CHAPTER 5

PROCESSING SOUNDING DATA

5.1 Introduction. The processing of the high data-rate, time-tagged, and quality-controlled information includes not only the preparation of the information for the meteorological message, currently (1997) using the character-code format described fully in Appendix E, but also the preparation of the information for the data archive described in Appendix F. In the future, the full data record will be encoded in the binary, self-defining BUFR code both for transmission on the communication services and for archiving purposes.

This Chapter describes data processing for the creation of information to be included in the Rawinsonde and Upper-Air messages, as defined in Appendix E. A complete description of the material in this Chapter can be found in References 7, 9, and 12. An important part of this procedure is the selection of a limited number of or a subset of points or levels at which the atmospheric sounding is represented in the message form. The types of levels and the techniques used in making the selections are covered. Automated processing of the information, coupled with observer interaction, is assumed.

5.2 Level Selection - Thermodynamic Variables. The following procedures are used for selecting atmospheric levels for transmission and for archiving. Levels are selected at points in the time-tagged file which enable the definition of a representative profile of the temperature and humidity (and wind vectors) as a function of pressure or altitude. Levels are selected either when the flight reaches a predetermined specific pressure level or when a defined, significant change occurs in the temperature, humidity, or wind profiles. The following criteria for selecting the levels meet minimum standards. The criteria for selecting levels for the wind vector data are given in Section 5.3.

Levels pertaining to temperature and humidity information are classified into three main types: standard, mandatory significant, and additional levels. Standard and mandatory significant levels are pre-defined; additional levels (5.2.3) occur at any point in the sounding. [This WMO classification (and resulting definitions 5.2.1, 5.2.2, and 5.2.3) does not correspond to traditional U.S. meteorological usage that contained only 'mandatory' (= standard) and 'significant' (= mandatory significant and additional).]

Level selection ***shall*** occur by examining the time-tagged and signal-processed data values for pressure, temperature, and relative humidity. Calculated data values for geopotential height, dew point, and dew point depression ***shall*** be determined for each level. The height of the surface level in geopotential meters is set to that appropriate for the release point of the radiosonde (Chapter 3). Temperature and relative humidity values ***shall*** be interpolated for periods of missing data of less than one minute. Special procedures are applied to strata with missing relative humidity or temperature data and cases of abnormal balloon ascension. Appendix D provides formulas and information on geopotential height, geometric altitude, and dew point computations.

The standard levels are selected first, then the mandatory significant levels, followed by selection of the additional levels evaluated with temperature criteria; additional levels with respect to relative humidity criteria are selected last.

5.2.1 Standard Pressure Levels. The standard isobaric levels are selected at the specified pressure levels — namely 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 hPa. These levels ***shall*** be reported in Part A and Part C of the coded message (refer to Appendix E-II.2.2.) In addition, the following levels ***should*** be considered as standard levels: 7, 5, 3, 2, and 1 hPa. Standard pressure levels ***shall*** be selected from the high data-rate time-tagged points closest to the specified pressures. Data are interpolated if a time-tagged point does not have a pressure exactly equal to the standard pressure.

5.2.2 Mandatory Significant Levels. The mandatory significant levels accommodate a number of important characteristics of the rawinsonde sounding which are included in the coded message. These levels are defined as:

- the surface;
- the highest level achieved (the termination level);
- one level between 110 and 100 hPa;
- the tropopause;
- the bases and tops of temperature inversions and isothermal layers greater than 20 hPa in thickness and at pressures greater than 300 hPa;
- the bases and tops of all inversion layers with temperature changes of 2.5°C or 20% relative humidity at pressures greater than 300 hPa; and
- levels delineating layers with missing or doubtful data.

In addition, WMO Regional and National Practice requirements define some supplemental mandatory significant levels. Mandatory significant levels ***shall*** be selected and reported according to the following:

5.2.2.1 Termination Level. The "termination level" ***shall*** be selected at the highest usable point of ascent. Listed below are the situations causing termination (Refer also to Chapter 3):

- Balloon Burst. When detected, the termination level ***shall*** be placed at the last identifiable pressure point.
- Floating Balloon. When a floating balloon has been detected, the termination level ***shall*** be placed at the last pressure point before the balloon began floating.
- Pressure Sensor Failure. When the pressure sensor fails the flight ***shall*** be terminated at the last pressure measurement before the failure. Pressure sensor failures are usually related to

a loss of signal or sensor dropouts causing a number of sampling points to be missing. Since the type of pressure sensor failure is dependent on the type of sensor used, requirements for this type of failure ***shall*** be stipulated by individual agencies.

- Temperature sensor failure or excessive missing temperature data (Table 3-1).

- Weak Signals. When the flight is terminated owing to weak signals, the termination level ***shall*** be placed at the last pressure point before the first weak signals were detected.

5.2.2.2 Descending and Reascending Levels. A "descending level" ***shall*** be selected when the balloon first descends. A "reascending level" ***shall*** be selected when the balloon reascends past the point of highest previous ascent. There are three cases where a reascending level ***shall not*** be selected following a descending level:

- If the balloon descends but never reascends past the highest ascent a reascending level ***shall not*** be assigned. In this case, the descending level ***shall*** be converted to a termination level.

- If the data become missing after the balloon descends and do not reappear until the balloon is above the prior highest ascent point, a reascending level cannot be selected since the data were missing where the balloon ascended past the prior highest point. Instead, an end missing data level ***shall*** be selected where the data reappeared.

- If the reascending level coincides with a standard pressure, the standard level ***shall*** be selected because these levels have higher priority.

5.2.2.3 Missing Temperature and End Missing Temperature Levels. If all data are missing at the point selected for the level, the level ***shall*** be classified as a "missing data level" rather than a "missing temperature level". The level at which the data return ***shall*** be classified as an "end missing temperature level". There are three cases where there will not be an end missing temperature level:

- If the data become missing and never return, an end missing temperature level ***shall not*** be assigned. The begin missing temperature level ***shall*** be converted to a termination level after the flight terminates.

- If the balloon descends after the data become missing and does not reascend until after the data return, an end missing temperature level ***should not*** be selected, since the balloon was not past the highest ascent when the data returned. Instead, a reascending level ***shall*** be selected where the balloon passed the highest ascent.

- If the end missing temperature level is the same point as a standard level, that level ***shall*** be selected because standard levels have higher priority.

If the flight has terminated before the return of temperature data the last level selected ***shall*** become the termination level.

5.2.2.4 Missing RH Levels. Missing relative humidity levels differ from missing temperature data levels in that the data for other variables between the begin missing relative humidity level and the end missing relative humidity level ***should*** still be checked against level criteria. Geopotential height calculations require pressure, temperature, and relative humidity for each incremental level, except when the relative humidity low value cutoff (dependent upon the humidity sensor used) has been reached or the relative humidity is missing.

5.2.2.5 Station Base Pressure Level. A level ***shall*** be selected at the station base pressure used for computation of the stability index. The station base level (the pressure at the release location of the sounding) ***should*** be determined in accordance with the criteria given in Table 5-1.

The base pressure level ***shall*** be selected from the high data-rate point closest to the release location pressure.

Table 5-1 Stability Index Station Base Levels

Station Elevation	Station Base Pressure Level
Less than 1000 gpm	850 hPa
1000 to 1400 gpm	800 hPa
1401 to 2000 gpm	750 hPa

5.2.2.6 Freezing Levels. For aviation purposes it is useful to know at what altitude(s) the sonde passes through the freezing level(s). Freezing levels are selected at zero degree (Celsius) temperatures. Two types of heights ***shall*** be assigned: the calculated heights computed for all levels and U. S. Standard Atmospheric heights rounded to the nearest 100 feet. Up to three crossings of 0°C ***shall*** be determined as follows:

- the one nearest the surface,
- the highest (lowest pressure) one, and
- the intermediate one between the above two with the highest relative humidity.

Additional freezing levels (more than three) ***shall not*** have Standard Atmospheric heights computed, but a count of the total number encountered maintained. Appendix E describes the coded message formats and Appendix D specifies the information for computing Standard Atmospheric heights.

5.2.2.7 Within 20 hPa of Surface Level. A level ***shall*** be selected within 20 hPa of the surface level if a level has not already been selected in this range for other reasons. This level is necessary to ensure that any significant lapse rate near the surface is properly identified. The point of maximum temperature deviation from a linear relation between time (or the logarithm of pressure) and the surface temperature and the temperature 20 hPa above the surface ***shall*** be selected. The level ***shall not*** be selected if temperature is missing.

5.2.2.8 Superadiabatic Lapse Rates. If a potential temperature lapse-rate between two consecutive levels exceeds 1.0°K, the level with the greater time ***shall not*** be selected provided:

- levels are less than or equal to 0.3 minutes apart,
- the level with the greater time is a temperature or relative humidity level, and
- it is not within 20 hPa of the surface.

5.2.2.9 Relative Humidity Cutoff. A level ***should*** be selected when the lower limit of the relative humidity sensor's measuring capacity is reached. This value will be sensor dependent.

5.2.3 Additional Level Selection. The data between standard and mandatory significant levels ***shall*** be examined for the additional levels and included in the coded message in Parts B and D. [E-II.1]. These levels are selected at points that are defined with respect to the temperature and relative humidity profiles based on the departure from linearity on a logarithmic pressure scale between two previously selected levels. Temperature levels ***shall*** be selected first, and relative humidity levels selected when no additional temperature levels can be identified.

5.2.3.1 Departure from Linearity. Temperature and relative humidity levels are selected at points of greatest departure from linearity (GDL). Departure from linearity is the absolute value of the difference between the measured temperature or relative humidity at each time-tagged point and the temperature or relative humidity at that point computed by linear interpolation, based on the logarithm of pressure, between the two nearest previously-selected levels on either side of the point. The point having the greatest absolute difference ***shall*** be selected as the point of GDL between the two levels. If two points have the same difference, the first point in time is selected. A level ***shall*** then be selected at the point of GDL if the data at that point meet certain criteria. The procedure ***shall*** then be repeated using the first point and the greatest departure point, then the greatest departure point and the second point, until no additional levels can be selected.

5.2.3.2 Selection Criteria. A temperature level ***shall*** be selected if the GDL exceeds ± 1.0°C for pressures from surface to 100 hPa and ±2.0°C for pressures from 100 hPa to termination.

A relative humidity level ***shall*** be selected if the GDL exceeds ± 10% for all pressures

5.3 <u>Wind Data</u>. After the thermodynamic level selection process is complete, wind levels are determined. Wind directions ***shall*** be reported in the rawinsonde messages with respect to true north to the nearest five degrees of the 360 degree compass. However, the processing and calculation of the winds and their use in the level selection ***shall*** be in whole degrees and in knots or tenths of meters per second.

The signal processing and creation of the time-tagged wind vector file will depend upon the type of wind-finding system employed. The procedures in this Section are given in terms of a nominal one-minute file structure. This does not necessarily mean that the wind-finding system is capable of accurate wind finding at one-minute intervals. It is suggested that such a structure or one similar to it ***should*** be employed.

Wind speeds and directions are derived for each level encoded in Parts A and C of the TEMP telecommunication message. In addition, wind speeds and directions ***shall*** be determined for the additional levels reported in Parts B and D. Winds are also reported in the PILOT message according to coding specifications given in E-I. The criteria for selecting and reporting fixed level and additional level winds are explained in the following subparagraphs.

- Standard Pressure Levels - The predefined pressure levels for which winds ***shall*** always be reported with accompanying thermodynamic data (see para. 5.2.1). (TEMP).

- Additional Levels - The levels chosen during the observation where either the wind direction or wind speed departs significantly from a linear change. As with the thermodynamic variables, the term is used with respect to the selection of the winds that will accurately replicate the wind profile of the observation. (TEMP and PILOT).

- Fixed Levels - These are predetermined altitude levels which are reported to supplement the winds provided with other data for the standard isobaric levels. Inclusion of winds for these fixed levels provides a more detailed profile of the vertical wind field than can be obtained from only the winds given for the standard and additional levels. (PILOT).

5.3.1 Fixed Levels for Reporting Purposes. Wind directions and speeds, when they are available, ***shall*** be selected on the basis of the altitudes of the fixed levels listed in Table 5-2. These levels have been defined by WMO Region IV as required levels for reporting wind measurements.

Table 5-2 Altitudes of the Fixed Wind Levels

Feet	Meters	Feet	Meters	Feet	Meters
1,000	300	12,000	3,600	70,000	21,000
2,000	600	14,000	4,200	80,000	24,000
3,000	900	16,000	4,800	90,000	27,000
4,000	1,200	20,000	6,000	100,000	30,000
6,000	1,800	25,000	7,500	110,000	33,000
7,000	2,100	30,000	9,000	*	**
8,000	2,400	50,000	15,000		
9,000	2,700	60,000	18,000		

* . . . and for every 10,000 feet upward.
* *. . . and for every 3,000 meters upward

5.3.2 Additional Winds. The criteria for determining the additional levels with respect to wind are based on the premise that these data alone would make it possible to reconstruct the wind speed and wind direction profiles within the limits of ten degrees for direction and five meters per second (ten knots) for speed. The number of additional levels ***should*** be kept to a minimum.

The additional level winds ***shall*** be selected without regard to the requirement for selecting fixed (regional) levels. In other words, an additional level wind could also be a fixed level wind.

5.3.2.1 Additional Level Selection Process. The additional wind levels for coding in the Part B and/or Part D of the coded message are selected in similar fashion to those for the thermodynamic variables. Levels are selected based on the departure of wind speed or direction from linearity when a function of the logarithm of pressure. To qualify, the wind speed must depart from such a linear interpolation by more than 10 knots or the wind direction must depart by more than 10 degrees. Winds whose speed is 10 knots or less are not considered at all in selecting additional wind levels. No additional wind levels occur within strata where the speed is 10 knots or less, regardless of the change in direction that may be occurring.

Some preference is given to speed over direction in selecting these levels. If the wind speed for a level exceeds the limit for departure from linearity and also is the greatest departure of wind speed from linearity, then the direction is not evaluated. If, however, the departure from linearity of wind speed is not sufficient to qualify a wind, then the direction is considered.

5.3.3 Terminating Wind. The terminating wind ***shall*** be selected if both of the following conditions are satisfied:

- the wind speed at the terminating level must exceed the speed of any other wind of the entire flight, and
- the wind speed at the terminating level must be greater than 60 knots.

5.3.4 Maximum Winds. Maximum winds are determined for Part A and/or Part C of the coded message (refer to Appendix E-II.2.4). Each maximum wind must satisfy <u>all</u> of the following criteria:

- the wind speed must be greater than 60 knots,
- it must occur at pressures less than 500 hPa, and
- a maximum wind level must be bounded by levels with winds of lower speeds than the maximum.

The following conditions disqualify a wind from being a maximum wind:

- a wind adjacent to a missing wind,
- a wind for a level whose pressure is equal to or less than 100 hPa (the dividing point for message Parts) if the adjacent wind at a level whose pressure is higher than 100 hPa is greater, or

- a wind for a level whose pressure is lower than 100 hPa if the adjacent wind below 100 hPa is larger.

Exception: The terminating wind qualifies as a level of maximum wind if it is the largest wind speed of the entire flight. It must be the largest wind speed in the range covered by a coded message Part (i.e., surface to 100 hPa or at pressures lower than 100 hPa).

5.3.5 Primary and Secondary Maximum Winds. If two winds with identical wind speeds satisfy the criteria for a maximum wind, the levels ***shall*** be encoded successively, beginning with the lowest altitude. The search for a secondary maximum does not start until a minimal wind is found. A minimal wind is identified when the previous trend is decreasing or missing and the current trend is increasing. When a minimal wind is identified, its speed is saved for further sequential analysis of candidate maximum winds.

A maximum wind is identified when the previous trend is increasing and the current trend is decreasing. When a maximum is found, it becomes a possible candidate for a secondary maximum wind if all of the following conditions are met:

- there has been no missing wind since the previous minimum wind,
- the speed of the maximum exceeds the speed of the two adjacent minima by at least ten meters per second (20 knots), and
- the speed of the maximum is greater than or equal to that of any candidate secondary maximum found.

The remaining winds are evaluated even after a secondary maximum is confirmed in case there is another wind with a higher speed, or the same speed but a higher altitude, that qualifies as another secondary maximum.

5.3.6 Wind Shear. The wind shear 915 meters (3000) ft above and 915 meters (3000 ft) below the maximum wind ***shall*** be computed and included in Part A and Part C of the coded messages. Refer to Appendices D and E for additional information on determining and coding wind shear.

5.3.7 Mean Winds. The mean wind direction and speed from the surface to 1525 meters (5000 ft) altitude and from 1525 to 3048 meters (5000 ft to 10,000 ft) ***shall*** be computed. The mean wind speed is a weighted average of wind vector components with respect to altitude. If the wind data are missing for 2500 ft altitude or more, then the mean wind is missing. Information for computing the mean wind is given in Appendix D.

5.3.8 Other Factors. In addition to the standard isobaric and fixed regional levels specified above, other factors are pertinent to the selection of wind levels.

- The surface level and the highest level of the wind sounding are specified as mandatory significant levels and they ***shall*** be recorded as the first and last additional levels.

- The highest level of the sounding is defined as the highest 1000 foot level for which observed data are available. For example, if the ascent ended at 94,900 feet, the 94,000 foot level is the highest level of the sounding because it is the highest 1000 foot level for which observed data are available.

- When two additional wind levels occur within the stratum from 150 meters (500 feet) below to 150 meters (499 feet) above a reportable altitude, the wind having the greater speed ***shall*** be recorded for that altitude. In the event that both the winds have the same speed, data for the one having the greater altitude ***shall*** be recorded. For example, if the two additional winds occurred within the 26,500 - 27,499 foot stratum, the altitude to be recorded would be the 27,000 foot level.

- When an additional wind level occurs within the stratum from 500 feet below to 499 feet above a fixed Regional level, the speed and direction of the wind ***shall*** be recorded for that fixed Regional level in lieu of the data observed at the fixed level. An exception to this rule is when this occurs just above the surface. In this case, the surface wind ***shall*** be the only one reported.

- When an additional level coincides with some other compulsory reporting level (standard isobaric, maximum wind, tropopause, etc.) the wind ***shall*** also be recorded as an additional wind level.

5.4 **Selecting the Tropopause**. The information required for selecting the tropopause(s) has been delayed to this Section because both thermodynamic and wind data are helpful in the determination; the tropopause is best determined by examining all the level data selected. The expected conditions at the tropopause, in simple terms, are an abrupt change in temperature lapse rate and a maximum in wind speed. There may be, however, more than one such occurrence.

5.4.1 **The First Tropopause**. The tropopause(s) ***shall not*** be selected if the radiosonde has not reached 200 hPa or if an adjacent stratum is missing temperature data. The criteria for selecting the first tropopause are:

A. At pressures from 500 to 30 hPa (all three must occur):

1) The first instance (i.e. pressure) where the temperature lapse rate becomes less than or equal to 2°C per kilometer.

2) The average lapse rate from the tropopause point (from A.1) to any point at a higher height, within the next 2 km, does not exceed 2°C.

3) The radiosonde ascends to 2 km or more above the tropopause point (from A.1).

No tropopause is reported at pressures less than 30 hPa.

B. At pressures greater than 500 hPa (and only if no tropopause is found in (A.)

1) The smallest pressure (greater than 500 hPa) where the temperature lapse rate becomes less than or equal to 2°C per kilometer.

C. Otherwise:

1) If the average lapse rate from the tropopause point (B.1) to any height within the next 1 km does not exceed 3°C, nor for any other subsequent 1 km layer at pressures greater than 100 hPa.

The results of the automated procedure for determining the tropopause ***shall*** be displayed for the observer to check. The purpose of such a display is to advise the observer that a possible tropopause was rejected and to allow an examination of the selected tropopause, if one was found, to ensure that it is correct.

5.4.2 Multiple Tropopause Levels. If more than one pressure level satisfies the criteria of para. 5.4.1, then an additional tropopause level(s) ***shall*** be selected and reported.

5.4.3 Reporting. The pressure, geopotential height, temperature, dew-point depression, and wind direction and speed ***shall*** be reported at the tropopause level(s) for the TEMP message, parts A or C. (Appendix E-II.2.3).

5.5 Coded Message Generation. Routinely, the processing of parts A and B of the coded messages ***should not*** begin until the observation has reached 70 hPa. The coded message sequence ***shall*** be processed as specified below.

The coded message generation sequence ***should*** be initiated in one of three ways: automatically (such as at 70 hPa), on flight termination, or when a command is invoked.

The ground-system computer ***shall*** alert the observer when the coded message generation is complete and ready for review.

Parts C and D of the message ***should*** be coded immediately upon termination of the sounding.

5.6 Additional Information. Additional information to be reported ***shall*** be logged. Included are the date and time, information about the tropopause and the computed stability index, a report of flight problems, type of sonde and ground equipment used, and actual release time. The requirements for these additional code groups are found in Appendix E and Table 0421.

The stability index (see definition, Appendix G) *may* be determined graphically on a thermodynamic diagram or calculated automatically. In the latter instance, a complicated algorithm must be constructed owing to the intractability of the moist adiabatic process; no specific algorithm is given in Appendix D.