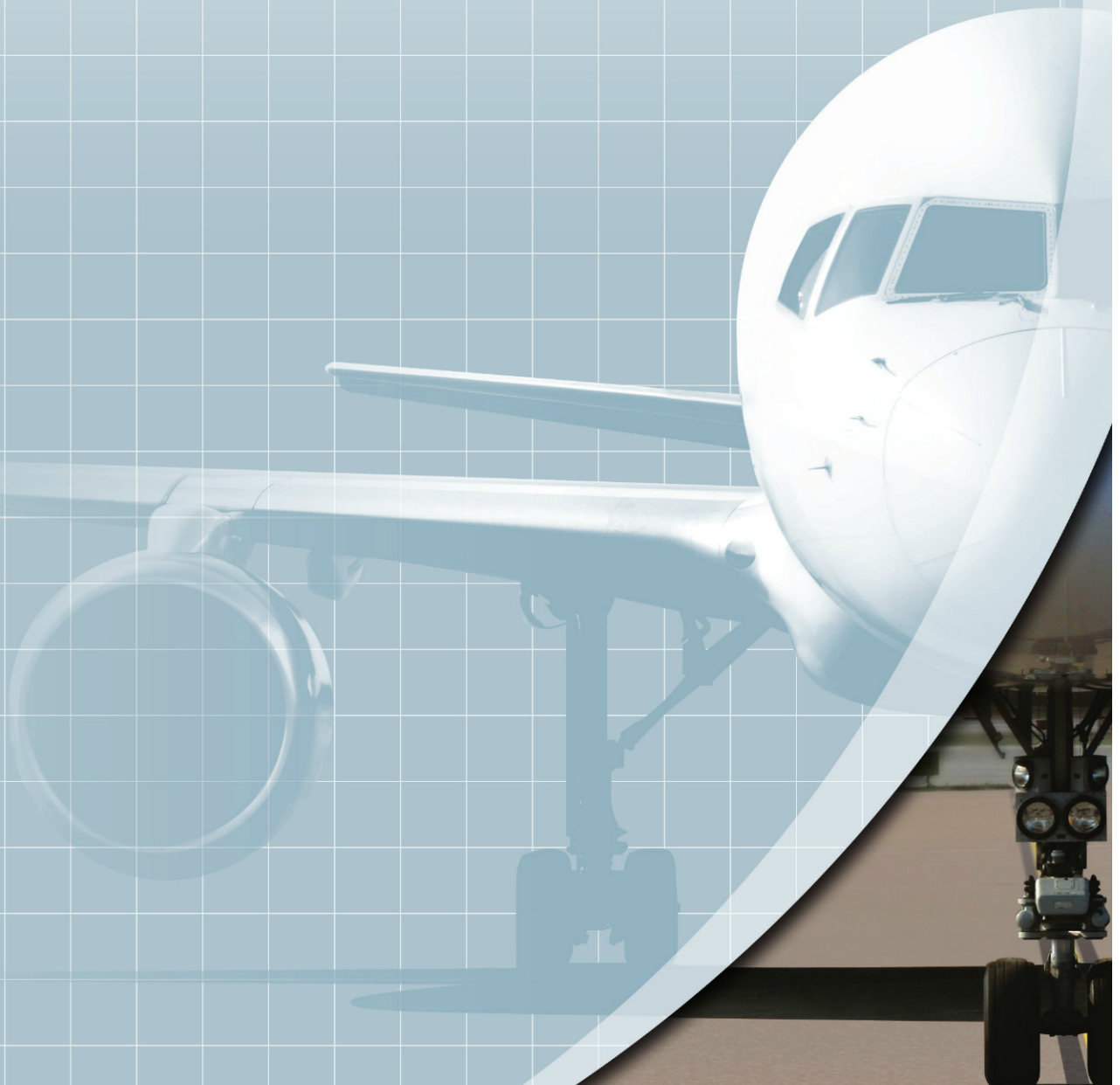


# **JAA Picture Supplements**

## **050 - Meteorology**

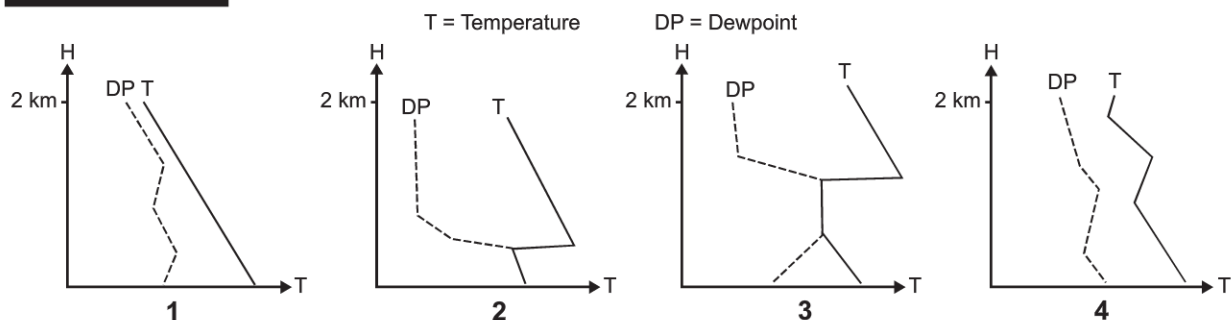




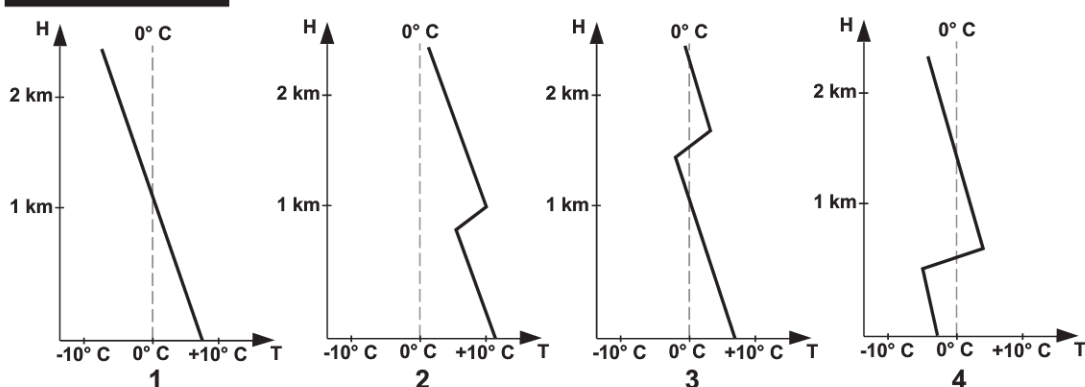


# PICTURE SUPPLEMENTS QUESTIONS

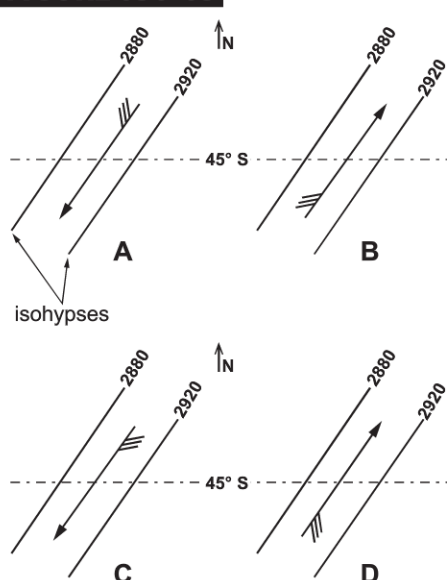
**FIGURE 050-01**



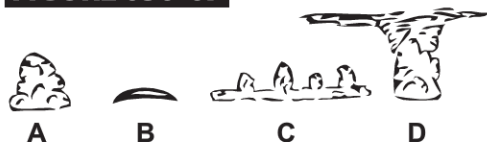
**FIGURE 050-02**



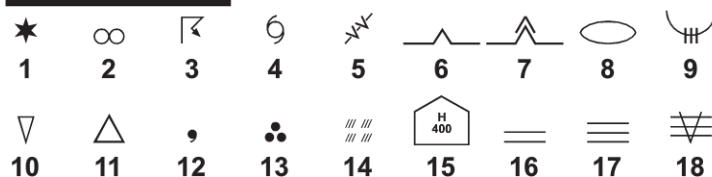
**FIGURE 050-03**



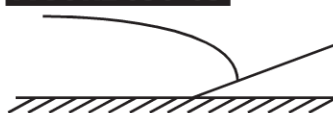
**FIGURE 050-07**



**FIGURE 050-04**



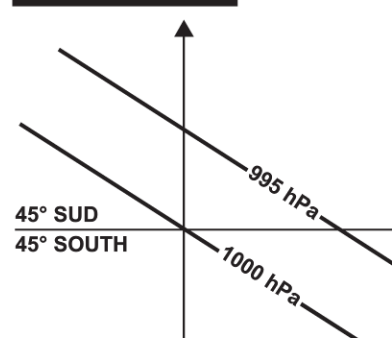
**FIGURE 050-05**



**FIGURE 050-06**



**FIGURE 050-08**



**FIGURE 050-09**

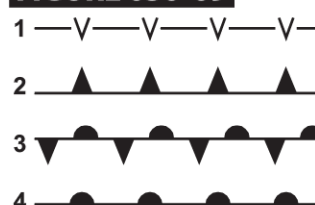


FIGURE 050-10

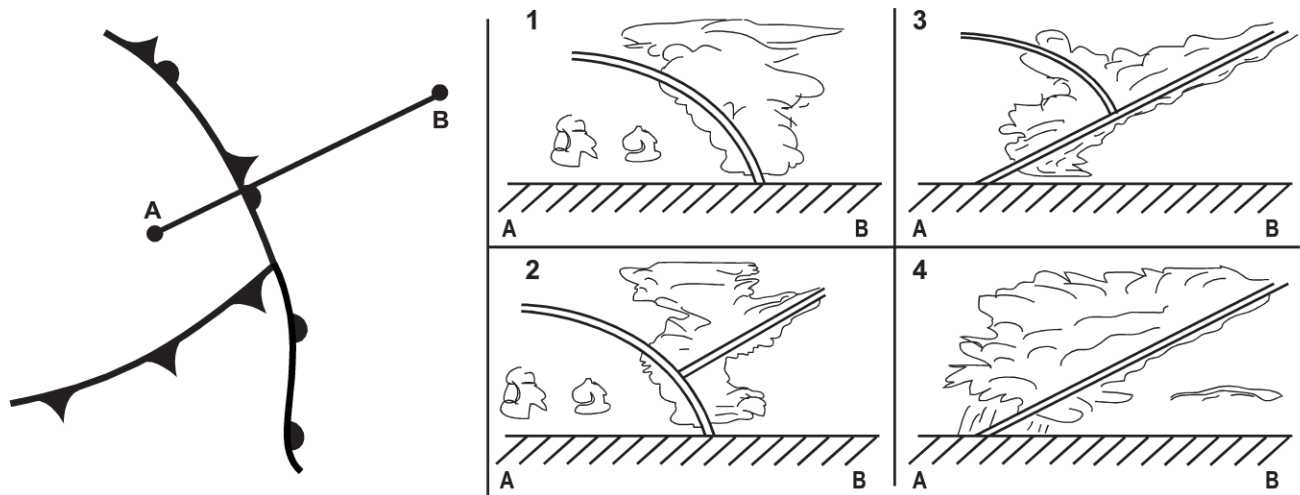


FIGURE 050-11

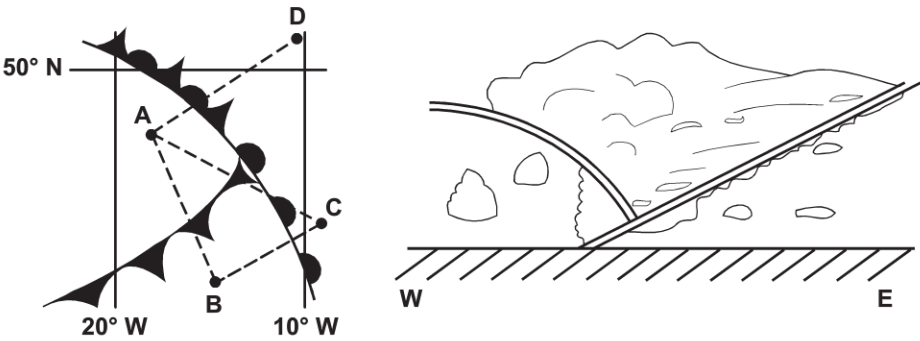


FIGURE 050-12

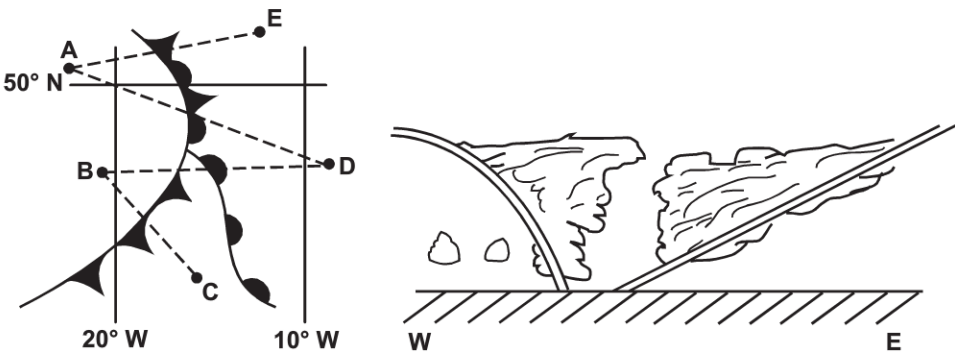
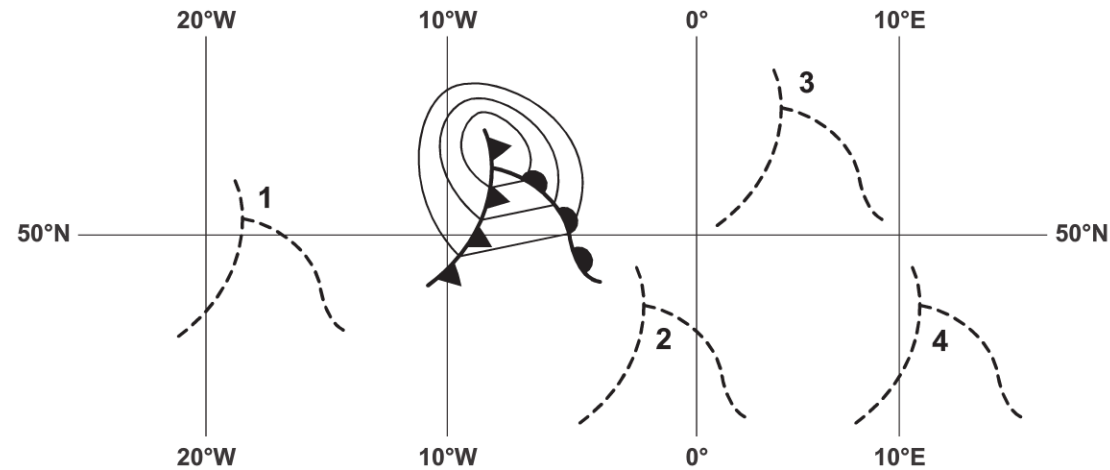
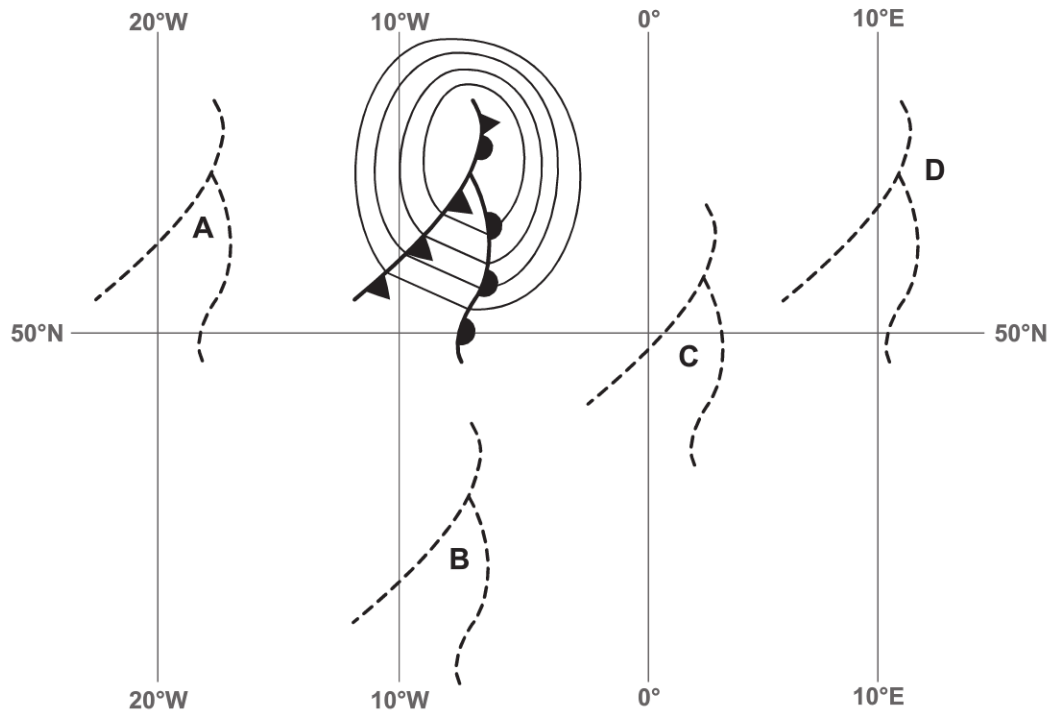


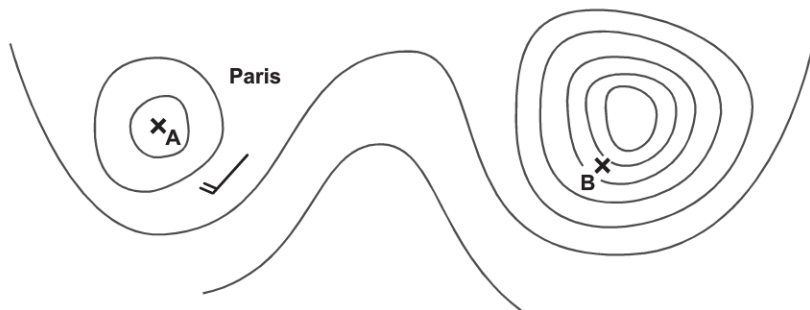
FIGURE 050-13



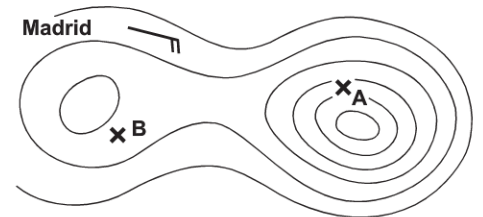
**FIGURE 050-14**



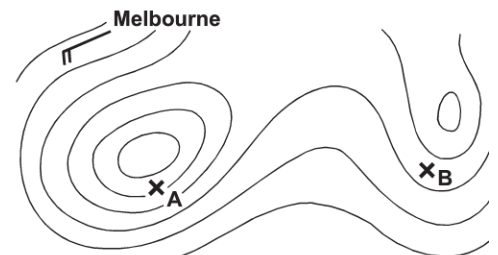
**FIGURE 050-15**



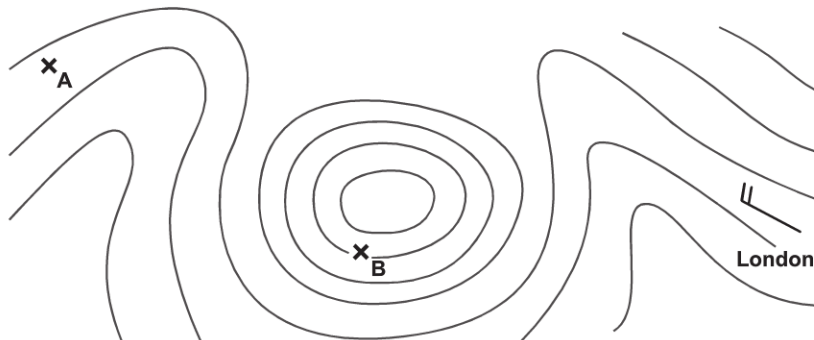
**FIGURE 050-16**



**FIGURE 050-17**



**FIGURE 050-18**



**FIGURE 050-19**

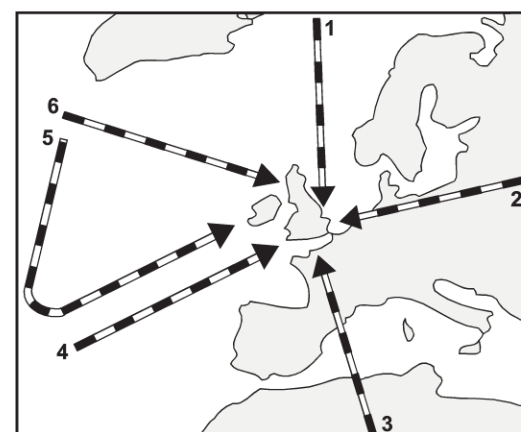


FIGURE 050-20

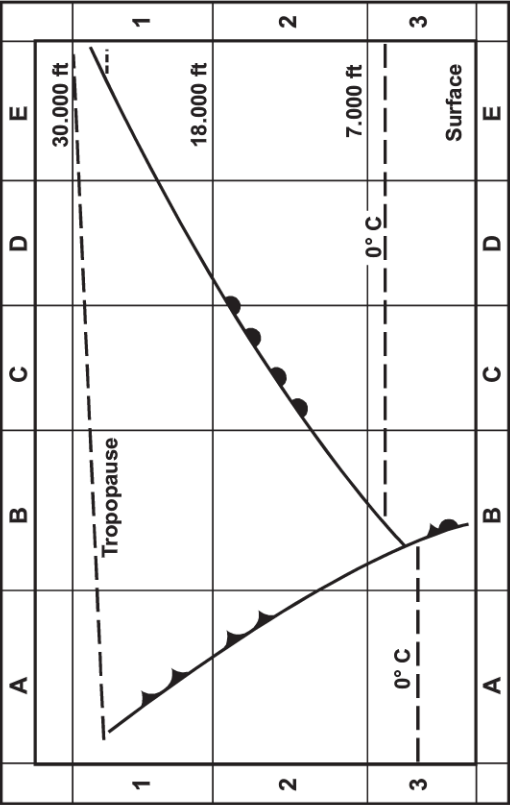


FIGURE 050-21

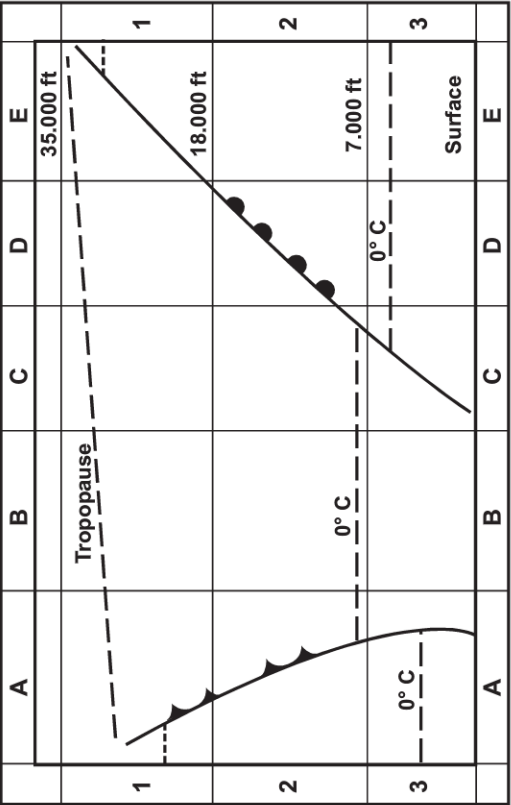


FIGURE 050-22

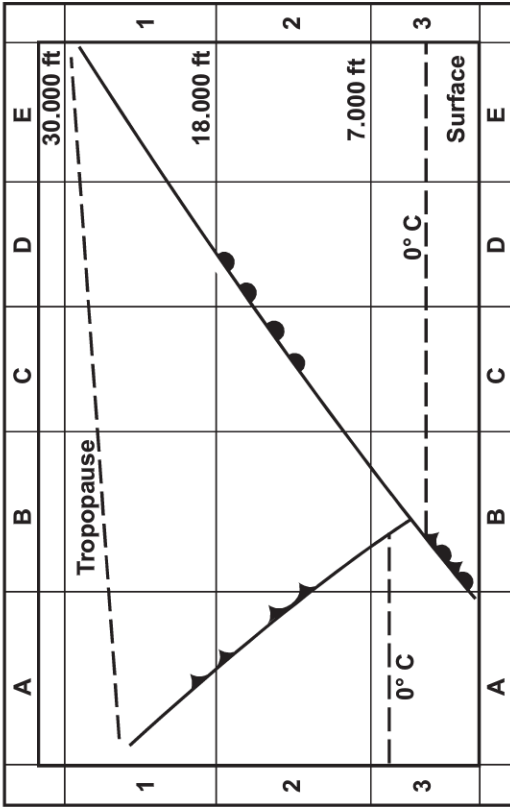
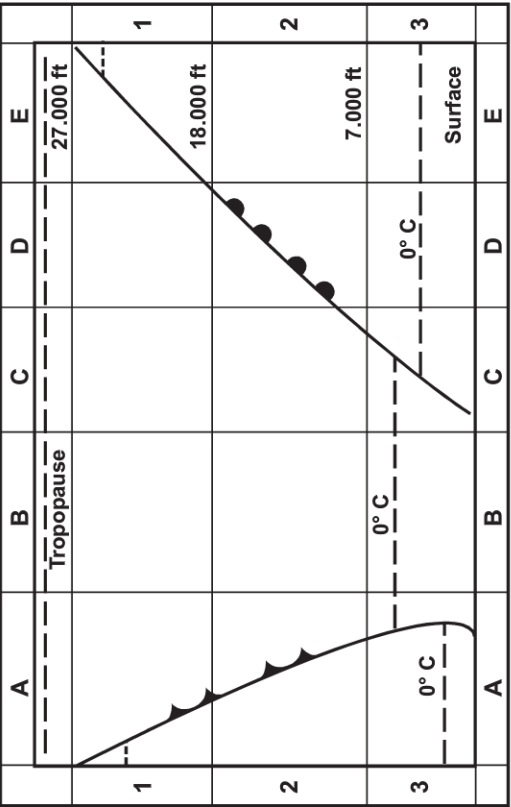
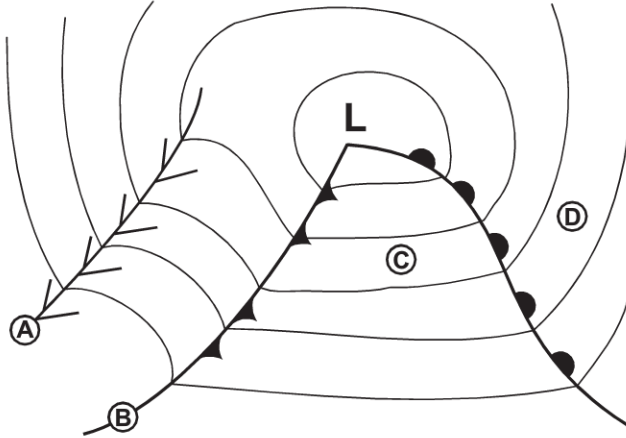


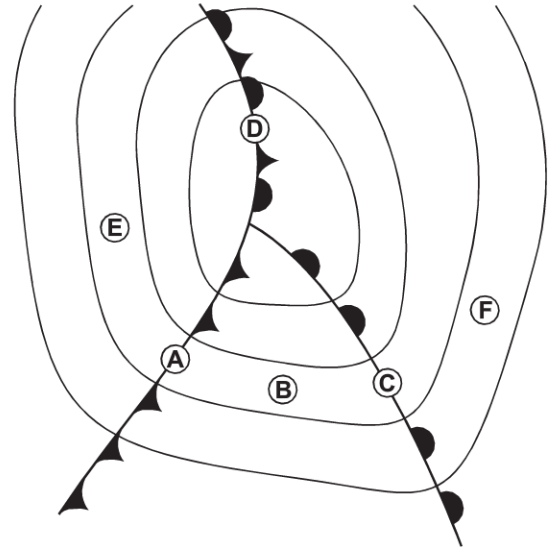
FIGURE 050-23



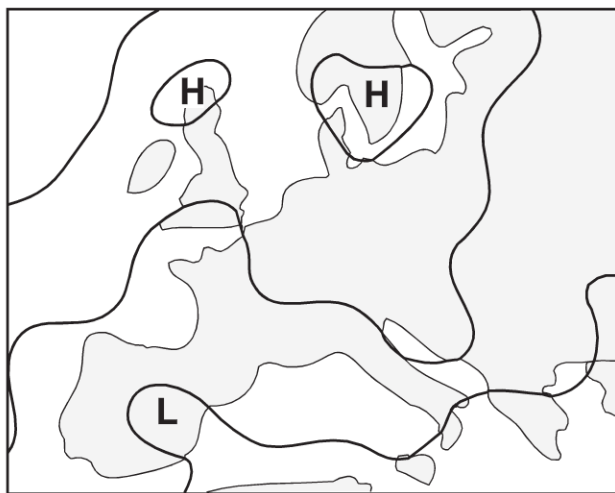
**FIGURE 050-24**



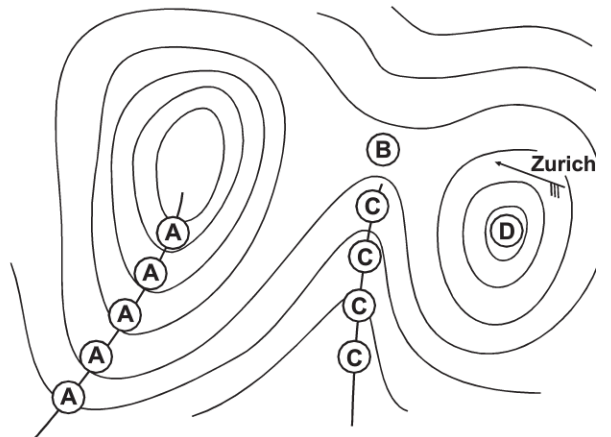
**FIGURE 050-25**



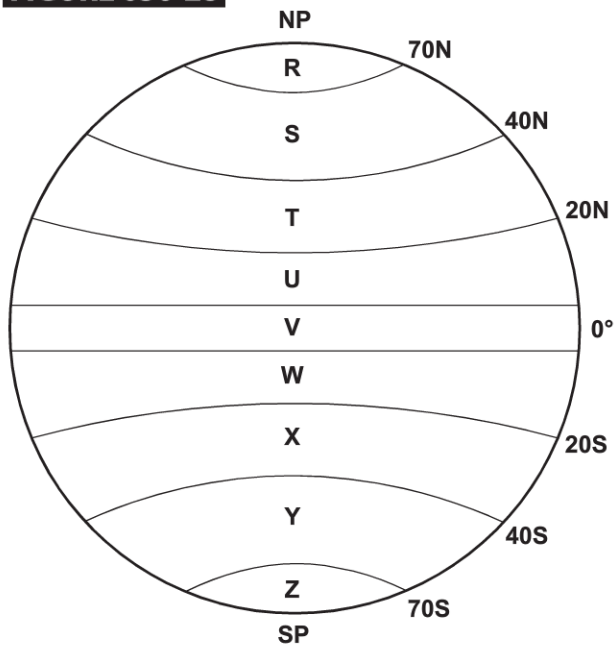
**FIGURE 050-26**



**FIGURE 050-27**



**FIGURE 050-28**



**FIGURE 050-29**

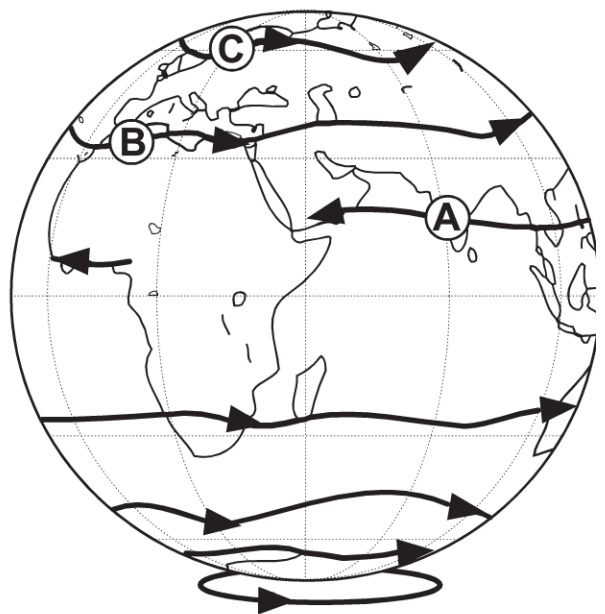


FIGURE 050-30

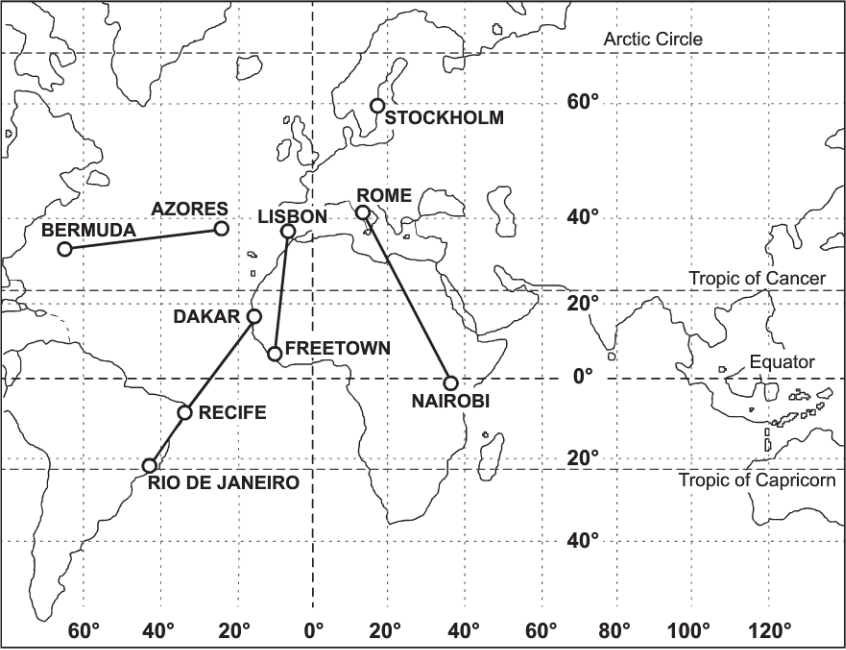
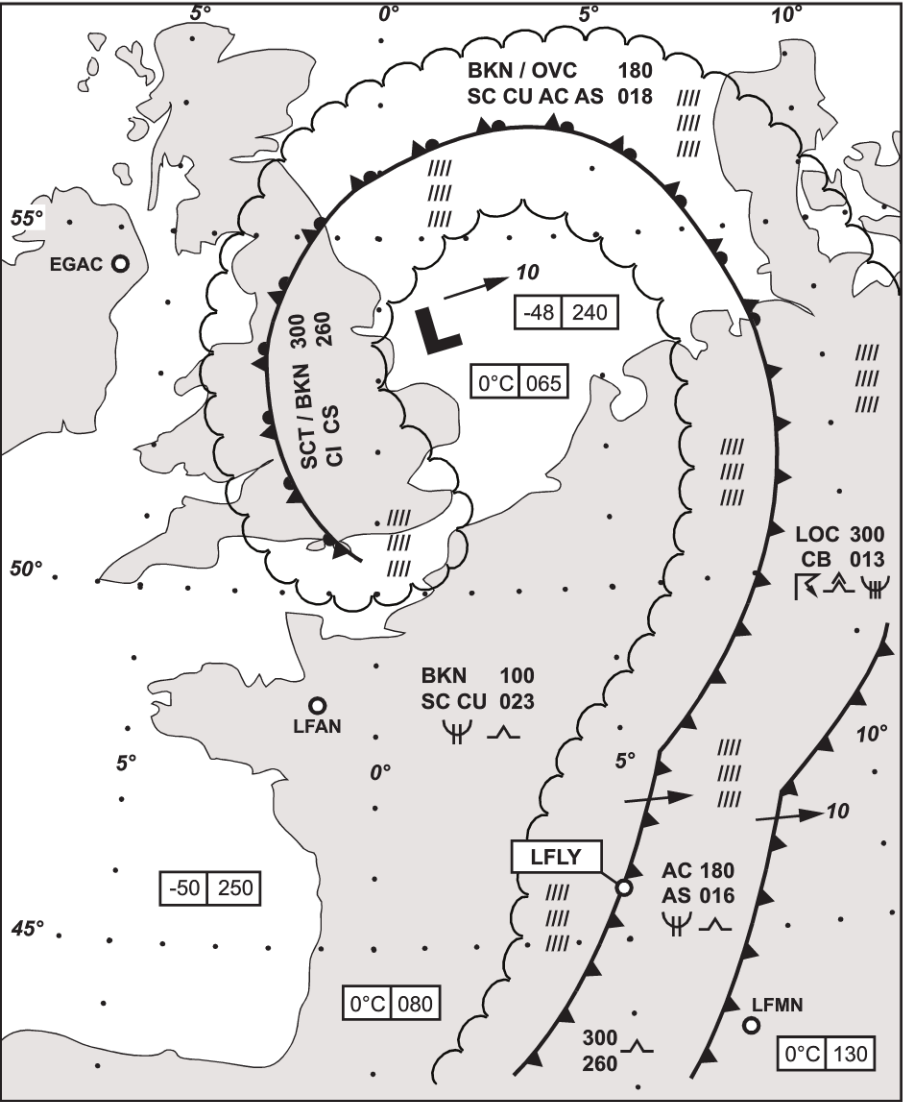
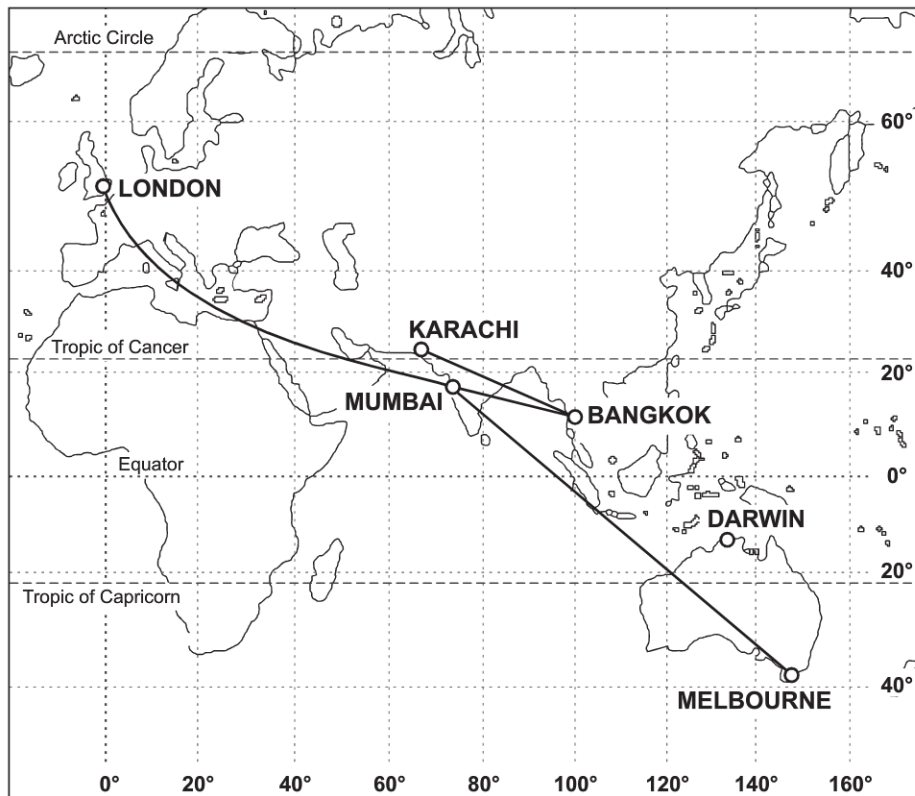


FIGURE 050-31



**FIGURE 050-32**



**FIGURE 050-33**

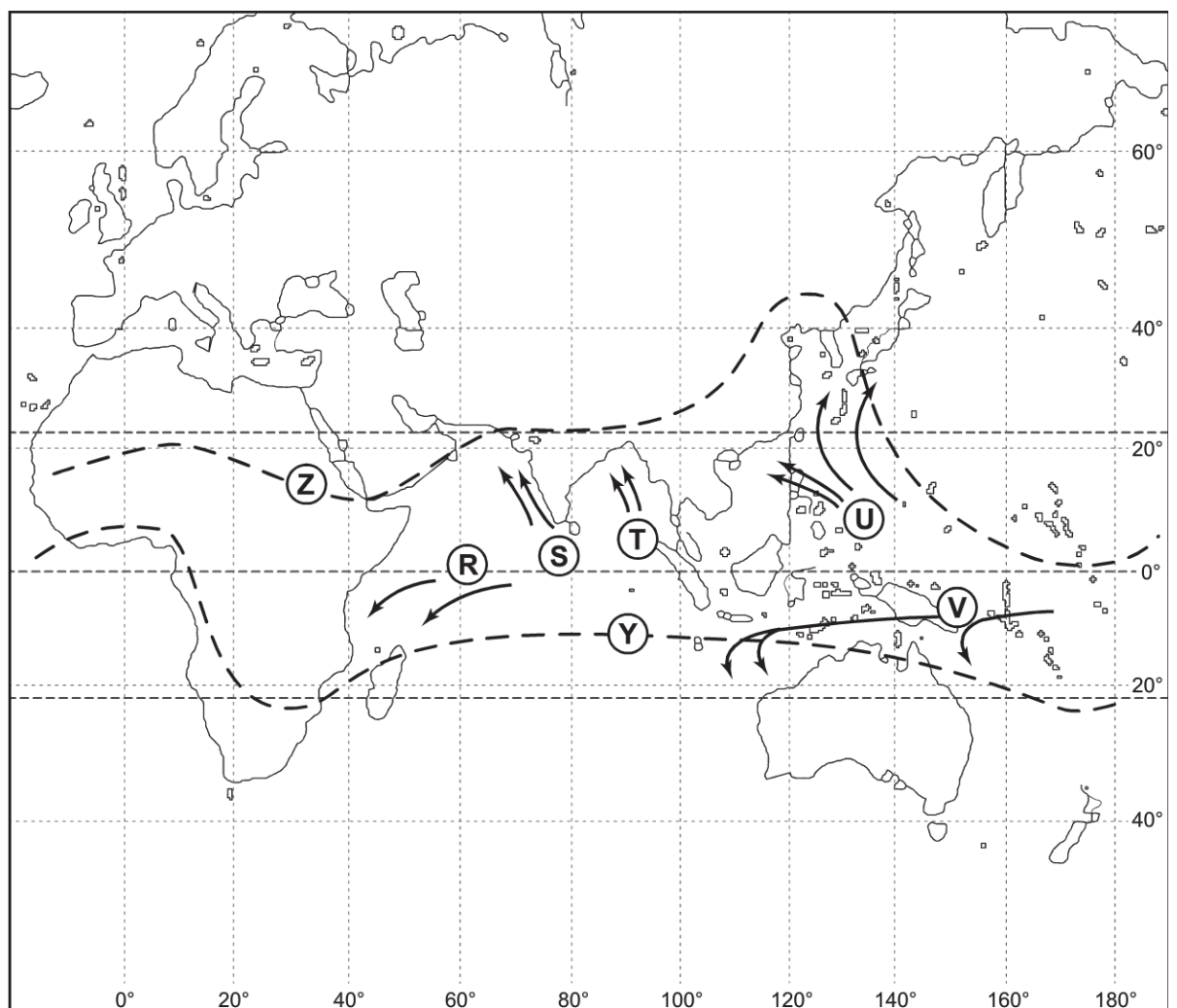




FIGURE 050-34

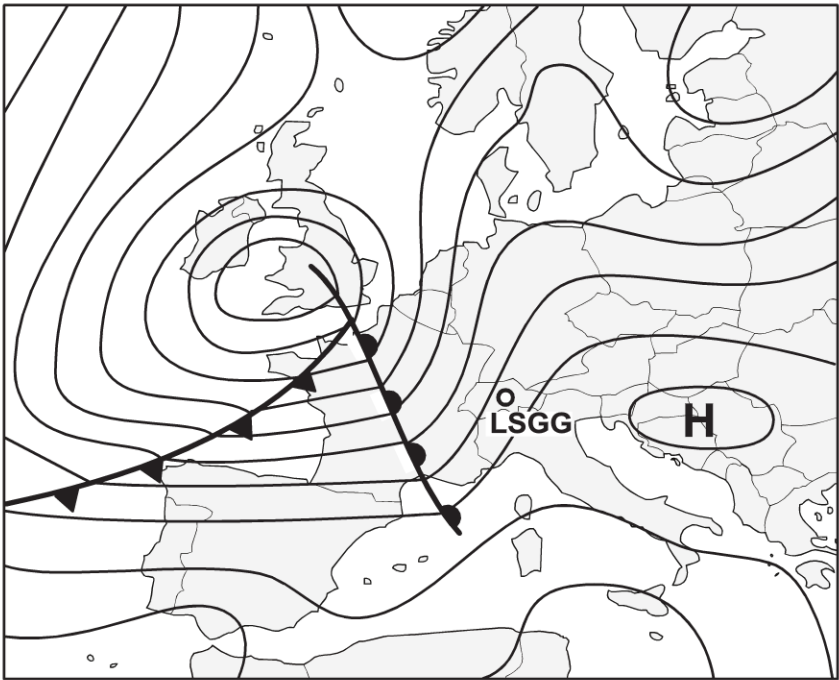
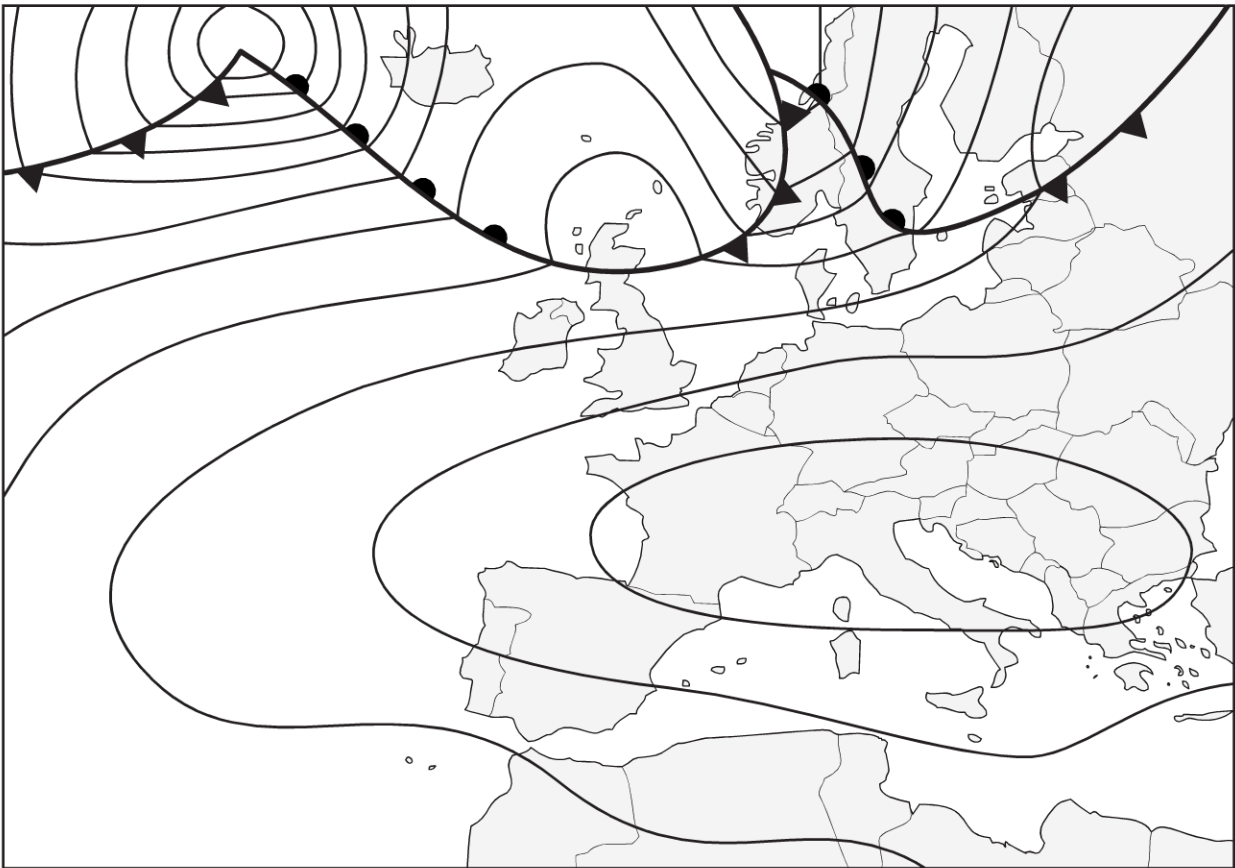
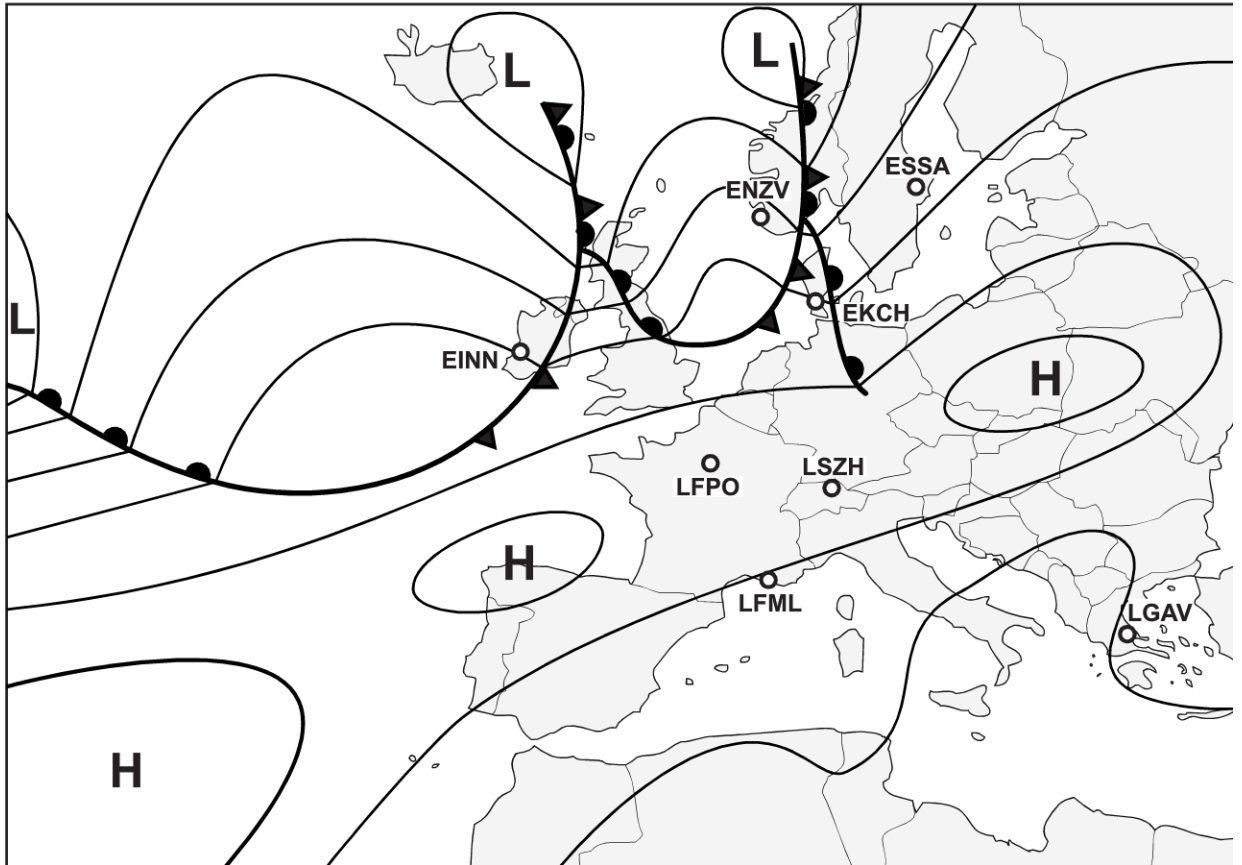


FIGURE 050-35





**FIGURE 050-36**



**FIGURE 050-37**

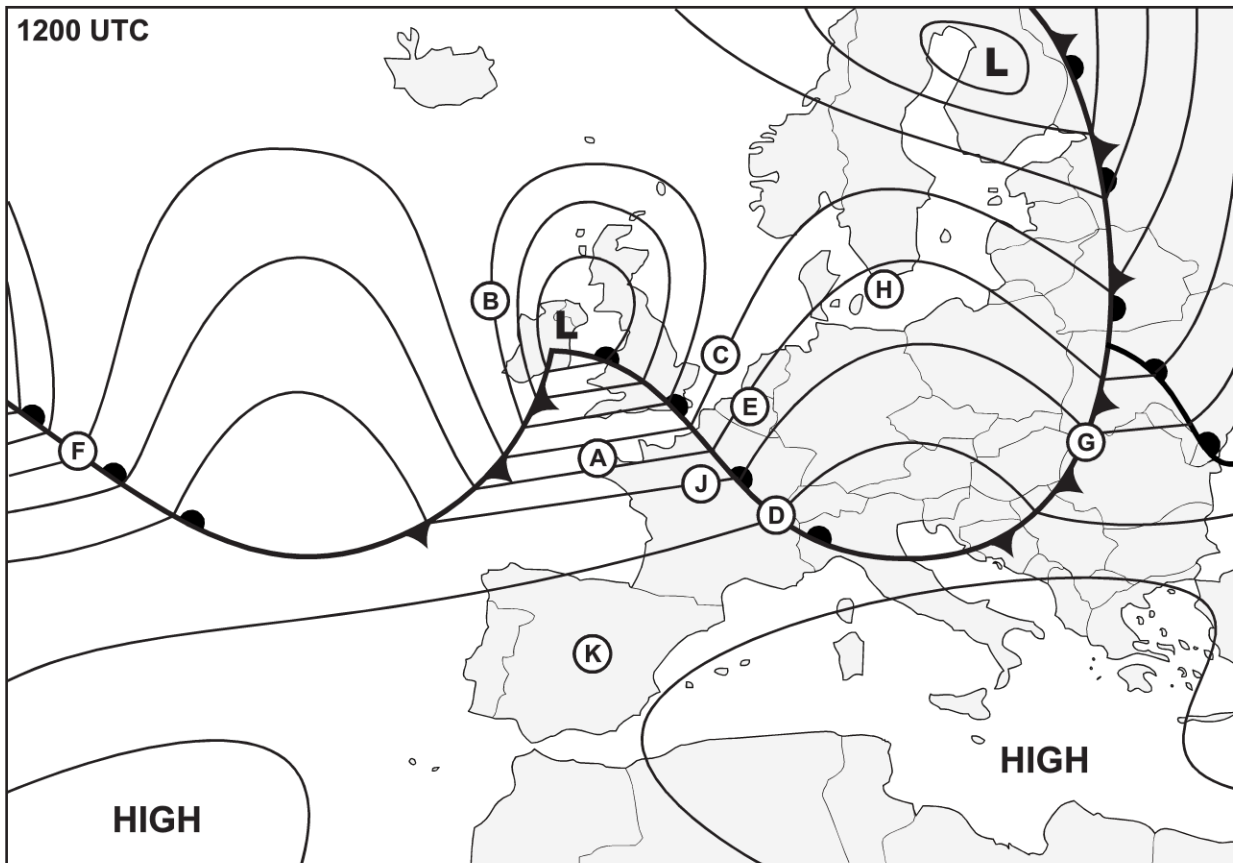


FIGURE 050-38

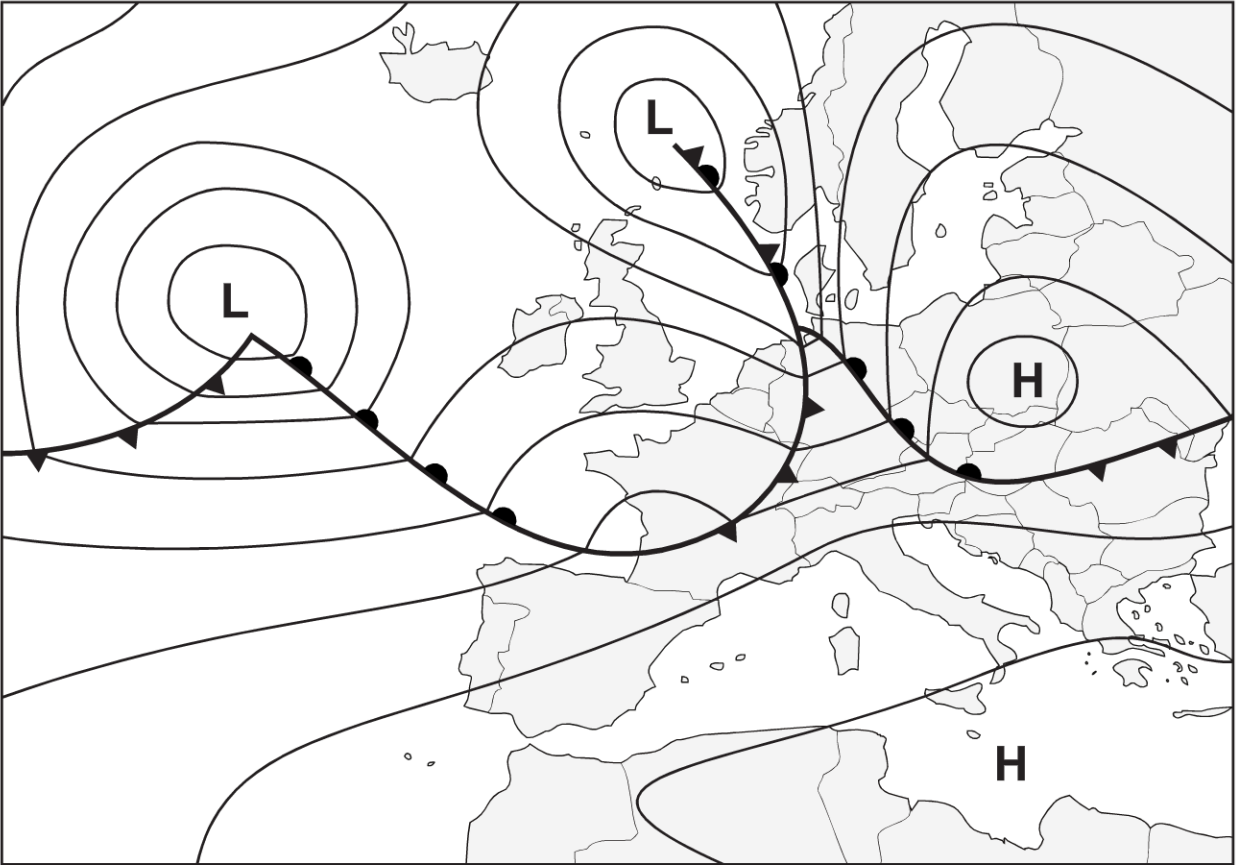
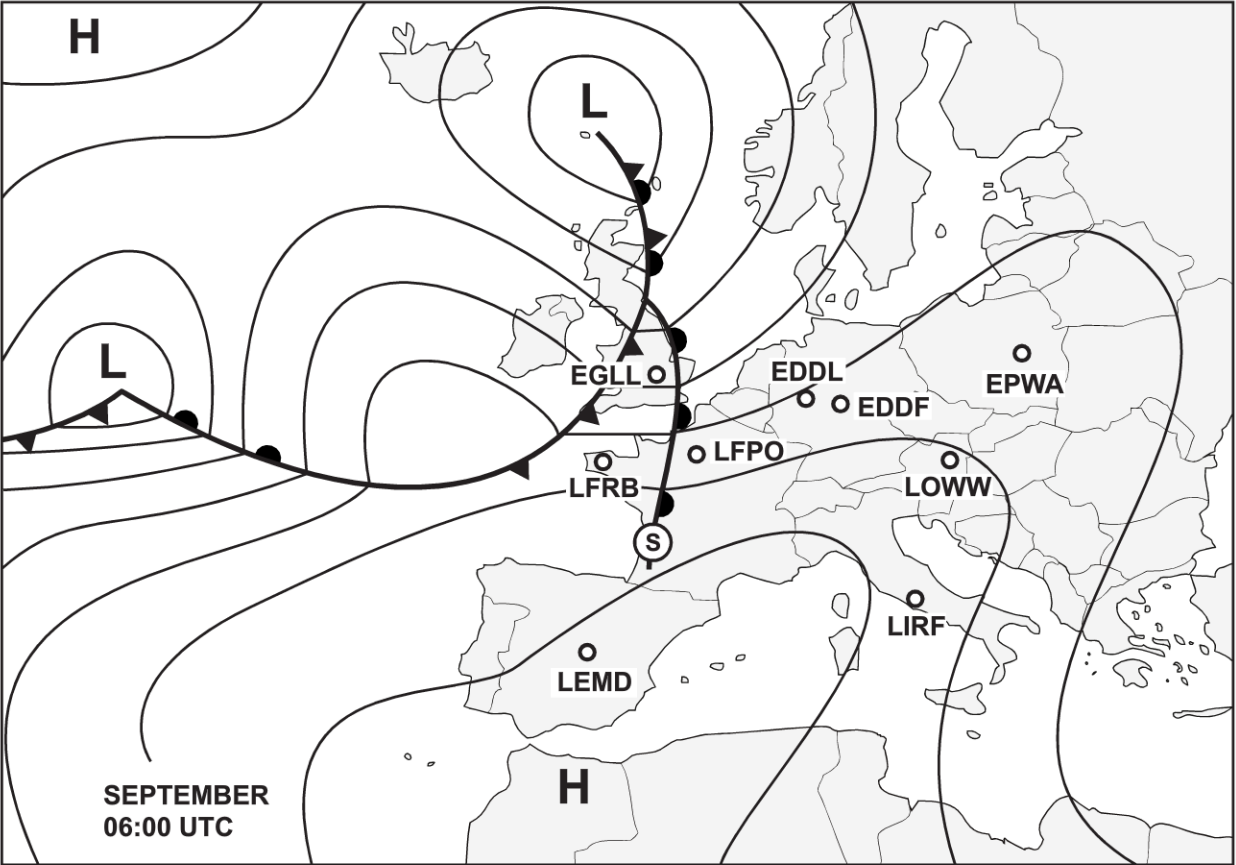
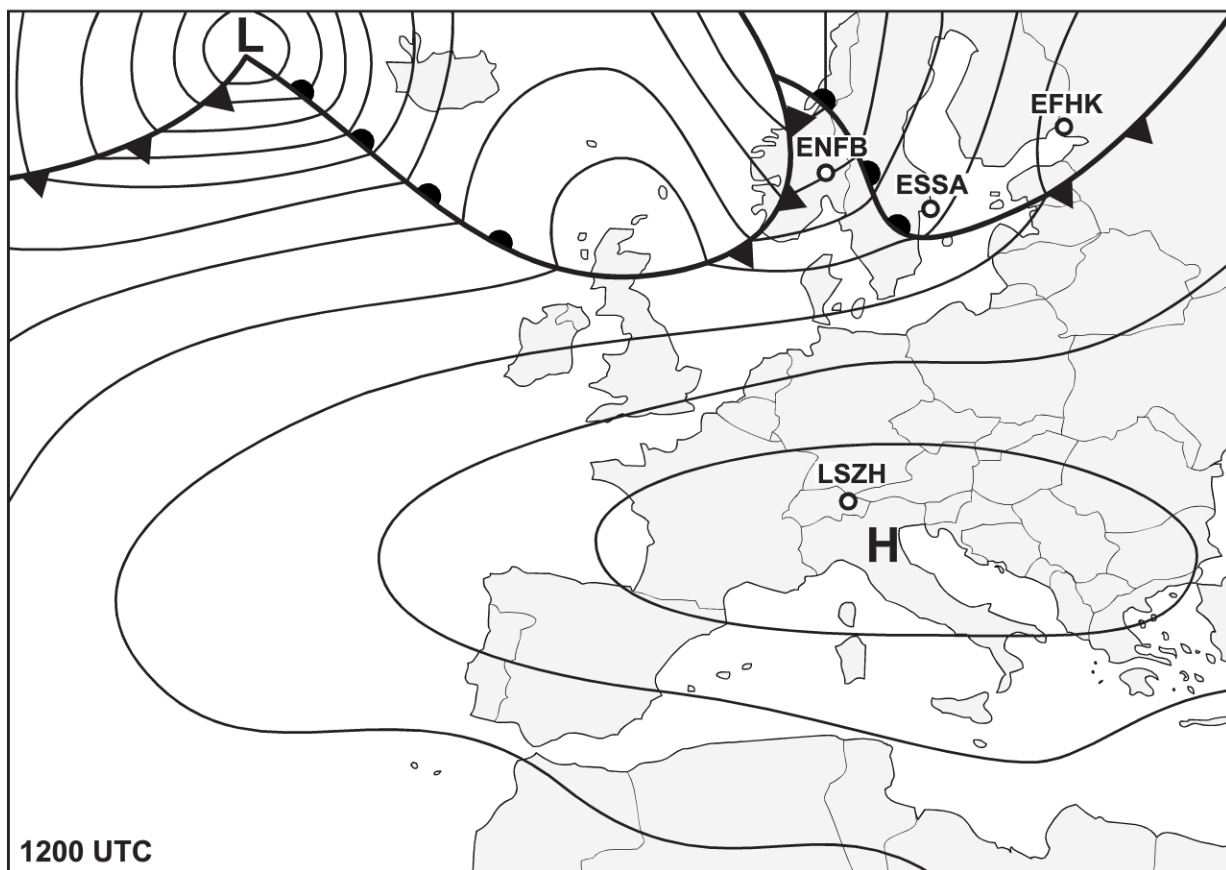


FIGURE 050-39



**FIGURE 050-40**



**FIGURE 050-41**

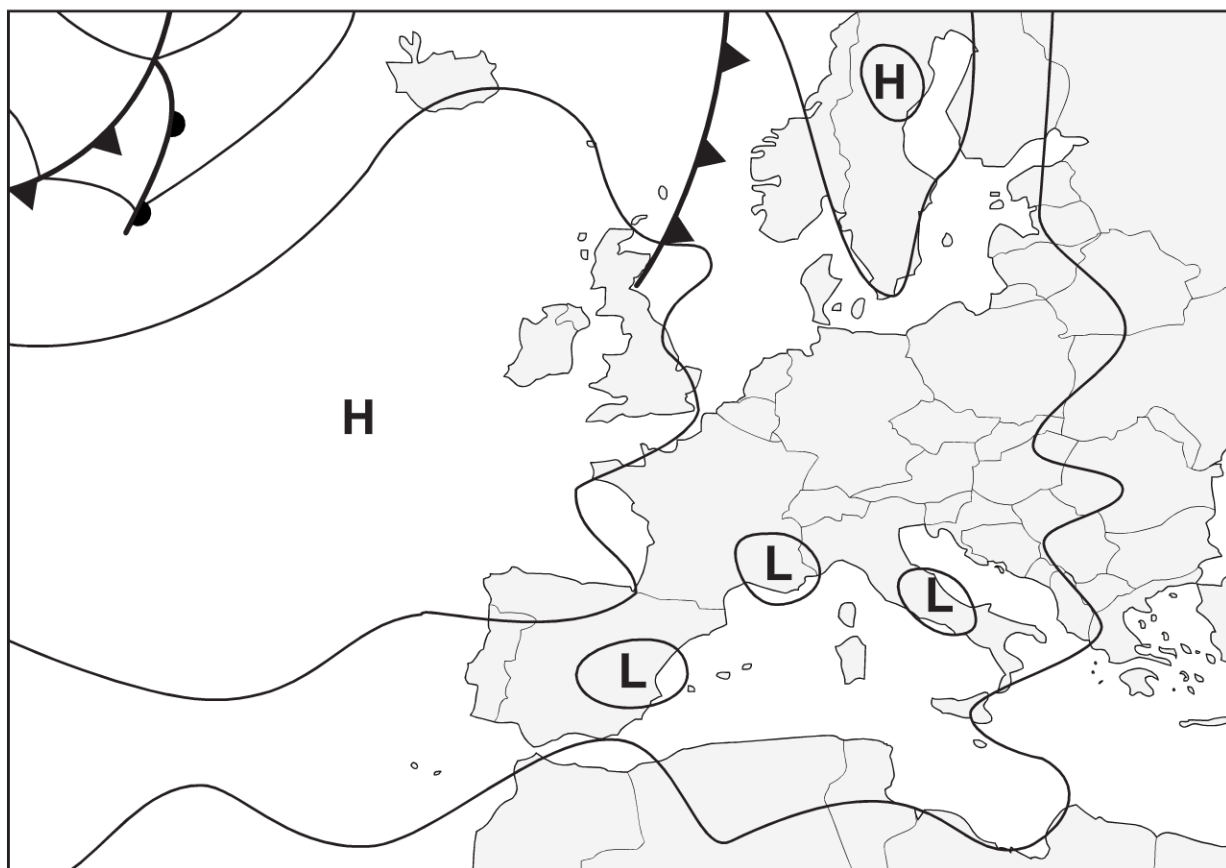


FIGURE 050-42

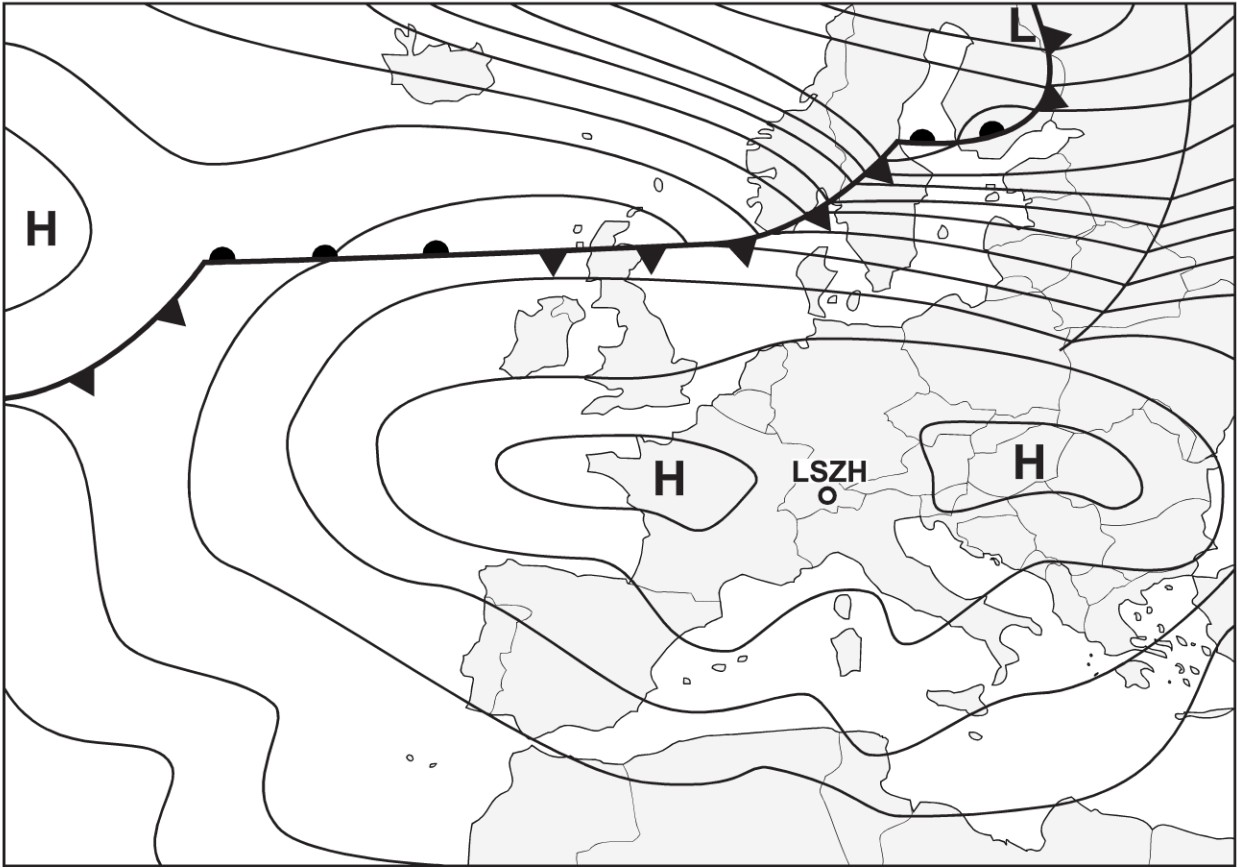


FIGURE 050-43

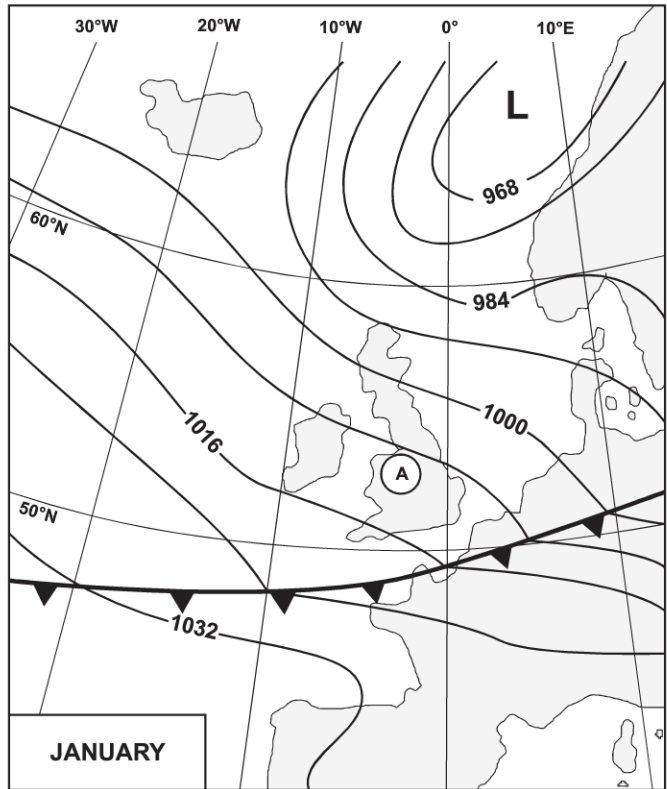
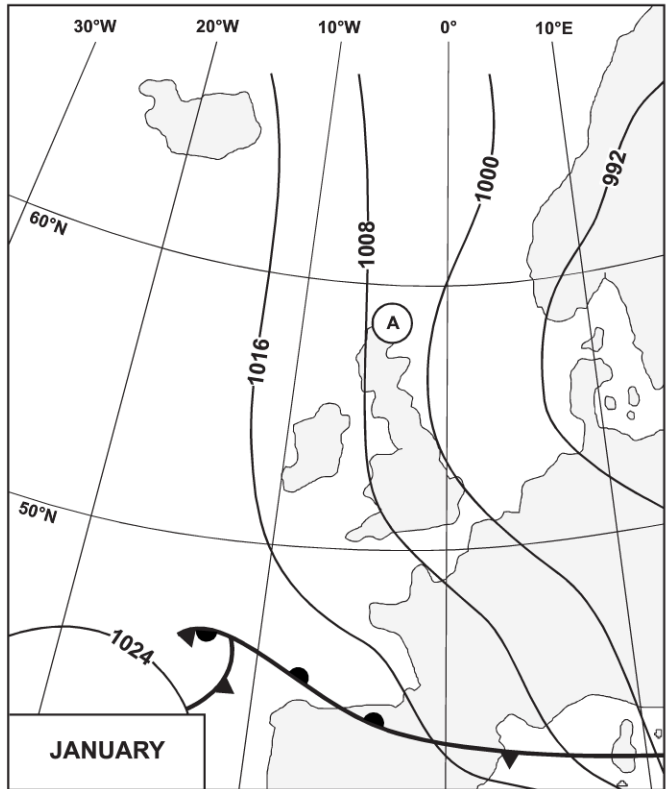
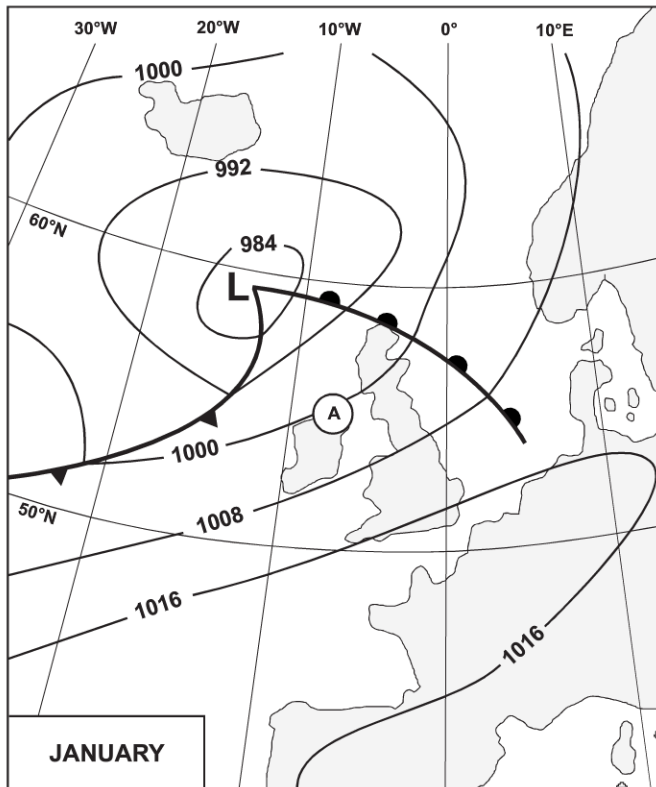


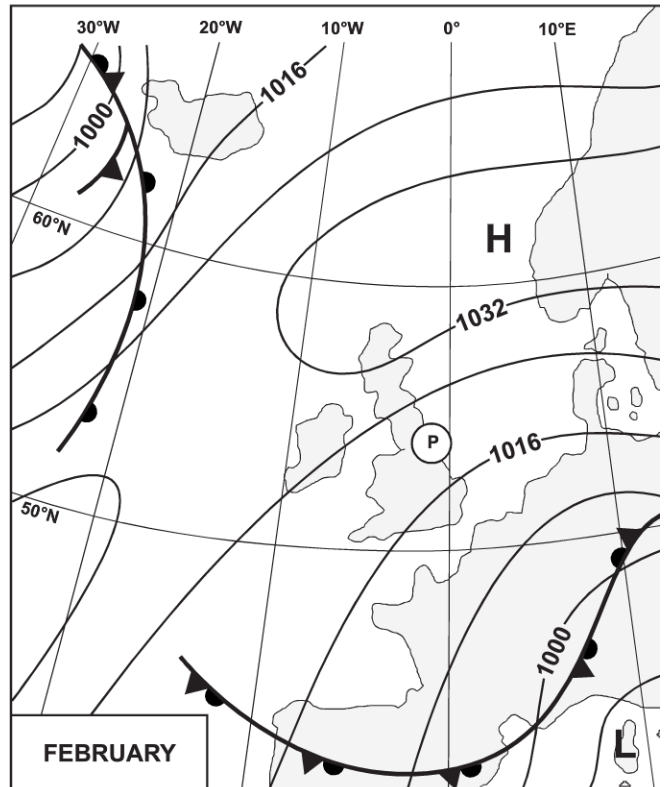
FIGURE 050-44



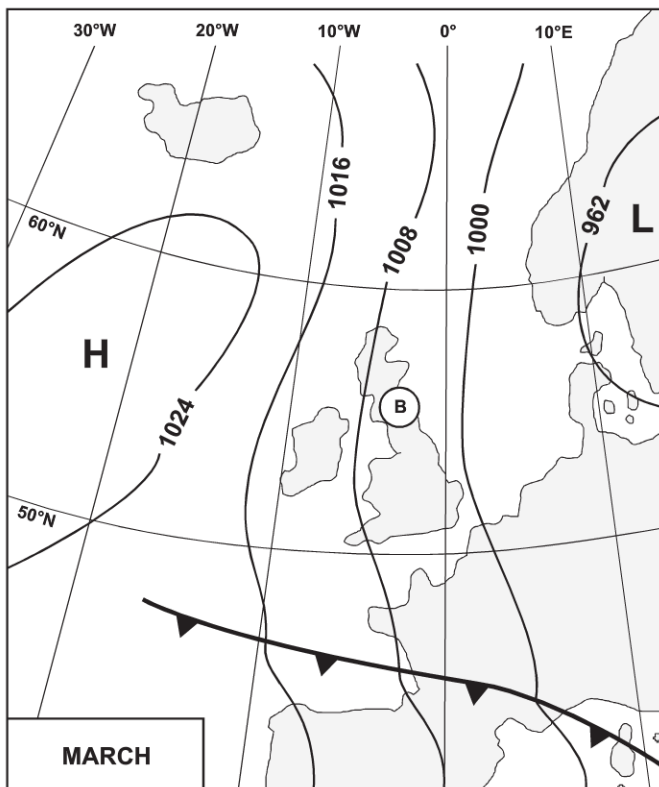
**FIGURE 050-45**



**FIGURE 050-46**



**FIGURE 050-47**



**FIGURE 050-48**

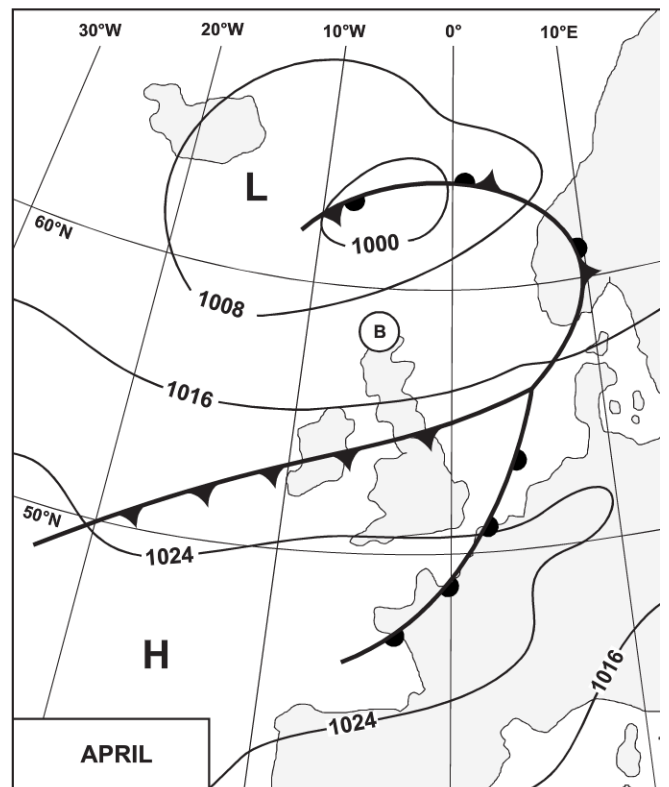




FIGURE 050-49

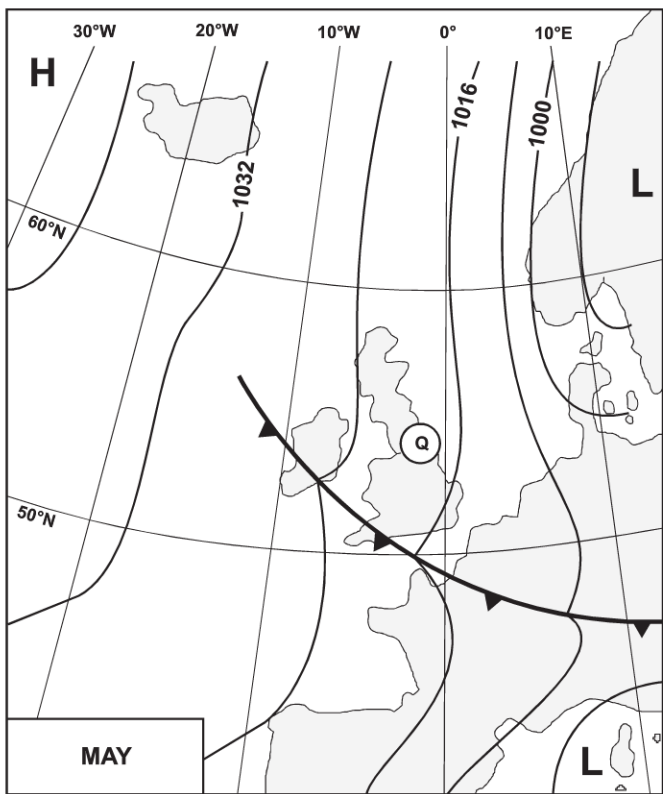


FIGURE 050-50

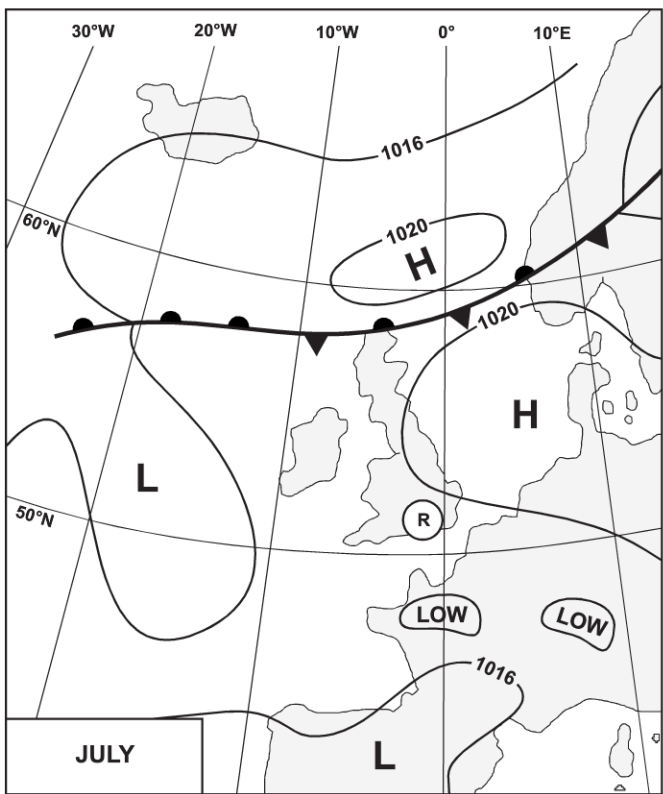


FIGURE 050-51

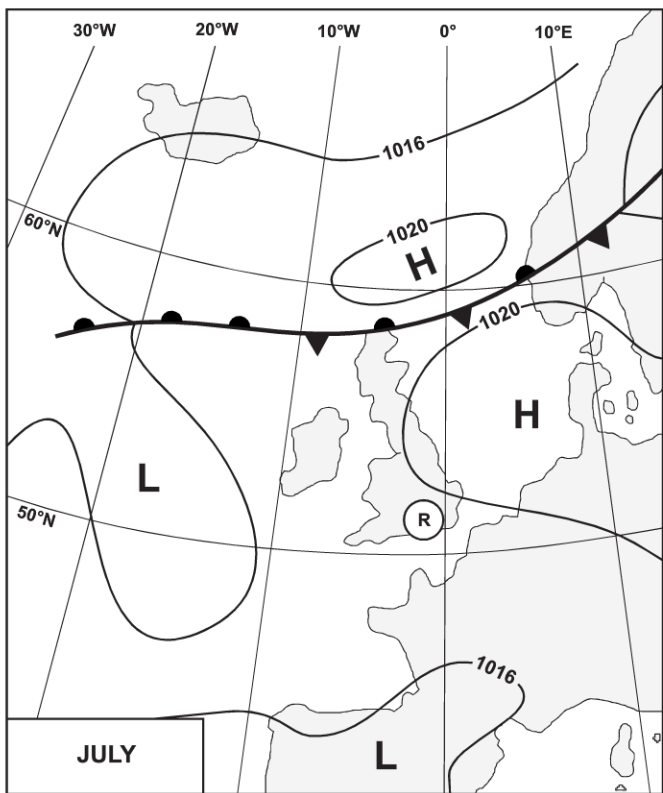
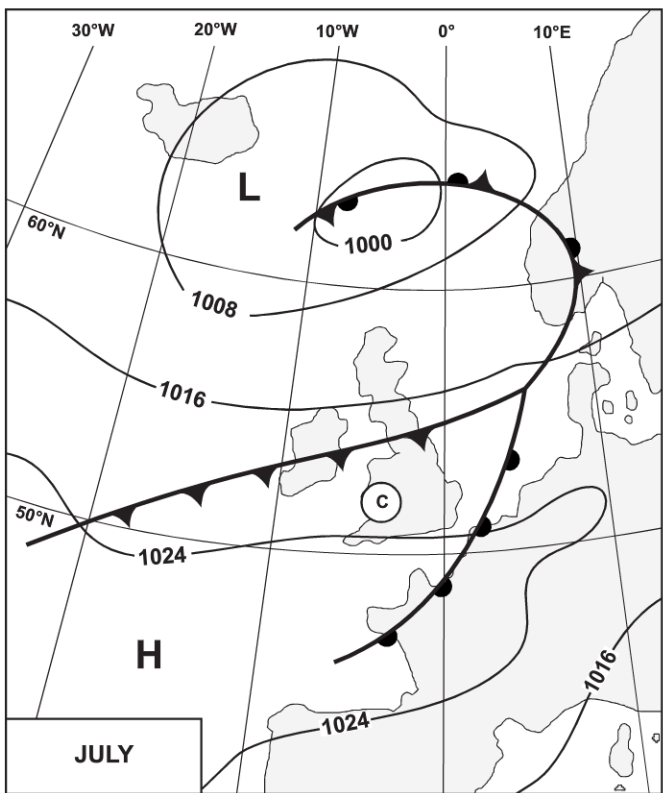
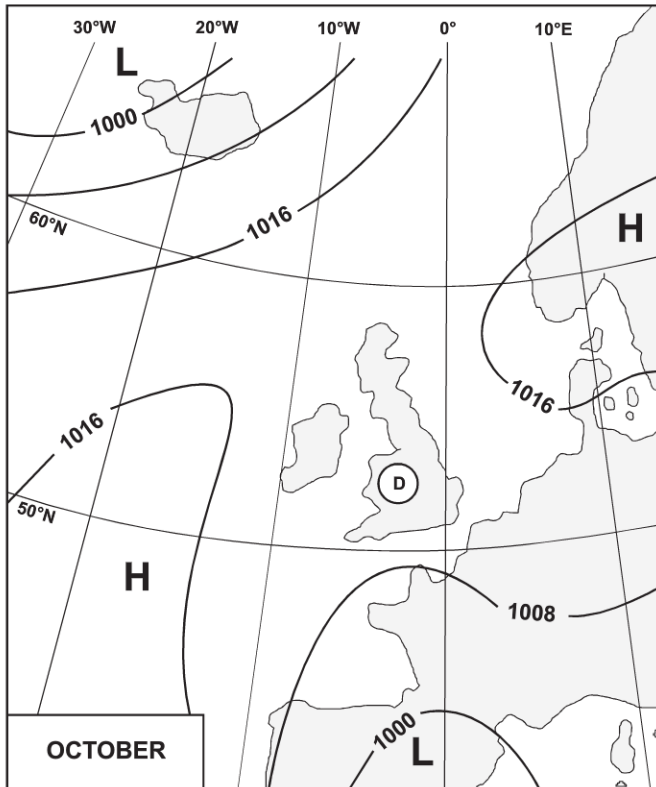


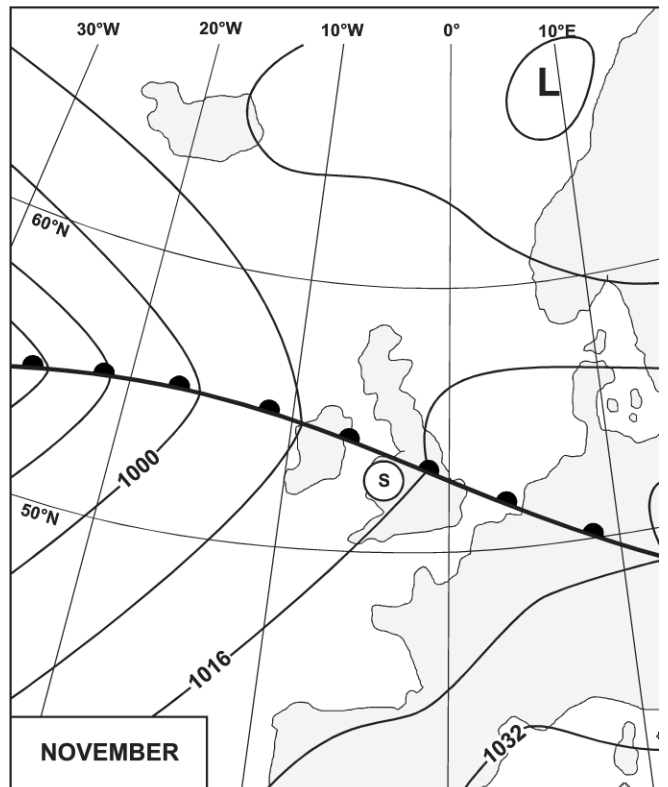
FIGURE 050-52



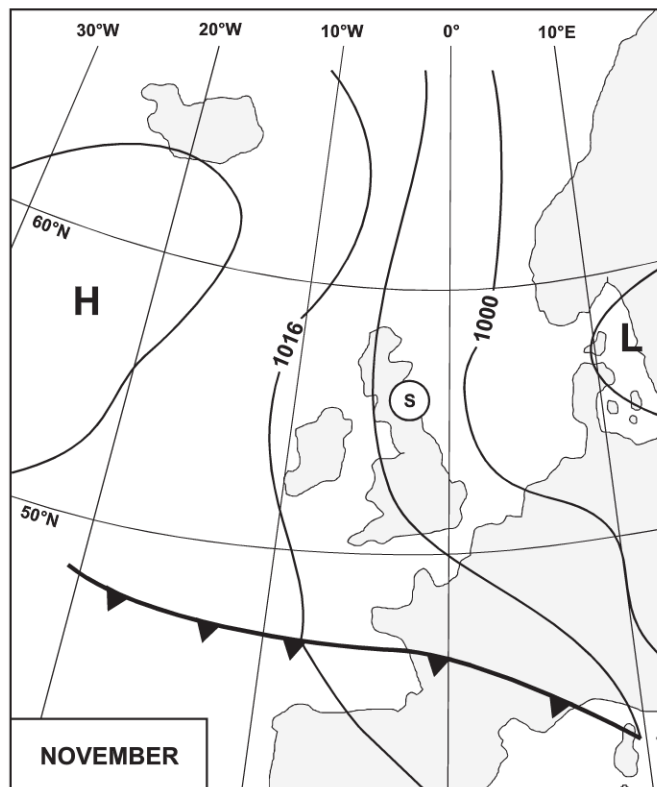
**FIGURE 050-53**

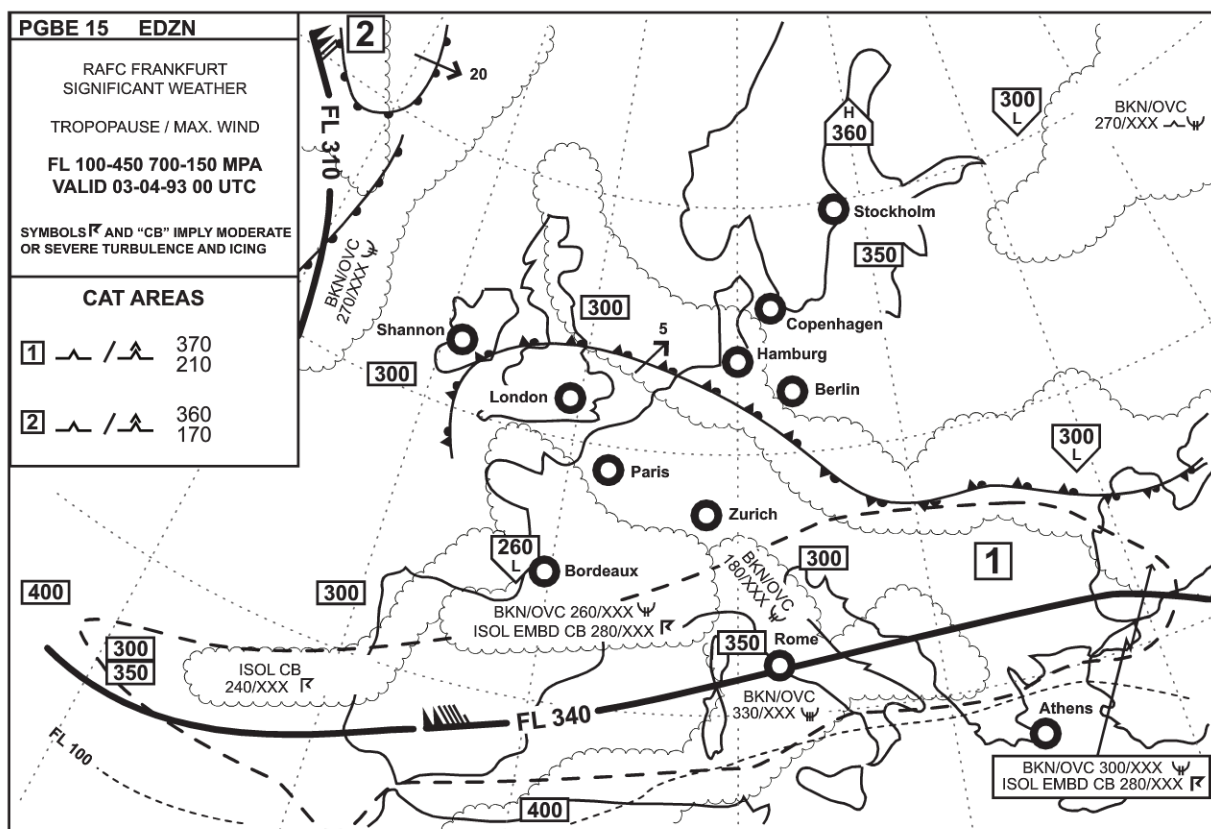
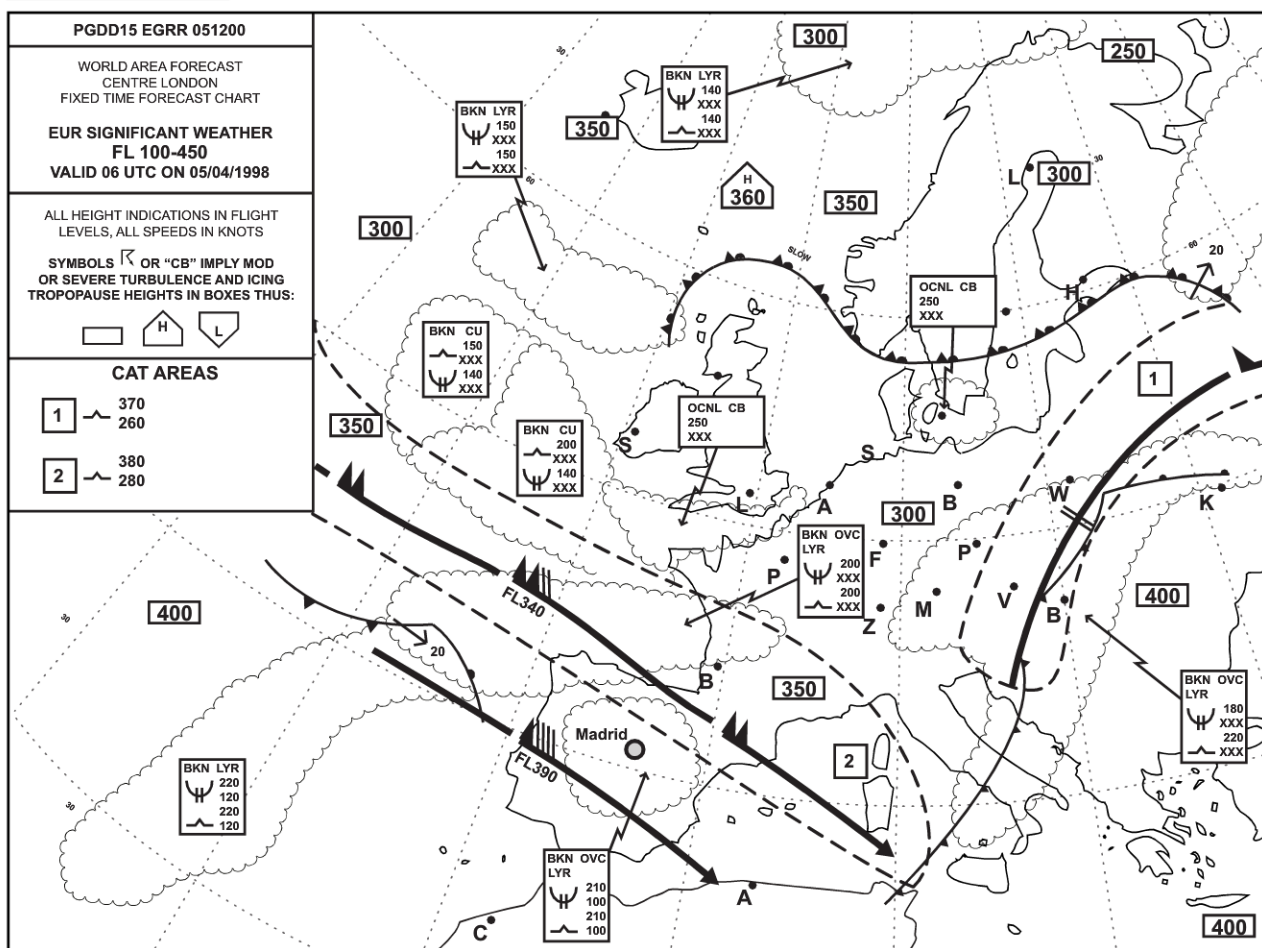


**FIGURE 050-54**

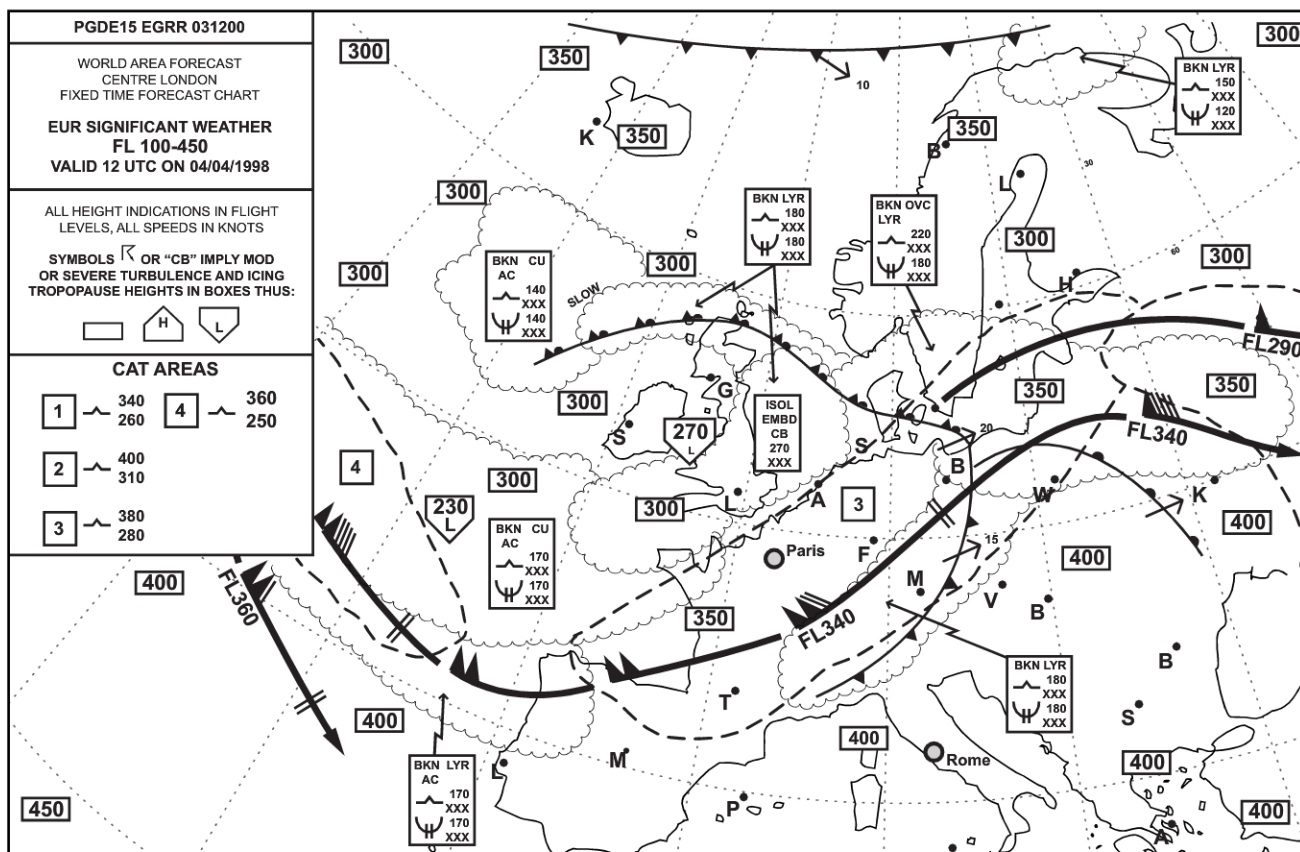
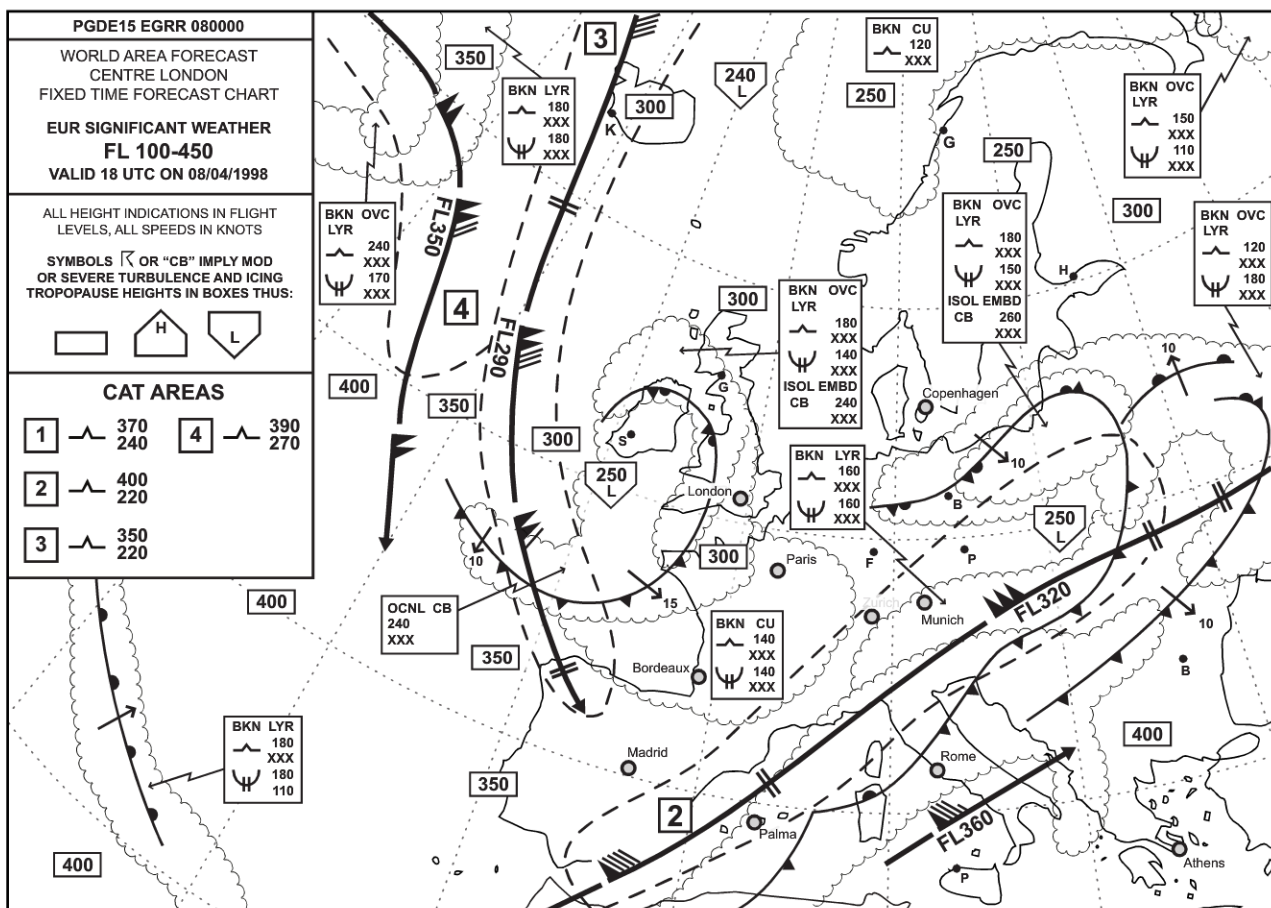


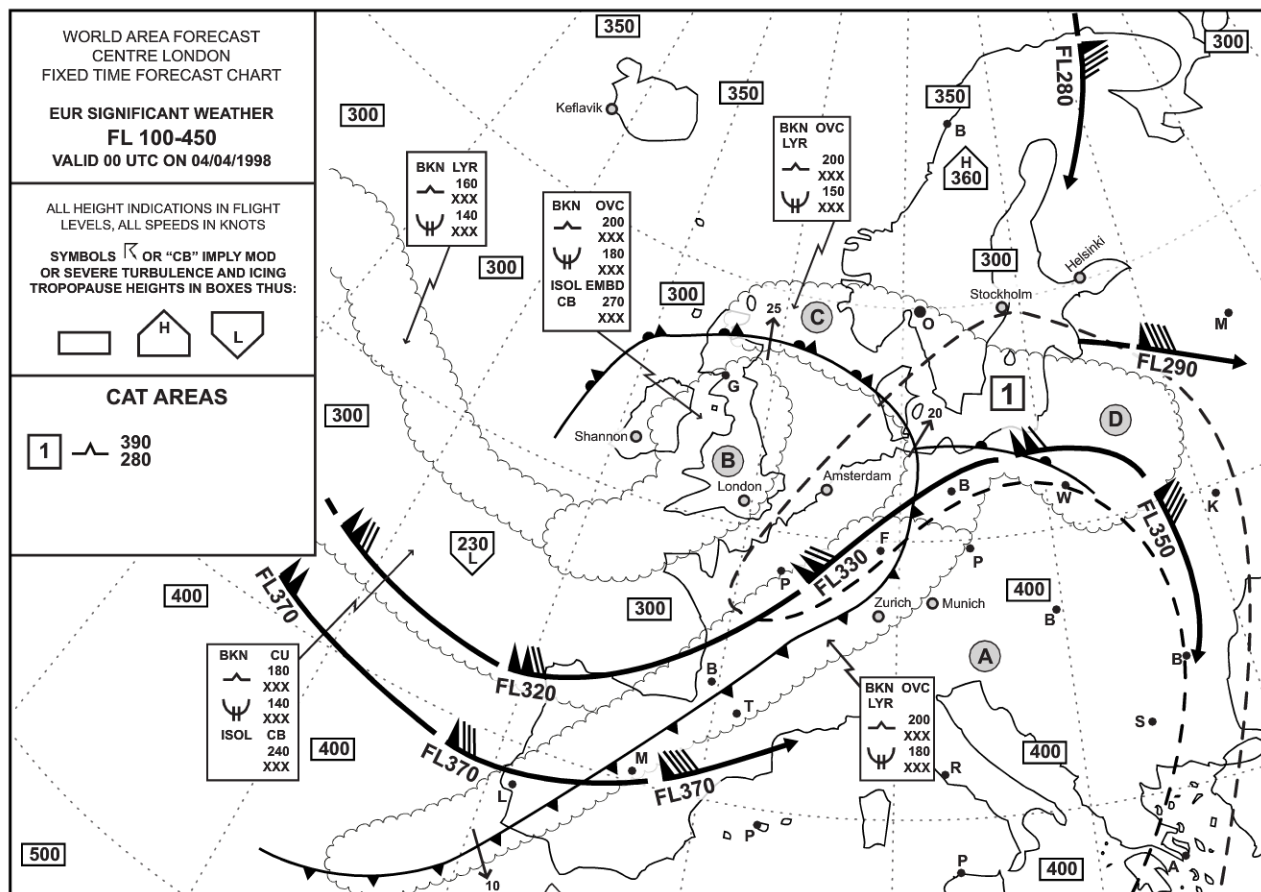
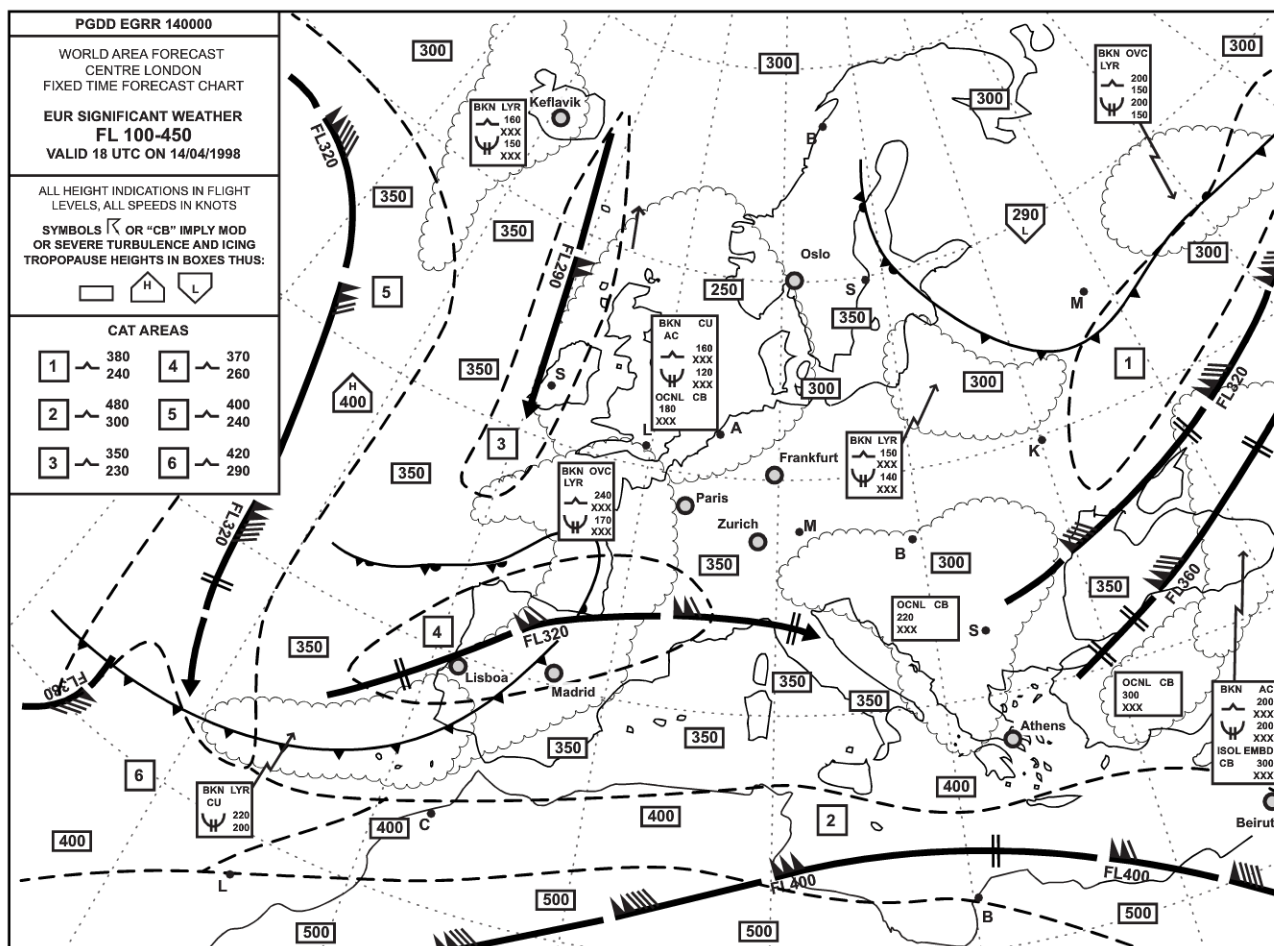
**FIGURE 050-55**

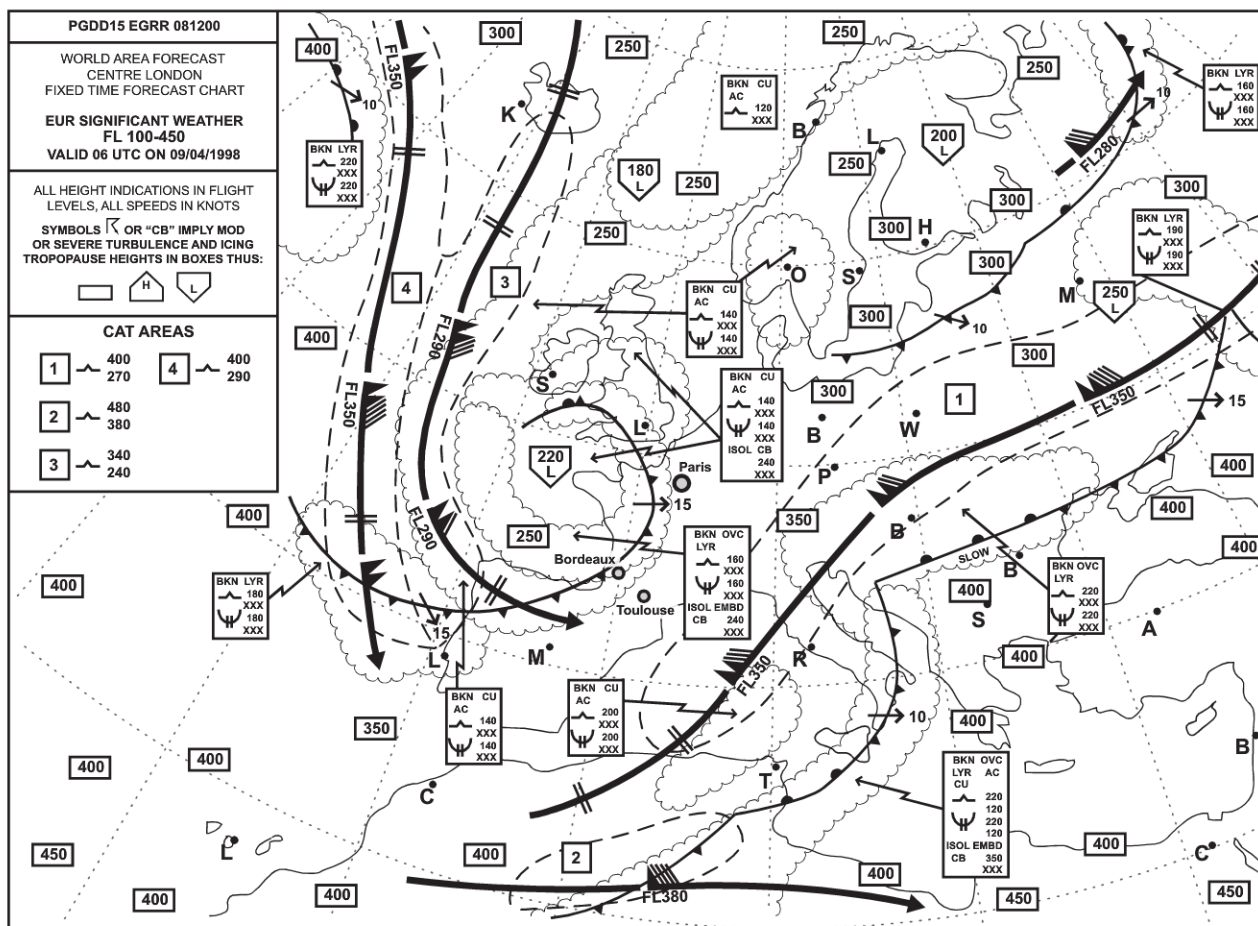
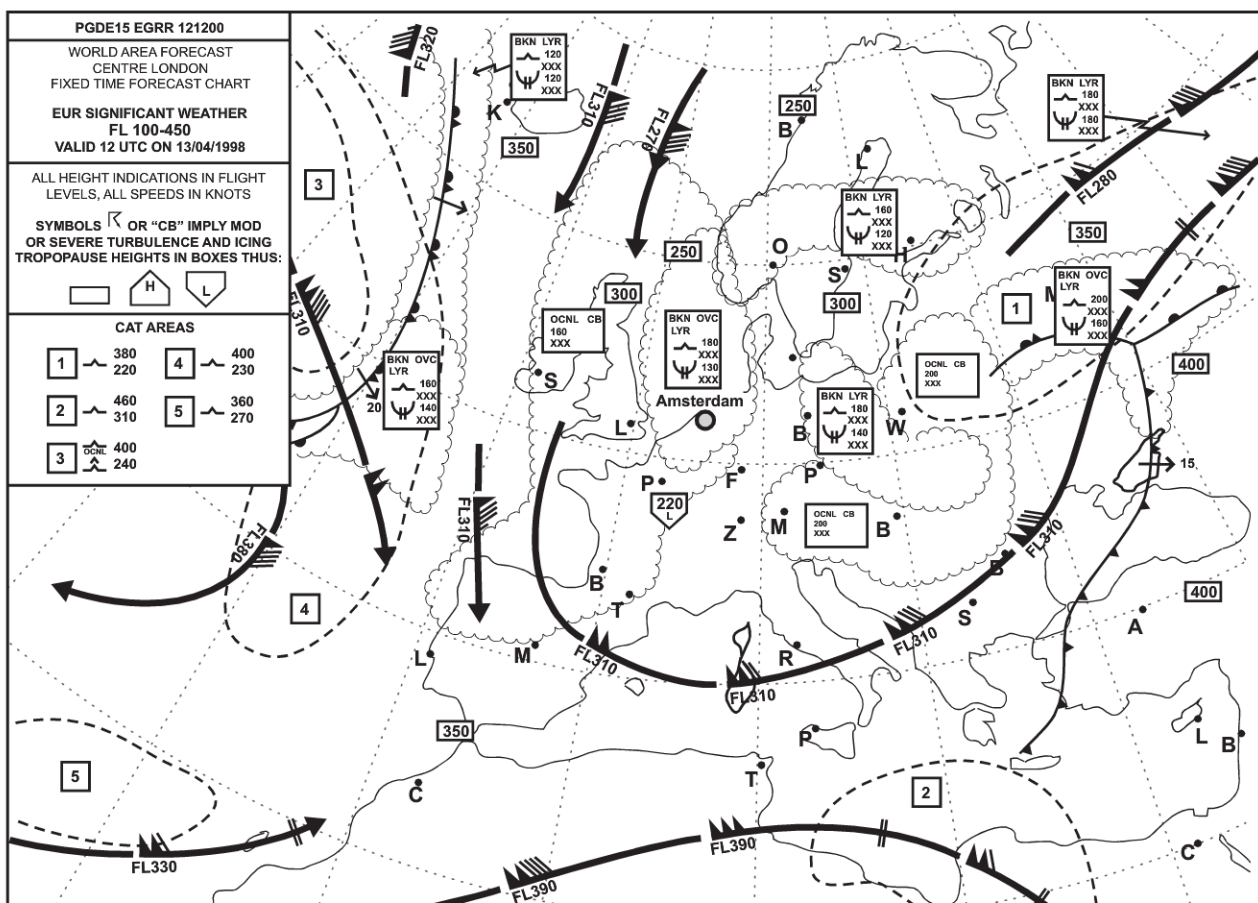


**FIGURE 050-56****FIGURE 050-57**

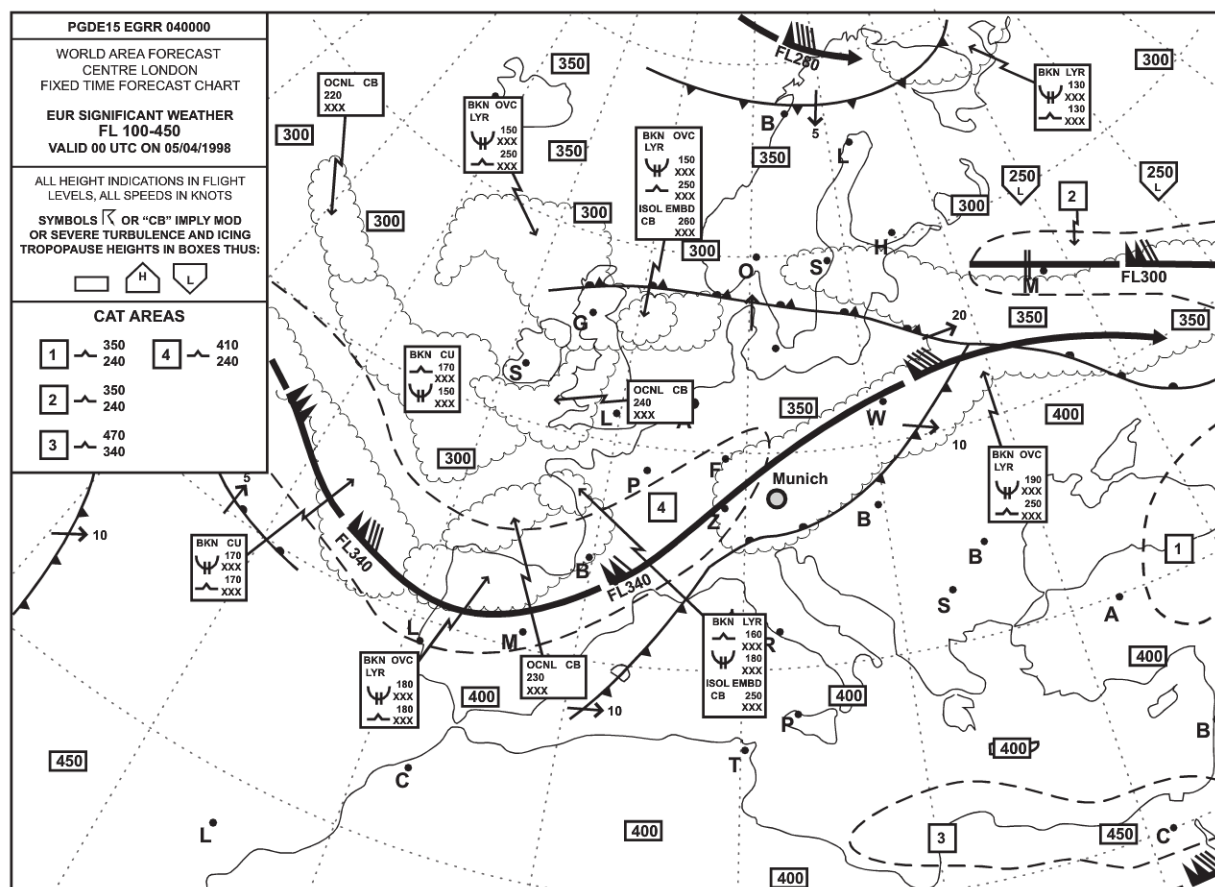
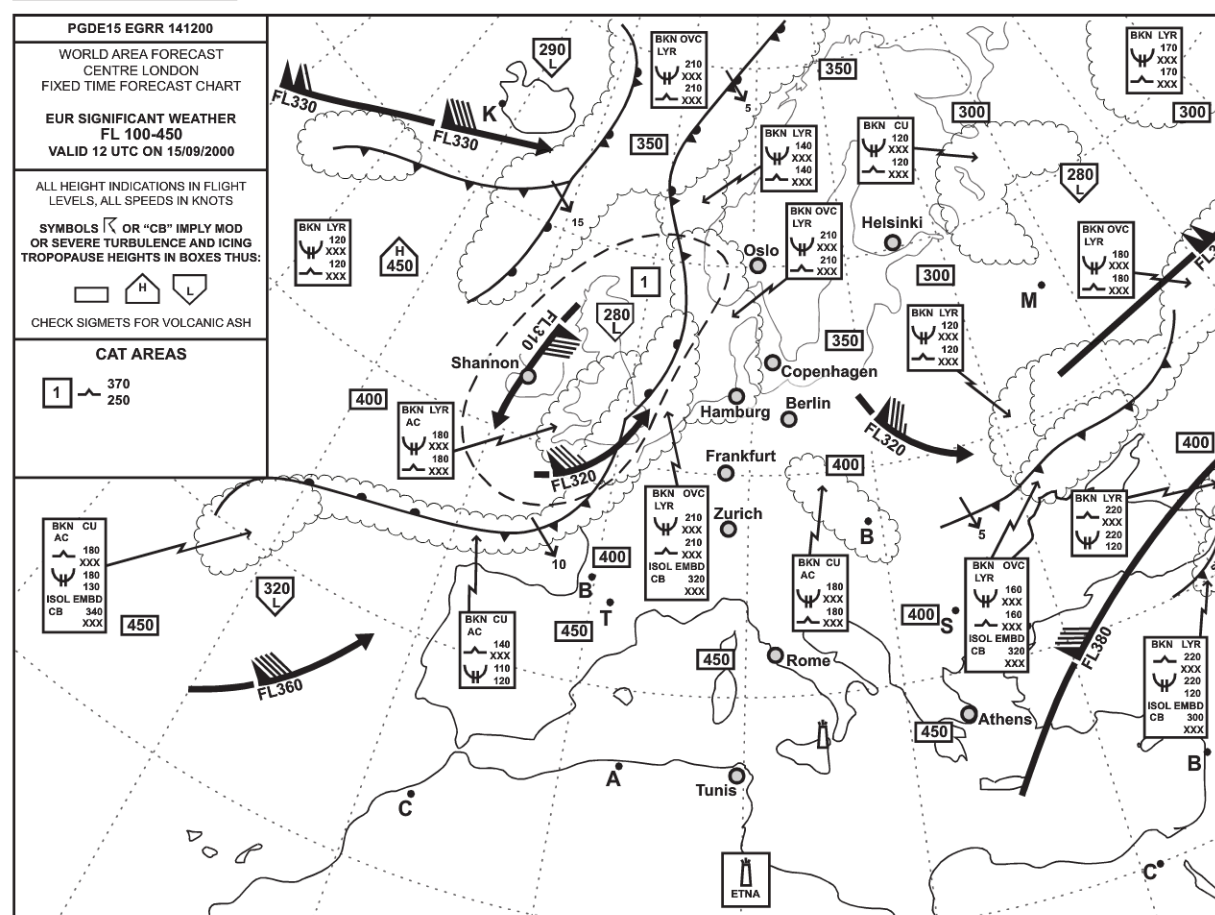


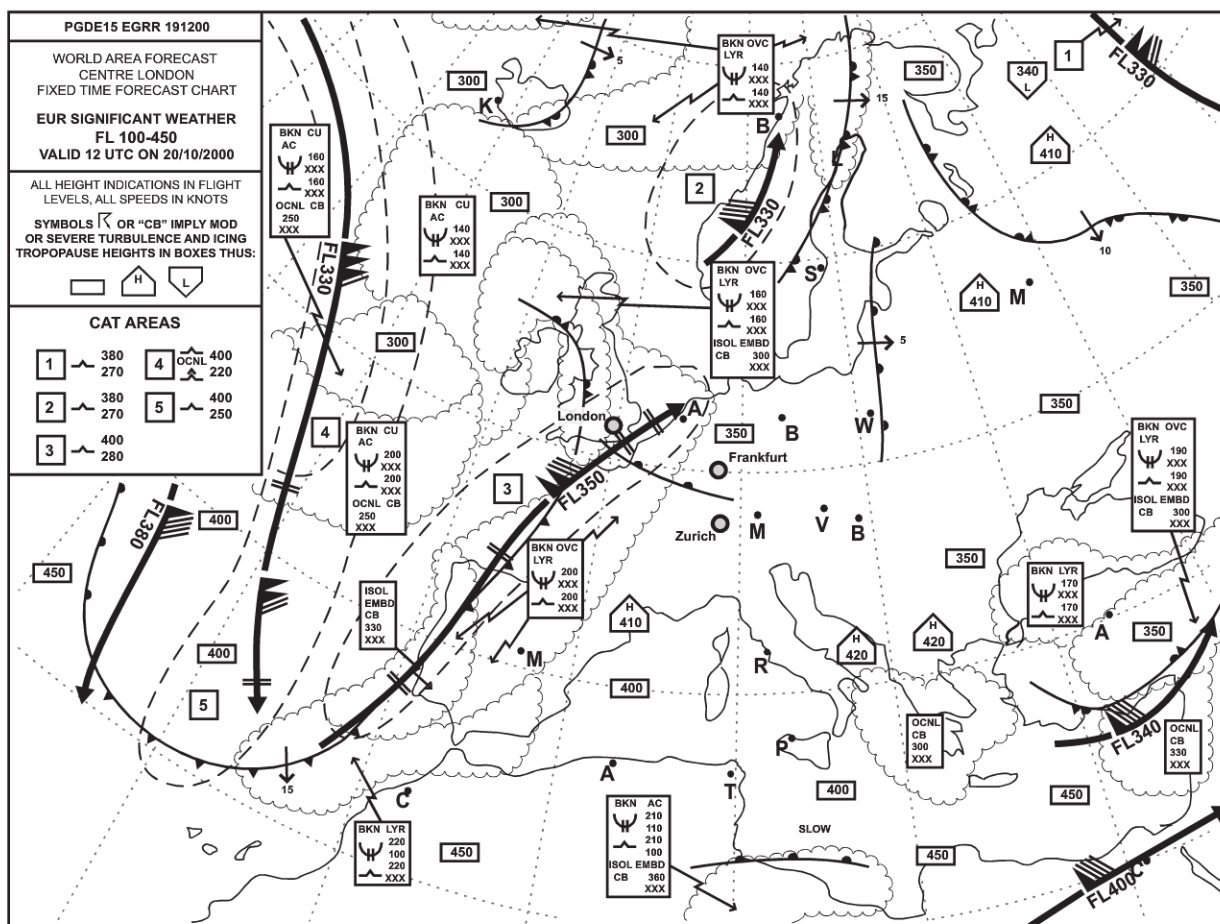
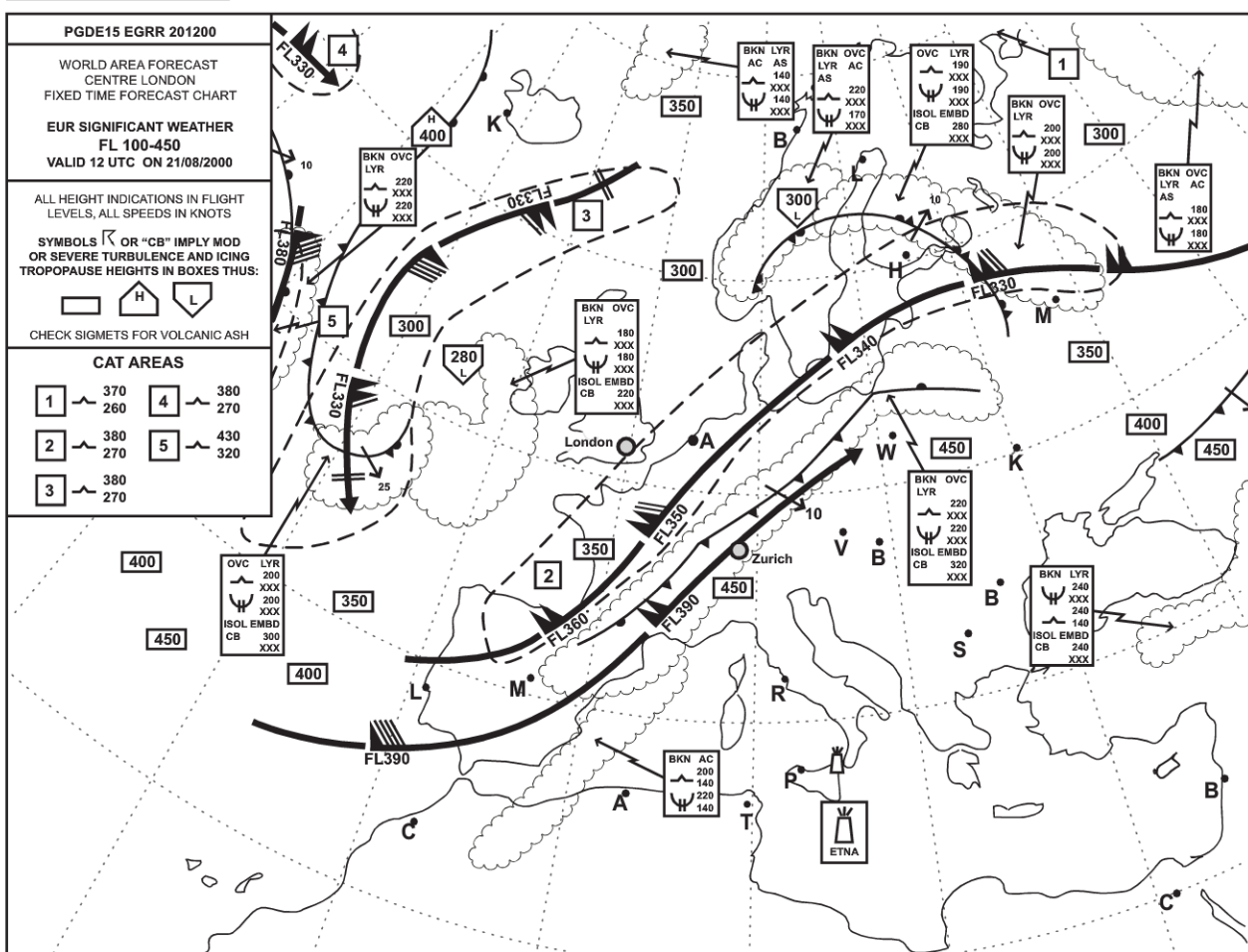
**FIGURE 050-58****FIGURE 050-59**

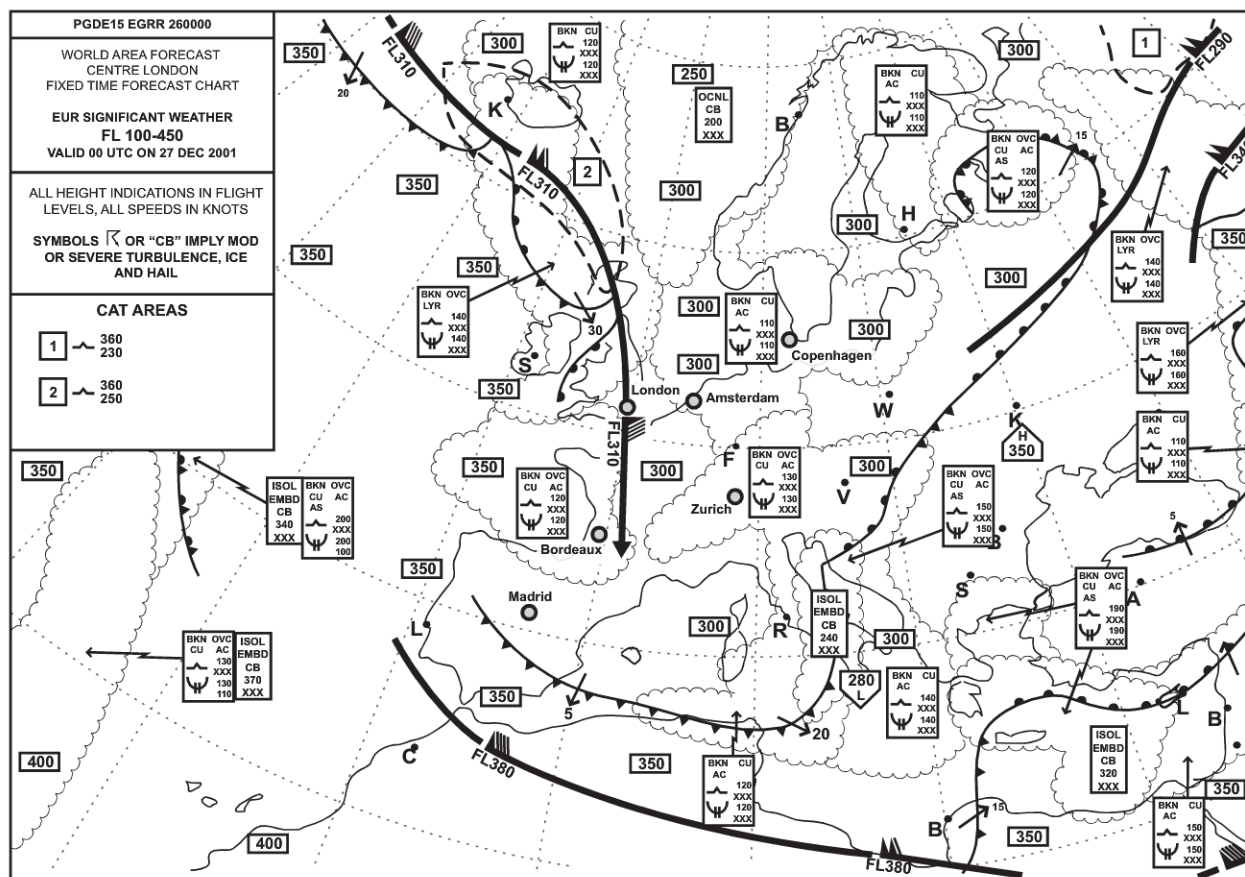
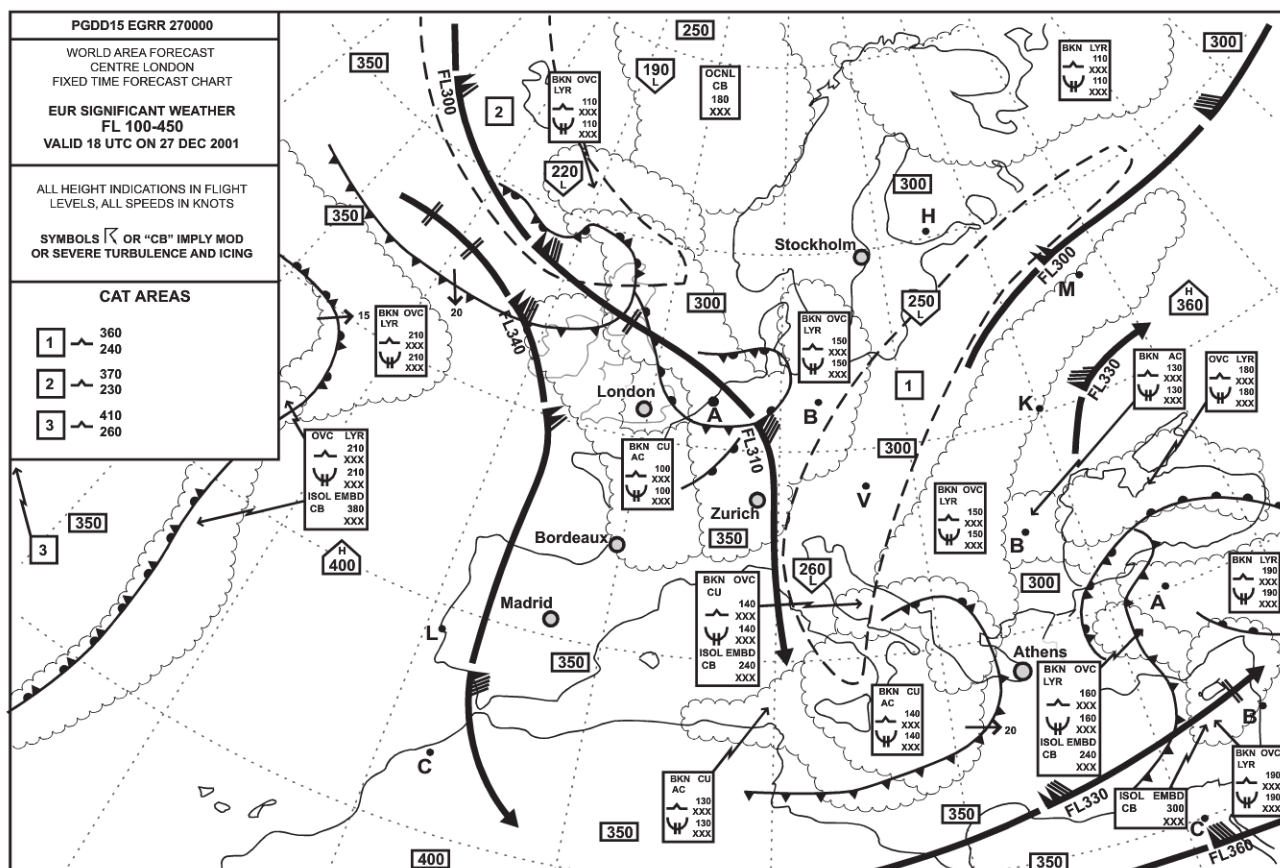
**FIGURE 050-60****FIGURE 050-61**

**FIGURE 050-62****FIGURE 050-63**

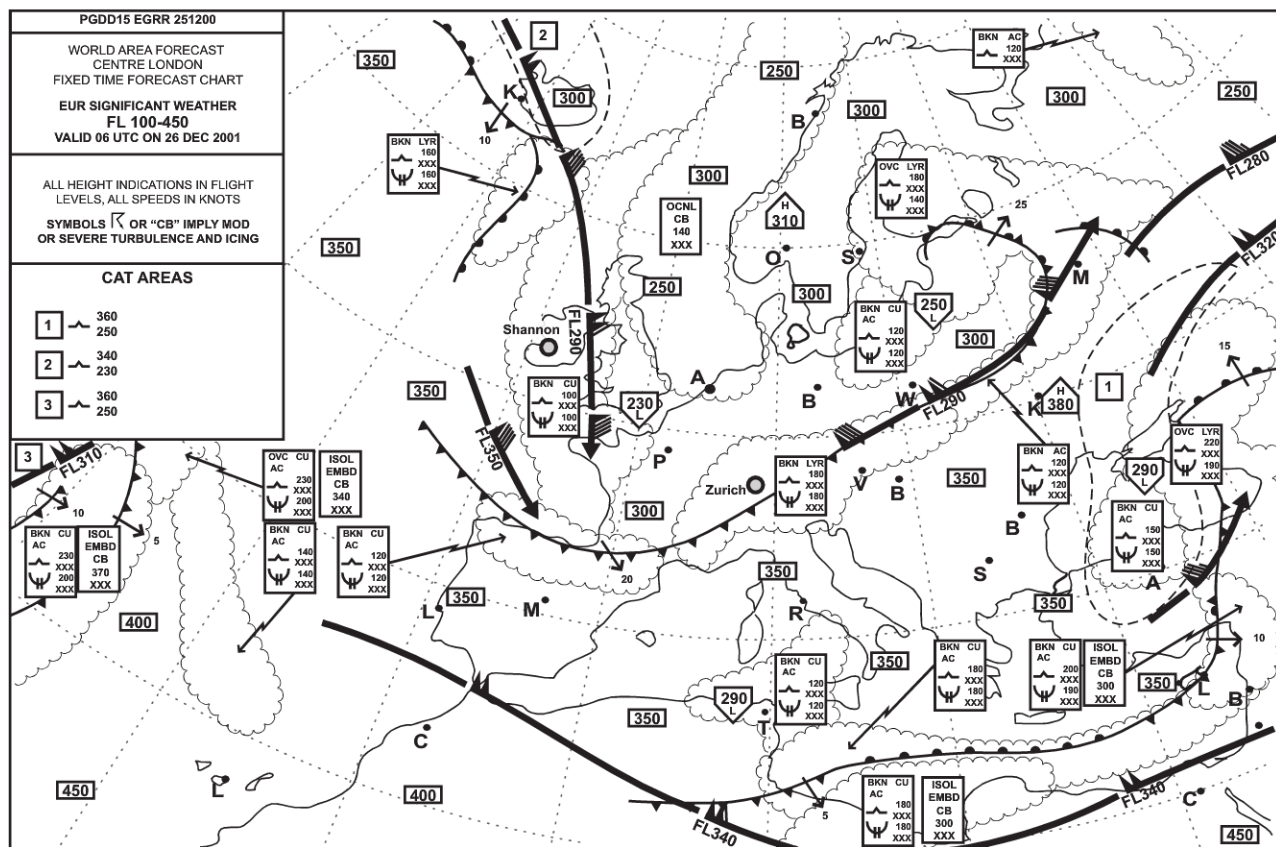
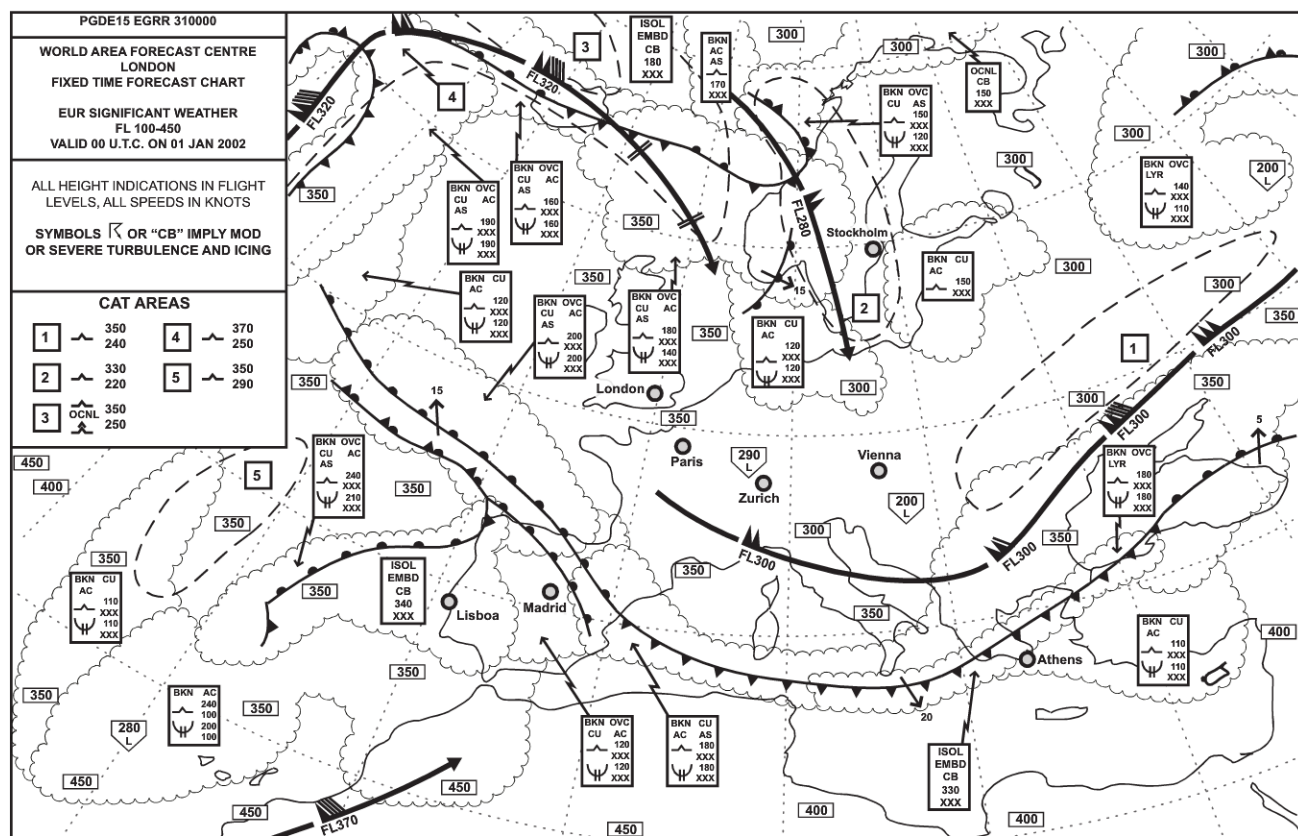


**FIGURE 050-64****FIGURE 050-65**

**FIGURE 050-66****FIGURE 050-67**

**FIGURE 050-68****FIGURE 050-69**



**FIGURE 050-70****FIGURE 050-71**

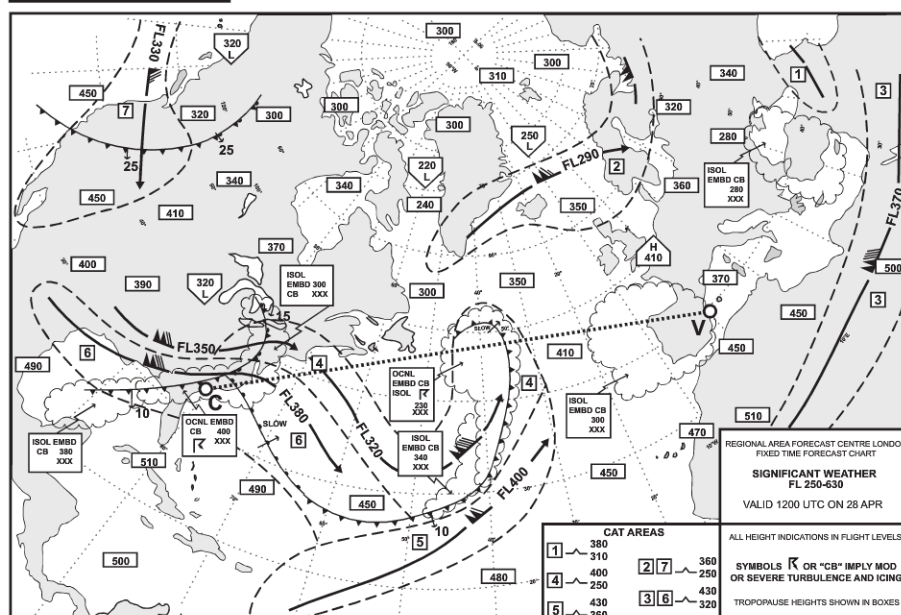
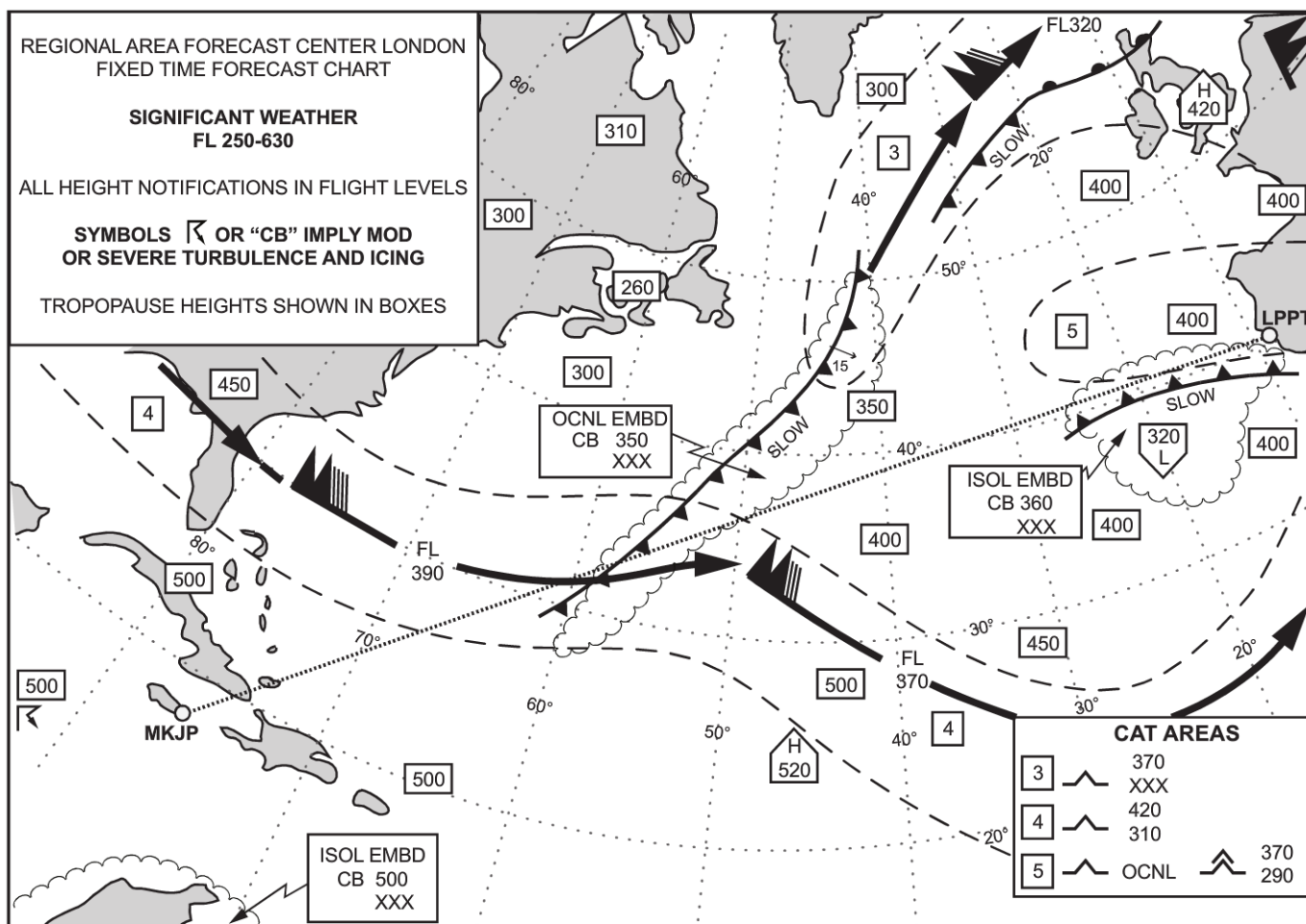
**FIGURE 050-72****FIGURE 050-73**



FIGURE 050-74

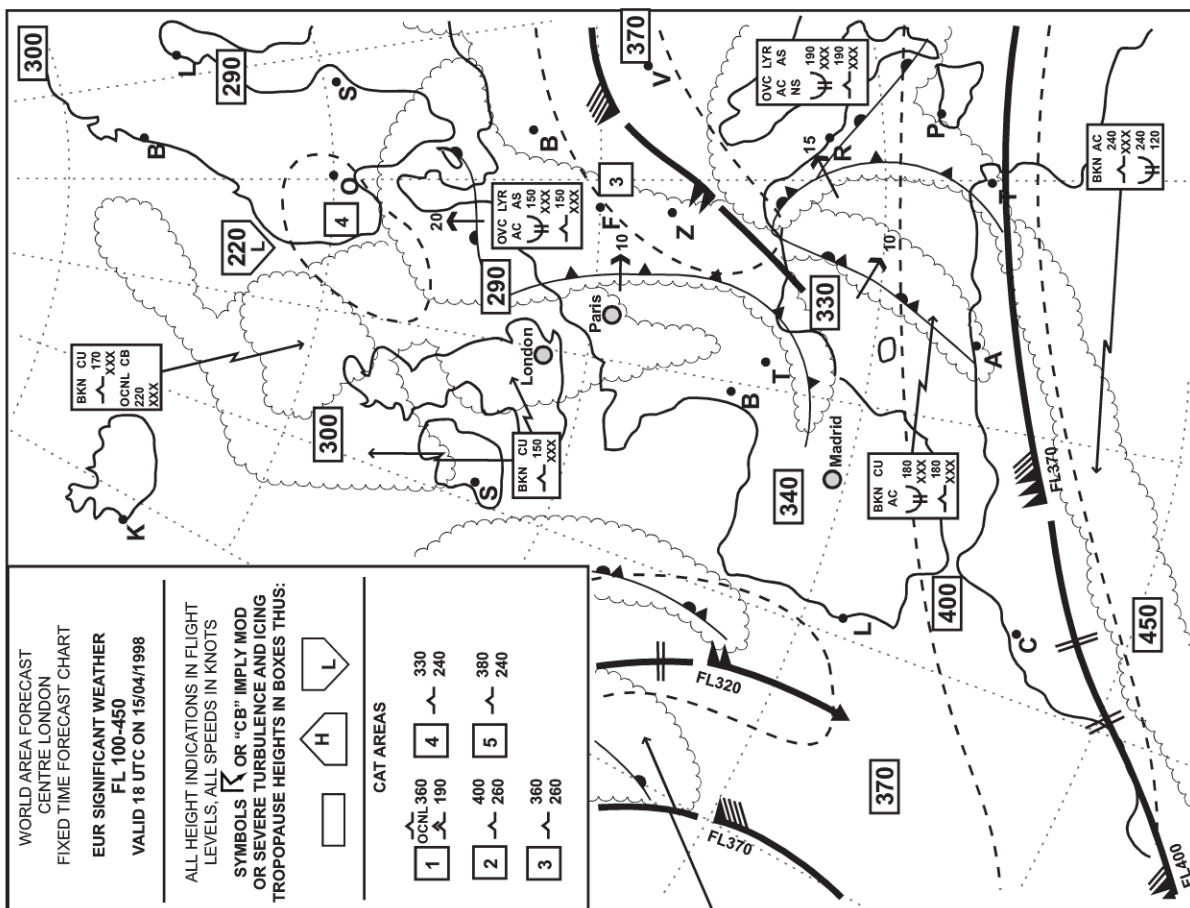
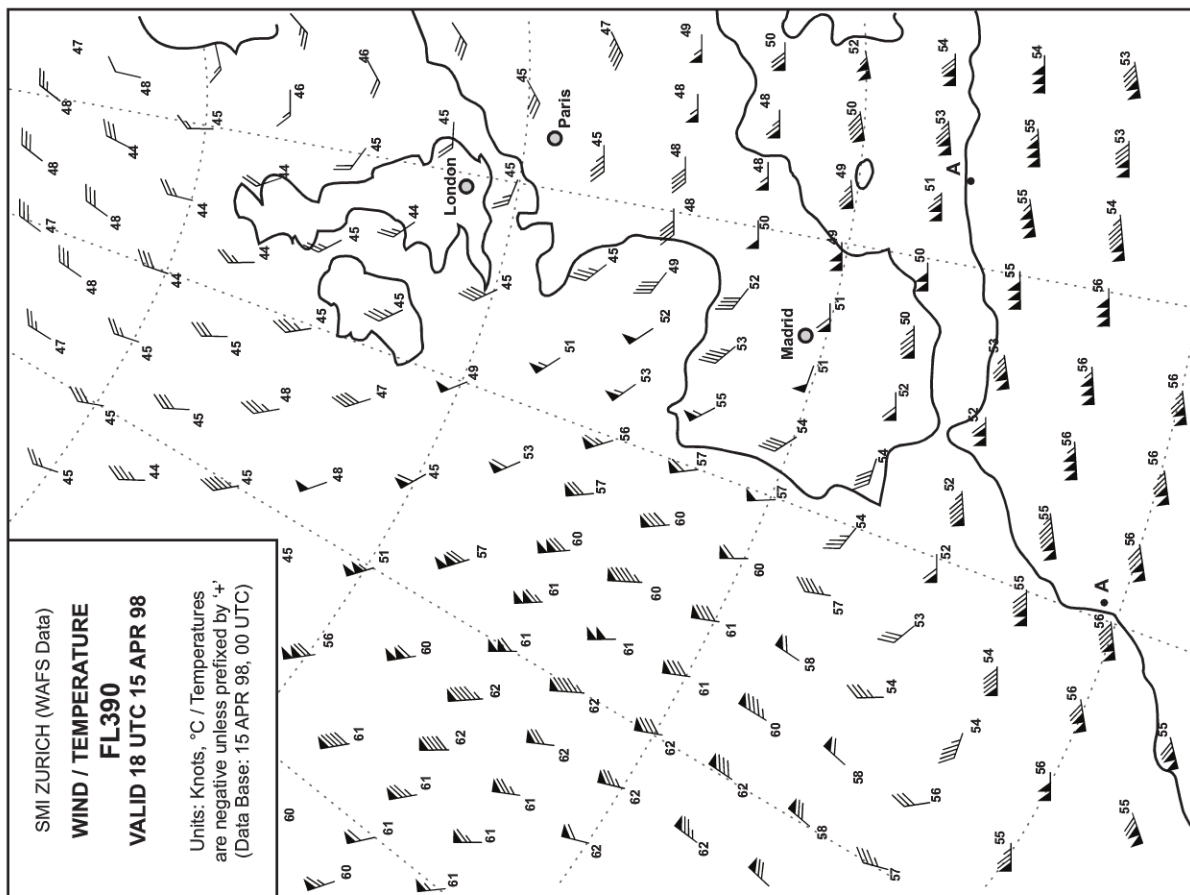


FIGURE 050-75

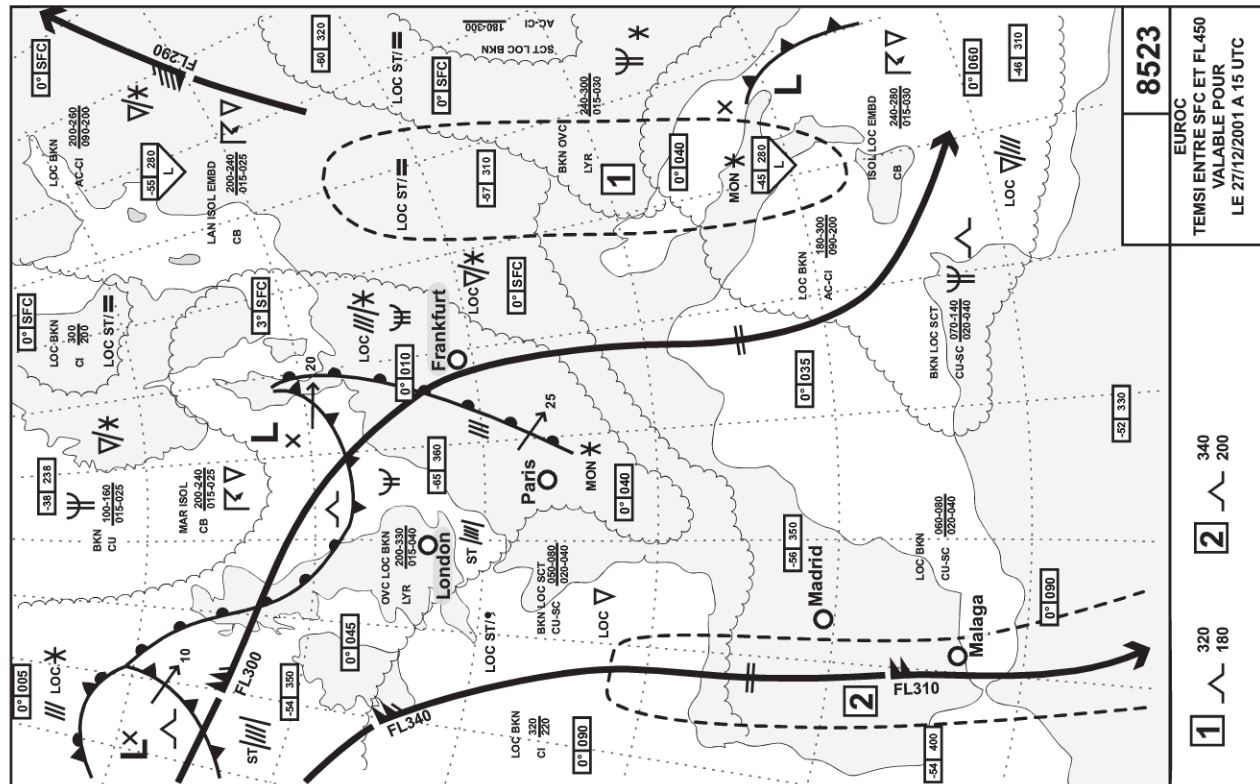
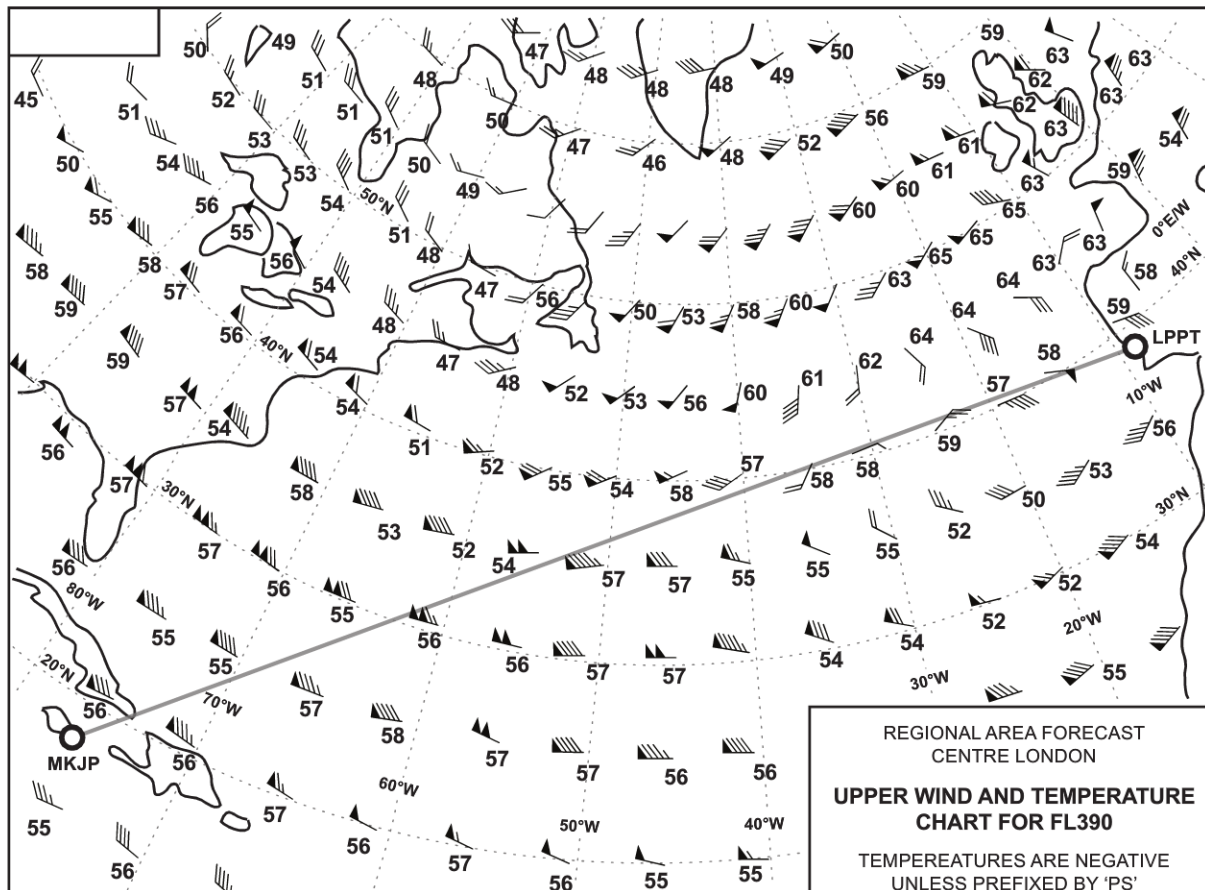
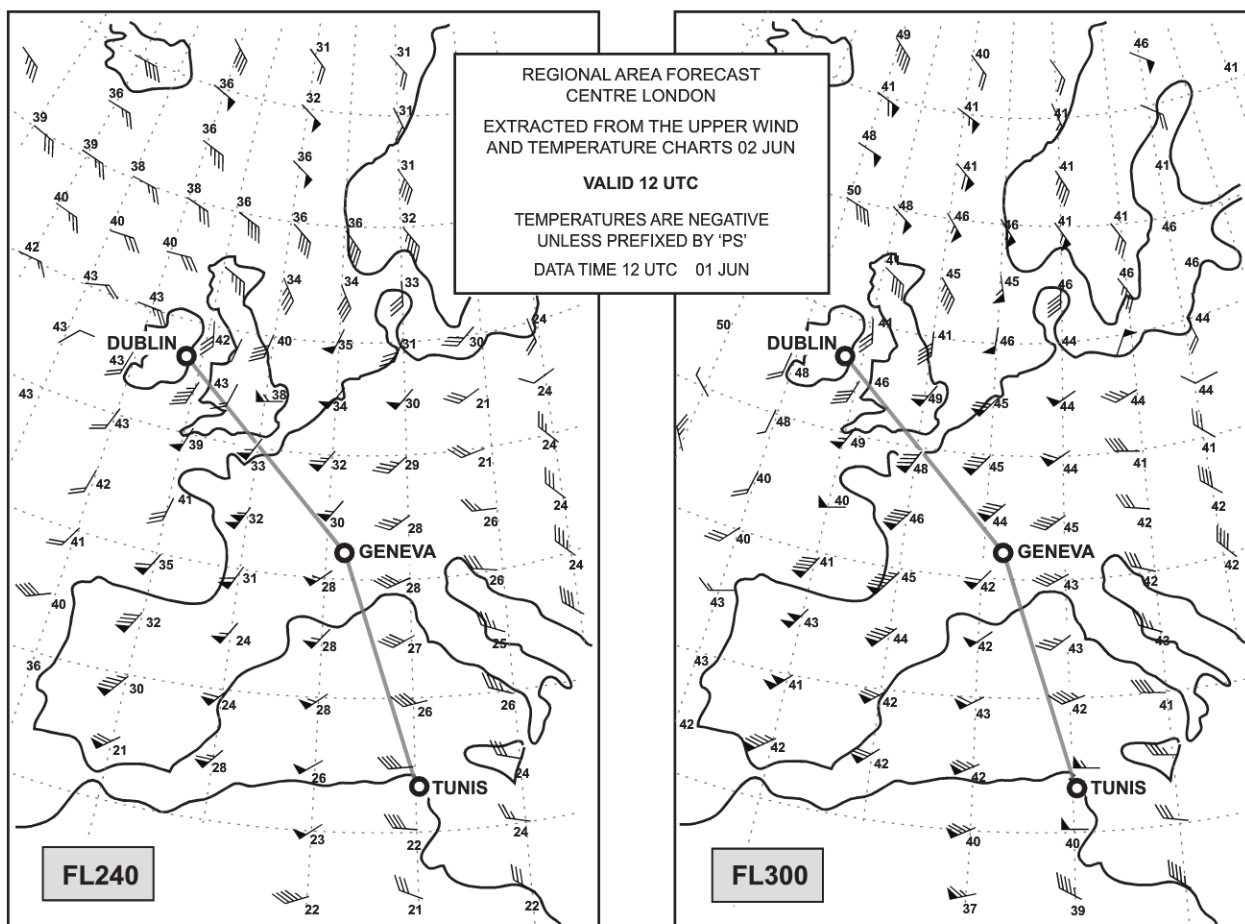
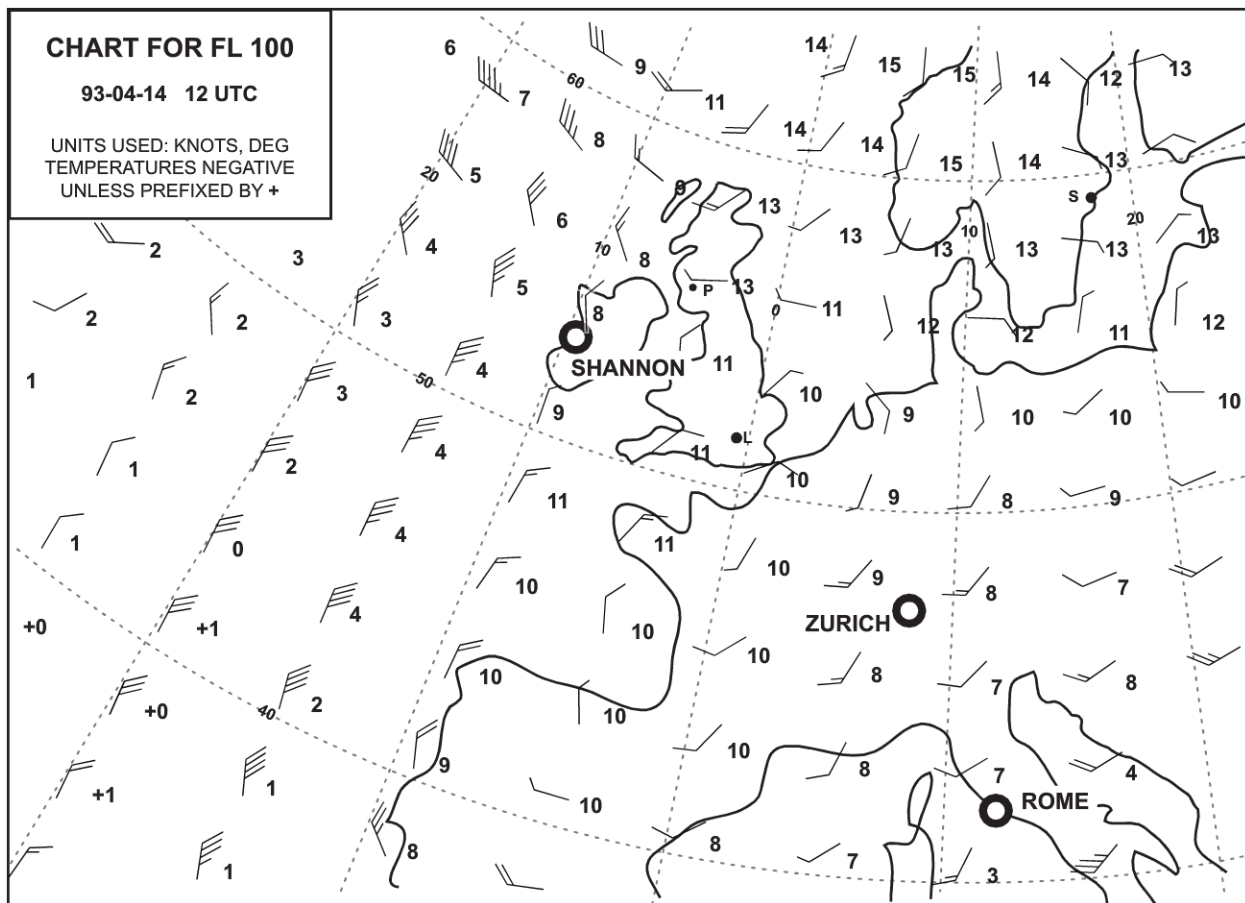
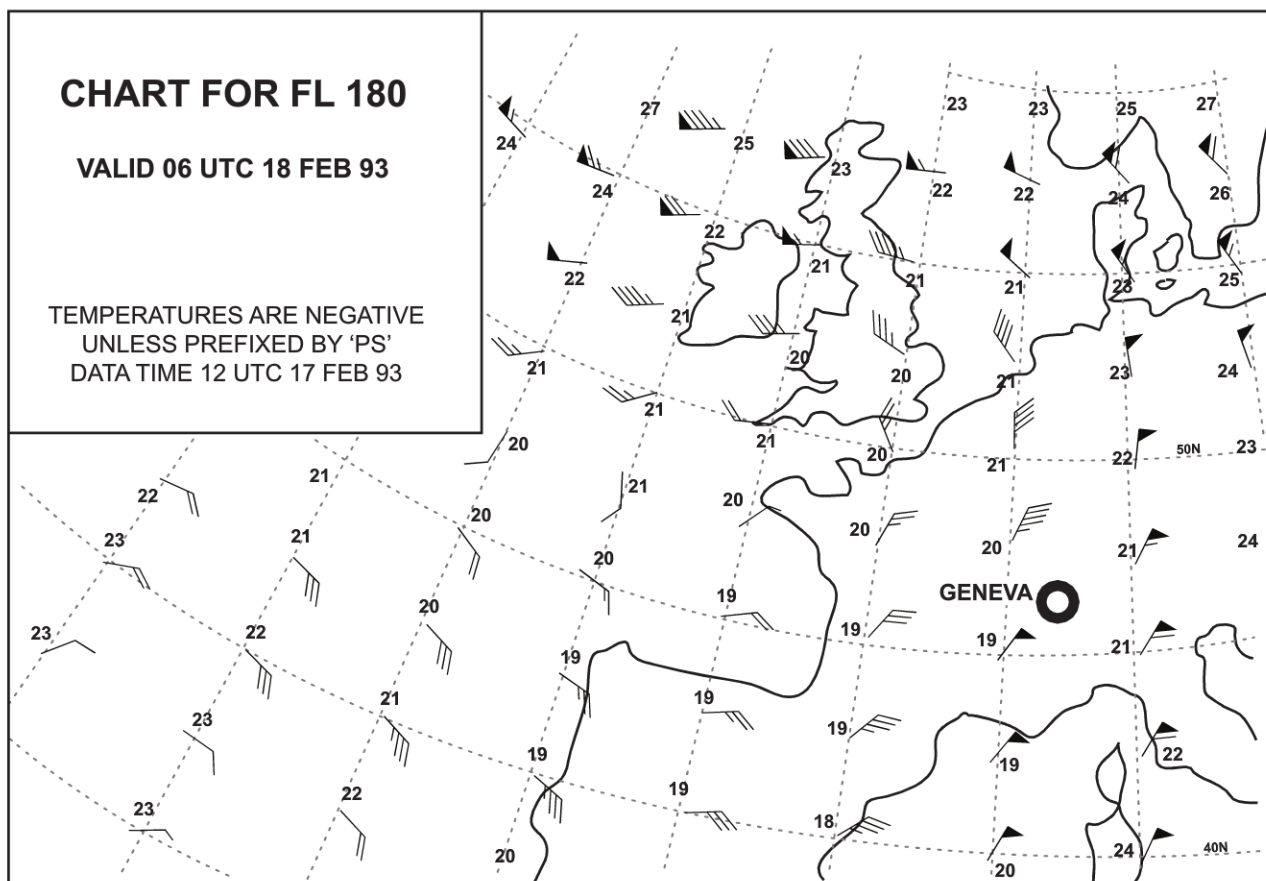


FIGURE 050-76

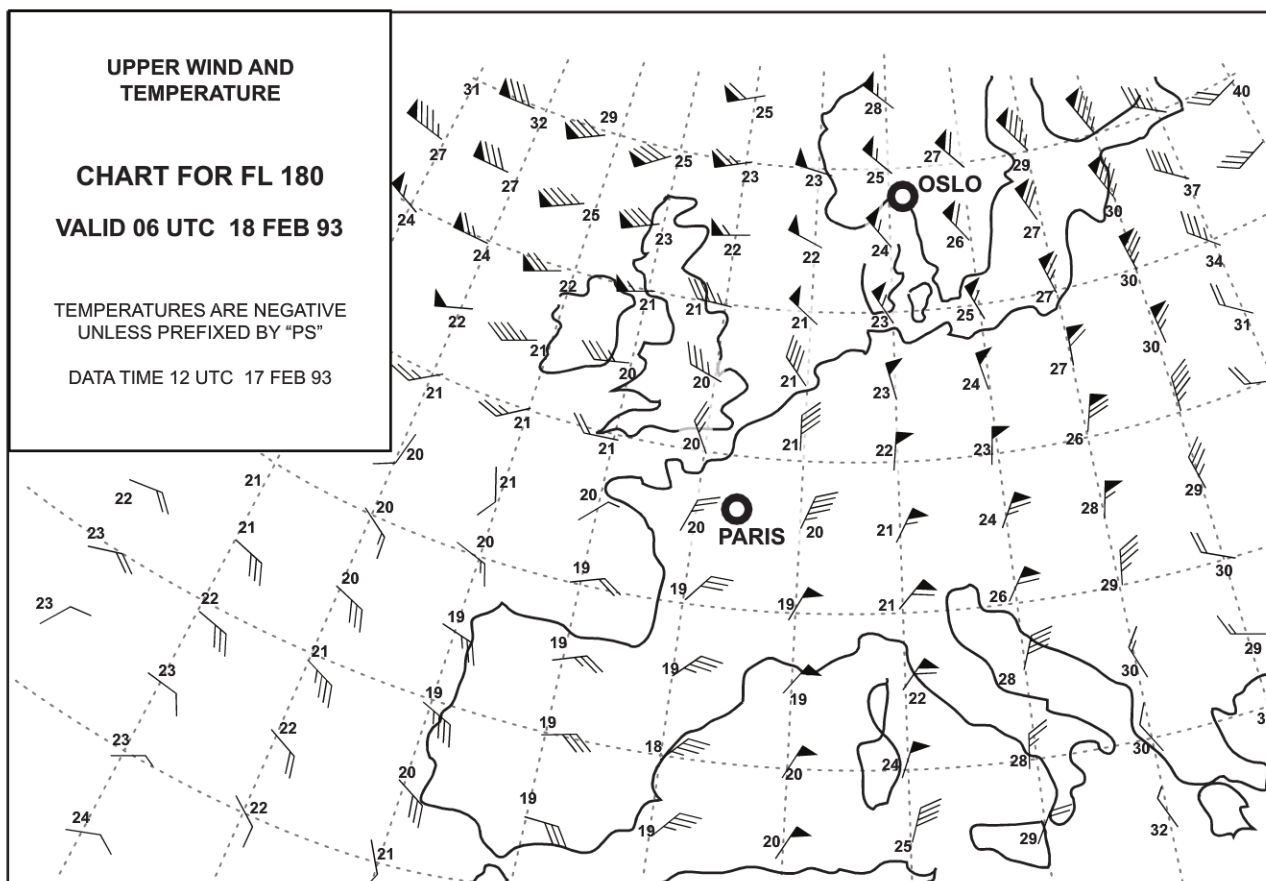


**FIGURE 050-77****FIGURE 050-78**

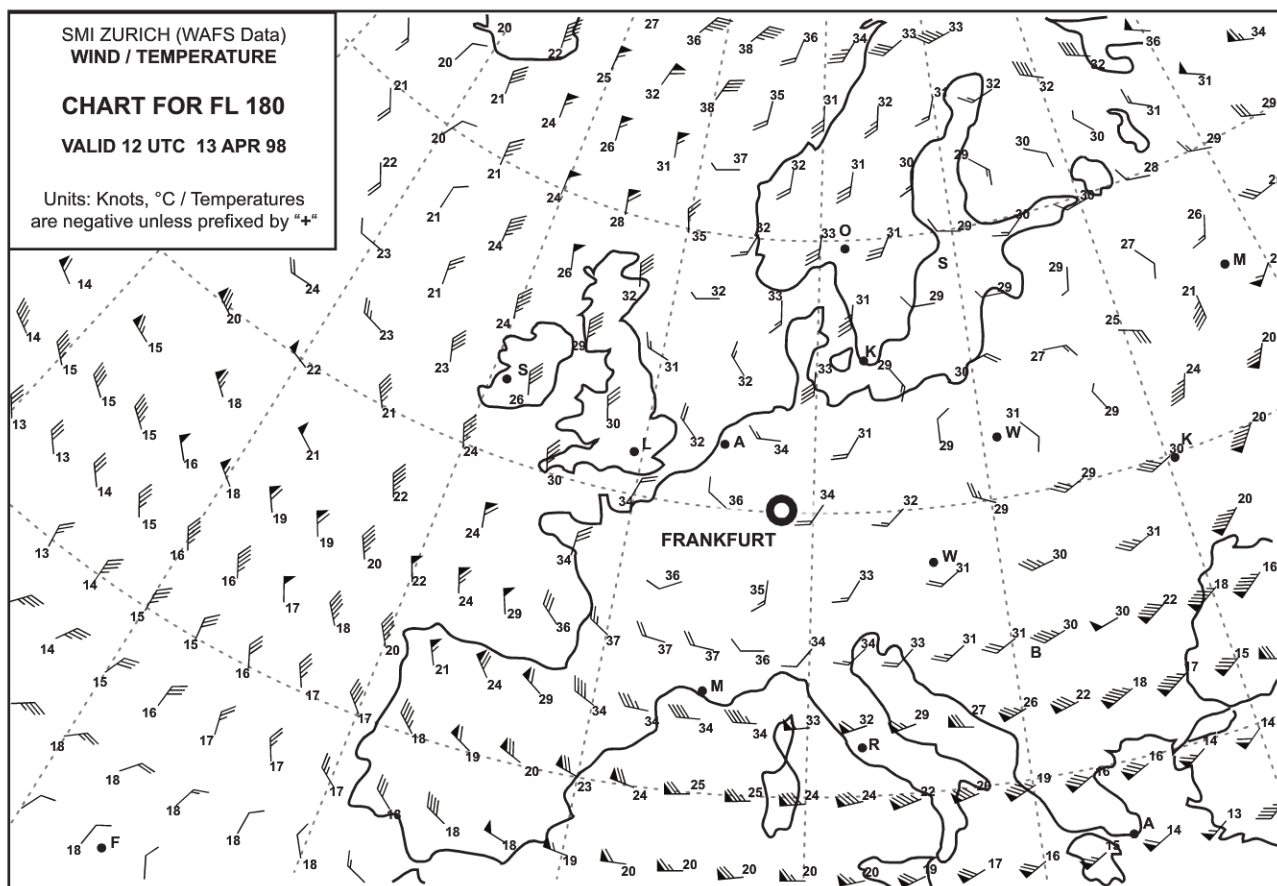
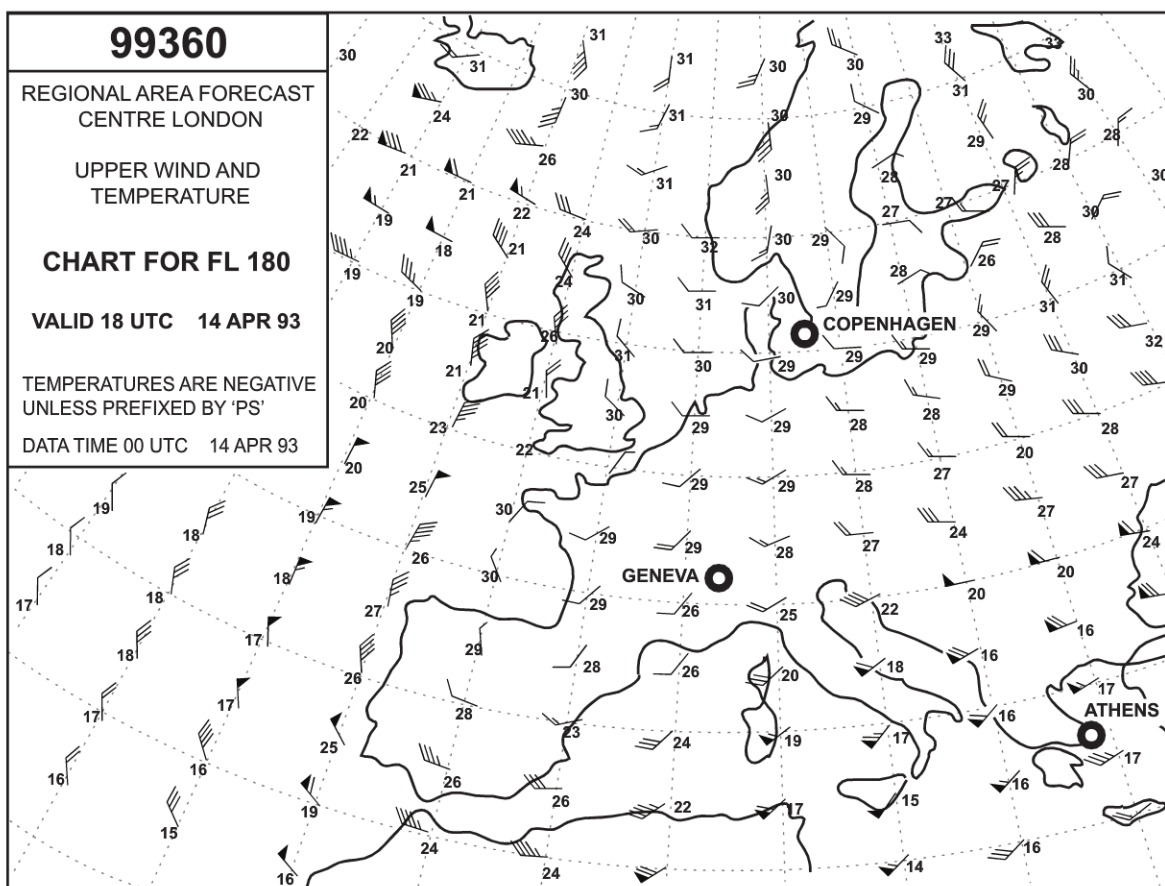
**FIGURE 050-79**

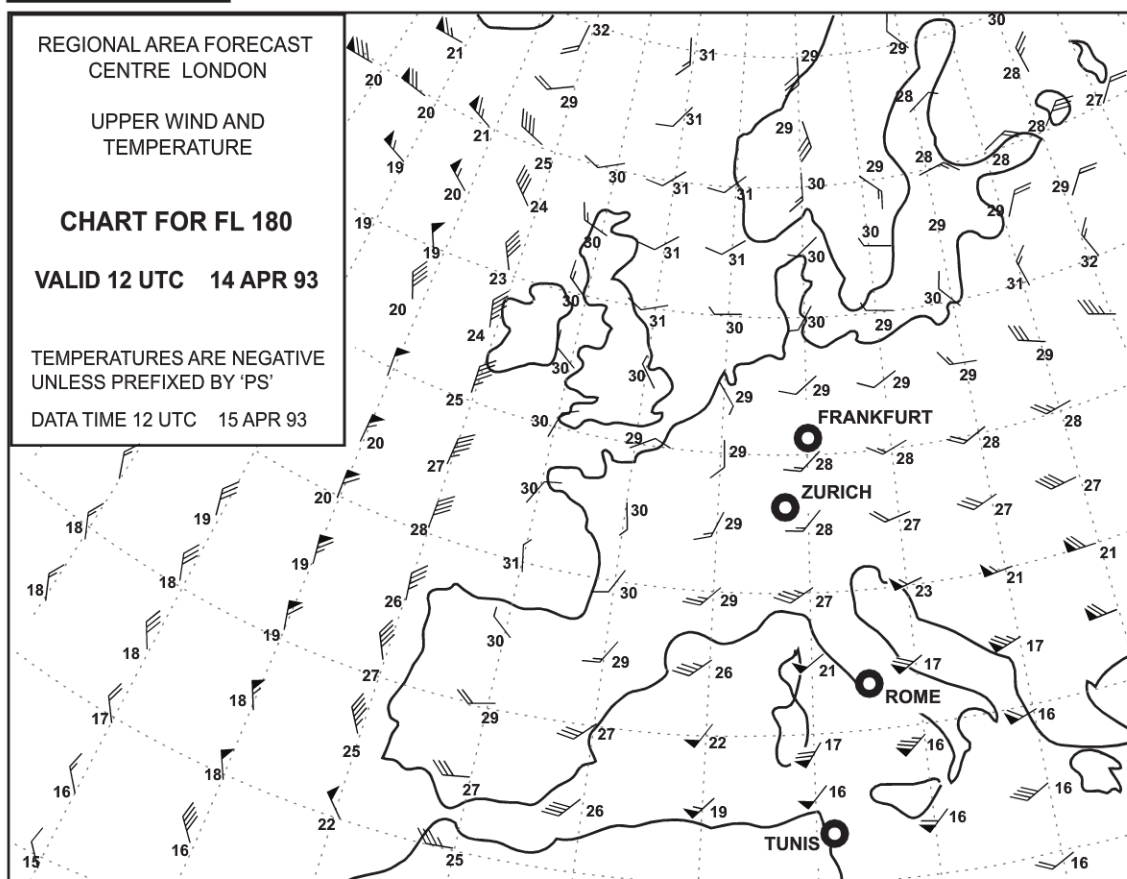
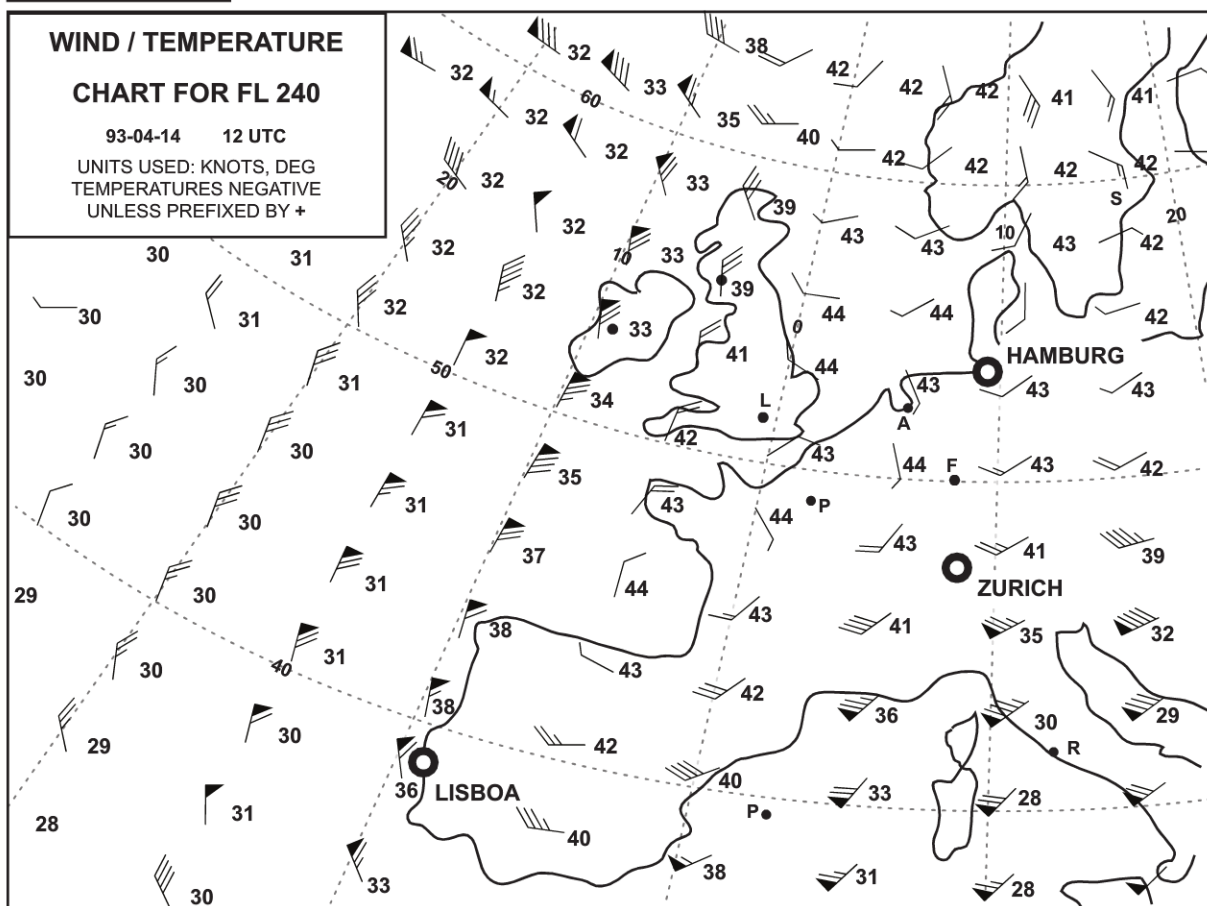


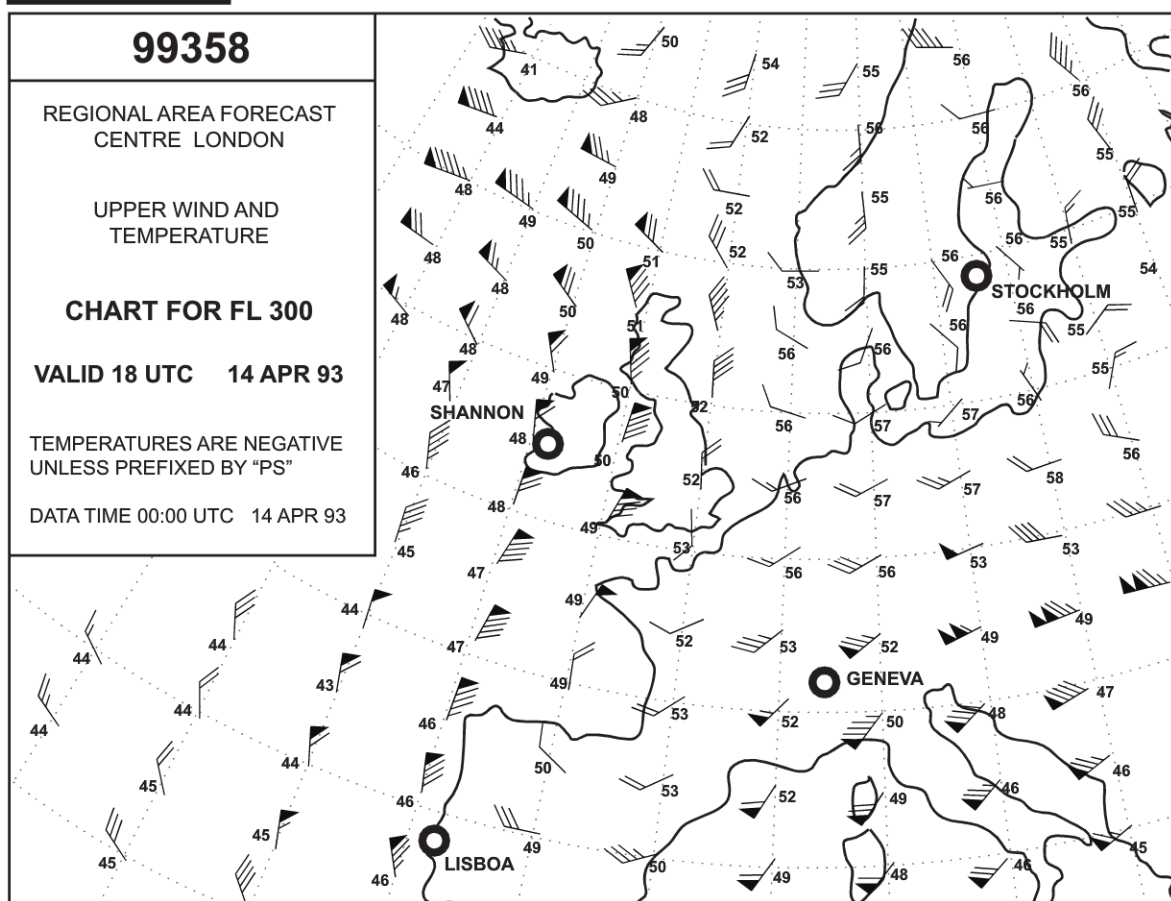
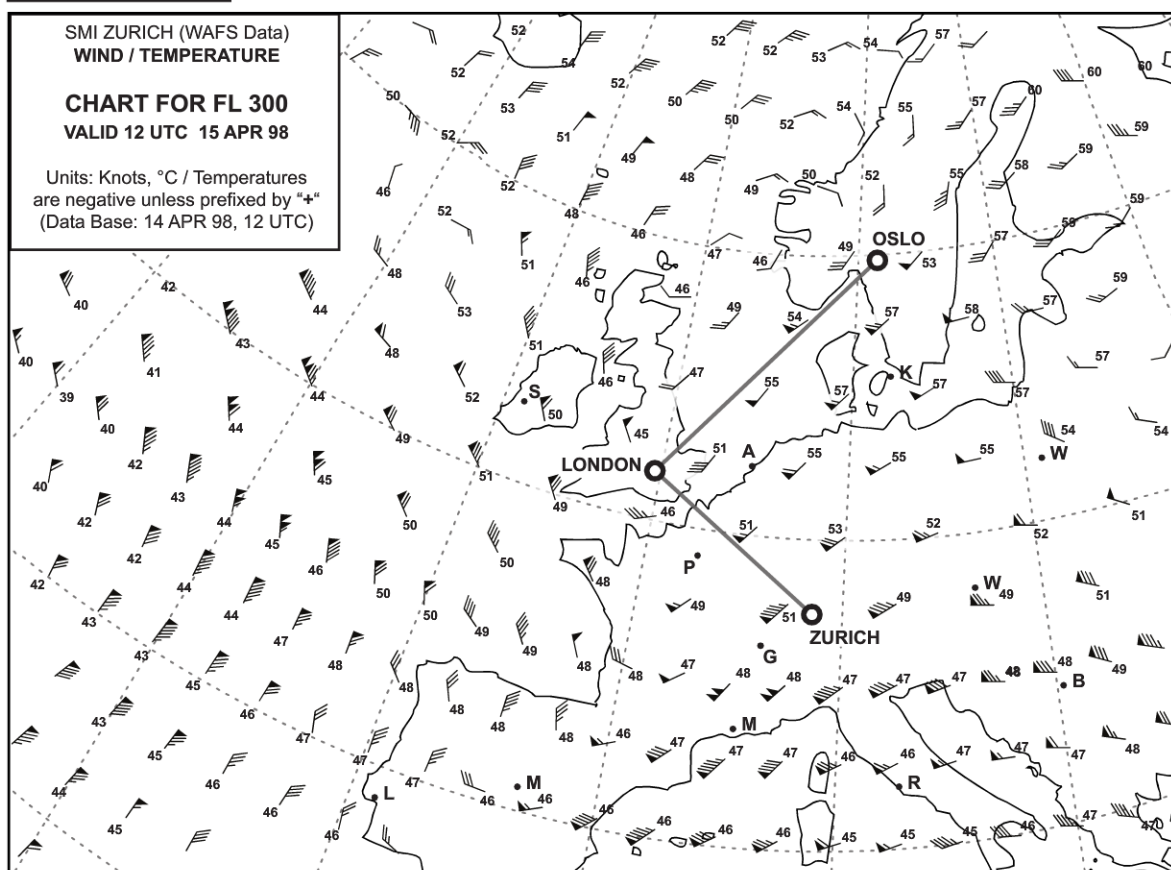
**FIGURE 050-80**



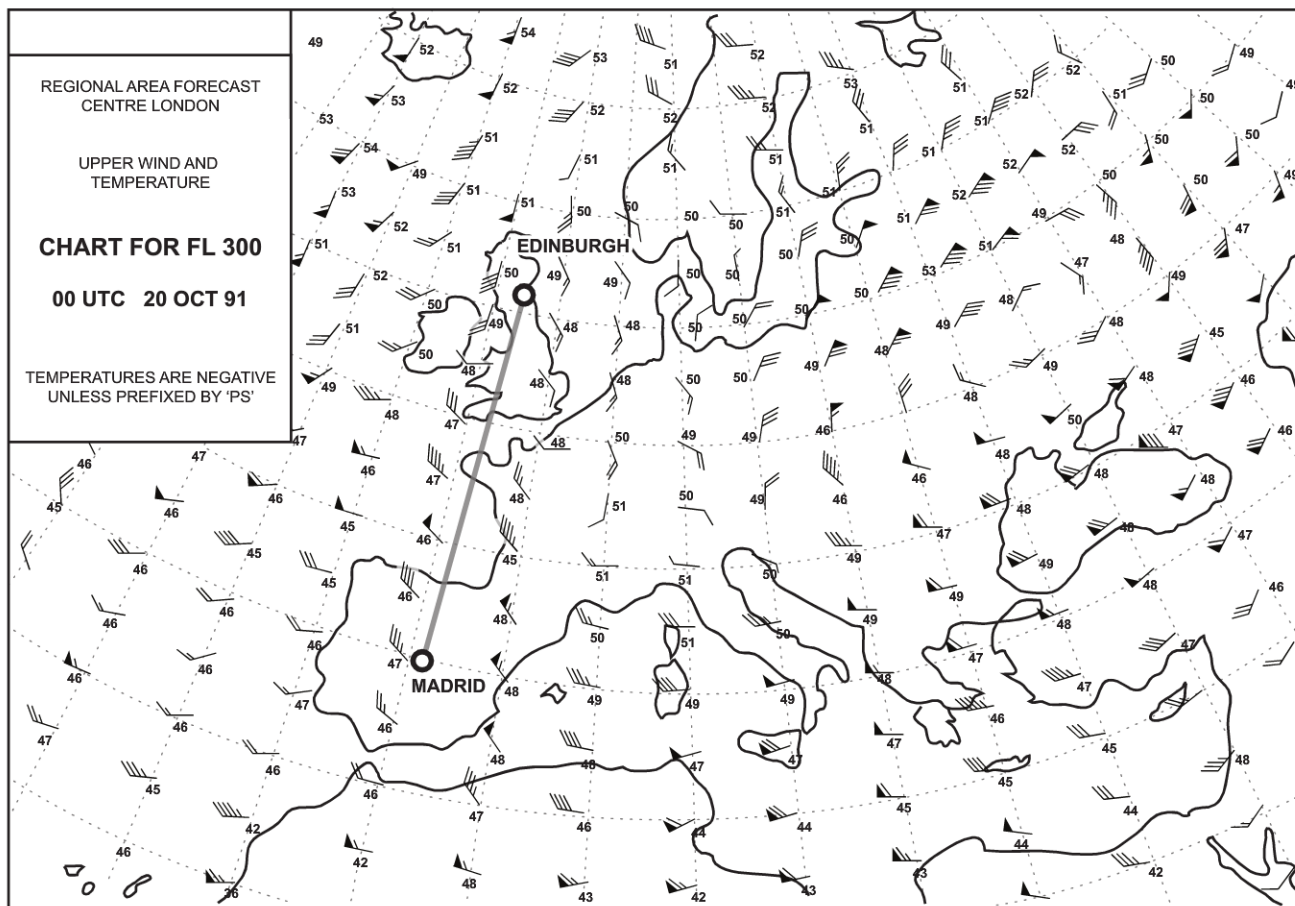


**FIGURE 050-81****FIGURE 050-82**

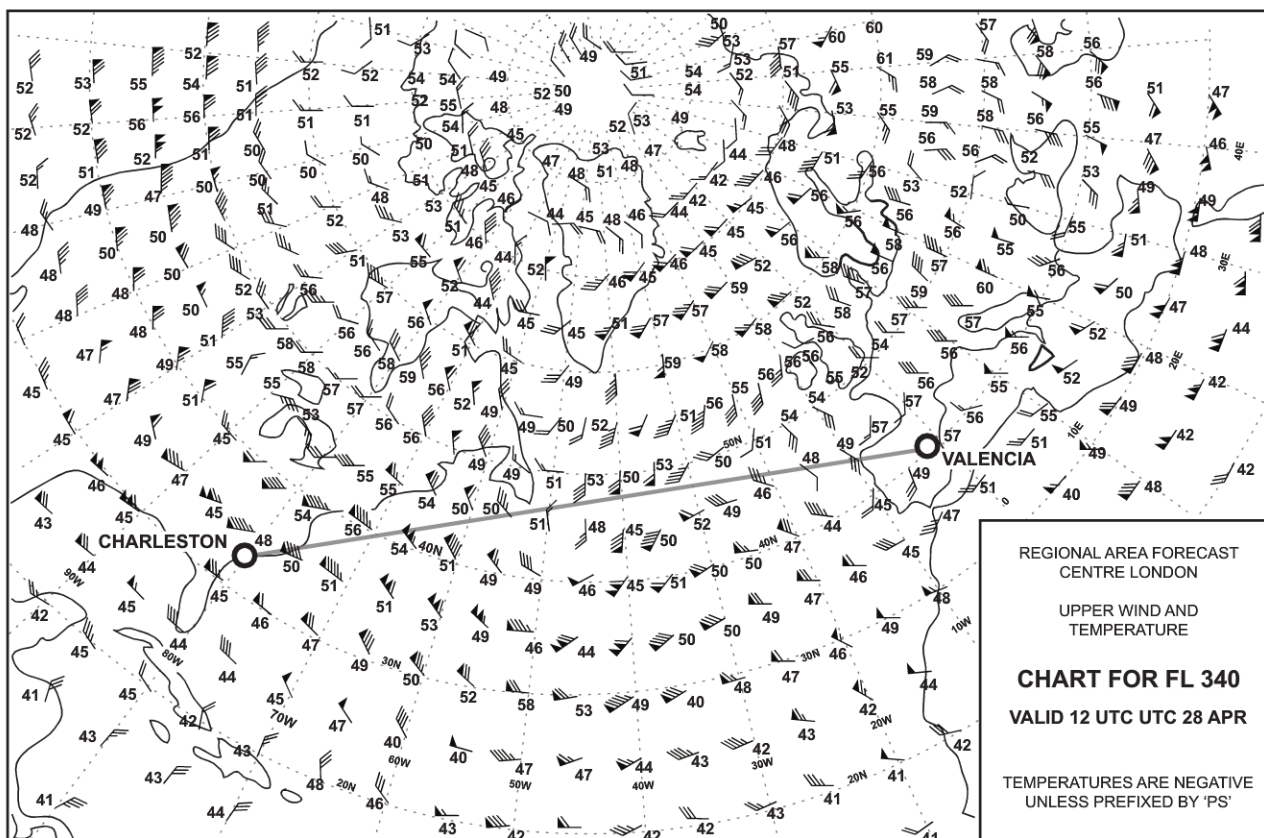
**FIGURE 050-83****FIGURE 050-84**

**FIGURE 050-85****FIGURE 050-86**

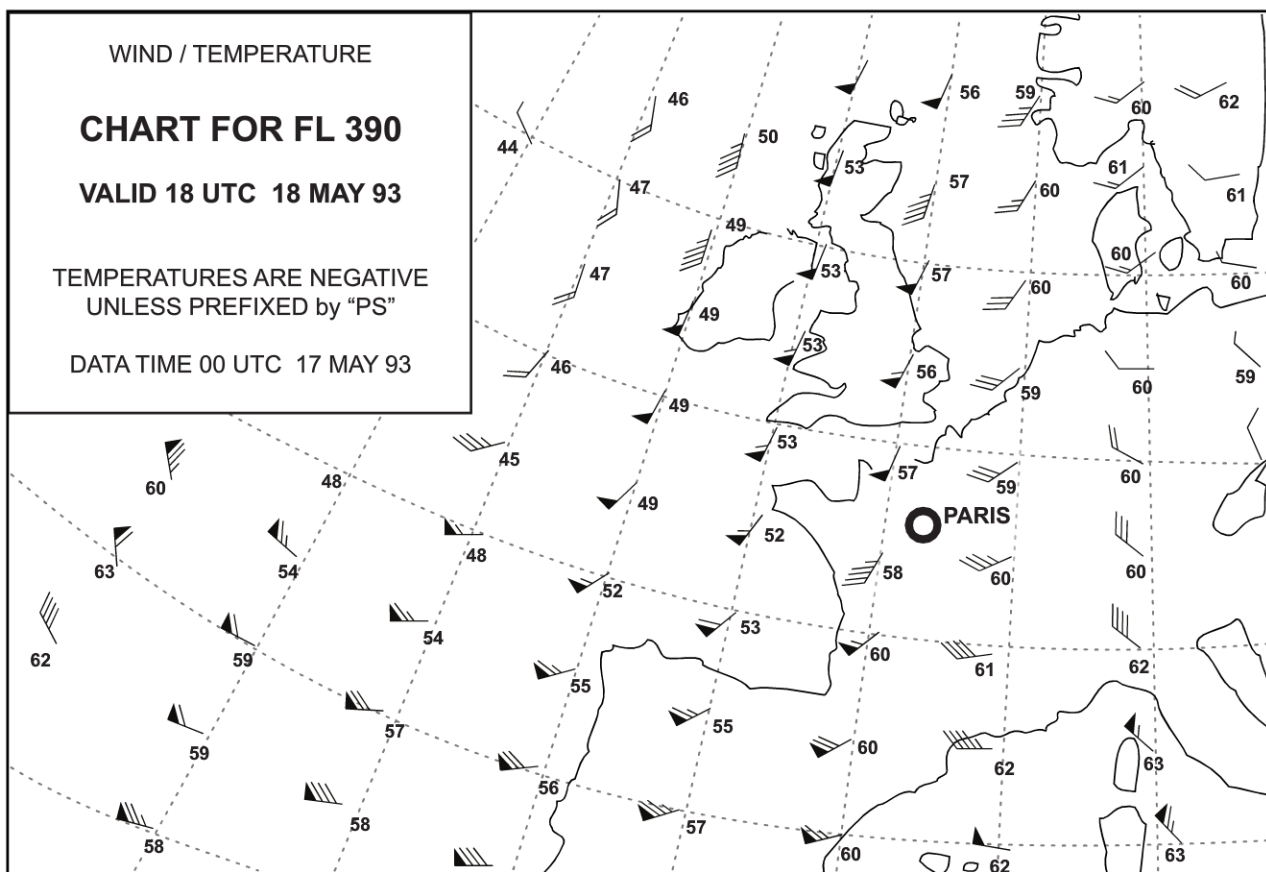
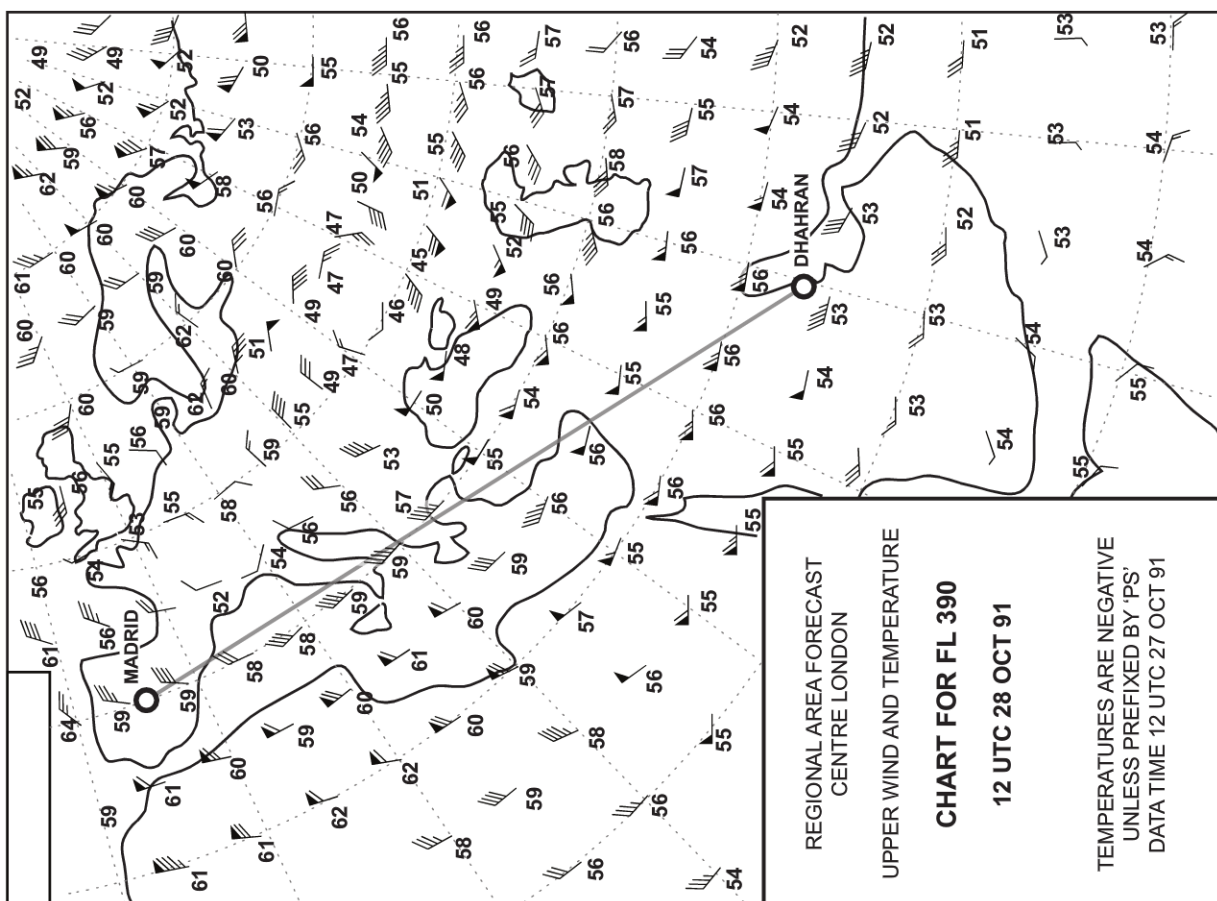
**FIGURE 050-87**



**FIGURE 050-88**





**FIGURE 050-89****FIGURE 050-90**

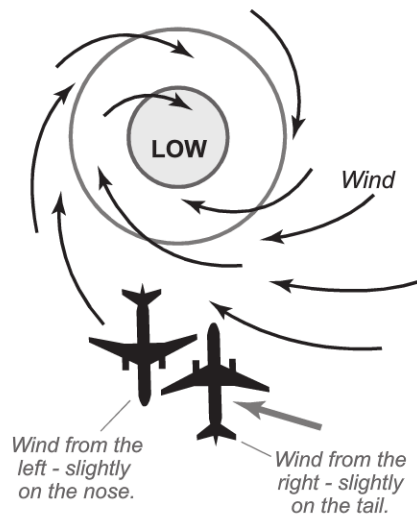


# PICTURE SUPPLEMENTS

## EXPLANATIONS

**FIGURE 050-E01**

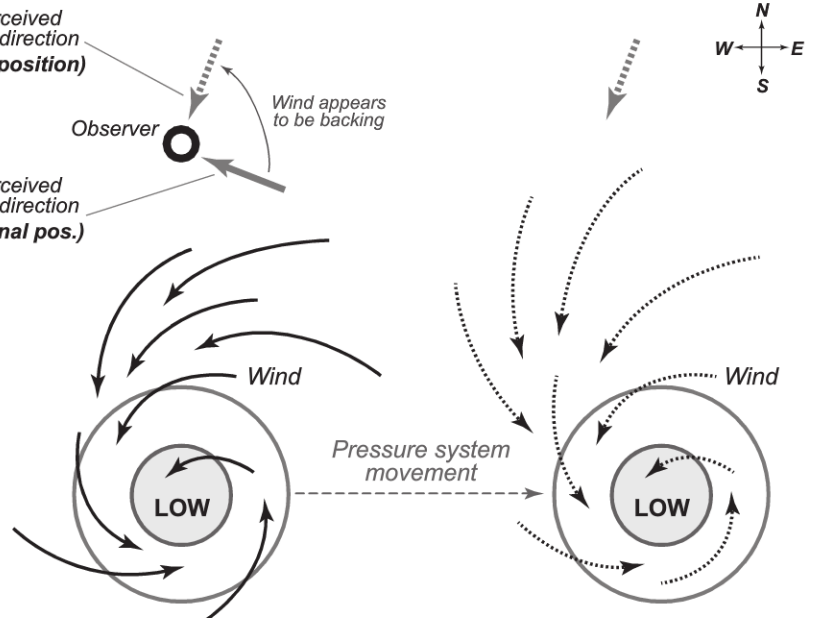
**LOW / CYCLONE**  
(Southern Hemisphere)



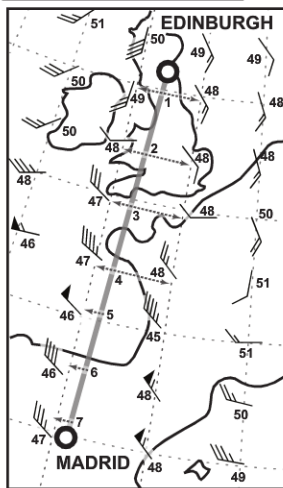
**FIGURE 050-E02**

Perceived wind direction  
(new position)

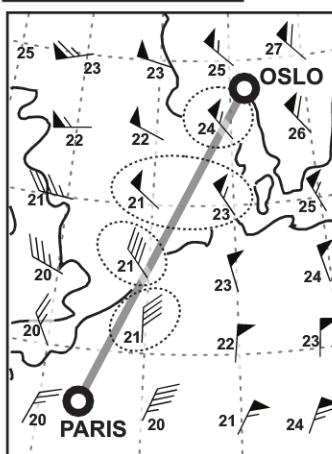
Perceived wind direction  
(original pos.)



**FIGURE 050-E03**



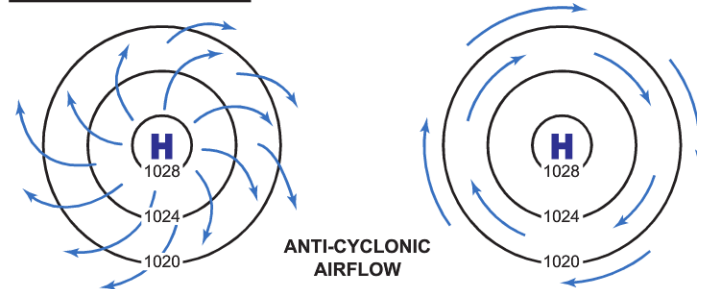
**FIGURE 050-E05**



**LOW / CYCLONE**  
(Northern Hemisphere)  
**ORIGINAL POSITION**

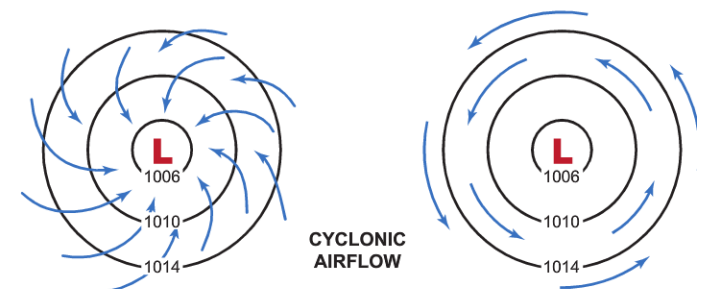
**LOW / CYCLONE**  
(Northern Hemisphere)  
**NEW POSITION**

**FIGURE 050-E04**



**SURFACE WINDS**  
(inside the friction layer)  
Northern hemisphere

**UPPER WINDS**  
(above the friction layer)  
Northern hemisphere



**SURFACE WINDS**  
(inside the friction layer)  
Northern hemisphere

**UPPER WINDS**  
(above the friction layer)  
Northern hemisphere

FIGURE 050-E06

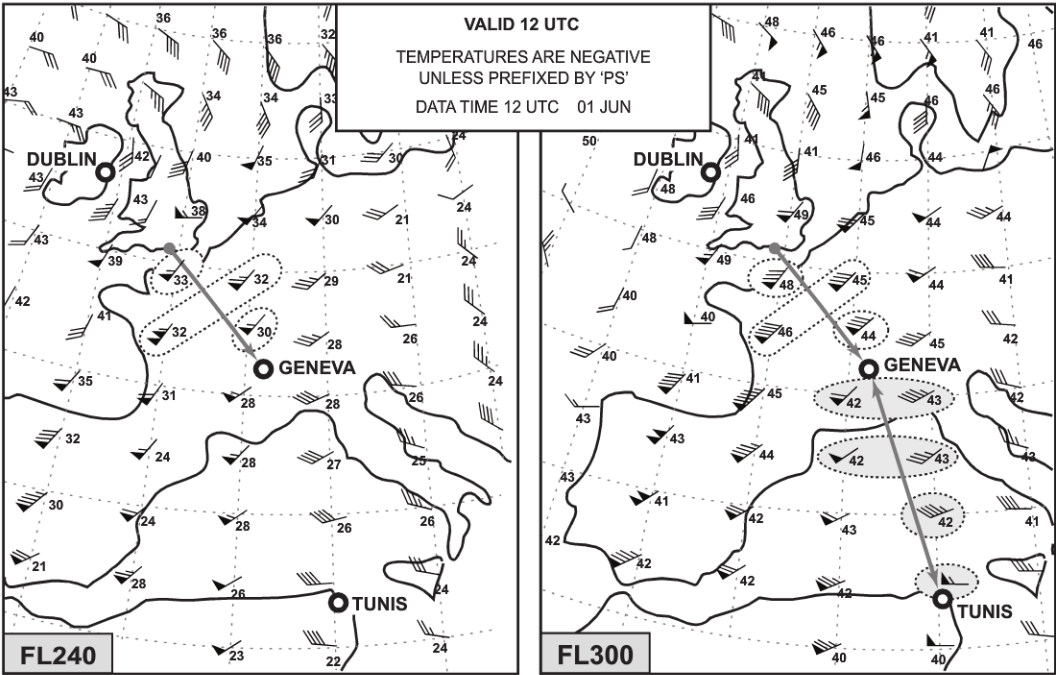


FIGURE 050-E07

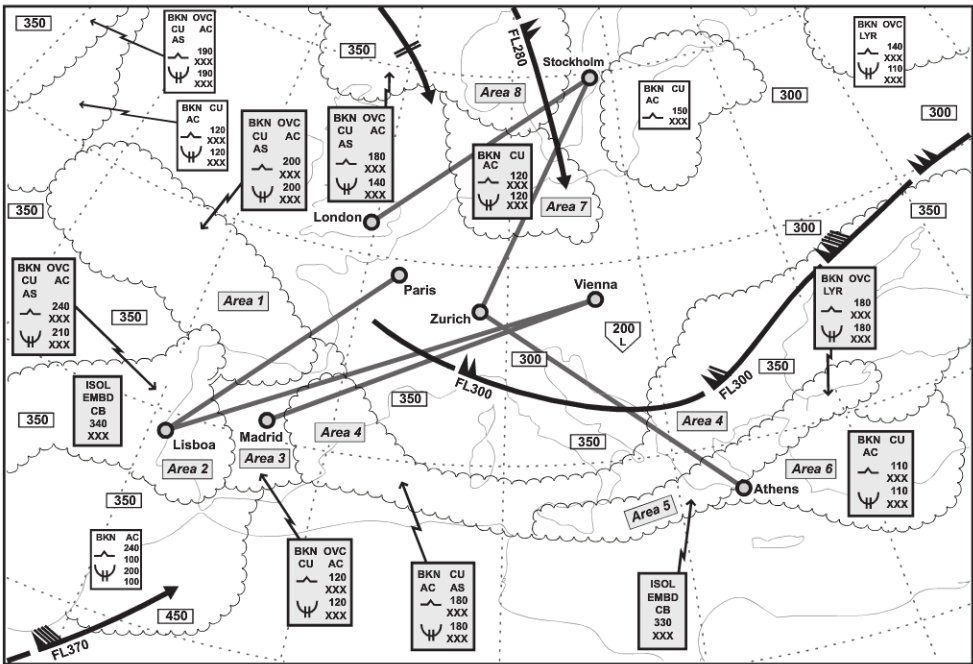
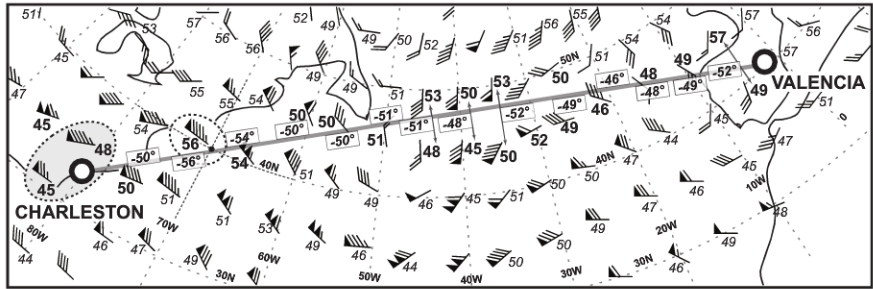
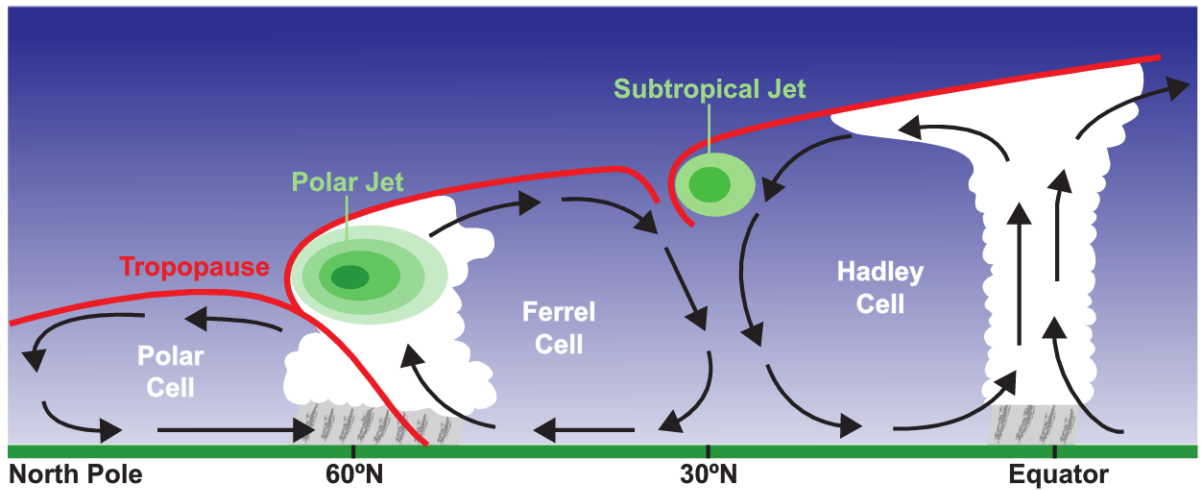


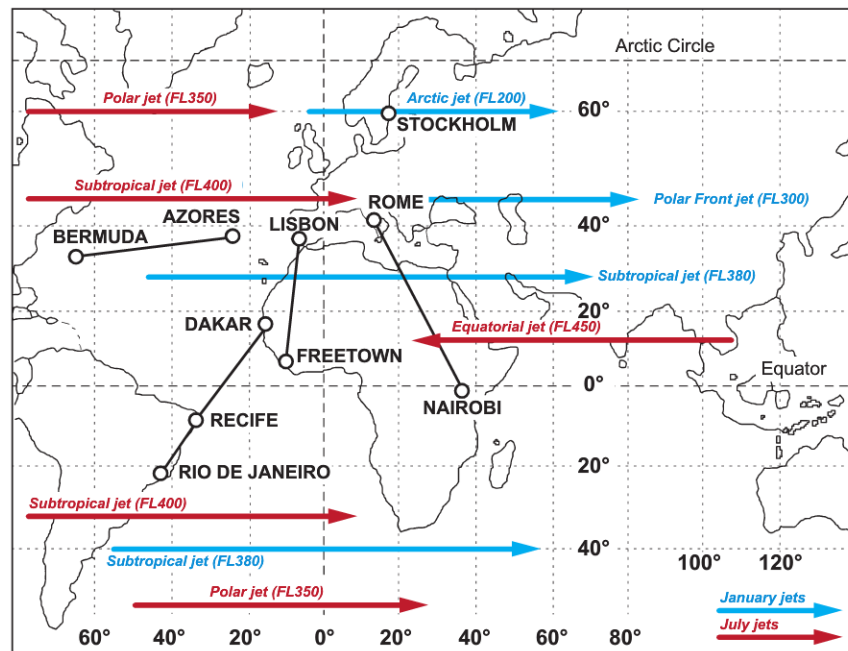
FIGURE 050-E08



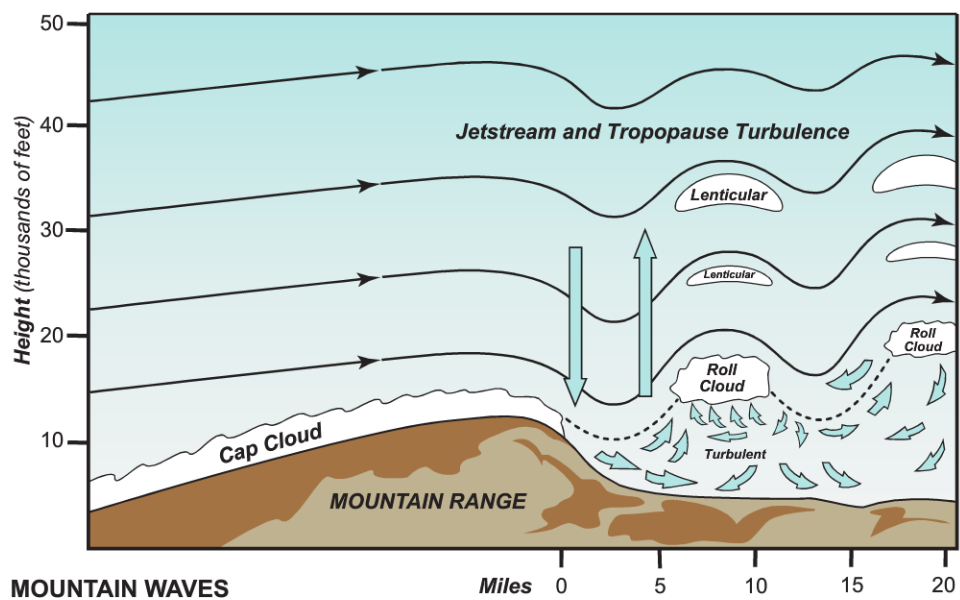
**FIGURE 050-E09**



**FIGURE 050-E10**

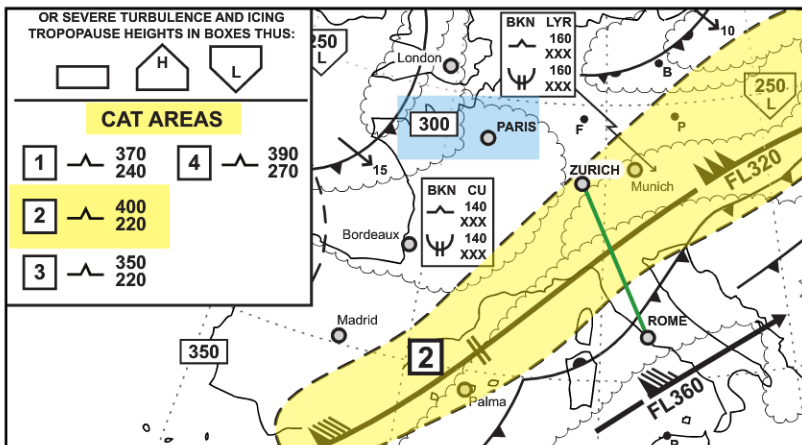


**FIGURE 050-E11**

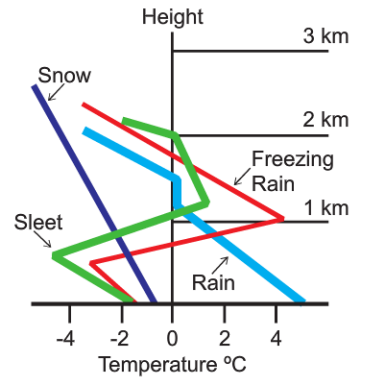




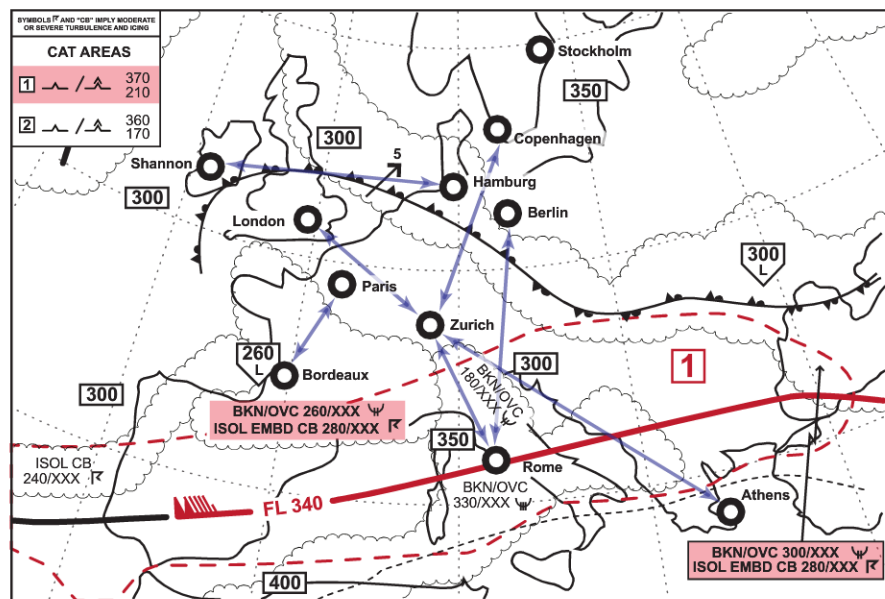
**FIGURE 050-E12**



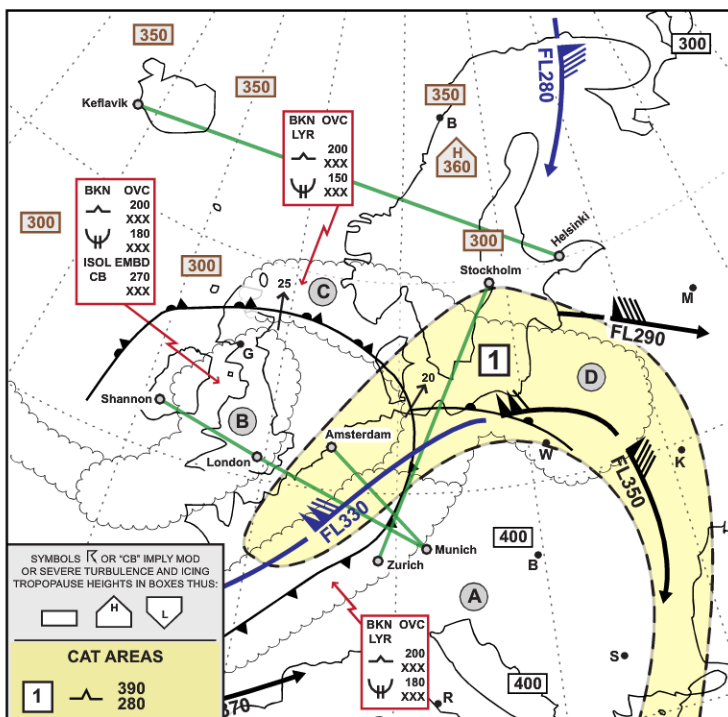
**FIGURE 050-E13**



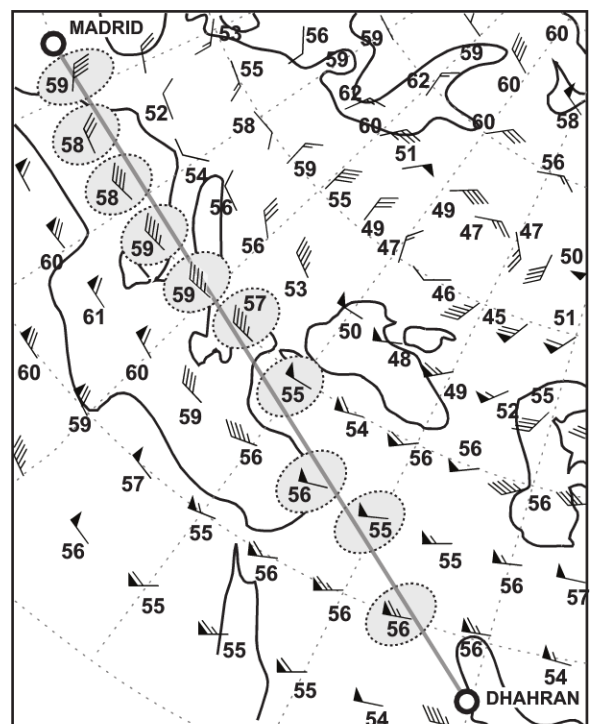
**FIGURE 050-E14**



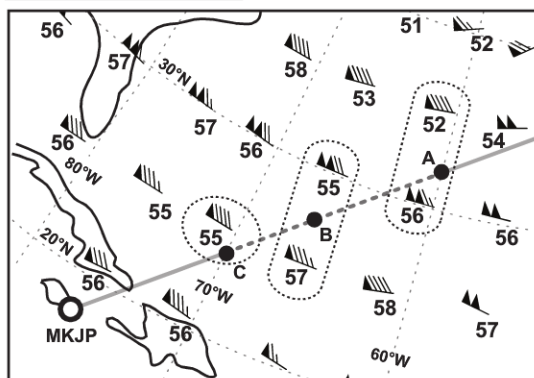
**FIGURE 050-E15**



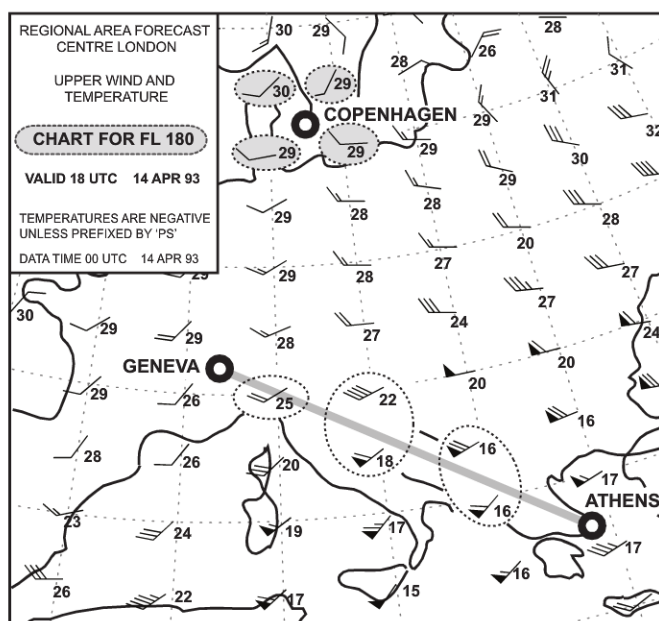
**FIGURE 050-E16**



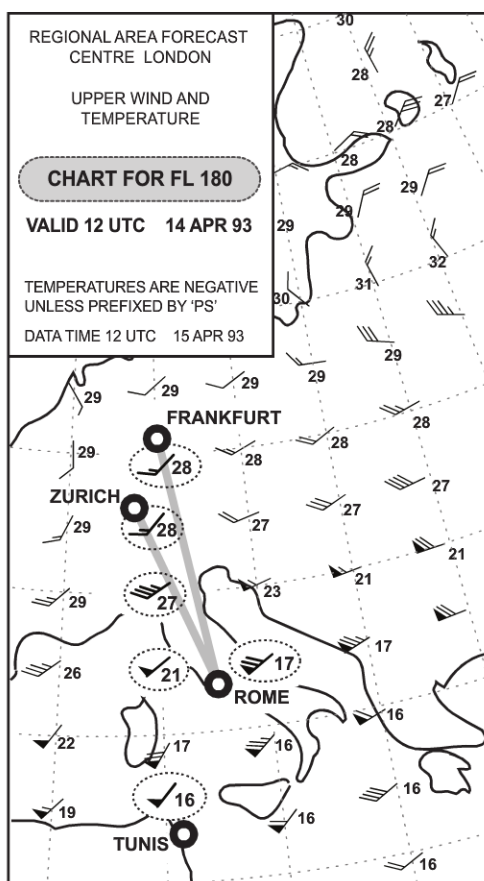
**FIGURE 050-E17**



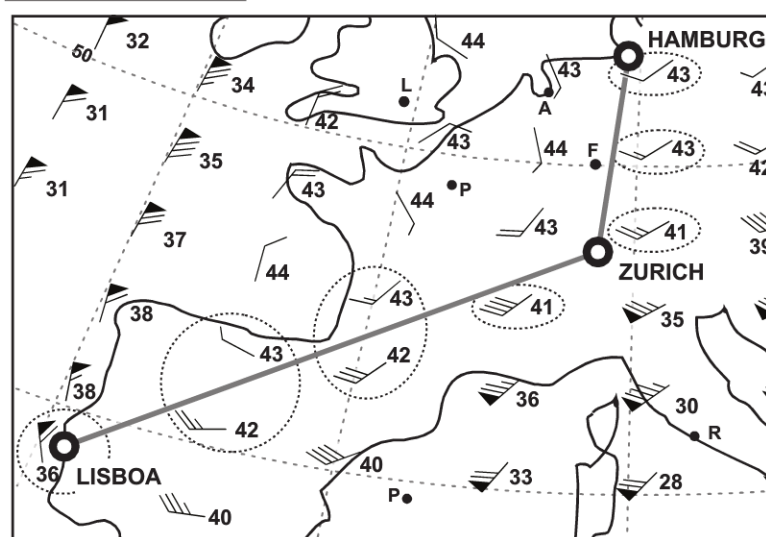
**FIGURE 050-E18**



**FIGURE 050-E19**



**FIGURE 050-E20**

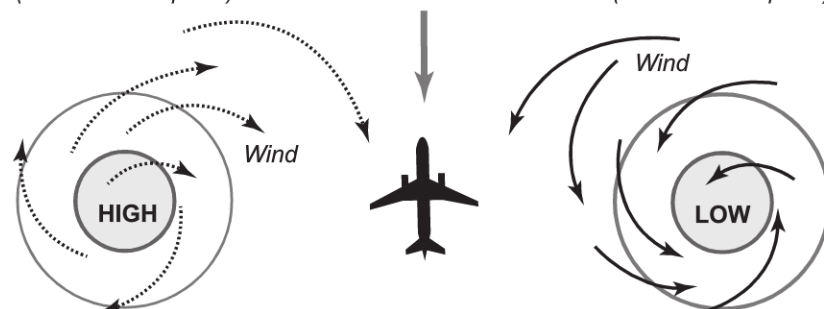


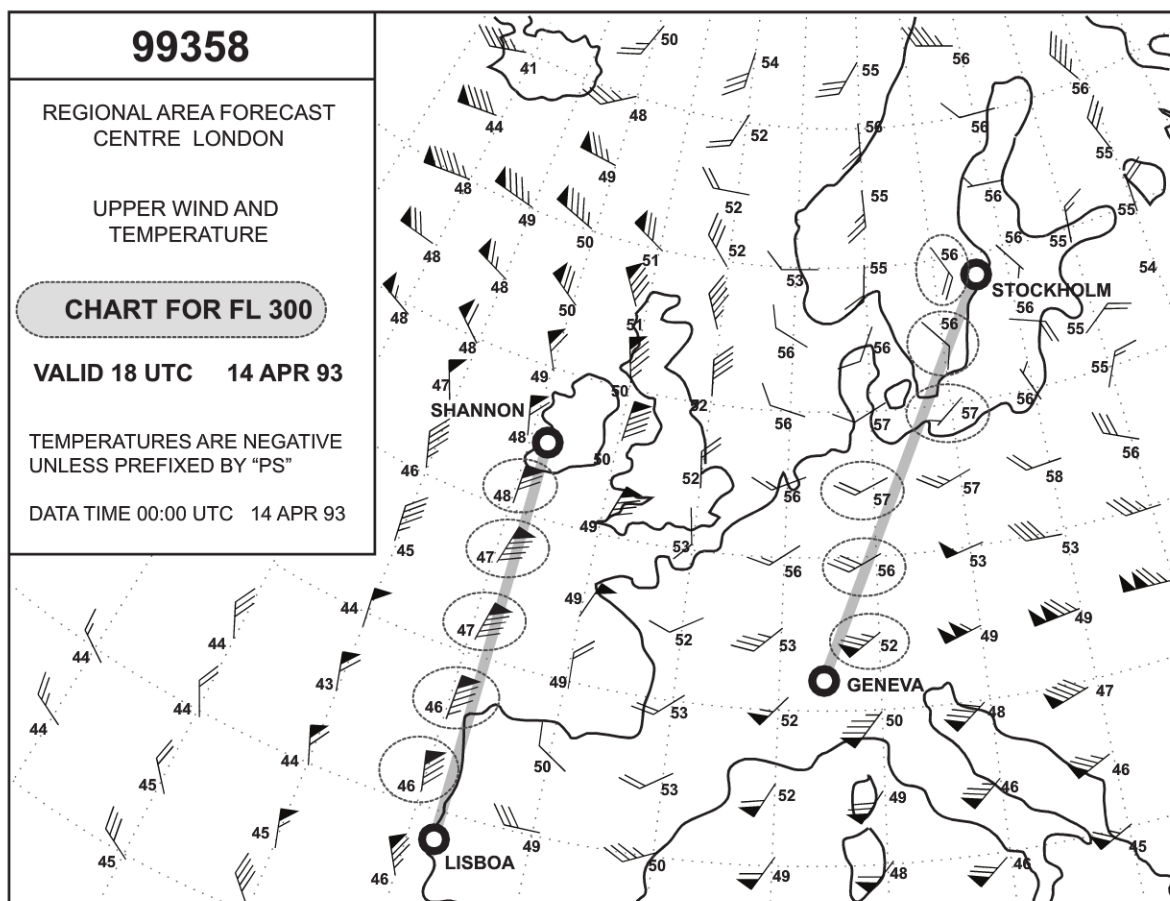
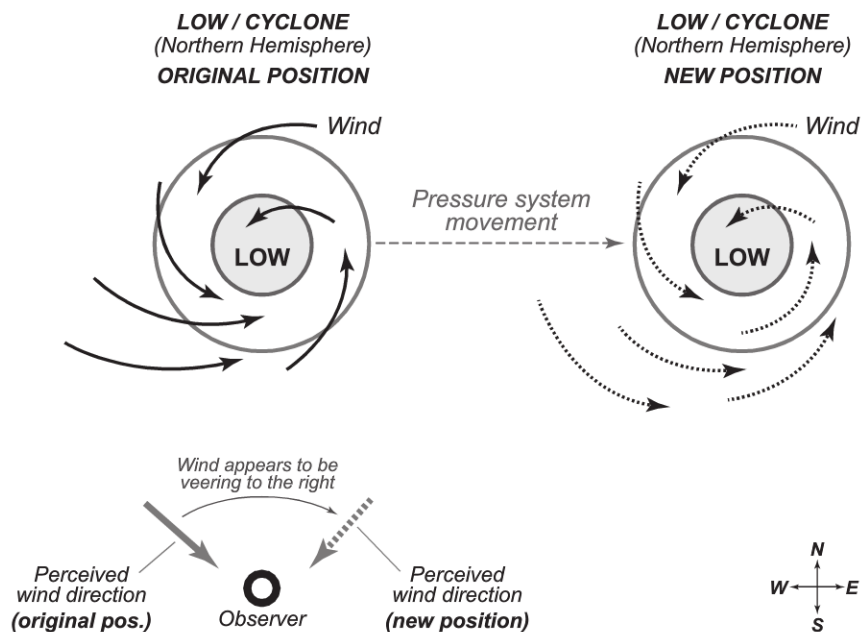
**FIGURE 050-E21**

**HIGH / ANTI-CYCLONE**  
(Northern Hemisphere)

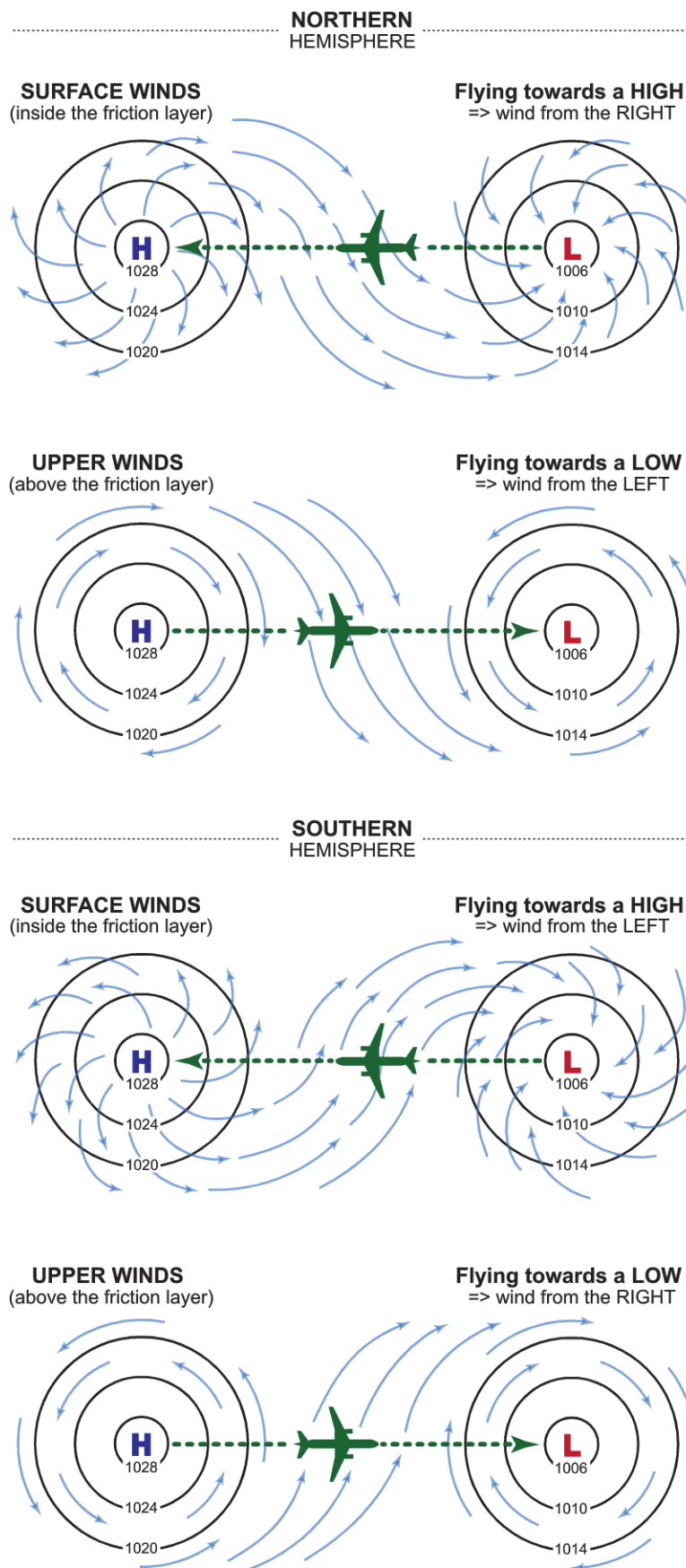
Experiencing  
headwind

**LOW / DEPRESSION / CYCLONE**  
(Northern Hemisphere)



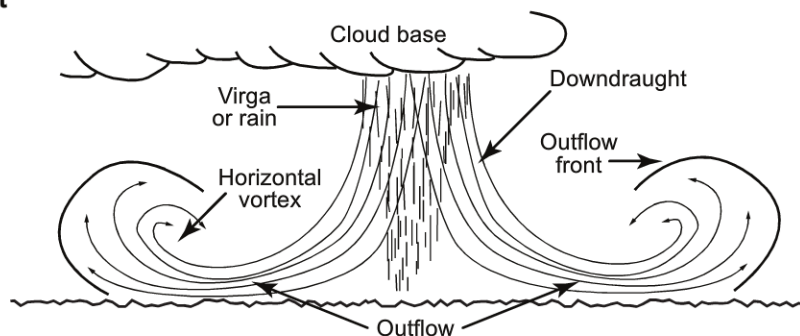
**FIGURE 050-E22****FIGURE 050-E23**

**FIGURE 050-E24**

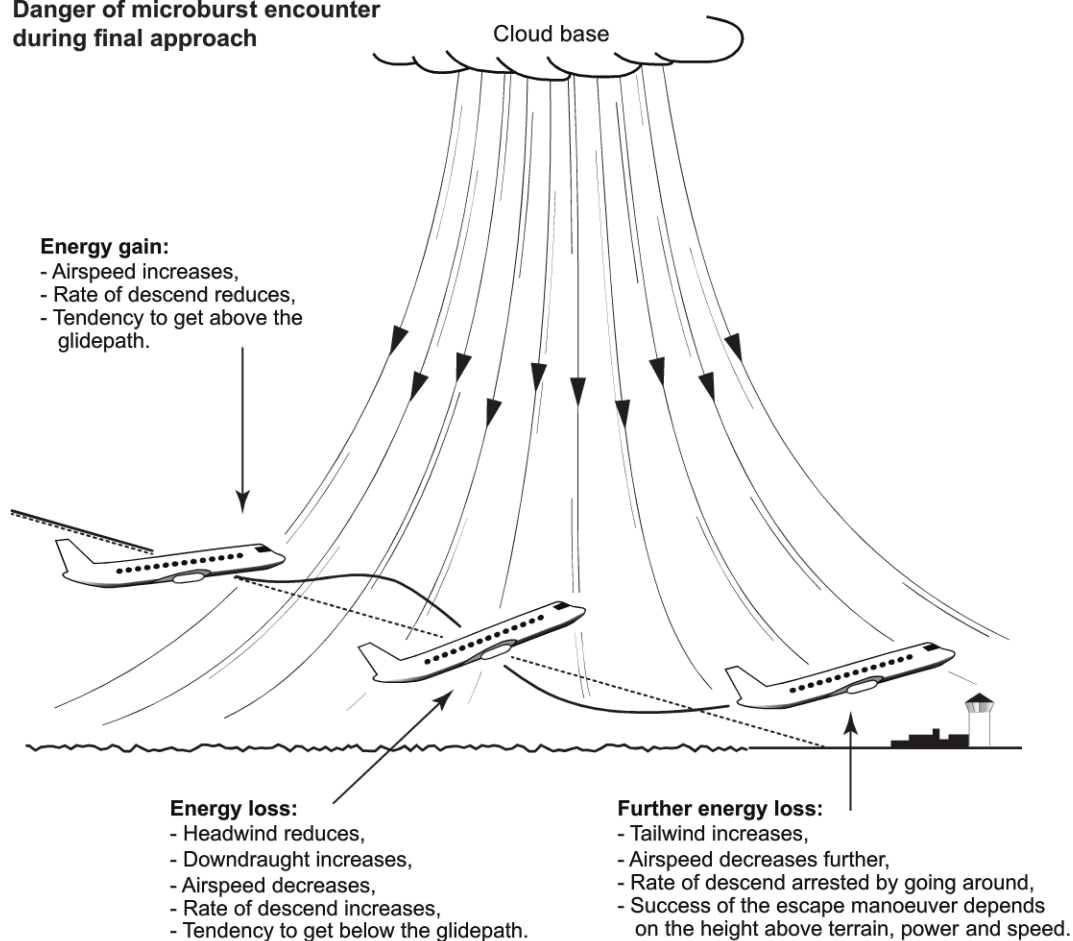


**FIGURE 050-E25**

**Microburst**



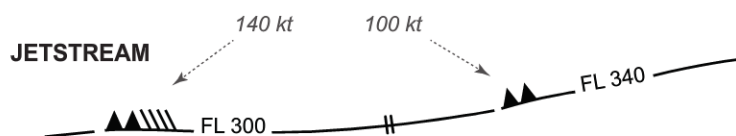
**Danger of microburst encounter during final approach**





**FIGURE 050-E26****METEOROLOGICAL CHART SYMBOLS****WIND**

	270° / 5 kts
	270° / 10 kts
	270° / 15 kts
	270° / 50 kts
	270° / 85 kts
	270° / 85 kts



Wind arrows indicate the maximum wind in the jet and the flight level at which it occurs. Significant changes (speed of 20 knots or more, 3000 ft (less if practicable) in flight level) are marked by the double bar. In the example, at the double bar the wind speed is 120 kt. The heavy line delineating the jet axis begins/ends at the points where a wind speed of 150 km/h - 80 kt is forecasted.

**SIGNIFICANT WEATHER, PRECIPITATION**

	Thunderstorms (TS)		Drizzle (DZ)		Intermittent Slight Rain
	Tropical cyclone		Rain (RA)		Continuous Slight Rain
	Severe squall line		Snow (SN)		Moderate Rain (RA)
	Moderate turbulence		Shower (SH)		Heavy Rain
	Severe turbulence		Widespread blowing snow		Freezing Drizzle (FZDZ)
	Light aircraft icing		Severe sand or dust gaze		Slight Freezing Rain (FZRA)
	Moderate aircraft icing		Sandstorm or dust storm		Moderate or heavy FZRA
	Severe aircraft icing		Widespread haze (HZ)		Snow Grains (SG)
	Mountain Waves		Widespread mist (BR)		Ice Pellets (PL)
	Visible ash cloud		Widespread fog (FG)		Rain and Snow
	Volcanic ash / eruption		Shallow Fog (MIFG)		Rain Showers (RASH)
	Tornado / Funnel Cloud		Widespread smoke (FU)		Hail (GR)

**FRONTS, TROPOPAUSE AND OTHER SYMBOLS**

	Cold Front (blue)
	Warm Front (red)
	Occluded Front (violet)
	Stationary Front (blue + red parts)
	Squall Line
	Convergence Line
	Intertropical Convergence Zone
	Boundary of area of Significant Weather
	Boundary of area of Clear Air Turbulence
	Sea Wave Height (m)
	Sea Temp (°C)

380

Tropopause Level

0°:100

Freezing Level

H  
460

Tropopause High

270  
L

Tropopause Low

OVC	LYR
	210 XXX
	210 XXX
ISOL EMBD	380 XXX
CB	

Boxes such as this one describe the conditions inside areas of significant weather. Each box is connected to the respective area by an arrow. In this case we can expect:

- an overcast (OVC) layer (LYR) of clouds,
- moderate turbulence () up to FL210,
- moderate icing () up to FL210,
- isolated (ISOL) embedded (EMBD) cumulo-nimbus (CB) clouds up to FL380. It is important to realize that severe icing and/or severe turbulence can be encountered in CBs.
- the letters "xxx" below the FL info mean that the described phenomenon (icing, turbulence, cloud cover, etc...) is expected to continue below the vertical coverage of the chart (typically FL100) => in this case both the icing and turbulence can be expected to be encountered also below FL100, assuming that FL100 is the bottom of the vertical chart coverage (can be found in the top-left chart corner).

SKC	Sky clear	0 oktas
FEW	Few clouds	1-2 oktas (1/8 to 2/8 of sky covered)
SCT	Scattered clouds	3-4 oktas (3/8 to 4/8 of sky covered)
BKN	Broken clouds	5-7 oktas (5/8 to 7/8 of sky covered)
OVC	Overcast clouds	8 oktas (sky completely covered with clouds)

**FIGURE 050-E27****SIGWX - Significant Weather Charts**

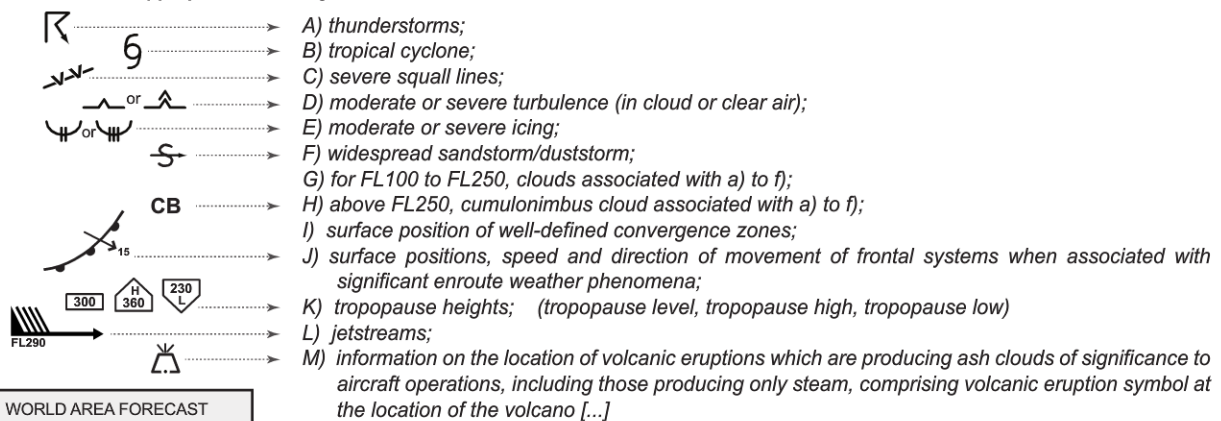
As the name of the chart suggests, it is a visual presentation of significant weather phenomena for a given geographical region. Significant Weather charts are issued by World Area Forecast Centres (WAFC) every six hours (00:00, 06:00, 12:00 and 18:00 UTC. Specifications for the Significant Weather charts are outlined in ICAO Annex 3. Some important sections are listed below:

**ICAO Annex 3 - Appendix 8:**

1.3.3 Forecasts of significant weather phenomena shall include all the items listed in Appendix 8, 4.3.1.1. The forecasts shall be issued for the following flight levels:

- a) between FL250 to FL630; and
- b) between FL100 to FL250 for limited geographical areas, as determined by regional air navigation agreement. If the average elevation of the topography of the area could extend a significant topographical effect to FL100, a higher level should be specified for the base of the charts [...]

4.3.1.1 Where information on significant en-route weather phenomena is supplied in chart form to flight crew members before departure, the charts shall be significant weather charts valid for a specified fixed time. Such charts shall show, as appropriate to the flight:



WORLD AREA FORECAST  
CENTRE LONDON  
FIXED TIME FORECAST CHART  
**EUR SIGNIFICANT WEATHER**  
**FL 100-450**  
**VALID 00 UTC ON 04/04/1998**

HEIGHT INDICATIONS IN FL  
SPEEDS IN KNOTS

**SYMBOLS  $\text{R}$  OR "CB" IMPLY MOD OR SEVERE TURBULENCE AND ICING**

**CAT AREAS**

1	390 280	2	OCNL 350 250
---	------------	---	-----------------

**Note 1:** For aircraft operating above FL250, items a) to f) are only required if expected to be above that level, and in the case of item a), only those thunderstorms which warrant the issuance of a SIGMET as given in Appendix 6 (guidance on the use of term "FRQ TS" is given in Appendix 6).

**Note 2:** The abbreviation "CB" should only be included where it refers to the occurrence or expected occurrence of an area of widespread cumulonimbus clouds or cumulonimbus along a line with little or no space between individual clouds, or to cumulonimbus embedded in cloud layers or concealed by haze. It does not refer to isolated or scattered cumulonimbus not embedded in cloud layers or concealed by haze.

**SIG WX chart header**

Each SIGWX chart has an information section, typically in one of the corners (see picture on the left for a sample header), where you can find out by which meteo agency the chart has been issued, what is the vertical chart coverage (e.g. FL 100-450) + the date/time for which the chart has been issued. Notice the middle section of the chart header => all height indications are given in terms of Flight Levels (FLs) and speeds in KTS. A very important statement follows: if you encounter the **thunder-**

**storm symbol ( $\text{R}$ )** or a mention of a **Cumulo-Nimbus cloud (CB)** anywhere on the chart, it automatically means that you can expect moderate or severe turbulence and/or icing in that area, even if other symbols on the chart specify lower intensity of turbulence / icing. The last section of the chart header provides information on the areas of Clear Air Turbulence (CAT). These are identified on the chart as areas outlined by thick dashed lines and each of these areas has a box with a number inside it that links it to the detailed information in the chart header. See the sample header above: in CAT area 1 we can expect **moderate turbulence** ( $\text{---}$ ) from FL280 up to FL390. In CAT area 2 we can expect moderate turbulence, with occasional (OCNL) **severe turbulence** ( $\text{---}$ ) from FL250 up to FL350.

**Jetstream** - if windspeed is not specified for a jetstream segment, it is considered to be a minimum of 80 kts. Individual segments are separated by breaks in the lines. Speed symbols are located at the beginning of the segment, thus also helping to identify the direction from which the wind is blowing.

**Significant Weather Area (e.g. #2)** with a box listing the WX phenomena: Broken (BKN) cumulus (CU), alto-cumulus (AC) and alto-stratus (AS) clouds with moderate turbulence up to FL200 and moderate icing up to FL180.

"XXX" means that the lower vertical limit (floor) of the corresponding wx phenomena (turb. and icing here) is expected to be located below the vertical coverage of the chart (typically FL100).

**Tropopause level** in this area (FL300)

**Tropopause low** in this area (FL260)

**Icing level ( $0^{\circ}\text{C}$  at FL090)**

$0^{\circ}\text{C}$  090

**CAT (Clear Air Turbulence) area**, including its identification: [2]

**Jetstream** - core at FL320, wind speed 135 kts (triangle = 50 kts, long line = 10 kts, short = 5 kts).

**Double bar** = significant changes (speed of 20 kts or more and/or 3000 ft (less if practicable) in FL).

**Significant Weather Area (e.g. #1)**

Listing of significant WX phenomena that can be encountered in the sig. weather area #1 = area to which the box is connected by the arrow:

**Cold front**  
The short line with an arrow indicates direction (SE) and the speed (20 kts) of the frontal movement.

Isolated (ISOL) embedded (EMBD) CB clouds with thunderstorms up to FL330. **Note that the conditions in places with the underlying sig. wx. area (#2) can also be applicable!**



**FIGURE 050-E28****UPPER WIND AND TEMPERATURE CHARTS**

As the name of the chart suggests, the Upper Wind and Temperature charts are a visual presentation of the forecasted wind and temperature conditions at a particular Flight Level (FL) for the time listed on the chart. The charts are issued by World Area Forecast Centres (WAFC) every six hours (00:00, 06:00, 12:00 and 18:00 UTC for certain constant hPa surfaces = Flight Levels (the pressure is constant all over the chart)).

For high-level flights, the charts cover the vertical area between FL50 to FL450 and are typically issued for the following specific **FLs in Europe: 50, 100, 180, 240, 300, 340, 390 and 450**. For low-level flights, the charts are issued typically for the following altitudes: **2000 ft, 5000 ft and 10000 ft**. For the high-level charts, each FL corresponds to a specific pressure surface (pressure value):

- FL50 = 850 hPa
- FL100 = 700 hPa
- FL180 = 500 hPa
- FL240 = 400 hPa
- FL300 = 300 hPa
- FL340 = 250 hPa
- FL390 = 200 hPa
- FL450 = 150 hPa

When planning a flight at a specific FL for which the upper wind / temp chart is not published, you have to use the chart that is the "closest" to your actual planned FL. For example - you are planning a flight at FL110, but there is no upper wind / temp chart available for this level - in this case the first FLs below and above for which the charts are available are FL100 and FL180 => you will obviously use the closest one to your planned cruising level => FL100 (700 hPa) chart.

*Note: For flights from Europe to other regions (North Atlantic, Middle + Far East, Africa, Caribbean + South America), the upper wind / temp charts are typically available for the following specific FLs: 180, 240, 300, 340, 390, 450 and 530.*

Specifications for the Upper Wind and Temperature charts are outlined in **ICAO Annex 3** (some sections are listed below):

1.2.1 *The forecasts of upper winds; upper-air temperatures; and humidity; direction, speed and height of maximum winds and tropopause heights and temperatures prepared four times daily by a WAFC shall be valid for 6, 12, 18, 24, 30 and 36 hours after the time (00:00, 06:00, 12:00 and 18:00 UTC) of the synoptic data on which the forecasts were based [...]*

1.2.2 *Recommendation: the grid point forecasts prepared by a WAFC should comprise:*

- a) *wind and temperature data for FLs: 50, 100, 140, 180, 240, 300, 340, 390, and 450;*
- b) *tropopause height and temperature, and direction, speed and height of maximum wind;*
- c) *humidity data for FL 50 (850 hPa), FL100 (700 hPa), FL140 (600 hPa) and FL180 (500 hPa);*
- d) *wind and temperature data for FL530 (100 hPa) and FL600 (70 hPa) when and where required*

4.2.1.2 *Upper wind and upper-air temperature charts for low-level flights shall be supplied for points separated by no more than 500 km (300 NM) and for at least the following altitudes: 600 m, 1500 m and 3000 m (2000, 5000 and 10000 ft).*

**Chart header:** each Upper Air / Temp chart has an information section (header), typically in one of the corners (see picture on the left for a sample header), where you can find out by which meteo agency the chart has been issued and especially the Flight Level, Date and Time for which the chart is valid.

REGIONAL AREA FORECAST  
CENTRE LONDON

**UPPER WIND AND  
TEMPERATURE  
CHART FOR FL 390**

**12 UTC 28 OCT 91**

TEMPERATURES ARE  
NEGATIVE UNLESS  
PREFIXED BY "PS" OR "+"

DATA TIME 12 UTC 27 OCT 91

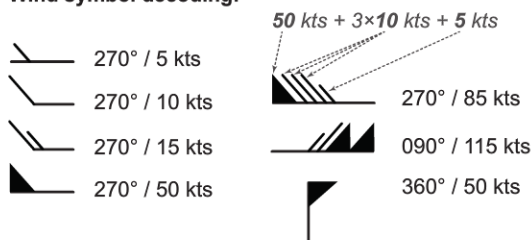
**IMPORTANT:** Another important piece of information is listed in the chart header: on most charts, all of the numbers representing temperatures, are considered to be negative temperatures - i.e. a number "49" on the chart in fact means a temperature of -49°C, unless the number is specifically prefixed by a "+" sign or a prefix "PS". On some charts you will also find the date/time at which the forecast has been prepared (Data Time).

**Use of Upper Wind / Temp Chart**

Standard wind symbols (wind arrows) are used to identify the direction and velocity. **Wind direction is referenced to the True North and wind velocity is expressed in kts.** These symbols are typically given for each 5° of Latitude and Longitude. Each "wind arrow" is telling us the direction from which the wind is blowing + its speed using the standard symbology. Next to each wind arrow a number is listed. This number represents the temperature in that specific location (remember - typically this number is a negative temperature).

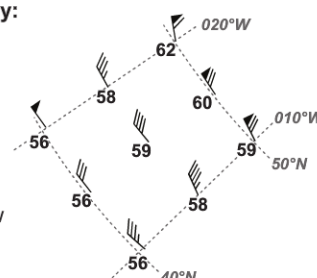
**Interpolation:** As mentioned above, the wind/temp symbols (data) are typically given for each 5° of Lat/Long. When you need to find wind / temp information for a position other than that in full increments of 5° of Lat/Long careful interpolation / calculation must be performed - you need to find the two closest symbols to your position, either in horizontal or vertical direction, determine the wind / temp for both of these symbols and then carefully interpolate between the two values (keep in mind how close to each symbol your position is and apply the correct interpolation - it does not necessarily have to be the average of the two values).

**Average wind / temp for a route:** When you need to find an average wind and temperature for a specific route of flight, you need to split the route into several segments and obtain multiple wind / temp values along your route, then find their mathematical average. When calculating the average wind direction, keep in mind that if the winds vary through 360° you have to be extremely careful not to make a mistake - for example: to find an average wind direction of 350°, 360° and 010° you can not use the formula  $((350+360+010)+3) \Rightarrow$  you would end-up with an incorrect result of 240°. Instead, you have to use a formula  $((350+360+370)+3) =$  correct average of 360°.

**Wind symbol decoding:****Example of chart section display:**

Wind arrows indicate the direction and wind velocity. Wind direction is referenced to the True North (estimate or measure the angle between the wind arrow and a meridian or line of parallel to decode the direction).

Numbers listed next to each arrow represent the temperature in °C (typically negative).



**FIGURE 050-E29****AVIATION WEATHER MESSAGES - METAR, SPECI, TAF**

Aside from graphical weather charts, the pilots receive very useful and important information concerning weather conditions, either actual or forecasted, in a textual format. The textual weather reports that you are likely to encounter most frequently are the following: METAR, SPECI, TAF.

**METAR**

It is an abbreviation used for the "Aerodrome Meteorological Report". METARs provide information on the meteorological conditions that actually exist at an airport at a given time = observations of the actual weather. METARs are issued every hour or every 30 minutes (ICAO Annex 3 - paragr. 4.3.1.) - in Europe, it is typically every 30 minutes. Even though a METAR is not a forecast, but rather an actual observation at a given time, sometimes a short-term forecast may be added at the end of the standard METAR code - titled "TREND" and it is a forecast valid for the next 2 hours. Especially in the winter, information on runway conditions is also typically added to METARs.

**SPECI** is an abbreviation used for the "Special Aerodrome Meteorological Report". Just like the METARs, the SPECIs are observations of actual weather conditions - think of it as a special METAR which is issued when the weather conditions change significantly between the regular times when METARs are scheduled to be issued. ICAO Annex 3 - Appendix 3 - paragr. 2.3.1 and 2.3.2 define the criteria when a SPECI report must be issued - some of the criteria are:

- Temperature increase of 2°C or more,
- Wind direction change of 60° or more / wind speed change of 10 kts or more,
- Visibility changes and it passes through 800 m, 1500 m or 3000 m (5000 m in airport with frequent VFR flights).
- RVR (Runway Visual Range) changes and it passes through 150 m, 350 m, 600 m, or 800 m.
- Onset, cessation or change in intensity of significant phenomena, such as freezing precipitation, moderate or heavy precipitation, dust or sand storm, thunderstorm, squall, tornado, etc...
- Significant changes in cloud bases - when the cloud base change passes through 100 ft, 200 ft, 500 ft or 1000 ft.

METARs and SPECIs always have a structured format. In Europe, this format consists of a 3 component identifier:

- 1) **Type of report:** METAR (SA) or SPECI (SP)
- 2) **Airport identifier:** ICAO 4-letter aerodrome code
- 3) **Date / Time of observation (221630Z):** day of the month, followed by time in UTC and a suffix "Z".

*Example: "221630Z" = the report has been issued on the 22<sup>nd</sup> day of the month at 16:30 UTC.*

Initial report identification is followed by 10 components of the actual meteorological data:

- 1) **Surface Wind:** the first 3 numbers indicate the wind direction (°True) rounded to the nearest 10°, followed by 2 numbers (exceptionally 3 numbers) indicating the mean wind speed during the previous 10 minutes of the report issuance time. The speed is typically in kts (suffix "KT") or km/h (suffix "KMH"). If the letter "G" is listed it means "gusting" (used when avg. gust speed exceeds avg. wind speed by 10 kts or more) and it will be followed by another 2 digits indicating the maximum gust speed.

If the wind direction varies by 60° or more within the 10 minutes preceding the report issue time, a 3 digit number, followed by letter "V" and another 3-digit number will be used to indicate the variation of the wind direction - e.g. "180V250" => wind direction varies between 180° and 250°.

If "0000KT" is listed in this section, it means the wind is calm. "VRB02KT" means variable wind direction with a speed of 2 kts.

*Example: "22030G45KT" = wind direction 220° at 30 kts, with gusts up to 45 kts.*

- 2) **Horizontal Visibility:** value of the horizontal visibility in meters. If "0000" is listed it means that visibility is less than 50 metres. If "9999" is listed it means that visibility is 10 km or more. If local conditions vary greatly then two groups may be displayed showing the visibility variation in different sectors (e.g. "1000NW 6000S" = visibility to the North-West of the aerodrome is only 1000 metres but it is 6000 meters to the South).

*Example: "2500" = visibility 2500 m.*

- 3) **RVR:** Runway Visual Range is an indication of the real visibility as measured down the runway either electronically or manually. It is included in the report only when the visibility drops below 1500 m. RVR values are always prefixed by letter "R", followed by the runway number for which the RVR value applies and the actual RVR value in meters behind a "/" symbol. If more than 1 runway is in use, RVR values will be listed separately for each of the active runways.

Prefix "P" is used when the RVR is greater than the maximum measurable value (e.g. R06/P1500 = RVR for runway 06 is greater than 1500 m).

Prefix "M" is used when the RVR is lower than the minimum measurable value (e.g. R06/M0050 = RVR for runway 06 is less than 50 meters).

Suffixes can be listed after the RVR value to indicate a tendency for a significant change (100 m or more from the first 5 minutes to the second 5 minutes of the 10 minute observation window). The suffixes are: "D" for decreasing tendency, "U" for increasing tendency or "N" for no change.

If the RVR values changed minute by minute during the 10 minute observation "window", this will be indicated as the minimum and maximum values measured during the 10 minute window with a letter "V" in between the values (e.g. R24/0250V0650 = RVR for runway 24 varied between 250 m and 650 m).

*Example: "R24L/1000D R24R/800N" = RVR for runway 24L is 1000 m with decreasing tendency and the RVR for runway 24R is 800 m with no significant change tendency.*

- 4) **Weather:** Weather is identified by one or more 2-letter groups. A mixture of weather can be reported using up to 3 groups to indicate different weather types. Most frequently used abbreviations are:

- **Intensity or proximity** (prefix): light (-), heavy (+), moderate (no prefix); "VC" = in the vicinity (8 km) of the aerodrome



- **Precipitation:** DZ = Drizzle, RA = Rain, SN = Snow, SG = Snow Grains, IC = Ice Crystals, PE = Ice Pellets, GR = Hail
- **Obscuration:** BR = Mist, FG = Fog, FU = Smoke, VA = Volcanic Ash, DU = Dust, SA = Sand, HZ = Haze
- **Descriptors:** MI = Shallow, BC = Patches, PR = Partial, DR = Drifting, BL = Blowing, SH = Showers, FZ = Freezing
- **Other:** TS = Thunderstorm, SQ = Squalls, FC = Tornado, DS = Dust Storm, SS = Sand Storm, PO = Sand/Dust Whirls

Examples: “-SHRA” = Light Rain Showers, “MIFG” = Shallow Fog, “SN” = Moderate snow, “+SN” = Heavy Snow

Note: when visibility > 5000 m the following phenomena will not be listed in reports: BR, HZ, FU, IC, DU and SA.

- 5) **Clouds:** This is typically a 6-figure group, consisting of 3 letters (cloud amount) and 3 numbers (height of the cloud base in hundreds of ft above the airport level). If there are more than one cloud groups present, they are listed in ascending order of height (lowest cloud base first, then higher one, etc...). Cloud cover abbreviations used:

- **FEW** = Few clouds, 1-2 oktas (eighths) of the sky covered,
- **SCT** = Scattered clouds, 3-4 oktas (eighths) of the sky covered,
- **BKN** = Broken clouds, 5-7 oktas (eighths) of the sky covered,
- **OVC** = Overcast = Solid cloud cover - 8 oktas (eighths) of the sky covered.

Note: a suffix may be used to further define the type of cloud: **CB** = Cumulo-Nimbus, **TCU** = Towering Cumulus

Other abbreviations used in the cloud group:

- **SKC** = Sky clear of any cloud (no clouds),
- **NSC** = No significant clouds,
- **CAVOK** = Clouds and Visibility OK (defined by ICAO Annex 3 - Appendix 3 - 2.2). When the following conditions occur simultaneously at the time of observation:

- a) visibility, 10 km or more;

Note: In local routine and special reports, visibility refers to the value(s) to be reported in accordance with 4.2.4. and 4.2.4.3; in METAR and SPECI, visibility refers to the value(s) to be reported in accordance with 4.2.4.4.

- b) no cloud of operational significance;

- c) no weather of significance to aviation as given in 4.4.2.3 and 4.4.2.5; information on visibility, runway visual range, present weather and cloud amount, cloud type and height of cloud base shall be replaced in all meteorological reports by the term “CAVOK”.

Cloud of operational significance. A cloud with the height of cloud base below 1500 m (5000 ft) or below the highest minimum sector altitude, whichever is greater, or a cumulonimbus cloud or a towering cumulus cloud at any height.

In conditions of fog when the cloud cover cannot be seen then the vertical visibility will be reported using abbreviation “VV” as the “cloud” code (e.g. “VV003” = vertical visibility 300 feet). If the fog is so bad that no measurement can be taken then you may possibly see “VV//” in a METAR.

Example: “SCT025 BKN070CB” = Scattered clouds at 2500 ft, Broken “CB” clouds at 7000 ft

- 6) **Temperature / Dew Point:** Temp and Dew Point are measured in °C. Minus value = prefix “M”.

Example: “25/12” = Temp 25°C / Dew Point 12°C, “00/M02” = Temp 0°C / Dew Point -2°C

- 7) **QNH:** QNH is rounded down to the next whole millibar and reported as a 4-figure group preceded by letter “Q”. If the value is less than 1000 mbs then the first digit will be 0. The pressure value may also be listed in inches of mercury - in that case it is preceded by letter “A” followed by the pressure value in hundredths of inches.

Example: “Q0998” = QNH 998 hPa, “A2992” = QNH 29.92 Inches of Mercury

- 8) **Recent Weather:** This section may be included in the report if significant weather was observed during the last hour or since last report was issued, whichever is shorter, but not occurring any more now. Weather codes listed in section 4) would be used prefixed with letters “RE” (abbreviation for “recent”).

Example: “RERA” = Recent Rain, “RETS” = Recent Thunderstorms

- 9) **Wind Shear:** This section will only be included in the report if windshear has been reported below 1600 ft in the approach and/or departure paths. If used, it will be identified by letters “WS” followed by the phase of flight (LDG or TKOF) and runway affected.

Example: “WS LDG RWY08” = Windshear reported in the approach (LDG) path to runway 08.

- 10) **Trend:** Even though a METAR and SPECI are observations of actual weather conditions, some airport reports may include a forecast if significant changes in weather conditions are expected to occur within 2 hours of the observation. If the change is temporary then an indicator “TEMPO” (temporarily) is used, whereas if the change is permanent then an indicator “BECMG” (becoming) will be used. Indicator “NOSIG” is used when no significant changes in weather are expected within 2 hours from the observation time.

Prefixes “BECMG” and “TEMPO” may be followed by a “time group” in hours and minutes UTC (time group may include additional descriptors: “FM” = From, “TL” = until or “AT” = at). Description of the actual forecast follows.

Examples: “BECMG FM1030 22035KT” = from 10:30 UTC the wind is becoming 220° / 35 kts

“TEMPO 1030 TL 1130 2000 TSRA” = temporarily from 10:30 UTC until 11:30 UTC visibility will be 2000 m with moderate Thunderstorms and Rain.

## TAF - Terminal Aerodrome Forecast

As the unabbreviated title suggests, TAFs provide information on forecasted weather conditions at an airport (they are relevant for an area of 5 SM radius around the airport). TAFs typically cover periods of minimum 9 hours and a maximum 24 (sometimes 30) hours. TAFs that are valid for a period of less than 12 hrs are issued at 3 hour intervals and are identified by a prefix “FC”. TAFs that are valid for periods of 12 hours or more are issued every 6 hours and are identified by a prefix “FT”. Regulations pertaining to TAFs can be found in ICAO Annex 3 - Chapter 6 - paragraph 6.2.

TAFs use basically the same format and coding system of groups and abbreviations as METARs and SPECIs. There are



however, some differences:

- **Date / Time Issued:** in TAFs, the first group following the airport identifier is the date/time when the TAF has been issued - in a METAR this group represents the date / time when the observation has been taken.
- **Validity Period:** the group which follows the "Date/Time issued" group represents the period of validity of the forecast. A format of this section has been modified in November 2008. In the JAA questions you will most likely encounter the old format, while in real life flying you will encounter the new format.

**OLD format:** 4-digit group representing the hours of validity - e.g. "0618" = valid from 06:00 until 18:00 UTC.

**NEW format:** 4-digit group followed by " / " and another 4-digit group. The first group represents the day + hour when the validity starts, while the group behind the " / " represents the day + hour when the validity ends. This format is used also throughout the entire TAF when a period of validity of any kind is needed to be expressed: e.g. "0718 / 0806" = valid from 7<sup>th</sup> day (of the month) 18:00 UTC until 8<sup>th</sup> day 06:00 UTC.

- **Visibility:** only the minimum forecasted visibility is listed, in the same format as in a METAR.
- **Weather:** if there is no significant weather expected during the forecasted period, this group is not listed in the TAF. If a change indicator (BECMG, TEMPO, etc...) is used to identify a change into conditions of no significant weather, an abbreviation "NSW" is used = No Significant Weather.
- **Change Indicators:** just like in a METAR, change indicators can be used:
  - FM** = From. It is followed by the time from which changes apply. It indicates a beginning of a self-contained new section of the forecast - all previous conditions become invalid (no longer apply) after this time.
  - BECMG** = Becoming. It is followed by a time group indicating the earliest and the latest time when changes of permanent character are expected to start.
  - TEMPO** = Temporarily. It is followed by a time group indicating the start time + end time of the period, during which changes of a temporary nature are expected to occur. These forecasted changes can occur at any time during the given time window and they can't last for more than 1 hour in each instance (but multiple instances of less than 1 hour each can occur within the given time window).
- **Probability:** abbreviation "PROB" followed by a weather condition indicates that the probability of the specified weather condition occurring is only 30% to 40%.

## FIGURE 050-E30

### AIR MASSES

An Air Mass is a large quantity of air that has a homogenous nature. That means that it has a fairly uniform distribution of temperature and humidity in a horizontal plane throughout the mass. Air masses moving over the surface of the Earth have the capacity to transport (advection) significant thermal and humidity characteristics over great distances. Air masses of different properties at low level largely decide the clouds and the various visibility conditions, thus greatly affecting the flight conditions. In summary - air of similar properties within a major region is called an air mass. Between areas of air with similar properties there are zones of transition = fronts, more or less distinct, where cloudiness mostly increases and precipitation intensifies.

A uniform air mass requires its horizontal properties to be the same within major parts of the air volume thereby minimising the distortion. That is to say, within the air volume each level has similar temperature and humidity, and the vertical change, the lapse rate, is the same. This in turn leads to the weather being similar over a major region often hundreds of miles across.

Information on air masses and fronts can be derived from synoptic surface charts. In general, the term "synoptic meteorology" can be defined as being concerned with the description of the current weather conditions for a given geographical region and then applied by the meteorologists to create weather prognosis - forecasts of future weather conditions.

The thin lines represent the isobars = lines of equal pressure = lines representing a constant pressure surface. Isobars are plotted on synoptic charts using QFF, typically for QFF of whole even numbers (QFF = the atmospheric pressure lowered to MSL corrected for actual temperature).

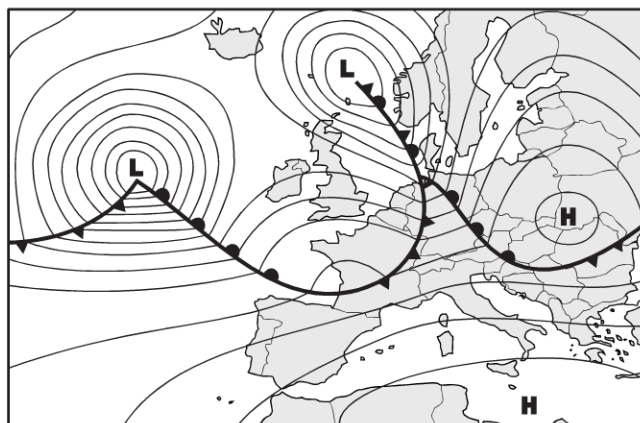
Air masses are created within the lowest layers of the atmosphere, when the air is fairly stationary over a major area of a uniform surface. The layers adjacent to the surface are affected first, and the properties are then spread up into the troposphere by turbulence, advection and radiation processes. The characteristics of an air mass depend on:

- The source region
- How long the air has been over the source region
- Modifications (if any) of the air mass as it moves away from the source.

### Air Mass Classification

To classify an air mass, its geographic origin and temperature are used. The main types are:

- **Arctic (A)** - originates in the polar ice cap in the winter (in the Southern Hemisphere it is Antarctic air mass)
- **Polar (P)** - originates between 40° and 60° latitude, in the summer up to 80°
- **Tropical (T)** - originates in the subtropical high pressure cells, but in the summer it also forms over large continents



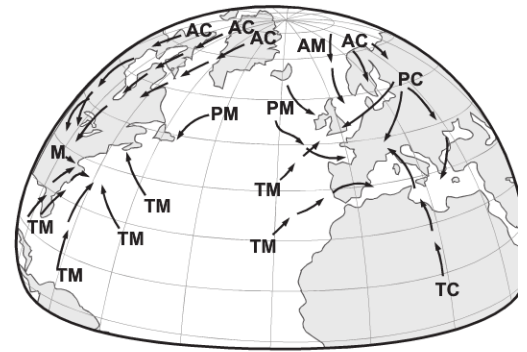
- **Equatorial (E)** - forms in the region between the subtropical highs on both sides of Intertropical Convergence Zone

To indicate if the air mass contains little or much humidity - i.e. if it originates over land or sea, the following designations are used:

- m = maritime (forms over water)
- c = continental (originates over land).

As a result we get air mass designations as follows:

- |                                   |                                      |
|-----------------------------------|--------------------------------------|
| • <b>Am</b> = maritime Arctic     | • <b>Ac</b> = continental Arctic     |
| • <b>Pm</b> = maritime Polar      | • <b>Pc</b> = continental Polar      |
| • <b>Tm</b> = maritime Tropical   | • <b>Tc</b> = continental Tropical   |
| • <b>Em</b> = maritime Equatorial | • <b>Ec</b> = continental Equatorial |



### Air Masses Affecting Europe

Polar and tropical are the most important air masses in our region, but arctic air masses can also occur.

#### Arctic air

Arctic air only occurs in the winter when the Polar Regions are covered by snow / ice. The surface is uniform, and the pressure picture often shows a HIGH with light winds at low level. Arctic air comes from Spitsbergen and Greenland down over northern Europe, mostly behind a LOW, which is moving east. Sometimes the pressure field causes a northeasterly wind, e.g. a high at Iceland or a low over Russia, and then the arctic air will sweep down from Novaya Zemlja or northern Siberia.

If the air from northwest moves over an open sea and is heated from below, it becomes destabilized at the same time as it picks up humidity from the sea. The air mass is modified from Ac to Am. The typical weather consists of convective cloud Cu / CB with a lot of snow showers. However, when moving from the northeast the air passes snow or ice covered areas at the time, and the modification becomes marginal. The air mass remains dry and gives clear but extremely cold weather.

#### Polar air

The maritime polar air forms, when air from Canada and the Greenland region moves out over the Atlantic. The air is initially dry and stable in layers, but it is gradually modified into a maritime air mass picking up large amounts of heat and humidity from the underlying, comparatively warm, water surface provided by the effects of the Gulf Stream. The air mass becomes unstable with a lot of Cu and Cb clouds. Outside the showers visibility is mostly good.

When the air reaches a heated continent on a summer day the instability is increased and the convection becomes widespread with heavy showers or thunderstorms often with hail. The radiation cooling over land during the summer night has on the other hand a stabilising effect on the air mass. If the ground surface has been cooled down during a longer period of time in the winter, Pm air will cause large areas covered with ST clouds and fog when it passes further into Europe.

Continental polar air has its source region over Siberia and continental Eastern Europe. The air mass holds more humidity than Arctic air, it is not as cold but causes weather similar to Ac, and is modified over the Baltic in the same way in winter. In summer the Pc is less obvious since the continent is warm but it usually arrives over the rest of Europe as a dry, often cloudless, mass of air thereby showing large temperature variations between day and night. If the northeast wind reaches the relatively cold North Sea the air is cooled from below and stratus clouds (ST) and advection fog can develop before the air reaches Britain.

Polar air is the predominant air mass over Scandinavia and the Baltic coasts of Germany and Poland. Scandinavia is particularly affected by the maritime polar air.

#### Tropical air

The Azores HIGH is the source region of maritime tropical air that is common over Western Europe and periodically reaches Scandinavia. At the source region the air is stable, warm and humid.

Maritime tropical air is fairly warm and humid. As the air moves towards the European region it passes over a surface that is becoming progressively colder. The air mass becomes stable over a significant depth and the relative humidity increases. In the summer, as a result of overland heating, light Cu clouds form inland, and the weather gets rather misty at low level. In wintertime, the warm air is cooled by the underlying surface and extensive areas with mist, advection fogs and stratus (ST) clouds form. Occasionally drizzle, freezing drizzle or snow grains occur.

Continental tropical air moves north when, in the summer, a HIGH forms over Russia or a LOW over the Mediterranean. The air then comes from southern Russia, the Middle East and North Africa. But during the passage of the Mediterranean Sea and the Alps and other mountain ranges in the southern Europe the continental air is subjected to large modifications. The continental tropical air is warm and dry leading to a sky free of clouds but rather hazy. Occasionally the air may be conditionally unstable and thunderstorms then appear over high terrain, mainly over the European continent.

Tropical air originating over continental Africa is predominant in the Mediterranean area, where it is modified into maritime tropical air. It is generally the maritime air masses that characterise weather in Northern Europe. Sometimes the continental air masses dominate, which leads to unusually cold winters or warm and dry summers.

The great difference between a maritime and a continental air mass depends upon its humidity content. An air mass with a high humidity content (high dew point) gives poorer visibility, lower cloud bases and more clouds.

### Thermodynamic Classification of Air Masses

A better way of classifying air masses for aviation weather service is to let the stability of the air define the type of air mass. As a starting point we use the temperature of the air in relation to the ground surface:

- **Warm air mass** = the air is warmer than the surface below => the air is cooled from below and becomes stable.
- **Cold air mass** = the air is colder than the surface below => the air is heated from below and becomes unstable.



### Warm air mass

This air mass is warmer than the underlying surface and is cooled from below. It becomes stable and a ground inversion develops if the wind is light. Stronger winds cause a mixing at low level and a turbulent inversion forms some distance above the ground. Initially the tops of the inversion are fairly low, but gradually, as the cooling spreads upwards, the inversion is lifted up towards 1500 to 3000 ft. Pollution and humidity stay below the inversion, causing reduced visibility values and a diffuse horizon. Clouds form, if the inversion remains long enough, fog, stratus (ST) or stratocumulus (SC) clouds depending on wind speed and humidity. Above the inversion there will be little cloudiness and far better visibility values than below the inversion.

The wind below a ground inversion is mostly light, while it is stronger above the inversion and sometimes blows from quite another direction.

This type of air mass always causes limitations to those who fly VFR, and in the winter there may be problems to IFR traffic also due to dense fogs, low cloud bases, the risk of icing in clouds and freezing precipitation. Typical weather in a **maritime warm air mass** is thus as follows:

- Poor visibility below the inversion, otherwise moderate
- ST or SC clouds, drizzle, fog, mist
- In the winter maybe freezing drizzle, snow grains and occasionally heavy snowfall from SC clouds occur.
- Calm or stable surface winds.

The warm air mass is cooled from below, and occasionally the temperature of the air adjacent to the ground falls below zero. Precipitation from warmer layers above will then fall down into the "below 0 °C" layer, and precipitation is supercooled. The risk of icing within the cold layers is always very extensive (severe icing, clear ice). Always be cautious when drizzle is reported together with temperatures below 0 °C, since it is generally supercooled. Also be careful with snow grains, which indicate freezing drizzle in a layer above the surface of the ground.

**Continental warm air** is generally dry offering good flying weather, but below the inversion visibility is reduced by dust and smoke etc. Over the sea mist will reduce / prevent the possibility of recognising the horizon. This makes it difficult or impossible to fly VFR over the sea even at visibility values around 8 km (occasionally much higher values) if the sea is calm. At times the warm air mass shows an unstable lapse rate at altitude, and the intense insolation during the summer can then create convective clouds of the CU or CB type. Convection is often reinforced by the wind or the nature of the terrain, and powerful warm air mass thunderstorms occur if the air has enough humidity.

### Cold air mass

The cold air mass is colder than the underlying surface and heat spreads up through the air. We get an unstable cold air mass, and the convection causes CU and CB clouds. If the air is dry enough (continental cold air) no clouds form, but the vertical motions may still be great, and we talk about dry thermal. Turbulent air is thus common in cold air masses. The CB clouds cause rain showers, snow showers, hail showers and thunderstorms depending on temperature and instability.

Optimum cloud development occurs in daytime due to insolation, and the clouds collapse in the evening. During the night a ground inversion develops, in which radiation fog and wind shear problems may occur. Typical cold air mass weather:

- Convective clouds: CU, TCU and CB
- Precipitation such as: rain showers, snow showers, hail showers or thunderstorms
- Gusty surface wind
- Turbulence at low level: mechanical up to about 2000 ft and thermal up to the tops of clouds
- Good visibility outside showers and thunderstorms
- Often radiation fog at night in the spring and autumn

A continental air mass contains small amounts of humidity and generally only causes light CU clouds. This doesn't apply, however, if the air mass moves out over a warm sea, since it rapidly picks up humidity from below.

### Air Mass Modifications

When the air mass leaves its source region, it will be modified depending on the surface over which it moves. An air mass, which has formed over a continent and then moves out over the sea will pick up humidity and acquire characteristics similar to those of an air mass, which has formed over the sea.

Air moving out **over a colder sea** will be cooled from below, at the same time as it picks up humidity. An inversion is established probably with stratus or stratocumulus clouds, but occasionally advection fogs occur. When the air mass later returns over land heated by the sun, the inversion dissolves, the stratification becomes unstable and the sky becomes convective (common in the spring). The opposite also applies when the air moves out over a warmer water surface and is destabilised from below with convective clouds as a result. If the air later comes in over a colder ground surface, the stratification once more becomes stable (common in the autumn).

Air Mass Modification due to the character of the terrain: on the **windward side** of obstructions the cloud bases are lower and the precipitation heavier than on the **leeward side** of the same obstruction, where the subsiding air motion leads to a Foehn. With Foehn we mean in this case decreasing precipitation, a tendency towards cloud dissipation and a somewhat higher air temperature. The Foehn effect is notable in many areas of Europe. In Switzerland, from where the name originated, it results in the temperatures to the lee (down wind) side of the mountain ranges to be considerably warmer than those on the upwind side. This frequently causes avalanches as the warmer air rapidly melts the snow.

The Scandinavian mountain range causes Foehn effects on the Swedish side at westerly and northwesterly winds and on the Norwegian side at the somewhat more uncommon easterly winds. The mountains do not have to be very high for the air to be modified. Even some of the lower hill areas of Europe will experience some Foehn effect. If very humid air is involved, an obstruction of some 10 meters can be enough for condensation processes to start on the windward side of the obstruction.

**FIGURE 050-E31****HEATING OF THE ATMOSPHERE**

The temperature of the air is defined as a measure of the kinetic energy of the air molecules. High kinetic energy is experienced as heat, while low kinetic energy of the air molecules is experienced as cold air. The temperature concept of hot and cold in everyday speech thus requires an atmosphere of a certain density. In the very high regions of the atmosphere the concentration of air molecules is too small for temperature to be measured according to the above. In these regions we would have to compare the incoming amount of solar energy with the amount of heat energy emitted from a well-known object. Furthermore it is important to remember that the atmosphere is largely transparent to the extremely short wavelength solar energy. This means that the air in the lower parts of the atmosphere is not heated directly by the Sun but indirectly by long-wave radiation from the ground.

The Sun releases considerable energy (Solar radiation) into the solar system. Some of this reaches the Earth => heating the atmosphere. This heating causes instability which we experience as weather. The solar radiation consists of electromagnetic waves. Not only the Sun emits electromagnetic waves, but all substances having a temperature above  $-273^{\circ}\text{C}$  emit some kind of radiation. Wavelength may be measured in micrometers ( $1 \times 10^{-6} \text{ m}$ ), sometimes referred to as microns. Radiation having a wavelength exceeding 1 micron is known as long-wave radiation while shorter wavelengths correspond to shortwave radiation. The Sun emits most of its radiation at wavelengths around 0.5 micron (green light) corresponding to 5800K while the average temperature of the Earth,  $+15^{\circ}\text{C} = 288 \text{ K}$ , gives the radiation maximum at approximately 10 micron. The Sun emits shortwave radiation while the heat radiation from the Earth's surface is long-wave. The atmosphere is heated by 5 different processes listed below:

**Solar Radiation:**

At the extreme end of the atmosphere we have hydrogen and helium and to some extent also oxygen. Here the shortest wavelengths of the Sun's radiation spectrum are absorbed. In the stratosphere we find the ozone layer which selectively absorbs radiation at wavelengths shorter than 0.3 micron, which causes a heating of the stratosphere at a height of 20-50 km. Further down in the atmosphere we find mostly nitrogen ( $\text{N}_2$ ) and oxygen ( $\text{O}_2$ ), but these gases are not affected by the remaining radiation, since its energy is not sufficient to decompose these molecules. Instead other gases will be affected so that a minor part of the remaining radiation is absorbed in the lower parts of the stratosphere and in the troposphere. It's mostly water vapour but also carbon dioxide and pollution, which act as absorbers of certain radiation and thus causing heating. Another and perhaps more obvious effect is the scattering and reflection of light (albedo) caused by the air molecules. The most apparent example is the reflection of the clouds albedo. Depending on density and whiteness the clouds can reflect up to 90% of incoming solar radiation.

As a summary we can say that some solar radiation is absorbed in the upper parts of the atmosphere, some is reflected by the clouds and water on the surface. The rest of the solar radiation is absorbed by the surface and thus heats the Earth surface. This process of solar radiation heating the Earth surface is called **insolation**.

**Terrestrial Radiation:**

In principle the Earth will re-radiate to Universe the same amount of energy that it receives. Without balance between incoming short-wave and outgoing long-wave radiation, the climate would constantly change in one direction or other. The Earth surface therefore radiates heat at all times, in the form of a long-wave radiation (4 - 10 microns). The primary method of heating of the atmosphere is by terrestrial radiation = from below and therefore it explains the lapse rate = decrease in temperature with an increase in altitude.

Terrestrial radiation is absorbed by the water vapour and  $\text{CO}_2$  in the atmosphere and re-transmitted throughout the surrounding air as heat.

**Conduction:**

Conduction in this sense means the temperature change of the air in contact with the Earth surface. During the day the conduction will cause the air in contact with the surface being heated, while at night this air will be cooled by the conduction. During the night the air at higher levels will remain unaffected (air has poor conductivity) by this conduction cooling of air at the surface and an inversion may occur.

**Convection:**

The air which has been heated by the conduction process at the surface will become less dense (higher temperature = lower density). As a result of this lower density it will start rising. This rising of air with lower density will cause vertical up-currents referred to as thermals or convection currents. These currents will transport the warmer air into the higher levels and thus warm the higher levels.

**Condensation:**

As the convection lifts the warmer air into the higher levels it will start cooling by adiabatic processes (*adiabatic process is cooling or warming of a gas as a result from its pressure change*). As a result of the adiabatic cooling the water vapour contained in the air will start to condense into visible droplets, forming clouds. During this condensation process latent heat is released by the water vapour into the atmosphere, again heating the atmosphere.



**FIGURE 050-E32****ALTIMETRY**

The purpose of an altimeter installed in an aircraft is to indicate an approximate distance between two pressure surfaces. In principle an aneroid capsule measures the static pressure surrounding the aircraft and with a knob on the instrument you can set a reference pressure; e.g. QNH. The distance between these two pressure surfaces depends on the density of the air in between. Since density in most cases is unknown, the conditions of the standard atmosphere have been used, where density, pressure and temperature are known, in calibration of the instrument. The altimeter is constructed to indicate the distance between two pressure surfaces in the atmosphere, and the altimeter thus only indicates the correct altitude in one instance, namely when everything is standard. It is thus important to understand how the altimeter works so that you can correct "indicated" altitude to "true" altitude.

The altitude from the reference pressure surface (e.g. QNH) to the static pressure surface (level of the aircraft), depends on the mean temperature of the layer between these two surfaces and on the amount of pressure. Compared to the altitude indicated by the altimeter the true altitude will increase with increasing temperature and decrease with decreasing temperature.

- In an atmosphere **COLDER than ISA** (standard) you are **flying LOWER than indicated**.
- In an atmosphere **WARMER than ISA** (standard) you are **flying HIGHER than indicated**.

The correction is 1 % (of height) per 2.5°C (4% per 10°C) of temperature deviation from standard atmosphere. The distance between two pressure surfaces is dependent on pressure. The distance between 1050 - 1010 hPa is e.g. smaller than the distance between 950 - 910 hPa though the difference is 40 hPa in both cases.

The difference between QFE and QNH can vary a little, but once you have set QNH on the subscale of your altimeter, you only have the temperature error plus potential aircraft-related errors such as speed errors etc to deal with. Take a look at the technical description of your aircraft. If the subscale of your altimeter is set to the standard setting of 1013 hPa you must also compensate for barometric (pressure) differences when checking your terrain clearance. When it is time to adjust altimeter readings into pressure differences or vice versa it is important to know how many feet (m) correspond to one hPa:

- At sea level 1 hPa is equivalent to 27 ft,
- At 2000 ft above mean sea level (AMSL) 1 hPa is equivalent to 27 ft,
- 20 000 ft (AMSL) gives 1 hPa = 50 ft,
- 40 000 ft (AMSL) gives 1 hPa = 100 ft.

For practical purposes the calculations below 5 000 ft may use **1 hPa = 27 ft** (8 m).

**Terminology**

- **QFE** is air pressure reduced to the datum level of the airport applying corrections for the outside air temperature.
- **QNH** is QFE reduced to mean sea level using the assumed conditions of standard atmosphere and the elevation of the airport
- **QFF** is QFE reduced to mean sea level with regard to the actual outside air temperature. This is for meteorological purpose only and must never be used in pressure altimetry.
- **MSL** Mean sea level means that the aircraft uses a reference pressure converted to sea level, QNH.
- **Altitude** means the vertical distance between actual level and MSL.
- **True altitude** is the exact vertical distance of the aircraft above MSL. This differs from the indicated altitude if the temperature deviates from ISA and the subscale setting is different from the value of QNH directly below the aeroplane.
- **Corrected (approximately true) altitude** is the value we get when the indicated altitude is corrected for temperature and barometric error. This is usually called "true altitude", which of course is not quite true, since in most cases very rough estimates have been made of the temperature distribution between the aircraft and the ground.
- **Pressure altitude** is the altitude in the standard atmosphere, where the pressure is the same as that of the air where the aircraft is at the moment. For a specific "pressure altitude" the air pressure will always be the same. A constant isobaric surface (e.g. 300 hPa) is always equivalent to a constant "pressure altitude" (compare Flight level).
- **Flight level (FL)** is one of a number of levels, based on the datum pressure of 1013 hPa, separated by notified intervals and expressed in hundreds of feet. A flight level is the equivalent pressure altitude in hundreds of feet. Flight levels are separated by a minimum of 500 feet at lower levels and by 1000 feet at higher levels.
- **Standard Pressure Setting** is the ISA MSL pressure of 1013 hPa which can be at, above, or below MSL. When we say altimeter setting standard we mean that the value of 1013 hPa is set in the altimeter reference window.
- **Altimeter setting** refers to the value set on the altimeter subscale. If this is set to the current value of QNH the altimeter should always indicate elevation of the airport (correct true altitude) when the wheels are on the runway.
- **Elevation** means the vertical distance from mean sea level to a stated level.
- **Height** marks the vertical distance from a fixed level, mostly from the ground (QFE) up to another level.

**Flying and the Altimeter**

If QFE is used as reference pressure, the altimeter indicates the height between the datum level of the airport and the aircraft. When the aircraft is on the runway, the altimeter should indicate 0 ft. Since all topographical maps use the surface of the sea as datum level, you must fly with QNH (MSL) as reference pressure to ensure a safe terrain clearance. When the aircraft is on the runway, the altimeter, set to QNH, should indicate the elevation of the airport.

- True Altitude + QFE = QNH
- QNH - QFE = True Altitude

Note that QNH varies from one place to another and that when navigating you must adjust QNH en route in order to ensure the correct datum for your altimeter. In many states there is an arrangement by which you can be provided with a forecast of the lowest expected value of QNH for an area. This provides a safe margin and should be used if available. Standard setting (1013 hPa) is used when flying at a Flight Level (FL) and this procedure guarantees that two aircraft meeting each other always have the same reference pressure and thus the same deviation.



### Wrong Altimeter Setting

Suppose an aircraft has QNH of 1008 hPa set as an altimeter reference. The indicated altitude is 3 000 ft. It is flying into an area where the correct local QNH setting is 995 hPa, but the pilot fails to set this new QNH and maintains the original setting of 1008 hPa. As a consequence the indicated altitude will be still 3 000 ft, but the true altitude will be reduced to 2 650 ft  $((1008 - 995) \times 27 \text{ ft}) \Rightarrow$  the aircraft will be 350 ft lower than the pilot thinks and this can make a significant difference when performing an instrument approach for example.

Remember: you are flying over a pressure surface. If this surface inclines, you change altitude without the altimeter indicating it. When you fly towards lower pressure you lose altitude.

### Changing from QNH to 1013 hPa (standard) and vice versa

Standard setting is never used at take-offs and landings. The take-off is carried out using QNH as a reference, and during the climb you switch to standard when passing the Transition Altitude. On approach you switch from standard to QNH when you pass the Transition Level. Around an airport there is thus a layer where traffic is using both QNH and standard. This is the Transition Layer.

- **Transition Altitude (TA)** is that altitude at or below which we refer to our vertical position in terms of altitude based on QNH.
- **Transition level (TL)**, is the lowest usable flight level and TL is determined locally with consideration taken to surrounding terrain, temperature and air pressure.

During an instrument approach to an airport you will note that pressure altitude readings will deviate from the ideal glidepath. The reason is the temperature error of the altimeter.

### Altimeter corrections

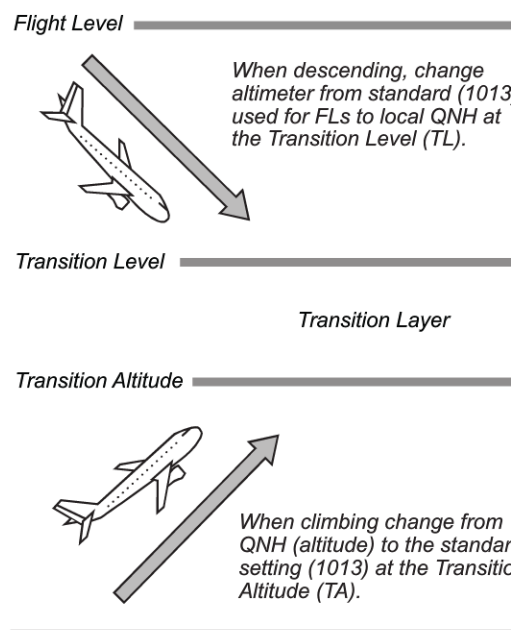
Computing the approximate True altitude from:

#### A) Flight level:

- Compare the ambient air temperature at your level with ISA. Alternatively, compare forecast temperature at your planned flight level with ISA. Determine the temperature deviation from ISA.
- Adjust for pressure deviation (lowest QNH from 1013 hPa): 1 hPa = 27 ft. Add if QNH is higher than 1013 hPa; reduce if QNH is lower.
- Correct altitude error due to temperature deviation from ISA. 1 % error per 2,5 °C deviation from ISA. Reduce if colder than ISA, add if warmer than ISA.
- The result will be the approximate True altitude.

#### B) QNH:

- Compare the ambient air temperature of your altitude with ISA. Alternatively, compare forecast temperature of your planned altitude with ISA. Determine the temperature deviation from ISA.
- Correct altitude error due to temperature deviation from ISA. 1 % error per 2,5 °C deviation from ISA. Reduce if colder than ISA, add if warmer than ISA.
- The result is the approximate True altitude. If the result is greater than the Minimum Safe Altitude (MSA) your aeroplane is safe for the time being.
- Note: Always check that correct QNH is used as reference pressure.



## FIGURE 050-E33

### CLOUDS

Clouds consist of small water droplets or ice crystals suspended in the air. They form when water vapour condenses. Water droplets will naturally form, even if temperature is far below 0 °C. It is in fact possible to find these sub-freezing or supercooled droplets down to -40 °C. Conditions for the formation of clouds are that the air is saturated with water vapour and that there are small particles in the air - condensation nuclei - e.g. microscopic sea salt particles or pollution, on which the condensation can start.

### Basic information on clouds

When the cloud "amount" is measured and reported, it is reported as "oktas". 1 okta = 1 eighth (1/8) of the sky. The sky is therefore "divided" into 8 equal parts and the total cloud amount is reported in terms of how many of these "sectors" of the sky it covers. When we talk about the "**cloud BASE**" we talk about the lowest height at which the "bottom" of the cloud is situated above the aerodrome level. When we talk about the "**cloud CEILING**" we talk about the lowest height above the aerodrome level at which the cloud amount exceeds 4 oktas (= 5 - 8 oktas).

### Cloud classification

There are 3 basic cloud types:

- **STRATUS / Stratiform clouds:** Widespread clouds of great horizontal, but very little vertical extension, layered.
- **CUMULUS / Cumuliform clouds:** Clouds with a flat "base" and an extensive vertical extent, often rounded and heaped with the tops looking like a cauliflower.
- **CIRRUS / Cirriform clouds:** High level clouds with a "feathery" look

Combinations of these 3 terms gave another 3 cloud types: **Cirro-Stratus, Cirro-Cumulus and Strato-Cumulus.**

To make it easier to distinguish between different clouds, the air was roughly divided into 3 layers depending upon the height (vertical division). The following general classification of cloud types can be made according to the height of their cloud base from the ground surface below:

- **Low clouds:** bases 0 - 6500 ft
- **Mid-level clouds:** bases 6500 ft - 23 000 ft
- **High clouds:** bases 16 500 ft - 45 000 ft

Moreover an additional term "**Alto**" was introduced - meaning "medium level" clouds and a term "**Nimbus**" for clouds producing extensive precipitation. Certain cloud types have great vertical extension and pass several levels, so a fourth group was introduced: clouds with great vertical extension.

As a result of the various combinations of the above, we can list the 10 main types of clouds:

#### LOW clouds

**STRATUS (ST)** - *bases from ground level to 6500 ft, no turbulence, occasional Light to Moderate icing*

A generally grey cloud layer typically very close to the ground - base appears fairly uniform. Veils often hang down under the cloud itself. ST often covers the whole sky and is frequently found at heights below 1000 ft. ST can form 1) from lifting of a fog, 2) due to moderate or continuous precipitation, or 3) by mixing of warm and cold air. ST consists mainly of water droplets, freezing in wintertime. Light precipitation may occur in the form of drizzle, freezing drizzle, snow grain or simple ice crystals. Sun is sometimes slightly visible through the cloud layer. ST sometimes appears in the form of ragged patches.

**STRATOCUMULUS (SC)** - *bases from ground level to 6500 ft, Light to Moderate turbulence, Light to Moderate icing*

Rather thin Stratiform cloud, sometimes, subdivided into cloud elements, sometimes covering the whole sky. SC is formed by turbulence and exhibits curved patches at the base (typically between 1000 - 6500 ft). SC consists mainly of water droplets, in wintertime mainly freezing water droplets. SC can produce typically a light precipitation, heavy snowfall precipitation in winter may occur.

#### MIDDLE clouds

**ALTOCUMULUS (AC)** - *bases from 6500 ft to 23 000 ft, Light to Moderate turbulence and/or icing*

Relatively thin layer of cloud of lighter color than SC, but darker than CC. AC often forms as sheets or patches with wavy, rounded masses, rolls or parallel bands. AC can cover the whole sky, but the general structure can still be recognized. AC most often consists of freezing water droplets and ice crystals. Precipitation typically in the form of a virga (precipitation not reaching the ground). AC are often seen preceding a cold front, and their presence on a warm, humid, summer morning usually signals the development of thunderstorms later in the day.

**ALTOSTRATUS (AS)** - *bases from 6500 ft to 23 000 ft, Light to Moderate turbulence and/or icing*

Generally a uniform greyish layer or a sheet of clouds, often without structure, lighter in color than nimbostratus (NS) and darker than cirrostratus (CS). AS usually covers the whole or the major part of the sky, but is typically of a relatively small vertical extent (Sun can be seen through thin AS), but thicker layers can form as well (they will appear quite opaque). AS clouds can look similar to lower altitude ST clouds. AS are composed of water droplets (primarily), freezing water droplets and ice crystals. AS can produce light precipitation, often in the form of a virga. If AS thickens (vertically) it can transform into NS.

#### HIGH Clouds

**CIRRUS (CI)** - *bases from 16 500 ft to 45 000 ft, no turbulence, no icing*

Wispy, feathery appearance. CI consists of ice crystals and is usually thin. The cloud is generally associated with warm fronts and can be frequently found along jet streams.

**CIRROSTRATUS (CS)** - *bases from 16 500 ft to 45 000 ft, no turbulence, no icing*

Sheet-like, sometimes the veil is wispy or has a band-like structure. Causes a bright ring around the Sun and the moon, a so called "halo" phenomenon. CS consists of ice crystals.

**CIRROCUMULUS (CC)** - *bases from 16 500 ft to 45 000 ft, no turbulence, no icing*

Typically a large, white patch or cluster without a gray shadow. Each cloudlet appears no larger than a finger held at arms length. It occurs in patches or sheets along with other cirrocumulus. These often are organized in rows like other cumulus, but since they are so small, cirrocumulus patches take on a finer appearance, sometimes also referred to colloquially as "herringbone" or "mackerel". CC clouds never cast self-shadow and are translucent to a certain degree. They are also typically found amongst other cirrus clouds in the sky, and are usually themselves seen to be transforming into these other types of cirrus. CC clouds consists of ice crystals and occasionally freezing water droplets.

#### Clouds With Great Vertical Development (unstable clouds)

**CUMULUS (CU)** - *vertical span from ground level to 25 000 ft, Moderate to Severe turbulence and icing*

Stack-like clouds (convective), often with greater vertical than horizontal extension. Typical summer type of cloud over land. CU consists of water droplets, freezing above the 0° level, cloud base in the summer 3000 - 7000 ft, winter 700 - 4000 ft. In autumn and winter CU clouds are common above an open sea if the sea temperature is significantly warmer than the air. When the cloud becomes thoroughly towering without being "iced" at the top (see CB), it is called "Towering cumulus", TCU and the cloud type is reported in METAR and MET REPORT.

**CUMULONIMBUS (CB)** - *vertical span from ground level to 45 000 ft, Moderate to Severe turbulence and icing*

CB clouds usually form from cumulus clouds situated at a much lower height, thus making them (like CU clouds) grow vertically instead of horizontally => giving the CB its "mushroom" shape. The base of a CB can be several miles across and extend through all 3 levels (low, medium, high) - typically the bases of CBs are between 500 - 13 000 ft, but may be found in the "high clouds" levels as well. When the air is very unstable CB clouds



can push the tropopause upwards and sometimes the CB clouds are able to “break through” the tropopause into the stratosphere. CBs contain water droplets, supercooled water droplets and ice crystals. CBs give precipitation in the form of showers, frequently thunderstorm and occasionally tornadoes.

Well-developed CB clouds are also characterized by a flat, “anvil-like” top (anvil dome), having a fibrous and diffuse appearance. It is caused by straight-line winds at the higher altitudes which shear off the top of the cloud as well as by an inversion over the thunderstorm caused by rising temperatures above the tropopause. This anvil shape can precede the main CB cloud structure for many miles, causing anvil lightning.

**NIMBOSTRATUS (NS)** - bases from surface to 6500 ft (sometimes up to 10-15000 ft), Mod. turbulence, Mod. to Severe icing

Grey, diffuse cloud which produces precipitation in the form of rain or snow. NS often forms as an AS with sufficiently large vertical extension for precipitation to form and then subsides to the lower altitude range. NS is typically widespread and vertically deep, often consisting of several cloud layers on top of each other. NS produces continuous (moderate to heavy) precipitation and consists of freezing as well as ordinary water droplets and ice crystals.

Note: very good source of information on almost any possible cloud type is: [http://en.wikipedia.org/wiki/List\\_of\\_cloud\\_types](http://en.wikipedia.org/wiki/List_of_cloud_types)

## FIGURE 050-E34

### FOG, MIST, HAZE

The most common visibility reducing phenomena are Fog, Mist and Haze - with fog as the greatest menace. Just to refresh some basic terminology: “**Condensation**” is the process where water vapour changes to water droplets (change from gaseous state to liquid state). “**Evaporation**” is the process during which liquids change into gaseous state. “**Dew point**” is the temperature to which a given parcel of humid air must be cooled, at constant barometric pressure, for water vapor to condense into water.

**Mist** is basically the same phenomenon as fog, but it is defined as a visibility of more than 1000 m (up to 5000 m).

**Haze** is defined as a condition when the visibility is extremely reduced by extremely small solid particles suspended in the air (such as smoke, dust or sand). Haze is not reported if the visibility is more than 5000 m.

**Fog** is defined as a cloud formed at or close to the surface of the ground which reduces the visibility to below 1000 m and the constituents of a fog (obscuring agents) are microscopic water droplets (< 0.5 mm) suspended in a saturated air mass (relative humidity about 100%). When the temperature drops below 0°C, the fog droplets are supercooled and gradually some ice crystals also form in the fog. However, fog solely consisting of ice crystals does not form until at temperature down between -30°C and -40°C (ice fog).

In industrial areas there may be hygroscopic substances expediting condensation of the water vapour of the air and the formation of fog starts even before the air mass has become saturated (relative to pure water). Furthermore large quantities of pollution may be mixed with the fog, which is then called smog (smoke + fog).

The water vapour of the air must condense if fog is to form, and this can happen in three different ways: Cooling, Addition of moisture or Mixing of two air masses. Depending upon how the condensation occurs, we distinguish between various types of fog, but actually nearly all fogs are combinations of the processes just mentioned.

### RADIATION FOG

Is formed by cooling of the land by thermal radiation of the Earth's heat after sunset (when insolation is not present) in condition of calm or very small wind and clear sky (no clouds) => the cool ground surface cools the layer of air just above the ground through conduction (air that is in contact with the underlying ground) => if this layer of air is moist and gets cooled below the dew point radiation fog will form. Radiation fogs occur at night, and usually do not last long after sunrise. Radiation fog is common in autumn and early winter.

#### Conditions for development of radiation fog:

- Clear sky (minimum amount of clouds) => increases the terrestrial radiation and the cooling of the ground
- Relatively high humidity of the air => cooling of the air causes condensation (from humidity to water vapour)
- Calm or very light wind => calm wind will result in rapid cooling.
- Land surface => only occurs over land, because ground surface is a better heat conductor than sea surface.

#### Factors affecting the fog characteristics and formation probability:

- Wind speed => calm wind will limit the fog to a thin, but very heavy layer close to the ground (< 2m). Wind speeds between 2 - 8 kts can cause mixing of the layers of air and promote a thicker layer. Wind speeds up to 5 kts result in the greatest vertical fog extension.
- Time of day / season => most likely to form in the Autumn and Winter (longer nights provide a longer cooling period), but it can form all year round. Likely to form late at night or just after dawn (lowest diurnal temp). As soon as insolation starts, it creates “turbulence” and the fog thickens initially - as the insolation increases the evaporation of the fog from below starts, eventually dissipating the fog.
- Structure of ground => cooled air is heavier, thus it is drawn into the valleys and depressions of broken terrain where the condensation starts. Also a vicinity of stationary and confined water surfaces (lakes, etc...) means additional humidity of the air and higher likelihood of fog formation.
- Presence of pressure systems => Anticyclones, Ridges and Troughs are very favourable to radiation fog formation

#### Conditions leading to dissipation of radiation fog:

- Insolation => when the insolation from the sun starts or increases during the day (warming the ground), the fog starts to evaporate from below and eventually dissipates.
- Wind speed => at wind speeds of 8 - 10 kts the fog mixes with surrounding air and dissipates, or it is lifted and transforms into a ST (stratus) cloud some hundred ft above the ground. Higher wind speeds cause the cold surface layer to mix with warmer / drier

air above, thus increasing the air temp over the saturation point.

- Clouds => if a cloud layer is present during the night it prevents further cooling of the surface => the Earth's terrestrial radiation is reflected back towards the surface and thus warming the lower layers of air above their dew point, thus dispersing the fog.

### ADVECTION FOG

Is formed by a horizontal motion (advection) of warm and moist air over an underlying surface of lower temperature. The result is, that the air mass is cooled from below and an inversion forms. If the air is sufficiently humid, or the cooling intense enough, the water vapour condenses into fog droplets. Continued cooling while the air moves in deeper over the underlying surface will lead to a significant vertical extension (thousands of feet), and the density of the fog increases. If the fog is to maintain its density at low level, a continuous cooling from below is required.

#### Conditions for development of advection fog:

- Cold surface => temperature of the surface is lower than the dew point of the air moving over it,
- Wind speeds => up to 20 kts over sea or up to 15 kts over land areas to move the air,
- Humid air => if relatively high humidity of air exists, then even little cooling causes its saturation + condensation.

#### Factors affecting the fog characteristics and formation probability:

- Wind speed => wind speeds over 5 kts are sufficient for advection fog formation, but the speeds of 10 - 15 kts provide the conditions for maximum vertical development of advection fog.
- Initial humidity => if the initial humidity of the air being moved is relatively high, fog will form more likely
- Type of surface => movement of air over damp ground or water surface increases its humidity
- Temperature difference => the greater the temperature difference between the warmer air and the colder ground, the greater the likelihood of fog formation.
- Season => in Europe, advection fog is most likely to form over land areas between winter and early spring, while over sea areas between spring and early summer.

#### Conditions leading to dissipation of advection fog:

- Wind direction change => change of air mass
- Wind speed => at wind speeds >15 kts in rough terrain areas or >20 - 25 kts over seas and smooth ground areas the fog is lifted into a low stratus cloud.
- Insolation => insolation during the day, resulting in an increase of the ground temperature up to that of the air, leads to a lifting of the fog to a low stratus cloud.
- Terrain => rough terrain may cause a mechanical turbulence within the fog layer, create mixing of air and eventually the fog may be lifted up and transforms into a low stratus cloud.
- Humidity => if the humidity of the air decreases such as after a prolonged movement over a dry ground surface or after a wind direction change a drier air mass replaces the humid one, fog dissipates.

#### Differences between advection fog and radiation fog:

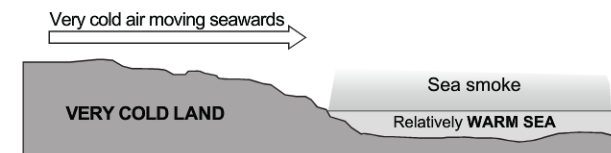
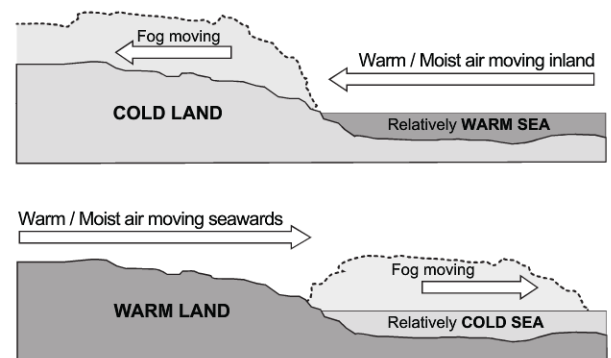
- Advection fog lacks the pronounced daily periodicity of radiation fog
- Advection fog covers larger areas and reaches higher altitudes than radiation fog.
- Advection fog can form irrespective of time of the day
- Advection fog it can stand much heavier winds
- There are often other clouds on top of the advection fog

### STEAM FOG (Arctic smoke)

Is formed over sea in wintertime, mainly in the polar / high latitude regions. Cold air from a land mass moves out over a comparatively warmer sea / water surface. The air adjacent to the water will be heated, simultaneously as water vapour will be added to the air. Heating of air at low level results in the layer of air becoming unstable and rises. The heated air ascends and the water vapour will condense during the lifting process => it looks as if there is smoke coming from the water surface since the condensation starts just above the surface. Steam fog is typically up to 500 ft thick, persistent and may drift inland.

#### Conditions for development of steam fog:

- Cold air moving over a warmer water surface,
- Light wind causing the movement stated above.



#### Factors affecting the fog characteristics and formation probability:

- Temperature difference => the greater the temperature difference between the colder air and the warmer water surface, the greater the likelihood of fog formation.
- Initial humidity => if the initial humidity of the air being moved is relatively high, fog will form more likely.

#### Conditions leading to dissipation of steam fog:

- Wind => change of wind direction or increase of wind speed disperses the fog.



## FRONTAL FOG

Occurs ahead of a warm front or ahead of an occlusion. If rain, consisting of small water droplets, higher temperature than that of the ambient air and with comparatively low falling speed has been falling for several hours, it causes the air below the raincloud to become saturated (by mixing of air or by evaporation of standing water). Sometimes fog or low stratus forms, at other time equilibrium is established with saturated air and, occasionally, stratus clouds almost at the ground level form. In the latter case a slight lifting over an elevated area will produce sufficient cooling for fog or very low clouds to form. Frontal fog may cover area up to 100 - 200 NM ahead of a warm front and will "travel" with the front. Unless the front is a very slow moving one, the fog is typically present for only about 2 to 3 hours.

Frontal fog does not form ahead of cold fronts, because the rain and showers connected with a cold front are made up of drops that are too large => they have a high falling speed and at the same time the temperature of the drops is low (it's often melted snow).

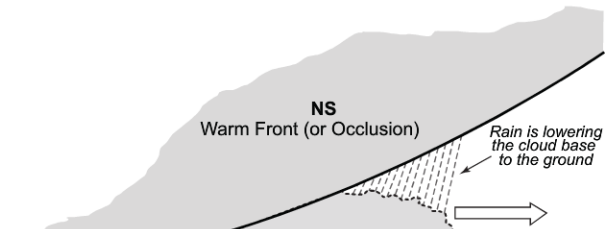
### Conditions for development of frontal fog:

- Rain showers remaining over an area for prolonged period of time.
- Warm front or occlusion

### Factors affecting the fog characteristics:

- Orographic lifting => increases the fog intensity.

**Dissipation of frontal fog:** by passing of the front



## OROGRAPHIC FOG / HILL FOG

Is formed when humid air is forced to ascend along the side of a mountain or a hill. As the air rises, it cools adiabatically, condensation level is reached and a cloud forms. If the lapse rate is unstable, the lifting results in a convective cloud. When the lapse rate is stable, the vertical motion is counteracted and a fog cloud will cap the mountain. Orographic fog persists as long as the flow of air over the obstruction is maintained, and the fog only dissolves when the air flow changes.

Orographic fog requires a wind up the slopes of a mountain and is promoted by high humidity. The hill fog quickly disappears if the wind changes. Note that if the air is moist enough, an obstruction only some 10 m high may cause condensation. Great areas of hills in Europe are exposed to prevailing moist airflows from the Atlantic Ocean and show clear signs of formation of fog or stratus due to enforced lifting despite slight vertical extension.

Besides hiding mountain tops orographic fog/cloud can be a sign of extreme low-level wind conditions on the leeward side of the mountain, so called rotors.

## FIGURE 050-E35

### THUNDERSTORMS

The thunderstorms are directly associated with the development of CB clouds with strong updrafts - thunderstorm (TS) is likely to occur in vertically well developed CB cloud, but it is not a rule - not all CBs always produce a TS. For a TS to occur several requirements must be met, or in other words several conditions must exist to enable a TS to develop:

- 1) The ambient air is so unstable that the thermals are allowed to rise to high levels => environmental lapse rate (ELR) is greater than the Saturated Adiabatic Lapse Rate (SALR) through a layer that is sufficiently thick (at least 10 000 ft) and extends well above the freezing level (0° isotherm).
- 2) Relatively high humidity available from lower levels - sufficient to form and maintain the cloud.
- 3) Trigger action that will start the vertical movement of the warm moist air (lifting action) from the ground level upward to produce an early saturation, release of latent heat (release of energy) - thus enhancing the instability and further vertical airflow. At least one of the following triggers is necessary - frequently more than one triggers will be present simultaneously, acting at the same time to produce greater lifting force:
  - Convection
  - Frontal uplift
  - Advection
  - Orographic uplift
  - Convergence of air often associated with low pressure areas

### Air Mass (Heat) Thunderstorms:

- Occur mostly during the summer and more likely over land surface than over water surface
- Isolated - triggered by anything but frontal uplift (most commonly by convection or orographic)
- Typically form during the day and clear by the night
- Very likely to form in weak low pressure areas or cols
- TS formed by advection can occur at any time (day / night / summer / winter) over any surface (water / land).
- Are further subdivided into:

- i) **Convective TS:** are generated mainly over land in the summer in a warm airmass. They are frequently called "heat TS" and form when thermals, strongly heated by the sun, are allowed to generate CBs. High air humidity and light wind in a low-pressure area or at a col provide the extra push needed for the cloud to become a TS. These cells grow large both vertically and horizontally, often show a multi-cell structure and become rather stationary. They can become self-propagating and do not dissolve until late night.

Convective TS occurring in a cold airmass when compared to a warm airmass TS are typically smaller, usually of a single cell structure, more isolated, more frequent and typically of weaker intensity.

Convective CB/TSs follow a diurnal periodicity with TS forming in the afternoon and dissipation in the evening. Likewise, the cloud tends to dissolve, if it moves in over a colder surface.

Another weather situation, generating the same type of TS cells, arises when cold air moves out over a warm water surface - sea Cumulus. This is fairly frequent during the autumn and winter along the coasts of Western Europe.



but it also occurs over the Atlantic and the Pacific. Since the water surface temperature is the same all day, this type of TS may exist independent of the sun's elevation. It is generally possible to fly round the convective air mass TSs due to their rather isolated nature.

- ii) **Orographic TS:** form when air, moving over an obstruction (mountain), is forced to rise to its level of condensation, after which it may rise to high levels (conditionally unstable air). It is associated with the obstruction and can appear very suddenly and cover a whole mountain range. Other thunderstorm types that reach a mountain range are strengthened, and aviation weather generally becomes very poor.
- iii) **High-level convection TS:** are sometimes observed during the night or day without there being any convection from the ground. These thunderstorms are initiated when air above an unstable air mass is being cooled either 1) by advection of colder air or 2) by cooling through radiation. In most cases the cloud base is very high, and the convection starts from a SC or AC layer, or AC-castellanus. This type of TS is most frequent during the summer- and autumn months.

### Frontal Thunderstorms:

- Occur mostly during the winter and can form over any surface - both land and water - day or night
- Typically formed in a line associated with a cold front or occlusion
- Very frequently occur in active depressions or troughs
- Often can produce squall lines - series of the most severe TSs
- Are further subdivided into:

- i) **Cold front TS:** is a type of TS that often occurs along a frontal surface and often forms a whole series of TS cells that are very difficult to fly around. The cell itself forms as cold air pushes itself under and thus lifts the warm humid air ahead of the front. Over irregular / mountainous terrain or on a very active cold front, this may develop into a very intense TS type, which you should avoid flying through. The best way is to fly well above the visible CB cells. If this should prove impossible, you will have to use your radar to find a way between the CB clouds, but always avoid flying in below the CB anvils.
- ii) **Warm front TS:** This is a very mean type of TS, since the CB cloud may be impossible to distinguish among the other frontal clouds (embedded). The TS cell forms conditionally unstable (ELR > SALR) warm air with sufficient moisture is lifted by the frontal surface. These TSs are generally weak with high cloud bases, but there are exceptions, especially when the warm air has a high water content.

Warm front TSs consist of individual cells, which can be avoided by flying around them at altitudes where visual references prevail. It is not always possible to get an early warning due to precipitation cluttering of the aircraft's weather radar. The early stages of the occluded fronts can create similar weather patterns. This type of TS leads to the dissemination of SIGMET of the EMBD TS or OBSC TS types.

- iii) **Squall-line:** is a line (or a "band") of very intensive TSs. The CBs in an unstable active cold front cause the cold air to blow into the warm sector at upper levels and this can create the squall lines approximately 50-100 NM ahead of the front (in the warm airmass ahead of the cold front). The length of the squall lines can be from some 100 NM to several hundred NM long. Squall phenomena are most frequent during the evening and early night. The CB clouds along the squall often seem very small and insignificant compared to the frontal clouds behind. In practice, however, the most severe thunderstorms and most severe hazardous weather phenomena can often be encountered in squall lines - such as severe turbulence and icing, heavy hail, frequent lightning, extremely heavy precipitation, destructive winds and sometimes tornadoes.

### Forecasting TS

The difference between "Air Mass" and "Frontal" thunderstorms becomes evident in the weather forecasts. The Frontal TS (not at the warm front) can be relatively precisely predicted as to position, direction and speed, whereas the Air Mass TS only can be denoted as TEMPO (temporarily) during a period of time, mostly in the afternoon/evening as their precise forecast is not possible.

- **1<sup>st</sup> stage of TS development - INITIAL:** also referred to as the "Growth", "Developing" or "Cumulus" stage. During this stage small CU clouds merge together into a larger CU cloud, typically with a base diameter of 1-5 NM. This larger CU cloud continues to grow, entraining air from the surrounding atmosphere and developing vertically beyond the 0° isotherm due to the continuous rising air currents. Diameter of the CU cloud is now at least 5 -10 NM. Strong updraughts are present - typically in the range of 1000 - 2000 ft/min, but can be as much as 6000 ft/min in case of extremely unstable air and/or intensely heated thermals. There is no precipitation during this stage and it typically lasts 15 - 20 minutes.
- **2<sup>nd</sup> stage of TS development - MATURE:** begins as some of the ice crystals and water droplets become so heavy that they start to fall => the first downdraughts start to appear within the cloud = precipitation occurs. The cloud continues to develop vertically (with top now typically over 20 000 ft) and both updraughts and downdraughts are present during this stage. The downdraughts bring cold air into lower levels of the cloud - as the air descends it slowly warms at SALR, therefore remaining colder than the surrounding air and sinking faster. Downdraughts are also intensified by evaporation of some of the rain - thus absorbing more latent heat from the air, making it even colder and denser / heavier.

If the downdraught is strong enough it may break out of the cloud base as a cold squall - often referred to as the "first gust". Severe turbulence can be experienced in the vicinity (in, below, around) of the CB cloud. At the leading outflow edge of the CB so called "roll clouds" (rolls of SC clouds) can form and strong gust fronts can occur - up to a distance of 15 NM ahead of the CB center. Microbursts can occur as a result of strong downdraughts. The falling and rising water droplets and ice crystals create a significant amount of static electricity that eventually results in lightning discharge and thunder. Usually a positive charge of static electricity is present at the top of the cloud and the negative charge at the bottom. Mature stage lasts for 20 - 30 minutes and it is during this stage that the Thunderstorm reaches its greatest intensity: downdraughts can be over 2000 ft/min, updraughts now as much as 10 000 ft/min, cloud tops still vertically growing at rates of up to 5000 ft/min.

- **3<sup>rd</sup> stage of TS development - DISSIPATING:** is the final stage during which the updraughts die-out (as the TS used up all the local "supply" of moist air) and downdraughts predominate, causing heavy precipitation and severe turbulence. As the top of the cloud extends up to the tropopause the ice crystals at the top of the cloud are often spread out by the upper winds and form the familiar "CB Anvil". Lightning can occur as a result of the static electricity buildup - either from the cloud to the ground, between clouds or between the cloud and surrounding air.

Precipitation starts to die out as the cloud dissipates from below. The dissipating stage can last anywhere from 30 minutes (the active part of the dissipating stage) to 2,5 or 3 hrs until the cloud dissipates.

#### Well developed CB / TS cloud tops, bases and temperatures

Well developed TS will typically consist of several "cells", each at a different stage of development. In some cases the cold downdraught from a mature cell can re-energise a dissipating cell and self propagate or trigger. If TS is to develop, from a CB the cloud-tops must typically reach temperatures below at least  $-20^{\circ}\text{C}$ , although an exceptionally high moisture content may enable TS development at higher temperatures. If the temperature of the cloud-top falls towards or even below  $-40^{\circ}\text{C}$ , electrical phenomena (lightning discharge, static) and hail always occur. Tops of the CB clouds reach very high levels, generally over 25 000 ft in temperate latitudes (even higher during the summer). In the tropics - the area with the highest rate of TS occurrence - the tops of CBs can reach as high as over 50 000 ft. The bases of CB clouds greatly vary - from as low as 100 ft in humid climate to several thousand feet in drier regions.

**TS movement:** TS typically move in the direction of FL100 (700 hPa pressure level) wind. However, TS formed in a weak low pressure system or in a "col" typically move erratically in various directions. Frontal thunderstorms can be the fastest moving storm as they move at the speed of the associated frontal systems.

#### Hazards associated with TS

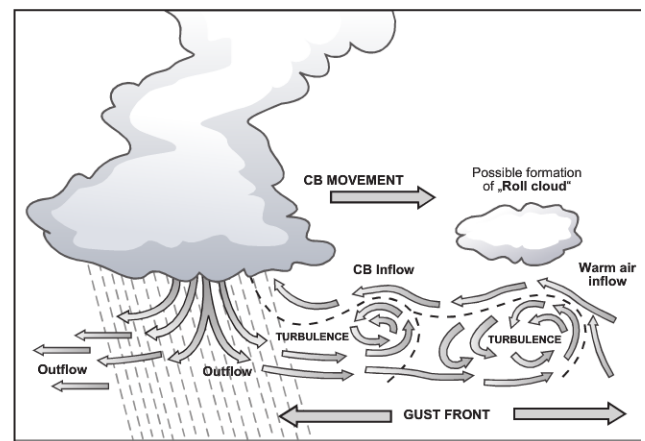
- **Microburst:** very dangerous phenomenon caused by suddenly strengthened cold downdraughts from CB clouds. They are relatively concentrated, can reach vertical speeds of 2000 - 7000 ft/min and as already mentioned are typically colder than the temperature of its surrounding air (making them heavier / denser  $\Rightarrow$  faster descent speeds). Close to the surface (at few hundred feet) they are deflected outwards (to the sides) from below the CB as a reaction of interference with the ground, causing extreme turbulence and sudden gusts of very strong horizontal winds (typically up to 50 kts)  $\Rightarrow$  danger of significant low level wind shear with wind speed changes of 50-90 kts.

Microburst is a very erratic phenomenon which is very difficult to predict. Typical microburst affects an area (has an effective diameter) of about 4000 m (2,2 NM) and has a "life-time" of about 1 to 5 minutes. It is most often encountered during the summer months in Air Mass thunderstorms during the Mature and Dissipating stages of TS development. Microbursts are more frequent in low-latitude regions and a typical "warning sign" that microburst is likely to occur is virga (streaks of precipitation that do not reach the ground) below the CB cloud.

- **Gust Fronts:** are associated with the Mature stage of a TS. The cold air subsiding from the upper levels of the CB cloud has a high speed relative to the ground. As the downdraughts occur in the CB, the cold air has a tendency to flow out all around - particularly from the leading edge of the cloud) ahead of the cloud. If it is strong enough, it will break out from the CB cloud and the cold (and thus heavier) air then sweeps along the ground as a gust front. At the leading edge of this gust front a rapid wind change takes place and in the tongue of cold air the wind is very strong and turbulent. If the ground is dry, dust is whirled up along the gust front. This dust-cloud is mostly the only sign of the phenomenon. Gust fronts from the CB cloud may extend up to about 15 NM ahead. It may exist as small waves even after the dissipation of the CB and then drifts at some 10 kts in a stable layer along the ground surface.
- **Hail:** well developed CBs can be a source of hail at any height of the cloud (up to about 45 000 ft) as well as below the "anvil top". Aircraft damage due to hail can be severe (hailstones as large as 10 or 13 cm in diameter have been found at the ground).
- **Icing:** a high risk of severe icing exists when flying through CB clouds - especially during the mature and dissipating stages of a TS when downdraughts are present - these are a source of plentiful super-cooled water droplets. Remember that icing can occur at any level inside a CB cloud where the temperatures are between  $0^{\circ}\text{C}$  and  $-45^{\circ}\text{C}$ .
- **Turbulence:** as with icing, CBs and TSs always offer a high risk of severe turbulence due to the strong updraughts and downdraughts. Unlike icing, turbulence can be experienced not only inside a CB / TS, but also anywhere below and around the side of the CB.
- **Lightning strike:** can occur both inside as well as outside of the CB cloud. The greatest possibility of a lightning strike is in areas of  $+10^{\circ}\text{C}$  to  $-10^{\circ}\text{C}$  = approximately in the region of 5000 ft above and below the freezing level, with some risk also above especially at high levels around the tops of the CBs. If the aircraft sustains a lightning strike, it becomes part of the lightning's trajectory (channel). The lightning most frequently strikes at the nose section or at the wingtips, sweeps over the aircraft and leaves it somewhere at the tail section. An aircraft of metal construction leads the charge at the outside of the skin (Faraday's cage) and the damages are mostly slight - electronic instruments and compasses may sometimes be affected, but typically no or only minor structural damage typically occurs.

Aircraft containing composite materials that have not been made conductive by paint etc. will be severely damaged in case of a lightning strike  $\Rightarrow$  the non-conductive materials will be vaporized / splintered. The pilots may also be dazzled, receive a minor electric shock and be deafened or blinded for a little while.

- **Static:** the buildup of static electricity in CB clouds may cause interference with aircraft communication and navigation equipment especially in the MF / HF bands, and sometimes, to a lesser degree in the VHF frequency bands.





**General TS/CB hazard avoidance criteria**

The safest way to deal with the hazards associated with TS is to avoid the CB clouds by sufficient margins as outlined below. When it is not possible to avoid the TS for some reason and it is necessary to fly through it, it is best to pass it through the side of the CB cloud on the upwind side, at an altitude outside of  $+10^{\circ}\text{C}$  to  $-10^{\circ}\text{C}$  range (most likely lightning strikes).

- When overflying a TS, maintain at least 5 000 ft vertical separation from the cloud top.
- Always avoid flying under the “anvil” at the top of a CB cloud (likelihood of hail, severe turbulence and lightning strike).
- If the aircraft does not have a WX radar, you should avoid by 10 NM any CB that is tall, growing rapidly or has anvil top.
- Between surface and FL 200 avoid TS cells by at least 5 NM (by 10NM if they are growing rapidly or if their shape as seen on a WX radar screen has “fingers”, hooks or other protrusions, scalloped edges or rapid change of intensity).
- Between FL200 - FL250 avoid TS cells by at least 10 NM.
- Between FL250 - FL300 avoid TS cells by at least 15 NM.
- Above FL300 avoid TS cells by at least 20 NM.

**FIGURE 050-E36****TEMPERATURE VARIATIONS**

The surface temperature of a specific place, among other things, is dependent on the following factors:

- The elevation of the Sun - i.e. latitude, season and time of the day.
- Altitude above the sea level, topography, causing the temperature to decrease on an average  $2^{\circ}/1000$  ft.
- If you are approaching an airfield in wintertime without any weather service but with access to information from a lower situated airfield in the vicinity, you should reduce this temperature by  $2^{\circ}/1000$  ft for a rough estimate of the probability of frost on your intended runway.
- The condition of the surface of the ground.
- Sand and bitumen surfaces are heated much more than water surfaces and vegetation due to the evaporation from the latter. This causes vertical air currents (convection) and, as a consequence, an aircraft at low level has a tendency to descend over water surfaces and vegetation but to climb over sand and bitumen.
- Weather affects incoming and outgoing radiation.
- Overcast versus clear sky gives variations as you have already seen. After rain, the air cools somewhat. This is partly due to the cooling effect of the precipitation (cold droplets of a rain shower) and partly because heat is consumed by the evaporation. You have probably noticed the steam from woods and asphalt surfaces after a rain shower. Also the wind affects the temperature so that a strong wind leads to extensive mixing and a lower temperature by day but higher by night, while a light wind gives less mixing and a higher temperature by day but lower by night.

At temperatures close to  $0^{\circ}\text{C}$  ( $0^{\circ}\text{C}$  to  $+5^{\circ}\text{C}$ ) you must always be careful when roads and runways are wet. Particularly if the sky is clearing or if it is getting windy, this directly leads to a decrease of temperature and often also an icy surface. In clear weather, with the dewpoint below  $0^{\circ}\text{C}$ , the outgoing radiation during the evening may lead to frost both on runways and parked aircraft.

**Temperature variations**

There is an important difference between the incoming radiation and the emitted heat radiation from the ground. The terrestrial emission takes place round the clock, while the incoming radiation only occurs in daylight. The maximum and minimum temperatures of the day are marked in the figure on the right. Note the displacement in relation to the insolation.

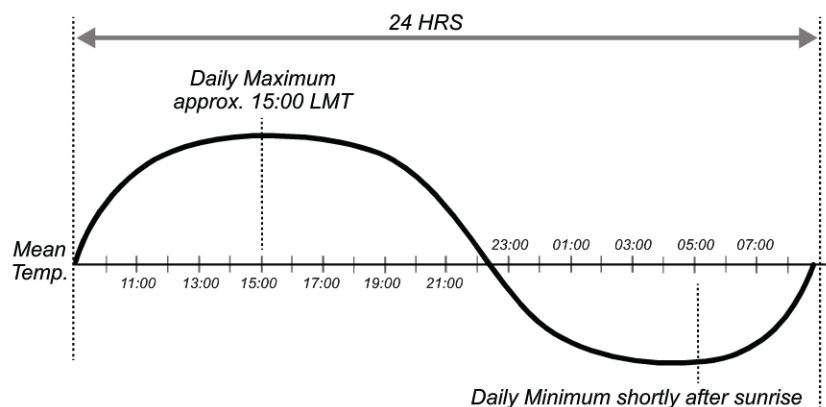
If the sky is clear and there are light winds, the temperature will rise rapidly during the morning. At noon the increase of temperature levels out, and the maximum temperature of the day is reached at around 14 - 15:00.

In the afternoon the temperature decreases, at first slowly, but towards sunset more significantly and sometimes we get a back swing with rising temperature immediately after sunset. The reason for the levelling out of temperature or the back swing is heat radiation from the ground and upper air layers. During the night the temperature slowly falls to reach its lowest value one to two hours after sunrise.

The most significant differences between day and night occur in areas of great daily insolation, i.e. at low latitudes (Equator regions). In the same way we realise, that Northern Europe has a greater variation in the summer than in the spring or autumn. In those cases when a ground inversion develops at night, especially over snow covered surfaces, the variation of temperature can be significant.

Diurnal Variation (variation in temperature that occurs from the highs of the day to the cool of nights) is typically within  $\pm 6^{\circ}\text{C}$  (in mid-latitudes). Greatest variations occur with clear skies and little wind. High desert areas typically have the greatest diurnal temperature variations. Low lying, humid areas typically have the least.

Since the Sun is at its highest elevation at noon (12:00) one would think that the highest daily temperatures would be reached at this time, but instead it takes about 2 to 3 hours more to reach the highest daily temperatures. It is because during these 2 to 3 hours the Earth is receiving more solar radiation than it is giving out in the form of terrestrial radiation (phenomenon referred to as “Thermal Inertia”).



**FIGURE 050-E37****TROPICAL REVOLVING STORMS**

A tropical revolving storm (TRS) is the most devastating and extensive weather phenomenon affecting earth (one might say that tornado is more destructive - yes, but its life cycle is typically measured in minutes, while with a TRS the life cycle is measured in days or weeks and affects a widespread area). TRS is a cyclone that develops from a cluster of convective clouds over warm tropical oceans and has a sustained wind speed of more than 64 kts. TRS is also referred to as a Hurricane, Typhoon or Tropical Cyclone, depending on the geographical area concerned. As the TRS starts "building" (as it intensifies) it goes through several stages before becoming TRS:

- Tropical disturbance = wind speed < 20 kts
- Tropical Depression = wind speed of 20 - 34 kts
- Tropical Storm = wind speed of 35 - 64 kts
- Tropical Revolving Storm = wind speed > 64 kts

**Formation of TRS**

A TRS can only form where certain definite conditions are fulfilled. Among these are:

- Warm and humid surface, water temperature of at least 27°C (24°C for "survival" of the TRS) - the higher the water temperature, the higher the pressure drop in the core.
- Uniform Trade winds at all levels, otherwise the Cb-clouds will be scattered,
- Sufficiently unstable atmosphere at low level for the convective clouds to penetrate the Trade wind inversion,
- Divergence in the upper part of the troposphere poleward of the area where large scale convection develops e.g. a branch of the subtropical jet interacts with the area,
- Influence of the Coriolis force since vorticity is an essential part of the circulation, hence tropical cyclones do not occur at the Equator and can only form at latitudes between 5° and 25° (below 5° Coriolis force is too small, while above 25° the sea temperature is typically too low).

Looking at the above requirements for a formation of TRS it is quite clear that the TRS can not form over land (too dry) neither over the South Atlantic or South-East Pacific, because the sea currents keep the water temperature down and the ITC is usually north of the Equator. Another restricting factor is the Trade wind inversion, which is lowest over the eastern parts of the oceans and highest in the west. In the eastern parts convection is stopped almost at once, while in the western parts the rate of ascent can be considerable, making penetration of the trade wind inversion possible. This is why we find fewer hurricanes in the eastern parts of the oceans, while they are fairly frequent in the west.

TRS obtains its "energy" from the release of relatively large amounts of latent heat from the moisture gained by the air over the warm ocean areas. The release of latent heat results in expansion of the air and thus further reducing the pressure at the surface, creating even stronger convergence => more moist air to be forced to rise which causes cooling of the air, condensation and release of more latent heat.

Most TRSs form between 8°-15° latitude north and south of the Equator. They are caught by the prevailing easterly flow in the tropics and carried away westwards or North (South)-Westwards at a speed of about 10 to 20 kts. When the TRS passes the 25°-30° latitude they turn pole-wards in a North (South), later North (South)-east direction.

**Geographical and time occurrence of TRSs**

The name and time of occurrence of TRSs varies over the earth:

- In the Atlantic (incl. Caribbean) and Eastern-Pacific regions (N Hemisphere) TRS is referred to as a "**Hurricane**" and occurs approximately 10 times per year, mainly in the period July - November.
- In the Indian Ocean TRS is referred to as a "**Cyclone**" and occurs on average 12 times per year, mainly in the period April - May and October - November.
- Off the coast of East Africa TRS is referred to as a "**Cyclone**", but occurs only occasionally, mainly in the period December - April.
- In the Western Pacific (N Hemisphere) and South China sea (e.g. Japan, Korea, Chinese coastline) TRS is referred to as a "**Typhoon**". This is the area with the highest rate of TRS occurrence - typically 20 times per year, mainly in the period June - November. In this area, there is a possibility of occurrence of a small TRS all year round.
- In the Western Pacific (S Hemisphere), incl. Australia, TRS is referred to as a "Cyclone" (in Australia TRS is referred to as "**Willy-Willy**") and occurs occasionally, mainly in the period December - April.

**TRS dangers for aircraft**

The typical characteristics of a fully developed TRS are circular isobars, strong gusty winds, spiral cloud pattern and a typical eye in the centre. From a pilot's point of view any TRS should be avoided, because there is always a potential risk of severe turbulence in and around the CB-spiral bands and **especially in the border around the eye**. At low levels devastating winds and turbulence affect (close) the airports. The change to lighter winds occurs at heights above approximately 30 000 feet in the outflow region from the TRS. The most intense parts of a TRS is found in the right front quarter of the storm where the storm movement and winds interact while the weakest portion is in the left rear quarter. In the tropical regions there are often extensive areas with Cirrus clouds. These are no real threat to flight but it is vital, when operating in these areas, to distinguish between these clouds and the spiral band CB.



**FIGURE 050-E38****VARIATIONS OF THE TROPOPAUSE**

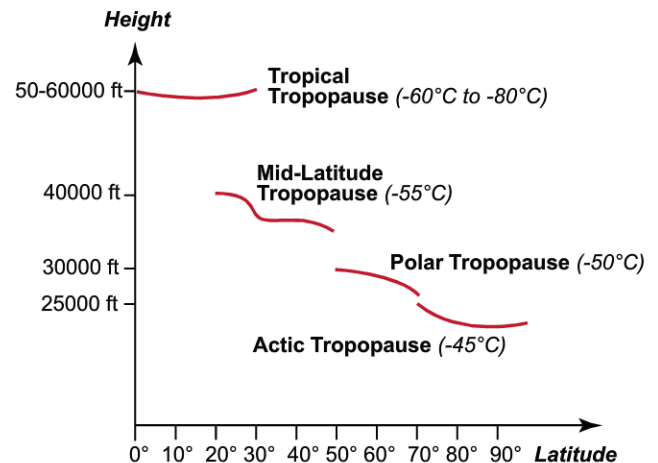
In the standard atmosphere the temperature is  $+15^{\circ}\text{C}$  at sea level and decreases with an increasing height at the rate of  $2^{\circ}\text{C}$  per 1000 ft (more exactly  $1.98^{\circ}\text{C}$  per 1000 ft or  $0.65^{\circ}\text{C}$  per 100 m). This is called the International Standard Atmosphere Lapse Rate. At an average height of 11 km (36090 ft) the vertical heat exchange decreases  $\Rightarrow$  the temperature remains almost constant with further increase in height. This break-point is called the **TROPOPAUSE** and it also constitutes the upper limit for most water vapour and dust emanating from the surface of the Earth. All weather, except for wind and turbulence is, in principle, limited to the troposphere (from the surface of the Earth to the tropopause). The height of the tropopause varies according to the temperature on the surface:

- WARM surface = large mixing  $\Rightarrow$  HIGH tropopause.
- COLD surface = small mixing  $\Rightarrow$  LOW tropopause.

Thus the tropopause at the Equator is significantly higher than the tropopause at the North and South poles. Also the tropopause is higher in the summer than in the winter months.

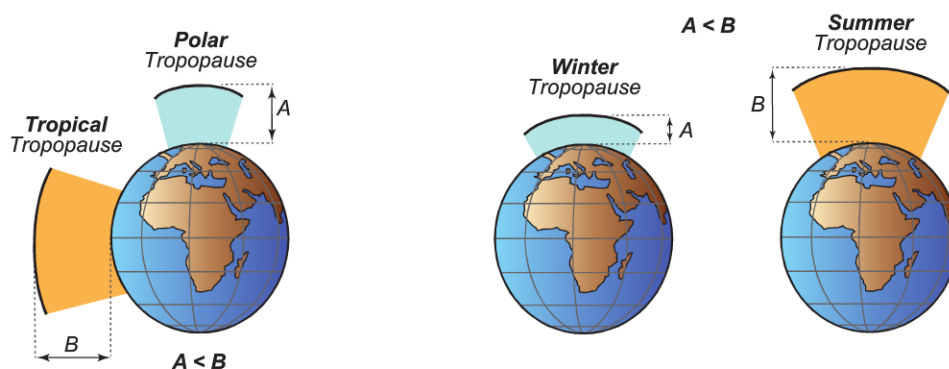
Since the thickness of the troposphere is determined from the amount of solar energy and the vertical mixture, the tropopause will be lower over areas where the air is cold, than where it is warm. The thickness of the troposphere and thus the height of the tropopause depend on the season and the latitude (the distance from the Equator). The chart on the right is showing the typical variations in the tropopause heights at different latitudes along with the average temperatures at the tropopause:

- **Tropical tropopause**  
- approx. 50 000 ft and temperature  $-60^{\circ}\text{C}$  to  $-80^{\circ}\text{C}$
- **Subtropical or Middle latitude tropopause**  
- approx. 40 000 ft and temperature about  $-55^{\circ}\text{C}$ .
- **Polar tropopause**  
- approx. 30 000 ft and temperature about  $-50^{\circ}\text{C}$ .
- **Arctic tropopause**  
- approx. 25 000 ft and temperature about  $-45^{\circ}\text{C}$ .



In the summertime the Arctic air disappears and the Polar air moves further north. The borderline between the Polar and Tropical air moves to about  $60^{\circ}$  and the borderline between Tropical and Equatorial air settles around  $30^{\circ}$ . If an extensive area has a uniform temperature distribution the air pressure at the surface can cause the height of the tropopause to vary. Generally speaking, the following applies:

- Low air pressure = less air in the air column  $\Rightarrow$  lower tropopause than in the surroundings.
- High air pressure = more air in the air column  $\Rightarrow$  higher tropopause than in the surroundings.

**FIGURE 050-E39****FRONTS**

Let's start with a very brief review of some definitions:

- **Air mass:** It is a large quantity of air that has a homogenous nature. That means that it has a fairly uniform distribution of temperature and humidity in a horizontal plane throughout the mass (air mass = air of similar properties within a major geographical region). Air masses contain thermal and humidity characteristics of their source region. They are advected (move) along the surface of the Earth and carry these thermal and humidity characteristics with them (although they can be modified, especially in their lower levels, by the surface over which they are advected).
- **Zone of transition:** As the various air masses move over the surface of the Earth it is inevitable that eventually some of them will "meet" or in other words "come together". As they meet, they will most likely have different thermal, stability and humidity characteristics. The first "zone of meeting" is covering a relatively long distance (can be as much as 300 NM) - this is referred to as the zone of transition.
- **Frontal surface:** As the air masses move closer and closer together in the zone of transition, a transition from one air mass to another will eventually become sharply marked  $\Rightarrow$  this sharp zone, or "boundary" between two air masses, is referred to as the frontal surface. Its width varies between 60 - 90 NM at upper levels, while the typical values at the



ground surface are 30 - 50 NM.

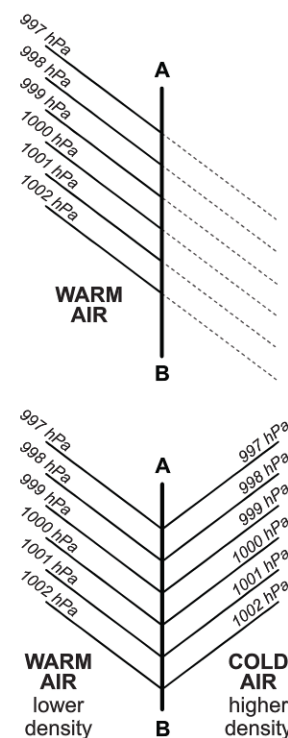
- **Front:** The location where the frontal surface “touches” or intersects the ground surface is referred to as the front.

### Types of fronts

- **Warm front:** warm air displacing cold air - chart symbol (red):
- **Cold front:** cold air displacing warm air - chart symbol (blue):
- **Occluded front:** forms when the cold front overtakes the warm front - chart symbol (violet):
- **Warm front occlusion:** the air behind the occluded front is the warmest
- **Cold front occlusion:** the air ahead of the occluded front is the warmest
- **Stationary front:** essentially no movement across the frontal zone - chart symbol:

### Slope of a frontal surface

Frontal weather is closely associated with the slope of the frontal surface, and in principle we can say, that the steeper the slope is, the more intense will be the vertical motion of the air. We can therefore say that a relatively steep front (e.g. a cold front) affects a relatively narrow geographical area, but produces a lot of significant weather phenomena, mostly CBs and/or thunderstorms. On the other hand, a relatively shallow front (e.g. a warm front) affects a larger geographical area but the weather phenomena present will not typically be so significant in terms of CB/TS - typical weather phenomena will be of the nimbostratus (NS) cloud type, sometimes with fog or fog clouds. This very simplified generalisation assumes that there is a convergence along the front creating an ascending motion of air along the front. Typical slope of a WARM front is 1:100 - 1:150, whereas for a COLD front it is typically 1:50 - 1:100.



### Pressure around a front

Fronts are typically areas associated with converging and ascending air. Let's look at an example of a warm front, where warm air is replacing cold air (figure on the right).

Let's now take a look at the top picture on the left and assume that the line A-B is the boundary that divides the warm air and the cold air. The spacing of the isobars on the left side of the “A-B” line corresponds to the density of warm air. If the same density of air was present also on the right side of the “A-B” line, the isobar would continue as they are depicted by the dashed lines.

However, if we realize that the air on the right side of the “A-B” line is actually a cold air that has a much higher density, we get an isobar pattern as depicted on the lower picture on the left. The line “A-B” in this case represents the front. The isobar (pressure) distribution pattern shown on the lower left picture clearly shows that fronts are situated in a trough => and this is the location where we always find the fronts - in more or less well-developed troughs.

We can therefore conclude that atmospheric pressure decreases as a front approaches. Lowest value of atmospheric pressure is reached at the frontal boundary and then the pressure increases again.



### Permanent fronts of the world

There are 4 major quasi-stationary fronts that we can find in both hemispheres:

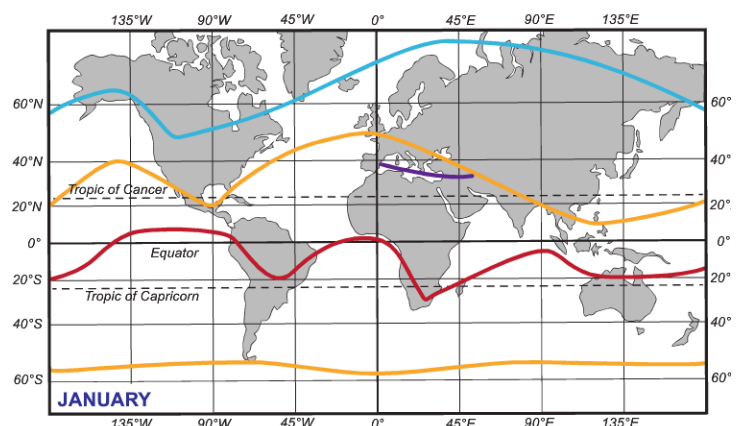
- Arctic / Antarctic front
- Polar front
- Mediterranean front
- Inter-Tropical Front / ITCZ

#### Arctic / Antarctic front:

Generally located in high latitudes (arctic typically above 60°N and antarctic even closer to the S pole) and represents a boundary (transition) between the **cold Arctic** (or Antarctic) airmass and a slightly **warmer Polar** airmass. The exact position of the front changes on a daily basis. Its general position can be affected by seasonal changes - in the winter and spring it can move to lower latitudes in Northern Hem. (e.g. as low as 50°N in Western Canada). It is frequently associated with Jetstreams.

#### Polar front:

Represents a boundary (transition) between the **cold Polar** airmass and the **warm Tropical** airmass. In the Northern Hemisphere the position of the polar front is affected by seasonal changes => during the winter it typically moves to lower latitudes (between 50°N and 20°N) whereas during the summer it is typically situated further north (between 40°N and 65°N). In the Southern Hemisphere the position of the Polar front remains almost constant regardless of the season - around 50°S (with some minor variations).



fluctuations). Frontal waves are frequently present along the Polar front, causing frequent occurrence of frontal depressions.

#### Northern Hemisphere in the summer:

- Global / worldwide position: between 40°N and 65°N
- Position around Europe: between 50°N and 65°N

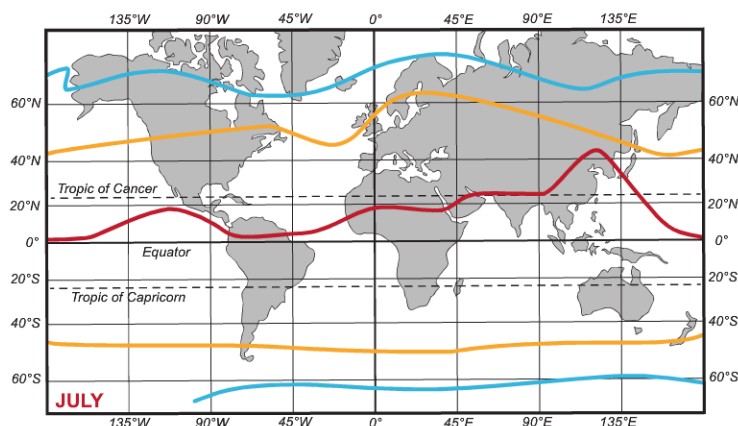
*Spans from N.Canada (Newfoundland) across the Atlantic towards Ireland and UK, turns toward North Scotland and continues towards Scandinavia (Gulf of Botnia - around 60°-65°N) and then further East/South-East.*

#### Northern Hemisphere in the winter:

- Global / worldwide position: between 50°N and 20°N
- Position around Europe: between 40°N and 50°N

*Spans from Florida (USA) across the Atlantic towards the Southern part of Ireland / UK (50°N) and then curves in SE direction towards the Northern part of the Black Sea - then towards the Southern part of the Caspian Sea.*

- Southern Hemisphere (all year round) fluctuates slightly around 50°S.



#### LEGEND:

Arctic / Antarctic front  
Polar front

Mediterranean Front  
Inter-Tropical front (ITCZ)

#### Mediterranean front:

Represents a boundary (transition) between the relatively **cold Polar (maritime or continental)** airmass from Northern Europe and the **warmer Tropical continental** airmass from North Africa. This front is seasonal - it occurs only during the winter and disappears during the summer. During the winter it stretches over the Mediterranean areas - from the coast of Spain around Barcelona (40°N) towards Sicily, then towards the islands of Crete and Cyprus (35°N) - then continues towards the Southern edge of the Caspian Sea where it ends.

#### Inter-Tropical Front / Intertropical Convergence Zone (ITCZ):

Represents a relatively wide zone of convergence of the airmasses carried by the Trade Winds - an area where the airmasses from either side of the heat Equator meet. ITCZ location is greatly affected by seasonal changes - although it tends to change its position more significantly over land than over the sea areas. The sections of this front that are situated over the seas/oceans are referred to as the "Intertropical Convergence Zone" (ITCZ), while the sections situated over land are referred to as "Inter-Tropical Front" (FIT).

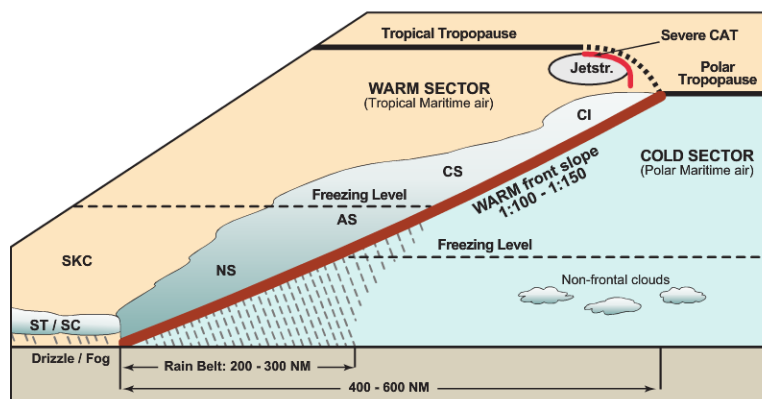
### FIGURE 050-E40

#### WARM FRONT

A warm front can be defined as warm air displacing cold air. When the warm air is overtaking (displacing) the cold air, it will ride up and over the heavier cold air while advancing. The cold air thus forms a "wedge" in below the warm air. The slope of the frontal surface is gentle - on average 1:100 - 1:150. Warm front moves at right angle to itself at  $\frac{2}{3}$  of the geostrophic wind speed - typically between 10 - 30 kts, but deviations may be great => typically a warm front will pass through an area in about 24 hours after you have seen the first Cirrus clouds. Warm fronts generally tend to move from the SW to NE direction. The air behind a warm front is warmer and more moist than the air ahead of it => when the front passes, the air becomes noticeably warmer and more humid. On the charts, a warm front is represented by a solid (red) line with semi-circles pointing towards the colder air and in the direction of the front movement.

As the warm moist air moves into the area of cold air and starts "sliding" on top of the cold air it cools adiabatically and clouds form above the frontal surface in the warm sector. Since the warm air is mostly stable, the clouds that form are mostly stratiform. As the warm front approaches, we typically see this sequence of clouds: CI, CS, AS, NS.

- **CI** (cirrus) clouds at FL250-350 as far as 600 NM ahead of the front.
- **CS** (cirro-stratus) clouds at FL200-250 gradually replace the CI. No precipitation yet from CS clouds.
- **AS** (alto-stratus) clouds are encountered at around FL150-200 as the front gets closer. These are already quite compact layers consisting of ice crystals, supercooled water droplets (0° to -15°C) or ordinary water drops. Precipitation starts to fall (from as high as 18 000 ft) but it usually evaporates before it reaches the ground (virga).
- **NS** (nimbo-stratus) clouds with bases typically between 6000 - 8000 ft causing overcast (OVC) skies are a sign





that the frontal ground surface is now approx. 150-200 NM away (in some cases up to 300 NM). At this point the precipitation is reaching the ground - we refer to this area as the "rain belt". The precipitation can be initially light and intermittent, but gradually intensifies into a continuous moderate to heavy as the frontal surface gets closer.

- **ST or SC** (stratus or strato-cumulus) clouds can be encountered ahead of the "rain-belt". Inside the "rain-belt" (below the NS) **ST-Fractus** or **CU-Fractus** clouds can be encountered at any level.
- **Frontal FOG** can sometimes be encountered 20-50 NM ahead of the frontal ground surface.

If the lapse rate in the ascending warm air becomes unstable, convective cells will form as the warm and moist air is lifted along the frontal surface => formation of **CB clouds can occur**. They are typically "embedded" in the stratiform cloud layers, therefore not distinctly visible from the ground (at higher altitudes yes). When present they cause an increase in the intensity of precipitation (not a change from continuous to showery).

Other factors indicating an **approaching warm front** are: 1) gradual fall of pressure, 2) slow but gradual increase in temp, 3) increase of surface windspeed + backing in wind direction shortly before the frontal surface, 4) visibility decreases mainly due to precipitation.

**Frontal passage** takes typically 40 - 60 minutes. During this time 1) the pressure reaches its lowest value, 2) temperature suddenly increases and 3) wind veers sharply (danger of low level windshear) and windspeed stabilizes.

**After the front passes:** 1) temperature may continue to increase slightly, 2) pressure may rise slightly or remains stable before starting to gradually fall again as frequently a warm front is closely followed by a cold front, 3) wind veers (clockwise) and 4) upper level clouds vanish and ST / SC clouds with very low bases remain.

Note that in winter warm fronts can create hazardous icing conditions - if rain falls from the warm sector and enters the cold air (with temperatures below 0°C) below the warm front surface, the rain becomes supercooled and freezes instantly if it comes into contact with the aircraft structure.

WARM front	Front is approaching	During frontal passage	Behind the front
<b>Winds</b>	Gradual increase in speed, slight backing, typically Southerly	Wind direction veers sharply, windspeed starts to decrease	Direction stabilizes, typically on SW values, steady windspeed
<b>Temperature</b>	Steady - typically cold, or slowly increasing	Sudden increase, then steadily rising	Steady or only minor changes
<b>Pressure</b>	Steady decrease	Lowest value - stops decreasing	Slight rise, then steady or slow fall
<b>Clouds</b>	Sky coverage gradually increasing to low OVC layer, cloud bases lowering. Sequence of clouds: CI, CS, AS, NS. Possibility of low ST or fog close (20-50 NM) to frontal surface	OVC layer of NS / ST, very low bases	OVC layers changing into BKN to SCT layers of ST or SC clouds with very low bases typically persist
<b>Precipitation</b>	Continuous light rain / snow, then moderate from NS. Precipitation at surface 200-300 NM ahead of front.	Continuous moderate or heavy rain / snow, mainly from NS.	Occasional drizzle, light rain/snow - from ST/SC, or no precipitation at all
<b>Visibility</b>	Relatively good, but gradually reducing to poor as the frontal surface approaches	Very poor due to heavy precipitation, mist / fog can occur frequently	Slight improvement, but remains moderate to poor (possible haze, mist, fog or drizzle)

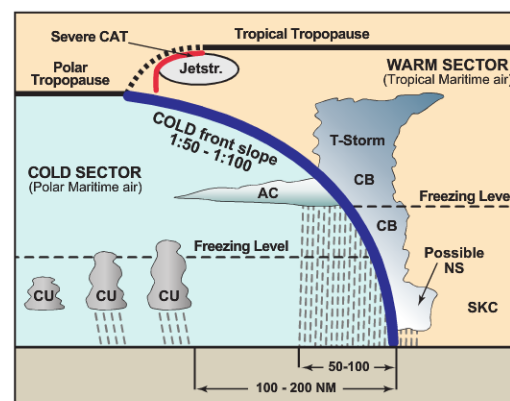
## FIGURE 050-E41

### COLD FRONT

A cold front can be defined as cold air displacing warm air. When the heavier (denser) cold air is overtaking (displacing) a less dense warm air, the cold air will "slide itself" under the warm air and forces it to rise. The slope of a cold front varies a great deal, and we distinguish between passive (kata) fronts with a slope of 1:100 and active (ana) fronts with a slope of up to 1:50 - however, in general the slope is steeper than that of the warm fronts. Cold front moves at right angles to itself at a speed equal to the full geostrophic interval (determined by the isobar spacing) measured along the front - therefore the cold fronts are typically much faster moving than warm fronts.

Cold fronts generally tend to move from NW to SE direction. The air behind a cold front is much colder and drier than the air ahead of it (when cold front passes, temps can drop as much as 15°C or more within the first hour). A chart symbol for a cold front is a solid (blue) line with triangles along the front, towards the warmer air and in the direction of the front movement.

The cold fronts can create similar weather conditions as warm fronts, but in a reverse order. Typical cloud types for a cold front are CU and CBs. We can also find AC or AS clouds at medium levels, typically spreading as a solid layer in the cold sector behind the main frontal clouds (CBs). Since the slope of a cold front is much steeper than that of a warm front, the area affected by a cold front is much smaller. Precipitation associated with the surface of a cold front usually affects only a narrow geographical area - a typical "rain belt" is 50 - 100 NM wide with mainly showery precipitation on both sides of the front (however, mostly behind it).



## Typical cold front weather conditions

COLD front	Front is approaching	During frontal passage	Behind the front
<b>Winds</b>	Backing, increase in speed, becoming squally	Sharp and sudden veers, strong gusts (frequently violent), possible squalls	Speeds decrease and stabilize, direction steady or slight veer to NW
<b>Temperature</b>	Steady - but falling rapidly close to the frontal ground surface	Sudden decrease	Remains steady (cold) or only minor changes
<b>Pressure</b>	Steady decrease	Lowest value - stops decreasing	Gradually and slowly increases
<b>Clouds</b>	Typically ST / SC if sufficient moisture present, or clear skies, then increasing coverage in NS and CB.	BKN to OVC with CU / CB, possible NS just ahead of the frontal surface, low cloud bases	Rapidly lifting BKN to OVC layers, short periods of AC / AS, occasional CU / CB
<b>Precipitation</b>	Occasional drizzle, light rain/snow - from ST/SC, or no precipitation at all, showers close to the frontal surface	Heavy showers of rain / snow, Thunderstorms, possibility of hail	Same as during frontal passage for a short period, then no precip., later occasional showers from CU / CB
<b>Visibility</b>	Fair to poor - possibility of haze, fog, mist or drizzle if moisture present	Temporarily poor in precipitation, then rapid improvements to good	Very good, except in showers

## Ana / Kata cold fronts

As already mentioned earlier, cold fronts can be classified into active (ana-) or passive (kata-) fronts, based on the speed at which the fronts move and on the vertical motion of air at the frontal surface, which in turn is defined by the stability of the air in the warm sector ahead of the cold front. An unstable warm airmass and/or a rapidly advancing cold front leads to an active cold front, while a stable warm airmass together with a slow-moving cold front results in a passive cold front.

- **Passive cold front (kata front):** when the stable warm air is slowly lifted, a typical cloud system occurs that is similar to that of a warm front, but in reverse order: NS, AS, CS, CI. Sometimes only a dense / thick SC clouds form along the frontal surface if the warm air ahead of the front does not have sufficient moisture content. The precipitation area is typically 100-150 NM wide with major part of it behind the frontal surface (inside cold air sector). Precipitation is rather continuous and steady, as opposed to the showers that predominate in active cold fronts. Kata fronts are moving slower than Ana fronts - typically at a speed of 10 - 15 kts.
- **Active cold front (Ana front):** the slope of Ana fronts is steeper than Kata fronts => warm air is pushed upwards at a greater rate. Add to this an unstable and humid characteristics of the warm air and we have perfect conditions for convective activity. The latent heat released from the warm air as it is being lifted rapidly and cooled will boost the formation of CBs with great vertical development. Mature CBs, frequently with T-storms, will occur in a narrow band of typically 50 NM along the ground frontal surface. Cross section of Ana front is fairly similar to the cross-section of a general cold front at the top-right section of this page. Ana fronts offer severe weather - strong gusty winds with sudden direction changes (=> low level windshear), squalls, heavy showers, possibly hail.

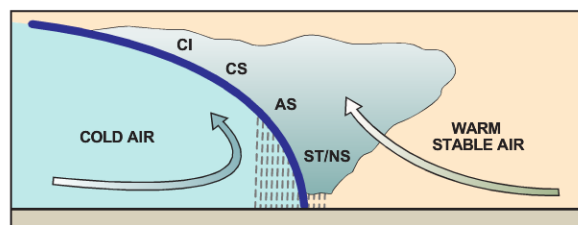
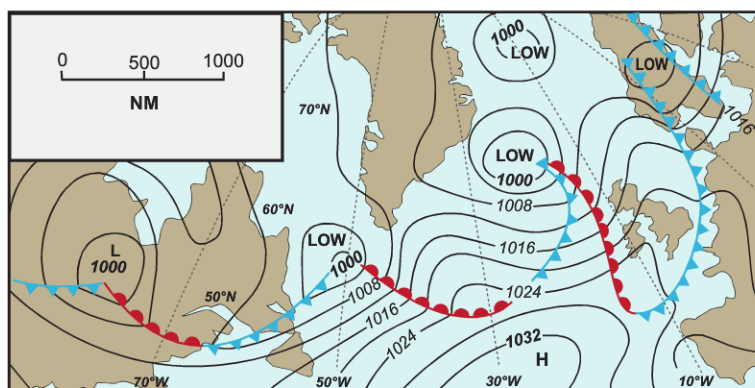


FIGURE 050-E42

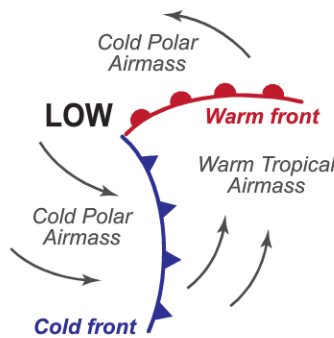
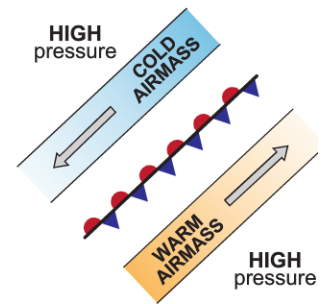
## POLAR FRONT DEPRESSIONS

In the Northern Hemisphere, there is an area between the latitudes of approx 35°N and 65°N where we can find a semi-permanent stationary front referred to as the Polar Front. We know that fronts (in very simple terms) are the "zones of contact" or "boundaries" between 2 airmasses of different characteristics (temperature, humidity, etc...). In the case of the Polar Front it represents a boundary between the cold Polar airmass and the warm Tropical airmass. Typically this front is of a quasi-stationary type, which means that there is no tendency of either airmass to move in place of the other airmass - neither of them has sufficient "strength" or dynamics of movement to replace the other one. In other words, we can also look at a stationary front as a situation when a warm front or a cold front stops moving => there is no horizontal motion perpendicular to the front (no movement across the frontal zone) => the two air masses have stopped. The winds on both sides of the stationary front blow parallel with the front.

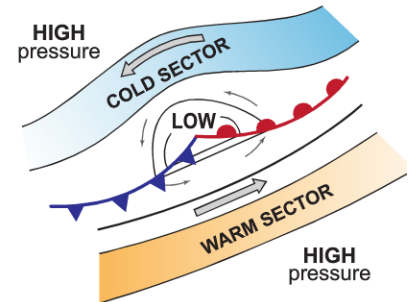




The surfaces of the two adjacent airmasses forming the stationary front are subject to disturbances - formation of short waves (ripples) along the surface. When a significant short-wave disturbance interacts with a stationary front it increases the temperature contrast between the two airmasses by pushing cold air slightly towards the Equator and the warm air slightly towards the Pole. As this happens the warm air is lifted "poleward" over the Polar Front and the cold air subsides across the front below the warm air. Cyclonic rotation is generated with the lowest surface pressure at the tip of the rotation axis. The depression (LOW) then deepens and grows in size, depending on the wave-length of the short-wave (ripple) disturbances along the frontal surface. The LOWs are initially stationary, then become slow moving and finally as the fronts fully develop the circulating winds occur.

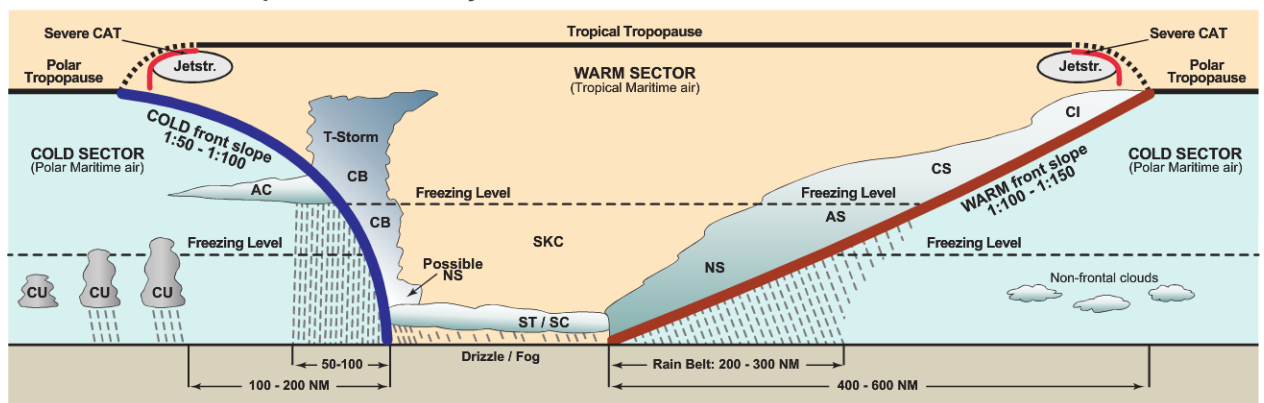


The frontal section, where the warm air has displaced the cold air becomes a warm front, whereas the section where the cold air has displaced the warm air becomes a cold front. A region between the warm front and the cold front is formed - this is referred to as the "warm sector". The area ahead of the warm front until the area "behind" the cold front is referred to as the "cold sector". As the Polar depressions (LOWs) start to move, they move in a direction that is parallel to the isobars in the warm sector. Speed of the depression movement equals to geostrophic wind speed



at the warm sector. The Polar depressions form in groups or "series" - one after another one => another depression usually form at the "tail" of the cold front of the preceding depression. Small ridges of high pressure are usually located in between the LOWs. These series of Polar LOWs (Extra-Tropical Cyclones) over the Atlantic are the source of most "bad" weather in Europe (especially Northern parts) and are also referred to as the "Westerly Waves".

#### Cross-section of a Polar depression frontal system:

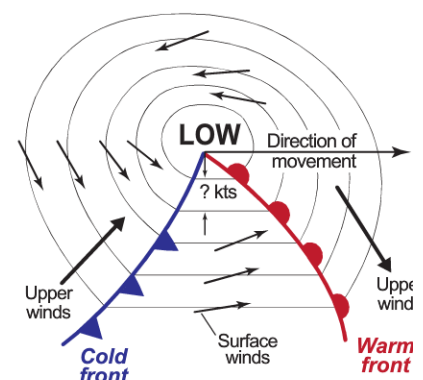


#### Winds and Direction of travel of Polar Depressions

The direction of travel of a Polar depression (at the tip of the warm sector) is parallel to the isobars of the warm sector. The speed of depression movement is equal to the geostrophic interval defined by the distance between the first and second isobar of the warm sector.

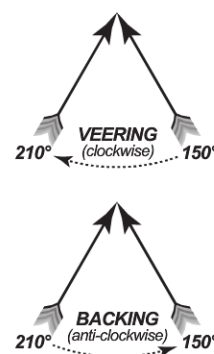
The general circulation of air around the depression is the same as for any other LOW pressure system = anti-clockwise in the Northern Hemisphere.

The surface wind in a frontal depression system has a tendency to blow parallel to the isobars, but it is affected by the friction and backs a little bit towards the lower pressure. With an increase in height (above the friction layer) the surface friction no longer effects the wind => it strengthens and tends to become geostrophic (affected by the pressure gradient force + coriolis force) = blowing parallel to the equidistant isobars at a speed proportional to the distance between the isobars. Just before the frontal passage the wind will back even more until almost parallel to the front, resulting in a somewhat sharper turning of the wind towards the lower pressure than normal. As the front passes, the wind veers (turns clockwise) at low level in the Northern Hemisphere. The sudden changes of wind direction in the vicinity of a front are likely to produce turbulence and wind shear.

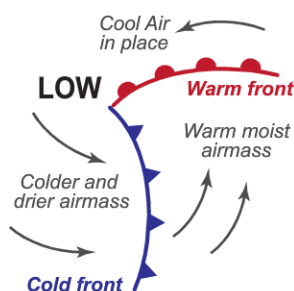


Upper winds around the fronts equal to the surface geostrophic wind + thermal wind => with increasing height the wind veers (turns clockwise) in the Northern Hemisphere. With significant thermal effects the upper winds will blow parallel to the isotherms and these are often parallel to the frontal surface.

- **Ahead of the warm front** the upper wind direction will be typically NW. Associated jetstream can typically be found near the tropopause, approximately 400 NM ahead of the warm front ground position and blowing parallel to it.
- **Above the warm sector** the upper wind direction will be almost identical to the geostrophic direction, but the wind speed will be greater.
- **Behind the cold front** the upper wind direction will be typically SW. Associated jetstream can typically be found near the tropopause, approximately 200 NM behind the cold front ground position and blowing parallel to it.

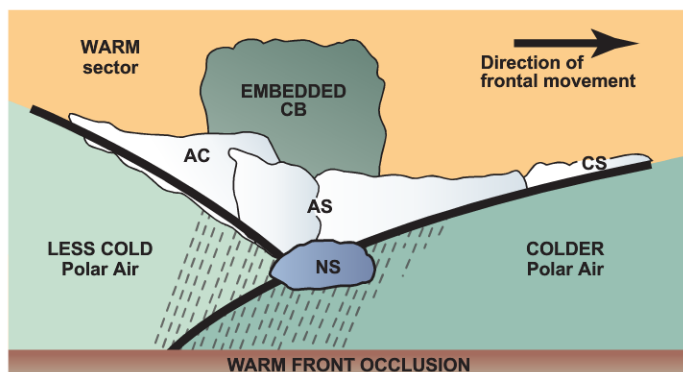
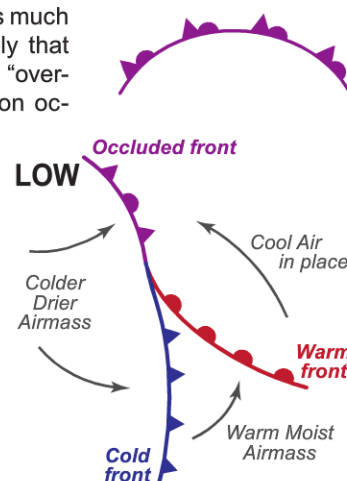


## OCCUSIONS



Cold fronts typically move at higher speeds than warm fronts (as much as twice the speeds of warm fronts). It is therefore very likely that in a frontal depression system the cold front will catch-up or "overtake" the slower moving warm front ahead. When this situation occurs, an occluded front is formed. There are now 3 adjacent air masses: 1) cold air ahead of the warm front, 2) warm air in the warm sector and 3) cold air behind the cold front. On the picture on the left we can see a warm front (cool air ahead of it and a warm moist air behind it) and a faster moving cold front (with a cold air behind it). When the cold front "catches-up" the warm front ahead of it closely enough,

an occluded front is formed (picture on the right). Occluded front is the boundary between the new cold air mass brought from the west in this picture (a cold air mass behind the cold front) and the older cool air mass already in place ahead of the warm front.

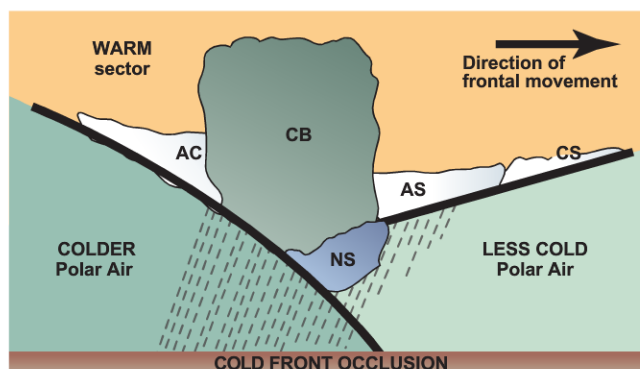


When the cold front catches up with the warm front, the whole warm air sector is lifted, and we say that the frontal system is occluded. The subsequent course of events depends on whether the advancing cold air is warmer or colder than the air ahead of the warm front. The properties of the occlusion vary from time to time and in effect combine the properties of the original fronts. The position, on the surface front, where the cold and warm air meet is called the triple point and it denotes the area with maximum frontal activity. Each occluded front must be studied carefully. Its properties depend on:

- the humidity content of the air masses
- their stability and
- how old the occlusion is.

**WARM FRONT OCCLUSION** (see cross-section on previous page) is generated when the coldest air lies ahead of the fronts => the less cold air rises over the leading colder air. In a warm front occlusion lifting of warm, moist, unstable air occurs. The occlusion shows a permanent warm front structure. 2 to 5 days have passed since the first tendency to a wave on the polar front (a thickening of the mass of clouds in an area with a weak gradient) could be seen. Most clouds form and precipitation occurs approx. 100 - 200 NM ahead of the occluded front. As the surface position of the front passes the wind veers, atmospheric pressure increases and temperature changes. In Europe, the warm occlusions occur most commonly during the winter.

**COLD FRONT OCCLUSION** is generated when the coldest air is behind the cold front => the colder air is moving in below the less cold that can be found air ahead of the warm front and thus lifting it aloft. In a cold front occlusion lifting of warm, moist, stable air occurs. Some precipitation may reach the ground even before passage of the front - however, majority of the precipitation occurs behind the frontal surface. After the passage of the frontal surface, the wind, pressure and temperature change.





**SUMMARY OF FRONTAL WEATHER:**

<b>WARM front</b>	<b>Front is approaching</b>	<b>During frontal passage</b>	<b>Behind the front</b>
<b>Winds</b>	Gradual increase in speed, slight backing, typically Southerly	Wind direction veers sharply, windspeed starts to decrease	Direction stabilizes, typically on SW values, steady windspeed
<b>Temperature</b>	Steady - typically cold, or slowly increasing	Sudden increase, then steadily rising	Steady or only minor changes
<b>Pressure</b>	Steady decrease	Lowest value - stops decreasing	Slight rise, then steady or slow fall
<b>Clouds</b>	Sky coverage gradually increasing to low OVC layer, cloud bases lowering. Sequence of clouds: CI, CS, AS, NS. Possibility of low ST clouds or fog close (20-50 NM) to frontal surface	OVC layer of NS / ST clouds, very low bases	OVC layers changing into BKN / SCT, ST / SC clouds with very low bases typically persist
<b>Precipitation</b>	Continuous light rain/snow from AS, then moderate from NS. Precipitation at surface 200-300 NM ahead of front.	Continuous moderate or heavy rain/snow mainly from NS.	Occasional drizzle, light rain/snow - from ST/SC, or no precipitation at all
<b>Visibility</b>	Relatively good, but gradually reducing to poor as the frontal surface approaches	Very poor due to heavy precipitation, mist / fog can occur frequently	Slight improvement, but remains moderate to poor due to possible haze, mist, fog or drizzle

<b>COLD front</b>	<b>Front is approaching</b>	<b>During frontal passage</b>	<b>Behind the front</b>
<b>Winds</b>	Backing, increase in speed, becoming squally	Sharp and sudden veers, strong gusts (frequently violent), possible squalls	Speeds decrease and stabilize, direction steady or slight veer to NW
<b>Temperature</b>	Steady - but falling rapidly close to the frontal ground surface	Sudden decrease	Remains steady (cold) or only minor changes
<b>Pressure</b>	Steady decrease	Lowest value - stops decreasing	Gradually and slowly increases
<b>Clouds</b>	ST / SC with low bases, increasing sky coverage in ST / SC / CB	BKN to OVC with CU / CB, possible NS just ahead of the frontal surface, low cloud bases	Rapidly lifting BKN to OVC layers, short periods of AC / AS, occasional CU / CB
<b>Precipitation</b>	Occasional drizzle, light rain/snow - from ST/SC, or no precipitation at all	Heavy showers of rain / snow, Thunderstorms, possibility of hail	Same as during frontal passage for a short period, then no precip., later occasional showers from CU / CB
<b>Visibility</b>	Moderate to poor due to possible haze, fog, mist or drizzle	Temporarily poor in precipitation, then rapid improvements to good	Very good, except in showers

<b>OCCUSION</b>	<b>Front is approaching</b>	<b>During frontal passage</b>	<b>Behind the front</b>
<b>Winds</b>	Typically South-Eastern	Variable	Typically West / North-West
<b>Temperature</b> (cold occlusion) (warm occlusion)	Cold to Cool Cold	Decreasing Increasing	Colder Milde
<b>Pressure</b>	Steady decrease	Lowest value - stops decreasing	Gradually increases
<b>Clouds</b>	CI, CS, AS, NS (in this order)	NS, sometimes TCU and CB	NS, AS or scattered CU
<b>Precipitation</b>	Anything from light to heavy	Light to heavy - continuous or showers	Light to moderate, then general clearing
<b>Visibility</b>	Poor in precipitation	Poor in precipitation	Improving

**FIGURE 050-E43****ICING**

Problems with icing can occur both on the ground and in the air. It is very important for pilots to be familiar with the meteorological conditions in which icing may occur, so that risks and safety hazards associated with the effects of icing accretion to aircraft structure can be avoided or minimized. There are 3 requirements for ice to form on aircraft structure:

- Water is present in liquid state (such as some types of clouds, rain, fog, etc...)
- The temperature of the ambient air is below freezing = below 0°C
- The airframe temperature is below freezing = below 0°C

Note that **icing does not typically occur at ambient air temperatures of -40°C and colder**, simply because at these temperatures there is typically no water present in liquid state - only ice crystals / snow = no ice accretion.

If ice does form on an aircraft structure ICAO Doc 4444 (Appendix 1 - sect.3) defines the intensity of icing qualifying terms:

**LIGHT:**

- Conditions less than moderate icing = change of heading and/or altitude not necessary.
- The ice accretion rate is such that it may become problematic if the flight in these icing condition continues for more than 1 hour. This level of icing does not represent a problem if the aircraft is equipped with suitable de-icing and/or anti-icing equipment, because its occasional activation (use) prevents the ice accretion or completely removes the existing ice accretion.

**MODERATE:** - Conditions in which change of heading and/or altitude may be considered desirable.

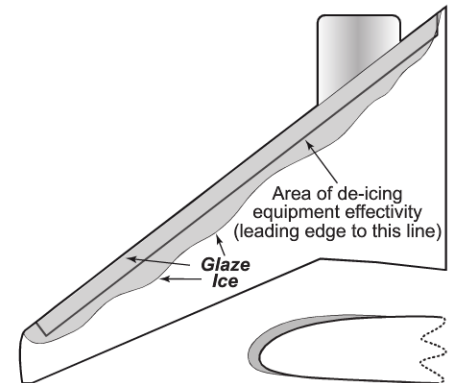
- The ice accretion rate is such that even short periods of flight in these conditions can become potentially hazardous to the safety of the flight. The use of de-icing and/or anti-icing equipment is necessary to remove or prevent ice accretion. Diversion may be necessary.

**SEVERE:**

- Conditions in which immediate change of heading and/or altitude is considered essential.
- The ice accretion rate is so high that the use of de-icing and/or anti-icing equipment is not capable of effective removal or prevention of the ice formation on the airframe structure => aircraft control hazard is imminent and immediate diversion is necessary.

The most typical types of ice accretion are:

- **GLAZE (CLEAR) ICE:** a smooth, clear, transparent and homogenous coating of ice that occurs mainly in Freezing Rain (FZRA) or in clouds containing large water droplets as a result of these **LARGE** super-cooled water droplets coming into contact with the aircraft surface (as opposed to small super-cooled water droplets that result in the "rime" ice type formation - e.g. Freezing Drizzle). When a large super-cooled water droplet hits an aircraft surface, only a fraction of the droplet freezes immediately on impact (only approx. 1/80 of the droplet for every 1°C below freezing temperature) => during this freezing process latent heat is released which delays the freezing of the remaining liquid part of the droplet and makes it easier for it to flow back over the surface and gradually / slowly freeze further away from the initial impact point. As a result, a hard layer of transparent ice layer is formed that spreads from the point of impact to areas further away on the structure. As more large super-cooled droplets impact the structure the glaze ice layer gets progressively thicker and heavier.



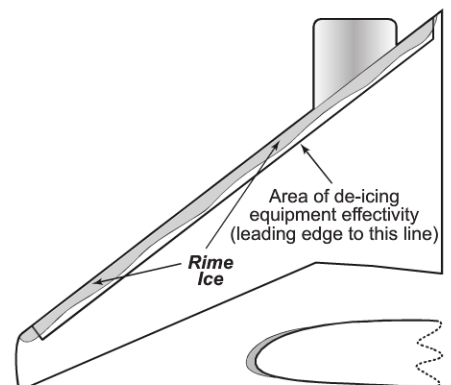
Due to its very clear transparency it may be difficult to visually detect and it may be very difficult to remove after a period of time. It will typically form as an uneven buildup - at some airfoil sections the unfrozen parts will be allowed to flow back further away from the initial impact point, while at other sections the flowback will not be so pronounced. As a result of this uneven buildup, additional aircraft control problems may be experienced as the deterioration of lift and the increase in drag over the airfoil surfaces may be asymmetrical. The increase in mass is quite significant in case of glaze ice as it creates thick layers of ice that are spreading over larger area of the airfoil - additional risks involve the possibility of CG change as a result of this.

Due to the fact that large super-cooled water droplets are allowed to flow back further away from the leading edge (point of impact) it may be difficult to remove this type of ice if its accretion spreads beyond the area protected by the deicing equipment of the aircraft. It is usually classified as **moderate to severe** icing category, making it probably the most dangerous type of airframe icing that can be encountered. It forms most frequently in NS, CU and CB clouds.

*Note: This type of ice is transparent because there is no air trapped between the ice layer and the aircraft surface.*

- **RIME ICE:** a white opaque coating of ice with a slight granular or powdery texture (not as smooth and homogenous layer as glaze ice). Rime ice occurs mainly in Freezing Drizzle (FZDZ), Freezing Fog (FZFG) conditions or in clouds consisting of small water droplets. It is formed as a result of **SMALL** super-cooled water droplets or small water droplets inside the clouds coming into contact with the aircraft surface (as opposed to large super-cooled water droplets that result primarily in the "glaze/clear" ice type formation). When a small super-cooled water droplet hits an aircraft surface it freezes immediately on impact - at the point of impact - becoming completely solid immediately.

This ice accretion type derives its opacity from the fact that pockets of air are trapped in between the individual frozen droplets. It forms primarily only along the leading edges of the airfoils (or leading / windward edges of any other airframe structures) as there is no flowback as in the case of glaze ice because the droplet freezes instantly upon impact. It is compacted by the airflow around the airfoil. Due to its white and opaque appearance it is easy to visually detect and it can typically be easily removed using the de-icing equipment as it is quite brittle, therefore typically falls into the **light to moderate** icing category. It can occur in clouds where small super-cooled water droplets are present - ST, SC, AS, AC and the tops of NS. As mentioned above, also likely to form in Freezing Drizzle (FZDZ) or Freezing Fog (FZFG).

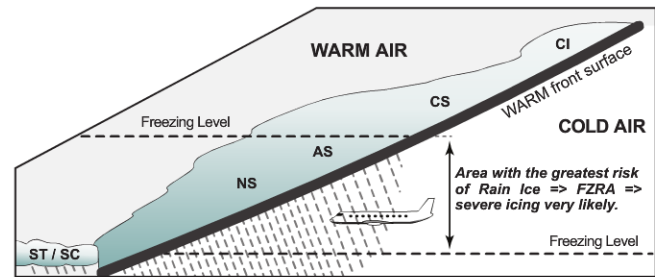


- **MIXED ICE:** is type of ice accretion that forms as a result of both **LARGE** and **SMALL** super-cooled water droplets coming into contact with the aircraft surface - it is basically a combination of **GLAZE** and **RIME** ice. In appearance it is not as clear and transparent as the **GLAZE** ice and not as white as the **RIME** ice - instead it is rather a cloudy or dark milky looking layer. It forms in clouds that **1)** contain both small and large super-cooled water droplets, **2)** contain both strong and weak up- and down-draughts, **3)** temperature is in between the temperatures conducive to formation of either glaze or rime ice.

- CU / CB clouds (or orographic NS) at temps between -17°C and -23°C,
- NS clouds at temps between -7°C and -13°C.



- **RAIN ICE:** is basically the same form of ice as the GLAZE ice. Rain ice occurs as a result of an aircraft flying through an area of Freezing Rain (FZRA) = rain containing large super-cooled water droplets. Most frequently this condition is associated with inversions, warm fronts or occlusions and a continuous moderate rain (typically NS clouds) => situations when the rain is initially falling from warmer areas (where temperatures are above 0°C) and then through a layer of air with temperatures below 0°C => water droplets become super-cooled.



Rain ice is typically the most dangerous type of icing (classified as severe), as it builds-up on the airframe structure very quickly, has a large degree of flowback and the ice buildup becomes very heavy. Because it is quite difficult to remove using the aircraft's de-icing equipment, typically the best action is to turn around. Rain ice is quite frequent in winter in Central Europe and North America.

- **HOAR FROST:** is a very thin white crystal-like deposit (appears similar to frost on the ground) that can form over the entire surface of the aircraft in a **clear air**. It will form when the temperature of the airframe structure is below 0°C and the aircraft flies through an area of warmer moist air - for example after a prolonged flight at high altitude the aircraft then descends rapidly (so that airframe does not have "time" to warm up) to altitudes where a warm moist air is present. When the water vapour contained in the warm air comes into contact with the cold airframe it is converted directly into tiny ice crystals without ever becoming liquid. Hoar frost can also occur when an aircraft departs from an airport where sub-freezing temperatures exist and enters an area of warmer moist air during the climbout - during a temperature inversion. This icing type is usually not severe as it can be very easily removed by flying through an area of warmer air (above 0°C) or by increasing the speed sufficiently for kinetic heating of the airframe structure to occur.

Factors affecting the severity and the type of icing that occurs:

- **Size of the super-cooled water droplet:**

- |                              |   |
|------------------------------|---|
| LARGE super-cooled droplets: | <ul style="list-style-type: none"> <li>• Freezing Rain (FZRA)</li> <li>• CU and CB mainly at temperatures of 0°C to -20°C</li> <li>• NS mainly at temperatures of 0°C to -10°C (to -20°C if NS formed orographically)</li> </ul>  |
| SMALL super-cooled droplets: | <ul style="list-style-type: none"> <li>• Freezing Drizzle (FZDZ) or Freezing Fog (FZFG)</li> <li>• tops of NS mainly at temperatures of -10°C to -40°C</li> <li>• tops of developed CU / CB mainly at temperatures of -20°C to -40°C</li> <li>• stratiform clouds: ST / SC / AS mainly at temperatures of 0°C to -15°C (but light icing can occur up to -30°C)</li> </ul> |

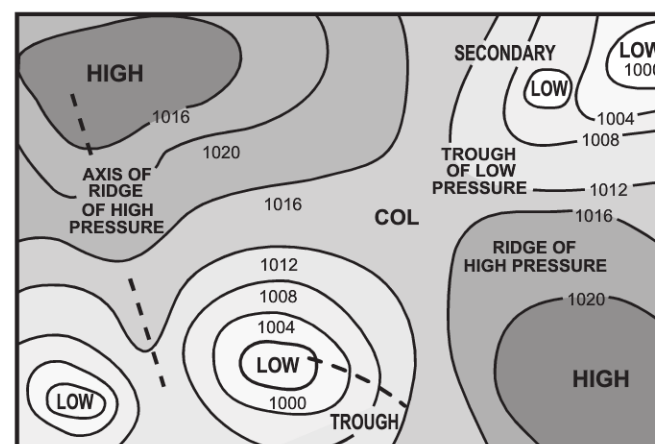
- **Concentration of water droplets:** the higher the concentration of super-cooled water droplets, the greater the intensity of icing. Concentrations of water droplets is highest in convective clouds due to the up- and down-draughts => CU / CI clouds typically produce severe icing. Bases of the clouds typically have greater concentrations than tops of the clouds.
- **Shape of the airfoil / object:** ice tends to form especially on objects with sharp edges at the leading edges (windward sides) - such as antennas. The ice will also have a higher accretion rate on airfoils that are thin (sharp profiles) than on airfoils that are rather thick (high drag - thick profile).
- **Aircraft speed:** ice tends to form at a greater accretion rate on faster flying aircraft than on slower flying aircraft (faster aircraft "hits" more water droplets in a given period of time than slower aircraft). However, as we get into jet speeds, this is no longer true because of the kinetic heating => higher Mach number = higher airframe temp.

## FIGURE 050-E44

### PRESSURE SYSTEMS

Temperature contrasts along the surface of the Earth cause variations in density as a result of which pressure differences arise. The air pressure may therefore vary quite considerably between different places on Earth. These pressure differences are of decisive importance to the Earth's weather and winds. As part of the regular recording of the atmospheric conditions, the meteorological service measures the air pressure at a number of places - charts depicting the pressure distribution in relation to geographical regions are then prepared by the meteorological services. On these charts we can find the pressure pattern, delineated by the isobars.

To clearly show the pressure differences, lines are drawn (isobars) on the weather chart between places with the same air pressure, QFF, usually with a 2 hPa spacing. The isobar indicates how a pressure surface intersects ground level. A pressure surface is thus a level in the atmosphere along which the air pressure is always constant, also known as an isobaric surface. Remember that QFF is the pressure recorded at station level reduced to Mean Sea Level (MSL) using the actual conditions that prevail - it is NOT an altimeter setting.



When the isobars are depicted on synoptic charts, they form certain patterns (as illustrated in the sample picture above). From these patterns we can determine valuable information, including the pressure distribution - in this case we talk about "pressure distribution systems" and these include:

- **Low pressure areas** (also referred to as "Depressions, Lows or Cyclones")
- **High pressure areas** (also referred to as "Anticyclones")
- **Troughs** of low pressure
- **Ridges** of high pressure (sometimes referred to as "wedges")
- **Cols** (sometimes referred to as the "saddles")

### LOWs / Depressions / Cyclones

LOWs are areas on the chart having lower air pressure than the surroundings - they are also referred to as the CYCLONES or DEPRESSIONS. The low pressure centre is of varying size but is always surrounded by higher pressure. Occasionally several different centres within a larger area of low pressure occur, so-called "secondary lows". In a LOW the isobars are normally closely spaced (large gradient), resulting in windy weather except in the centre of the LOW where the wind is calm. The air is sucked in at low level (**convergence**) and is then forced aloft and cools adiabatically (LOWs are regions of converging and rising air). If the air is initially humid, this general lifting leads to condensation and formation of clouds. In terms of terminology: when the pressure in the centre of the LOW reduces, we say that the LOW is "intensifying" (or deepening). When the pressure in the center of the LOW rises, we say that the LOW is "filling" (or weakening). There are 2 basic types of LOWs:

- **Dynamic = cold LOW** (the low is deepening at altitude and the winds are increasing)
- **Thermal = warm LOW** (the low is weakening aloft and turns into a high pressure)

Rotation of air (winds) around a LOW is:

- Northern Hemisphere = inward and anti-clockwise,
- Southern Hemisphere = inward and clockwise.

Above the boundary layer, the wind follows a circuit parallel to the isobars. Friction acts as a brake on the wind in the boundary layer, and the wind blows at an angle towards the low pressure centre. The result is a general lifting of the air within the low pressure area, therefore in general strengthening of convective movements, frequently leading to formation of CB clouds (if the air is or becomes unstable). However, even if the air is stable, clouds will form if the air is humid enough, and in this case there will be extensive stratiform cloud layers. Visibility at low level is generally better than in a HIGH, due to a stronger mixing of the air. Typical weather in the vicinity of a LOW is increased cloudiness, increased winds, upward motion in the atmosphere which leads to an increased chance of precipitation. Summary of typical weather for a LOW:

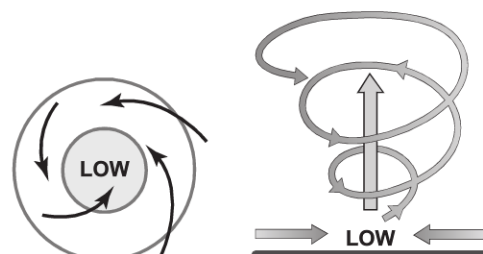
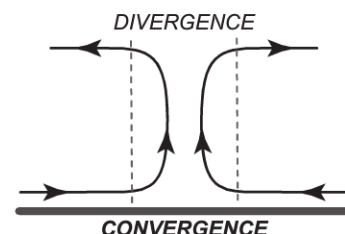
- **Clouds:** overcast with a low base extending to tropopause,
- **Temperatures:** mild,
- **Visibility:** poor in precipitation, otherwise good due to the ascending air,
- **Winds:** typically strong - the deeper the LOW and the closer the isobars, the stronger the wind,
- **Precipitation:** can be continuous - light to moderate, but also heavy showers and thunderstorms.

### TROUGHS of low pressure

TROUGH is an elongated region of relatively low atmospheric pressure, often associated with fronts. It is an area indicated by isobars that extend outwards from an area of low pressure (typically forming a "V" shaped pattern). We can look at a trough as an atmospheric "pressure valley" - the air on the rear side of the trough will not rise as fast as the air descends on the front side of the trough. The pressure in the trough is lower than the pressure on either side of the trough. If a trough forms in the mid-latitudes, a temperature difference between two sides of the trough usually exists in the form of a weather front. A weather front is usually less convective than a trough in the tropics or subtropics. The winds will converge in a trough and much of the air will ascent.

A specific type of a TROUGH is an Orographic (or "lee-side") trough: when a current of air flows towards a mountain range, especially one with north-south orientation, the barrier will force the air to compress on the windward side and over the mountain and the air will thereafter stretch on the leeward side of the mountain. From the air circulation point of view, there will be a tendency for anti-cyclonic curvature over the mountain with closely spaced pressure surfaces, and on the lee-side there will be a clearly visible cyclonic curvature. This leads to falling air pressure, and a TROUGH of low pressure forms on the leeward side of the mountain ("lee-trough"). It is usually a stationary TROUGH as long as the air stream remains the same and no deepening low forms. Summary of typical weather for a TROUGH:

- **Clouds:** for a non-frontal trough mostly CU and CB clouds with a great vertical development. For a frontal trough the cloud type depends on the front - if cold air is displacing warm air (cold front) then mostly CU and CB clouds with great vertical development will form, while if warm air is displacing cold air (warm front) the clouds will have a much lower vertical development.
- **Precipitation:** for a non-frontal trough or a cold front trough typically showers, thunderstorms, occasionally hail. For a warm-front trough typically continuous drizzle or light to moderate rain.
- **Visibility:** relatively good, except for showers. For a warm-front trough visibility poor due to continuous rain,
- **Winds:** moderate, with possibility of gusts and squalls.





## HIGHs / Anti-Cyclones

A high pressure system (HIGH) is an area having a higher air pressure than the surroundings - it is also referred to as the ANT CYCLONE. It is an area enclosed by almost circular isobars with a relatively wider spacing than a LOW - the value of the isobar around a HIGH decreases with distance from the centre = area in the center has the highest pressure. The wider spacing (isobars) (weak gradient) results in relatively light winds, but in areas where a HIGH is located close to a LOW the pressure gradient can become steep and moderate to strong winds can be experienced.

When we look at the vertical airflow in a HIGH, we see mass convergence at high levels and **divergence** at low levels, creating a descending air movement (referred to as "**subsidence**") within the core of the HIGH with an outflow away from the center at low level (HIGHs are regions of diverging and descending air). As mentioned above, a subsidence (sinking motion of air) is present in the core of a HIGH - as a result, the air gets compressed and adiabatically heated. Together with thermal mixing in the surface layer the result can be seen as a **subsidence inversion**, within which the temperature rises significantly and the humidity decreases. The height of the subsidence inversion depends on the intensity of the HIGH, the thermal mixing and on the distance from the core. Values from 2000 to 5000 ft are not unusual for cold HIGHs while warm HIGHs can show values up to FL100. The air above the inversion is dry, while the air below may or may not be humid depending on the circumstances that prevail. Rotation of air (winds) around a HIGH is:

- Northern Hemisphere = outward from center and clockwise,
- Southern Hemisphere = outward from center and anti-clockwise.

Above the boundary layer, the wind blows parallel to the isobars. In the boundary layer, friction slows the wind down and it will blow at an angle out from the centre. In terms of terminology: when the pressure in the centre of the HIGH reduces, we say that the HIGH is "weakening" (or collapsing).

When the pressure in the center of the HIGH rises, we say that the HIGH is "building-up". There are 2 main types of HIGHs depending on whether they consist of warm or cold air (we assume, that the distribution of temperature is symmetric around the centre):

- **Subtropical highs (warm anticyclones):** these HIGHs are caused by air from the Equatorial regions streaming northwards (southwards in S.Hem.) at altitudes around the Equatorial tropopause. They are deflected to the right (left in S.Hem.), which generates the subtropical jet and an accumulation of air around the 30° latitude north (south). At low level the air pressure increases and there is a return flow out from the system. Within the subtropical high there is subsidence from aloft and the centers consist of warm air. The subsidence inversion in these cells is sometimes called Trade inversion.

These HIGHs are often stationary or very slow moving (more or less a seasonal movement) and are therefore referred to as permanent highs. Towards the Polar side of the centre itself, the high pressure is clearly visible on the 500 hPa charts (FL 180) in the summer. In the winter, however, the high may be difficult to identify above 700 hPa (FL 100) at the same latitude.

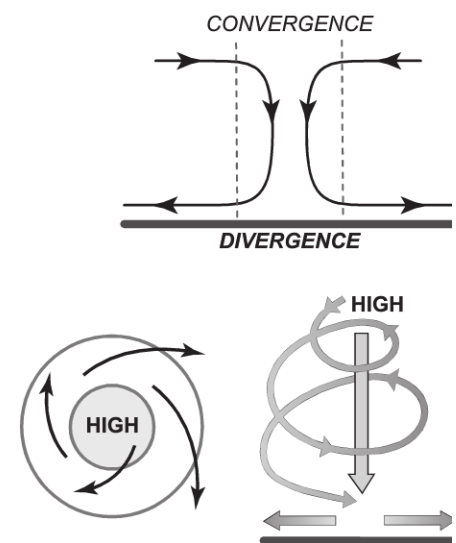
Europe's nearest subtropical anticyclone is the Azores High, which consists of, and is the source region of maritime tropical air. The air below the subsidence inversion is humid and unstable, above it is dry and stable. The height of the inversion varies within the high pressure cell. The highest values are found in the western parts nearest the Equator (5000 - 7000 ft) and the lowest in the north-eastern part (1500 - 2000 ft). This is the reason why Tropical showers are more likely to develop in the western part of an ocean than in the eastern. On its way to the north the low-level air normally picks up large amounts of humidity. At the same time, as the sea temperature decreases, the air is cooled from below and, in the winter, this frequently leads to vast areas of low clouds, drizzle and fog when the air reaches NW Europe.

In the summer the anticyclone occasionally is intensified over the North Atlantic. This causes lows and their associated rain areas to move in a wide arc north of Scandinavia, forming a blockage ("a blocking high") with dry and sunny weather over western Europe.

- **Continental highs (cold anticyclones):** These consist of polar air and form over the cold continents in the winter. At low level they consist of chilled air and seldom reach higher than 700 hPa (FL 100), but their horizontal extension may be considerable. The thermal highs are not as stable as the dynamic ones, and travelling depressions may temporarily break them down. The Siberian and the Canadian highs consist of, and are the source regions of continental polar air. In midwinter they also constitute the source region of arctic air from within the arctic and Antarctic permanent cold anticyclones.

If the pressure system spreads over a coastal area, e.g. along the coasts of the North Sea or the Baltic in the winter before any appreciable icing has started, there will be convection and snow showers over the open water surface and mostly fog and mist below the inversion inland. If the air is dry and there is no advection from open water, weather can be cold, bright and cloudless. In clear and extremely cold areas, ice and fog may form.

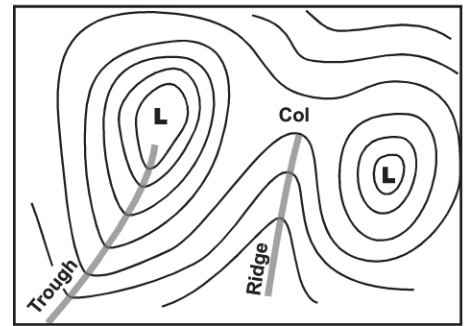
Another category of a HIGH is a so-called "**Blocking-HIGH**". These are warm anticyclones, frequently an extension of a high pressure area originating in the subtropical regions. Blocking anticyclones may divert or hold-up the typical East <=> West passage of the polar front lows. They typically form in the North Atlantic regions (between 30°N and 60°N) around 10°W to 20°W and may persist for several days. Air is subsiding in these systems from high levels => extensive layers of Stratus / Strato-Cumulus clouds with very little vertical extent form.





Typical weather in the vicinity of a HIGH is clear skies due to the sinking motion of air, lighter winds than in a LOW, overall reduced chance of precipitation. Normally a greater range between minimum and maximum temperatures due to the presence of a drier air. Summary of typical weather for a HIGH:

- **Precipitation:** none,
- **Winds:** light.
- **Temperatures:** vary with the type of a HIGH,
- **Clouds:** none, except typically some on the edge of a HIGH,
- **Visibility:** poorer than when compared to visibility in a LOW, but generally good, except for a typical early morning fog/haze during the winter and the possibility of haze during the summer.



Sample pressure distribution chart

### RIDGEs of High Pressure

An elongated region of relatively high atmospheric pressure (opposite of a trough) is referred to as a RIDGE or a WEDGE. It is a high pressure area forming between two LOWs of a family of depressions. Ridges can be identified on the charts by isobars that extend outwards from an area of high pressure and always form rounded pattern ("U" shaped) - never a "V" shaped pattern that we can typically see for a Trough of low pressure. The pressure falls either side of the RIDGE axis

The high pressure ridges follow the LOWs in their movements and constitute a break in the storms associated with the frontal systems of the LOWs. Weather conditions in a RIDGE are generally similar to those of a HIGH pressure (anti-cyclonic) areas => they typically represent a brief period of good weather in between two depressions.

### COLs

A neutral area (almost level pressure) between two HIGHS and two LOWS is referred to as a COL - it is an area of stagnation. Col weather depends on the pressure changes - in the winter cols typically offer poor visibility conditions with fog, while during the summer cols typically offer thunderstorms.

## FIGURE 050-E45

### ADIABATIC PROCESSES

The term "adiabatic process" refers to the process of energy conversion in a volume of air without exchange of heat with the surroundings. We know that when a volume of a parcel of air changes the temperature changes. If the parcel of air is compressed, its temperature increases. If it is allowed to expand, its temperature decreases. This change of volume is most frequently caused by lifting the parcel of air or its subsidence:

As a parcel of air "sitting" over a warm ground surface is gradually heated after a while it becomes lighter than the surrounding air. As soon as this light bubble of air, the thermal, starts to ascend, we can disregard the heat exchange with the environment, since the air largely functions as an insulator, and the influence from the surroundings becomes marginal. We now have a parcel of air of higher temperature (lower density) than the surroundings, which has begun to ascend in the atmosphere. We know that as altitude increase, the air pressure decreases. When the air pressure of the surrounding air decreases, an excess pressure is created inside the "warmer bubble", which is equalised by the increase of its volume - its expansion. As we mentioned above, an expansion leads to a decrease in temperature inside the "bubble" => gradually the temperatures equalize and the "bubble" stops to ascend at that point.

The opposite occurs in subsiding air motions. As a parcel of air becomes colder than its surroundings, it becomes denser and starts to sink. As it sinks the pressure of the surrounding air becomes greater and the parcel of air is compressed => its temperature increases.

The decrease or increase of temperature with altitude is termed "lapse rate". We distinguish 3 types of lapse rate:

**Dry Adiabatic Lapse Rate (DALR):** provided the parcel of air is not saturated (it is dry), the lapse rate will be 3°C per 1000 ft (1°C per 100 m), independent of temperature or pressure of the surrounding air.

**Saturated Adiabatic Lapse Rate (SALR):** when saturated (humid) air is lifted or subsides the lapse rate is affected by condensation or evaporation processes. When water vapour condenses into water droplets due to the cooling of the air parcel, latent heat is released. This release of latent heat will warm the air, and the lapse rate will be lower than that of dry air. The opposite is true about evaporation, which occurs when saturated air is heated = the increase of temperature will be less than that of dry air because some of the compression heat will be used in the evaporation process (latent heat is absorbed). The saturated adiabatic rate varies depending on the actual amount of water vapor in the air that evaporates / condenses. The average value is about 1.8°C per 1000 ft at the surface and temperature +15°C, with the SALR value approaching that of the DALR at low temperatures (little humidity).

**Environmental Lapse Rate (ELR):** the actual rate of change of the air temperature with altitude in the atmosphere. ELR varies throughout the atmosphere, but its average value is 2 °C per 1000 ft (0.65 °C per 100 m).

Stability of the atmosphere can be defined using the relationship of ELR, DALR and SALR:

**Stable atmosphere:** when the wind causes a parcel of air to be lifted along the side of a mountain - if the parcel of air returns back to its original position when this lifting force is removed, the atmosphere is considered to be stable. In this case the parcel of air will always be colder than its surrounding air at every level and therefore more dense - it will have a tendency to sink back to its original position. **ELR < SALR < DALR**

**Unstable atmosphere:** if we look at the same situation as above - parcel of air is lifted by wind along the side of a mountain. If the parcel of air continues to rise even if the initial lifting force (wind) is removed, the atmosphere is considered to be unstable. In this case the parcel of air will always be warmer than its surrounding air and therefore less dense - it will have a tendency to continue rising. **SALR < DALR < ELR**

**Conditionally unstable atmosphere:** the same situation as above again - a parcel of air is lifted by wind along the side

of a mountain. Upon removal of this lifting force, if the parcel of air either continues to rise if saturated (moist - Relative Humidity 100%) or return to its original position if unsaturated (dry), we refer to this situation as “conditionally unstable atmosphere. In this case the stability of the atmosphere depends not only on the ELR as was the case with stable and unstable atmosphere, but also on the moisture content of the air.  $SALR < ELR < DALR$

**In summary we can say that:**

- **Absolute stability** = ELR is less than 1.8°C per 1000 ft. Typical weather is low visibility, light or no turbulence, stratiform cloud and rather continuous (or intermittent) precipitation. Clouds are typically of large horizontal extent with very little vertical extent frequently layered clouds.
- **Absolute instability** = ELR is greater than 3°C per 1000 ft. Typical weather is good visibility, moderate turbulence, cumulonimbus clouds and rather a showery precipitation. Clouds are typically of a small horizontal extent but with a large vertical extent.
- **Conditional instability** = ELR is between 1.8°C and 3°C per 1000 ft.

## FIGURE 050-E46

### CLEAR AIR TURBULENCE (CAT)

Clear Air Turbulence or CAT can be defined in the following way:

**“Turbulence that occurs in the free atmosphere away from visible convective activity. CAT includes high level frontal and jet stream turbulence and strong vertical wind shear.”**

The free atmosphere in this case means layers higher than 15 000 ft above ground level. CAT is associated with:

- Jetstreams,
- Tropopause,
- Long waves (Rossby waves),
- Mountain waves,
- Convective clouds outside the cloud itself at mid- or high levels.

General info concerning CAT:

- CAT occurs more frequently in winter than in summer,
- most common in the mid troposphere up to the lower stratosphere and decreases rapidly above FL450,
- mountain ranges affect the airflow and CAT occurrences are more frequent to the leeward of mountains,
- CAT doesn't occur randomly, there is always a connection with the flow patterns and the stability of the air,
- CAT usually occurs in thin layers stretched 50 miles or so downwind. On average they are about 2000 feet in depth and their lateral extension is about 10 to 40 miles. Severe turbulence in the upper troposphere is usually of larger dimensions than other turbulence, and turbulence in the stratosphere has the smallest dimensions.

### CAT associated with jetstreams

The wind distribution around the jetstream core is such that the wind shift is very rapid along the cyclonic or “cold” side of the jet. The rapid wind shift combined with a stable layer creates small waves, typical wavelength is from about a few hundred feet to a mile or so, inside the stable layer. These waves are referred to as “shearing gravity waves” since gravity seems to pull back vertically displaced air to its original position. In the case of strong winds (e.g. jetstreams) combined with strong vertical shear (> 5 kt / 1000 ft), the waves might suddenly amplify and finally overturn like the sea waves.

Small-scale waves are felt like light turbulence or different intensities of “chop”.

Overturning gravity waves are violent phenomena creating significant intensities of CAT. Most severe CAT should be expected where the shear is greatest.

CAT is typically found along the jetstreams in “sheets” 500 - 3000 ft thick, extending 10 - 50 NM along the jet. In the vertical plane the CAT can be stratified in several layers. The strongest wind shear associated with jetstreams (and therefore CAT of greatest intensity) is found on the “cold air” side - approximately at the cold air tropopause level (below the warm air tropopause level). Another area of strong shear is situated at the border of the upper level front. Both of these areas are indicated by the red arrow in the illustration on the right. Notice that these areas are defined by close spacing of the isotachs (lines of the same wind speed). Remember that when moving in to and out from a jetstream core the highest probable CAT areas are to be found around the sloping tropopause above the jet core, and along the sloping front towards the “cold side” just below the jet stream.

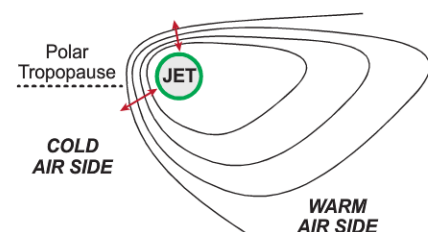
All jetstreams are not associated with severe CAT. However, an intensive CAT can be expected in areas where the normal wind shear associated with jetstream is intensified - e.g. by converging or diverging airflow (2 jetstreams approach each other) in areas where the jetstream curves sharply or in areas of deep LOW pressure (trough) at the ground surface. Severe CAT is most likely when:

- Wind in the jet core >110 kts,
- Vertical shear > 5 kts / 1000 ft,
- Horizontal shear > 45 kts / 150 NM.

### CAT associated with the tropopause

The tropopause is the boundary between the troposphere and the overlying stratosphere. It is visualised as a stable layer where the environmental lapse rate is measured. The Tropopause varies in height in the vicinity of long waves, rises to higher level in the ridges and falls to lower levels in the troughs.

When there is a vertical shear in the tropopause CAT occurs. The CAT is rather light here, except when associated with jet cores below the tropopause level. However, flying close to the tropopause + / - 1000 ft should still be avoided in order to reduce stress on the aircraft and for the sake of the comfort of the passengers. In the case of high wind speed at the tropopause level





then avoid prolonged flights + / - 5000 ft from the tropopause level.

### CAT associated with the mountain waves

Lee-waves behind mountain ranges can also generate CAT. Remember that the combination of mountain waves and simultaneous jet stream may cause incredibly severe CAT, especially in the tropopause level. Airflow disturbances caused by high mountains can reach 5000 ft above the tropopause, and upwards of 100 NM beyond the mountain.

## FIGURE 050-E47

### GENERAL CIRCULATION AND CLIMATIC ZONES

The term "climate" is used to describe a characteristic weather for a specific geographical location - it includes elements such as temperature, precipitation, wind direction and velocity, humidity and sunshine. Climate of a specific location is affected for example by the latitude of the location, location type (land / sea), circulation of pressure systems and the general circulation of air.

#### Circulation of air

The general circulation of air is a very complex "system", based on the fact that air flows from high pressure areas towards low pressure areas. It is however not this simple - the circulation of air is affected by the unequal heating of the surface (land / sea / latitude / season), rotation of the Earth (coriolis force) and the 23.5° inclination of the Earth's axis that causes the movement of the Thermal Equator.

If we ignore the above mentioned elements that affect the circulation and assume a perfectly round Earth with uniform surface type (sea) where the temperature varies only with the latitude, we would come-up with the following general circulation model - an "idealised one":

The Equator receives more insolation than the poles, therefore the temperature is higher. Higher temperature means that the air at the surface expands and rises => causing a high pressure at high altitudes and thus a low pressure at the surface which "draws" the air in. As a result the air would blow at high altitudes from the Equator towards the poles. At the poles the low temperatures result in high pressure at the surface and subsidence of air from higher altitudes, creating a low pressure at high altitudes. Again, this would result in the wind blowing from the poles towards the Equator at the surface.

In reality, however, the ideal conditions do not exist. First of all we have the **rotation of the Earth** => Coriolis force => airflow is deflected to the right in the Northern hemisph. and to the left in the Southern hemisph. As the airflow at high levels (blowing from the Equator towards the poles) reaches a latitude of approx. 30°N or 30°S it gets deflected by the Coriolis force, in both cases towards the East. The air now blows parallel to the Equator and gets cooled => as a result it subsides to the surface, resulting in a high pressure area forming at the surface. These high pressure areas are known as the "Sub-Tropical Highs". These high pressure systems result in an outflow of air at lower levels towards both the Equator and towards the poles. In addition to this airflow we already have a general airflow at lower levels from the poles towards the Equator => therefore there will be a moment where the airflow at lower levels will "meet" => this will occur in temperate latitudes (50° - 60°) and the result of this airflow convergence will be rising of air and formation of low pressure areas at the surface. At high altitudes airflow will diverge towards both the Equator and the poles. The final result, a general circulation model, will show 3 distinctive circulation cells:

1) Hadley cell, 2) Ferrel cell and the 3) Polar cell.

Another factor affecting the circulation is the **23.5° tilt of the Earth's axis**. It is causing the Equatorial Low pressure belt to travel towards the tropic of Cancer during the Northern hemisphere summer and towards the tropic of Capricorn during the Southern hemisphere summer.

#### Prevailing surface winds

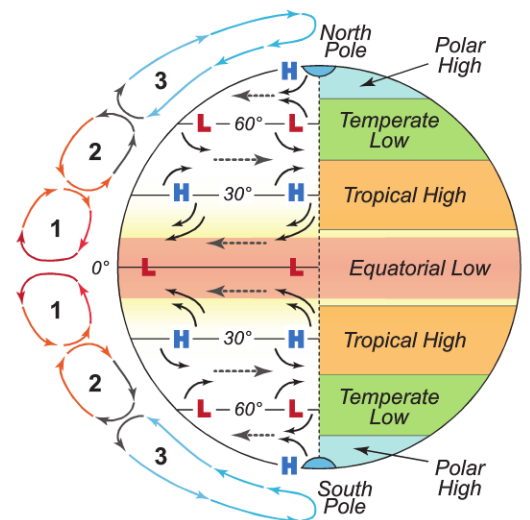
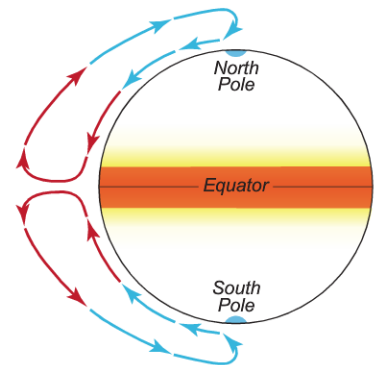
- **Polar easterlies:** the chilled air from the anticyclones around the North poles moves south at low level and is then deflected to the right by Coriolis force => cold North-Easterly winds (usually found between 80° - 60° N). In the Southern hemisphere the winds will be South-Easterly.
- **Westerlies:** the subtropical high pressure areas are causing the air to move towards the pole in mid-latitudes - again due to Coriolis force the wind is deflected to the right in the Northern hemisphere (to the left in the Southern hemisph.) resulting in westerly winds between 40° - 60° latitude. These winds can be quite strong, especially in the Southern hemisphere where they are referred to as the "Roaring Forties".
- **Trade winds:** the circulation around the high pressure areas in the Subtropical High pressure belt (around 30° lat.) is causing the air to flow towards the Equatorial low pressure areas (Equatorial trough). This motion is known as the Trade Wind. Their direction is North-Easterly in the Northern hemisphere and South-Easterly in the Southern hemisphere.

#### Climatic Zones

The world can be divided into several "climatic zones" based on the latitude:

- **0° - 10° => Equatorial climate:**

Tropical areas with high temperatures and high humidity. Very frequent thunderstorms, CB clouds and heavy rain





showers. Light surface winds (Doldrums). Strong sea breezes on the coast. Two rainy seasons (September and March)

• **10° - 20° => Savannah / Tropical Transition climate:**

Wet and dry seasons - dry trade wind conditions prevail in the winter and equatorial rainy conditions prevail during the summer.

• **20° - 35° => Steppe / Arid Sub-tropical climate:**

Under the influence of the sub-tropical high pressure belt. Typical prevailing weather conditions are a warm and dry descending air, cloudless skies. Large diurnal temperature changes during the summer. Short wet season (north and south of the deserts) at the low latitude during the summer (due to ITCZ) and at the high latitude during the winter. Most of the world deserts are located in this zone. This zone includes part of the "Trade wind belt" => consistent direction Trade winds. Upper winds are the westerly sub-tropical jetstreams.

• **35° - 40° => Mediterranean / Warm Temperate climate:**

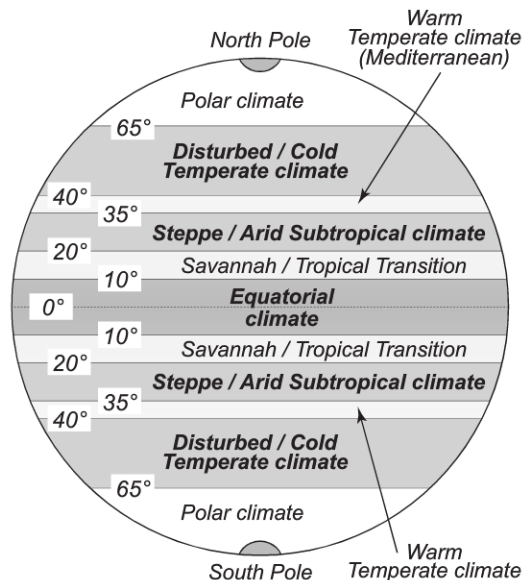
Typical weather conditions during the winter are similar to the Disturbed Temperate climate = frontal and thermal depressions, cloudy with frequent precipitation, windy and cool conditions. During the summer (as the Thermal Equator moves slightly towards the pole) dry sub-tropical climate prevails (anti-cyclonic in nature) = hot and dry air, cloudless skies, land and sea breezes on the coasts. Upper winds are westerly.

• **40° - 65° => Disturbed (cold) Temperate climate:**

The weather conditions are affected primarily by the travelling frontal depressions (especially during the winter when the polar depressions are more frequent), high pressure areas are less frequent. No distinctive dry season. Westerly winds. Cold and wet winters, especially in Western Europe, with the possibility of Gale-force winds.

• **65° - 90° => Polar climate:**

Anti-cyclonic weather conditions prevail most of the time = very cold and dry, occasionally affected by the peripheral regions of the travelling depressions (precipitation). Temperatures below the surface remain permanently below 0 °C - permanently frozen (permafrost). Polar areas are subject to 24 hours of darkness a day for 3 months in the winter and 24 hours of daylight a day for 3 months in the summer.

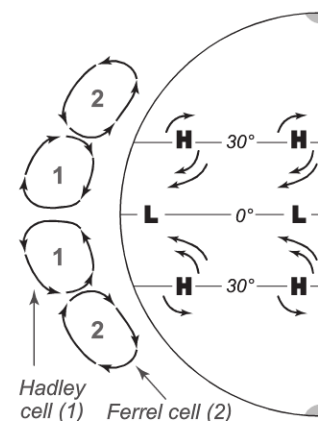


**FIGURE 050-E48**

### ITCZ / TROPICAL CLIMATOLOGY

The part of the globe that includes the regions between the Tropic of Cancer (23.5° N) and the Tropic of Capricorn (23.5° S) is called the "Tropics". This is also the area where the sun's position varies from the Tropic of Cancer in the Northern Hemisphere summer to the Tropic of Capricorn in the Southern Hemisphere summer. The latitudinal limits of tropical weather vary greatly with longitude and season, and tropical weather conditions may reach well beyond the tropics of Cancer and Capricorn.

If we take a look at the general circulation model we will note 3 circulation cell mechanisms (Hadley, Ferrel and Polar) that transport heat and humidity around the globe. The Equatorial regions receive maximum levels of insolation => high temperatures => air at the surface expands and rises, causing high pressure area at the high levels and a low pressure area that "draws" the air in at the surface => Equatorial low pressure area. The air that rises then diverges at higher levels, resulting in winds blowing from Equator towards the poles at high levels (anti-trades). Due to the rotation of the Earth (Coriolis force) these winds are deflected to the right in Northern hemisphere and to the left in Southern hemisphere (in both cases towards the east) - due to this deflection the high level winds are almost parallel to the line of latitude at about 20° - 30° N/S and as they get cooled they subside towards the surface. This subsidence around 30° N/S creates high pressure areas - the "Sub-Tropical High Pressure Belt". We now have a low pressure area around the Equator and a high pressure area around 30° latitude N/S => the air will flow towards the Equator at the surface while being affected by the Coriolis force = deflected to the right in the Northern hemisphere and to the left in the Southern hemisphere. We refer to these relatively persistent and steady winds as the "Trade winds"

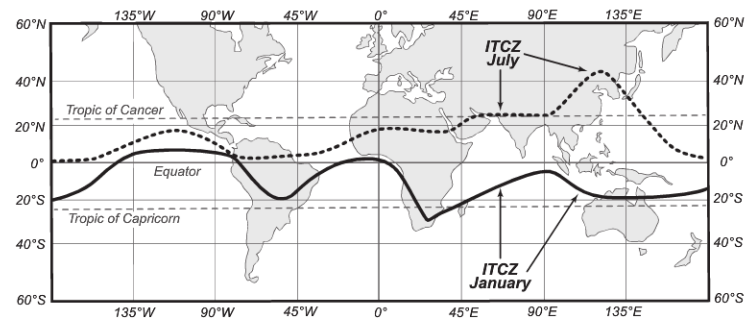


(North-Easterly in the N hemisph and South-Easterly in the S hemisph). They are low-level winds - considered to exist up to about 10 000 ft.

### ITCZ - InterTropical Convergence Zone

The North-Easterly Trade winds converge ("meet") with the South-Easterly Trade winds in an area referred to as the ITCZ. The position of the ITCZ does not coincide with the geographical Equator, but is generally located at about 5°N. However, the ITCZ position is greatly influenced by the type of surface (land / sea) and by the seasons. Over land areas the ITCZ position tends to move towards the areas where maximum heating of the land occurs = slightly towards the South pole in the winter months (January) and slightly towards the North pole in the summer months (July). There is very little variation of ITCZ position over the oceans. Position summary:

- **Summer months** (July) => over land generally North of the Equator (between 0°N - 25°N, up to 45°N over Eastern China). Over oceans approximately between 10°N - 15°N.
- **Winter months** (January) => over land generally well South of the Equator (up to 30°S over Africa). Over oceans relatively close to the Equator in most areas.



### ITCZ Weather

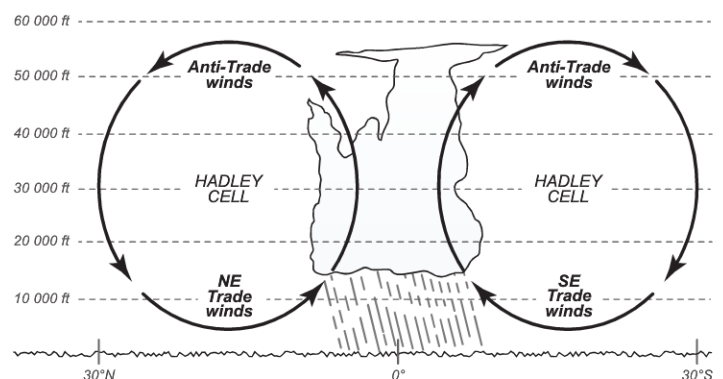
Trade winds originating from the sub-tropical high pressure belt typically bring dry and stable air. However, as the air passes along the warm oceans, it picks-up significant moisture content and becomes unstable due to the heating from below. Together with additional increase in moisture content due to evaporation at low levels formation of CU / CB occurs.

There are relatively large variations in the weather conditions around the ITCZ. Over land areas the ITCZ can be quite narrow and similar (in width and in the associated weather conditions) to a mid-latitude cold front. Over the oceans the ITCZ can vary in width from some 30 NM to as much as 300 NM and is frequently associated with intensive CU / CBs. The intensity of the weather depends on the pressure gradient between the sub-tropical HIGHS (the Equatorial side) and the Equatorial LOWs. When the gradient is relatively shallow (slack), the trade winds are light and the ITCZ is weak, producing typically only fair weather CU clouds with only some of them producing showers. This situation is referred to as the "**Doldrums**".

However, when the pressure gradient intensifies, the the converging trade winds become stronger and produce a very active ITCZ, usually referred to as the "**Equatorial trough**". Significant CU and CBs usually form (both day and night) in the confluence area. On such "active" days very intensive thunderstorms frequently develop, often with tops reaching the Tropopause levels (50 000 ft +) and bases as low as 1000 ft.

Generally speaking, all zones of wind convergence give rise to ascending motion. This may occur when two air streams approach each other, e.g. land breeze meeting a trade wind, or when the wind speed is reduced, e.g. due to increased surface friction or due to orographic effect. The effect is always accentuated if divergence takes place simultaneously in the upper troposphere. The intensity of the generated weather depends on the scale of convergence and the position of convergence, that is the strength of the flow of the air mass and the angle of interaction, for example head on confluence will usually result in severe storms. Typical weather along a tropical convergence line:

- Ceilings as low as 1000 ft, but may be practically down to the surface in combination with heavy rain.
- Tops of the CU or CB clouds spread out at the Equilibrium Level, that is the level where the lapse rate turns into a stable rate, or at the Tropopause level - CB tops frequently over 50 000 ft.
- Sometimes SC- or AC-layers can be spread around the convective cloud at low to medium levels.
- Extensive sheets of cirrus cloud can be present at high levels (making meteo satellite pictures difficult to use).
- The height of the 0°C isotherm is usually around 16 000 to 17 000 ft, the -40°C level is usually at about 35 000 ft.
- Visibility along the convergence line is usually good outside the cloud, except in heavy rain where it may be reduced to as low as few metres in a tropical downpour.
- Surface winds may produce sudden squalls.



*Note: when the main convergence zone (ITCZ) is well North or South from the equator, a secondary zone of convergence is often found close to the equator where the wind direction of the trades undergoes rapid changes in direction due to the reversal of the coriolis force.*



### Low level winds / Monsoons

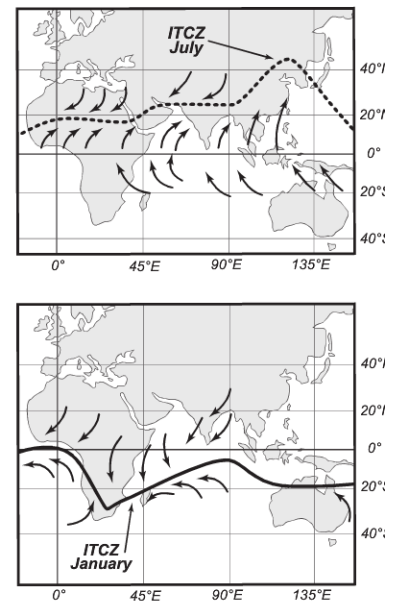
The prevailing low level winds at latitudes above 40° N/S are westerly. In the Trade wind belt (between 30° N/S) and the ITCZ the winds tend to be North-Easterly in the Northern hemisphere and South-Easterly in the Southern hemisphere.

However, the above assumes that the ITCZ position is identical to the position of the geographic Equator, which we know is not the case most of the times. During the **summer months (July)** the ITCZ moves away from the Equator further up North => the SE trade winds blowing from the Southern hemisphere change direction into SW as they pass the geographic Equator (as they "enter" Northern hemisphere) because the Coriolis force deflects them to the right => **"SW Monsoons"** occur in places such as parts of Africa, India and SE Asia.

In the **winter months (January)** the ITCZ moves away from the Equator towards the South (especially over land areas) => the NE trade winds have to cross the geographic Equator as they blow towards the ITCZ => the Coriolis force deflects them to the left in the Southern hemisph, changing their direction from NE to NW => as a result the **"NW Monsoons"** occur in parts of the Southern hemisphere (e.g. southern parts of Africa, North Australia), while **"NE Monsoons"** occur in places in the Northern hemisphere as a result of winds blowing from the Siberian HIGH and affecting where the "SW Monsoons" were experienced during the summer months (parts of Africa, India, etc...).

We can see this concept very clearly on the example of India. During the summer months (e.g. July) most of the mid- to southern parts of India are located south of the ITCZ => prevailing trade winds will be from the SW, bringing moist maritime air. During the winter months (e.g. January) all of India is located North of ITCZ => prevailing trade winds will be from the NE, bringing dry continental air.

*Note: the term "Monsoon" is of an Arabic origin and means "season" => Monsoon winds are seasonal winds in areas close to the ITCZ. By definition a "monsoon" is a Trade wind that blows either TO a continental low pressure area or blows FROM a continental high pressure area. Monsoon winds prevail for long periods of time - they are blowing from a relatively steady direction depending on the season of the year or more precisely the location of the ITCZ as influenced by the season => Monsoon winds are the Trade winds, therefore the location of ITCZ with reference to the geographical Equator is of the determining factor for the wind direction.*



## FIGURE 050-E49

### WINDSHEAR

In its simplest form a general definition of windshear can be described as "a significant change in wind direction and / or speed including both downdraughts and updraughts". A more complex way to define windshear, taking into account its effects on aircraft in flight, would be: "variations in the wind vector along the flight path of an aircraft with a pattern, intensity and duration that will displace an aircraft abruptly from its intended flight path such that substantial control input and action is required to correct it". We can also define specific types, or let's say qualifying descriptors of windshear:

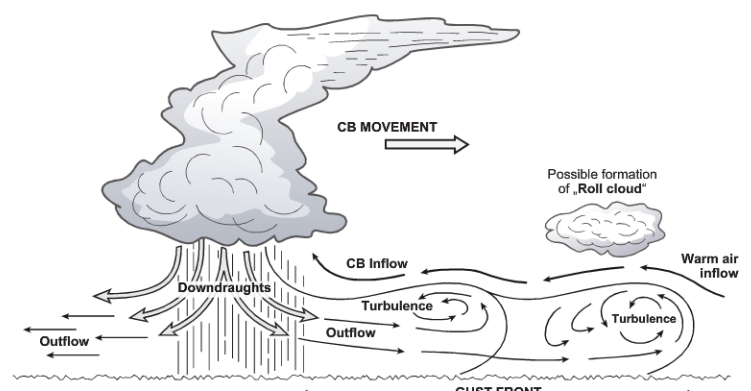
- **Low Level (altitude) windshear:** windshear along the final approach path or along the runway and along the take-off and initial climb-out flight paths. It is generally accepted standard that when talking about Low Level windshear we refer to heights below 1600 ft above the ground level.
- **Vertical windshear:** the change of horizontal wind vector with height, as might be determined by two or more anemometers at different heights on a mast. In other words, a change in the horizontal wind direction and / or speed experienced as a result of a change in altitude (vertical variation of position). The units used in reports are "kts / 100 feet" or "degree / 100 feet" ... (wind speed / direction change per 100 ft of altitude change).
- **Horizontal windshear:** the change of the horizontal wind vector with horizontal distance, as might be determined by two or more anemometers mounted at the same height along a runway. In other words, a change in the horizontal wind direction and / or speed experienced as a result of a change in location in the horizontal plane (horizontal variation of position).
- **Updraught or downdraught shear:** the changes in the vertical component of wind vector with horizontal distance.

### Formation (where and how)

Windshear occurrence is most frequently associated with thunderstorms, but other meteorological phenomena can also be the cause of windshear occurrence - these

are for example a frontal passage, significant temperature inversion, low level jets, katabatic (downslope) winds or jetstreams. Windshear can also be caused by the topographical relief of the ground (e.g. mountains) or by buildings.

**Thunderstorms (TS):** We know that strong up- and down- draughts are associated with TS, therefore an updraught or downdraught windshear can be experienced anywhere in the thunderstorm CB cloud. Sometimes a very strong downdraught of cold air





"breaks out" from the CB cloud (typically from the leading edge of the cloud) creating a so called "**gust front**" ahead of the cloud. This air sweeps along the ground and a rapid wind change (and thus also turbulence) usually takes place at the leading edge of the gust front.

Another very dangerous phenomenon associated with TS that almost guarantees a very dangerous windshear possibility is the "microburst". It is a highly concentrated and powerful down-draught of air from the CB cloud (typically up to 4 km in diameter and a duration of 1 - 5 minutes). Close to the surface (at few hundred feet) this down-draught is deflected outwards (to all directions) from below the CB cloud as a reaction of interference with the ground. The most lethal horizontal windshear situations can occur as a result of microburst, with horizontal gusts of up to 50 kts => low level windshear with wind speed changes of 50 - 90 kts is not unusual.

**Frontal passage:** windshear can be encountered especially in well-developed active fronts with narrow surface frontal zones and significant temperature differences between the two air masses.

**Inversions:** low level temperature inversions can sometimes "block" a relatively strong winds above the inversion to penetrate the inversion layer and relatively light or calm winds prevail near the surface. Windshear can therefore be encountered when passing through the inversion layer. Both a wind speed change as well as wind direction change can be experienced.

**Low Level Jet:** is a term used for "low level maximum wind". This phenomenon can sometimes form just below the top or sometimes within a radiation inversion layer during clear night skies. Low Level Jets can also be encountered in association with surface fronts - especially ahead of active cold fronts.

**Topographical windshear:** certain terrain features such as mountains or some buildings can affect the steady flow of air and create "disturbances". These disturbances can sometimes cause windshear of varying intensity, depending on the strength of the "original undisturbed" airflow, its direction in relation to the terrain feature and the characteristics of the terrain feature (e.g. its height and terrain roughness). A good example can be the formation of mountain waves and the associated "rotor zones". Another example can be a wind blowing between two hills or through a valley, where it gets "funneled" and increases in speed.

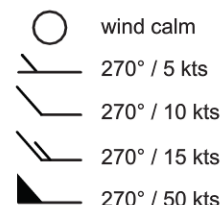
## FIGURE 050-E50

### WIND - DEFINITIONS and MEASUREMENT

In general, the wind can be defined as a large scale flow of gases. In meteorology, we define the wind as a horizontal movement of air as a result of forces acting on it. We describe the wind in terms of its direction, its speed and sometimes also its characteristics (e.g. in terms of stability of the direction and speed values). When we talk about "wind velocity" (W/V) we refer to both the direction and speed.

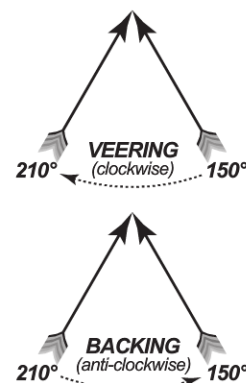
The wind direction is expressed in terms of "where the wind is blowing FROM" and in majority of meteo reports and charts it is referenced to the True North (e.g. in Upper wind charts, METARs, TAFs). An exception is a wind report given to the pilot by the ATC when landing at or departing from an airport (or in the ATIS reports) where the wind direction is referenced to the Magnetic North in order to maintain the same reference datum as the runway orientation. The wind direction in meteo reports is given in terms of Magnetic also in Arctic areas where the compass variation is significant.

On aviation meteo charts the graphical representation of wind direction and speed is standardized. The wind direction is identified by a line extending from the periphery of a circle (the circle may not be shown) and it indicates the direction from which the wind is blowing. The wind speed is indicated by "feathers" or "flags" at the end of this line. Each filled triangle represents 50 kts, long line represents 10 kts and a half-line (short line) represents 5 kts. A wind direction line without any "speed flags" represents a wind speed of 1 - 2 kts. A circle without the direction line represents a calm wind.



There are various terms used in connection with wind description:

- **Wind is veering:** a clockwise change in wind direction.
- **Wind is backing:** an anti-clockwise change in wind direction.
- **Gust:** a short burst of high speed wind. More precise definition is: a sudden and temporary (< 1 minute) increase in wind speed that exceeds the mean wind speed measured during the preceding 10 minute interval by  $\geq 10$  kts.
- **Squall:** an increase in wind speed of a duration longer than gust, typically lasting for a few minutes. The term "squall" can be used if the wind increases by at least 16 kts to a value of  $\geq 22$  kts and these values are sustained for at least 1 minute.
- **Lull:** sudden a decrease in wind speed (lasting from few seconds to few minutes).
- **Gale:** surface wind with a mean speed of  $\geq 34$  kts or a wind gusting to  $\geq 43$  kts.
- **Hurricane:** surface wind with a mean wind speed of at  $\geq 64$  kts.



### Measurement of wind

The surface wind is always affected by variations in the ground surface. It is very frequently affected by terrain features such as forests, buildings or other "obstacles". In order to obtain a surface wind direction and speed that is least affected by the terrain features it is measured by a device mounted on a 10 m tall mast over level ground. The wind direction is measured by a "wind vane" that aligns itself with the direction of airflow and it is typically reported rounded to the nearest 10°. The wind speed is measured by a "3-cup anemometer", where the wind causes the 3 "cups" mounted on a shaft to rotate and the rotational velocity is directly proportional to the speed of the wind. Another device that can be used for measuring the wind speed is the "pressure tube" anemometer which works on a similar principle as the pitot tube.

### Units of measurement

As described above, the wind direction is reported in degrees (°), most frequently referenced to the True North except for wind direction readouts given to the pilots by ATC controllers during arrivals and departures to/from airport and wind direction

information contained in ATIS broadcasts => in these two cases the wind direction is given in degrees Magnetic. It is rounded to the nearest 10°.

Wind speed can be measured in km/h (kilometers per hour), NM/h (NM per hour) or in m/s (meters per second). In aviation the most frequently used unit of wind speed measure is "kts" (knots = Nautical Miles per hour). Occasionally the "m/s" may be used in some countries. To convert wind speed values from one set of units to another:

- **m/s => kts:** the rule of thumb is to double the "m/s" value to obtain "kts" (e.g. 20 m/s = 40 kts),
- **kts => m/s:** the opposite of above - divide the "kts" value by 2 to obtain "m/s" value (e.g. 40 kts = 20 m/s),
- **kts => km/h:** 1 NM (kt) = 1852 m, therefore we need to multiply the "kts" value by 1.852 to obtain "km/h" value,
- **km/h => kts:** 1 NM (kt) = 1852 m, therefore we need to divide the "km/h" value by 1.852 to obtain "kts" value.

## FIGURE 050-E51

### JETSTREAMS

We can define a jetstream as a narrow band of strong high altitude winds (speeds > 60 kts). We can think of a jetstream as a "tube" that is vertically flattened, through which the winds are blowing at high speeds. Jetstreams are situated in the upper troposphere - typically just below the tropopause. Jetstreams are belts of strong horizontal and vertical shears, where the wind speeds can range from 60 kts up to about 250 kts. The typical dimensions are:

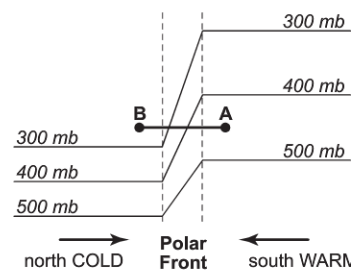
- **Length:** can be several thousand NM (avg. 1500 NM),
- **Width:** few hundreds NM wide (avg. 200 NM),
- **Thickness:** 5000 - 20 000 feet.

### Formation of jetstream

Jetstreams occur as a result of strong horizontal temperature contrasts in the atmosphere => inclination of the pressure surface => pressure gradient force => movement of air. For such strong winds to occur the temperature contrast and therefore the pressure gradient must be quite high - we can typically encounter such steep pressure gradients along the fronts. Let's review the relationship between the temperature and atmospheric pressure:

When a column of air in the atmosphere is **warm**er than its surroundings it expands and since it cannot expand downward (below the surface) it will expand vertically => the density of air reduces. The spacing between isobaric layers increases. If the column of air is **colder** than standard atmosphere, the air will have a tendency to vertically "shrink" => the density of air increases. The spacing between isobaric layers reduces.

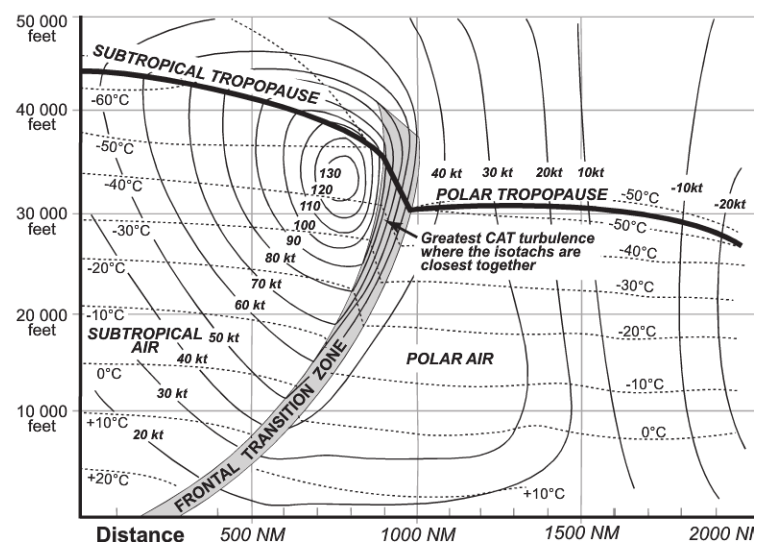
When we take a look at the example of a Polar Front. South of the front we have a warm airmass = wider spacing between isobaric layers. North of the front we have a cold airmass = closer spacing of the isobaric layers. At the Polar Front the pressure gradient becomes very steep = rapid change in pressure over a relatively short distance. In the picture on the right, the pressure at point A is approx. 450 mb, while the pressure at point B is approx. 250 mb = very steeply inclined pressure surface => strong gradient force => strong winds that have a tendency to blow from the south towards the north (A to B = high pressure to low pressure). The winds are deflected by Coriolis force resulting in westerly winds. The pressure gradient is steepest and thus the wind speed greatest at the upper levels => jetstreams.



An important aspect to realize is the fact that the temperature remains constant above the tropopause. In tropical areas (and areas with low surface temperatures) the tropopause will be situated at a higher altitude, but the temperature at the tropopause will be quite low. In polar areas (and areas with low surface temperatures) the tropopause level will be lower, but the temperature at the tropopause will be higher. For example: the polar tropopause may be situated at an altitude of 20 000 ft and if the surface temp is -10°C then the tropopause temp will be -50°C while a mid-latitude tropopause may be situated at 30 000 ft and if the surface temp is +5°C the tropopause temp will be -55°C.

The wind accelerates with increasing altitude up to the level where the temperature contrast between the air masses is equalised. At altitudes above that the wind speed decreases. This is due to the fact that the slope of the pressure surfaces increases as long as the warmest air is to the right (Northern hemisphere). The steepest slope will be at the level where the temperature is the same on both sides of the frontal surface. Above that level, the distance between the pressure surfaces will decrease on the "warm side", while it becomes constant or greater on the "cold side", and the pressure surfaces slowly turn back towards the horizontal plane (the wind abates). Maximum wind speed is found on the "warm side" of the frontal zone at altitudes just above the tropopause of the cold air (about 1000 - 5000 ft below the "warm" tropopause). In most cases the direction of the jet stream is parallel to surface front (parallel to isotherms).

The figure on the right represents a vertical cross-section of the polar jetstream. The broken lines show isotherms, while the continuous lines connect areas of the same wind speed (isotachs) around the jet core or zone.



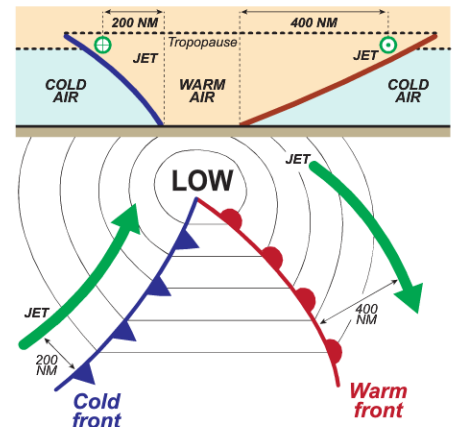
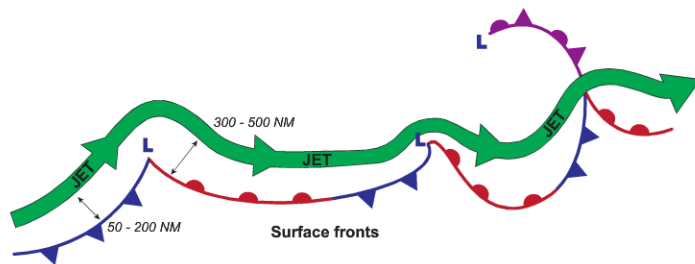


maximum winds. Direction of the jetstream is “up” from the picture (towards us) since the cold area (polar air in this case) is always on the left side of the jet when we are looking downstream.

When the airflow is straight the jet core is at a constant altitude. But when the flow goes through troughs and ridges, the altitude of the core may vary by about 3000 - 4000 ft.

In the picture on the right we can see a cross-section of a polar front in the upper part of the image. Notice that the cores of the jetstreams are situated in the WARM AIR sector, roughly 1000 - 5000 ft below the “warm sector” tropopause. When comparing the location of the jetstream in relation to the position of the surface fronts, the typical rough estimates are:

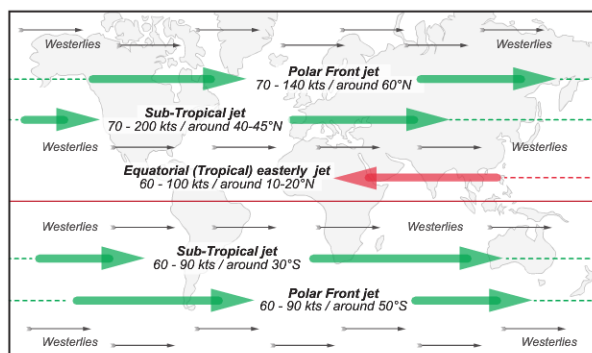
- 50 - 200 NM behind a cold front,
- 300 - 500 NM ahead a warm front.



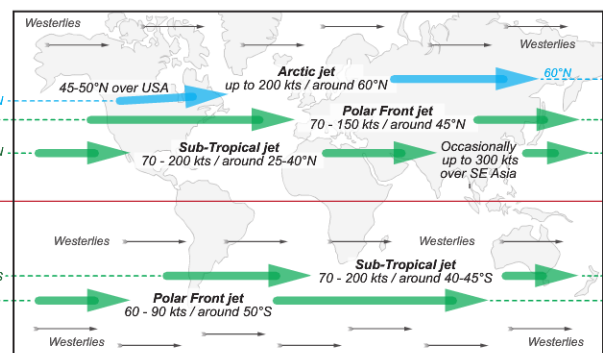
### Jetstream locations

There are 2 permanent jetstreams that exist all year around (although their average position changes with the seasons) - the Polar Front jetstream and the Sub-Tropical jetstream and several other jetstreams of a seasonal character. In general, the altitudes at which the jetstream cores can be found typically vary with seasons - where a range is mentioned, in the paragraphs below, the lower FL is more likely to be experienced in winter, while the higher FL in summer.

- **ARCTIC jetstream:** westerly jet that occurs in the winter in a boundary between the arctic and polar airmasses. The position is typically around 60°N, but it can be as low as 45°N - 50°N in some places such as the USA. The speeds may reach as much as 200 kts, with the core located typically between FL200 - FL250. Core width is usually 100 - 300 NM. Arctic jet is strongest when very cold conditions prevail = when larger temperature contrast between the airmasses exists.
- **POLAR front jetstream:** a permanent westerly jetstream occurring along the Polar Front as a result of horizontal temperature gradient (and resulting upper level pressure gradient) between the warm Tropical maritime and the cold Polar maritime airmasses. Its position tends to “travel” with the Polar Front = towards the South in the winter and towards the North in the summer. An average position can be quoted as approx. 50°N - 60°N. Wind speeds of 125 - 140 kts are common, with extremes up to 220 - 240 kts. The core is typically 100 - 300 NM wide and can be found usually between FL300 - FL350 (in extreme cases up to FL400). In the Southern hemisph the position is more stable - around 50°S and with lower wind speeds (60 - 90 kts).
- **Polar night jetstream:** occurs in the winter in the stratosphere above FL500. It is westerly jet with average speeds of around 150 kts, but in extreme occasional cases the speeds can be as high as 350 kts.
- **SUB-TROPICAL jetstream:** a permanent westerly jetstream occurring in the area of sub-tropical anti-cyclones (sub-tropical high pressure belt) as a result of the “Hadley” and “Ferrel” cell circulations. Its position varies with seasons as the sub-tropical high pressure belt moves - the jet can be typically found between 25°N - 40°N in the winter and further north in the summer - between 40°N - 45°N. The core can typically be found at around FL400, with the speeds between 70 - 200 kts, but in extreme cases (during the winter) the speeds may be as high as 300 kts over SE Asia.
- **EQUATORIAL easterly jetstream:** a seasonal easterly jetstream that occurs during the summer between June and August as a result of a monsoon climate (the summer monsoon blows SW at low level towards Asia - the return high altitude flow is towards the South and deflected by Coriolis to form the easterly jet). Notice that it is the only easterly jetstream. It can be found between SE Asia then passing over Southern India towards central Africa. The position is typically around 15°N with the core situated at high altitudes - usually between FL450 - FL500. Wind speeds of 60 kts are typical, occasionally slightly higher, but seldom over 100 kts. At lower levels the wind is often westerly but light, which means, that the Equatorial jet cannot be identified on e.g. a FL 300-chart.



upper winds - JULY



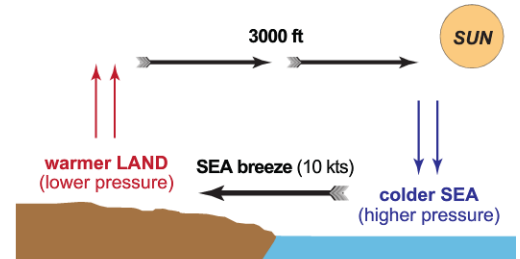
upper winds - JANUARY



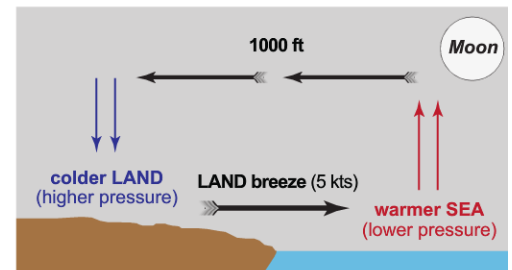
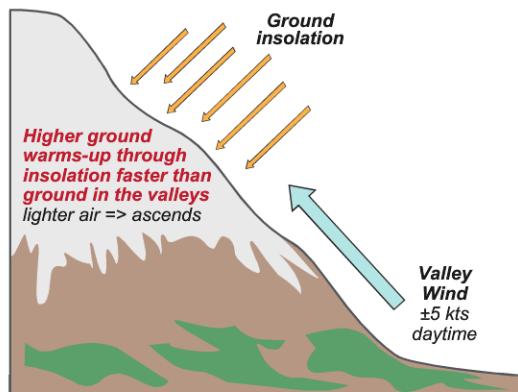
**FIGURE 050-E52****THERMAL EFFECT - LOCAL WINDS**

Land and sea breezes are a result of an uneven surface heating - thermal effects. The land surface cools and heats more rapidly than the sea surface which tends to maintain its temperature at a more stable level, without significant diurnal variations. The resulting uneven heating of a land and sea surface causes variations in pressure => pressure gradient between the land and sea surface develops. In the mid-latitudes the Sea and Land breezes occur typically between late-spring to mid-autumn. In the tropics the breezes are a usually daily occurrence all year around.

**SEA breeze** is a surface wind blowing from sea to the land. Sea breezes occur especially during warm afternoons with cloudless skies (e.g. anti-cyclonic conditions) when the insolation heats the land surface more rapidly than the adjacent sea surface. The layer of air in contact with the land surface starts to warm up and expand. As the warm air over land expands it results in a situation where the pressure at approximately 3000 ft is higher than the pressure at 3000 ft over the sea. This creates a pressure gradient => the air at altitude starts to flow from land to the sea. In this situation a LOWER pressure area is formed at the surface over land and HIGHER pressure area at the surface over sea => surface wind starts to blow from the sea inland. Sea breeze is usually generated late in the morning and ceases around 18:00 in the evening. Typical wind speed is around 10 kts (in the tropics it can be 15 - 20 kts). The area affected by sea breeze typically extends 8 - 15 NM either side of the coast (up to 35 NM in the tropics). Vertical extent of the affected area is typically up to 3000 ft. Direction of the wind is at approx. 90° to the coastline, however as the wind picks-up on the speed the Coriolis force deflects it gradually (it veers in the Northern hemisphere and backs in the Southern hemisphere).



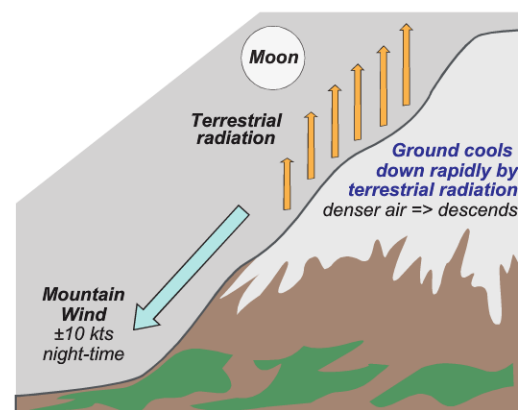
**LAND breeze** is a surface wind blowing from land to the sea. It occurs during the night when the land surface cools down more rapidly than the sea surface. It results in an opposite situation than described above for the sea breeze. In the case of a land breeze the warmer sea results in a lower pressure at the surface and the colder land surface results in a higher surface pressure => pressure gradient will cause the wind to blow from land to the sea. The typical land breeze speed is 5 kts and the area affected by land breeze typically extends 5 NM either side of the coast.

**ANABATIC (up-slope) winds**

Anabatic wind is an up-slope wind blowing from the colder valley (lower areas) up towards the mountain top as a result of thermal effects (up-slope airflow of warm air). Frequently a so-called "valley wind" can be encountered in mountainous areas. Valley wind is a light wind of typically  $\pm 5$  kts blowing up-slope during the day (from the valleys up towards the mountain tops). It is caused by the sun heating the areas along the sides of the mountain more (through insolation) than the lower areas in the valleys, especially if the mountain-side is south-facing. The increased temperature of the surface at higher areas causes the adjacent air to warm-up and thus expand => lower density of air (becomes lighter) => it tends to ascend up along the mountain side. Lower density also means an area of lower pressure = creating a flow of air from the valley up towards this lower pressure area above => up-slope blowing wind => valley wind.

**KATABATIC (down-slope) winds**

Katabatic wind is a down-slope wind blowing from the higher (colder) areas along the mountain sides down towards the lower (warmer) areas in the valleys, again as a result of thermal effects. Frequently a so-called "mountain wind" can be encountered in mountainous areas. Mountain wind is a light wind of typically  $\pm 10$  kts blowing down-slope during the night (from the mountain tops down into the valleys). It is caused by rapid cooling of the ground at higher levels due to terrestrial radiation => adjacent air cools down and its density increases (becomes heavier) => it tends to descend down along the mountain sides into the valleys. The thermal effect causing the katabatic wind is most pronounced (wind strongest) when the mountain sides are snow-covered, the skies are clear and the pressure gradient is shallow => greater radiation cooling. Result of cold air descending into the valleys is frequently a temperature inversion or easier frost and/or fog formation in the valleys.



**FIGURE 050-E53****PRIMARY CAUSE OF WIND**

In meteorology we define the wind as a horizontal movement of air as a result of forces acting on it. Temperature contrasts along the surface of the Earth cause variations in density as a result of which pressure differences arise. Since the only force acting on air that is at rest is the weight of the atmosphere above, it is obvious that a horizontal difference in pressure will cause that air to try to move from the area of higher pressure towards the area of lower pressure. The magnitude of the horizontal differences in air pressure is directly proportional to the horizontal force acting on the air.

To clearly identify the pressure differences over geographical areas the lines called “**isobars**” are drawn on weather charts between places with the same air pressure (QFF), typically with a spacing of 2 or 4 hPa. The “isobar” indicates how a pressure surface intersects ground level. A pressure surface is thus a level in the atmosphere along which the air pressure is always constant, also known as an isobaric surface. QFF is the pressure recorded at station level reduced to mean sea level using the actual conditions that prevail (QFF is NOT an altimeter setting). Isobars form various patterns on the weather charts - the two main patterns that are of interest to us in relation to wind are the “**LOWs**” and “**HIGHs**”. **LOW** is an area on the chart having a lower pressure than its surroundings, with the lowest pressure values found in its center. **HIGH** is an area on the chart having a higher pressure than its surroundings, with the highest pressure value found in its center.

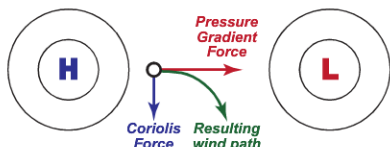
**Horizontal Pressure Gradient / Pressure Gradient Force (PGF)**

By the term “horizontal pressure gradient” we mean a change of pressure per unit of distance (in the horizontal plane). When the isobars are spaced closely together (small distance between the isobars on a weather chart) we refer to this pattern as a **strong (steep) gradient** while a pattern with a greater distance between the isobars is referred to as a **weak (shallow) gradient**. The pressure gradient is a measure of inclination of the pressure surface and it is directly proportional to the force acting on the air and forcing it to move. The “**pressure gradient force**” (PGF) can be defined as a force acting perpendicular to an isobar, pointing towards the lower pressure. The force is attempting to equalise the pressure difference. The magnitude of the force is inversely proportional to the spacing of the isobars, therefore directly proportional to the pressure gradient. Strong PGF => strong winds; weak PGF => light winds.

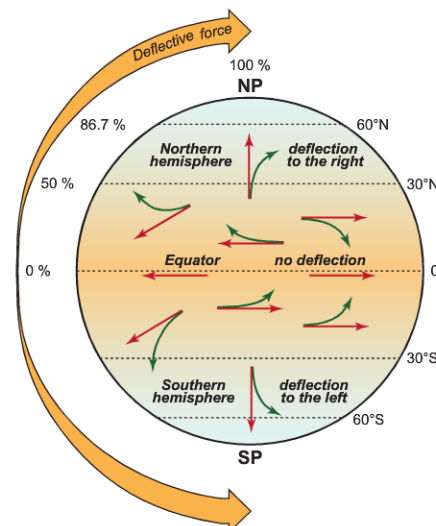
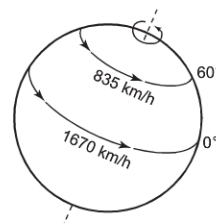
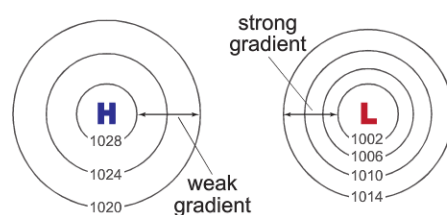
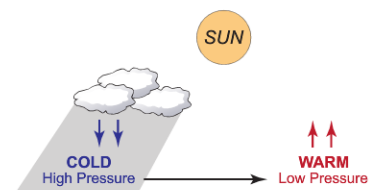
**Coriolis Force (CF) / Geostrophic Force**

From Newton's laws of physics we know that an object in space maintains its direction and speed as long as it is not affected by some external force (the law of inertia). Likewise a sudden change is proportional to the deflecting force and takes place in the direction of this force. The same laws apply also to the wind - it will blow in straight line from high pressure to low pressure area unless disturbed by another force => the “Coriolis force”, sometimes referred to as the “Geostrophic force”. Coriolis force is caused by the rotation of the Earth and acts on the wind at a 90° angle. It is causing the wind to be deflected to the right in the Northern hemisphere and to the left in the Southern hemisphere. It is maximum at the poles and minimum at the Equator.

The magnitude of the Coriolis force depends primarily on the latitude and the wind speed. The formula for calculating the Coriolis force is:  $2\Omega \sin\theta V$  ... where “ $\Omega$ ” is the angular speed of Earth rotation, “ $\theta$ ” is the latitude and “ $V$ ” is the velocity of the object (wind in our case). From the formula above we can conclude that the Coriolis force is zero at the Equator (latitude of 0° =>  $\sin 0^\circ = \text{zero}$ ) and increases with an increase in latitude to reach its maximum values at the poles. The formula also tells us that the Coriolis force is directly proportional to the wind speed => higher wind speed means a higher Coriolis force and vice versa. Coriolis force is universally applicable to all directions of movement - not only to the North => South directions. The only place where Coriolis does not apply is the Equator - however, between the Equator and latitudes of 15°N / 15°S it is so small that for practical purposes we assume that it is zero in these areas.



As a result of the Coriolis force the wind does not blow directly from **HIGHS** to **LOWs**, but creates cyclonic and anti-cyclonic circulation patterns around these pressure areas.

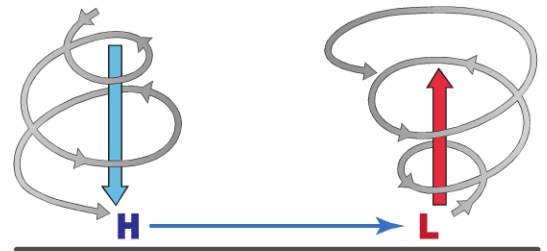
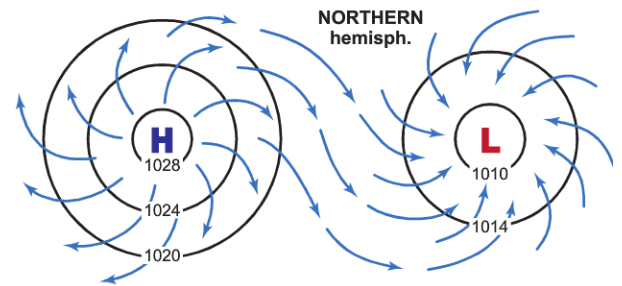
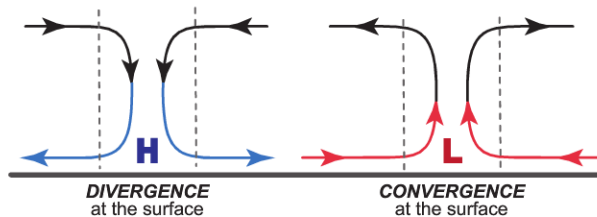




In the **Northern hemisphere** the winds flow clockwise around a HIGH pressure area and anti-clockwise around a LOW pressure area. In the **Southern hemisphere** it is the opposite => anti-clockwise around a HIGH and clockwise around a LOW because the Coriolis force deflects the winds to the left in the Southern hemisphere (right in the Northern hemisphere).

The surface winds blow at an angle to the isobars - away from the center of a HIGH / towards the center of a LOW.

In a vertical cross-section of a **HIGH** we would see a **subsidence** (descending air from higher levels to lower levels) and **divergence** of the air at low levels (moving away from the center). In a cross-section of a **LOW** we would see **ascending (rising)** air from lower to upper levels and a **convergence** of the air at low levels (moving towards the center).



### Geostrophic Wind

The geostrophic wind is a wind that blows in a straight line parallel to isobars => it occurs only when there are straight (parallel and equidistant (constant gradient) isobars that are not changing with time. The geostrophic wind is affected by 2 forces only - the Pressure Gradient Force (PGF) and the Coriolis Force (CF).

Initially a particle of air is subjected to a PGF, and the particle starts to move from high pressure towards the low pressure. As soon as the motion is started, a CF is built up, and the particle is deflected somewhat to the right. The PGF is still constant and the velocity of the particle increases, leading to an increase in CF, and further deflection. Eventually the velocity increases to such a value where the PGF and the CF completely compensate each other and the motion becomes parallel to the isobars => geostrophic wind.

For a geostrophic wind the following relationship exists:  $PGF = CF = 2\Omega \sin\theta V$ . The geostrophic wind speed can therefore be expressed as:  $PGF \div (2\Omega \sin\theta)$ . The geostrophic wind speed is therefore inversely proportional to latitude - the same isobar spacing will result in different wind speeds at different latitudes. For example, if we are experiencing a geostrophic wind speed of 40 kts at 30°N, the geostrophic wind speed resulting from the same isobar spacing, but at a latitude of 60°N will be 23 kts ( $40 \text{ kts} \times \sin 30^\circ = ? \text{ kts} \times \sin 60^\circ$ ).

For a geostrophic wind to exist, the following conditions must be met:

- Latitude is greater than 15°N or 15°S,
- Straight and parallel isobar pattern exists,
- The pressure system is not changing rapidly,
- No surface friction (wind is blowing above the friction layer).

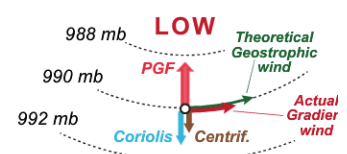
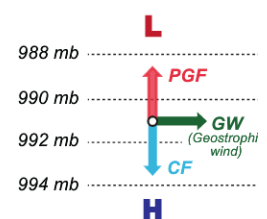
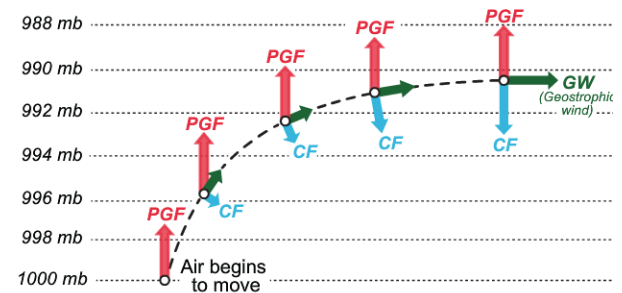
Buy Ballot's law states that:

- In the Northern Hemisphere with your back to the wind, the low pressure is on your left,
- In the Southern Hemisphere, with your back to the wind, the low pressure is on your right.

### Gradient Wind

We can define the gradient winds as non-geostrophic winds which blow parallel to curved isobars. If we take a closer look at a typical weather chart we will see that in reality the isobars are rarely arranged in the pattern of straight and parallel lines with constant spacing - instead the isobars are most often curved lines with varying gradients => therefore the gradient wind is a more common one than the geostrophic wind. Gradient winds are slightly more complex than geostrophic winds because they include the action of yet another physical force in addition to the Pressure Gradient Force (PGF) and the Coriolis Force (CF) => the "**centrifugal force**" - an apparent force that acts on objects moving along a curved path and "pulls" them away from the center of the path curvature. The centrifugal force alters the original 2-force balance and creates the non-geostrophic gradient wind.

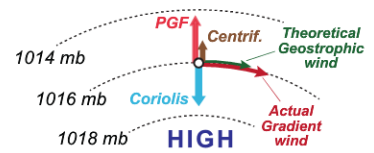
Let's take a look at an anti-clockwise (cyclonic) **circulation around a LOW** in the Northern hemisphere - the Pressure Gradient Force (PGF) acts towards the center of the LOW, while the Coriolis Force acts in the opposite direction (at a 90° angle to the wind direction). In addition, the Centrifugal Force acts in the same direction as the Coriolis force = away from the center. As the parcel of air "tries" to continue to move in a straight line (slightly away from the center), the Centrifugal force decreases. The PGF now becomes slightly more dominant and "pulls" the parcel of air back to its original radius. As a result the gradient wind blows parallel to the curved isobars. Since the PGF remains constant and all the forces must be in balance, the Coriolis force becomes weaker => overall wind





speed decreases. Therefore, in the case of a circulation around a LOW, the gradient wind speed is lower than the full geostrophic wind speed = subgeostrophic.

In the case of a clockwise (anti-cyclonic) **circulation around a HIGH** in the Northern hemisphere, the PGF acts in the direction away from the center of the HIGH, while the Coriolis Force acts in the opposite direction (at a 90° angle to the wind direction). The Centrifugal Force now acts in the same direction as the PGF. As the parcel of air "tries" to continue to move in a straight line (slightly away from the center), the Centrifugal force decreases. The Coriolis Force now becomes slightly more dominant and "pulls" the parcel of air back to its original radius. Since the PGF remains constant the Coriolis Force again adjusts to maintain the forces in balance - this time it must become stronger to balance the PGF + Centrifugal Force => overall wind speed increases. Therefore, in the case of a circulation around a HIGH, the gradient wind speed is higher than the full geostrophic wind speed = supergeostrophic.



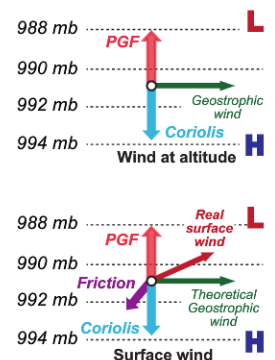
### Effect of Surface Friction

Surface winds on a weather map do not blow exactly parallel to the isobars as in geostrophic and gradient winds. Instead, surface winds tend to cross the isobars at an angle. It is because the surface of the Earth exerts a frictional drag on the air blowing closely above it. This friction is a resistive force and decreases the wind speed. We know that the value of Coriolis Force depends on the latitude and also on the wind speed. With a decrease of wind speed the Coriolis Force also decreases => resulting in a change of force vectors => change of wind direction.

The frictional force is greatest at the surface and gradually decreases with altitude until becoming zero at the top of the friction (boundary) layer = at this point the winds blow parallel to isobars at normal geostrophic or gradient speeds. The thickness of the friction layer depends on the type of terrain (sea = lower friction / land = higher friction), type of land terrain (flat surface = lower friction / forest = higher friction), wind speed, vertical temperature profile, stability of the air, etc... On the average the friction layer extends up to about 2000 ft with moderate winds over relatively flat terrain, but can be as high as 4000 ft with strong winds and rough terrain.

Surface winds (in the friction layer = between the surface and on avg. 2000 ft) blow at a slower speed than winds aloft. Surface winds blow at an angle to isobars (pointing towards LOW pressure areas) as opposed to the winds aloft that blow parallel to isobars. Summary of surface wind direction / speed changes (speed given as a % of 2000 ft wind):

- **LAND - NIGHT:** direction change of about 45° / speed reduces to 25%
- **LAND - DAY:** direction change of about 25°-30° / speed reduces to 50%
- **SEA:** direction change of about 10° / speed reduces to 70%
- **Northern hemi:** change in direction = "backing",
- **Southern hemi:** change in direction = "veering".



### Diurnal Variations (DV) of Surface Wind

The surface wind (wind within the friction layer) has distinct diurnal (time of day) variations in speed and direction. These variations are caused by differences in the stability of the air => convection in the afternoon and inversions at night. During the day friction layer will be approx. 2000 ft - thermal turbulence / convection will cause mixing of the surface winds with the winds moving freely above the friction layer => increase in the surface winds. DV is therefore highest on clear sunny afternoons (thermal turbulence), especially with polar maritime and unstable air (convection).

During the night the friction layer drops to between approx. 1000 - 1500 ft. The air along the ground is cooled and an inversion builds up. In the chilled air friction has full effect, the air is considerably slowed down, and the wind abates in the evening. Absence of thermal turbulence and convection => no mixing of surface wind and freely blowing wind above friction layer => low DV.

- **DAY:** friction layer approx. 2000 ft / max. wind speeds around 15:00 LT
- **NIGHT:** friction layer approx. 1500 ft / min. wind speeds around sunrise
- **SFC:** LAND = greater DV / SEA = minimum DV because diurnal temp. change is very small.

	during the day	for example	during the night	for example
• <b>2000 ft winds:</b>	out of friction layer	270° / 40 kt	out of friction layer	270° / 40 kt
• <b>1500 ft winds:</b>	in the friction layer	260° / 35 kt	out of friction layer	265° / 35 kt
• <b>surface winds:</b>	land	245° / 20 kt	land	225° / 10 kt

## FIGURE 050-E54

### UPPER WINDS

When using meteorology charts we can encounter several types of "lines", each representing a different meaning:

- **Isotachs:** lines of constant wind speed = lines that connect points having the same wind speed.
- **Isotherms:** lines of constant temperature = lines that connect points having the same temperature.
- **Isobars:** lines of constant pressure = lines on meteorological surface pressure charts that connect points having the same pressure at MSL (QFF - atmospheric pressure lowered to MSL corrected for actual temperature).
- **Isohyps (contour lines):** lines of equal height of a given isobaric surface above MSL (can be found on "Constant pressure charts" or on the "Contour charts"). The actual height of a specific pressure level (isobaric surface) above the sea level varies due to temperature variations. For example, in ISA conditions, the height of 500 hPa level would be approx. 18 000 ft, but in warmer atmosphere the height of the same pressure level above MSL would be higher, while in colder atmosphere it would be lower. The contour lines connect points having the same height of a given

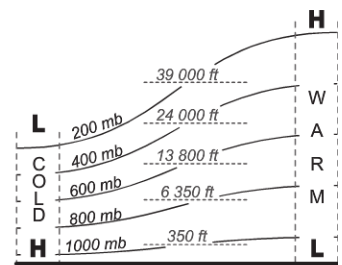
Contour charts available for:

- 700 hPa = 10 000 ft (in ISA)
- 500 hPa = 18 000 ft (in ISA)
- 300 hPa = 30 000 ft (in ISA)
- 250 hPa = 34 000 ft (in ISA)
- 200 hPa = 39 000 ft (in ISA)
- 100 hPa = 53 000 ft (in ISA)

isobaric surface (e.g. 500 hPa level) above MSL.

### Isobaric surface spacing

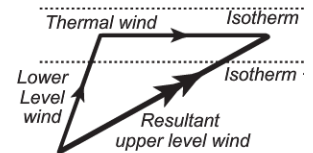
When a column of air in the atmosphere is **warmer** than its surroundings it expands and since it can not expand downward (below the surface) it will expand vertically => the density of air reduces. The spacing between isobaric layers increases => the thickness of the layer between for example 800 mb and 600 mb levels increases. HIGH pressure area will exist at high levels and a LOW pressure area at the surface. If the column of air is **colder** than standard atmosphere, the air will have a tendency to vertically "shrink" => the density of air increases. The spacing between isobaric layers reduces. LOW pressure area will exist at upper levels and a HIGH pressure area at the surface.



### Thermal wind component / Upper winds

We know that the surface wind is affected by friction with the Earth's surface and it is slower than the geostrophic wind just above the friction layer (typically 2000 ft). When we compare the geostrophic winds at 2000 ft with winds at higher levels we will see that as the altitude increases the wind speed increases and direction changes. This is the result of a so called "thermal wind component". As we can see from the picture above, the variations in temperature will result in a pressure gradient at higher level => the higher the altitude, the steeper the pressure gradient => the greater the Pressure Gradient Force (PGF) => the greater the wind speed. Lower air density at high levels also causes an increase in wind speeds.

We know that the wind will have a tendency to blow from HIGH pressure area towards the LOW pressure area => at the upper levels it means from the warmer area at the surface towards the colder area at the surface. As the altitude increases the pressure gradient between the warmer and colder columns of air increases => PGF increases => wind speed increases => Coriolis Force increases. Ultimately the direction will be parallel to the isotherms. With your back to the wind and looking downstream the COLD air area will be to your left in the Northern hemisphere and to your right in the Southern hemisphere. In general, the temperature in the troposphere decreases from the Equator towards the poles, therefore the isotherms of mean temperature will be approximately parallel to the parallels of latitude => outside the Tropics the average "**thermal wind**" will be **westerly**. In the Tropics (between 20°N and 20°S) the upper winds will be typically Easterly. It is actually not a wind in itself, but rather a wind vector that is added to the geostrophic wind. In other words, "thermal wind" refers only to the component (vector) of the actual upper level wind that is caused by the horizontal temperature gradient = difference between the lower and higher level geostrophic winds.



### Upper level wind rules of thumb

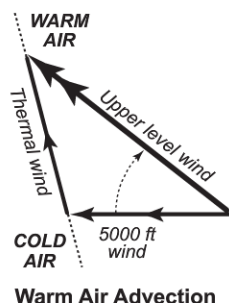
We have determined that outside the Tropics (Tropics = between 20°N and 20°S) the thermal wind is generally westerly. Therefore, we can deduce the following typical relationships between the lower and upper level winds (rules of thumb):

- Easterly surface wind => Upper wind veers or backs towards Westerly / speed decreases.
- Westerly surface wind => Upper wind remains westerly / speed increases
- Northerly surface wind => Upper wind backing towards westerly / speed increases,
- Southerly surface wind => Upper wind veering towards westerly / speed increases,

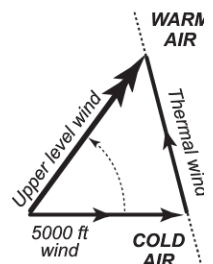
Thermal wind is a good way of identifying temperature advection.

For example - in the Northern hemisphere:

- wind direction is **veering** (changing clockwise) with altitude increase = **warm air advection**,
- wind direction is **backing** (changing anti-clockwise) with altitude increase = **cold air advection**.



Warm Air Advection



Cold Air Advection

