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OTHER BUSINESS

Pressure Reduction Formula

(Submitted by the Secretariat)

Summary and purpose of document

This document provides information on a request made to CIMO to clarify which pressure reduction formula should preferably be used to compare barometer readings taken at stations at different altitudes.

ACTION PROPOSED

The Meeting is invited to decide how it will address this matter and to designate one expert from among the team should carry out this task.

Appendices:		
	I	Excerpt from the CIMO Guide, Part I, Chapter 3 (Edition 2008, Updated in 2010)
	II	Request from Sweden

Pressure Reduction Formula

1. The CIMO Guide (Part I, Chapter 3, para 3.11) states the following:

> **3.11 Adjustment of barometer readings to other levels**
> In order to compare barometer readings taken at stations at different altitudes, it is necessary to reduce them to the same level. Various methods are in use for carrying out this reduction,but WMO has not yet recommended a particular method, except in the case of low-level stations. The recommended method is described in WMO (1954; 1964; 1968). WMO (1966) contains a comprehensive set of formulae that may be used for calculations involving pressure.

The complete excerpt from this CIMO Guide chapter is provided in Appendix I.

2. Sweden has approached WMO to seek guidance as to which formula should be used. The request of Sweden is provided in the Appendix II.

3. The CIMO Management Group, at its ninth session (Brussels, Belgium, 19-20 October 2012) addressed this matter. It recognized that it would be desirable to provide a clear recommendation on the use of a single formula. However, it also noted that this could have significant implications for Members. The CIMO Management Group therefore requested CIMO Expert Team on Standardization to develop a technical report on the implication of the use of a single formula and a recommendation on which formula should be used.

4. The CIMO Management Group further recommended that this development be carried out in close liaison with CAS.

B_R: A barometer of category B which the National Meteorological Services of the Region agree to use as the standard barometer for that Region, in the event that the category A barometer is unavailable in the Region.

Annex 3.B contains the list of regional standard barometers.

3.10.5.2 System of interregional comparison

The following measures must be considered when planning interregional comparisons:

(a) Member countries in each Region will designate a primary or secondary standard barometer A to serve as A_r for the Region. If a primary or secondary barometer is not available within the Region, a category B barometer will be designated jointly as the regional standard barometer for that Region, with the barometer so chosen being denoted by the symbol B_r. Relative costs will determine whether a Region may deem it advantageous to designate more than one standard barometer;

(b) A competent person carrying travelling standard barometers will travel from a central station equipped with a barometer of category A_r to a nearby Region equipped with a barometer of at least category B or B_r. A comparison of the barometers should then be performed in accordance with the method outlined in section 3.10.3. For the purposes of verification and intercomparison, it is sometimes desirable to repeat the process by comparing the B_r barometer with a barometer of category A_r from a different Region;

(c) Copies of the comparison records should be transmitted to each of the central stations equipped with a category A barometer and to the station where the barometer B or B_r compared is located. Summaries of the comparison results should be forwarded to all National Meteorological Services in the Region where the barometer B or B_r is located.

3.10.5.3 System of international comparison within a Region

The following measures must be considered when planning international comparisons:

(a) Each National Meteorological Service will compare its category B barometer with the category A barometer within the Region, if available, using the system outlined in section 3.10.4. Where possible, preference should be given to the category A barometer for the Region as the standard instrument for the area;

(b) When a category A barometer is not available in the Region, the category B barometers of the respective National Meteorological Service of the Region will be compared with the category B_r barometer for the Region, in accordance with section 3.10.4;

(c) When a competent person is engaged in the execution of the programme to compare barometers of categories B with B_r, it is desirable that additional en route comparisons be made with barometers of categories B and C, while the person is travelling both to and from the station where the instrument B_r for the Region is located;

(d) Copies of records and summaries of comparisons will be prepared and forwarded to interested agencies as outlined in paragraph 3.10.5.2 (c).

3.11 ADJUSTMENT OF BAROMETER READINGS TO OTHER LEVELS

In order to compare barometer readings taken at stations at different altitudes, it is necessary to reduce them to the same level. Various methods are in use for carrying out this reduction,but WMO has not yet recommended a particular method, except in the case of low-level stations.

The recommended method is described in WMO (1954; 1964; 1968). WMO (1966) contains a comprehensive set of formulae that may be used for calculations involving pressure.

3.11.1 Standard levels

The observed atmospheric pressure should be reduced to mean sea level (see Part I, Chapter 1) for all stations where this can be done with reasonable accuracy. Where this is not possible, a station should, by regional agreement, report either the geopotential of an agreed “constant pressure level” or the pressure reduced to an agreed datum for the station. The level chosen for each station should be reported to the WMO Secretariat for promulgation.

Reduction formula for sea-level pressure feasible for stations below 750 m (from WMO, 1964, p. 22, equation 2):

$$\log_{10}\frac{p_0}{p_S} = \frac{K_p \cdot H_p}{T_{mv}} = \frac{K_p \cdot H_p}{T_S + \frac{a \cdot H_p}{2} + e_S \cdot C_h} \qquad (3.1)$$

where p_0 is the pressure reduced to sea level in hPa; p_S is the station pressure in hPa; K_p is the constant = 0.0148275 K / gpm; H_p is the station elevation in gpm; T_{mv} is the mean virtual temperature in K; T_S is the station temperature in K; $T_S = 273{,}15 + t$, t is the station temperature in °C; a is the assumed lapse-rate in the fictitious air column extending from sea level to the level of the station elevation level = 0.0065 K / gpm; e_S is the vapour pressure at the station in hPa; and C_h is the coefficient = 0.12 K / hPa.

The same formula is often used in the exponential form:

$$p_0 = p_S \cdot \exp\left(\frac{\frac{g_n}{R} \cdot H_p}{T_S + \frac{a \cdot H_p}{2} + e_S \cdot C_h}\right) \qquad (3.2)$$

where g_n is the standard acceleration of gravity = 9.806 65 m s^{-2} and R is the gas constant of dry air = 287,05 J /kg / K.

3.11.2 Low-level stations

At low-level stations (namely, those at a height of less than 50 m above mean sea level), pressure readings should be reduced to mean sea level by adding to the station pressure a reduction constant C given by the following expression:

$$C = p \, . \, H_p / 29.27 \, T_v \qquad (3.3)$$

where p is the observed station pressure in hectopascals; H_p is the station elevation in metres; and T_v is the mean annual normal value of virtual temperature at the station in kelvins.

Note: The virtual temperature of damp air is the temperature at which dry air of the same pressure would have the same density as the damp air. WMO (1966) contains virtual temperature increments of saturated moist air for various pressures and temperatures.

This procedure should be employed only at stations of such low elevation that when the absolute extreme values of virtual temperature are substituted for T_v in the equation, the deviation of the result due to the other approximations of the equation (used for height rather than standard geopotential, and with C to be small compared with p) is negligible in comparison.

3.12 PRESSURE TENDENCY AND PRESSURE TENDENCY CHARACTERISTIC

At surface synoptic observing stations, pressure tendency and the pressure tendency characteristic should be derived from pressure observations from the last 3 h (over 24 h in tropical regions). Typically, the pressure tendency characteristic can be expressed by the shape of the curve recorded by a barograph during the 3 h period preceding an observation (WMO, 2010*b*). In the case of hourly observations, the amount and characteristic can be based on only four observations, and misinterpretations may result. Therefore, it is recommended that the characteristic should be determined on a higher frequency of observations, for example with 10 min intervals (WMO, 1985). Nine types of pressure tendency characteristics are defined (see WMO, 2010*a*, p. II-4-8).

SWEDISH ARMED FORCES
METOC CENTRE

Abstract from Mission 2007010

2007-05-22

Pressure reductions

Background

A large difference in reduced pressure (QFF) at low temperatures was observed in northern Sweden in late January 2007 and the background of the differences had to be cleared out. At the same time the calculation of QNH was controlled.

Data used

Raw data from military automatic weather stations 02154 and 02141 (temperature, dewpoint, QFE, QFF and QNH) from January 22nd – 25th 2007. Source code of local reduction programs of Milmet (Swedish military weather information system) dated around 1996. Documents ”*MILOS PRESSURE AND DEWPOINT CALCULATIONS*” (1998-09-08) and ”*FMV M500 upgrade QNH calculation formula*” (1998-10-08) from Vaisala. QFF formula from Swedish Meteorological and Hydrological Institute (SMHI, 1978-10-11). OBS2000 (SMHI automatic weather stations) reduction formulas (probably from the middle of 1980s). Report I-TWR 012 / 2006 (2006-12-21) on calculations of QFE, QNH and QFF in Swedish versions of Vaisala Milos 5x0. Information from the Danish (DMI), Norwegian (DNMI) and Finnish (FMI) meteorological institutes on their formulas. ICAO definition of QNH (ICAO Doc 9837 ”*Manual of Automatic Meteorological Observing Systems at Aerodromes*”, 2005, from work group AMOSSG, referencing to ICAO Doc 7488). WMO Technical Note No. 61: WMO-No. 154. TP. 74. ”*Note on the standardisation of pressure reduction methods in the international network of synoptic stations*”, 1964. WMO Technical Note No. 91: WMO-No.226. TP.120 ”*Methods in use for the reduction of atmospheric pressure*”, 1968. WMO-No 8 ”*Guide to Meteorological Instruments and Methods of Observation*”, preliminary seventh edition, 2006. WMO-No. 306 ”*Manual on Codes*”. U.S. Standard Atmosphere 1976 (http://modelweb.gsfc.nasa.gov/atmos/us_standard.html).
Pressure reduction theory and basic constants from ”*Definitioner, formler och konstanter inom termodynamik, hydrostatik och molnfysik*”(Definitions, formulas and constants in thermodynamics, hydrostatics and cloud physics, Swedish only), Birger Rindert, Meteorological department, Uppsala University (1978). Latest internationally recommended values of physical constants (CODATA 2006) from the U.S. National Institute of Standards and Technology (http://physics.nist.gov/cuu/Constants/index.html). Richard Shelquist at http://wahiduddin.net. ”*Smithsonian Meteorological Tables*”, sixth edition (1963). Gas constants of dry air and water vapour from the International Union of Pure and Applied Chemistry (IUPAC, http://www.iupac.org).
Gravitation formulas from Geophysics vol 66 no 6 p 1660-1668, Xiong Li and Hans-Jürgen Götze. Geological Survey of Canada (http://gsc.nrcan.gc.ca/gravity/theory_e.php?p=1). Professor emeritus Judson L Ahern, University of Oklahoma (http://geophysics.ou.edu/solid_earth/notes/potential/igf.htm).
Vapour pressure formulas from WMO: *Instruments and Observing Methods Report no 19, ”Some General considerations and specific examples in the design of algorithms for synoptic automatic weather stations”*, 1987; WMO/TD-No.230. University of Colorado (http://cires.colorado.edu/~voemel/vp.html). *”Smithsonian Meteorological Tables”,* sixth edition (1963).

Result

WMO-No. 306 (Manual on Codes) says that reduction of station pressure to sea level (QFF) shall be done so that pressure analysis doesn't give discontinuities. It doesn't tell what formula to use, i e every country (or station owner) can use its own. In Sweden the formula 1 has been used at least since the 1970s for manual stations (ref George Ericsson, SMHI). It has been used to make reduction tables to all manual stations and had a reduction of the measurement to 0°C and standard gravity for the mercury barometers before using formula 1. Today mercury isn't allowed in Sweden and the aneroid or electrical barometers are calibrated to give 0°C, standard gravity.

1.
$$^{10}\log\frac{QFF}{QFE}=\frac{H}{18372}*\frac{1-\frac{0.0025}{273}*H}{1+\frac{t_v}{273}}$$

QFF is the reduced pressure (hPa) and QFE the official station pressure (hPa).
H is the stations official elevation (m).

$$t_v = t''+\frac{r}{100}\left(0.378*T*\frac{e_{t''}}{1000}\right)$$

t = station temperature (°C)
t'' = t if t>0°C, otherwise t'' = t/2+1
r = 70 if t>0°C, otherwise r = 70-t
T = t+273
$e_{t''}$ = vapour saturation pressure over water (hPa)

Pressure reduction is based on the fundamental law of gas:
2. $dp = -\rho gdz$
The change of pressure (dp) is proportional to the change in height (dz), where minus density (ρ) times gravity (g) is the proportionality factor. This can be rewritten as

3.
$$dp=-\frac{p}{R_sT}gdz$$

R_s is the specific gas constant (J/kg/K), i e the mole gas constant R (≈ 8.3143 J/mol/K) divided to the mole weight of the gas (kg/mol, $m_d \approx 28.964$ g/mol dry air and $m_v \approx 18.015$ g/mol water vapour) and T temperature (K). If g and R_s(= R_d i e dry air) are considered constant with respect to height and T varies linearly (constant $\gamma = dT/dz$) the general formula is derived:

4.
$$p=p_0*\left(\frac{T}{T_0}\right)^{-\frac{g}{R_d\gamma}}$$

Since $T = T_0+\gamma(z-z_0)$ this can be rewritten as:

5.
$$p=p_0*\left(\frac{T_0+\gamma(z-z_0)}{T_0}\right)^{-\frac{g}{R_d\gamma}}$$

If the temperature is constant the integration ends up to:

6. $$p = p_0 * e^{-\frac{g(z-z_0)}{R_d T_0}}$$

With suitable basic values the equation becomes the International Standard Atmosphere (ISA) up to 11 km.

7. $$QNH = QFE\left\{1 - \frac{\gamma H}{T_0[\frac{QFE}{p_0}]^{-\frac{R_d\gamma}{g}}}\right\}^{-\frac{g}{R_d\gamma}}$$

R_d = specific gas constant of dry air (287.04 J/kg/K Rindert 1978)
$T_0 \equiv 288.15$ K (+15°C)
$p_0 \equiv 1013.25$ hPa
$g \equiv 9.80665$ m/s² (standard gravity)
$\gamma \equiv -0.0065$ K/m
H = airport elevation in m
The elevation should be replaced with the geopotential height (gpm) but the difference can normally be neglected. See the section on gravity.
New estimates of R (≈ 8.314 472±0.000 015 J/mol/K according to CODATA 2006), m_d (≈ 28.9644 g/mol) and m_v (≈ 18.016 g/mol) are hinted by Richard Shelquist at http://wahiduddin.net. This gives R_d ≈ 287.05 J/kg/K that is used by some sources. U.S. Standard Atmosphere 1976 uses R = 8.31432 J/mol/K and m_d = 28.9644 g/mol.

Swedish Armed Forces version of Milos 5x0 uses formula 8 to calculate QNH:

8.
$$QNH = QFE * e^{\frac{gH}{R_d(T_0 + \frac{\gamma H}{2})}}$$

R_d = 287 J/kg/K (specific gas constant)
T_0 = 288.15 K (ISA surface temperature)
g = 9.81 m/s^2 (standard gravity)
H = airport (weather station) elevation (m)
$\gamma = -6.5*10^{-3}$ K/m (ISA temperature gradient)
The formula means that the linear temperature profile is approximated with a constant mean temperature.

Milmet local forecasting program (*Måltryck* and *QFE-QNH*) has formulas for QFF and QNH calculations. The QFF formula is essentially the same as for the manual stations (formula 1) but slightly rewritten and with other approximations of the constants.

9.
$$QFF = QFE * e^{\frac{9.8213594*H}{R_d(t_v + 0.0025*H)}}$$

R_d = 287.04 J/kg/K
g = 9.8213594 m/s²
$\gamma = 0.5*10^{-3}$ K/m
t_v is a kind of virtual temperature

10.
$$t_v = t'' + \frac{r}{100} * 0.378 * \frac{(t + 273) * e_{t''}}{1000} + 273$$

t = air temperature (°C)
$t'' = t$ if $t>0$
$t'' = 0.5*t + 1$ if $t<=0$
$r = 70 - t$ if $t>0$
$r = 70$ otherwise
$e_{t''}$ = saturation vapour pressure at temperature t''

Milmet uses the approximation:

11.
$$e_{t''} = 6.11 * e^{5418*(\frac{1}{273} - \frac{1}{t''+273})}$$

This is the simplest approximation and sometimes called Magnus' approximate formula (see the discussion on vapour saturation pressure). It considers the latent heat to be constant with temperature and gives good result between –20°C and +20°C. t_v is a way of using a ”normal” humidity.

QNH is calculated as:

12. $$QNH = QFE * e^{\frac{9.986*H}{287.04*(288-\frac{0.0065*H}{2})}}$$

i e the same as formula 8 but with other approximations of the constants.

R_d = 287.04 J/kg/K (specific gas constant)
T_0 = 288 K (ISA surface temperature)
g = 9.986 m/s^2 (standard gravity)
H = airport (weather station) elevation (m)
$\gamma = -6.5*10^{-3}$ K/m (ISA temperature gradient)
The formula has almost 2% gravity error.

The original Vaisala formula in Milos 500 was (1998-09-08):

13. $$QNH = QFE * e^{\frac{0.03416*H*(1-0.19025\ln(\frac{QFE}{1013.2315}))}{288.2+0.00325*H}}$$

Milos (and Vaisala standard) reduces from the sensor value to QFE (the official station pressure)

14. $$QFE = p_s * e^{\frac{H_s}{7996+0.0086*H_s+29.33*t}}$$

p_s = pressure sensor value (hPa)
t = air temperature (°C)
H_s = airport elevation above pressure sensor (m)

Today's Milos 5x0 of the Swedish Armed Forces uses Vaisala standard formula for QFF. It is exactly the same as the reduction from sensor elevation to airport elevation. FMI (ref Jussi Haapalainen, FMI) uses the formula and says it gives good result for most of Finland (stations below 200 m elevation) but they have some problems in Lapland at low temperatures.

15. $$QFF = QFE * e^{\frac{H}{7996+0.0086*H+29.33*t}}$$

SMHI uses the formula below for automatic stations (ref Ann-Christine Andersson, SMHI):

16. $$QFF = QFE * e^{\frac{H*0.034163(1-0.0026373\cos(2\varphi))}{T_1}}$$

φ=station latitude (correction due to gravitation variation with latitude)

T_l is a way of describing the winter inversions:

t < -7°C ==> $T_l = 0.5 * t + 275$
-7°C <= t < +2°C ==> $T_l = 0.535 * t + 275.6$
t >= +2°C ==> $T_l = 1.07 * t + 274.5$

According to Ann-Christine Andersson SMHI doesn't use the QNH reduction since that is only used for airports, where the Swedish Civil Aviation Administration (LFV) is responsible. Earlier the formula below was used.

17. $$QNH = QFE * e^{-5.25588*\ln(1-2.25577*10^{-5}*H)}$$

The formula is almost identical to the one used in Milos (formula 8) but slightly rewritten and with other approximations of the constants.

Anders Eriksson (+46 11-19 25 25) at the Swedish Civil Aviation Administration has given the following formulas used in their stations (AWOS). They use the Vaisala pressure sensor but have their own reduction formulas.

18. QFE = ?

19. $$QFF = QFE * (1 + \frac{B}{T} + \frac{1}{2}(\frac{B}{T})^2)$$

$B = 3.4163[1-2.6373*10^{-3}*\cos(2*\varphi)]*H/100$

T is defined by:

t < -7°C ==> $T = 0.5 * t + 275$
-7°C <= t < +2°C ==> $T = 0.54 * t + 275.6$
t >= +2°C ==> $T = 1.07 * t + 274.5$

It is the same formula as SMHI use for automatic stations but with slight rounding of T and only the first two terms in the Taylor series of the exponential function.

20. $$QNH = QFE * e^{-5.25588*\ln(1-2.25577*10^{-5}*H)}$$

The QNH formula is exactly the one SMHI used earlier.

DMI (ref Svend Aage Falkedal) uses the formulas below (valid up to 200-m reduction):

21. $$QFE = p_s * (1 + 0.034 * \frac{H_s}{T})$$

22. $$QFF = QFE * (1 + 0.034 * \frac{H}{T})$$

23. $$QNH = QFE(1 + \frac{H}{8518 - 0.84 * H - 1.61 * (1013 - QFE)})$$

DMI uses the same formula to reduce between sensor and station elevation, as between station elevation and mean sea level.

DNMI (ref Dag Roger Kristoffersen) uses reduction formulas close to the ones discussed by WMO (1964).

24. $$QFE = p_s + \frac{H_s}{t + 273.2} * 34.68$$

The above reduction is only to be done for $H_s \leq 20$ m.

25. $$QFF = QFE * e^{\frac{H}{Y}}$$

where $$Y = (C_u + 0.00325 * H + 273.2 + t_s) * 29.29$$

and $$C_u = U_m * (2.5 * 10^{-5} H + 0.10701) * 0.0611213 * e^{\frac{17.5043 * t_m}{241.2 + t_m}}$$

t_m = annual average temperature (°C)
U_m = annual average relative humidity (%)
Thus C_u is a constant for each station.
t_s will take care of surface inversions and is for most stations equal to t. Stations with frequent inversions instead has
$t < 1.5$°C ==> $t_s = 0.315 * t + 1.0$
$t > 1.5$°C ==> $t_s = t$
This gives a slightly discontinues t_s as does T_l of SMHI and T of LFV.

When calculating QNH the DNMI first calculates the elevation of pressure QFE in ISA, then calculates QNH of the elevation difference.

26. $$H_{QNH} = \frac{8439.9135 * \ln \frac{1013.25}{QFE}}{1 + 0.0951925 * \ln \frac{1013.25}{QFE}}$$

27. $$QNH = \left(1 - \frac{H_{QNH} - H}{44308}\right)^{\frac{1}{0.190}} * 1013.25$$

ICAO describes how to calculate QNH in ICAO Doc 7488 (generally) and ICAO Doc 9837 (for automatic stations. The calculation is made in the same two steps as DNMI use: first the elevation in ISA that has pressure QFE (formula 28), then QNH (formula 29).

28. $$H_{ISA} = 44330.77 - 11880.32 * QFE^{0.190263}$$

29. $$QNH = 1013.25 * \left(1 - 0.0065 * \frac{H_{ISA} - H}{288.15}\right)^{5.25588}$$

World Meteorological Organization (WMO) has a recommended formula for reducing to mean sea level only for low level stations (<50 m).

30. $$QFF = QFE\left(1 + \frac{H}{29.27\overline{T}_v}\right)$$

$\overline{T}_v$ = annual average of virtual temperature (K). It is only to be used when the variations of virtual temperature are small compared to the errors in elevation, temperature and station pressure.

31. $$T_v = T\left(1 + \left(\frac{1}{\varepsilon} - 1\right)q\right)$$

q = specific humidity, ε = relation between water vapour and dry air molar weight.

32. $$\varepsilon = \frac{m_v}{m_d}$$

33. $$q = \frac{\varepsilon e}{p - (1 - \varepsilon)e}$$

p = total air pressure, e = vapour pressure. The vapour pressure is per definition the same as the saturation vapour pressure at dew point temperature.

For higher elevations Technical note no. 61 ”*Note on the standardization of pressure reduction methods in the international network of synoptic stations*” discusses difficulties and possible ways of reducing the pressure. Technical note no. *7 ”Reduction of atmospheric pressure (Preliminary report on problems involved)*” is referenced further. The discussion ends up for a reduction downward (fictive air column) in equation

34. $$\log_{10}\frac{QFF}{QFE} = 0.0148275 * \frac{H_g}{T_s + \frac{a * H_g}{2}} * \left(1 - 0.378\frac{e_m}{p_m}\right)$$

where H_g is the geopotential, i e elevation times the integrated local gravity divided by standard gravity, a is the fictive mean temperature gradient, T_s relevant temperature, e_m fictive mean vapour pressure and p_m fictive mean air pressure. Combining the gravity formulas G4 and G5 give

35. $$H_g = H\left(\frac{9.80620\left(1 - 2.6442 * 10^{-3}\cos(2\varphi) + 5.8 * 10^{-6}\cos^2(2\varphi)\right) - \frac{3.086 * 10^{-6}H}{2}}{9.80665}\right)$$

Formula 33 is rewritten as

35. $$\log_{10}\frac{QFF}{QFE} = \frac{0.0148275 * H_g}{T_s + \frac{a * H_g}{2} + e_s C_h}$$

The denominator is some kind of average virtual temperature, e_s a relevant vapour pressure and C_h a temperature depending constant.

36. $$T_{mv} = T_s + \frac{a * H_g}{2} + e_s C_h$$

Fluctuations in calculated pressure due to local temporal variations in temperature can be reduced by using the mean value of the actual temperature (T) and the temperature 12 hours ago (T_{12}). a is set to ISA temperature gradient (-0.0065 K/m) and C_h to 0.12°C/hPa. To consider long-term temperature inversions a constant F is used ending in equation

37. $$T_{mv} = \frac{T + T_{12}}{2} + F + \frac{0.0065 * H_g}{2} + 0.12 * e_s$$

To get a number that can be used as F the average conditions of the station are considered. This gives:

38. $$F = \frac{0.0148275 * H_g}{\log_{10} \frac{\overline{QFF}}{\overline{QFE}}} - \overline{T} - \frac{0.0065 * H_g}{2} - 0.12 * \overline{e_s}$$

Overbars mean monthly averages. Since F should describe the variation from the large-scale mean temperature $\frac{T + T_{12}}{2}$ it will mostly become zero (0).

Stations where the ISA temperature gradient is considered too high are suggested to neglect humidity dependence since it's primarily places close to the poles that has low temperature gradient and they also have low absolute humidity.

This way of reducing is difficult to handle especially for stations without calculated standard values (e g new or mobile stations). Every station has to have a large number of unique values or a whole database that selects values upon station id. Apart from that an automatic criteria to select inversion or not has to be obtained. To use humidity, mean temperature of observation and 12 hours earlier, plus using local gravity is suitable for automatic stations, even mobile ones.

Comparing the theoretical calculation of QNH (formula 7) with Milmet (formula 12), Milos' (formula 8), Vaisala old (formula 13), LFV/SMHI old (formula 20), DMI (formula 23) and DNMI (formula 27) the differences below are obtained (formula 7 minus each approximation) in hPa.

100 m reduction

QFE	QNH theory	Milmet	Milos	Vaisala old	LFV/SMHI old	DMI	DNMI
940 hPa	951.4	0.1	-0.1	0.0	-0.1	-0.1	-0.2
965 hPa	976.6	0.1	-0.1	0.0	-0.1	-0.1	-0.1
990 hPa	1001.8	0.2	0.0	0.0	0.0	-0.1	0.0
1015 hPa	1027.1	0.3	0.0	0.0	0.0	-0.1	0.0
1040 hPa	1052.3	0.3	0.1	0.0	0.1	-0.1	0.1

200 m reduction

QFE	QNH theory	Milmet	Milos	Vaisala old	LFV/SMHI old	DMI	DNMI
930 hPa	952.6	0.2	-0.3	0.0	-0.3	0.0	-0.2
955 hPa	978.1	0.3	-0.1	0.0	-0.2	0.0	-0.1
980 hPa	1003.6	0.4	0.0	0.0	0.0	0.0	0.0
1005 hPa	1029.1	0.5	0.1	0.0	0.1	0.0	0.0
1030 hPa	1054.6	0.7	0.2	0.0	0.2	0.0	0.1

300 m reduction

QFE	QNH theory	Milmet	Milos	Vaisala old	LFV/SMHI old	DMI	DNMI
920 hPa	953.8	0.2	-0.4	0.0	-0.4	*0.2*	-0.2
945 hPa	979.6	0.4	-0.2	0.0	-0.2	*0.2*	-0.1
970 hPa	1005.3	0.6	0.0	0.0	-0.1	*0.2*	0.0
995 hPa	1031.0	0.8	0.1	0.0	0.1	*0.2*	0.0
1020 hPa	1056.8	1.0	0.3	0.0	0.3	*0.2*	0.1

400 m reduction

QFE	QNH theory	Milmet	Milos	Vaisala old	LFV/SMHI old	DMI	DNMI
910 hPa	954.9	0.3	-0.5	0.0	-0.5	*0.5*	-0.2
935 hPa	980.9	0.6	-0.3	0.0	-0.3	*0.5*	-0.1
960 hPa	1006.9	0.8	0.0	0.0	-0.1	*0.5*	0.0
985 hPa	1032.9	1.1	0.2	0.0	0.2	*0.5*	0.0
1010 hPa	1058.9	1.4	0.4	0.0	0.4	*0.5*	0.1

600 m reduction

QFE	QNH theory	Milmet	Milos	Vaisala old	LFV/SMHI old	DMI	DNMI
890 hPa	956.8	0.5	-0.7	0.0	-0.8	*1.5*	-0.2
915 hPa	983.3	0.9	-0.4	0.0	-0.4	*1.5*	-0.1
940 hPa	1009.8	1.3	0.0	0.0	0.0	*1.6*	-0.1
965 hPa	1036.3	1.7	0.4	0.0	0.3	*1.6*	0.0
990 hPa	1062.8	2.1	0.7	0.0	0.7	*1.6*	0.1

800 m reduction

QFE	QNH theory	Milmet	Milos	Vaisala old	LFV/SMHI old	DMI	DNMI
870 hPa	958.4	0.7	-0.9	0.0	-1.0	*3.0*	-0.2
895 hPa	985.4	1.3	-0.5	0.0	-0.5	*3.1*	-0.1
920 hPa	1012.4	1.8	0.0	0.0	0.0	*3.2*	-0.1
945 hPa	1039.4	2.4	0.5	0.0	0.5	*3.3*	0.0
970 hPa	1066.4	2.9	1.0	0.0	1.0	*3.3*	0.1

1000 m reduction

QFE	QNH theory	Milmet	Milos	Vaisala old	LFV/SMHI old	DMI	DNMI
850 hPa	959.5	0.9	-1.2	-0.1	-1.2	*5.1*	-0.2
875 hPa	987.1	1.6	-0.5	-0.1	-0.6	*5.3*	-0.2
900 hPa	1014.6	2.3	0.1	0.0	0.0	*5.4*	-0.1
925 hPa	1042.2	3.0	0.7	0.0	0.7	*5.6*	0.0
950 hPa	1069.7	3.7	1.4	0.0	1.3	*5.7*	0.1

1500 m reduction

QFE	QNH theory	Milmet	Milos	Vaisala old	LFV/SMHI old	DMI	DNMI
800 hPa	960.5	1.4	-1.7	-0.1	-1.8	*13.1*	-0.3
825 hPa	989.4	2.5	-0.8	-0.1	-0.8	*13.5*	-0.2
850 hPa	1018.4	3.6	0.3	-0.1	0.2	*13.9*	-0.1
875 hPa	1047.3	4.8	1.3	-0.1	1.2	*14.2*	0.0
900 hPa	1076.2	5.9	2.3	-0.1	2.3	*14.6*	0.0

2000 m reduction

QFE	QNH theory	Milmet	Milos	Vaisala old	LFV/SMHI old	DMI	DNMI
750 hPa	958.5	1.8	-2.5	-0.2	-2.5	*25.4*	-0.4
775 hPa	989.0	3.3	-1.1	-0.1	-1.1	*26.2*	-0.3
800 hPa	1019.4	4.9	0.4	-0.1	0.3	*26.9*	-0.2
825 hPa	1049.8	6.5	1.8	-0.1	1.7	*27.7*	-0.1
950 hPa	1080.2	8.2	3.3	-0.1	3.2	*28.4*	0.0

Milmet formula gives largest differences up to 400-m reduction. Both the formulas used in Milos and LFV / SMHI old gives as large variations but centred around zero. The DMI approximation is very good up to approximately 240 m (differs <0.1 hPa) but should only be used up to 200 m. The old Vaisala approximation gives almost identical results as the theoretical formula (formula 7). Max difference up to 400 m is <0.02 hPa, up to 2000 m <0.18 hPa. The difference between the theoretical formula, ICAO formula and changing the gas constant of dry air (R_d) in formula 7 to the most recent accepted value gives a difference of <0.02 hPa up to 2000 m. The DNMI formula gives <0.18 hPa difference up to 400 m, <0.36 hPa up to 2000 m. The other formulas (except Milmet with incorrect gravity constant) differs 0.5 hPa or less up to 400 m.

For the QFF reduction only the SMHI OBS2000-formula and the almost identical from LFV considers gravitation variation with latitude. Comparison is made for latitude 60° in the first tables. After that the variation of the OBS2000-formulan for different latitudes is shown (variation from the result at latitude 60°). The differences between Milmet, Milos/FMI, OBS2000 and DMI compared to SMHI manual is shown in the table below. Differences of ½ - 1 hPa are marked yellow, differences >1 hPa blue. To calculate the DNMI reduction the station climate has to be known. For the comparing the annual average temperature has been set to +10°C-0.0065*station elevation and an annual average relative humidity of 80%. Reducing 2000 m gives a difference of 0.11-0.18 hPa with a 5°C variation in annual average temperature, 0.25-0.41 hPa difference with annual average relative humidity varying between 50% and 100%.

100 m reduction
Temperature -50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
940 hPa	0.0	0.0	1.5	1.3	-0.6
965 hPa	0.0	0.0	1.6	1.4	-0.6
990 hPa	0.0	0.0	1.6	1.4	-0.6
1015 hPa	0.0	0.0	1.6	1.4	-0.6
1040 hPa	0.0	0.0	1.7	1.5	-0.6

Temperature -25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
940 hPa	0.0	0.0	0.7	0.5	-0.3
965 hPa	0.0	0.0	0.7	0.5	-0.3
990 hPa	0.0	0.0	0.7	0.5	-0.3
1015 hPa	0.0	0.0	0.7	0.6	-0.3
1040 hPa	0.0	0.0	0.7	0.6	-0.3

Temperature ±0°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
940 hPa	0.0	0.0	0.0	-0.1	-0.1
965 hPa	0.0	0.0	0.0	-0.1	-0.1
990 hPa	0.0	0.0	0.1	-0.1	-0.1
1015 hPa	0.0	0.0	0.1	-0.1	-0.1
1040 hPa	0.0	0.0	0.1	-0.1	-0.1

Temperature +25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
940 hPa	0.0	-0.1	0.0	-0.1	0.0
965 hPa	0.0	-0.1	0.0	-0.1	0.0
990 hPa	0.0	-0.1	0.0	-0.1	0.0
1015 hPa	0.0	-0.1	0.0	-0.1	0.0
1040 hPa	0.0	-0.1	0.0	-0.1	0.0

Temperature +50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
940 hPa	0.0	-0.1	0.1	0.0	0.0
965 hPa	0.0	-0.1	0.1	0.0	0.0
990 hPa	0.0	-0.1	0.1	0.0	0.0
1015 hPa	0.0	-0.1	0.1	0.0	0.0
1040 hPa	0.0	-0.1	0.1	0.0	0.0

200 m reduction

Temperature -50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
930 hPa	0.0	-0.1	3.1	2.5	-1.1
955 hPa	0.0	-0.1	3.1	2.5	-1.2
980 hPa	0.0	-0.1	3.2	2.6	-1.2
1005 hPa	0.0	-0.1	3.3	2.7	-1.2
1030 hPa	0.0	-0.1	3.4	2.7	-1.2

Temperature -25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
930 hPa	0.0	0.0	1.4	0.9	-0.6
955 hPa	0.0	0.0	1.4	0.9	-0.6
980 hPa	0.0	0.0	1.4	0.9	-0.6
1005 hPa	0.0	0.0	1.5	1.0	-0.6
1030 hPa	0.0	0.0	1.5	1.0	-0.7

Temperature ±0°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
930 hPa	0.0	-0.1	0.1	-0.3	-0.1
955 hPa	0.0	-0.1	0.1	-0.3	-0.1
980 hPa	0.0	-0.1	0.1	-0.3	-0.1
1005 hPa	0.0	-0.1	0.1	-0.3	-0.1
1030 hPa	0.0	-0.1	0.1	-0.3	-0.1

Temperature +25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
930 hPa	0.0	-0.1	0.1	-0.2	0.0
955 hPa	0.0	-0.1	0.1	-0.2	0.0
980 hPa	0.0	-0.1	0.1	-0.2	0.0
1005 hPa	0.0	-0.1	0.1	-0.3	0.0
1030 hPa	0.0	-0.1	0.1	-0.3	0.0

Temperature +50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
930 hPa	0.0	-0.1	0.2	-0.1	0.1
955 hPa	0.0	-0.1	0.2	-0.1	0.1
980 hPa	0.0	-0.1	0.2	-0.1	0.1
1005 hPa	0.0	-0.1	0.2	-0.1	0.1
1030 hPa	0.0	-0.1	0.2	-0.1	0.1

300 m reduction

Temperature -50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
920 hPa	0.0	0.0	4.6	*3.5*	-1.7
945 hPa	0.0	-0.1	4.8	*3.5*	-1.7
970 hPa	0.0	-0.1	4.9	*3.6*	-1.8
995 hPa	0.0	-0.1	5.0	*3.7*	-1.8
1020 hPa	0.0	-0.1	5.1	*3.8*	-1.9

Temperature -25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
920 hPa	0.0	0.0	2.1	*1.1*	-0.9
945 hPa	0.0	0.0	2.1	*1.1*	-0.9
970 hPa	0.0	0.0	2.2	*1.2*	-1.0
995 hPa	0.0	0.0	2.2	*1.2*	-1.0
1020 hPa	0.0	0.0	2.3	*1.2*	-1.0

Temperature ±0°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
920 hPa	0.0	-0.1	0.2	*-0.6*	-0.2
945 hPa	0.0	-0.1	0.2	*-0.6*	-0.2
970 hPa	0.0	-0.1	0.2	*-0.6*	-0.2
995 hPa	0.0	-0.1	0.2	*-0.7*	-0.2
1020 hPa	0.0	-0.1	0.2	*-0.7*	-0.2

Temperature +25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
920 hPa	0.0	-0.1	0.2	*-0.5*	0.0
945 hPa	0.0	-0.1	0.2	*-0.5*	0.0
970 hPa	0.0	-0.1	0.2	*-0.5*	0.0
995 hPa	0.0	-0.1	0.2	*-0.5*	0.0
1020 hPa	0.0	-0.1	0.2	*-0.6*	0.0

Temperature +50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
920 hPa	0.0	-0.1	0.3	*-0.3*	0.1
945 hPa	0.0	-0.1	0.3	*-0.3*	0.1
970 hPa	0.0	-0.1	0.3	*-0.3*	0.1
995 hPa	0.0	-0.1	0.3	*-0.3*	0.1
1020 hPa	0.0	-0.1	0.3	*-0.3*	0.1

400 m reduction

Temperature -50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
910 hPa	0.0	0.0	6.2	*4.2*	-2.3
935 hPa	0.0	0.0	6.4	*4.4*	-2.3
960 hPa	0.0	0.0	6.6	*4.5*	-2.4
985 hPa	0.0	0.0	6.8	*4.6*	-2.5
1010 hPa	0.0	0.0	6.9	*4.7*	-2.5

Temperature -25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
910 hPa	0.0	0.0	2.8	*1.2*	-1.2
935 hPa	0.0	0.0	2.9	*1.2*	-1.2
960 hPa	0.0	0.0	3.0	*1.3*	-1.3
985 hPa	0.0	0.0	3.1	*1.3*	-1.3
1010 hPa	0.0	0.0	3.1	*1.3*	-1.3

Temperature ±0°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
910 hPa	0.0	0.0	0.3	*-1.0*	-0.3
935 hPa	0.0	0.0	0.3	*-1.1*	-0.3
960 hPa	0.0	0.0	0.3	*-1.1*	-0.3
985 hPa	0.0	0.0	0.3	*-1.1*	-0.3
1010 hPa	0.0	0.0	0.3	*-1.2*	-0.3

Temperature +25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
910 hPa	0.0	-0.1	0.3	*-0.9*	-0.1
935 hPa	0.0	-0.1	0.3	*-0.9*	-0.1
960 hPa	0.0	-0.1	0.3	*-0.9*	-0.1
985 hPa	0.0	-0.1	0.3	*-0.9*	-0.1
1010 hPa	0.0	-0.1	0.3	*-1.0*	-0.1

Temperature +50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
910 hPa	0.0	-0.1	0.4	*-0.6*	0.1
935 hPa	0.0	-0.1	0.4	*-0.6*	0.1
960 hPa	0.0	-0.1	0.4	*-0.6*	0.1
985 hPa	0.0	-0.1	0.4	*-0.6*	0.1
1010 hPa	0.0	-0.1	0.5	*-0.6*	0.1

600 m reduction

Temperature -50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
890 hPa	0.0	0.1	9.6	5.3	-3.5
915 hPa	0.0	0.1	9.8	5.5	-3.6
940 hPa	0.0	0.1	10.1	5.6	-3.7
965 hPa	0.0	0.1	10.4	5.8	-3.7
990 hPa	0.0	0.1	10.6	5.9	-3.8

Temperature -25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
890 hPa	0.0	0.2	4.4	0.9	-1.9
915 hPa	0.0	0.2	4.5	1.0	-1.9
940 hPa	0.0	0.2	4.6	1.0	-2.0
965 hPa	0.0	0.2	4.7	1.0	-2.0
990 hPa	0.0	0.2	4.9	1.0	-2.1

Temperature ±0°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
890 hPa	0.0	0.1	0.6	-2.3	-0.4
915 hPa	0.0	0.1	0.6	-2.3	-0.4
940 hPa	0.0	0.1	0.6	-2.4	-0.5
965 hPa	0.0	0.1	0.6	-2.4	-0.5
990 hPa	0.0	0.1	0.6	-2.5	-0.5

Temperature +25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
890 hPa	0.0	0.0	0.5	-1.9	-0.1
915 hPa	0.0	0.0	0.5	-1.9	-0.1
940 hPa	0.0	0.0	0.6	-2.0	-0.1
965 hPa	0.0	0.0	0.6	-2.0	-0.1
990 hPa	0.0	0.0	0.6	-2.1	-0.1

Temperature +50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
890 hPa	0.0	0.0	0.7	-1.3	0.2
915 hPa	0.0	0.0	0.7	-1.4	0.2
940 hPa	0.0	0.0	0.7	-1.4	0.2
965 hPa	0.0	-0.1	0.8	-1.4	0.2
990 hPa	0.0	-0.1	0.8	-1.5	0.2

1000 m reduction

Temperature -50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
850 hPa	-0.1	0.7	16.5	*5.6*	-5.9
875 hPa	-0.1	0.7	17.0	*5.7*	-6.1
900 hPa	-0.1	0.7	17.5	*5.9*	-6.2
925 hPa	-0.1	0.8	18.0	*6.0*	-6.4
950 hPa	-0.1	0.8	18.5	*6.2*	-6.6

Temperature -25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
850 hPa	0.0	0.7	7.7	*-1.1*	-3.2
875 hPa	0.0	0.8	8.0	*-1.2*	-3.3
900 hPa	0.0	0.8	8.2	*-1.2*	-3.4
925 hPa	0.0	0.8	8.4	*-1.2*	-3.5
950 hPa	0.0	0.8	8.6	*-1.3*	-3.6

Temperature ±0°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
850 hPa	0.0	0.6	1.4	*-5.9*	-0.8
875 hPa	0.0	0.6	1.4	*-6.1*	-0.8
900 hPa	0.0	0.6	1.4	*-6.3*	-0.8
925 hPa	0.0	0.6	1.5	*-6.5*	-0.9
950 hPa	0.0	0.7	1.5	*-6.6*	-0.9

Temperature +25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
850 hPa	0.1	0.4	1.2	*-4.9*	-0.2
875 hPa	0.1	0.4	1.3	*-5.0*	-0.2
900 hPa	0.1	0.4	1.3	*-5.2*	-0.2
925 hPa	0.1	0.4	1.3	*-5.3*	-0.2
950 hPa	0.1	0.4	1.4	*-5.5*	-0.2

Temperature +50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
850 hPa	0.1	0.3	1.5	*-3.7*	0.3
875 hPa	0.1	0.3	1.5	*-3.8*	0.3
900 hPa	0.1	0.3	1.6	*-3.9*	0.3
925 hPa	0.1	0.3	1.6	*-4.0*	0.3
950 hPa	0.1	0.3	1.7	*-4.2*	0.3

1500 m reduction

Temperature -50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
800 hPa	-0.2	2.0	25.9	*2.5*	-9.1
825 hPa	-0.2	2.0	26.7	*2.6*	-9.3
850 hPa	-0.2	2.1	27.5	*2.7*	-9.6
875 hPa	-0.2	2.2	28.3	*2.8*	-9.9
900 hPa	-0.2	2.2	29.1	*2.9*	-10.2

Temperature -25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
800 hPa	-0.1	2.0	12.4	*-6.3*	-4.9
825 hPa	-0.1	2.0	12.8	*-6.5*	-5.1
850 hPa	-0.1	2.1	13.2	*-6.7*	-5.3
875 hPa	-0.1	2.2	13.6	*-6.9*	-5.4
900 hPa	-0.1	2.2	14.0	*-7.1*	-5.6

Temperature ±0°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
800 hPa	0.0	1.7	2.8	*-12.6*	-1.3
825 hPa	0.1	1.8	2.9	*-13.0*	-1.4
850 hPa	0.1	1.8	2.9	*-13.4*	-1.4
875 hPa	0.1	1.9	3.0	*-13.8*	-1.5
900 hPa	0.1	1.9	3.1	*-14.2*	-1.5

Temperature +25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
800 hPa	0.2	1.3	2.5	*-10.4*	-0.4
825 hPa	0.2	1.3	2.6	*-10.7*	-0.4
850 hPa	0.2	1.4	2.7	*-11.1*	-0.4
875 hPa	0.2	1.4	2.7	*-11.4*	-0.4
900 hPa	0.2	1.5	2.8	*-11.7*	-0.4

Temperature +50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
800 hPa	0.3	1.1	2.8	*-8.1*	0.5
825 hPa	0.3	1.1	2.9	*-8.4*	0.5
850 hPa	0.3	1.2	3.0	*-8.6*	0.5
875 hPa	0.3	1.2	3.1	*-8.9*	0.5
900 hPa	0.3	1.2	3.2	*-9.1*	0.5

2000 m reduction

Temperature -50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
750 hPa	-0.4	3.9	35.8	*-3.7*	-12.3
775 hPa	-0.4	4.0	37.0	*-3.8*	-12.7
800 hPa	-0.4	4.1	38.1	*-3.9*	-13.1
825 hPa	-0.4	4.3	39.3	*-4.0*	-13.5
850 hPa	-0.4	4.4	40.5	*-4.2*	-14.0

Temperature -25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
750 hPa	-0.1	3.8	17.6	*-14.0*	-6.8
775 hPa	-0.1	3.9	18.2	*-14.5*	-7.0
800 hPa	-0.1	4.0	18.8	*-14.9*	-7.2
825 hPa	-0.1	4.2	19.4	*-15.4*	-7.5
850 hPa	-0.1	4.3	20.0	*-15.9*	-7.7

Temperature ±0°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
750 hPa	0.1	3.4	4.6	*-21.3*	-1.9
775 hPa	0.1	3.5	4.8	*-22.0*	-2.0
800 hPa	0.1	3.6	5.0	*-22.7*	-2.1
825 hPa	0.1	3.7	5.1	*-23.4*	-2.1
850 hPa	0.1	3.8	5.3	*-24.1*	-2.2

Temperature +25°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
750 hPa	0.4	2.7	4.2	*-17.5*	-0.5
775 hPa	0.4	2.8	4.3	*-18.0*	-0.6
800 hPa	0.4	2.9	4.5	*-18.6*	-0.6
825 hPa	0.4	3.0	4.6	*-19.2*	-0.6
850 hPa	0.4	3.1	4.7	*-19.8*	-0.6

Temperature +50°C

QFE	Milmet	OBS2000	Milos/FMI	DMI	DNMI
750 hPa	0.5	2.3	4.5	*-13.8*	0.6
775 hPa	0.5	2.4	4.7	*-14.3*	0.6
800 hPa	0.5	2.5	4.8	*-14.7*	0.6
825 hPa	0.6	2.6	5.0	*-15.2*	0.7
850 hPa	0.6	2.6	5.2	*-15.6*	0.7

Latitude difference OBS2000
200 m reduction
Temperature -50°C

QFE	75°	50°	25°	Equator
930 hPa	0.0	0.0	-0.1	-0.1
955 hPa	0.0	0.0	-0.1	-0.1
980 hPa	0.0	0.0	-0.1	-0.1
1005 hPa	0.0	0.0	-0.1	-0.1
1030 hPa	0.0	0.0	-0.1	-0.1

Temperature -25°C

QFE	75°	50°	25°	Equator
930 hPa	0.0	0.0	-0.1	-0.1
955 hPa	0.0	0.0	-0.1	-0.1
980 hPa	0.0	0.0	-0.1	-0.1
1005 hPa	0.0	0.0	-0.1	-0.1
1030 hPa	0.0	0.0	-0.1	-0.1

Temperature ±0°C

QFE	75°	50°	25°	Equator
930 hPa	0.0	0.0	-0.1	-0.1
955 hPa	0.0	0.0	-0.1	-0.1
980 hPa	0.0	0.0	-0.1	-0.1
1005 hPa	0.0	0.0	-0.1	-0.1
1030 hPa	0.0	0.0	-0.1	-0.1

Temperature +25°C

QFE	75°	50°	25°	Equator
930 hPa	0.0	0.0	-0.1	-0.1
955 hPa	0.0	0.0	-0.1	-0.1
980 hPa	0.0	0.0	-0.1	-0.1
1005 hPa	0.0	0.0	-0.1	-0.1
1030 hPa	0.0	0.0	-0.1	-0.1

Temperature +50°C

QFE	75°	50°	25°	Equator
930 hPa	0.0	0.0	-0.1	-0.1
955 hPa	0.0	0.0	-0.1	-0.1
980 hPa	0.0	0.0	-0.1	-0.1
1005 hPa	0.0	0.0	-0.1	-0.1
1030 hPa	0.0	0.0	-0.1	-0.1

500 m reduction

Temperature -50°C

QFE	75°	50°	25°	Equator
900 hPa	0.1	-0.1	-0.2	-0.3
925 hPa	0.1	-0.1	-0.2	-0.3
950 hPa	0.1	-0.1	-0.2	-0.3
975 hPa	0.1	-0.1	-0.2	-0.3
1000 hPa	0.1	-0.1	-0.2	-0.3

Temperature -25°C

QFE	75°	50°	25°	Equator
900 hPa	0.1	-0.1	-0.2	-0.2
925 hPa	0.1	-0.1	-0.2	-0.3
950 hPa	0.1	-0.1	-0.2	-0.3
975 hPa	0.1	-0.1	-0.2	-0.3
1000 hPa	0.1	-0.1	-0.2	-0.3

Temperature ±0°C

QFE	75°	50°	25°	Equator
900 hPa	0.1	-0.1	-0.2	-0.2
925 hPa	0.1	-0.1	-0.2	-0.2
950 hPa	0.1	-0.1	-0.2	-0.2
975 hPa	0.1	-0.1	-0.2	-0.3
1000 hPa	0.1	-0.1	-0.2	-0.3

Temperature +25°C

QFE	75°	50°	25°	Equator
900 hPa	0.1	0.0	-0.2	-0.2
925 hPa	0.1	0.0	-0.2	-0.2
950 hPa	0.1	0.0	-0.2	-0.2
975 hPa	0.1	-0.1	-0.2	-0.2
1000 hPa	0.1	-0.1	-0.2	-0.2

Temperature +50°C

QFE	75°	50°	25°	Equator
900 hPa	0.0	0.0	-0.1	-0.2
925 hPa	0.0	0.0	-0.2	-0.2
950 hPa	0.1	0.0	-0.2	-0.2
975 hPa	0.1	0.0	-0.2	-0.2
1000 hPa	0.1	0.0	-0.2	-0.2

1000 m reduction

Temperature -50°C

QFE	75°	50°	25°	Equator
850 hPa	0.1	-0.1	-0.4	-0.5
875 hPa	0.1	-0.1	-0.4	-0.5
900 hPa	0.1	-0.1	-0.4	-0.6
925 hPa	0.1	-0.1	-0.4	-0.6
950 hPa	0.1	-0.1	-0.4	-0.6

Temperature -25°C

QFE	75°	50°	25°	Equator
850 hPa	0.1	-0.1	-0.4	-0.5
875 hPa	0.1	-0.1	-0.4	-0.5
900 hPa	0.1	-0.1	-0.4	-0.5
925 hPa	0.1	-0.1	-0.4	-0.5
950 hPa	0.1	-0.1	-0.4	-0.6

Temperature ±0°C

QFE	75°	50°	25°	Equator
850 hPa	0.1	-0.1	-0.4	-0.5
875 hPa	0.1	-0.1	-0.4	-0.5
900 hPa	0.1	-0.1	-0.4	-0.5
925 hPa	0.1	-0.1	-0.4	-0.5
950 hPa	0.1	-0.1	-0.4	-0.5

Temperature +25°C

QFE	75°	50°	25°	Equator
850 hPa	0.1	-0.1	-0.3	-0.4
875 hPa	0.1	-0.1	-0.3	-0.4
900 hPa	0.1	-0.1	-0.3	-0.5
925 hPa	0.1	-0.1	-0.4	-0.5
950 hPa	0.1	-0.1	-0.4	-0.5

Temperature +50°C

QFE	75°	50°	25°	Equator
850 hPa	0.1	-0.1	-0.3	-0.4
875 hPa	0.1	-0.1	-0.3	-0.4
900 hPa	0.1	-0.1	-0.3	-0.4
925 hPa	0.1	-0.1	-0.3	-0.4
950 hPa	0.1	-0.1	-0.3	-0.4

1500 m reduction

Temperature -50°C

QFE	75°	50°	25°	Equator
800 hPa	0.2	-0.2	-0.6	-0.8
825 hPa	0.2	-0.2	-0.6	-0.8
850 hPa	0.2	-0.2	-0.6	-0.8
875 hPa	0.2	-0.2	-0.7	-0.9
900 hPa	0.2	-0.2	-0.7	-0.9

Temperature -25°C

QFE	75°	50°	25°	Equator
800 hPa	0.2	-0.2	-0.6	-0.8
825 hPa	0.2	-0.2	-0.6	-0.8
850 hPa	0.2	-0.2	-0.6	-0.8
875 hPa	0.2	-0.2	-0.6	-0.8
900 hPa	0.2	-0.2	-0.6	-0.8

Temperature ±0°C

QFE	75°	50°	25°	Equator
800 hPa	0.2	-0.2	-0.5	-0.7
825 hPa	0.2	-0.2	-0.6	-0.7
850 hPa	0.2	-0.2	-0.6	-0.8
875 hPa	0.2	-0.2	-0.6	-0.8
900 hPa	0.2	-0.2	-0.6	-0.8

Temperature +25°C

QFE	75°	50°	25°	Equator
800 hPa	0.2	-0.1	-0.5	-0.6
825 hPa	0.2	-0.1	-0.5	-0.7
850 hPa	0.2	-0.1	-0.5	-0.7
875 hPa	0.2	-0.2	-0.5	-0.7
900 hPa	0.2	-0.2	-0.5	-0.7

Temperature +50°C

QFE	75°	50°	25°	Equator
800 hPa	0.1	-0.1	-0.4	-0.6
825 hPa	0.1	-0.1	-0.5	-0.6
850 hPa	0.1	-0.1	-0.5	-0.6
875 hPa	0.2	-0.1	-0.5	-0.6
900 hPa	0.2	-0.1	-0.5	-0.7

2000 m reduction

Temperature -50°C

QFE	75°	50°	25°	Equator
750 hPa	0.3	-0.2	-0.8	-1.1
775 hPa	0.3	-0.2	-0.8	-1.1
800 hPa	0.3	-0.2	-0.9	-1.1
825 hPa	0.3	-0.3	-0.9	-1.2
850 hPa	0.3	-0.3	-0.9	-1.2

Temperature -25°C

QFE	75°	50°	25°	Equator
750 hPa	0.2	-0.2	-0.8	-1.0
775 hPa	0.3	-0.2	-0.8	-1.0
800 hPa	0.3	-0.2	-0.8	-1.1
825 hPa	0.3	-0.2	-0.8	-1.1
850 hPa	0.3	-0.2	-0.9	-1.1

Temperature ±0°C

QFE	75°	50°	25°	Equator
750 hPa	0.2	-0.2	-0.7	-0.9
775 hPa	0.2	-0.2	-0.7	-1.0
800 hPa	0.2	-0.2	-0.8	-1.0
825 hPa	0.3	-0.2	-0.8	-1.0
850 hPa	0.3	-0.2	-0.8	-1.1

Temperature +25°C

QFE	75°	50°	25°	Equator
750 hPa	0.2	-0.2	-0.6	-0.8
775 hPa	0.2	-0.2	-0.7	-0.9
800 hPa	0.2	-0.2	-0.7	-0.9
825 hPa	0.2	-0.2	-0.7	-0.9
850 hPa	0.2	-0.2	-0.7	-1.0

Temperature +50°C

QFE	75°	50°	25°	Equator
750 hPa	0.2	-0.2	-0.6	-0.8
775 hPa	0.2	-0.2	-0.6	-0.8
800 hPa	0.2	-0.2	-0.6	-0.8
825 hPa	0.2	-0.2	-0.6	-0.8
850 hPa	0.2	-0.2	-0.7	-0.9

Vapour saturation pressure (over water) is calculated in many ways. Goff-Gratch (published 1946) is one of the closest to experimental measurements and valid for –50°C to +102°C (Smithsonian Meteorological Tables). It gives good or very good approximations also for –100°C till +105°C. Polynomial approximations have been developed for different technical needs the last decades. Most of them are valid between the triple point and critical temperature of water. Goff-Gratch formula V1 slightly rewritten (Goff 1957) V2 is the vapour formula recommended by WMO when enough calculation capability is at hand.

V1. $$^{10}\log e_{sw} = -7.90298\left(\frac{T_s}{T}-1\right) + 5.02808\,^{10}\log\left(\frac{T_s}{T}\right) - 1.3816*10^{-7}\left(10^{11.334\left(1-\frac{T}{T_s}\right)}-1\right) + 8.1328*10^{-3}\left(10^{-3.49149\left(\frac{T_s}{T}-1\right)}-1\right) + {}^{10}\log e_{ws}$$

T_s = steam point = 373.16 K
e_{sw} = vapour saturation pressure over water (hPa) at temperature T (K)
T = temperature (K)
e_{ws} = vapour saturation pressure at steam point = 1013.246 hPa

V2. $$^{10}\log e_{sw} = 10.79574\left(1-\frac{T_0}{T}\right) - 5.02800\,^{10}\log\left(\frac{T}{T_0}\right) + 1.50475*10^{-4}\left(1-10^{-8.2969\left(\frac{T}{T_0}-1\right)}\right) + 4.2873*10^{-4}\left(10^{4.76955\left(1-\frac{T_0}{T}\right)}-1\right) + 0.78614$$

T_0 = triple point of water = 273.16 K

In Milmet the following approximation is used:

V3. $$e_{sw} \approx 6.11 * e^{5418\left(\frac{1}{273}-\frac{1}{t+273}\right)}$$

e_{sw} = vapour saturation pressure over water (hPa) at temperature t (°C). This is Magnus' approximate formula rewritten. Rindert in ”Kompendium i Termodynamik, hydrostatik och molnfysik”, 1978 (T = temperature in K) gives this version:

V4. $$^{10}\log e_{sw} \approx 9.40158 - \frac{2353.38}{T}$$

The approximation is sufficient around 0°C (max 1% difference from Goff-Gratch for –15°C to +15°C) and stipulates a constant latent heat value l_{wv}=2.5008 MJ/kg. With linear variation of l_{wv} with temperature it turns into Magnus' exact formula

V5. $$^{10}\log e_{sw} \approx 24.00948 - \frac{2957.03}{T} - 5.08862 *\,^{10}\log T$$

This differs from Goff-Gratch with max 1% for –50°C to +75°C.

Gravitation is part of the hydrostatic equation. In reducing the pressure according to local conditions local gravity should be used. The first internationally agreed formula of gravitation at surface level was based on measurements made in Potsdam and was often called the Potsdam value or similar. The official name was International Gravity Formula (IGF) and was agreed in 1930. It describes the gravitational acceleration (m/s²) at mean sea level at latitude φ.

G1. $$g_{1930} = 9.78049\left(1 + 5.2884 * 10^{-3} \sin^2 \varphi - 5.9 * 10^{-6} \sin^2(2\varphi)\right)$$

According to Smithsonian Meteorological Tables IGF was changed when the local acceleration measurements began at several other places. The first WMO formula is from 1949.

G2. $$g_{1949} = 9.7803569\left(1 + 5.2885 * 10^{-3} \sin^2 \varphi - 5.9 * 10^{-6} \sin^2(2\varphi)\right)$$

IGF of today is from 1980 and the base of e g WGS84. WMO has reformulated IGF1980 in WMO-No.8

G3. $$g_{1980} = 9.7803267714 * \frac{1 + 1.93185138639 * 10^{-3} \sin^2 \varphi}{\sqrt{1 - 6.69437999013 * 10^{-3} \sin^2 \varphi}}$$

G4. $$g_{WMO} = 9.80620\left(1 - 2.6442 * 10^{-3} \cos(2\varphi) + 5.8 * 10^{-6} \cos^2(2\varphi)\right)$$

To reduce the gravity with elevation the formula below is recommended up to 10 km.

G5. $$g = g_0 - 3.086 * 10^{-6} H$$

g_0 is the gravitation at mean sea level.

Conclusions

- The Swedish formulas of QNH approximate the Standard Atmosphere with a variable constant temperature. This means a reduction error of ½ hPa already with 400-m reduction. That is the same as DMI though their formula is only to be used with max 200-m reduction. The original Vaisala formula gives the same result as the theoretical formula and the ICAO recommendation. The variations are mainly due to precision in the gas constant used and rounding error. With reduction up to 2000 m the error is <0.2 hPa while the other formulas has errors >3 hPa. This is not acceptable for a mobile system to be used in international missions. Kabul airport is at 1790 m, Asmara (the residence of Eritrea) at 2325 m and Addis Ababa at 2355 m. A mobile system has to manage these reductions within ½ hPa.

- QFF is calculated in four different ways in Sweden today. This should be changed to one common formula considering gravity change with latitude. From the WMO recommendation (1964) the instantaneous temperature should be replaced with the mean value of the virtual temperature at the observation time and 12 hours earlier.

- The old pressure reduction formula of the Swedish manual stations and the formula of the automatic OBS2000 give similar results for Swedish environment. Below 600 m station elevation the difference is <0.2 hPa. Vaisala standard (used by FMI and the Swedish military MOMS) differs at 100-m reduction by almost 1 hPa at –30°C. At temperatures between –5°C and +50°C the differences are < ½ hPa up to 500-m reduction. At –25°C the difference is ¾ hPa per 100-m reduction!! From Swedish point of view the old manual formula and OBS2000 formula are more suitable than the Finnish or Danish QFF formulas. At low temperatures there are always a more or less pronounced surface inversion. Waiting for a recommended WMO formula both MOMS and Milmet Lokalprognosprogram should be reprogrammed to the OBS2000 formula before the winter 2007/2008. Documentation and information about formulas used should be exchanged on a regular basis between the Swedish weather actors (Swedish Meteorological and Hydrological Institute’s manual and automatic observational networks, Swedish Armed Forces and Swedish Civil Aviation Administration, possibly also Swedish Road Administration) and our neighbouring countries’ meteorological institutes (at least Norway, Finland and Denmark).

- WMO says in WMO-No.8 dated 2006 that there is no agreed common pressure reduction formula of QFF. Only vague discussions of possible solutions and difficulties is available in technical notes (Technical Note No. 7, No. 61). Hence Sweden (SMHI) should bring the subject to the WMO agenda.

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