World Meteorological Organization

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (OF UNESCO)

RECOMMENDED ALGORITHMS FOR THE COMPUTATION OF MARINE METEOROLOGICAL VARIABLES

2015

JCOMM Technical Report No. 63

[page left intentionally blank]

WORLD METEOROLOGICAL ORGANIZATION

____

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (OF UNESCO)

____

RECOMMENDED ALGORITHMS FOR THE COMPUTATION OF MARINE METEOROLOGICAL VARIABLES

2015

JCOMM Technical Report No. 63

NOTES

WMO DISCLAIMER

Regulation 42

Recommendations of working groups shall have no status within the Organization until they have been approved by the responsible constituent body. In the case of joint working groups the recommendations must be concurred with by the presidents of the constituent bodies concerned before being submitted to the designated constituent body.

Regulation 43

In the case of a recommendation made by a working group between sessions of the responsible constituent body, either in a session of a working group or by correspondence, the president of the body may, as an exceptional measure, approve the recommendation on behalf of the constituent body when the matter is, in his opinion, urgent, and does not appear to imply new obligations for Members. He may then submit this recommendation for adoption by the Executive Council or to the President of the Organization for action in accordance with Regulation 9(5).

Chairperson, Publications Board
World Meteorological Organization (WMO)
7 bis, avenue de la Paix
P.O. Box No. 2300
CH-1211 Geneva 2, Switzerland

Tel.: +41 (0)22 730 84 03
Fax: +41 (0)22 730 80 40
E-mail: Publications@wmo.int

IOC (OF UNESCO) DISCLAIMER

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariats of UNESCO and IOC concerning the legal status of any country or territory, or its authorities, or concerning the delimitation of the frontiers of any country or territory.

CONTENTS

RECORD OF CHANGES

Version	***Version date***	***Prepared by***	***Main editor***	***Main changes***
First version	February 2015	SOT Task Team on Instrument Standards	Henry Kleta, DWD, Germany	n/a

RECOMMENDED ALGORITHMS FOR THE COMPUTATION OF MARINE METEOROLOGICAL VARIABLES

INTRODUCTION

A range of variables observed under the Voluntary Observing Ship (VOS) scheme, and circulated over the Global Telecommunication System (GTS) in real-time (RT), or exchanged internationally in delayed mode (DM), may be computed shipboard or after receipt on shore. A general description of the different VOS variables and measurement methods can be found in the *Guide to Instruments and Methods of Observations* (WMO 2010; hereafter "WMO No-8").

This publication presents a summarized version of the WMO No-8 information, focusing on the instruments used by the VOS, but breaks new ground in making specific recommendations (including providing software modules and test validation cases) on the algorithms to be used to compute "derived" variables. These derived variables can be required for reporting the data within the constraints of existing RT/DM code/format systems, or are required after the reported data are received by the climate data management and scientific communities, for purposes of a wide range of downstream science applications. Additionally, the algorithms recommended in this publication should in due course form the basis of developing more internationally consistent approaches to the calculation of derived marine meteorological variables. Examples where such an approach would be beneficial include in national publications of VOS observing instructions (e.g. US/NWS 2004, UK Meteorological Office 1995), and in the algorithms used in electronic logbook (e-logbook) software used to record, convert and format VOS observations (e.g. TurboWin; http://www.knmi.nl/turbowin/).

While VOS (and precursor historical) ship observations have been gathered systematically for well over a century, and some software has been developed internationally to handle computation requirements for the uniform handling of early historical ship observations (e.g. ICOADS 2004), this publication represents a first attempt by JCOMM to harmonize the specific computational practices for modern-day VOS, as an important step towards seeking general improvements in data homogeneity.

This JCOMM Technical Report No. 63 is not limited to humidity variables, but will be extended with further variables when the need arises. This publication was prepared by the Task Team on Instrument Standards (TT-IS) of the Ship Observations Team (SOT), in consultation with the Expert Team on Marine Climatology (ETMC), of JCOMM.

PART I. DEWPOINT TEMPERATURE AND OTHER HUMIDITY VARIABLES

I.1) Overview

Humidity observations are required for most areas of marine meteorology and climatology, including air – sea interaction studies. A general description of the different humidity variables and measurement methods can be found in the *Guide to Instruments and Methods of Observations* (WMO No-8). This publication (as stated in the Introduction) presents a summarized version, focusing on the Voluntary Observing Ship (VOS) scheme, and makes recommendations on the algorithms to be used to calculate the derived humidity variables typically reported by the VOS, i.e. dew point temperature and relative humidity (of course it is dependent on the type of equipment used on the VOS which parameter is observed and reported).

.

I.2) Measurement Methods

I.2a) Psychrometer

The majority of the traditional manual VOS fleet use psychrometric methods to determine the humidity at sea, measuring the temperature difference between a dry bulb thermometer and a thermometer covered in a wetted wick. The difference (depression of the wet bulb temperature) is used to calculate the vapour pressure, from which other humidity variables can then be derived. The recommended formulae to calculate the vapour pressure are given by WMO No-8:

$$e' = e'_w(p, t_w) - A_w(1 + 0.000944 t_w) p (t - t_w) \qquad \text{water} \quad (1a)$$

Where e' is the vapour pressure (hPa); $e'_w(p, t_w)$ the saturation vapour pressure (hPa) of moist air with regard to water at the wet bulb temperature; t the dry bulb temperature (°C); t_w the wet bulb temperature (°C); p the pressure (hPa); and A_w the psychrometric coefficient for the wet bulb.

$$e' = e'_i(p, t_i) - A_i p (t - t_i) \qquad \text{ice} \quad (1b)$$

Where e' is the vapour pressure (hPa); $e'_i(p, t_i)$ the saturation vapour pressure (hPa) of moist air with regard to ice at the ice bulb temperature; t the dry bulb temperature (°C); t_i the ice bulb temperature (°C); p the pressure (hPa); and A_i the psychrometric coefficient for the ice bulb.

Note that in the psychrometric equations (1a and 1b) the saturation vapour pressure with regard to water (or ice respectively) at the wet bulb (ice bulb) temperature is used rather than at the dry bulb temperature.

The depression of the wet bulb thermometer relative to the dry bulb is a function of the humidity of the air, size and type of thermometers and flow rate past the thermometer bulbs (e.g. Folland 1977). This is reflected through a variable psychrometric coefficient in equation (1a and 1b). Flow rates through louvered marine screens are generally restricted to between 3 and 5 ms^{-1} depending on the design of the screen. Higher flow rates are generally achieved by artificial ventilation, either through the use of fans or whirling psychrometers. As a result, psychrometers housed in louvered screens generally require a higher psychrometric coefficient compared to other instruments. For example, the hygrometric tables published by the UK Met Office (1995) use a psychrometric coefficient of 0.799 x 10^{-3} for screens and 0.667 x 10^{-3} for psychrometers. The actual value to be used should be determined by the equipment manufacturers.

I.2b) Electrical Resistive and Capacitive Hygrometers

VOS Automatic Weather Stations (AWS) typically use electrical resistive or capacitive hygrometers to estimate the relative humidity directly. Both methods depend on the changes to the electrical properties of hygroscopic materials and give measurements of the relative humidity. The vapour pressure can be calculated from the relative humidity and dry bulb temperature with the following equations (ref. WMO No-8):

$$e' = \frac{U}{100} e'_w(p,t) \qquad (2)$$

Where U is the relative humidity (%).

I.2c) Hair Hygristor

Some VOS humidity observations are reported using hair hygrometers (or hygristors). These instruments measure the relative humidity using natural or synthetic hairs and more information can be found in WMO No-8. As with electrical hygrometers, the vapour pressure can be calculated using (2).

I.3) Calculation of the Saturation Vapour Pressure

The saturation vapour pressure is calculated as a function of dry bulb temperature and pressure (ref. WMO No-8):

$$e_w(t) = 6.112 \cdot exp\left(\frac{17.62 \cdot t}{243.12 + t}\right) \qquad (3a)$$

$$e'_w(p,t) = f(p) \cdot e_w(t) \qquad (3b)$$

Where e_w is the saturation vapour pressure (hPa) in the pure phase with regard to water at the dry bulb temperature. The term $f(p)$ adjusts for the pressure dependency of the saturation vapour pressure and is given by WMO No-8:

$$f(p) = 1.0016 + 3.15 \cdot 10^{-6}\, p - 0.074\, p^{-1} \qquad (4)$$

The saturation vapour pressure with regard to ice is given by:

$$e_i(t) = 6.112 \cdot exp\left(\frac{22.46 \cdot t}{272.62 + t}\right) \qquad (5a)$$

$$e'_i(p,t) = f(p) \cdot e_i(t) \qquad (5b)$$

Where e_i is the saturation vapour pressure (hPa) in the pure phase with regard to ice at the dry bulb temperature.

I.4) Calculation of the Dewpoint (or Frostpoint) Temperature

The recommended formulae for calculating the dewpoint and frostpoint temperatures are given by (ref. WMO No-8):

$$t_d = \frac{243.12 \cdot \ln[e'/6.112 \cdot f(p)]}{17.62 - \ln[e'/6.112 \cdot f(p)]} \quad (6a)$$

$$t_f = \frac{272.62 \cdot \ln[e'/6.112 \cdot f(p)]}{22.46 - \ln[e'/6.112 \cdot f(p)]} \quad (6b)$$

Where t_d and t_f are the dewpoint and frostpoint temperatures (°C) respectively.

I.5) Calculation of the Relative Humidity

The recommended formulae for calculating the relative humidity are given by (ref. WMO No-8):

$$U_w = 100\% \cdot \frac{e'}{e'_w(p,t)} \quad (7a)$$

$$U_i = 100\% \cdot \frac{e'}{e'_i(p,t)} \quad (7b)$$

Where U_w and U_i are the relative humidity with regard to water and ice respectively.

I.6) Applicability of Dewpoint vs. Frostpoint Calculations

Following WMO No-8 (Part I, Annex 4.B) the dewpoint formulae are valid for the temperature range of -45°C to 60°C, whereas the frostpoint formulae are valid for the range of -65°C to 0°C. While those ranges overlap, presently WMO No-8 provides only limited guidance on their appropriate application, tied in with suggested variations in observing practices (i.e. in its sec. 4.2.1.4, *Operation of the wet bulb below freezing*). This situation apparently has lead to some variations in national practices (e.g. some Port Meteorological Officers have advocated that the observer shall use the psychrometer as long as it takes for the ice on the wet bulb thermometer to dissolve; therefore there is no ice, and the dewpoint formulas shall be used).

After international discussion however, our conclusion is to adopt another interpretation: In all cases the dewpoint shall be reported (in accordance with WMO No-306). When the wet bulb thermometer is iced, the dewpoint (and not the frostpoint) shall be calculated with vapour pressures with regard to ice (obtained from equation 1b).

The main reason behind this decision is that the dewpoint shall always be reported (in accordance with WMO No-306), and can be regarded at all times as a theoretical value describing the air when and where measured, and not the measurement itself. This approach is to some extent already standard with e.g. AWS's calculating the dewpoint from measured humidity, and most hygrometers which are essentially responsive to the relative humidity indicate relative humidity with respect to water at all temperatures.

Nevertheless the better option is always to report the measured parameters, and not derived variables. This is consistent with regulation 12.3.6 from the Manual on Codes, part 1 and BUFR / CREX regulation B/C10 10.4.1.3.1.

I.7) Recommendations

The TT-IS (with guidance from ETMC) recommends the following:

1) Measured variables shall be reported instead of (or additional to) derived / calculated variables when possible.

2) All relevant metadata (used instruments, methods of calculation of derived variables, etc) shall be made available.

3) When reporting the dewpoint temperature or relative humidity calculated from a dry bulb thermometer and a wet / ice bulb thermometer, the wet / ice bulb temperature shall be reported too when possible.

4) When reporting in the FM13 code form or BUFR the appropriate indicator shall be used to indicate whether the wet bulb is iced, s_w from group $8s_wT_bT_bT_b$ in FM13 and 0 02 039 from BUFR.

5) Use of the algorithm described in Annex I for the computation of the dewpoint temperature.

6) When using the psychrometric equation to calculate the vapour pressure, the psychrometric coefficient appropriate to the instrumentation shall be used. Where necessary this shall be sought from the instrument manufacturer.

7) Use of all the test cases given in Annex II when testing own implementations of the recommended algorithm. Benchmark results for the test cases are available in Annex III, these shall be used to compare with the separately implemented results.

8) Own implementations of these algorithms shall be fully commented (in English). In addition the the source code shall be shared internationally through a proposed new collaborative JCOMM software repository.

9) The dewpoint temperature shall be reported (over GTS or in delayed-mode) to at least one decimal point (i.e. 0.1°C precision).

10) The pressure value used for the calculation of the dewpoint temperature shall be that observed closest to the height of the temperature / humidity measurements.
Where this value is not available, the pressure at mean sea level shall be used.
If no pressure observations are available the pressure of the ICAO standard atmosphere (1013.25 hPa) shall be used.

11) When calculating the relative humidity this should be done with respect to water at all temperatures as per WMO regulations (see Appendix B of WMO Technical Regulations (WMO-No. 49) Volume I) .

It should be noted that the values of the psychrometric coefficient used in the algorithm (A_w and A_i in equations 1a and 1b) are dependent on the type of instrument used and the ventilation rate applied to the instrument. These values should be made available if possible.

ANNEX I

DEWPOINT ALGORITHM: PSEUDOCODE

Implementations of this algorithm can be found under the following URL: [link currently unknown, and to be added in a future revision of this Publication]

```
; function to calculate the dewpoint from the given values
; for pressure, dry-bulb and wet-bulb temperature
;
; all used formulae are taken from
; WMO-No.8, 2008 edition, updated 2010, Part I, Annex 4.B
;
; IN:  pressure   - pressure of moist air in hPa
;      t_dry      - dry-bulb temperature in °C
;      t_wet      - wet-bulb temperature in °C
;      iced       - measurements over ice yes / no
; OUT: Dewpoint   - dewpoint in °C
;

Function Dewpoint(pressure, t_dry, t_wet, iced)

; psychrometric coefficient
; value is instrument dependent and should be given by manufacturer
; given value is for the Assmann psychrometer
;
If (NOT iced) then
  psychrometricCoeff = 0.000653
else
  psychrometricCoeff = 0.000575
endif


; interim values, for better readability of code
;
; pressure dependency
f_p = 1.0016 + 0.00000315 * pressure - 0.074 / pressure


; saturation and actual vapour pressure
If (NOT iced) then
  SatVapourPressure = f_p * 6.112 * Exp(17.62 * t_wet / (243.12 + t_wet))
  VapourPressure = SatVapourPressure - psychrometricCoeff *
                   (1 + 0.000944 * t_wet) * pressure * (t_dry - t_wet)
else
  SatVapourPressure = f_p * 6.112 * Exp(22.46 * t_wet / (272.62 + t_wet))
  VapourPressure = SatVapourPressure - psychrometricCoeff *
                   pressure * (t_dry - t_wet)
endif


Dewpoint = (243.12 * Log(VapourPressure / (6.112 * f_p))) /
                         (17.62 - Log(VapourPressure / (6.112 * f_p)))

; return result
return Dewpoint

End Function
```

ANNEX II

DEWPOINT ALGORITHM: RECOMMENDED TESTCASES

```
; calculation of dewpoint with the formulae from
; WMO-No.8, 2008 edition, updated 2010, Part I, Annex 4.B
; "Formulae for the computation of measures of humidity"
;
; testcases defined by SOT TT-IS and ETMC, such that each new
; algorithm should be tested against all possible combinations
; of these numeric values, and the results compared against the
; benchmark results available in Annex III

; dry-bulb temperatures
t_dry(0)=40.0
t_dry(1)=30.0
t_dry(2)=20.0
t_dry(3)=10.0
t_dry(4)=0.0
t_dry(5)=-10.0
t_dry(6)=-15.0

; wet-bulb temperatures
t_wet(0)=35.0
t_wet(1)=25.0
t_wet(2)=15.0
t_wet(3)=7.0
t_wet(4)=3.0
t_wet(5)=-2.0
t_wet(6)=-5.0
t_wet(7)=-12.0
t_wet(8)=-17.0

; airpressure
pressure(0)=980.0
pressure(1)=1000.0
pressure(2)=1013.3
pressure(3)=1040.0

; psychrometric coefficient
psychrometricCoeff = 0.000653 (wet bulb)
psychrometricCoeff = 0.000575 (ice bulb)
```

ANNEX III

DEWPOINT ALGORITHM: BENCHMARK RESULTS USING RECOMMENDED TESTCASES

Note: Invalid values resulting i.e. from a call of the logarithm function with a negative parameter are given here as –NaN. NaN stands for "Not A Number" and is the representation (in this case negative) of an invalid value given by the used software (here IDL) to clearly show that there was a problem while computing the values without stopping the computation.

Case No.	T_dry	T_wet	pressure	Dewpoint
1	40.0000	35.0000	980.000	33.9135
2	40.0000	35.0000	1000.00	33.8908
3	40.0000	35.0000	1013.30	33.8757
4	40.0000	35.0000	1040.00	33.8453
5	40.0000	25.0000	980.000	18.9258
6	40.0000	25.0000	1000.00	18.7791
7	40.0000	25.0000	1013.30	18.6808
8	40.0000	25.0000	1040.00	18.4820
9	40.0000	15.0000	980.000	-24.2691
10	40.0000	15.0000	1000.00	-29.4747
11	40.0000	15.0000	1013.30	-34.8902
12	40.0000	15.0000	1040.00	-NaN
13	40.0000	7.00000	980.000	-NaN
14	40.0000	7.00000	1000.00	-NaN
15	40.0000	7.00000	1013.30	-NaN
16	40.0000	7.00000	1040.00	-NaN
17	40.0000	3.00000	980.000	-NaN
18	40.0000	3.00000	1000.00	-NaN
19	40.0000	3.00000	1013.30	-NaN
20	40.0000	3.00000	1040.00	-NaN
21	40.0000	-2.00000	980.000	-NaN
22	40.0000	-2.00000	1000.00	-NaN
23	40.0000	-2.00000	1013.30	-NaN
24	40.0000	-2.00000	1040.00	-NaN
25	40.0000	-5.00000	980.000	-NaN
26	40.0000	-5.00000	1000.00	-NaN
27	40.0000	-5.00000	1013.30	-NaN
28	40.0000	-5.00000	1040.00	-NaN
29	40.0000	-12.0000	980.000	-NaN
30	40.0000	-12.0000	1000.00	-NaN
31	40.0000	-12.0000	1013.30	-NaN
32	40.0000	-12.0000	1040.00	-NaN
33	40.0000	-17.0000	980.000	-NaN
34	40.0000	-17.0000	1000.00	-NaN
35	40.0000	-17.0000	1013.30	-NaN
36	40.0000	-17.0000	1040.00	-NaN
37	30.0000	35.0000	980.000	36.0324
38	30.0000	35.0000	1000.00	36.0529
39	30.0000	35.0000	1013.30	36.0665
40	30.0000	35.0000	1040.00	36.0938
41	30.0000	25.0000	980.000	23.1851
42	30.0000	25.0000	1000.00	23.1463
43	30.0000	25.0000	1013.30	23.1205
44	30.0000	25.0000	1040.00	23.0685
45	30.0000	15.0000	980.000	2.52657
46	30.0000	15.0000	1000.00	2.14296
47	30.0000	15.0000	1013.30	1.88266
48	30.0000	15.0000	1040.00	1.34686

49	30.0000	7.00000	980.000	-NaN
50	30.0000	7.00000	1000.00	-NaN
51	30.0000	7.00000	1013.30	-NaN
52	30.0000	7.00000	1040.00	-NaN
53	30.0000	3.00000	980.000	-NaN
54	30.0000	3.00000	1000.00	-NaN
55	30.0000	3.00000	1013.30	-NaN
56	30.0000	3.00000	1040.00	-NaN
57	30.0000	-2.00000	980.000	-NaN
58	30.0000	-2.00000	1000.00	-NaN
59	30.0000	-2.00000	1013.30	-NaN
60	30.0000	-2.00000	1040.00	-NaN
61	30.0000	-5.00000	980.000	-NaN
62	30.0000	-5.00000	1000.00	-NaN
63	30.0000	-5.00000	1013.30	-NaN
64	30.0000	-5.00000	1040.00	-NaN
65	30.0000	-12.0000	980.000	-NaN
66	30.0000	-12.0000	1000.00	-NaN
67	30.0000	-12.0000	1013.30	-NaN
68	30.0000	-12.0000	1040.00	-NaN
69	30.0000	-17.0000	980.000	-NaN
70	30.0000	-17.0000	1000.00	-NaN
71	30.0000	-17.0000	1013.30	-NaN
72	30.0000	-17.0000	1040.00	-NaN
73	20.0000	35.0000	980.000	37.9563
74	20.0000	35.0000	1000.00	38.0123
75	20.0000	35.0000	1013.30	38.0495
76	20.0000	35.0000	1040.00	38.1239
77	20.0000	25.0000	980.000	26.6579
78	20.0000	25.0000	1000.00	26.6902
79	20.0000	25.0000	1013.30	26.7116
80	20.0000	25.0000	1040.00	26.7546
81	20.0000	15.0000	980.000	11.7671
82	20.0000	15.0000	1000.00	11.6947
83	20.0000	15.0000	1013.30	11.6463
84	20.0000	15.0000	1040.00	11.5489
85	20.0000	7.00000	980.000	-16.6585
86	20.0000	7.00000	1000.00	-17.9315
87	20.0000	7.00000	1013.30	-18.8511
88	20.0000	7.00000	1040.00	-20.9187
89	20.0000	3.00000	980.000	-NaN
90	20.0000	3.00000	1000.00	-NaN
91	20.0000	3.00000	1013.30	-NaN
92	20.0000	3.00000	1040.00	-NaN
93	20.0000	-2.00000	980.000	-NaN
94	20.0000	-2.00000	1000.00	-NaN
95	20.0000	-2.00000	1013.30	-NaN
96	20.0000	-2.00000	1040.00	-NaN
97	20.0000	-5.00000	980.000	-NaN
98	20.0000	-5.00000	1000.00	-NaN
99	20.0000	-5.00000	1013.30	-NaN
100	20.0000	-5.00000	1040.00	-NaN
101	20.0000	-12.0000	980.000	-NaN
102	20.0000	-12.0000	1000.00	-NaN
103	20.0000	-12.0000	1013.30	-NaN
104	20.0000	-12.0000	1040.00	-NaN
105	20.0000	-17.0000	980.000	-NaN
106	20.0000	-17.0000	1000.00	-NaN
107	20.0000	-17.0000	1013.30	-NaN
108	20.0000	-17.0000	1040.00	-NaN
109	10.0000	35.0000	980.000	39.7201
110	10.0000	35.0000	1000.00	39.8060
111	10.0000	35.0000	1013.30	39.8630
112	10.0000	35.0000	1040.00	39.9769

113	10.0000	25.0000	980.000	29.6028
114	10.0000	25.0000	1000.00	29.6861
115	10.0000	25.0000	1013.30	29.7413
116	10.0000	25.0000	1040.00	29.8517
117	10.0000	15.0000	980.000	17.7318
118	10.0000	15.0000	1000.00	17.7832
119	10.0000	15.0000	1013.30	17.8174
120	10.0000	15.0000	1040.00	17.8857
121	10.0000	7.00000	980.000	3.92109
122	10.0000	7.00000	1000.00	3.85198
123	10.0000	7.00000	1013.30	3.80587
124	10.0000	7.00000	1040.00	3.71289
125	10.0000	3.00000	980.000	-9.00001
126	10.0000	3.00000	1000.00	-9.37989
127	10.0000	3.00000	1013.30	-9.63818
128	10.0000	3.00000	1040.00	-10.1712
129	10.0000	-2.00000	980.000	-NaN
130	10.0000	-2.00000	1000.00	-NaN
131	10.0000	-2.00000	1013.30	-NaN
132	10.0000	-2.00000	1040.00	-NaN
133	10.0000	-5.00000	980.000	-NaN
134	10.0000	-5.00000	1000.00	-NaN
135	10.0000	-5.00000	1013.30	-NaN
136	10.0000	-5.00000	1040.00	-NaN
137	10.0000	-12.0000	980.000	-NaN
138	10.0000	-12.0000	1000.00	-NaN
139	10.0000	-12.0000	1013.30	-NaN
140	10.0000	-12.0000	1040.00	-NaN
141	10.0000	-17.0000	980.000	-NaN
142	10.0000	-17.0000	1000.00	-NaN
143	10.0000	-17.0000	1013.30	-NaN
144	10.0000	-17.0000	1040.00	-NaN
145	0.000000	35.0000	980.000	41.3502
146	0.000000	35.0000	1000.00	41.4617
147	0.000000	35.0000	1013.30	41.5355
148	0.000000	35.0000	1040.00	41.6830
149	0.000000	25.0000	980.000	32.1672
150	0.000000	25.0000	1000.00	32.2893
151	0.000000	25.0000	1013.30	32.3701
152	0.000000	25.0000	1040.00	32.5313
153	0.000000	15.0000	980.000	22.2060
154	0.000000	15.0000	1000.00	22.3269
155	0.000000	15.0000	1013.30	22.4068
156	0.000000	15.0000	1040.00	22.5663
157	0.000000	7.00000	980.000	12.5308
158	0.000000	7.00000	1000.00	12.6266
159	0.000000	7.00000	1013.30	12.6900
160	0.000000	7.00000	1040.00	12.8166
161	0.000000	3.00000	980.000	6.23055
162	0.000000	3.00000	1000.00	6.29005
163	0.000000	3.00000	1013.30	6.32950
164	0.000000	3.00000	1040.00	6.40839
165	0.000000	-2.00000	980.000	-5.68166
166	0.000000	-2.00000	1000.00	-5.76682
167	0.000000	-2.00000	1013.30	-5.82371
168	0.000000	-2.00000	1040.00	-5.93858
169	0.000000	-5.00000	980.000	-22.0754
170	0.000000	-5.00000	1000.00	-22.7947
171	0.000000	-5.00000	1013.30	-23.2967
172	0.000000	-5.00000	1040.00	-24.3692
173	0.000000	-12.0000	980.000	-NaN
174	0.000000	-12.0000	1000.00	-NaN
175	0.000000	-12.0000	1013.30	-NaN
176	0.000000	-12.0000	1040.00	-NaN

177	0.000000	-17.0000	980.000	-NaN
178	0.000000	-17.0000	1000.00	-NaN
179	0.000000	-17.0000	1013.30	-NaN
180	0.000000	-17.0000	1040.00	-NaN
181	-10.0000	35.0000	980.000	42.8667
182	-10.0000	35.0000	1000.00	43.0005
183	-10.0000	35.0000	1013.30	43.0889
184	-10.0000	35.0000	1040.00	43.2655
185	-10.0000	25.0000	980.000	34.4436
186	-10.0000	25.0000	1000.00	34.5964
187	-10.0000	25.0000	1013.30	34.6974
188	-10.0000	25.0000	1040.00	34.8987
189	-10.0000	15.0000	980.000	25.8145
190	-10.0000	15.0000	1000.00	25.9810
191	-10.0000	15.0000	1013.30	26.0910
192	-10.0000	15.0000	1040.00	26.3098
193	-10.0000	7.00000	980.000	18.2436
194	-10.0000	7.00000	1000.00	18.4119
195	-10.0000	7.00000	1013.30	18.5230
196	-10.0000	7.00000	1040.00	18.7439
197	-10.0000	3.00000	980.000	13.9300
198	-10.0000	3.00000	1000.00	14.0933
199	-10.0000	3.00000	1013.30	14.2010
200	-10.0000	3.00000	1040.00	14.4154
201	-10.0000	-2.00000	980.000	7.51632
202	-10.0000	-2.00000	1000.00	7.66204
203	-10.0000	-2.00000	1013.30	7.75823
204	-10.0000	-2.00000	1040.00	7.94964
205	-10.0000	-5.00000	980.000	2.65189
206	-10.0000	-5.00000	1000.00	2.77443
207	-10.0000	-5.00000	1013.30	2.85539
208	-10.0000	-5.00000	1040.00	3.01668
209	-10.0000	-12.0000	980.000	-20.6712
210	-10.0000	-12.0000	1000.00	-20.9226
211	-10.0000	-12.0000	1013.30	-21.0926
212	-10.0000	-12.0000	1040.00	-21.4406
213	-10.0000	-17.0000	980.000	-NaN
214	-10.0000	-17.0000	1000.00	-NaN
215	-10.0000	-17.0000	1013.30	-NaN
216	-10.0000	-17.0000	1040.00	-NaN
217	-15.0000	35.0000	980.000	43.5875
218	-15.0000	35.0000	1000.00	43.7313
219	-15.0000	35.0000	1013.30	43.8264
220	-15.0000	35.0000	1040.00	44.0161
221	-15.0000	25.0000	980.000	35.4939
222	-15.0000	25.0000	1000.00	35.6599
223	-15.0000	25.0000	1013.30	35.7696
224	-15.0000	25.0000	1040.00	35.9879
225	-15.0000	15.0000	980.000	27.3928
226	-15.0000	15.0000	1000.00	27.5769
227	-15.0000	15.0000	1013.30	27.6984
228	-15.0000	15.0000	1040.00	27.9401
229	-15.0000	7.00000	980.000	20.5385
230	-15.0000	7.00000	1000.00	20.7306
231	-15.0000	7.00000	1013.30	20.8572
232	-15.0000	7.00000	1040.00	21.1089
233	-15.0000	3.00000	980.000	16.7880
234	-15.0000	3.00000	1000.00	16.9804
235	-15.0000	3.00000	1013.30	17.1072
236	-15.0000	3.00000	1040.00	17.3589
237	-15.0000	-2.00000	980.000	11.5007
238	-15.0000	-2.00000	1000.00	11.6876
239	-15.0000	-2.00000	1013.30	11.8107
240	-15.0000	-2.00000	1040.00	12.0552

241	-15.0000	-5.00000	980.000	7.78915
242	-15.0000	-5.00000	1000.00	7.96765
243	-15.0000	-5.00000	1013.30	8.08529
244	-15.0000	-5.00000	1040.00	8.31895
245	-15.0000	-12.0000	980.000	-4.64118
246	-15.0000	-12.0000	1000.00	-4.52400
247	-15.0000	-12.0000	1013.30	-4.44659
248	-15.0000	-12.0000	1040.00	-4.29241
249	-15.0000	-17.0000	980.000	-33.3408
250	-15.0000	-17.0000	1000.00	-34.0688
251	-15.0000	-17.0000	1013.30	-34.5801
252	-15.0000	-17.0000	1040.00	-35.6826

REFERENCES

Folland, C. K., 1977: *The Psychrometer Coefficient of the Wet-bulb Thermometers used in the Meteorological Office Large Thermometer Screens*. Scientific Paper No. 38, UK Meteorological Office, Her Majesty's Stationary Office, London, 38pp.

ICOADS (International Comprehensive Ocean-Atmosphere Data Set), 2004. Tools to Assist Conversions into LMR 6. [http://icoads.noaa.gov/software/lmrlib].

UK Meteorological Office, 1995: *Marine Observer's Handbook*. 11th Edition, The Stationary Office, Norwich, UK, 227pp.

US/NWS (National Weather Service), 2004: *Marine Surface Weather Observations. National Weather Service Observing Handbook No. 1*. May 2010, Stennis Space Center, MS. [http://www.vos.noaa.gov/ObsHB-508/ObservingHandbook1_2010_508_compliant.pdf].

WMO, 2010: *Guide to Meteorological Instruments and Methods of Observation*, WMO-No 8 (2008 edition, updated 2010). [http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html]