or without trend forecast)
BUOY	Report of a buoy observation
RADOB	Report of ground radar weather observation
RADREP	Radiological data report (monitored on a routine basis and/or in case of accident)
PILOT	Upper-wind report from a fixed land station
PILOT SHIP	Upper-wind report from a sea station
PILOT MOBIL	Upper-wind report from a mobile land station
TEMP	Upper-level pressure, temperature, humidity and wind report from a fixed land station
TEMP SHIP	Upper-level pressure, temperature, humidity and wind report from a sea station
TEMP DROP	Upper-level pressure, temperature, humidity and wind report from a dropsonde released by carrier balloons or aircraft
TEMP MOBIL	Upper-level pressure, temperature, humidity and wind report from a mobile land station
ROCOB	Upper-level temperature, wind and air density report from a land rocketsonde station
ROCOB SHIP	Upper-level temperature, wind and air density report from a rocketsonde station on a ship
CODAR	Upper-air report from an aircraft (other than weather reconnaissance aircraft)
AMDAR	Aircraft report (Aircraft Meteorological DAta Relay)
ICEAN	Ice analysis
IAC	Analysis in full form
IAC FLEET	Analysis in abbreviated form
GRID	Processed data in the form of grid-point values
GRAF	Processed data in the form of grid-point values (abbreviated code form)

Table 9-1 (continued). Alphanumeric codes.

Name	Purpose
WINTEM	Forecast upper wind and temperature for aviation
TAF	Aerodrome forecast
ARFOR	Area forecast for aviation
ROFOR	Route forecast for aviation
RADOF	Radiological trajectory dose forecast (defined time of arrival and location)
MAFOR	Forecast for shipping
TRACK-OB	Report of marine surface observation along a ship's track
BATHY	Report of bathythermal observation
TESAC	Temperature, salinity and current report from a sea station
WAVEOB	Report of spectral wave information from a sea station or from a remote platform (aircraft or satellite)
HYDRA	Report of hydrological observation from a hydrological station
HYFOR	Hydrological forecast
CLIMAT	Report of monthly values from a land station
CLIMAT SHIP	Report of monthly means and totals from an ocean weather station
NACLI, CLINP, SPCLI, CLISA, INCLI	Report of monthly means for an oceanic area
CLIMAT TEMP	Report of monthly aerological means from a land station
CLIMAT TEMP SHIP	Report of monthly aerological means from an ocean weather station
SFAZI	Synoptic report of bearings of sources of atmospherics (e.g., from lightning)
SFLOC	Synoptic report of the geographical location of sources of atmospherics
SFAZU	Detailed report of the distribution of sources of atmospherics by bearings for any period up to and including 24 hours
SAREP	Report of synoptic interpretation of cloud data obtained by a meteorological satellite
SATEM	Report of satellite remote upper-air soundings of pressure, temperature and humidity
SARAD	Report of satellite clear radiance observations
SATOB	Report of satellite observations of wind, surface temperature, cloud, humidity and radiation

9.2.2. METAR and SPECI

METAR stands for routine Meteorological Aerodrome Report. It contains hourly observations of surface weather made at a manual or automatic weather station at an airport. It is formatted as a text message using codes (abbreviations, and a specified ordering of the data blocks separated by spaces) that concisely describe the weather.

Here is a brief summary on how to read METARs. Grey items below can be omitted if not needed.

Format

[METAR or SPECI] [corrected] [weather station ICAO code] [day, time] [report type] [wind direction, speed, gusts, units] [direction variability] [prevailing visibility, units] [minimum visibility, direction] [runway number, visual range] [current weather] [lowest altitude cloud coverage, altitude code] [higher-altitude cloud layers if present] [temperature/dewpoint] [units, sea-level pressure code] [supplementary] **RMK** [remarks].

Example (with remarks removed):

```
METAR KTTN 051853Z 04011G20KT 1 1/4SM
R24/6200FT VCTS SN FZFG BKN003 OVC010
M02/M03 A3006 RMK...
```

Interpretation of the Example Above

Routine weather report for Trenton-Mercer Airport (NJ, USA) made on the 5th day of the current month at 1853 UTC. Wind is from 040° true at 11 gusting to 20 knots. Visibility is 1.25 statute miles. Runway visual range for runway 24 is 6200 feet. Nearby thunderstorms with snow and freezing fog. Clouds are broken at 300 feet agl, and overcast at 1000 ft agl. Temperature minus 2°C. Dewpoint minus 3°C. Altimeter setting is 30.06 in. Hg. Remarks...

SPECI

If the weather changes significantly from the last routine METAR report, then a special weather observation is taken, and is reported in an extra, unscheduled SPECI report. The SPECI has all the same data blocks as the METAR plus a plain language explanation of the special conditions.

The criteria that trigger SPECI issuance are:

Wind direction: changes >45° for speeds ≥ 10 kt.
Visibility: changes across threshold: 3 miles, 2 miles, 1 mile, 0.5 mile or instrument approach minim.
Runway visual range: changes across 2400 ft.
Tornado, Waterspout: starts, ends, or is observed.
Thunderstorm: starts or ends.
Hail: starts or ends.
Freezing precipitation: starts, changes, ends.
Ceiling: changes across threshold: 3000, 1500, 1000, 500, 200 (or lowest approach minimum) feet.
Clouds: when layer first appears below 1000 feet.
Volcanic eruption: starts.

Details of METAR / SPECI Data Blocks

Corrected: COR if this is a corrected METAR.
Weather Station **ICAO** Code is a 4-letter ID specified by the Internat. Civil Aviation Organization.
Day, Time: 2-digit day within current month, 4-digit time, 1-letter time zone (Z = UTC. Chapter 1).
Type: AUTO=automatic; (blank)=routine; NIL= missing.
Wind: 3-digit direction (degrees relative to true north, rounded to nearest 10 degrees). VRB=variable. 2- to 3-digit speed. (000000=calm). G prefixes gust max speed. Units (KT=knots, KMH=kilometers per hour, MPS=meters per second).
Direction Variability only if > 60°. Example: 010**V**090, means variable direction between 010° and 090°.
Prevailing Visibility: 4 digits in whole meters if units left blank. If vis < 800 m, then round down to nearest 50 m. If 800 ≤ vis < 5000 m, then round down to nearest 100 m. If 5000 ≤ vis < 9999 m, then round down to nearest 1000 m. Else "9999" means vis ≥ 10 km. In USA: number & fraction, with SM=statute miles. NDV = no directional variations.
Minimum Visibility: 4 digits in whole meters if units are blank & 1-digit (a point from an 8-point compass)
Runway Visual Range (RVR): **R**, 2-digit runway identifier, (if parallel runways, then: L=left, C=center, R=right), **/** , 4-digit RVR. Units: blank=meters, FT=feet. If variable RVR, then append optional: 4 digits, **V**, 4 digits to span the range of values. Finally, append optional tendency code: U=up (increasing visibility), N=no change, D-down (decreasing visibility).
Weather: see Tables in this chapter for codes. 0 to 3 groups of weather phenomena can be reported.
Clouds: 3-letter coverage abbreviation (see Table 9-10), 3-digit cloud-base height in hundreds of feet agl. TCU=towering cumulus congestus, CB = cumulonimbus. If no clouds, then whole cloud block replaced by CLR=clear or by SKC=sky clear. NSC= no significant clouds below 5000 ft (1500 m) with no thunderstorm and good visibility. NCD if no clouds detected by an automated system.
Higher Cloud Layers if any: 2nd lowest clouds reported only if ≥ SCT. 3rd lowest only if ≥ BRN.
Note: if visibility > 10 SM and no clouds below 5,000 ft (1500 m) agl and no precipitation and no storms, then the visibility, RVR, weather, & cloud blocks are omitted, and replaced with CAVOK, which means ceiling & visibility are OK (i.e., no problems for visual flight). (Not used in USA.)
Temperature/Dew-point: rounded to whole °C. Prefix M=minus.

<u>Sea-level Pressure</u>: 4 digits. Unit code prefix: A = altimeter setting in inches mercury, for which last 2 digits are hundredths. Q = whole hectoPascals hPa). Example: Q1016 = 1016 hPa = 101.6 kPa.
<u>Supplementary</u>: Can include: RE recent weather; WS wind shear; W sea state; runway state (SNOCLO=airport closed due to snow); trend, significant forecast weather (NOSIG=no change in significant weather, NSW=no significant weather)
<u>Remarks</u>: **RMK**. For details, see the manuals cited three pages earlier.

Although you can read a METAR if you've memorized the codes, it is easier to use on-line computer programs to translate the report into plain language. Consult other resources and manuals to learn the fine details of creating or decoding METARs.

9.2.3. Weather-Observation Locations

Several large governmental centers around the world have computers that automatically collect, test data quality, organize, and store the vast weather data set of coded and binary weather reports. For example, Figs. 9.2 to 9.12 show locations of weather observations that were collected by the computers at the European Centre for Medium-Range Weather Forecasts (**ECMWF**) in Reading, England, for a six-hour period centered at 00 UTC on 30 Mar 2015.

The volume of weather data is immense. There are many millions of locations (manual stations, automatic sites, and satellite obs) worldwide that report weather observations near 00 UTC. At ECMWF, many hundreds of gigabytes (GB) of weather-observation data are processed and archived every day. The locations for some of the different types of weather-observation data are described next.

Surface observations (Fig. 9.2) include manual ones from land (SYNOP) and ship (SHIP) at key synoptic hours. Many countries also make hourly observations at airports, reported as METARs.

Surface automatic weather-observation systems make more frequent or nearly continuous reports. Examples of automatic surface weather stations are **AWOS** (Automated Weather Observing System), and **ASOS** (Automated Surface Observing System) in the USA. Those automatic reports that are near the synoptic hours are also included in Fig. 9.2.

Both moored and drifting buoys (BUOY; Fig. 9.3) also measure near-surface weather and ocean-surface conditions, and relay this data via satellite.

Small weather balloons (Fig. 9.4) can be launched manually or automatically from the surface to make **upper-air soundings**. As an expendable **radiosonde** package is carried aloft by the helium-filled latex balloon, and later as it descends by parachute,

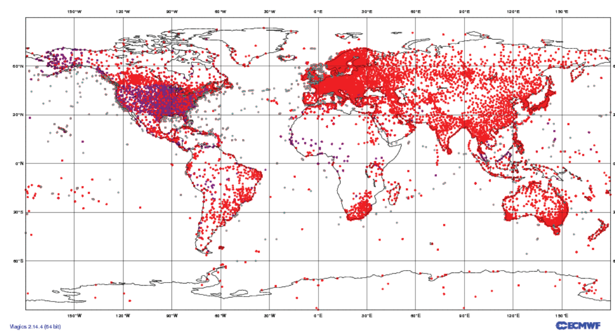


Figure 9.2
Surface data locations for observations of temperature, humidity, winds, clouds, precipitation, pressure, and visibility collected by synoptic weather stations on land and ship. Valid: 00 UTC on 30 Mar 2015. Number of observations: 36024 METAR (land) + 23742 SYNOP (land) + 376079 SHIP = 63526 surface obs. (From ECMWF.)

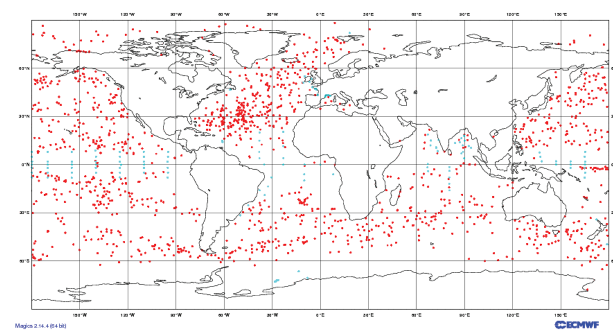


Figure 9.3
Surface data locations for temperature and winds collected by drifting and moored BUOYs. Valid: 00 UTC on 30 Mar 2015. Number of observations: 9114 drifters + 716 moored = 8830 buoys. (From ECMWF.)

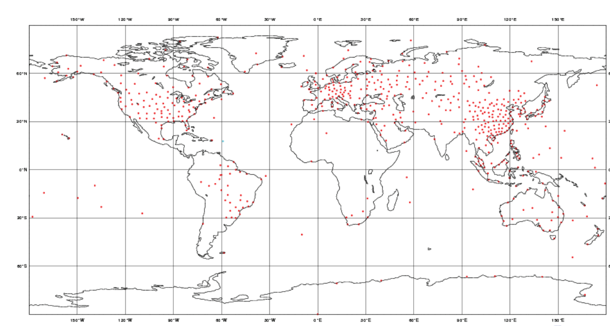


Figure 9.4
Upper-air sounding locations for temperature, pressure, and humidity collected by rawinsonde balloons launched from land and ship, and by dropsondes released from aircraft. Valid: 00 UTC on 30 Mar 2015. Number of observations: 596 land (TEMP) + 1 ship (TEMP SHIP) + 0 dropsondes (TEMP DROP) = 597 soundings. Extra dropsondes are often dropped over oceans at hurricanes, typhoons, and strong winter storms. (From ECMWF.)

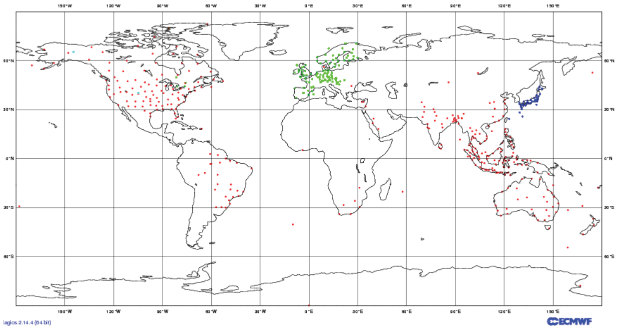


Figure 9.5
Upper-air data locations for winds collected by: PILOT balloons, ground-based wind profilers, and Doppler radars. Valid: 00 UTC on 30 Mar 2015. Number of observations: 324 pilot/rawinsonde balloons + 3158 microwave wind profilers = 3482 wind soundings. (From ECMWF.)

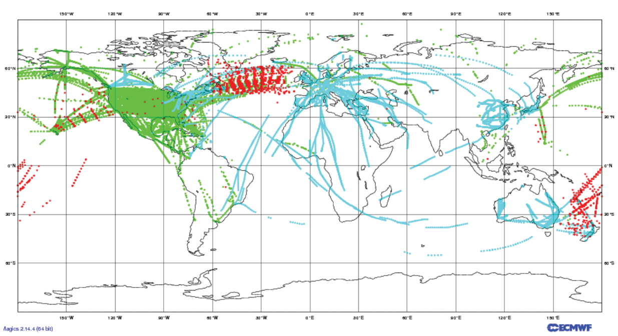


Figure 9.6
Upper-air data locations for temperature and winds collected by commercial aircraft: AIREP manual reports (black), and AMDAR & ACARS (grey) automated reports. Valid: 00 UTC on 30 Mar 2015. Number of observations: 2254 AIREP + 17661 AMDAR + 156136 ACARS = 176051 aircraft observations, most at their cruising altitude of 10 to 15 km above sea level. (From ECMWF.)

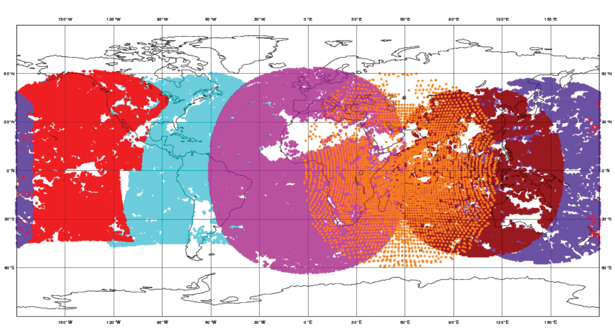


Figure 9.7
Upper-air data locations for winds collected by geostationary satellites (SATOB) from the USA (GOES), Europe (METEOSAT), and others around the world. Based atmospheric motion vectors (AMV) of IR cloud patterns. Similar satellite observations are made using water vapor and visible channels. Valid: 00 UTC on 30 Mar 2015. Number of observations: 442475. (From ECMWF.)

it measures temperature, humidity, and pressure. These radiosonde observations are called **RAOBs**.

Some radiosondes include additional instruments to gather navigation information, such as from **GPS** (Global Positioning Satellites). These systems are called **rawinsondes**, because the winds can be inferred by the change in horizontal position of the sonde. When a version of the rawinsonde payload is dropped by parachute from an aircraft, it is called a **dropsonde.**

Simpler weather balloons called **PIBALs** (Pilot Balloons) carry no instruments, but are tracked from the ground to estimate winds (Fig. 9.5). Most balloon soundings are made at 00 and 12 UTC.

Remote sensors on the ground include weather radar such as the **NEXRAD** (Weather Surveillance Radar WSR-88D). Ground-based microwave **wind profilers** (Fig. 9.5) automatically measure a vertical profile of wind speed and direction. **RASS** (Radio Acoustic Sounding Systems) equipment uses both sound waves and microwaves to measure virtual temperature and wind soundings.

Commercial aircraft (Fig. 9.6) provide manual weather observations called Aircraft Reports (**AIREPS**) at specified longitudes as they fly between airports. Many commercial aircraft have automatic meteorological reporting equipment such as **ACARS** (Aircraft Communication and Reporting System), **AMDAR** (Aircraft Meteorological Data Relay), & **ASDAR** (Aircraft to Satellite Data Relay).

Geostationary satellites are used to estimate tropospheric winds (Fig. 9.7) by tracking movement of clouds and water-vapor patterns. Surface winds over the ocean can be estimated from polar orbiting satellites using **scatterometer** systems (Fig. 9.8) that measure the scattering of microwaves off the sea surface. Rougher sea surface implies stronger winds.

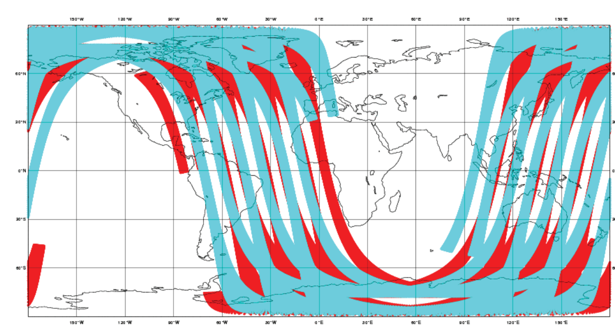


Figure 9.8
Surface-wind estimate locations from microwave scatterometer measurements of sea-surface waves by the polar-orbiting satellites. Valid: 00 UTC on 30 Mar 2015. Number of observations: 526159. (From ECMWF.)

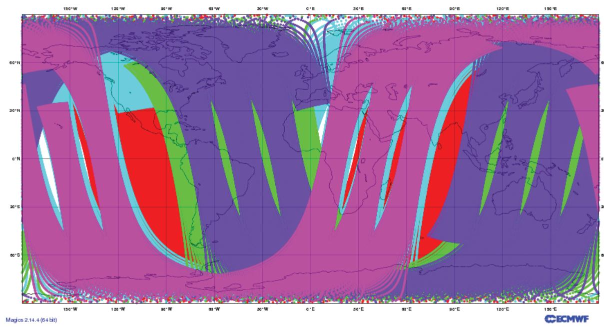


Figure 9.9
Temperature-sounding (SATEM) locations from radiation measurements by polar-orbiting satellites using the AMSU (Advanced Microwave Sounding Unit). Satellites: several NOAA satellites, Aqua, and MetOP. Valid: 00 UTC on 30 Mar 2015. Number of observations: 612703. (From ECMWF.)

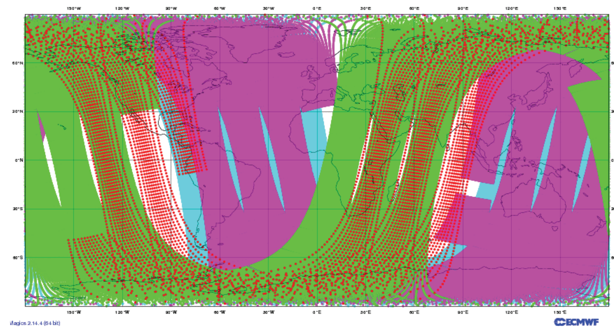


Figure 9.10
Temperature-sounding (SATEM) locations from high-spectral-resolution infrared radiation measurements by polar-orbiting satellites, using HIRS (High-resolution Infrared Radiation Sounder). Valid: 00 UTC on 30 Mar 2015. Number of observations: 5394127. (From ECMWF.)

Satellites radiometrically estimate air-temperature to provide remotely-sensed upper-air automatic data (Fig. 9.9). One system is the **AMSU** (Advanced Microwave Sounding Unit), currently flying on NOAA 15, 16, 17, 18, Aqua, and the European MetOp satellites.

Higher spectral-resolution soundings (Fig. 9.10) are made with the **HIRS** (High-resolution Infrared Radiation Sounding) system on polar-orbiting satellites.

Estimates of air density can also be made as signals from Global Positioning System (**GPS**) satellites are bent as they pass through the atmosphere to other satellites (Fig. 9.11). Other techniques (not shown) use ground-based sensors to measure the refraction and delay of GPS signals.

Polar orbiting satellites can also be used to estimate atmospheric motion vectors (AMV) from the movement of IR cloud patterns. These can give upper-air wind data over the Earth's poles (Fig. 9.12) — regions not visible from geostationary satellites.

Many more satellite products are used, beyond the ones shown here. Radiance measurements from geostationary satellites are used to estimate temperature and humidity conditions for numerical forecast models via variational data assimilation in three or four dimensions (**3DVar** or **4DVar**). Tropospheric precipitable water can be estimated by satellite from the amount of microwave or IR radiation emitted from the troposphere.

These synoptically reported data give a snapshot of the weather, which can be analyzed on **synoptic weather maps**. The methods used to analyze the weather data to create such maps are discussed next.

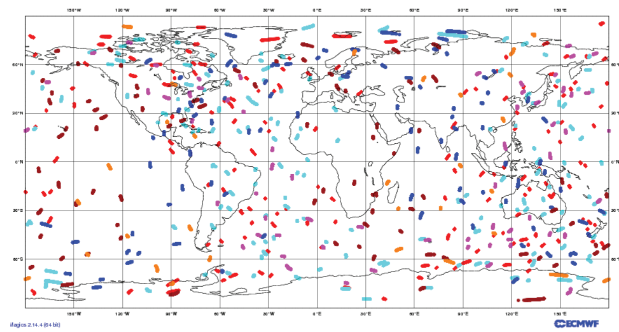


Figure 9.11
Air density estimates are made using Global Positioning System (GPS) Radio Occultation (GPS-RO). Valid: 00 UTC on 30 Mar 2015. Number of observations: 81236. (From ECMWF.)

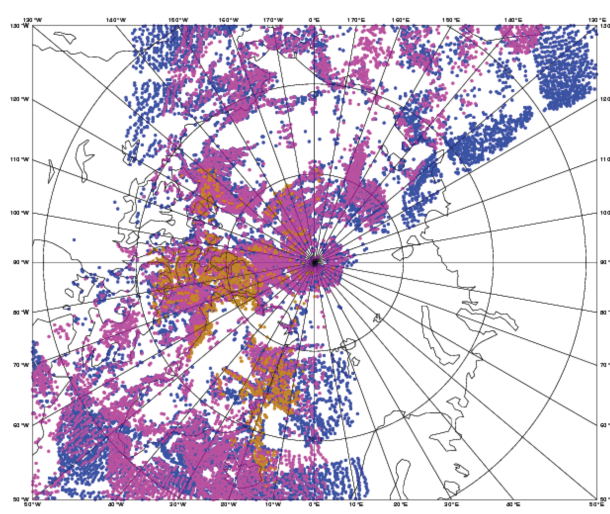


Figure 9.12
Atmospheric motion vector (AMV) locations from IR observations by polar satellites, over the N. Pole. Valid: 00 UTC on 30 Mar 2015. Number of observations: 33171. (From ECMWF.)

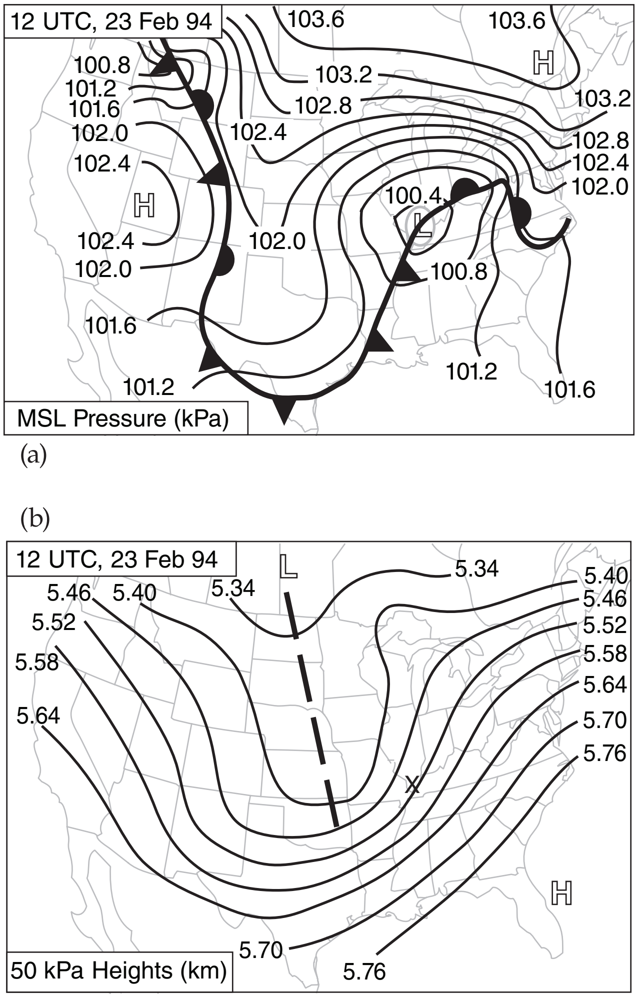


Figure 9.13

Examples of synoptic weather maps, which give a snapshot of the weather at an instant in time. Fig. 9.13a shows an example of a synoptic weather map for pressure at the bottom of the troposphere, based on surface weather observations. It shows pressure reduced to mean sea-level (MSL), fronts, and high (H) and low (L) pressure centers. Fig. 9.13b shows an upper-air synoptic map for geopotential heights of the 50 kPa isobaric surface (a surrogate for pressure) near the middle of the troposphere valid at the same time, using data from weather balloons, aircraft, satellite, and ground-based remote sensors. It also indicates high and low centers, and the trough axis (dashed line). By studying both maps, you can get a feeling for the three-dimensional characteristics of the weather.

Three steps are needed to create such maps. First, the weather data must be observed and communicated to central locations. Second, the data is tested for quality, where erroneous or suspect values are removed. These steps were already discussed.

Third, the data is analyzed, which means it is integrated into a coherent picture of the weather. This last step often involves interpolation to a grid (if it is to be analyzed by computers), or drawing of isopleths and identification of weather features (lows, fronts, etc.) if used by humans.

[Based on original analyses by Jon Martin.]

9.3. SYNOPTIC WEATHER MAPS

Weather observations that were taken **synoptically** (i.e., simultaneously) at many weather stations worldwide can be drawn on a weather map. For any one station, the weather observations include many different variables. So a shorthand notation called a **station-plot model** was devised to use symbols or glyphs for each weather element, and to write those data around a small circle representing the station location.

But the raw numbers and glyphs plotted on a map at hundreds of stations can be overwhelming. So computers or people can **analyze** the map to create a coherent picture that integrates together all the weather elements, such as in Fig. 9.13.

The resulting **synoptic-weather map** shows scales of weather (see table in the Forces & Winds chapter) that are called **synoptic-scale**. The field of study of these weather features (fronts, highs, lows, etc.) is called **synoptics**, and the people who study and forecast these features are **synopticians.**

9.3.1. Station Plot Model

On weather maps, the location of each weather station is circled, and that station's weather data is plotted in and around the circle. The standardized arrangement of these data in a grid is called a **station plot model** (Fig. 9.14). Before the days of computerized geographic information systems (GIS), meteorologists had to rely on abbreviated codes to pack as much data around each plotted weather station as possible. These codes are still used today.

Unfortunately, different weather organizations/countries use different station plot models and different codes. Here is how you interpret the surface station plot models for the World Meteorological Organization (WMO) and USA. Canada uses WMO. See WMO-No. 485 Appendix II-4 for details.

• **T** is a two-digit **temperature** in whole degrees (°C in most of the world; °F if plotted by the USA). WMO allows 3 digits plus decimal point and sign, where tenths of degrees is after the decimal point.

Example: **12** means 12°F in the USA. 12.3 means 12.3°C for WMO.

[CAUTION: On weather maps produced in the USA, temperatures at Canadian weather stations are often converted to °F before being plotted. The opposite happens for USA stations plotted on Canadian weather maps — they are first converted to °C. You should always think about the temperature value to see if it is reasonable for the units you assume.]

• **T_d** is a two-digit **dew-point temperature** in whole degrees (°C in most of the world; °F if plotted by the USA). WMO allows 3 digits plus decimal point and sign when precision is to tenths of degrees.

Example: **–4** means –4°F in the USA. –3.7 means –3.7°C for WMO. *[Same CAUTION as for T.]*

• **P** is the 3 least-significant digits of **mean sea-level pressure** in whole dekaPascals. To the left of the 3 digits, prefix either "9" or "10", depending on which one gives a value closest to standard sea-level pressure. For kPa, insert a decimal point two places from the right. For hPa, insert a decimal point one place from the right.

Example: **041** means 10041 daPa = 1004.1 hPa = 1004.1 mb = 100.41 kPa. *New example*: **957** means 9957 daPa = 995.7 hPa = 995.7 mb = 99.57 kPa.

[CAUTION: Some organizations report P in inches of mercury (in. Hg.) instead of hPa. P_{MSL} (in. Hg.) is an altimeter setting, used by aircraft pilots.]

• **Past wx** is a glyph (Table 9-2) for **past weather** in the past hour (or past 6 hours for Canada). It is blank unless different from present weather.

Example: ▽ means showers.

• **Current wx** is a glyph for **present weather** (at time of the weather observation). Tables 9-3 show the commonly used weather glyphs. *Examples*:

 means snow shower;  means thunderstorm with moderate rain.

• **Visib.** is a 2-digit code for **visibility** (how far away you can see objects).

In the USA, visibility is in statute miles.
(a) if visibility ≤ 3 1/8 miles, then *vis* can include a fraction.
(b) if 3 1/8 < visibility < 10 miles, then *vis* does not include a fraction.
(c) if 10 ≤ visibility, then *vis* is left blank.

Example: **2** 1/4 means visibility is 2 1/4 statute miles. New example: **8** means visibility is 8 miles.

In Canada, visibility is in kilometers, but is coded into a two-digit *vis* code integer as follows:
(a) if $vis \le 55$, then visibility (km) = $0.1 \cdot vis$
(b) if $56 \le vis \le 80$, then visibility (km) ≈ $vis - 50$
(c) if $81 \le vis$, then visibility (km) ≈ $5 \cdot (vis - 74)$

Examples: **35** means 3.5 km. **66** means 16 km. **82** means 40 km. See Fig. 9.15 on page 278 for a graph.

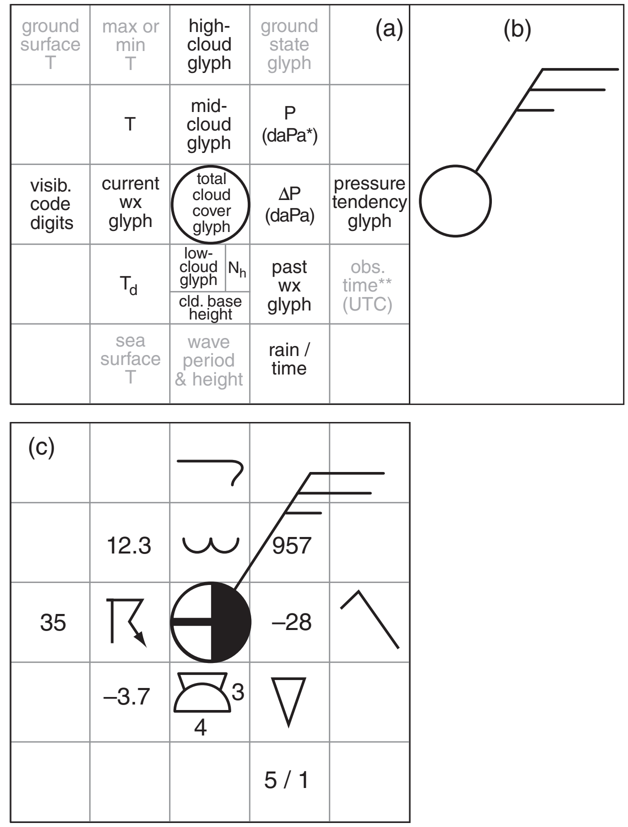


Figure 9.14
*WMO station plot model. (a) Fixed fields (see tables). Grey fields are used less often. [Notes: * only the last 3 digits are displayed for P. ** Observation time is not included if it is a normal observation time.] (b) Wind direction and speed. The circle represents the station location. Normally, the station circles in (a) and (b) are plotted superimposed. (c) Example.*

Table 9-2. WMO past or recent weather glyphs and codes (past wx).

Glyph	Meaning	METAR
,	Drizzle	DZ
●	Rain	RA
✱	Snow	SN
▽	Shower(s)	SH
	Thunderstorm (thunder is heard or lightning detected, even if no precipitation)	TS
≡	Fog (with visibility < 5/8 statute mile)	FG
	Sand Storm	SS
	Dust Storm	DS
	Drifting snow	DRSN
	Blowing snow	BLSN

Table 9-3a. Basic weather (wx) symbols and codes.

Glyph	Meaning	METAR
Precipitation:		
	Drizzle ‡	DZ
	Rain ‡	RA
	Snow ‡	SN
	Hail (large, diameter ≥ 5 mm)	GR
	Graupel (snow pellets, small hail, size < 5 mm)	GS
	Ice Pellets (frozen rain, called sleet in USA)	PL
	Ice Crystals ("diamond dust")	IC
	Snow Grain	SG
	Ice Needles	
	Unknown Precipitation (as from automated station)	UP
Obscuration:		
	Fog (with visibility < 5/8 statute mile) ‡	FG
	Mist (diffuse fog, with visibility ≥ 5/8 statute mile)	BR
	Haze	HZ
	Smoke	FU
	Volcanic Ash	VA
	Sand in air	SA
	Dust in air	DU
	Spray	PY
Storms & Misc.:		
	Squall	SQ
	Thunderstorm (thunder is heard or lightning detected, even if no precipitation)‡	TS
	Lightning	
	Funnel Cloud	FC
	Tornado or Waterspout	+FC
	Dust Devil (well developed)	PO
	Sand Storm	SS
	Dust Storm	DS

‡ Can be used as a "Past Weather" glyph.

Table 9-3b. Weather-code modifiers.

Glyph	Meaning	METAR prefix
Intensity, Proximity, or Recency: (Grey box □ is placeholder for a precipitation glyph from Table 9-3a. For example, ,, means light drizzle.)		
	Light	–
	Moderate	(blank)
	Heavy	+
	Intermittent and light ; moderate ; heavy	(no code for intermittent)
	In the vicinity. In sight, but not at the weather stn.	VC
	Virga (precip. in sight, but not reaching the ground).	VIRGA
	In past hour, but not now	
	Increased during past hour, and occurring now	
	Decreased during the past hour, and occurring now	
Descriptor:		
	Shower (slight)	–SH
	Shower (moderate)	SH
	Shower (heavy)	+SH
	Thunderstorm	TS
	Thunderstorm (heavy)	+TS
	Freezing. (if light, use left placeholder only) ***	FZ
	Blowing (slight)**	–BL
	Blowing (moderate)**	BL
	Blowing (strong, severe)**	+BL
	Drifting (low) (For DU, SA, SN raised < 2 m agl)	DR
	Shallow*	MI
	Partial*	PR
	Patchy*	BC

(* Prefixes for fog FG only.) (** Prefixes only for DU, SA, SN or PY.)
(*** Prefixes only for FG, DZ, or RN.)

Table 9-4. High clouds (WMO).	
Glyph	**Meaning**
	Cirrus (scattered filaments, "mares tails", not increasing).
	Cirrus (dense patches or twisted sheaves of filament bundles).
	Cirrus (dense remains of a thunderstorm anvil).
	Cirrus (hook shaped, thickening or spreading to cover more sky).
	Cirrus and cirrostratus increasing coverage or thickness, but covering less than half the sky.
	Cirrus and cirrostratus covering most of sky, and increasing coverage or thickness.
	Cirrostratus veil covering entire sky.
	Cirrostratus, not covering entire sky.
	Cirrocumulus (with or without smaller amounts of cirrus and/or cirrostratus).

Table 9-5. Mid-level clouds (WMO).	
Glyph	**Meaning**
	Altostratus (thin, semitransparent).
	Altostratus (thick), or nimbostratus.
	Altocumulus (thin).
	Altocumulus (thin, patchy, changing, and/or multi-level).
	Altocumulus (thin but multiple bands or spreading or thickening).
	Altocumulus (formed by spreading of cumulus).
	Multiple layers of middle clouds (could include altocumulus, altostratus, and/or nimbostratus).
	Altocumulus castellanus (has turrets or tufts).
	Altocumulus of chaotic sky (could include multi-levels and dense cirrus).

• **High-cloud glyphs** are shown in Table 9-4.

• **Mid-cloud glyphs** are shown in Table 9-5.

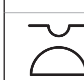
• **Low-cloud glyphs** are shown in Table 9-6.

• **N_h** is fraction of sky covered by low clouds. If no low clouds, then mid clouds. Units: oktas (eighths).

This can differ from the total sky coverage (see Table 9-10), which is indicated by the shading inside the station circle. *Example*: 3 means 3/8 coverage.

• **Cloud-base height** above ground is for the lowest cloud seen. It is a single-digit code (see Table 9-7).

• **ΔP** is 2 digits giving pressure change in the past 3 hours, prefixed with + or –. Units are hundredths of kPa (or tenths of hPa). *Example*: –28 is a pressure decrease of 0.28 kPa or 2.8 hPa.

Table 9-6. Low clouds (WMO).	
Glyph	**Meaning**
	Cumulus (Cu) humilis. Fair-weather cumulus. Little vertical development.
	Cumulus mediocris. Moderate to considerable vertical development.
	Cumulus congestus. Towering cumulus. No anvil top.
	Stratocumulus formed by the spreading out of cumulus.
	Stratocumulus. (Not from spreading cu)
	Stratus.
	Scud. Fractostratus or fractocumulus, often caused by rain falling from above.
	Cumulus and stratocumulus at different levels (not cause by spreading of Cu.
	Cumulonimbus. Thunderstorm. Has anvil top that is glaciated (contains ice crystals, and looks fibrous).

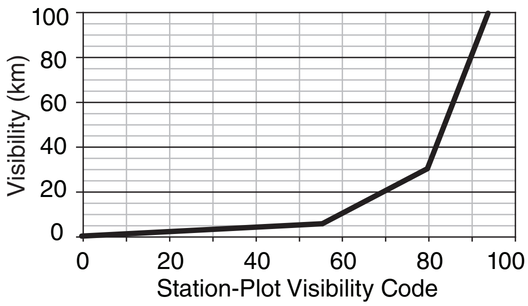
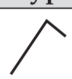


Figure 9.15
Visibility (vis) code for Canada.

Table 9-7. Codes for cloud-base height (z_c).

Code	meters agl	feet agl
0	0 to 49	0 to 149
1	50 to 99	150 to 299
2	100 to 199	300 to 599
3	200 - 299	600 to 999
4	300 - 599	1,000 to 1,999
5	600 to 999	2,000 to 3,499
6	1,000 to 1,499	3,500 to 4,999
7	1,500 to 1,999	5,000 to 6,499
8	2,000 to 2,499	6,600 to 7,999
9	≥ 2,500	≥ 8,000

Table 9-8. Symbols for pressure change (barometric tendency) during the past 3 hours. (a)

Glyph	Meaning
	Rising, then falling
	Rising, then steady or rising more slowly
	Rising steadily or unsteadily
	Falling or steady, later rising; or Rising slowly, later rising more quickly
	Steady
	Falling, then rising, but ending same or lower
	Falling, then steady or falling more slowly
	Falling steadily or unsteadily
	Steady or rising, then falling; or Falling, then falling more quickly

• **<u>Pressure tendency</u>** glyphs represent the pressure change (barometric tendency) during the past 3 hours (Table 9-8). It mimics the trace on a barograph.

• **<u>Δt_R</u>** is a single-digit code that gives the number of hours ago that precipitation began or ended. The WMO station-plot model does not include Δt_R. But Δt_R is on some of the US station-plot models, to the right of the past-weather glyph. Here is the code:

0 means no precipitation
1 means 0 to 1 hour ago
2 means 1 to 2 hours ago
3 means 2 to 3 hours ago
4 means 3 to 4 hours ago
5 means 4 to 5 hours ago
6 means 5 to 6 hours ago
7 means 7 to 12 hours ago
8 means more than 8 hours ago

• **<u>Rain/time-code</u>** is the accumulated liquid-equivalent precipitation amount during a past time interval. The time interval is in units of 6 hours, so a time code of 1 means 6 hours; a time code of 2 means 12 hours. In the USA, the units are hundredths of inches per 6 hours (the time code is not included). For example: 45 means 0.45 inches in the US. In Canada, the units are mm — the WMO standard.
Example: 5/1 means 5 mm in the past 6 hours.

• **<u>Wind</u>** is plotted as a direction shaft with barbs to denote speed (Fig. 9.14b). Table 9-9, reproduced from the Forces & Winds chapter, explains how to interpret it. *Example*: Fig. 9.14c shows 25 kt from the N.E.

Table 9-9. Interpretation of wind barbs.

Symbol	Wind Speed	Description
	calm	two concentric circles
	1 - 2 speed units	shaft with no barbs
	5 speed units	a half barb (half line)
	10 speed units	each full barb (full line)
	50 speed units	each pennant (triangle)

• The total speed is the sum of all barbs and pennants. For example,  indicates a wind from the west at speed 75 units. Arrow tip is at the observation location.
• *CAUTION: Different organizations use different speed units, such as knots, m s^{-1}, miles h^{-1}, km h^{-1}, etc. Look for a legend to explain the units. When in doubt, <u>assume knots</u> — the WMO standard. To good approximation, 10 knots ≈ 5 m s^{-1} .*

• **Total cloud cover** is indicated by the portion of the station-plot circle that is blackened (Fig. 9.14b). Table 9-10, reproduced from the Cloud chapter, explains its interpretation. *Example*: 5/8 coverage in Fig. 9.14c.

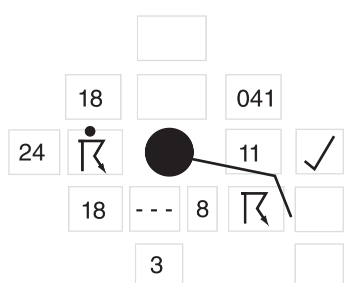
In the next subsection you will learn how to analyze a weather map. You can do a **hand analysis** (manual analysis) by focusing on just one meteorological variable. For example, if you want to analyze temperatures, then you should focus on just the temperature data from the station plot for each weather station, and ignore the other plotted data. This is illustrated in Fig. 9.16, where I have highlighted the temperatures to make them easier to see.

[*CAUTION: Do not forget that the plotted temperature represents the temperature at the station location (namely, at the plotted station circle), not displaced from the station circle as defined by the station plot model.*]

Sample Application

Decode the (a) station plot and the (b) METAR below, and compare the information they contain.

(a) Station Plot Example



(b) METAR

METAR CYYB
040000Z 11010KT
1 1/2SM TSRA BR
BKN008 OVC020
18/18 A2965 RMK
SF5SC3 CB
ASOCTD PRES
UNSTDY SLP041

(c) Translation of METAR (Info from Stn Plot underlined)

Meteorological Aviation Report for North Bay (CYYB) ON, Canada on 4th day of the month at 0000 UTC.
Wind from 110° true at 10 knots.
Visibility 1.5 statuate miles (= 2.4 km).
Present weather is thunderstorm with moderate rain and mist.
Cloud coverage: broken clouds with base at 800 feet above ground, overcast with base at 2000 feet.
Temperature is 18°C, and dew point is 18°C.
Altimeter is 29.65 inches of mercury.

Remarks:
Stratus fractus clouds with 5/8 coverage, and Stratocumulus clouds with 3/8 coverage, both associated with cumulonimbus.
Sea-level pressure is unsteady 100.41 kPa.
[Additional info in station plot, but not in METAR: past weather was thunderstorm; pressure first decreased, then increased with net increase of 0.11 kPa in 3 hr.]

Table 9-10. Sky cover. Oktas=eighths of sky covered.

Sky Cover (oktas)	Symbol	Name	Abbr.	Sky Cover (tenths)
0	○	Sky **Clear**	SKC	0
1	⦶	**Few*** Clouds	FEW*	1
2	◔			2 to 3
3	◔	**Scattered**	SCT	4
4	◑			5
5	◑	**Broken**	BKN	6
6	◕			7 to 8
7	◕			9
8	●	**Overcast**	OVC	10
(9)	⊗	Sky **Obscured**		unknown
(/)	⊖	Not Measured		unknown

* "Few" is used for (0 oktas) < coverage ≤ (2 oktas).

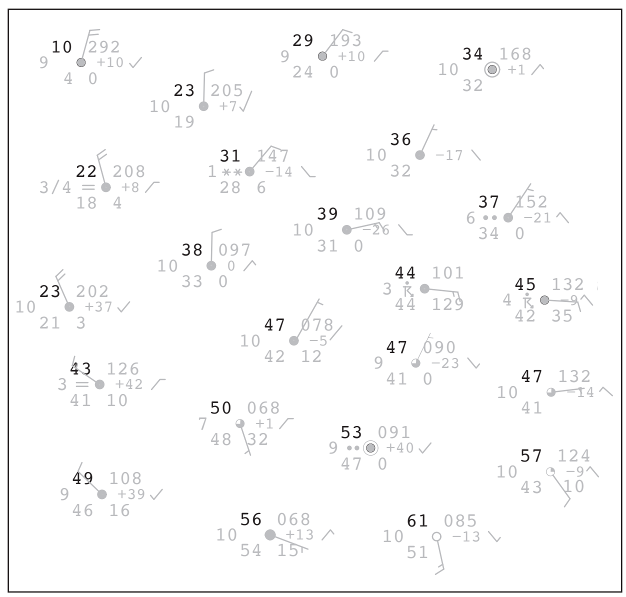
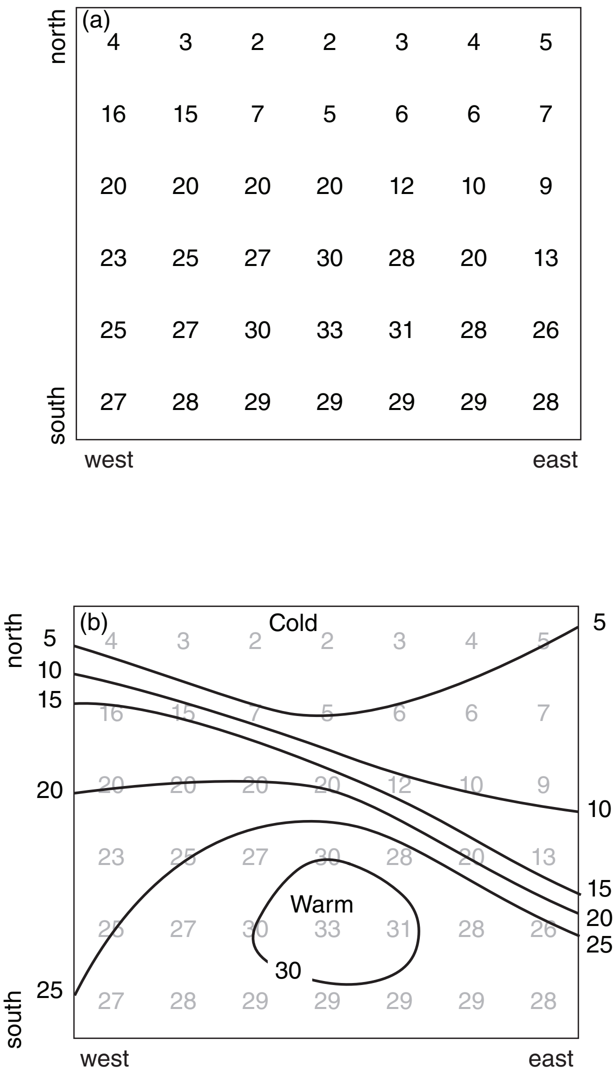


Figure 9.16
A surface weather map with temperatures highlighted. Units: T and T_d (°F), visibility (miles), speed (knots), pressure and 3-hour tendency (see text), 6-hour precipitation (hundredths of inches). Extracted from a "Daily Weather Map" courtesy of the US National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), National Centers for Environmental Prediction (NCEP), Hydrometeorological Prediction Center (HPC). The date/time of this map is omitted to discourage cheating during map-analysis exercises, and the station locations are shifted slightly to reduce overlap.



9.3.2. Map Analysis, Plotting & Isoplething

You might find the amount of surface-observation data such as plotted in Fig. 9.16 to be overwhelming. To make the plotted data more comprehensible, you can simplify the weather map by drawing **isopleths** (lines of equal value, see Table 1-6).

For example, if you analyze temperatures, you draw **isotherms** on the weather map. Similarly, if you analyze pressures you draw the **isobars**, or for humidity you draw **isohumes**.

Also, you can identify features such as fronts and centers of low and high pressure. Heuristic models of these features allow you to anticipate their evolution (see chapters on Fronts & Airmasses and Extratropical Cyclones).

Most weather maps are analyzed by computer. Using temperature as an example, the synoptic temperature observations are interpolated by the computer from the irregular weather-station locations to a regular grid (Fig. 9.17a). Such a grid of numbers is called a **field** of data, and this particular example is a **temperature field**. A discrete temperature field such as stored in a computer array approximates the continuously-varying temperature field of the real atmosphere. The gridded field is called an **analysis**.

Regardless of whether you manually do a **hand analysis** on irregularly-spaced data (as in Fig. 9.16), or you let the computer do an **objective analysis** on a regularly-spaced grid of numbers (as in Fig. 9.17a), the next steps are the same for both methods.

Continuing with the temperature example of Fig. 9.17, draw isotherms connecting points of equal temperature (Fig. 9.17b). The following rules apply

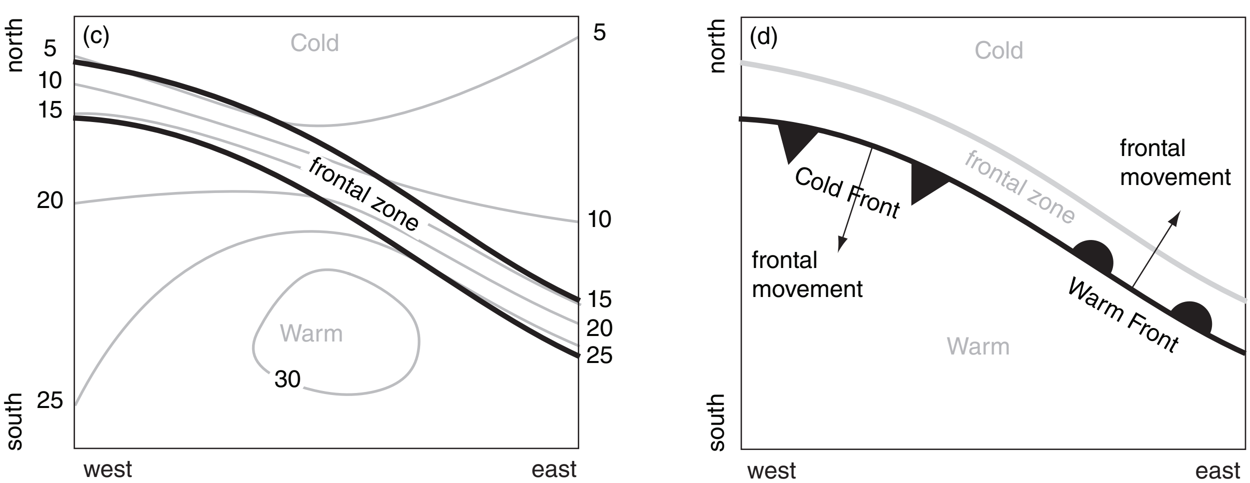


Figure 9.17
Weather map analysis: a) temperature field, with temperature in (°C) plotted on a Cartesian map; b) isotherm analysis; c) frontal zone analysis; d) frontal symbols added. [Note: The temperature field in this figure is for a different location and day than the data that was plotted in Fig. 9.16.]

to any line connecting points of equal value (i.e., **isopleths**), not just to isotherms:

- draw isopleths at regular intervals (such as every 2°C or 5°C for isotherms)
- interpolate where necessary between locations (e.g., the 5°C isotherm must be equidistant between gridded observations of 4°C & 6°C)
- isopleths never cross other isopleths of the same variable (e.g., isotherms can't cross other isotherms, but isotherms can cross isobars)
- isopleths never end in the middle of the map
- label each isopleth, either at the edges of the map (the only places where isopleths can end), or along closed-loop isopleths
- isopleths have no kinks, except sometimes at fronts or jets

Finally, label any relative maxima and minima, such as the warm and cold centers in Fig. 9.17b.

You can identify **frontal zones** as regions of **tight isotherm packing** (Fig. 9.17c), namely, where the isotherms are closer together. Note that no isotherm needs to remain within a frontal zone.

Finally, always draw a heavy line representing the front on the warm side of the frontal zone (Fig. 9.17d), regardless of whether it is a cold, warm, or stationary front.

Frontal symbols are drawn on the side of the frontal line toward which the front moves. Draw semicircles to identify warm fronts (for cases where cold air retreats). Draw triangles to identify a cold front (where cold air advances). Draw alternating triangles and semicircles on opposite sides of the front to denote a stationary front, and on the same side for an occluded front. Fig. 9.18 summarizes frontal symbols, many of which will be discussed in more detail in the Airmasses and Fronts chapter.

In Fig. 9.17d, there would not have been enough information to determine if the cold air was advancing, retreating, or stationary, if I hadn't added arrows showing frontal movement. When you analyze fronts on real weather maps, determine their movement from successive weather maps at different times, by the wind direction across the front, or by their position relative to low-pressure centers.

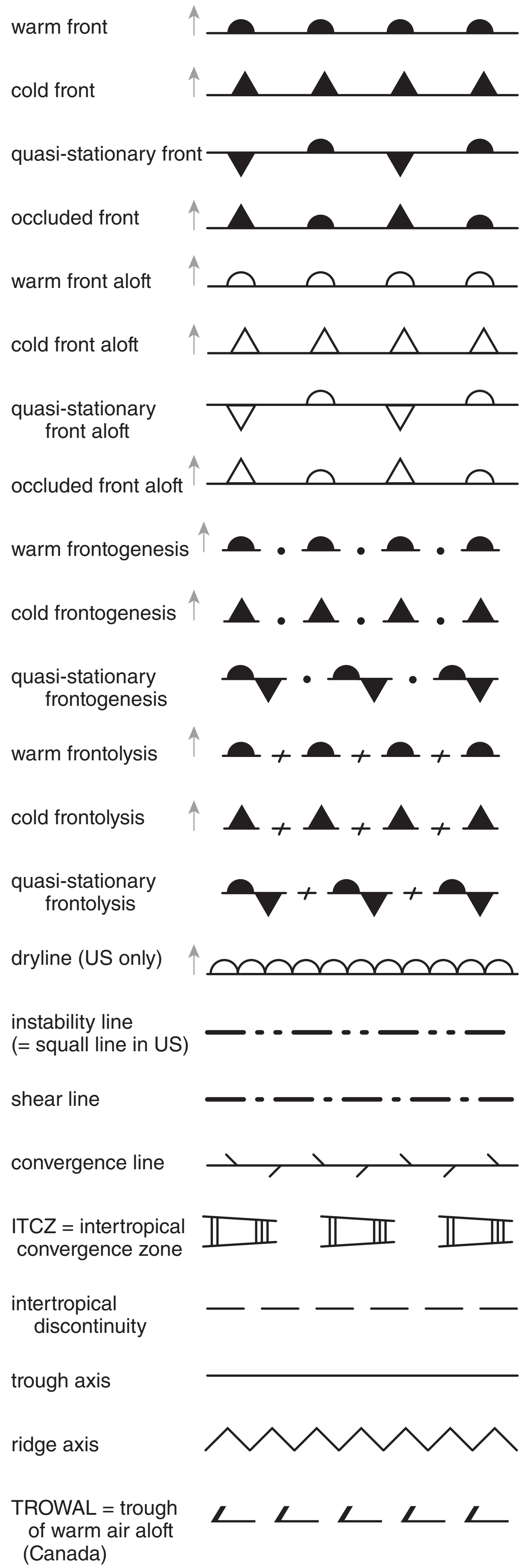


Figure 9.18 (at right)

Glyphs for fronts, other airmass boundaries, and axes. The suffix "genesis" implies a forming or intensifying front, while "lysis" implies a weakening or dying front. The thin grey arrow indicates the direction of frontal movement. A stationary front is a frontal boundary that does not move very much (WMO calls it a quasi-stationary front). Occluded fronts and drylines will be explained in the Fronts chapter. The ITCZ is explained in the General Circulation chapter.
[sources: WMO-No.485 Manual on the Global Data Processing and Forecasting System (2010, 2012, 2015), page II-4-12; and WMO-No.306 Manual on Codes].

9.4. REVIEW

Hundreds of thousands of weather observations are simultaneously made around the world at standard observation times. Some of these weather observations are communicated as alphanumeric codes such as the METAR that can be read and decoded by humans. A station-plot model is often used to plot weather data on weather maps. Map analysis is routinely performed by computer, but you can also draw isopleths and identify fronts, highs, lows, and airmasses by hand.

9.5. HOMEWORK EXERCISES

9.5.1. Broaden Knowledge & Comprehension

B1. Access a surface weather map that shows station plot information for Denver, Colorado USA. Decode the plotted pressure value, and tell how you can identify whether that pressure is the actual station pressure, or is the pressure reduced to sea level.

B2. Do a web search to identify 2 or more suggestions on how to reduce station pressure to sea level. Pick two methods that are different from the method described in this chapter.

B3. Search the web for maps that show where METAR weather data are available. Print such a map that covers your location, and identify which 3 stations are closest to you.

B13. Search the web for sites that give the ICAO station ID for different locations. This is the ID used to indicate the name of the weather station in a METAR.

B4. Access the current METAR for your town, or for a nearby town assigned by your instructor. Try to decode it manually, and write out its message in words. Compare your result with a computer decoded METAR if available.

B5. Search the web for maps that show where weather observations are made today (or recently), such as were shown in Figs. 9.2-13.16. Hint: If you can't find a site associated with your own country's weather service, try searching on "ECMWF data coverage" or "Met Office data coverage" or "FNMOC data coverage".

B6. For each of the different sensor types discussed in the section on Weather Observation Locations, use the web to get photos of each type of instrument: rawinsonde, dropsonde, AWOS, etc.

B7. Search the web for a history of ocean weather ships, and summarize your findings.

B8. Access from the web a current plotted surface weather map that has the weather symbols plotted around each weather station. Find the station closest to your location (or use a station assigned by the instructor), and decode the weather data into words.

B9 Access simple weather maps from the web that print values of pressure or temperature at the weather stations, but which do not have the isopleths drawn. Print these, and then draw your own isobars or isotherms. If you can do both isobars and isotherms for a given time over the same region, then identify the frontal zone, and determine if the front is warm, cold, or occluded. Plot these features on your analyzed maps. Identify highs and lows and airmasses.

B10. Use the web to access surface weather maps showing plotted station symbols, along with the frontal analysis. Compare surface temperature, wind, and pressure along a line of weather stations that crosses through the frontal zone. How do the observations compare with your ideas about frontal characteristics?

9.5.2. Apply

A1. Find the pressure "reduced to sea level" using the following station observations of pressure, height, and virtual temperature. Assume no temperature change over the past 12 hours.

	P (kPa)	z (m)	T_v(°C)
a.	102	–30	40
b.	100	20	35
c.	98	150	30
d.	96	380	30
e.	94	610	20
f.	92	830	18
g.	90	980	15
h.	88	1200	12
i.	86	1350	5
j	84	1620	5
k.	82	1860	2

A2. Decode the following METAR. Hint: It is not necessary to decode the station location; just write its ICAO abbreviation followed by the decoded METAR. Do not decode the remarks (RMK).

a. KDFW 022319Z 20003KT 10SM TS FEW037 SCT050CB BKN065 OVC130 27/20 A2998 RMK AO2 FRQ LTGICCG TS OHD MOV E-NE

b. KGRK 022317Z 17013KT 4SM TSRA BKN025 BKN040CB BKN250 22/21 A3000 RMK OCNL LTGCCCG SE TS OHD-3SE MOV E

c. KSAT 022253Z 17010KT 10SM SCT034 BKN130 BKN250 28/23 A2998 RMK AO2 RAE42 SLP133 FEW CB DSNT NW-N P0001 T02830233

d. KLRD 022222Z 11015KT M1/4SM TSRA FG OVC001 24/23 A2998 RMK AO2 P0125 PRESRR

e. KELD 022253Z AUTO 14003KT 4SM RA BR OVC024 23/21 A3006 RMK AO2 TSB2153E12 SLP177 T02280211 $

f. KFSM 022311Z 00000KT 10SM TSRA SCT030 22/21 A3004 RMK AO2 P0000

g. KLIT 022253Z 08009KT 7SM TS FEW026 BKN034CB OVC060 27/22 A3003 RMK AO2 RAB28E45 SLP169 OCNL LTGICCC OHD TS OHD MOV N P0000 T02720217

h. KMCB 022315Z AUTO 34010KT 1/4SM +TSRA FG BKN005 OVC035 24/23 A3009 RMK AO2 LTG DSNT ALQDS P0091 $

i. KEET 022309Z AUTO 05003KT 3SM -RA BR SCT024 BKN095 23/23 A3005 RMK AO2 LTG DSNT N AND E AND SW

j. KCKC 022314Z AUTO 20003KT 2SM DZ OVC003 13/11 A3009 RMK AO2

k. CYQT 022300Z 20006KT 20SM BKN026 OVC061 16/11 A3006 RMK SC5AC2 SLP185

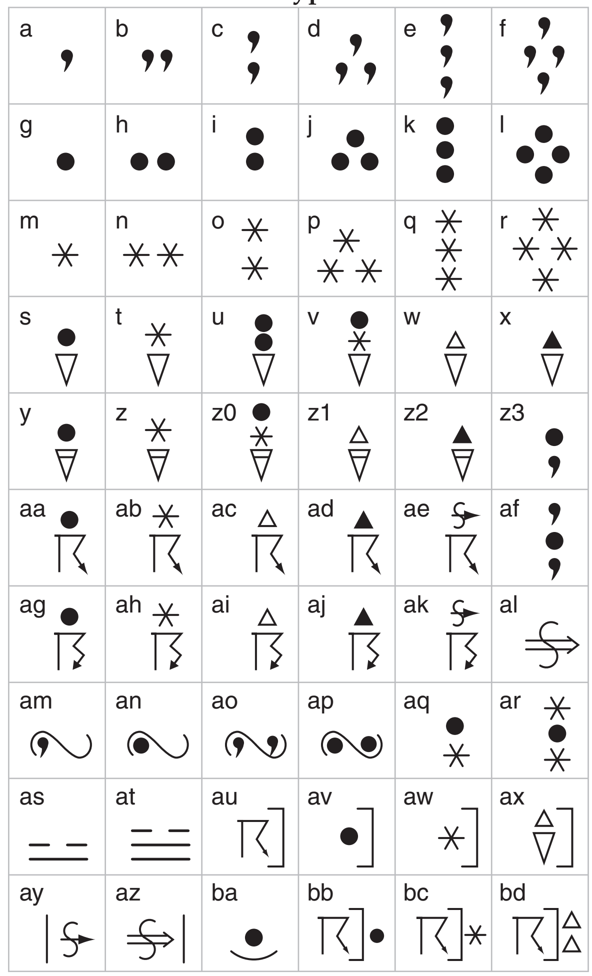
l. CYYU 022300Z 23013KT 15SM FEW035 BKN100 BKN200 BKN220 23/08 A3013 RMK CU2AS2CC1CI1 WND ESTD SLP207

m. CYXZ 022300Z 00000KT 15SM -RA OVC035 14/11 A3021 RMK SC8 SLP239

n. KETB 022325Z AUTO 10007KT 009V149 10SM -RA CLR 19/11 A3021 RMK AO2

o. CYWA 022327Z AUTO 33004KT 9SM RA FEW027 FEW047 BKN069 19/12 A3016

Table 9-11. Weather-Glyph Exercises.



A3. Translate into words a weather glyph assigned from Table 9-11.

A4 For a weather glyph from Table 9-11, write the corresponding METAR abbreviation, if there is one.

A5. Using the station plot model, plot the weather observation data around a station circle drawn on your page for one METAR from exercise A2, as assigned by your instructor.

A6. Using the USA weather map in Fig. 9.19, decode the weather data for the weather station labeled (a) - (w), as assigned by your instructor.

A7. Photocopy the USA weather map in Fig. 9.19 and analyze it by drawing isopleths for:
a. temperature (isotherms) every 5°F
b. pressure (isobars) every 0.4 kPa
c. dew point (isodrosotherms) every 5°F
d. wind speed (isotachs) every 5 knots
e. pressure change (isallobar) every 0.1 kPa

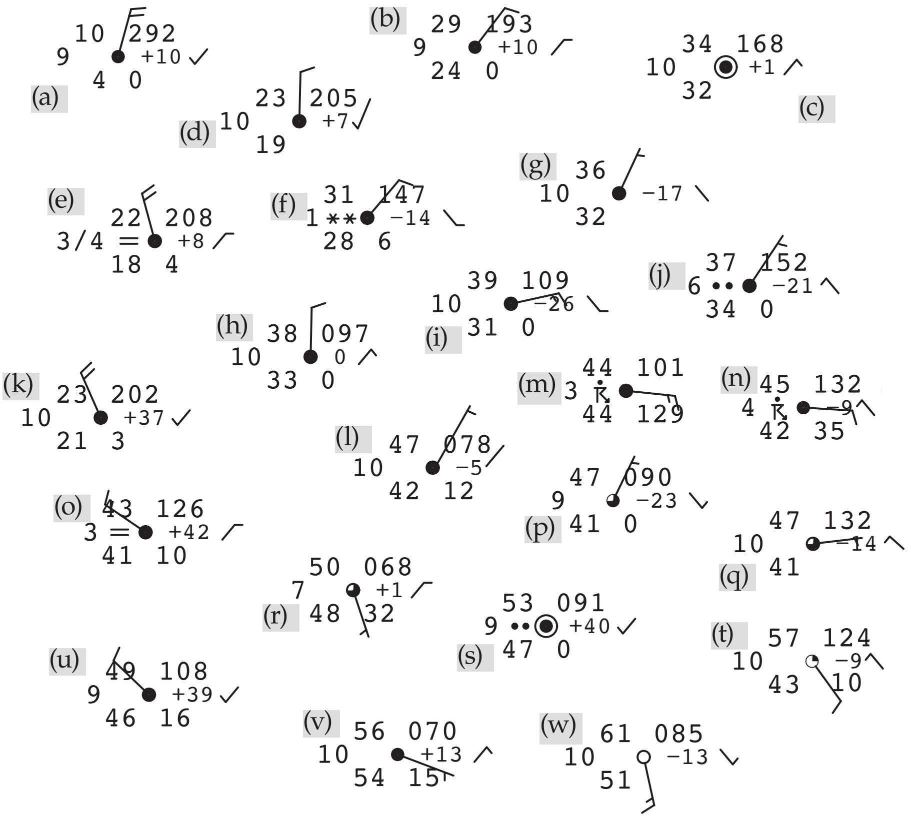


Figure 9.19
USA surface weather map. Units: T and T_d (°F), visibility (miles), speed (knots), pressure and 3-hour tendency (see text), 6-hour precipitation (hundredths of inches). Extracted from a "Daily Weather Map" courtesy of the US National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), National Centers for Environmental Prediction (NCEP), Hydrometeorological Prediction Center (HPC). The date/time of this map is omitted to discourage cheating during map-analysis exercises, and the station locations are shifted slightly to reduce overlap.

8	9	11	12	13	14	15
7	9	11	13	14	15	16
8	9	14	18	20	20	18
9	9	16	19	22	24	24
10	11	18	20	22	25	25
12	14	19	20	22	24	25
14	18	19	21	22	23	24
18	19	20	21	22	23	23

Figure 9.21-i
Temperature (°C). (These figures are show out of order because there was space on this page for it.)

9.5	9.4	9.4	9.5	9.6	9.7	9.8
9.4	9.3	9.2	9.3	9.4	9.6	9.7
9.5	9.2	8.9	9.2	9.3	9.4	9.6
9.5	9.4	9.1	9.4	9.5	9.5	9.6
9.6	9.4	9.2	9.5	9.6	9.7	9.7
9.6	9.4	9.4	9.6	9.7	9.8	9.9
9.6	9.4	9.6	9.7	9.8	9.9	0.0
9.6	9.6	9.7	9.8	9.9	0.0	0.1

Figure 9.21-ii
Pressure (kPa). [The first 1 or 2 digits of the pressure are omitted. Thus, 9.5 on the chart means 99.5 kPa, while 0.1 means 100.1 kPa.]

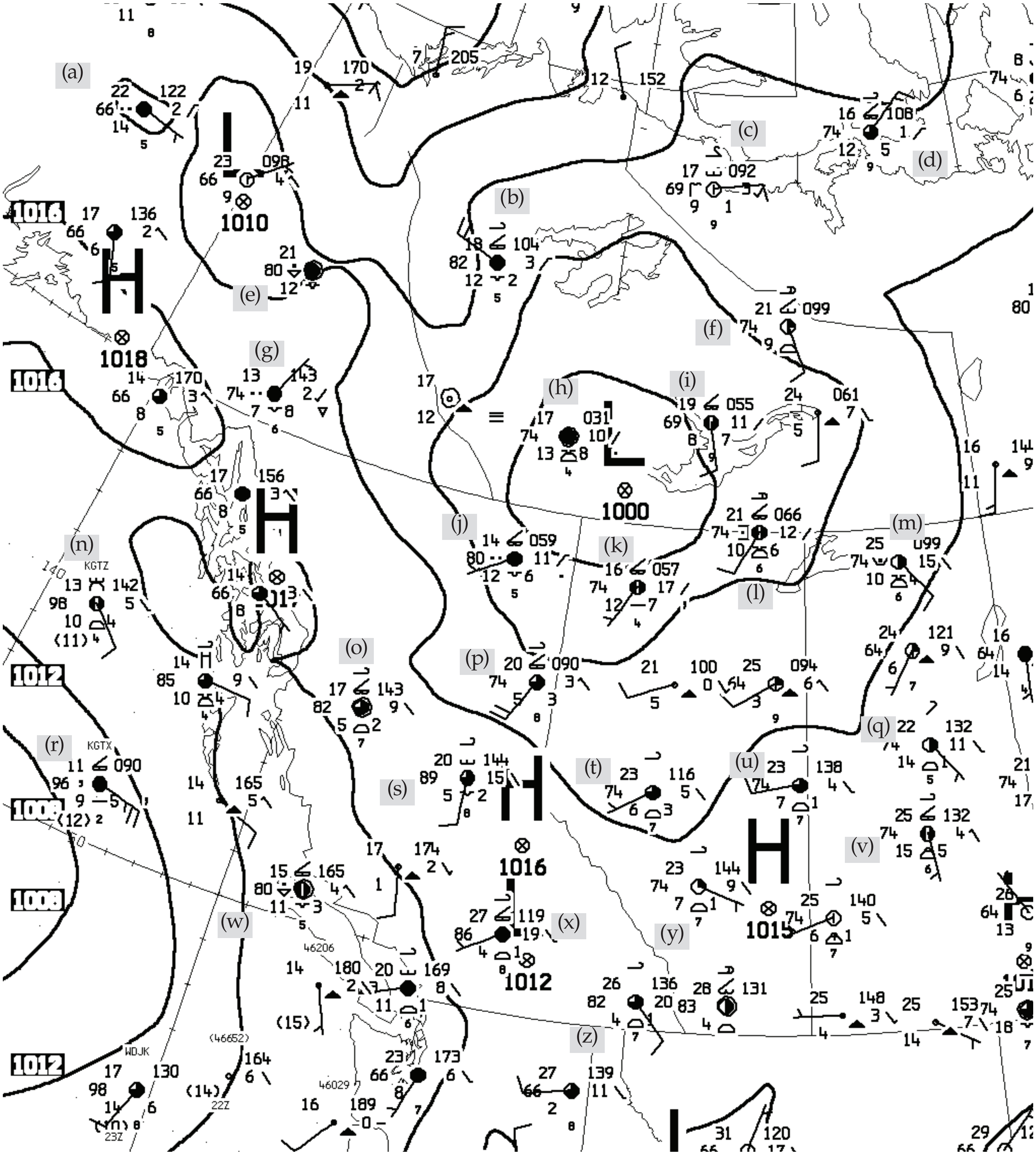


Figure 9.20
Canadian weather map courtesy of Environment Canada. http://www.weatheroffice.gc.ca/analysis/index_e.html

Figure 9.21
(see previous page)

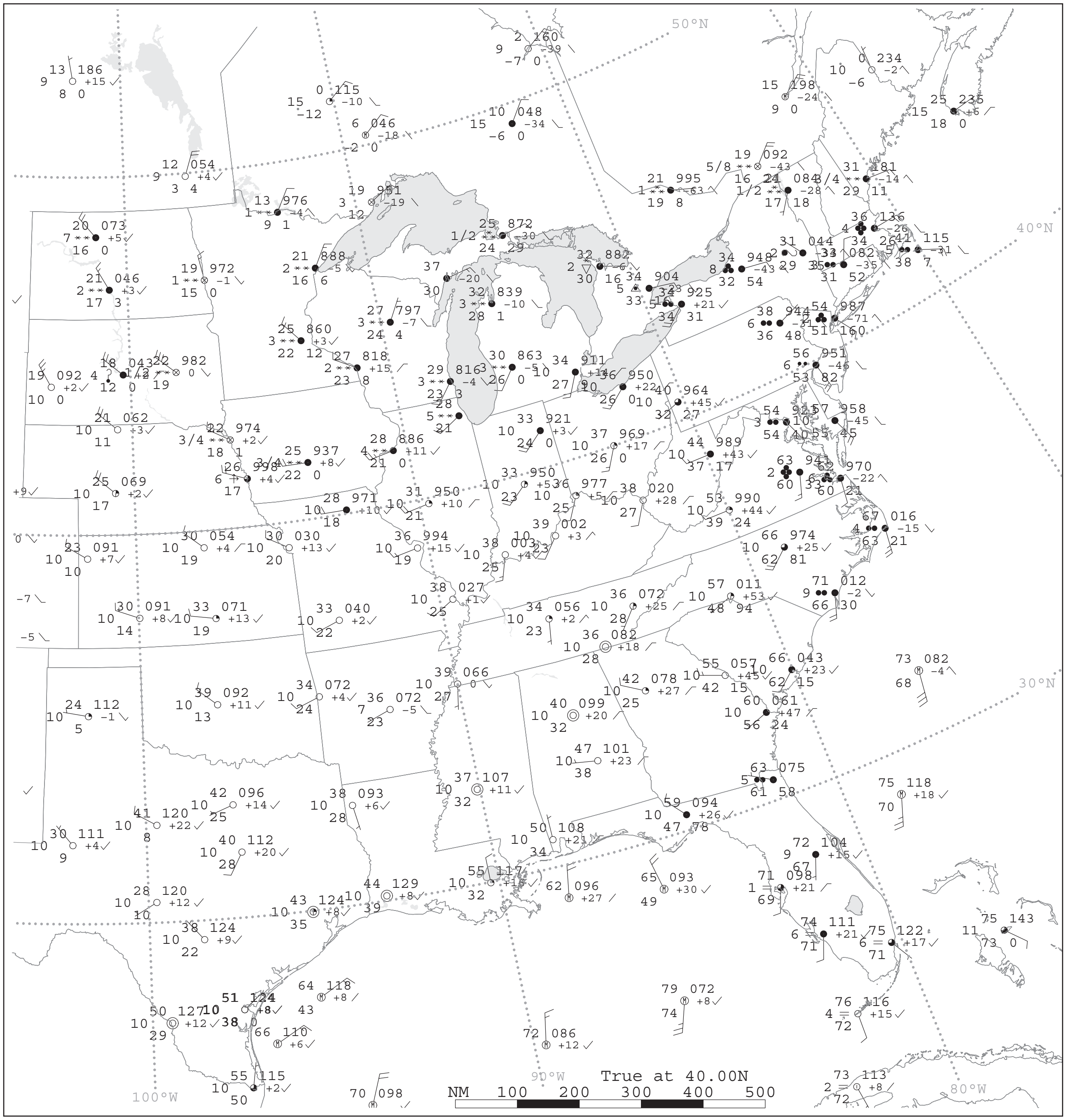


Figure 9.22
A surface weather map of central and eastern N. America. Units: T and T_d (°F), visibility (miles), speed (knots), pressure and 3-hour tendency (see text), 6-hour precipitation (hundredths of inches). Extracted from a "Daily Weather Map" courtesy of the US National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), National Centers for Environmental Prediction (NCEP), Hydrometeorological Prediction Center (HPC). The date/time of this map is omitted to discourage cheating during map-analysis exercises.

A8. Using the Canadian weather map of Fig. 9.20, decode the weather data for the station labeled (a) - (z), as assigned by your instructor.

A9. Photocopy the Canadian weather map of Fig. 9.20, and analyze it by drawing isopleths for the following quantities.
a. temperature (isotherms) every 2°C
b. dew point (isodrosotherms) every 2°C
c. pressure change (isallobar) every 0.1 kPa
d. total cloud coverage (isonephs) every okta
e. visibility every 5 km

A10. Both of the weather maps of Fig. 9.21 correspond to the same weather. Do the following work on a photocopy of these charts:
a. Draw isotherms and identify warm and cold centers. Label isotherms every 2°C.
b. Draw isobars every 0.2 kPa and identify high and low pressure centers.
c. Add likely wind vectors to the pressure chart.
d. Identify the frontal zone(s) and draw the frontal boundary on the temperature chart.
e. Use both charts to determine the type of front (cold, warm), and draw the appropriate frontal symbols on the front.
f. Indicate likely regions for clouds and suggest cloud types in those regions.
g. Indicate likely regions for precipitation.
h. For which hemisphere are these maps?

9.5.3. Evaluate & Analyze

E1. Are there any locations in the world where you could get a reasonable surface weather map without first reducing the pressure to mean sea level? Explain.

E2. What aspects of mean sea level reduction are physically unsound or weak? Explain.

E3. One of the isoplething instructions was that an isopleth cannot end in the middle of the map. Explain why such an ending isopleth would imply a physically impossible weather situation.

E4. Make a photocopy of the surface weather map (Fig. 9.22) on the next page, and analyze your copy by drawing isobars (solid lines), isotherms (dashed lines), high- and low-pressure centers, airmasses, and fronts.

9.5.4. Synthesize

S1. Suppose that you wanted to plot a map of thickness of the 100 to 50 kPa layer (see the General Circulation chapter for a review of thickness maps). However, in some parts of the world, the terrain elevation is so high that the surface pressure is lower than 100 kPa. Namely, part of the 100 to 50 kPa layer would be below ground.

Extend the methods on sea-level pressure reduction to create an equation or method for estimating thickness of the 100 to 50 kPa layer over high ground, based on available surface and atmospheric sounding data.

S2 What if there were no satellite data? How would our ability to analyze the weather change?

S3. What if only satellite data existed? How would our ability to analyze the weather change?

S4. a. Suppose that all the weather observations over land were accurate, and all the ones over oceans had large errors. At mid-latitudes where weather moves from west to east, discuss how forecast skill would vary from coast to coast across a continent such as N. America.

b. How would forecast skill be different if observations over oceans were accurate, and over land were inaccurate?

S5. Pilots flying visually (VFR) need a certain minimum visibility and cloud ceiling height. The **ceiling** is the altitude of the lowest cloud layer that has a coverage of broken or overcast. If there is an obscuration such as smoke or haze, the ceiling is the vertical visibility from the ground looking up.

Use the web to access pilot regulations for your country to learn the ceiling and visibility needed to land VFR at an airport with a control tower. Then translate those values into the codes for a station plot model, and write those values in the appropriate box relative to a station circle.

S6. In Fig. 9.4, notice that west of N. America is a large data-sparse region over the N.E. Pacific Ocean. This region, shown in Fig. 9.23 below, is called the **Pacific data void**. Although there is buoy and ship data near the surface, and aircraft data near the tropopause, there is a lack of mid-tropospheric data in that region.

Although Figs. 9.2 - 9.12 show lots of satellite data over that region, satellites do not have the vertical coverage and do not measure all the meteorological variables needed to use as a starting point for accurate weather forecasts.

Suppose you had an unlimited budget. What instruments and instrument platforms (e.g., weather ships, etc.) would you deploy to get dense spatial coverage of temperature, humidity, and winds in the Pacific data void? If you had a limited budget, how would your proposal be different?

[Historical note: Anchored weather ships such as one called **Station Papa** at 50°N 145°W were formerly stationed in the N.E. Pacific, but all these ships were removed due to budget cutbacks. When they were removed, weather-prediction skill over large parts of N. America measurably decreased, because mid-latitude weather moves from west to east. Namely, air from over the data void regions moves over North America.]

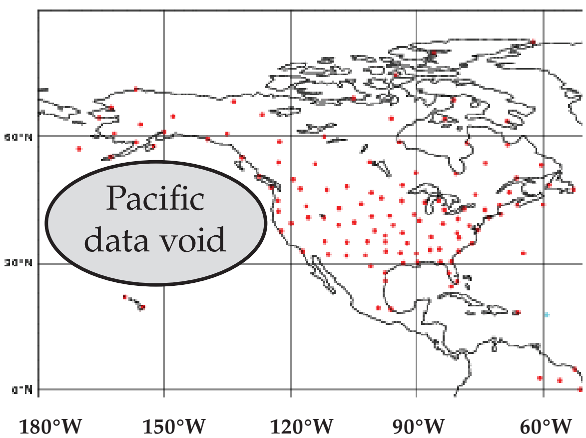


Figure 9.23
The "Pacific data void" & upper-air sounding locations (dots).

A SCIENTIFIC PERSPECTIVE • Creativity in Engineering

"Just as the poet starts with a blank sheet of paper and the artist with a blank canvas, so the engineer today begins with a blank computer screen. Until the outlines of a design are set down, however tentatively, there can be no appeal to science or to critical analysis to judge or test the design. Scientific, rhetorical or aesthetic principles may be called on to inspire, refine and finish a design, but creative things do not come of applying the principles alone. Without the sketch of a thing or a diagram of a process, scientific facts and laws are of little use to engineers. Science may be the theatre, but engineering is the action on the stage."

"Designing a bridge might also be likened to writing a sonnet. Each has a beginning and an end, which must be connected with a sound structure. Common bridges and so-so sonnets can be made by copying or mimicking existing ones, with some small modifications of details here and there, but such are not the creations that earn the forms their reputation or cause our spirits to soar. Masterpieces come from a new treatment of an old form, from a fresh shaping of a familiar genre. The form of the modern suspension bridge — consisting of a deck suspended from cables slung over towers and restrained by anchorages — existed for half a century before John Roebling proposed his Brooklyn Bridge, but the fresh proportions of his Gothic-arched masonry towers, his steel cables and diagonal stays, and his pedestrian walkway centered above dual roadways produced a structure that remains a singular achievement of bridge engineering. Shakespeare's sonnets, while all containing 14 lines of iambic pentameter, are as different from one another and from their contemporaries as one suspension bridge is from another."

– Henry Petroski, 2005: Technology and the humanities. *American Scientist*, **93**, p 305.