COMPARISON OF HUMIDITY MEASUREMENTS USING A DEW POINT METER AS A TRANSFER STANDARD
APMP-IC-1-97

REPORT

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Contents

1. Introduction

The APMP comparison on humidity measurement was first proposed at the 11th APMP committee meeting in October 1995. The first inquiry of interest was circulated in January 1996. Based on the feedback, a preliminary protocol was sent to all interested laboratories in June 1996. A final protocol was sent to and approved by all participating laboratories before the start of the comparison. NMIJ (formerly NRLM), Japan kindly offered a dew point meter as a transfer standard.

The comparison was started in September 1997 with the arrival of the transfer standard at NMC, SPRING Singapore (formerly PSB). The transfer standard was then sent to NRCCRM in China as scheduled. Unfortunately the transfer standard broke down during the measurement at NRCCRM and a later verification carried out by the manufacturer showed that the failure was fatal and that the transfer standard could not be repaired.

A new transfer standard was arranged in 1998 by NMIJ. The comparison was finally re-started in February 1999 with the revised protocol (Appendix 1). This time the comparison went quite well until tested by the last participant, NML in Australia. The transfer standard was found to be not functioning properly when NML had almost finished the measurement. The transfer standard was then sent back to the manufacturer for repair. This caused a long time delay. The transfer standard was finally returned to the first participant (NMIJ) in February 2001.

The participating laboratories, actual date of arrival of the transfer standard and report submission date for each laboratory are listed in the following table according to the transfer sequence. The full names of the laboratories are listed in the protocol.

Laboratory	Economy	Date of arrival	Report submission date
NMIJ	Japan	-	24/08/1999
NMC	Singapore	04/02/1999	-
NRCCRM	China	05/04/1999	22/06/2000
KRISS	South Korea	09/06/1999	25/02, 26/03, 16/04/2002
SIRIM	Malaysia	27/08/1999	04/02/2000
NMC	Singapore	19/10/1999	-
CMS	Chinese Taipei	08/12/1999	29/10/2001
SCL	Hong Kong	23/02/2000	23/06/2000
NML	Australia	06/05/2000	02/05/2001
NMIJ	Japan	13/02/2001	19/07/2001

2. Stability check of the transfer standard

The transfer standard travelled for more than 2 years from leaving the first participant to returning there. Moreover, the transfer standard was repaired during this time. Although the manufacturer claimed that the repair did not cause any change to either of the instrument’s two PRTs, its stability was still a great concern.

The stability was checked at three laboratories as scheduled in the protocol and at NML before and after repair. The details of the findings are summarised below.

2.1 Stability check at NIST (Sep 1998 – Sep 2000)

NIST conducted one measurement in September 1998 before the transfer standard was shipped to NMIJ to start the comparison. Another measurement was completed after the transfer standard was repaired in September 2000. After the repair, the transfer standard was first sent to NIST for verification before sending back to NML.

The two measurements were performed under the same conditions as defined in the protocol with one exception; M4 display reading, instead of M4RS232 reading, was measured. This would cause a larger uncertainty as M4 display has a 0.1 °C resolution. Results of measurements in terms of the difference between the transfer standard and the NIST reference are summarised in Table 1 and illustrated in Figures 1 and 2. The measurement uncertainty is not reported. Without the measurement uncertainty, it is difficult to judge how good the stability is. However, in this particular case, it is not difficult to conclude that there is no systematic difference between the two measurements. This can be seen by checking the difference in the two curves in each figure and cross checking the difference in the two curves in figures 1 and 2 at each test point.

Table 1. Differences between the transfer standard and the NIST reference.

Nominal frost/dew point (°C)	Difference in M4 display 1998 (°C)	Difference in M4 display 2000 (°C)	Difference in 2nd PRT 1998 (°C)	Difference in 2nd PRT 2000 (°C)
-70	0.02		0.42	
-60	0.00	0.25	0.36	0.31
-50	-0.03	0.12	0.31	0.13
-40	-0.16	-0.16	-0.02	-0.01
-30	0.00	0.25	0.24	0.26
-20	-0.14	-0.07	0.06	0.05
-10	-0.01	-0.01	0.05	0.09
0	-0.04	-0.04	0.10	0.07
10	0.03	-0.03	0.10	0.05
20	0.07	0.06	0.07	0.18

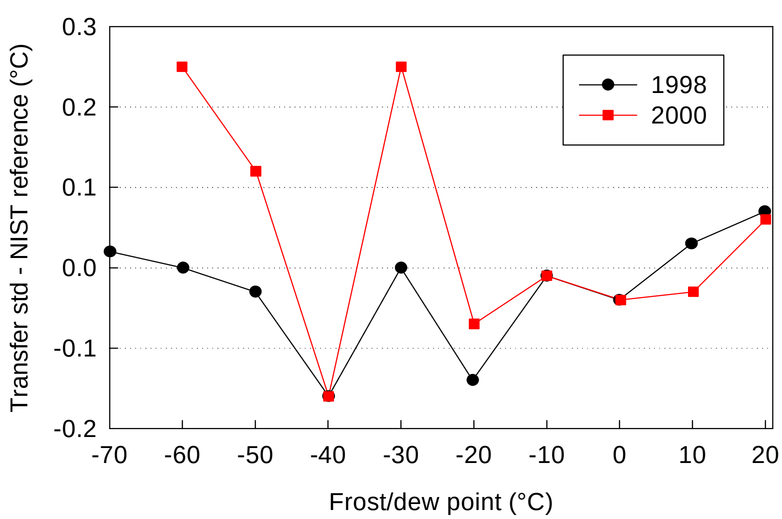


Figure 1. Difference between M4 display and NIST reference.

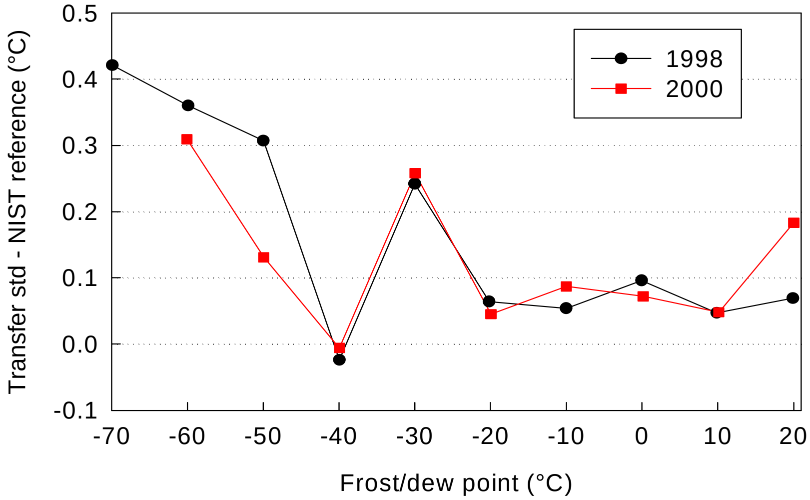


Figure 2. Difference between 2nd PRT and NIST reference.

2.2 Stability check at NMIJ (Nov 1998 – Feb 2001)

The transfer standard was measured at NMIJ before the start of the comparison in November 1998 and after the transfer standard was returned to NMIJ in February 2001. In November 1998, NMIJ was not able to measure below -10°C dew/frost point. Therefore, the stability could only be checked between -10°C and +20°C dew point.

Results of two measurements in terms of the difference between the transfer standard and the NMIJ reference are summarised in Table 2 and illustrated in Figures 3 and 4 together with uncertainty bars at approximately 95% level of confidence. It can be seen that the behaviour of M4 RS232 is quite different between the two measurements. Of the seven measurement points, three points have differences greater than the claimed measurement uncertainty. On the other hand, the 2nd PRT repeated very well. Unfortunately, only four data points are available.

Table 2. Differences between the transfer standard and the NMIJ reference.

Nominal frost/dew point (°C)	Difference in M4 RS232 1998 (°C)	Difference in M4 RS232 2001 (°C)	Difference in 2nd PRT 1998 (°C)	Difference in 2nd PRT 2001 (°C)
-10	-0.035	0.023*	0.082	0.090
-5	-0.032	-0.039	0.046	0.066
0	-0.019	-0.083	0.019	0.015
5	-0.020	0.047	-0.002**	-0.019**
10	-0.006	-0.008		
15	0.007	-0.052		
20	0.019	-0.094		

* Dew point data is taken so as to compare with 1998 data.
** At 5°C dew point, the coolant temperature for the second PRT reading is 5.5°C for 1998 and 5°C for 2001.

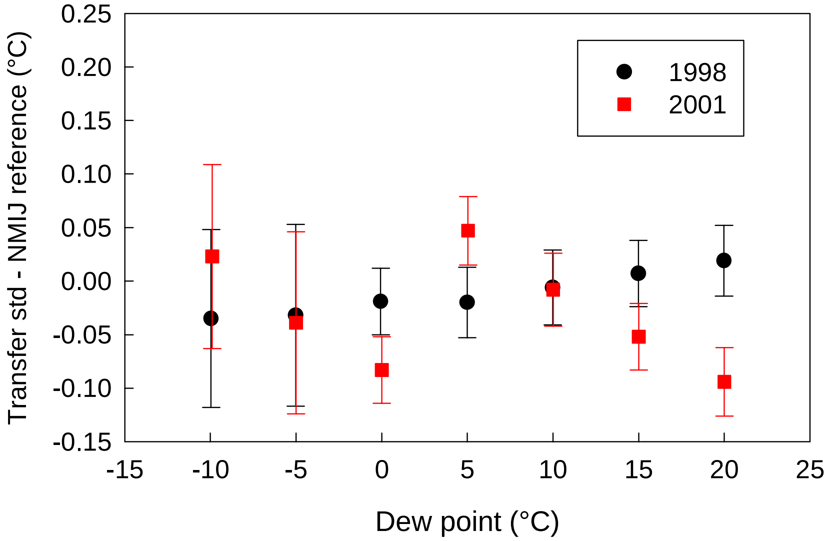


Figure 3. Difference between M4 RS232 and NMIJ reference.

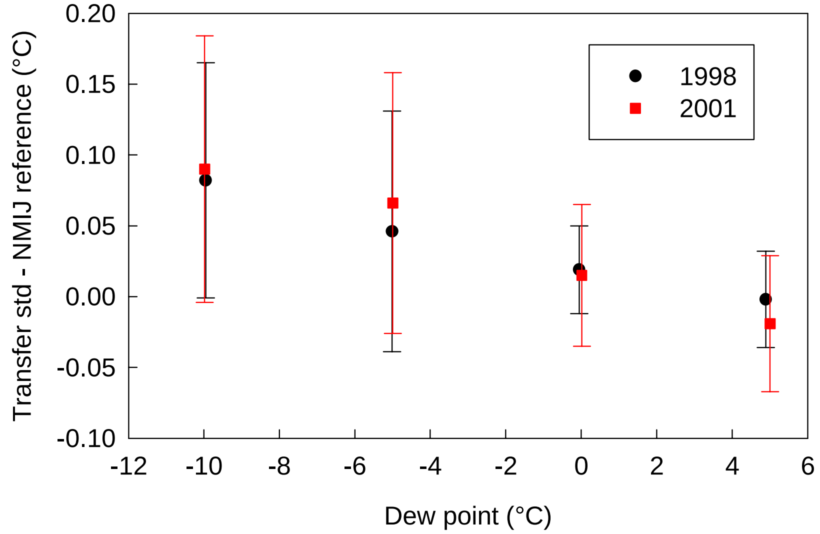


Figure 4. Difference between 2nd PRT and NMIJ reference.

2.3 Stability check at NMC (Feb 1999 – Oct 1999)

As defined in the protocol, the transfer standard was returned to NMC in the middle of the loop for a stability check due to the long period required to complete the whole loop. NMC completed the first measurement in February 1999 and the second measurement in October 1999. Results of the two measurements in terms of the difference between the transfer standard and the NMC references are summarised in Table 3 and illustrated in Figures 5 and 6 together with uncertainty bars at the 95% level of confidence. It can be seen that the differences between the two measurements are well within the measurement uncertainties for both M4RS232 and 2nd PRT.

Table 3. Differences between the transfer standard and the NMC references.

Nominal frost/dew point (°C)	Difference in M4 RS232 Feb 1999 (°C)	Difference in M4 RS232 Oct 1999 (°C)	Difference in 2nd PRT Feb 1999 (°C)	Difference in 2nd PRT Oct1999 (°C)
-70	0.193	0.188	0.569	0.563
-65	0.100	0.034	0.364	0.374
-60	0.014	-0.048	0.320	0.233
-55	-0.054	-0.087	0.183	0.198
-50	-0.067	-0.091	0.165	0.173
-45	-0.063	-0.076	0.158	0.165
-40	-0.066	-0.070	0.150	0.183
-35	-0.108	-0.066	0.186	0.159
-30	-0.109	-0.060	0.153	0.159
-25	-0.093	-0.060	0.136	0.196
-20	-0.055	-0.037	0.153	0.225
-15	-0.051	-0.033	0.113	0.165
-10	-0.053	-0.034	0.065	0.104
-5	-0.032	-0.041	0.041	0.030
0	-0.014	-0.013	0.012	0.000
5	-0.008	0.002	0.109	0.154
10	0.005	0.020	0.074	0.111
15	0.038	0.068	0.080	0.101
20	0.038	0.081	0.035	0.058

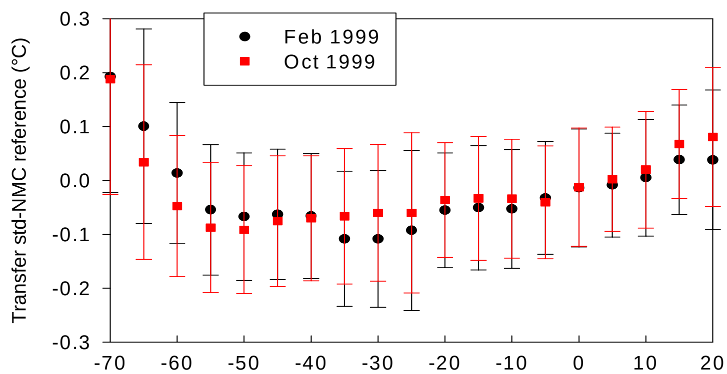


Figure 5. Difference between M4 RS232 and NMC reference.

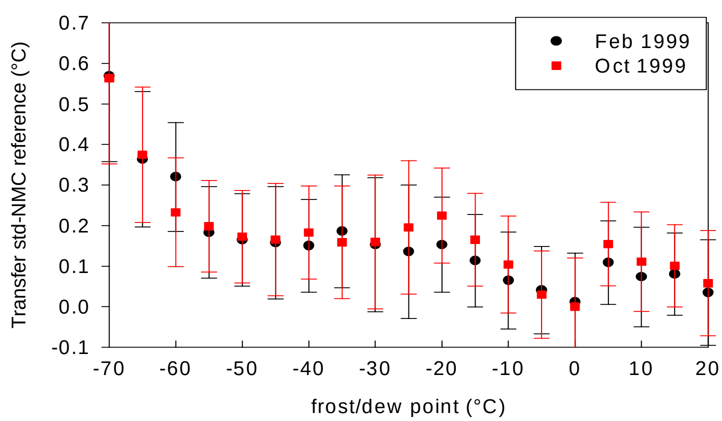


Figure 6. Difference between 2nd PRT and NMC reference.

2.4 Stability check at NML before and after repair (May 2000 – Dec 2000)

NML first received the transfer standard in May 2000. The transfer standard broke down during the measurement of the last two test points. Therefore, NML had gathered almost all data before repair. When the transfer standard was returned to NML in December 2000, NML repeated the measurement from the very first point. Although NML chose the after-repair data for its final submission, the pre-repair data can still be used to monitor any changes that may have occurred.

Results of the two measurements in terms of the difference between the transfer standard (M4 RS232 and 2nd PRT) and the NML references are summarised in Table 4 and illustrated in Figures 7 and 8 together with uncertainty bars at the 95% level of confidence. It can be seen that, although at some points the two measurements show significant differences for both M4RS232 and 2nd PRT, the differences at all of the measurement points are within the claimed measurement uncertainties.

Table 4. Differences between the transfer standard and the NML references.

Nominal frost/dew point (°C)	Difference in M4 RS232 May 2000 (°C)	Difference in M4 RS232 Dec 2000 (°C)	Difference in 2nd PRT May 2000 (°C)	Difference in 2nd PRT Dec 2000(°C)
-50	0.10	0.03	0.50	0.15
-45	-0.03	0.21	0.44	0.28
-40	-0.12	0.16	0.26	0.21
-35	-0.14	0.05	0.16	0.14
-30	-0.05	0.00	0.15	0.13
-29	0.02		0.40	
-25	-0.04	0.04	0.29	0.17
-20	-0.05	0.02	0.22	0.13
-15	-0.05	0.07	0.15	0.17
-10	-0.07	-0.02	0.09	0.09
-5	-0.04	0.01	0.06	0.13
0	-0.10		-0.06	
1		0.12		0.24
5	-0.03	0.13	0.15	0.24
10	-0.08	0.10	0.04	0.22
15	-0.02	0.01	0.06	0.12
20	-0.07	0.12	-0.03	0.24

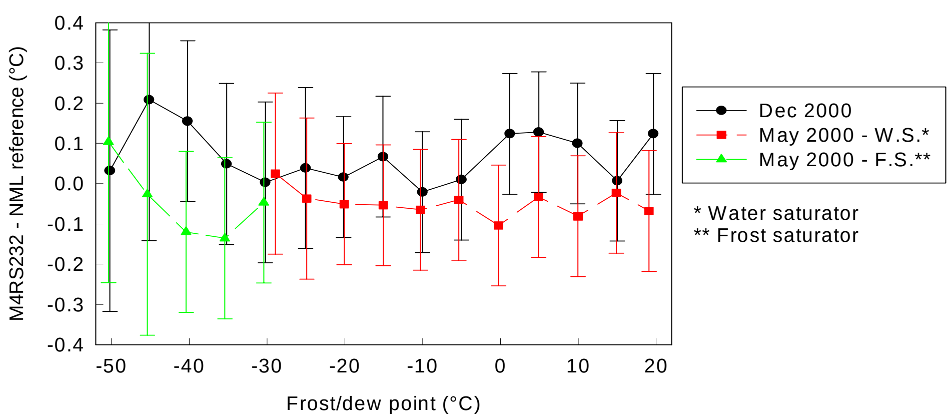


Figure 7. Difference between M4 RS232 and NML reference.

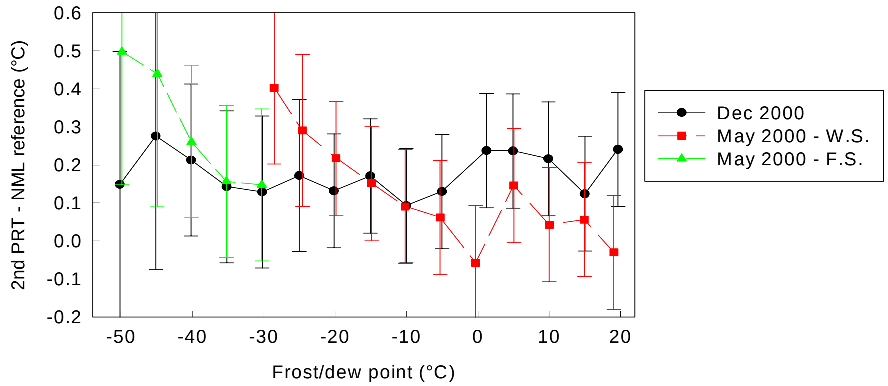


Figure 8. Difference between 2nd PRT and NML reference.

Note: The coolant temperature at the 0°C dew point is 5 °C and 25°C for the May and Dec 2000 measurements respectively.

3. Coolant temperature influence on the transfer standard

3.1 Coolant temperature effect tested at NMIJ

When the transfer standard was tested at NMIJ in November 1998, it was found that the 2nd PRT reading was affected by the coolant temperature. This conclusion was obtained from the measurement results at different coolant temperatures applied to dew points 0°C and 5°C. On the other hand, no such effect on the M4 RS232 reading was observed at that time. When the transfer standard was returned to NMIJ in 2001, it was found that both 2nd PRT and M4 RS232 readings were affected by the coolant temperature. The measurement results in both 1998 and 2001 are listed in Table 5. As can be seen, the effect on the 2nd PRT did not change significantly in more than 2 years time. If mean values of the two year measurements are taken, at 0°C dew point the change is about 0.15°C with a 20°C difference in coolant temperature, i.e., about 0.008°C/°C. On the other hand, the effect on the M4 RS232 reading did change. In 2001, at 0°C dew point, the difference in the M4 RS232 reading with a coolant temperature difference of 20°C is about 0.2°C, i.e., 0.01°C/°C. The protocol defined a coolant temperature for specific frost/dew point. If each laboratory closely follows the defined coolant temperature, which is true in most of the cases, the uncertainty caused by this effect should not be unacceptably large.

Table 5. NMIJ test results on coolant temperature effect.

	Dew point (°C)	**Coolant *T* (°C)**	**M4 RS232 –lab reference (°C)**	**Diff (°C)**	**2nd PRT –lab reference (°C)**	**Diff (°C)**
1998	0	5	-0.019		0.019	**0.129**
		25	-0.027	**0.008**	0.148	
	5	5.5	-0.009		-0.002	**0.114**
		25	-0.020	**0.011**	0.112	
2001	0	5	-0.083		0.015	**0.172**
		25	0.119	**0.202**	0.187	
	5	5	-0.120		-0.019	-
		25	0.046	**0.166**	-	

3.2 Coolant temperature effect tested at NMC

When the transfer standard was sent to NMC in February and October 1999, the same tests were performed at a dew point of 0°C. Similar results were obtained for the 2nd PRT readings for both measurements, while no effect was observed for M4 RS232 readings. The data are listed in Table 6.

Table 6. NMC test results on coolant temperature effect.

	Dew point (°C)	Coolant *T* (°C)	M4 RS232 –lab reference (°C)	Diff (°C)	2nd PRT –lab reference (°C)	Diff (°C)
Mar 1999	0	5	-0.01	**-0.05**	0.02	**0.11**
		25	-0.06		0.13	
Oct 1999	0	5	-0.01	**0.00**	0.02	**0.19**
		25	-0.01		0.21	

4. Summary of coolant temperature used by each laboratory

The coolant temperatures used by each participant are summarised in Table 7. The values in brackets are set values of the coolers and the rest are measured values. For NMIJ, NRCCRM, KRISS, SIRIM, SCL and NML, the reported values are measured temperatures in the cooler's bath. For NMC, the reported values are measured at the entrance of the coolant to the sensor head with a thermocouple attached to the surface of the fittings, which were covered with insulating materials.

Table 7. Summary of coolant temperature used by each laboratory.

Laboratory	**Frost/dew points (°C)**										
	-70	-65	-60/-45	-40/-25	-20	-15	-10	-5	0	5/20	25
NMIJ 1st	NA						(5)			(25)	(26)
NMIJ 2nd	NA		5.1/5.3			(1)	5.1/5.3	(5)		(25)	NA
NMC 1st	6.8/ 10.0	7.3/ 8.1	4.8/7.8							24.2/ 25.9	NA
NMC 2nd	4.8/5.6									24.8/25.4	NA
NRCCRM	NA			5 ± 0.25						25 ± 0.25	NA
KRISS	NA	5.15/5.16								25.07	NA
SIRIM	NA							5±0.15		25 ± 0.15	NA
CMS	NA				(5)					(25)	NA
SCL	NA		4.93/5.09							24.95/24.97	NA
NML	NA		5.00/5.01						25.00		NA

It is worth noting that most of the laboratories had followed closely the defined coolant temperature. There are only three cases with some deviation:

a. NML followed the defined coolant temperatures except at the 0°C dew point where 25°C was used instead of 5°C. In the before-repair measurement, 5°C was used for this point. As a consequence, a significant difference was found before and after repair as can be seen in Figure 8. This deviation caused a significant difference in the measured dew point as compared with the rest of laboratories as can be seen in the measurement results and discussions in Chapters 7 and 8.

b. NMC could not exactly follow the defined coolant temperature for the 1st measurement due to the instability of the cooler used. A test was done by changing the coolant temperature a few degrees Celsius at one test point. No significant difference was obtained. Therefore a mean value of data at different coolant temperatures was given.

c. NMIJ closely followed the defined temperatures with only one exception at –15°C in the 2001 measurement. The coolant temperature was 1°C instead of 5°C. No significant effect was observed due to this.

5. Summary of laboratory reference, measurement set-up and measurement conditions

The reference standard used, measurement set-up and critical measurement conditions are summarised in Table 8. It is worth noting that all participants except SCL used generators as reference standards. SCL used two TSC generators (models 8500 & 3900) to provide gas streams and their frost/dew points were defined using two dew point meters traceable to NPL.

Table 8. Summary of laboratory reference, measurement set-up and measurement conditions.

Laboratory	Lab reference	Tubing	Flow lpm	Stabilisation time (min)	Readings /interval (s)	runs
NMIJ 1st	2 T 2 P, Mk2	¼ s.s. and 6mm PFA	0.7	10-60	11/30-60	2
NMIJ 2nd	2 T 2 P, Mk3, -5°C/20°C	¼ PTFE	0.7	10-60	11/60	2
	2 T, LHG, -60°C/-10°C	¼ e.p.s.s.	0.7	30-90	20-70	1
NMC 1st & 2nd	2 P, TSC 2500 -20°C/+20°C	¼ s.s. and Teflon	0.7	30-60	5-30/60 1-3 samplings at different time and bef/aft pacer	2-3
	2 T 2 P, TSC 4500 -70°C/+10°C	¼ s.s.				
NRCCRM	2 P	¼ s.s.	0.7	60	11/120	3
KRISS	2 T 2 P -5°C/+20°C	¼ p.s.s.	0.7	30-120	100-800/30	1
	2 T, -65°C/-10°C					
SIRIM	2 P, TSC 9000	¼ s.s.	1	120	12/60	2
CMS	2 P, TSC 7000	Teflon	1	At least 60	10	5
SCL	GEI 1311DR/M3 -60°C/–40°C	¼ s.s.	0.7	120-870	10/60	1
	MBW DP30 -40°C/+20°C					
NML	Water saturator -30°C/+20°C	s.s.	0.7	60-240	30/10	1
	Frost saturator -60°C/–30°C					

6. Summary of ambient conditions in each laboratory

The ambient conditions during measurement in each participating laboratory are summarised in Table 9.

Table 9. Summary of ambient conditions in each laboratory.

Laboratory	Temperature (°C)	Relative Humidity (%)	Atmospheric pressure (kPa)
NMIJ 1st	23 ± 2	44 to 59	101.0 ± 0.7
NMIJ 2nd	23 to 30 ± 3	16 ± 2 to 30 ± 10	99.6 to 101.8
NMC 1st	22.2 - 27.4	40 - 50	100.1 - 100.9
NMC 2nd	21.0 - 28.2	42 - 62	99.9 - 100.9
NRCCRM	18 - 25	40 - 60	100.250 - 101.381
KRISS	24.3 - 25.4	53.2 - 58.6	98.55 - 99.92
SIRIM	24 ± 0.5	60 ± 5	100.7 ± 0.25
CMS	23 ± 1.5	45 ± 10%	Not measured
SCL	23 ± 1	45 ± 8	99.5 ± 1.0
NML	21.6 – 25.0	40.4 – 48.4	100.202 - 101.404

7. Comparison results

7.1 Comparison results

Comparison results of each participating laboratory are presented in the following tables according to the participation sequence. The combined uncertainty (u_c) and the effective degrees of freedom (ν) are also listed. NMIJ and NML claimed k=2 and approximately 95% level of confidence without providing a value for ν; an infinite ν is assumed. SIRIM claimed a very large ν, therefore ν is considered as infinite this case as well.

NMIJ November 1998

Nominal dew point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT °C	2nd PRT Ω	u_c °C	ν
-10	-9.957	-9.992	0.042	infinite	-9.875	96.1349	0.041	infinite
-5	-5.014	-5.046	0.043	infinite	-4.968	98.0571	0.042	infinite
0	-0.057	-0.076	0.016	infinite	-0.038	99.9851	0.015	infinite
5	4.996	4.976	0.017	infinite	5.108	101.9949	0.016	infinite
10	9.988	9.982	0.018	infinite	10.073	103.9309	0.017	infinite
15	14.985	14.992	0.016	infinite	15.041	105.8654	0.015	infinite
20	19.989	20.008	0.017	infinite	20.018	107.8006	0.016	infinite
25	24.995	25.024	0.018	infinite	25.003	109.7358	0.017	infinite

NMIJ February 2001

Nominal f/d point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT		u_c °C	ν	Ref
					°C	Ω			
-60	-60.007	-60.146	0.111	infinite	-60.075	76.2980	0.119	infinite	LHG
-55	-55.007	-54.949	0.062	infinite	-54.853	78.3774	0.065	infinite	LHG
-50	-50.007	-50.006	0.043	infinite	-49.883	80.3529	0.047	infinite	LHG
-45	-45.009	-45.033	0.041	infinite	-44.926	82.3197	0.045	infinite	LHG
-40	-40.013	-40.022	0.045	infinite	-39.920	84.3022	0.049	infinite	LHG
-35	-35.012	-34.972	0.038	infinite	-34.878	86.2960	0.043	infinite	LHG
-30	-30.014	-29.994	0.039	infinite	-29.891	88.2648	0.043	infinite	LHG
-25	-25.012	-25.005	0.040	infinite	-24.899	90.2322	0.045	infinite	LHG
-20	-20.011	-20.021	0.039	infinite	-19.899	92.1995	0.048	infinite	LHG
-15	-15.009	-14.973	0.049	infinite	-14.898	94.1644	0.050	infinite	LHG
-10	-10.006	-10.028	0.040	infinite	-9.957	96.1029	0.044	infinite	LHG
-5	-5.002	-5.040	0.042	infinite	-4.957	98.0613	0.046	infinite	LHG
(dp) -10	-9.884	-9.861	0.043	infinite	-9.894	96.1272	0.047	infinite	Mk.3
(dp) -5	-4.995	-5.034	0.042	infinite	-4.929	98.0721	0.046	infinite	Mk.3
0	0.015	-0.068	0.015	infinite	0.030	100.0116	0.025	infinite	Mk.3
5	5.040	5.087	0.016	infinite	-	-	-	-	Mk.3
10	10.016	10.008	0.017	infinite	-	-	-	-	Mk.3
15	15.012	14.960	0.015	infinite	-	-	-	-	Mk.3
20	20.008	19.914	0.016	infinite	-	-	-	-	Mk.3

NMC February 1999

Nominal f/d point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT		u_c °C	ν
					°C	Ω		
-70	-69.958	-69.765	0.107	342	-69.389	72.5789	0.106	1123
-65	-64.956	-64.856	0.088	49	-64.592	74.4959	0.084	119
-60	-59.954	-59.940	0.064	58	-59.634	76.4737	0.065	42
-55	-54.952	-55.006	0.061	1038	-54.769	78.4108	0.057	1403
-50	-49.949	-50.016	0.057	38	-49.784	80.3919	0.055	43
-45	-44.947	-45.010	0.061	359	-44.790	82.3736	0.065	23
-40	-39.945	-40.011	0.058	426	-39.795	84.3519	0.057	116
-35	-34.942	-35.050	0.063	472	-34.756	86.3441	0.062	12
-30	-29.940	-30.049	0.064	441	-29.787	88.3056	0.083	141
-25	-24.937	-25.030	0.074	1293	-24.801	90.2706	0.082	457
-20	-19.941	-19.996	0.053	373	-19.788	92.2432	0.059	222
-15	-14.939	-14.989	0.058	180	-14.825	94.1931	0.057	111
-10	-9.936	-9.988	0.055	256	-9.871	96.1364	0.057	27
-5	-4.933	-4.965	0.048	17	-4.892	98.0867	0.054	841
0	0.078	0.064	0.055	1159	0.090	100.0350	0.060	224
5	5.082	5.073	0.048	415	5.190	102.0270	0.052	1435
10	10.085	10.090	0.054	281	10.159	103.9643	0.061	974
15	15.079	15.117	0.051	3426	15.159	105.9114	0.051	2268
20	20.083	20.121	0.065	427	20.118	107.8393	0.065	195

NMC October 1999

Nominal f/d point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT °C	2nd PRT Ω	u_c °C	ν
-70	-69.961	-69.772	0.107	342	-69.397	72.5758	0.106	1123
-65	-64.959	-64.925	0.088	49	-64.584	74.4992	0.084	119
-60	-59.957	-60.004	0.064	58	-59.724	76.4379	0.065	42
-55	-54.955	-55.042	0.061	1038	-54.756	78.4158	0.057	1403
-50	-49.952	-50.043	0.057	38	-49.779	80.3938	0.055	43
-45	-44.950	-45.026	0.061	359	-44.785	82.3756	0.065	23
-40	-39.948	-40.018	0.058	426	-39.765	84.3636	0.057	116
-35	-34.946	-35.012	0.063	472	-34.787	86.3320	0.062	12
-30	-29.943	-30.003	0.064	441	-29.784	88.3070	0.083	141
-25	-24.940	-25.001	0.074	1293	-24.745	90.2928	0.082	457
-20	-19.942	-19.978	0.053	373	-19.717	92.2712	0.059	222
-15	-14.938	-14.971	0.058	180	-14.773	94.2134	0.057	111
-10	-9.936	-9.969	0.055	256	-9.832	96.1519	0.057	27
-5	-4.933	-4.973	0.048	17	-4.903	98.0824	0.054	841
0	0.078	0.066	0.055	1159	0.079	100.0307	0.060	224
5	5.082	5.084	0.048	415	5.236	102.0448	0.052	1435
10	10.085	10.105	0.054	281	10.196	103.9789	0.061	974
15	15.085	15.153	0.051	3426	15.186	105.9217	0.051	2268
20	20.089	20.170	0.065	427	20.147	107.8506	0.065	195

Note:
1. Between –20°C and +10°C, means of the two generators' values are given.
2. A pooled uncertainty estimation is done for Feb and Oct measurements to facilitate the comparison result analysis.

NRCCRM

Nominal f/d point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT °C	2nd PRT Ω	u_c °C	ν
-40	-40.25	-40.24	0.11	17	-39.96	84.286	0.14	13
-30	-30.36	-30.34	0.12	17	-30.05	88.202	0.16	13
-20	-20.01	-20.08	0.08	17	-19.80	92.239	0.08	13
-10	-10.04	-10.08	0.07	17	-9.88	96.134	0.07	13
0	0.12	0.06	0.05	17	0.33	100.130	0.06	13
10	10.48	10.45	0.05	17	10.63	104.149	0.05	13
20	19.69	19.62	0.05	17	19.73	107.691	0.05	13

KRISS

Nominal f/d point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT °C	2nd PRT Ω	u_c °C	ν
-65	-64.959	-64.691	0.037	infinite	-64.307	-	0.037	infinite
-60	-59.991	-59.967	0.038	infinite	-59.638	-	0.038	infinite
-55	-54.981	-55.093	0.040	infinite	-54.812	-	0.040	infinite
-50	-49.988	-50.127	0.041	infinite	-49.861	-	0.041	infinite
-45	-45.007	-45.149	0.043	infinite	-44.876	-	0.043	infinite
-40	-40.000	-40.162	0.045	infinite	-39.914	-	0.045	infinite
-35	-35.013	-35.173	0.046	infinite	-34.917	-	0.046	infinite
-30	-30.023	-30.178	0.048	infinite	-29.973	-	0.049	infinite
-25	-25.029	-25.185	0.050	infinite	-25.009	-	0.051	infinite
-20	-20.033	-20.176	0.052	infinite	-19.926	-	0.052	infinite
-15	-15.040	-15.179	0.054	infinite	-14.983	-	0.054	infinite
-10	-10.050	-10.176	0.056	infinite	-10.029	-	0.056	infinite
(dp) -5	-5.078	-5.135	0.047	13475.2	-5.066	-	0.049	537.3
(dp) 0	-0.033	-0.031	0.051	69.3	-0.013	-	0.047	629.5
5	5.087	5.063	0.019	156. 9	5.166	-	0.020	93.1
10	10.037	10.018	0.021	17.7	10.106	-	0.024	9.9
15	14.977	14.985	0.021	24.1	15.033	-	0.022	11.7
20	19.938	19.961	0.021	23. 7	19.968	-	0.021	23. 7

SIRIM

Nominal dew point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT °C	2nd PRT Ω	u_c °C	ν
-5	-5.265	-5.250	0.022	infinite	-5.124	97.996	0.022	infinite
0	-0.270	-0.219	0.024	infinite	-0.153	99.940	0.024	infinite
5	4.713	4.772	0.026	infinite	4.961	101.938	0.026	infinite
10	9.691	9.737	0.026	infinite	9.871	103.851	0.026	infinite
15	14.669	14.720	0.026	infinite	14.800	105.772	0.026	infinite
20	19.648	19.689	0.026	infinite	19.713	107.682	0.026	infinite

CMS

Nominal f/d point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT °C	2nd PRT Ω	u_c °C	ν
-20	-20.03	-20.11	0.05	52	-19.80	92.2389	0.05	52
-15	-15.01	-15.19	0.05	52	-14.91	94.1603	0.05	52
-10	-10.04	-10.26	0.06	44	-10.07	96.0589	0.06	44
(dp) -5	-5.04	-5.06	0.05	52	-4.93	98.0703	0.05	52
0	-0.02	-0.07	0.06	48	0.01	100.0023	0.06	48
5	5.00	5.05	0.05	52	5.19	102.0260	0.05	52
10	9.99	9.96	0.06	49	10.07	103.9283	0.06	49
15	15.02	15.02	0.05	52	15.06	105.8742	0.05	52
20	19.99	20.04	0.06	46	20.04	107.8091	0.06	46

SCL

Nominal f/d point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT °C	2nd PRT Ω	u_c °C	ν
-60	-59.88	-60.14	0.11	146	-59.82	76.398	0.11	147
-55	-54.85	-55.08	0.12	138	-54.83	78.387	0.12	138
-50	-49.90	-50.09	0.09	124	-49.82	80.377	0.09	125
-45	-44.89	-45.05	0.10	129	-44.81	82.365	0.10	128
-40	-39.99	-40.11	0.05	104	-39.90	84.311	0.06	104
-35	-34.99	-35.08	0.06	108	-34.80	86.327	0.06	92
-30	-29.99	-30.12	0.05	108	-29.83	88.290	0.06	61
-25	-24.94	-25.16	0.07	133	-24.80	90.269	0.07	136
-20	-19.93	-20.11	0.07	145	-19.82	92.229	0.07	147
-15	-14.93	-15.06	0.07	134	-14.83	94.190	0.07	134
-10	-9.97	-10.07	0.07	140	-9.91	96.122	0.07	140
(dp) -5	-5.05	-5.12	0.05	98	-5.01	98.042	0.05	99
0	-0.04	-0.09	0.05	94	-0.03	99.988	0.05	95
5	4.95	4.90	0.06	114	5.09	101.987	0.06	114
10	9.98	9.92	0.05	95	10.05	103.923	0.05	95
15	15.04	15.00	0.05	98	15.08	105.880	0.05	98
20	19.96	19.94	0.05	106	19.96	107.780	0.05	106

NML

Nominal f/d point °C	Lab ref °C	M4 RS232 °C	u_c °C	ν	2nd PRT °C	2nd PRT Ω	u_c °C	ν
-60	-60.093	-59.933	0.18	infinite	-59.858	76.3844	0.18	infinite
-55	-55.057	-54.896	0.18	infinite	-54.803	78.3972	0.18	infinite
-50	-50.179	-50.147	0.18	infinite	-50.030	80.2943	0.18	infinite
-45	-45.145	-44.937	0.18	infinite	-44.869	82.3421	0.18	infinite
-40	-40.193	-40.038	0.10	infinite	-39.980	84.2784	0.10	infinite
-35	-35.194	-35.145	0.10	infinite	-35.051	86.2278	0.10	infinite
-30	-30.215	-30.212	0.10	infinite	-30.086	88.1877	0.10	infinite
-25	-25.032	-24.993	0.10	infinite	-24.860	90.2477	0.10	infinite
-20	-20.170	-20.154	0.08	infinite	-20.038	92.1450	0.08	infinite
-15	-15.083	-15.016	0.08	infinite	-14.912	94.1590	0.08	infinite
-10	-10.024	-10.045	0.08	infinite	-9.931	96.1130	0.08	infinite
(dp) -5	-5.025	-5.015	0.08	infinite	-4.895	98.0855	0.08	infinite
0	1.200	1.324	0.08	infinite	1.438	100.5619	0.08	infinite
5	4.920	5.048	0.08	infinite	5.157	102.0142	0.08	infinite
10	9.896	9.996	0.08	infinite	10.112	103.9462	0.08	infinite
15	14.991	14.998	0.08	infinite	15.115	105.8942	0.08	infinite
20	19.634	19.758	0.08	infinite	19.875	107.7449	0.08	infinite

The results of each laboratory in terms of the difference between the transfer standard and the laboratory reference are shown in Figures 9 and 10 for M4 RS232 and 2nd PRT respectively. It is worth noting that in Figure 10 a significant increase from 0°C to 5°C was detected by most of the laboratories except NRCCRM and NML. This is very likely due to the change in coolant temperature from 5°C to 25°C as the 2nd PRT is affected by the coolant temperature as shown in section 3. NRCCRM did not measure the 5°C dew point so the effect was not detected. In the case of NML, a coolant temperature of 25°C was used for 0°C. Therefore, there is no effect observed at these points. However, the effect can be seen from –5°C to 0°C dew point where there is a big change in coolant temperature. The effect can also be seen from the measurement results before repair as shown in Figure 8, where the change occurred between 0°C and 5°C dew point as a coolant temperature of 5°C was used for the 0°C dew point for that measurement.

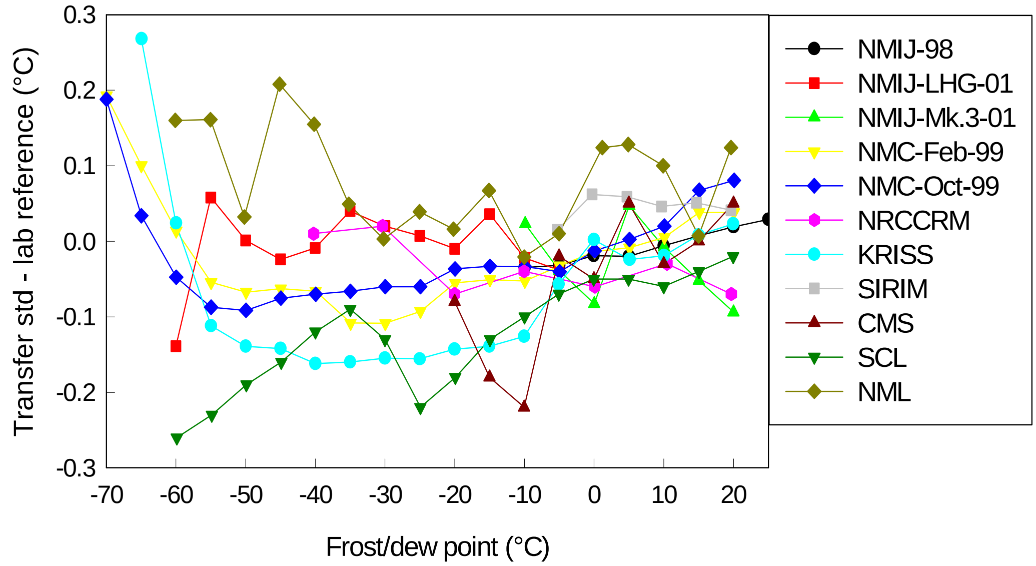


Figure 9. Difference between M4RS232 and laboratory reference.

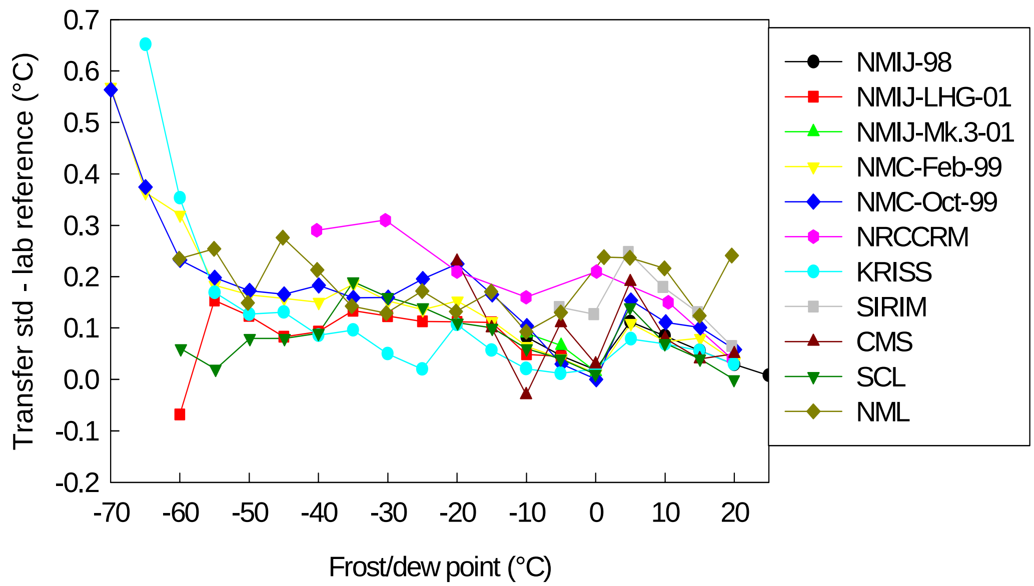


Figure 10. Difference between 2nd PRT and laboratory reference.

8. Elaboration of comparison results

8.1 Simple mean evaluation

The results of the comparison in terms of the difference between the transfer standard and the laboratory reference at each nominal frost/dew point are averaged without any weight in the following way:

1. As only NMC and KRISS measured the nominal frost point –65°C and below and only NMIJ measured the 25°C dew point in its 1998 measurement, only data in the range between 20°C dew point and -60°C frost point are considered.
2. Considering that NML used a coolant temperature of 25°C instead of 5°C at nominal 0°C dew point and that this fact caused significant differences as compared with other laboratories, the NML data at this nominal dew point are excluded.
3. NMIJ has multiple data for one nominal test point for the 2001 measurement. The LHG reading at –10°C frost point is taken and the Mk.3 reading at –5°C (dew point) is taken as requested by the laboratory.
4. For laboratories who performed two measurements, namely NMIJ from –10°C to +20°C frost/dew point for M4 RS232, from –10°C to 0°C frost/dew point for 2nd PRT, and NMC for the whole measurement range, the mean of two measurements is taken for each laboratory with exception of NMIJ at –10°C frost point where only the 2nd measurement value (frost point) is taken.

As such, each laboratory has only one entry for the mean values and at the nominal test point -10°C and below, all laboratories measured frost point, while at the nominal test point –5°C, all laboratories measured dew point except NMC.

The obtained mean values are then compared with the laboratory values (differences between transfer standard and laboratory reference at each nominal frost/dew point). The differences from the mean values are shown in Figures 11 and 12 for M4 RS232 and 2nd PRT respectively, together with ±2*s*; *s* being the standard deviation from the mean values.

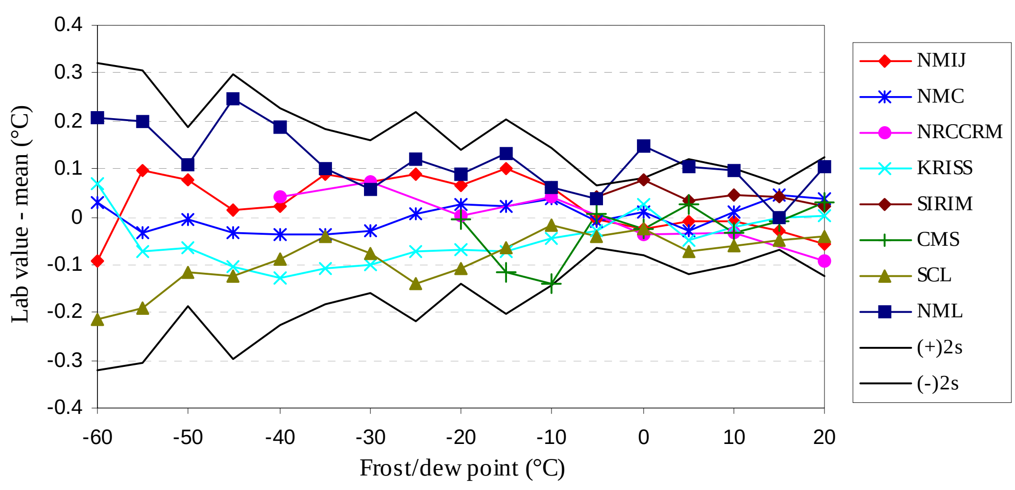


Figure 11. Difference between laboratory value and the M4RS232 mean.

It can be seen that the NML data at the 0°C dew point are outside the ±2*s* limits for both M4RS232 and 2nd PRT. The exclusion of these data seems to be reasonable. Besides these data, there are no other obvious outliers. Only the SIRIM 0°C dew point for M4RS232 and the NML 20°C dew point for 2nd PRT are slightly outside the ±2*s* limits. It is decided to take the mean values as final without further exclusion of data.

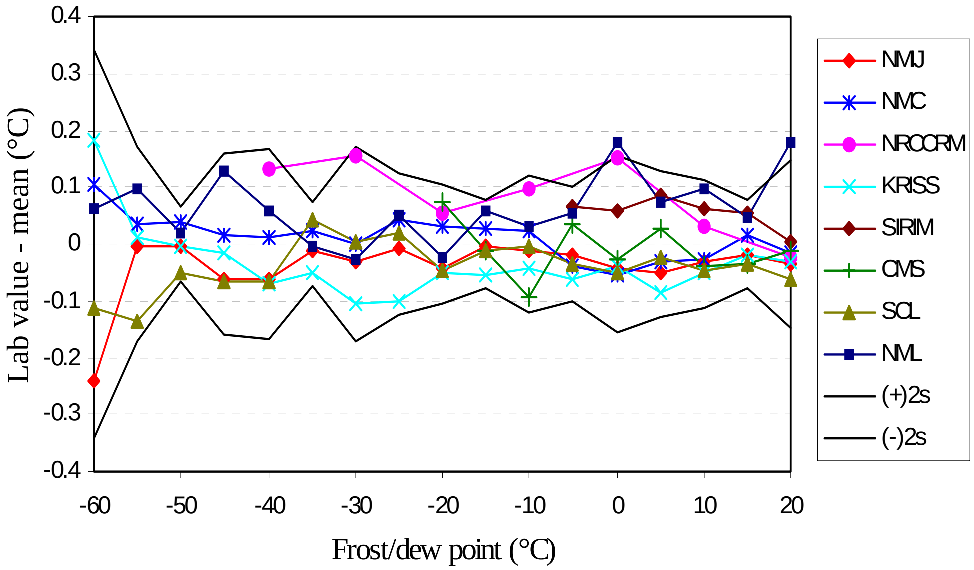


Figure 12. Difference between laboratory value and the 2nd PRT mean.

The mean values are reported in Table 10 together with the standard deviations from the mean values for both M4 RS232 and 2nd PRT.

Table 10. Mean values and uncertainties for M4 RS232 and 2nd PRT

Nominal frost/dew point °C	M4 RS232		2nd PRT	
	Mean values °C	*s* °C	Mean values °C	*s* °C
-60	-0.046	0.160	0.171	0.172
-55	-0.039	0.152	0.158	0.086
-50	-0.075	0.093	0.130	0.033
-45	-0.037	0.148	0.146	0.080
-40	-0.032	0.112	0.156	0.083
-35	-0.050	0.091	0.147	0.036
-30	-0.054	0.079	0.155	0.086
-25	-0.081	0.109	0.122	0.062
-20	-0.073	0.070	0.156	0.052
-15	-0.065	0.101	0.113	0.039
-10	-0.082	0.073	0.062	0.060
-5	-0.028	0.032	0.075	0.051
0	-0.024	0.041	0.059	0.077
5	0.025	0.060	0.163	0.064
10	0.002	0.051	0.118	0.057
15	0.008	0.035	0.077	0.039
20	0.021	0.062	0.063	0.075

8.2 Bilateral equivalence

For the bilateral equivalence evaluation, final data from NMIJ and NMC are taken in the same way as in the simple mean evaluation. The uncertainties associated with the final data are claimed in the following way:

a. For NMIJ, the claimed uncertainties for the 1998 and 2001 measurements are very similar. Therefore, the uncertainties of the 2001 measurements are taken as the uncertainties of the final data. For the 2nd PRT, 2001 measurement results are not available from 5°C to 20°C nominal dew point, the uncertainties of the 1998 measurements are taken for those points.
b. For NMC, pooled uncertainties are given for Feb and Oct 1999 measurements as well as the mean of the two.

The bilateral equivalence is evaluated in two ways. One way is in terms of pair difference and its associated uncertainty at each test point. The pair difference is defined as laboratory 1 value (transfer standard – laboratory 1 reference) – laboratory 2 value (transfer standard - laboratory 2 reference). The expanded uncertainty of the pair difference is calculated according to the ISO GUM [1] assuming that there is no correlation in each pair of laboratories' values. The combined uncertainty of the two laboratories is first obtained by combining the standard uncertainty (u_c) of each laboratory. The stability analysis in section 2 of this report shows that the transfer standard stability is much better than the uncertainty of the measurement. Therefore, there is no additional uncertainty due to this effect is deemed necessary. The combined uncertainty is then multiplied by the *k* factor so as to obtain the expanded uncertainty with a 95% level of confidence. The *k* factor value is calculated according to a student's t-distribution with information of the effective degree of freedom. The effective degree of freedom is calculated using Welch-Satterthwaite formula suggested in the ISO GUM. The other way is in terms of a single parameter, $QDE_{0.95}$ (Quantified Demonstrated Equivalence) [2], between any pair of laboratories' values. The $QDE_{0.95}$ between laboratory 1 and laboratory 2 is defined as the interval where measurements performed in the two laboratories are expected to agree with a 95% level of confidence and is calculated using the following formula:

$$QDE_{0.95} \approx |m_2 - m_1| + a\{1.645 + 0.3295\exp[-4.05(|m_2 - m_1|/u)]\}u,$$

where $a = 0.283+0.717b+0.042b^3\exp[-0.399(|m_2-m_1|/u)^2]$,
$b = [1.960-3.162/\nu+5.46/(\nu-0.607)]/1.96$,
and m_2-m_1 = pair difference between laboratory 1 and laboratory 2,
u = combined uncertainty of m_2-m_1,
ν = effective degrees of freedom.

The results of the evaluation for all tested points are presented in Appendix 2. The graphic demonstration of $QDE_{0.95}$ of one laboratory referred to the rest of the laboratories at each test point is presented in Appendix 3.

9. References

[1] Guide to the Expression of Uncertainty in Measurement, International Organisation for Standardization, Geneva, Switzerland, 1993.
[2] Wood, B.M., Douglas R.J., Confidence-Interval Interpretation of a Measurement Pair for Quantifying a Comparison, Metrologia, 1998, **35**, pp.187-196

Acknowledgements

We would like to thank Dr Peter Huang of NIST, USA for his strong support in checking the stability of the transfer standard before the start of the comparison and after the repair. Thanks also go to Dr Chiharu Takahashi of NMIJ, Japan, who twice provided the transfer standard.

Appendix 1

PROTOCOL TO THE APMP COMPARISON ON HUMIDITY MEASUREMENT

Contents

Appendices

APMP COMPARISON ON HUMIDITY MEASUREMENT

1. Introduction.

An APMP comparison on humidity measurement has been discussed since January 1996. It is concluded to circulate a transfer standard chilled mirror dew point meter among eight participating members. The transfer standard will cover a dew point range from -80°C to +20°C. This will meet the needs of almost all the participating laboratories. The result of the comparison will be evaluated by September 2000.

The comparison schedule, information on transfer standard, measurement procedure and report format are listed bellow. It is very important that each participating laboratory follow strictly each of the instructions and procedures so as to achieve a successful comparison.

2. Comparison schedule

A round robin method is used for the comparison. The transfer standard will be sent to each participating laboratory via air cargo on the date as indicated in **Appendix 1**. Each laboratory will have 8 weeks time to perform the calibration. One extra week is given for shipment. The date indicated for each laboratory is the date of arrival of the transfer standard. Each laboratory needs to ship the transfer standard one week before the arrival date of the following laboratory to ensure that the transfer standard will arrive on time. Upon receipt of the transfer standard, the “receive confirmation form”, attached in **Appendix 2**, has to be filled in and sent to co-ordinator within one week. Each laboratory should submit the comparison report within 4 weeks after completion of the measurement. Information on the eight participating laboratories is listed in **Appendix 3**.

3. General information on transfer standard

3.1. Chiller

The transfer standard is 1311XR/M4 from General Eastern Instruments. It does not have integral refrigeration system. A separate chiller providing liquid coolant is absolutely necessary. However, such a chiller will NOT be provided with the transfer standard. Therefore, each laboratory must have a chiller in order to participate.

Two copper tubes with half inch hose connectors and fittings are provided for connection to the chiller.

3.2. Sample line connection

The 1311XR has 1/4 inch stainless steel tubing with swagelock fittings for both sample gas inlet and sample gas outlet.

3.3. Handling instruction

The handling instruction for unpacking and packing are shown below. Each participating laboratory must follow strictly this instruction. If any damage is found upon receipt, contact the co-ordinator immediately.

3.3.1. Unpacking

Take out the 1311XR and M4 from their carrying boxes. Cables, coolant connection tubes and manuals are inside the 1311XR cabinet. Check the contents with the Packing List. Connect the cables and coolant connection tubes following this protocol and the Chapter 2 of 1311XR operator's manual.

3.3.2. Packing

Remove the coolant connection tubes and cables from the 1311XR and M4. To be sure no coolant is remained inside the 1311XR system, lean the 1311XR backward. Replace the cables, coolant connection tubes and manuals in the cabinet of the 1311XR. Ensure that they will not cause damage to the 1311XR. Replace 1311XR and M4 in their carrying boxes respectively.

3.4. Shipment and insurance

The transfer standard will be shipped to each participating laboratory via air cargo. Each laboratory is strongly recommended to use SHINYEI as shipping agent. The SHINYEI branches in different countries are listed in **Appendix 4**. NML/CSIRO, Australia, can select its own reliable agent as there is no SHINYEI branch in Australia.

All costs for customs clearance of the transfer standard once it has landed in your country/territory and for the transport of the transfer standard from your laboratory to the next participating country/laboratory have to be borne by your laboratory.

The transfer standard is insured until 19/01/2001. The insurance covers transports by air and on surface, stay and the operations during the calibration of the transfer standard at each participating laboratory.

3.5. Attached documentation

1. Packing list
2. Pro-forma invoice
3. Covering note for custom purpose
4. Hygro M4/E4 Dew Point Monitor Operator’s Manual
5. 1311XR Chilled-Mirror Hygrometer Operator’s Manual

Documents 1, 2 and 3 are to be attached to the case of the transfer standard. Documents 4 and 5 are to be contained in the case.

4. Measurement procedure

Very important notes:

1. **The 1311XR dew point meter must be operated with liquid coolant.**
2. **The 1311XR dew point meter must be purged at least for three days upon receipt. The purge shall be done for the sample line (connected to sample gas inlet) and the sensor head through the purge inlet. The dew point meter must be purged through the purge inlet during operation either with sample gas or with another dry gas source.**
3. **The power supply of the M4/1311XR system is 100 VAC/50Hz**
4. **Before operating M4/1311XR system, read carefully the 1311XR Chilled-Mirror Hygrometer Operator's Manual and the M4 Operator's Manual which are used as general guides.**
5. **Whenever there is discrepancies between 1311XR/M4 manuals and this protocol, follow the protocol.**

4.1. Set up 1311XR/M4

Be sure all electrical cables are connected correctly. For details of connection, refer to 1311XR Operator's Manual.

Clean the mirror according to 1311XR Operator's Manual.

The heat-pump controller RANGE switch must be set to AUTO and the FROST POINT LOWER LIMIT (FPLL) control must set to -80°C all the time.

The 1311XR dew point meter must be operated with liquid coolant re-circulated by a chiller. The chiller used should have a capacity of at least 600 watts at the coolant temperature. The flow rate of the coolant should be between 1 and 2 litre per minute. The coolant temperature should not change by more than 0.5°C within any half-hour period. The coolant temperature must be adjusted according to the measured frost/dew point as follows:

Frost point ≤ 0°C: the coolant temperature = 5°C
Dew point ≥ 5°C: the coolant temperature = 25°C

The coolant temperatures shall be measured and recorded.

The 1311XR dew point meter must be purged during operation either with sample gas or with another dry gas source. However, the purging gas must have a dew/frost point which is lower than the coolant temperature.

4.2. Set up measuring system

The connecting tube between the generator and the 1311XR shall be as short as possible and made of stainless steel pipe of 1/4 inch diameter. If an open system is used, the 1311XR outlet should be connected with a stainless steel tube about one or two meters long to avoid back-flow of ambient moisture.

The comparison of the readout of the 1311XR against the generated dew point shall be made at the same pressure conditions. Should it be different, the pressure difference between the pressure measuring point of the generator and the 1311XR's sensor should be measured in order to make the appropriate correction.

The saturated gas from the generator should be drawn across the 1311XR by natural way. If the 1311XR is connected in the re-circulating mode, a pump will promote the circulation of the sampling gas across it. If the 1311XR sensor is connected to the generator together with other sensors, a parallel connection must be used. Refer to the 1311XR Operator’s Manual for details of the connection method. In any case, the gas flow rate in the 1311XR must be 0.7 litre per minute all the time.

4.3. Measuring range

The measuring range of 1311XR is from 20 °C to -80 °C dew/frost point. However, it is very difficult to measure frost point below -70°C. Therefore, the comparison will be made from 20°C to -70°C dew/frost point. The calibration program should start from the lowest dew point upward as indicated below:

-70°C, -65°C, -60°C, -55°C, -50°C, -45°C, -40°C, -35°C, -30°C,-25°C, -20°C, -15°C, -10°C, -5°C, 0°C, +5°C, +10°C, +15°C, +20°C.

As not all the participating laboratories can measure frost point down to -70°C, each laboratory will adapt the calibration program to the range limits of its standards.

Although the above values of measuring points are not the exact values one has to follow, it is recommended that each laboratory keep its calibration points as close to the proposed measruing points as possible to facilitate the comparison of results among all the laboratories.

4.4. Preliminary test

Preliminary test carried out within a reduced portion of the whole range of the comparison is recommended. This test enables the participating laboratories to detect relevant information about the repeatability and the reproducibility of the 1311XR/M4’s reading. The test will also confirm that the dew point meter has not been damaged during trasportation. A series of 5 experimental points, i.e., from -10 °C to 20 °C, repeated back and forth at least twice, is enough for the laboratories to collect some meaningful information. For this test, the M4 display reading can be taken.

4.5. Readings from 1311XR/M4

Three readings should be taken at each measuring point. They are M4 display and M4 digital output in dew point temperature and resistance value of a separate platinum resistance thermometer (PRT) housed in the 1311XR dew point sensor.

The M4 display reading is useful to check whether the 1311XR is working properly. However, the resolution of the reading in only 0.1°C.

The M4 can give a higher resolution by using its digital output through RS232C. The M4 operator’s manual provides detailed information in how to use RS232C. Hyper-terminal of Windows can be used in getting the digital output data. A detailed procedure in getting digital output by using PC through RS232C is attached in appendix 5 for participant's convenience.

Resistance measurement of the separate PRT provides data that are independent on the M4. The separate PRT can be measured through the four-wire terminal mounted on the back of the 1311XR.

The four-wire resistance measurement can be carried out by means of a bridge or a multimeter set in the 100 Ω or 1 KΩ range, with 1 mA measurement current across the PRT. Bridge or multimeter readouts should be directly referred to the SI unit of resistance as maintained in each participating country or territory equal to or better than 10 ppm.

A conventional value of dew point temperature, (t), from the measured resistance, (Rt), may also be obtained using the following relationship, according to the draft IEC 751 Amendment 2:

$Rt= R_0\ (1+At+Bt^2)$ For the temperature above 0 °C;

$Rt= R_0\ (1+At+Bt^2+C(t-100)t^3)$ For the temperature below 0 °C;

where:

R_0=100.00 ;
$A=3.9083\ x10^{-3}\ °C^{-1}$; $B=-5.775\ 10^{-7}\ °C^{-2}$; $C=-4.183\ 10^{-12}\ °C^{-4}$,

as stated, according to ITS 90, in the draft.

Each participant shall strictly follow the above equations to covert the resistance to temperature so as to exclude possible errors caused by resistance to temperature conversion.

Both the M4 digital output and the separate PRT readings will be used for the final comparison results.

The readings from the 1311XR dew point meter must be collected after stabilisation of the given dew point. The stabilisation time needed for each dew point level is listed in the 1311XR Operator's Manual, page 17-18. The number of the readings depends on the stability, the ripple and/or the noise in the measurement line, etc. A set of typically ten readings within ten minutes should be sufficient.

4.6. Laboratory ambient conditions

Laboratory ambient conditions, i.e., temperature, relative humidity and atmospheric pressure, should be recorded at the time of measurement.

5. Report format

A report should be drafted at the end of measurement by the staff member in charge of the tests at each participating laboratory. The report must include the following information:

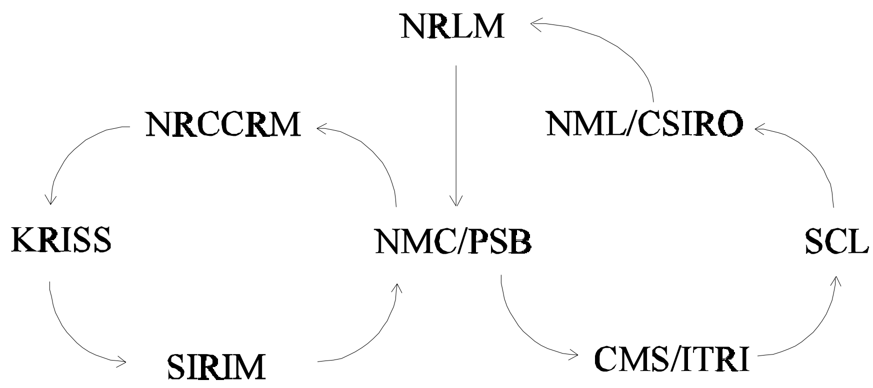
- Description of the dew point generation facilities used for comparison and their traceability status;
- Methods used for comparison, such as details of the connection between the generator and the transfer standard, stabilising time before measurement readings are taken, number of readings and the time interval of each reading for each measurement point, flow rate of 1311XR, measurement condition different from the protocol if any, and so on.
- Results of the comparison, including dew point reading of generator, M4 display, M4 digital output and the separate PRT readings both in resistance and the converted value in temperature using the method stated in 4.5.
- Description of chiller including cooling power, flow rate, temperature stability within half-hour period, coolant temperature at each dew point and so on.
- Laboratory ambient conditions.
- Combined uncertainty together with the effective degree of freedom. Each uncertainty component in terms of standard uncertainty and the degree of freedom should be stated as well.

The report should be submitted within 4 weeks after completion of the measurement via fax or e-mail. The report is preferably in the format of MSWord 97 or WP 6.1 if it is sent via e-mail.

At the end of the comparison exercise, a report will be drafted and published following the CIPM Guidelines for CIPM Key Comparisons.

Appendix 1 Circulation scheme and time schedule

1. Circulation scheme



2. Time Schedule

Participating laboratory	Date of arrival
NRLM	
NMC/PSB	1 February 1999
NRCCRM	5 April 1999
KRISS	7 June 1999
SIRIM	9 August 1999
NMC/PSB	11 October 1999
CMS/ITRI	13 December 1999
SCL	14 February 2000
NML/CSIRO	17 April 2000
NRLM	19 June 2000

Remarks:

1. *Dates referred to are ultimate deadlines. In any case, the transfer standard should be sent to the next laboratory as soon as possible after completion of the measurement.*
2. *Before sending the transfer standard, the laboratory should contact the next laboratory to confirm the shipping address in case of any change and to inform the approximate arrival date of the transfer standard.*

Appendix 2

Confirmation form on the receipt and status of the transfer standard

1. The transfer standard was received on ____________ (day/month/year).

2. There are following documents attached with the transfer standard*:

   a. Packing list;
   b. Pro-forma invoice;
   c. Covering note for custom purpose;
   d. HygroM4/E4 Dew Point Monitor Operator's Manual;
   e. 1311XR Chilled-Mirror Hygrometer Operator's Manual.

3. After inspection, the transfer standard seems*:

   a. to be in working condition.
   b. to be damaged. Please indicate the details of damage.

** Please tick whichever is applicable*.

Laboratory: ____________________

Contact Person: ____________________

Tel: ____________________

Fax: ____________________

In order to monitor the progress of the comparison, we kindly ask each participating laboratory, upon arrival of the transfer standard, to fill in this confirmation form and return it to:

Dr. Wang Li
National Measurement Centre
Singapore Productivity and Standards Board
1 Science Park Drive
Singapore 118221
Tel: +65 7729776
Fax: +65 7783798

Appendix 3

Information on participants

No.	Acronym	Name of organisation	Address	Telephone Telefax E-mail	Personnel responsible	Position in the comparison organisation
1	NRLM	National Research Laboratory of Metrology	1-1-4, Umezono, Tsukuba-Shi, Ibaraki, 305 Japan	81-298-54-4068 81-298-54-4135 chiharu@nrlm.go.jp	Dr Chiharu Takahashi Scientist in charge	Main partner
2	NMC/PSB	National Measurement Centre, Singapore Productivity and Standards Board	1 Science Park Drive, Singapore 118221	65-7729776 65-7783798 wangli@psb.gov.sg	Dr Wang Li Scientist in charge + coordinator	Coordinator
3	SIRIM	SIRIM Berhad	Persiaran Dato' Menteri, Section 2, P.O.Box 7035, 40911 Shah Alam Selangor, Malaysia	603-5567802/5567816 603-5567841 faridah@sirim.my	Ms F. Hussain Scientist in charge	Main partner
4	NRCCRM	National Research Center for Certificated Reference Material	No.7 District 11, Hepingjie 100013 Beijing, China	86-10-6422-8405 86-10-6422-8404 nrccrm@public3.bta.net.cn	Mr Yi Hong Scientist in charge	Main partner
5	KRISS	Korea Research Institute of Standards and Science	P.O. Box 102, Yusong, Taejon 305-600, Republic of Korea	82-42-868-5195 82-42-868-5290 nhseml@krissol.kriss.re.kr	Dr H.S. Nham Scientist in charge	Main partner
6	CMS/ITRI	Centre for Measurement Standards, Industrial Technology Research Institute	321 Kuang Fu Road, Section 2 Hsinchu Taiwan 30042, R.O.C.	886-35-721321 886-35-724952 740357@cms.itri.org.tw	Mr K.H. Chan Scientist in charge	Main partner
7	SCL	Standards and Calibration Laboratory	36/F Immigration Tower, 7 Gloucester Road, Wanchai, Hong Kong	852-2829-4848 852-2824-1302	Mr L.T. Lee Scientist in charge	Main partner
8	NML	National Measurement Laboratory	CSIRO Division of Applied Physics, Bradfield Road, West Lindfield, Sydney NSW, Australia	61-2-4137211 61-2-4137204 ecmo@dap.csiro.au	Dr Ed Morris Scientist in charge	Main partner

Appendix 4

Branches of the recommended airfreight agent

Singapore	Shinyei Singapore Pte.Ltd. No.705 Sims Drive No.03-03 Shun Li Industrial Complex Singapore 387384 Phone: +65-747-8011 Fax : +65-747-7323 Staff: Mr. Takehisa Okumura, Manager
Hong Kong	Shinyei Kaisha , Hong Kong Branch Unit 1301B, 13-Floor, Mirror Tower 61 Mody Road, Tsim Sha Tsui East Kowloon, Hong Kong Phone: +852-2369-7348 Fax: +852-2739-7999 Staff: Mr. N. Yamamizu, Manager
Taiwan	Shinyei Kaisha, Taiwan Liaison Office No 1109 Cha-Jen Commercial Bldg, Jen Tso No. 148 Section 4 Chung Hsiao East Road Taipei, Taiwan (R.O.C.) Phone: +886-2-773-1023, 1024 Fax : +886-2-773-1025 Staff: Mr. T. Fukushiro, Manager
Seoul, Korea	Shinyei Kaisha, Seoul Office Room 801, Dong Hwa Bldg. 19-2 Non Hyun Dong Kang Nam-ku, Seoul Korea Phone: +82-2-547-4944, 4945 Fax: +82-2-547-4946 Staff: Mr. A. Mori, Manager
China	Shinyei Kaisha, Beijing Office Poly Plaza Office Tower Room No.0573 14 Dongzhimen South Street Dongcheng District Beijing People's Republic of China Phone: 86-10-6592-1025, 1026, 1027 Fax : 86-10-6592-1024 Person in charge: Mr.Xue Guo Dong, Sales Engineer
Malaysia	Shinyei Kaisha Electronics (M) Sdn. Bhd. No.313, Lot 2557, 61/2 Miles Jalan Skudai

8120 Johor Bahru
Malasia
Phone: +60-7-2386017, 2386018
Fax : +60-7-2386022
Staff: NIL
(Malaysian destination cargo is handled by
Shinyei Singapore Pte.Ltd.)

Appendix 5

Getting digital output of M4 by using PC through RS232C

1. Making a RS232C connector adapted to M4. The detail of connection is stated at P30 of M4 Operator's Manual.
2. Connect M4 to one of the com ports of PC.
3. Let the PC work in Windows and go to Hyper-terminal.exe.
4. Go to "Call" function, click on "Connect", the Connection Description window turns up, key in a name (can be any name), click OK.
5. The Phone Number window should turn up now, choose right com port and click OK.
6. In the Com Property window, set the following parameters:

   Bit per second = 1200
   Data bit = 8
   Parity = non
   Stop bit = 1
   Flow control = Hardware

   Click OK.

6. The M4 digital output data will be shown on the screen.

Appendix 2 - Bilateral equivalence in terms of pair difference/uncertainty and $QDE_{0.95}$.

In the following tables, values above the diagonal are the differences between the rows and columns with their 95% level of confidence uncertainties. Values below the diagonal (shaded ones) are the $QDE_{0.95}$.

	M4RS232, Nominal Value: -65°C	
	NMC	KRISS
	°C	**°C**
NMC	-	-0.201 ± 0.191
KRISS	0.361	-

	2nd PRT, Nominal Value: -65°C	
	NMC	KRISS
	°C	**°C**
NMC	-	-0.283 ± 0.180
KRISS	0.434	-

	M4RS232, Nominal Value: -60°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.122 ± 0.251	-0.163 ± 0.230	0.121 ± 0.307	-0.299 ± 0.406
NMC	0.340	-	-0.041 ± 0.148	0.243 ± 0.251	-0.177 ± 0.365
KRISS	0.360	0.172	-	0.284 ± 0.230	-0.136 ± 0.351
SCL	0.389	0.455	0.477	-	-0.420 ± 0.405
NML	0.646	0.494	0.443	0.763	-

	2nd PRT, Nominal Value: -60°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.344 ± 0.266	-0.421 ± 0.245	-0.128 ± 0.318	-0.303 ± 0.415
NMC	0.568	-	-0.077 ± 0.150	0.216 ± 0.252	0.041 ± 0.366
KRISS	0.627	0.206	-	0.293 ± 0.230	0.118 ± 0.351
SCL	0.406	0.430	0.486	-	-0.175 ± 0.405
NML	0.658	0.387	0.427	0.528	-

	M4RS232, Nominal Value: -55°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.129 ± 0.172	0.170 ± 0.146	0.288 ± 0.267	-0.103 ± 0.365
NMC	0.276	-	0.041 ± 0.143	0.159 ± 0.265	-0.232 ± 0.363
KRISS	0.293	0.168	-	0.118 ± 0.250	-0.273 ± 0.352
SCL	0.513	0.387	0.334	-	-0.391 ± 0.416
NML	0.427	0.544	0.573	0.744	-

	2nd PRT, Nominal Value: -55°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.037 ± 0.169	-0.015 ± 0.150	0.134 ± 0.269	-0.100 ± 0.366
NMC	0.190	-	0.022 ± 0.137	0.171 ± 0.262	-0.063 ± 0.361
KRISS	0.158	0.148	-	0.149 ± 0.250	-0.085 ± 0.352
SCL	0.367	0.395	0.364	-	-0.234 ± 0.416
NML	0.426	0.394	0.401	0.593	-

	M4RS232, Nominal Value: -50°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.080 ± 0.142	0.140 ± 0.116	0.191 ± 0.197	-0.031 ± 0.353
NMC	0.202	-	0.060 ± 0.140	0.111 ± 0.210	-0.111 ± 0.361
KRISS	0.238	0.181	-	0.051 ± 0.195	-0.171 ± 0.352
SCL	0.357	0.293	0.225	-	-0.222 ± 0.386
NML	0.371	0.430	0.477	0.555	-

	2nd PRT, Nominal Value: -50°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.045 ± 0.145	-0.003 ± 0.122	0.044 ± 0.200	-0.025 ± 0.355
NMC	0.173	-	0.042 ± 0.138	0.089 ± 0.209	0.020 ± 0.360
KRISS	0.128	0.163	-	0.047 ± 0.195	-0.022 ± 0.352
SCL	0.224	0.271	0.222	-	-0.069 ± 0.386
NML	0.371	0.376	0.368	0.422	-

	M4RS232, Nominal Value: -45°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.046 ± 0.144	0.118 ± 0.116	0.136 ± 0.204	-0.232 ± 0.352
NMC	0.173	-	0.072 ± 0.147	0.090 ± 0.222	-0.278 ± 0.363
KRISS	0.217	0.199	-	0.018 ± 0.206	-0.350 ± 0.353
SCL	0.311	0.284	0.215	-	-0.368 ± 0.390
NML	0.534	0.588	0.649	0.699	-

	2nd PRT, Nominal Value: -45°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.078 ± 0.159	-0.048 ± 0.122	0.003 ± 0.216	-0.193 ± 0.354
NMC	0.215	-	0.030 ± 0.157	0.081 ± 0.236	-0.115 ± 0.366
KRISS	0.155	0.172	-	0.051 ± 0.215	-0.145 ± 0.353
SCL	0.226	0.288	0.244	-	-0.196 ± 0.395
NML	0.499	0.439	0.453	0.539	-

	M4RS232, Nominal Value: -40°C					
	NMIJ	NMC	NRCCRM	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.060 ± 0.145	-0.019 ± 0.244	0.153 ± 0.125	0.111 ± 0.134	-0.164 ± 0.216
NMC	0.187	-	-0.079 ± 0.253	0.093 ± 0.143	0.051 ± 0.151	-0.224 ± 0.227
NRCCRM	0.253	0.300	-	0.172 ± 0.243	0.130 ± 0.247	-0.145 ± 0.296
KRISS	0.258	0.216	0.377	-	-0.042 ± 0.131	-0.317 ± 0.214
SCL	0.225	0.183	0.341	0.158	-	-0.275 ± 0.219
NML	0.348	0.416	0.400	0.497	0.460	-

	2nd PRT, Nominal Value: -40°C					
	NMIJ	NMC	NRCCRM	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.074 ± 0.148	-0.197 ± 0.322	0.007 ± 0.130	0.003 ± 0.152	-0.120 ± 0.218
NMC	0.202	-	-0.123 ± 0.326	0.081 ± 0.143	0.077 ± 0.163	-0.046 ± 0.226
NRCCRM	0.468	0.404	-	0.204 ± 0.320	0.200 ± 0.328	0.077 ± 0.359
KRISS	0.136	0.204	0.473	-	-0.004 ± 0.148	-0.127 ± 0.215
SCL	0.159	0.218	0.477	0.154	-	-0.123 ± 0.229
NML	0.309	0.251	0.398	0.312	0.321	-

	M4RS232, Nominal Value: -35°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.127 ± 0.144	0.200 ± 0.117	0.130 ± 0.132	-0.009 ± 0.210
NMC	0.250	-	0.073 ± 0.153	0.003 ± 0.164	-0.136 ± 0.232
KRISS	0.298	0.206	-	-0.070 ± 0.141	-0.209 ± 0.216
SCL	0.241	0.172	0.192	-	-0.139 ± 0.224
NML	0.218	0.336	0.392	0.331	-

	2nd PRT, Nominal Value: -35°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.038 ± 0.155	0.038 ± 0.123	-0.056 ± 0.146	-0.009 ± 0.213
NMC	0.175	-	0.076 ± 0.158	-0.018 ± 0.174	0.029 ± 0.232
KRISS	0.147	0.211	-	-0.094 ± 0.149	-0.047 ± 0.216
SCL	0.183	0.182	0.222	-	0.047 ± 0.229
NML	0.222	0.247	0.242	0.254	-

	M4RS232, Nominal Value: -30°C					
	NMIJ	NMC	NRCCRM	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.104 ± 0.147	0.000 ± 0.259	0.175 ± 0.121	0.150 ± 0.125	0.017 ± 0.210
NMC	0.230	-	-0.104 ± 0.275	0.071 ± 0.157	0.046 ± 0.160	-0.087 ± 0.233
NRCCRM	0.268	0.342	-	0.175 ± 0.263	0.150 ± 0.265	0.017 ± 0.311
KRISS	0.277	0.207	0.398	-	-0.025 ± 0.136	-0.158 ± 0.217
SCL	0.255	0.188	0.375	0.149	-	-0.133 ± 0.219
NML	0.220	0.291	0.322	0.344	0.322	-

	2nd PRT, Nominal Value: -30°C					
	NMIJ	NMC	NRCCRM	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.033 ± 0.184	-0.187 ± 0.357	0.073 ± 0.129	-0.037 ± 0.146	-0.006 ± 0.213
NMC	0.201	-	-0.154 ± 0.379	0.106 ± 0.191	-0.004 ± 0.202	0.027 ± 0.255
NRCCRM	0.490	0.480	-	0.260 ± 0.360	0.150 ± 0.365	0.181 ± 0.392
KRISS	0.185	0.271	0.561	-	-0.110 ± 0.154	-0.079 ± 0.219
SCL	0.167	0.211	0.463	0.242	-	0.031 ± 0.229
NML	0.222	0.269	0.517	0.271	0.245	-

	M4RS232, Nominal Value: -25°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.084 ± 0.166	0.163 ± 0.127	0.227 ± 0.160	-0.032 ± 0.212
NMC	0.228	-	0.079 ± 0.175	0.143 ± 0.200	-0.116 ± 0.244
KRISS	0.270	0.231	-	0.064 ± 0.169	-0.195 ± 0.219
SCL	0.361	0.314	0.212	-	-0.259 ± 0.239
NML	0.228	0.328	0.381	0.461	-

	2nd PRT, Nominal Value: -25°C				
	NMIJ	NMC	KRISS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.053 ± 0.184	0.093 ± 0.132	-0.027 ± 0.164	-0.059 ± 0.215
NMC	0.216	-	0.146 ± 0.189	0.026 ± 0.212	-0.006 ± 0.254
KRISS	0.206	0.307	-	-0.120 ± 0.169	-0.152 ± 0.219
SCL	0.178	0.225	0.265	-	-0.032 ± 0.239
NML	0.250	0.265	0.340	0.256	-

	M4RS232, Nominal Value: -20°C						
	NMIJ	NMC	NRCCRM	KRISS	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.036 ± 0.130	0.060 ± 0.186	0.133 ± 0.129	0.070 ± 0.127	0.170 ± 0.150	-0.026 ± 0.167
NMC	0.152	-	0.024 ± 0.197	0.097 ± 0.146	0.034 ± 0.144	0.134 ± 0.165	-0.062 ± 0.180
NRCCRM	0.222	0.207	-	0.073 ± 0.196	0.010 ± 0.194	0.110 ± 0.209	-0.086 ± 0.221
KRISS	0.242	0.222	0.243	-	-0.063 ± 0.142	0.037 ± 0.164	-0.159 ± 0.179
CMS	0.179	0.163	0.200	0.187	-	0.100 ± 0.162	-0.096 ± 0.177
SCL	0.297	0.274	0.290	0.184	0.239	-	-0.196 ± 0.195
NML	0.180	0.220	0.278	0.311	0.249	0.361	-

	2nd PRT, Nominal Value: -20°C						
	NMIJ	NMC	NRCCRM	KRISS	CMS	SCL	NML
	°C	°C	°C	°C	°C	°C	°C
NMIJ	-	-0.077 ± 0.149	-0.098 ± 0.198	0.005 ± 0.139	-0.118 ± 0.137	0.002 ± 0.167	-0.020 ± 0.175
NMC	0.206	-	-0.021 ± 0.208	0.082 ± 0.154	-0.041 ± 0.152	0.079 ± 0.180	0.057 ± 0.187
NRCCRM	0.267	0.217	-	0.103 ± 0.202	-0.020 ± 0.200	0.100 ± 0.220	0.078 ± 0.226
KRISS	0.145	0.215	0.275	-	-0.123 ± 0.142	-0.003 ± 0.172	-0.025 ± 0.179
CMS	0.234	0.177	0.208	0.244	-	0.120 ± 0.170	0.098 ± 0.177
SCL	0.174	0.236	0.290	0.179	0.265	-	-0.022 ± 0.201
NML	0.185	0.223	0.275	0.192	0.251	0.213	-

	M4RS232, Nominal Value: -15°C					
	NMIJ	NMC	KRISS	CMS	SCL	NML
	°C	°C	°C	°C	°C	°C
NMIJ	-	0.078 ± 0.150	0.175 ± 0.144	0.216 ± 0.139	0.166 ± 0.169	-0.031 ± 0.177
NMC	0.208	-	0.097 ± 0.156	0.138 ± 0.151	0.088 ± 0.179	-0.109 ± 0.186
KRISS	0.297	0.231	-	0.041 ± 0.145	-0.009 ± 0.174	-0.206 ± 0.181
CMS	0.333	0.266	0.170	-	-0.050 ± 0.170	-0.247 ± 0.177
SCL	0.309	0.243	0.181	0.200	-	-0.197 ± 0.201
NML	0.193	0.269	0.359	0.396	0.368	-

	2nd PRT, Nominal Value: -15°C					
	NMIJ	NMC	KRISS	CMS	SCL	NML
	°C	°C	°C	°C	°C	°C
NMIJ	-	-0.028 ± 0.149	0.054 ± 0.144	0.011 ± 0.139	0.011 ± 0.169	-0.060 ± 0.177
NMC	0.164	-	0.082 ± 0.154	0.039 ± 0.150	0.039 ± 0.178	-0.032 ± 0.185
KRISS	0.180	0.215	-	-0.043 ± 0.145	-0.043 ± 0.174	-0.114 ± 0.181
CMS	0.146	0.172	0.171	-	0.000 ± 0.170	-0.071 ± 0.177
SCL	0.177	0.199	0.199	0.178	-	-0.071 ± 0.201
NML	0.216	0.202	0.270	0.226	0.248	-

	M4RS232, Nominal Value: -10°C						
	NMIJ	NMC	NRCCRM	KRISS	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.021 ± 0.135	0.018 ± 0.158	0.104 ± 0.136	0.198 ± 0.136	0.078 ± 0.151	-0.001 ± 0.168
NMC	0.145	-	-0.003 ± 0.173	0.083 ± 0.154	0.177 ± 0.154	0.057 ± 0.168	-0.022 ± 0.182
NRCCRM	0.166	0.179	-	0.086 ± 0.174	0.180 ± 0.173	0.060 ± 0.185	-0.019 ± 0.199
KRISS	0.220	0.216	0.236	-	0.094 ± 0.155	-0.026 ± 0.169	-0.105 ± 0.183
CMS	0.312	0.306	0.325	0.227	-	-0.120 ± 0.168	-0.199 ± 0.183
SCL	0.209	0.204	0.223	0.182	0.264	-	-0.079 ± 0.195
NML	0.176	0.194	0.208	0.263	0.353	0.249	-

	2nd PRT, Nominal Value: -10°C						
	NMIJ	NMC	NRCCRM	KRISS	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.036 ± 0.144	-0.111 ± 0.161	0.028 ± 0.140	0.079 ± 0.139	-0.011 ± 0.163	-0.044 ± 0.170
NMC	0.164	-	-0.075 ± 0.176	0.064 ± 0.158	0.115 ± 0.158	0.025 ± 0.179	-0.008 ± 0.186
NRCCRM	0.247	0.227	-	0.139 ± 0.173	0.190 ± 0.173	0.100 ± 0.192	0.067 ± 0.198
KRISS	0.155	0.202	0.286	-	0.051 ± 0.155	-0.039 ± 0.176	-0.072 ± 0.183
CMS	0.199	0.250	0.335	0.187	-	-0.090 ± 0.176	-0.123 ± 0.183
SCL	0.170	0.191	0.265	0.198	0.242	-	-0.033 ± 0.201
NML	0.196	0.193	0.240	0.232	0.280	0.218	-

	M4RS232, Nominal Value: -5°C						
	NMIJ	NMC	KRISS	SIRIM	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.000 ± 0.129	0.021 ± 0.125	-0.051 ± 0.095	-0.016 ± 0.130	0.034 ± 0.130	-0.046 ± 0.169
NMC	0.135	-	0.021 ± 0.134	-0.051 ± 0.109	-0.016 ± 0.139	0.034 ± 0.139	-0.046 ± 0.176
KRISS	0.136	0.144	-	-0.072 ± 0.102	-0.037 ± 0.135	0.013 ± 0.135	-0.067 ± 0.173
SIRIM	0.133	0.144	0.159	-	0.035 ± 0.109	0.085 ± 0.108	0.005 ± 0.153
CMS	0.138	0.146	0.157	0.131	-	0.050 ± 0.140	-0.030 ± 0.177
SCL	0.150	0.158	0.142	0.177	0.173	-	-0.080 ± 0.177
NML	0.197	0.203	0.219	0.160	0.193	0.234	-

	2nd PRT, Nominal Value: -5°C						
	NMIJ	NMC	KRISS	SIRIM	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.021 ± 0.139	0.044 ± 0.132	-0.085 ± 0.100	-0.054 ± 0.134	0.016 ± 0.134	-0.074 ± 0.172
NMC	0.150	-	0.023 ± 0.143	-0.106 ± 0.114	-0.075 ± 0.145	-0.005 ± 0.145	-0.095 ± 0.181
KRISS	0.160	0.155	-	-0.129 ± 0.105	-0.098 ± 0.138	-0.028 ± 0.138	-0.118 ± 0.176
SIRIM	0.170	0.203	0.218	-	0.031 ± 0.109	0.101 ± 0.108	0.011 ± 0.153
CMS	0.171	0.200	0.216	0.127	-	0.070 ± 0.140	-0.020 ± 0.177
SCL	0.142	0.151	0.153	0.192	0.191	-	-0.090 ± 0.177
NML	0.224	0.252	0.269	0.160	0.187	0.243	-

	M4RS232, Nominal Value: 0°C							
	NMIJ	NMC	NRCCRM	KRISS	SIRIM	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.038 ± 0.112	0.009 ± 0.113	-0.053 ± 0.106	-0.103 ± 0.057	-0.001 ± 0.115	-0.001 ± 0.104	-0.175 ± 0.150
NMC	0.137	-	0.047 ± 0.151	-0.015 ± 0.148	-0.065 ± 0.118	0.037 ± 0.153	0.037 ± 0.146	-0.137 ± 0.182
NRCCRM	0.117	0.180	-	-0.062 ± 0.146	-0.112 ± 0.118	-0.010 ± 0.152	-0.010 ± 0.145	-0.184 ± 0.180
KRISS	0.145	0.155	0.189	-	-0.050 ± 0.112	0.052 ± 0.149	0.052 ± 0.141	-0.122 ± 0.178
SIRIM	0.150	0.167	0.211	0.147	-	0.102 ± 0.120	0.102 ± 0.110	-0.072 ± 0.154
CMS	0.120	0.174	0.158	0.182	0.203	-	0.000 ± 0.147	-0.174 ± 0.183
SCL	0.109	0.168	0.150	0.175	0.195	0.154	-	-0.174 ± 0.177
NML	0.302	0.293	0.336	0.275	0.206	0.329	0.324	-

	2nd PRT, Nominal Value: 0°C							
	NMIJ	NMC	NRCCRM	KRISS	SIRIM	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.011 ± 0.128	-0.193 ± 0.137	-0.003 ± 0.104	-0.100 ± 0.068	-0.013 ± 0.121	0.007 ± 0.110	-0.221 ± 0.155
NMC	0.134	-	-0.204 ± 0.171	-0.014 ± 0.150	-0.111 ± 0.127	-0.024 ± 0.161	-0.004 ± 0.154	-0.232 ± 0.188
NRCCRM	0.306	0.347	-	0.190 ± 0.155	0.093 ± 0.136	0.180 ± 0.165	0.200 ± 0.159	-0.028 ± 0.191
KRISS	0.109	0.157	0.319	-	-0.097 ± 0.104	-0.010 ± 0.143	0.010 ± 0.135	-0.218 ± 0.174
SIRIM	0.157	0.219	0.207	0.185	-	0.087 ± 0.120	0.107 ± 0.110	-0.121 ± 0.154
CMS	0.127	0.173	0.318	0.149	0.189	-	0.020 ± 0.147	-0.208 ± 0.183
SCL	0.115	0.160	0.332	0.141	0.200	0.157	-	-0.228 ± 0.177
NML	0.351	0.391	0.204	0.364	0.253	0.362	0.377	-

	M4RS232, Nominal Value: 5°C						
	NMIJ	NMC	KRISS	SIRIM	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	0.017 ± 0.099	0.038 ± 0.049	-0.045 ± 0.060	-0.036 ± 0.105	0.064 ± 0.123	-0.114 ± 0.150
NMC	0.108	-	0.021 ± 0.101	-0.062 ± 0.107	-0.053 ± 0.137	0.047 ± 0.151	-0.131 ± 0.175
KRISS	0.080	0.113	-	-0.083 ± 0.063	-0.074 ± 0.107	0.026 ± 0.124	-0.152 ± 0.152
SIRIM	0.096	0.154	0.136	-	0.009 ± 0.112	0.109 ± 0.129	-0.069 ± 0.156
CMS	0.128	0.173	0.165	0.117	-	0.100 ± 0.154	-0.078 ± 0.177
SCL	0.170	0.181	0.138	0.219	0.232	-	-0.178 ± 0.189
NML	0.242	0.280	0.280	0.204	0.232	0.338	-

	2nd PRT, Nominal Value: 5°C						
	NMIJ	NMC	KRISS	SIRIM	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.020 ± 0.107	0.033 ± 0.052	-0.136 ± 0.061	-0.078 ± 0.105	-0.028 ± 0.123	-0.125 ± 0.151
NMC	0.118	-	0.053 ± 0.109	-0.116 ± 0.114	-0.058 ± 0.142	-0.008 ± 0.156	-0.105 ± 0.179
KRISS	0.077	0.148	-	-0.169 ± 0.064	-0.111 ± 0.107	-0.061 ± 0.125	-0.158 ± 0.152
SIRIM	0.187	0.213	0.223	-	0.058 ± 0.112	0.108 ± 0.129	0.011 ± 0.156
CMS	0.168	0.182	0.201	0.155	-	0.050 ± 0.154	-0.047 ± 0.177
SCL	0.139	0.163	0.169	0.218	0.186	-	-0.097 ± 0.189
NML	0.253	0.259	0.287	0.163	0.205	0.260	-

	M4RS232, Nominal Value: 10°C							
	NMIJ	NMC	NRCCRM	KRISS	SIRIM	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.020 ± 0.111	0.023 ± 0.114	0.012 ± 0.054	-0.053 ± 0.061	0.023 ± 0.115	0.053 ± 0.105	-0.107 ± 0.151
NMC	0.122	-	0.043 ± 0.150	0.032 ± 0.114	-0.033 ± 0.118	0.043 ± 0.152	0.073 ± 0.145	-0.087 ± 0.181
NRCCRM	0.125	0.175	-	-0.011 ± 0.116	-0.076 ± 0.119	0.000 ± 0.152	0.030 ± 0.145	-0.130 ± 0.180
KRISS	0.061	0.133	0.121	-	-0.065 ± 0.066	0.011 ± 0.118	0.041 ± 0.107	-0.119 ± 0.153
SIRIM	0.105	0.138	0.177	0.121	-	0.076 ± 0.121	0.106 ± 0.111	-0.054 ± 0.156
CMS	0.127	0.178	0.159	0.123	0.180	-	0.030 ± 0.147	-0.130 ± 0.183
SCL	0.143	0.198	0.160	0.135	0.200	0.163	-	-0.160 ± 0.177
NML	0.236	0.244	0.284	0.249	0.191	0.286	0.310	-

	2nd PRT, Nominal Value: 10°C							
	NMIJ	NMC	NRCCRM	KRISS	SIRIM	CMS	SCL	NML
	°C	°C	°C	°C	°C	°C	°C	°C
NMIJ	-	-0.007 ± 0.125	-0.065 ± 0.114	0.016 ± 0.062	-0.095 ± 0.062	0.005 ± 0.116	0.015 ± 0.105	-0.131 ± 0.151
NMC	0.130	-	-0.058 ± 0.158	0.023 ± 0.129	-0.088 ± 0.130	0.012 ± 0.162	0.022 ± 0.155	-0.124 ± 0.190
NRCCRM	0.162	0.196	-	0.081 ± 0.118	-0.030 ± 0.119	0.070 ± 0.151	0.080 ± 0.144	-0.066 ± 0.179
KRISS	0.071	0.141	0.180	-	-0.111 ± 0.071	-0.011 ± 0.120	-0.001 ± 0.110	-0.147 ± 0.155
SIRIM	0.147	0.200	0.135	0.170	-	0.100 ± 0.121	0.110 ± 0.111	-0.036 ± 0.156
CMS	0.120	0.169	0.200	0.125	0.203	-	0.010 ± 0.147	-0.136 ± 0.183
SCL	0.113	0.166	0.203	0.115	0.204	0.153	-	-0.146 ± 0.177
NML	0.260	0.287	0.223	0.278	0.176	0.292	0.297	-

	M4RS232, Nominal Value: 15°C						
	NMIJ	NMC	KRISS	SIRIM	CMS	SCL	NML
	°C	°C	°C	°C	°C	°C	°C
NMIJ	-	-0.076 ± 0.105	-0.031 ± 0.053	-0.074 ± 0.060	-0.023 ± 0.105	0.017 ± 0.104	-0.030 ± 0.150
NMC	0.166	-	0.045 ± 0.108	0.002 ± 0.112	0.053 ± 0.141	0.093 ± 0.140	0.046 ± 0.178
KRISS	0.076	0.139	-	-0.043 ± 0.066	0.008 ± 0.108	0.048 ± 0.107	0.001 ± 0.153
SIRIM	0.124	0.117	0.100	-	0.051 ± 0.112	0.091 ± 0.111	0.044 ± 0.156
CMS	0.117	0.176	0.113	0.148	-	0.040 ± 0.140	-0.007 ± 0.177
SCL	0.112	0.213	0.141	0.186	0.164	-	-0.047 ± 0.177
NML	0.167	0.205	0.160	0.182	0.184	0.205	-

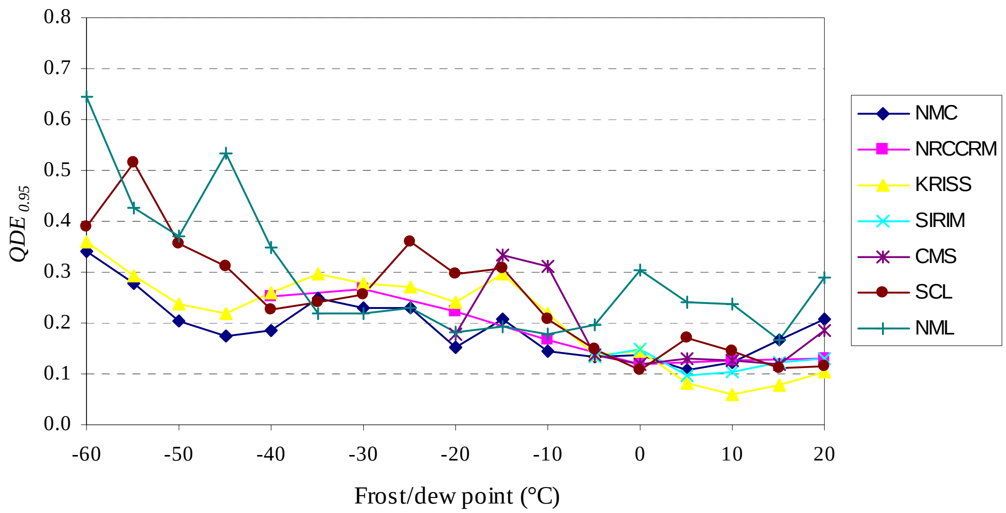
	2nd PRT, Nominal Value: 15°C						
	NMIJ	NMC	KRISS	SIRIM	CMS	SCL	NML
	°C	°C	°C	°C	°C	°C	°C
NMIJ	-	-0.034 ± 0.105	0.000 ± 0.056	-0.075 ± 0.060	0.016 ± 0.105	0.016 ± 0.104	-0.068 ± 0.150
NMC	0.126	-	0.034 ± 0.109	-0.041 ± 0.112	0.050 ± 0.141	0.050 ± 0.140	-0.034 ± 0.178
KRISS	0.058	0.130	-	-0.075 ± 0.068	0.016 ± 0.109	0.016 ± 0.108	-0.068 ± 0.153
SIRIM	0.125	0.139	0.132	-	0.091 ± 0.112	0.091 ± 0.111	0.007 ± 0.156
CMS	0.113	0.174	0.117	0.186	-	0.000 ± 0.140	-0.084 ± 0.177
SCL	0.112	0.173	0.116	0.186	0.147	-	-0.084 ± 0.177
NML	0.199	0.196	0.201	0.162	0.238	0.238	-

	M4RS232, Nominal Value: 20°C							
	NMIJ	NMC	NRCCRM	KRISS	SIRIM	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.097 ± 0.132	0.032 ± 0.113	-0.061 ± 0.053	-0.079 ± 0.060	-0.088 ± 0.115	-0.018 ± 0.104	-0.162 ± 0.150
NMC	0.209	-	0.129 ± 0.165	0.036 ± 0.134	0.018 ± 0.138	0.009 ± 0.168	0.079 ± 0.161	-0.065 ± 0.195
NRCCRM	0.131	0.269	-	-0.093 ± 0.116	-0.111 ± 0.119	-0.120 ± 0.152	-0.050 ± 0.145	-0.194 ± 0.180
KRISS	0.105	0.156	0.190	-	-0.018 ± 0.066	-0.027 ± 0.118	0.043 ± 0.107	-0.101 ± 0.153
SIRIM	0.129	0.147	0.211	0.077	-	-0.009 ± 0.121	0.061 ± 0.111	-0.083 ± 0.156
CMS	0.185	0.175	0.249	0.132	0.126	-	0.070 ± 0.147	-0.074 ± 0.183
SCL	0.113	0.219	0.176	0.137	0.157	0.197	-	-0.144 ± 0.177
NML	0.289	0.236	0.346	0.232	0.218	0.234	0.295	-

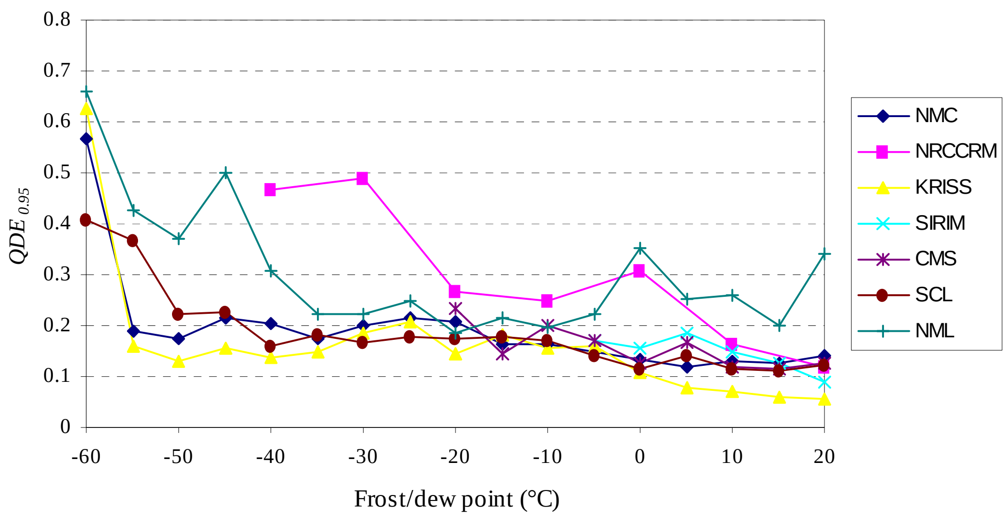
	2nd PRT, Nominal Value: 20°C							
	NMIJ	NMC	NRCCRM	KRISS	SIRIM	CMS	SCL	NML
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
NMIJ	-	-0.017 ± 0.132	-0.011 ± 0.114	-0.001 ± 0.054	-0.036 ± 0.061	-0.021 ± 0.115	0.029 ± 0.104	-0.212 ± 0.151
NMC	0.141	-	0.006 ± 0.165	0.016 ± 0.135	-0.019 ± 0.138	-0.004 ± 0.168	0.046 ± 0.161	-0.195 ± 0.195
NRCCRM	0.118	0.171	-	0.010 ± 0.116	-0.025 ± 0.119	-0.010 ± 0.151	0.040 ± 0.144	-0.201 ± 0.179
KRISS	0.056	0.143	0.120	-	-0.035 ± 0.066	-0.020 ± 0.118	0.030 ± 0.107	-0.211 ± 0.153
SIRIM	0.088	0.147	0.131	0.092	-	0.015 ± 0.121	0.065 ± 0.111	-0.176 ± 0.156
CMS	0.126	0.175	0.157	0.128	0.128	-	0.050 ± 0.147	-0.191 ± 0.183
SCL	0.122	0.189	0.167	0.125	0.161	0.179	-	-0.241 ± 0.177
NML	0.339	0.360	0.352	0.339	0.307	0.346	0.390	-

Appendix 3 - Graphic demonstration of $QDE_{0.95}$ of each laboratory at different test points.

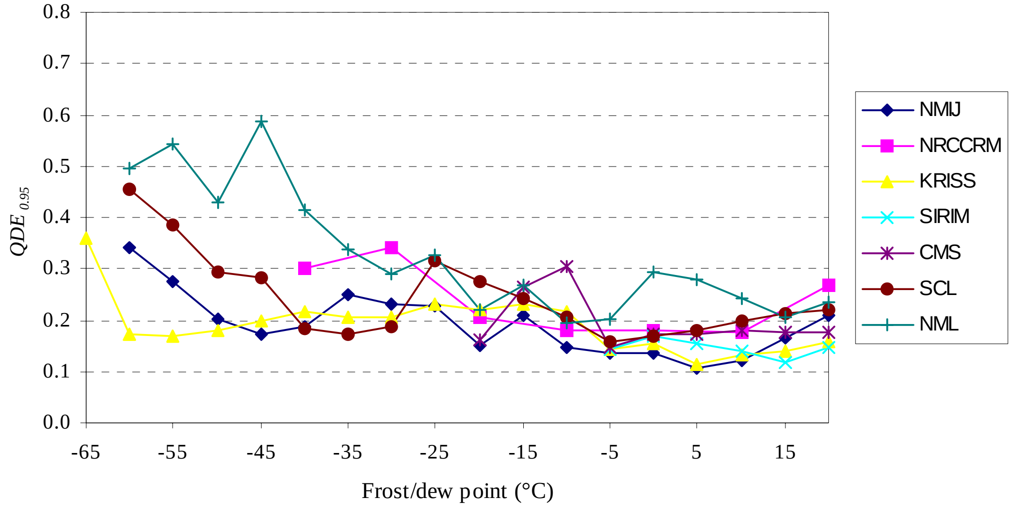
NMIJ M4RS232



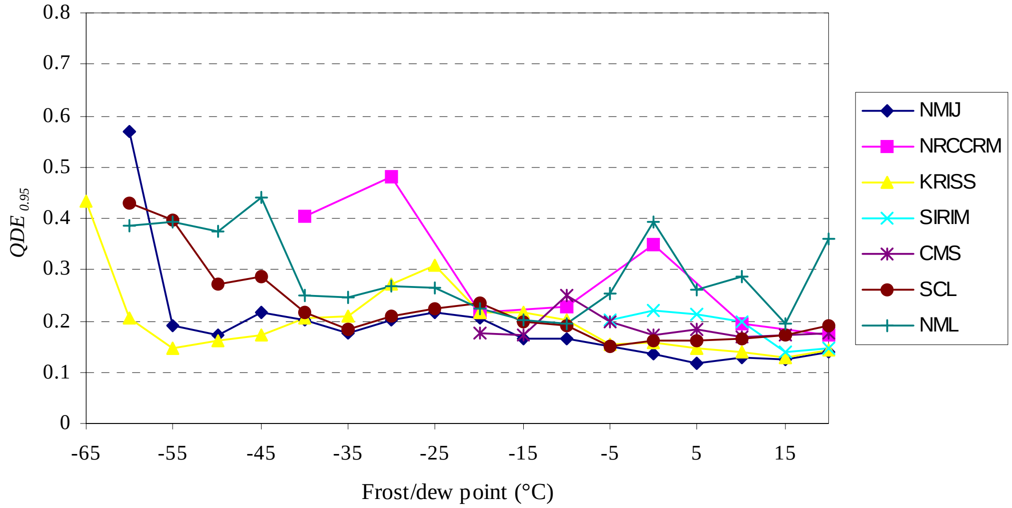
NMIJ 2nd PRT



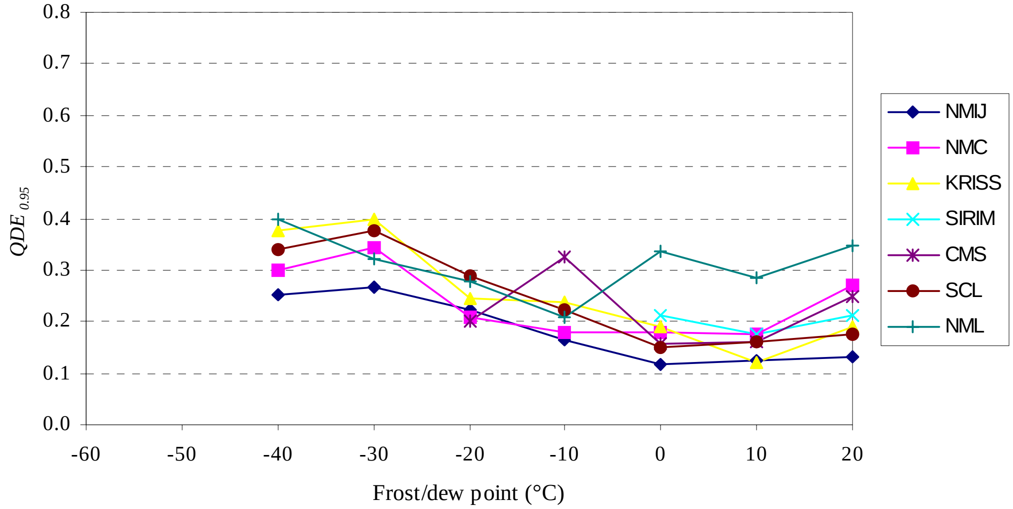
NMC M4RS232



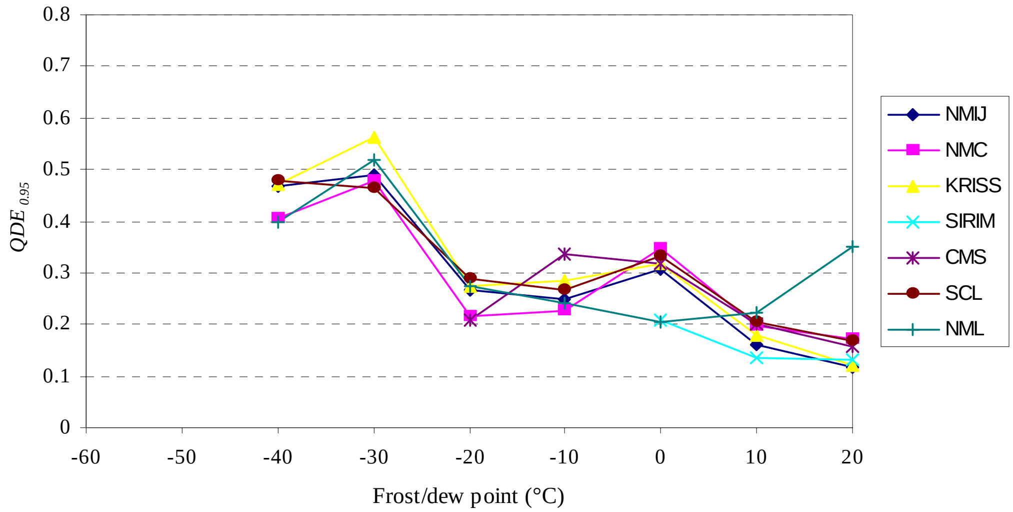
NMC 2nd PRT



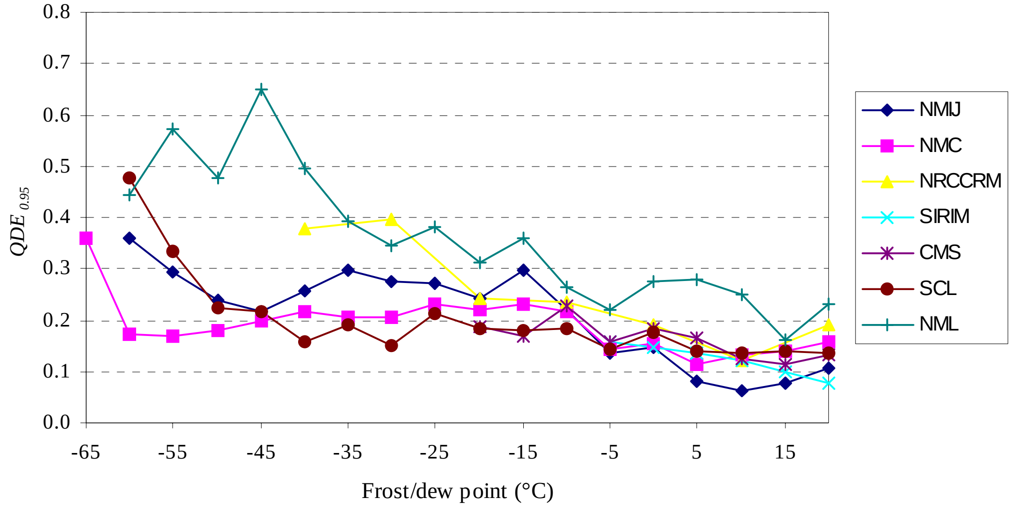
NRCCRM M4RS232



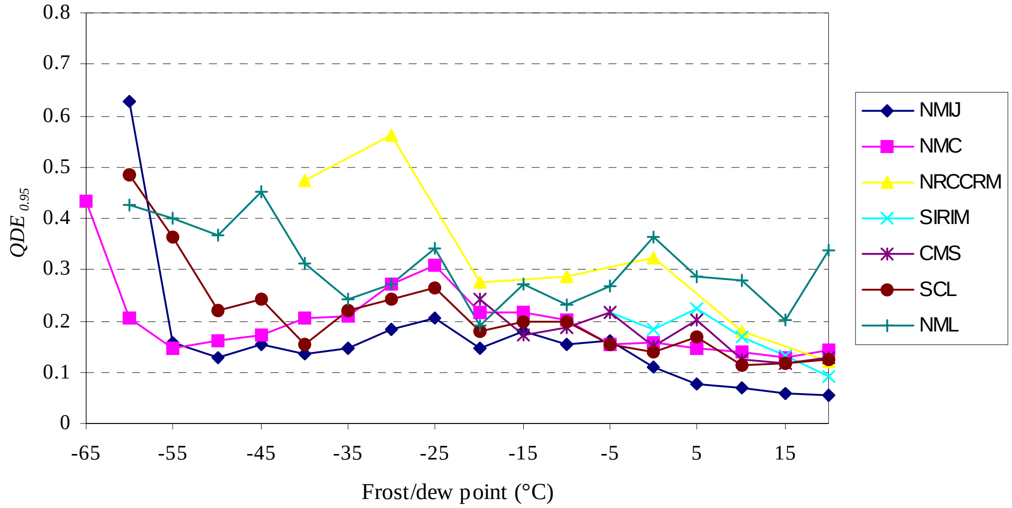
NRCCRM 2nd PRT



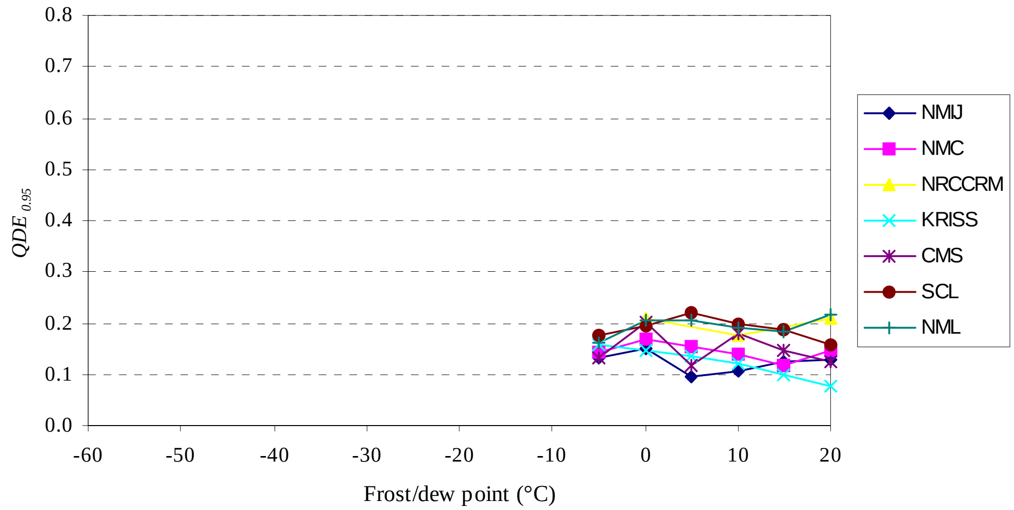
KRISS M4RS232



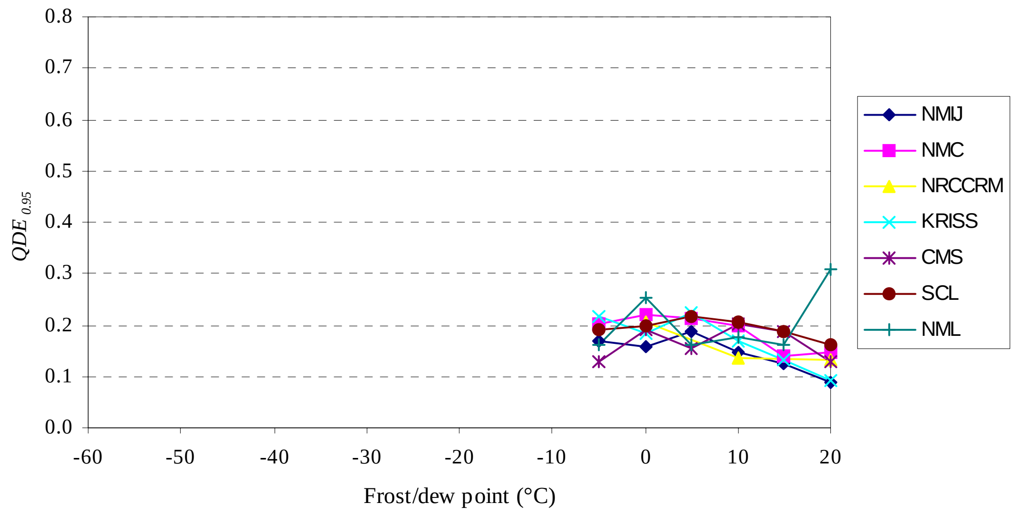
KRISS 2nd PRT



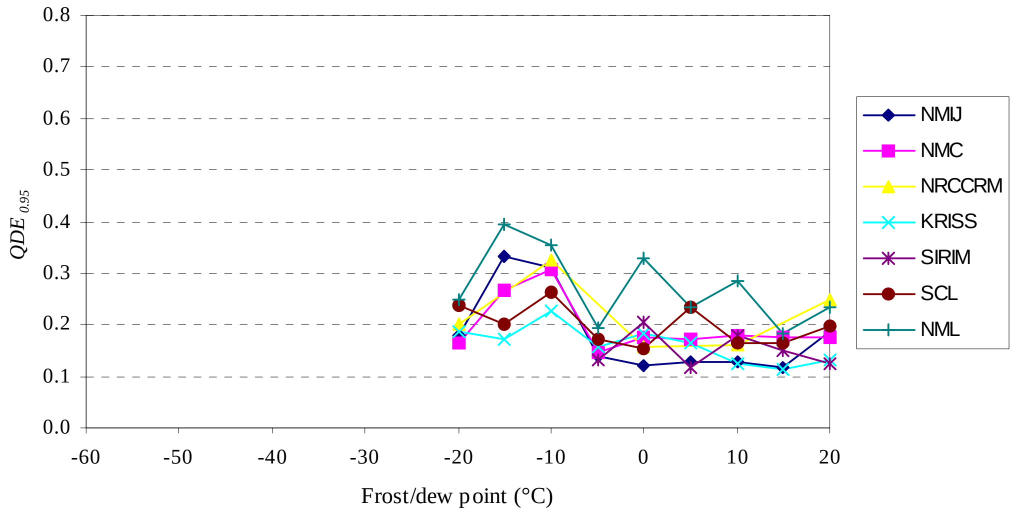
SIRIM M4RS232



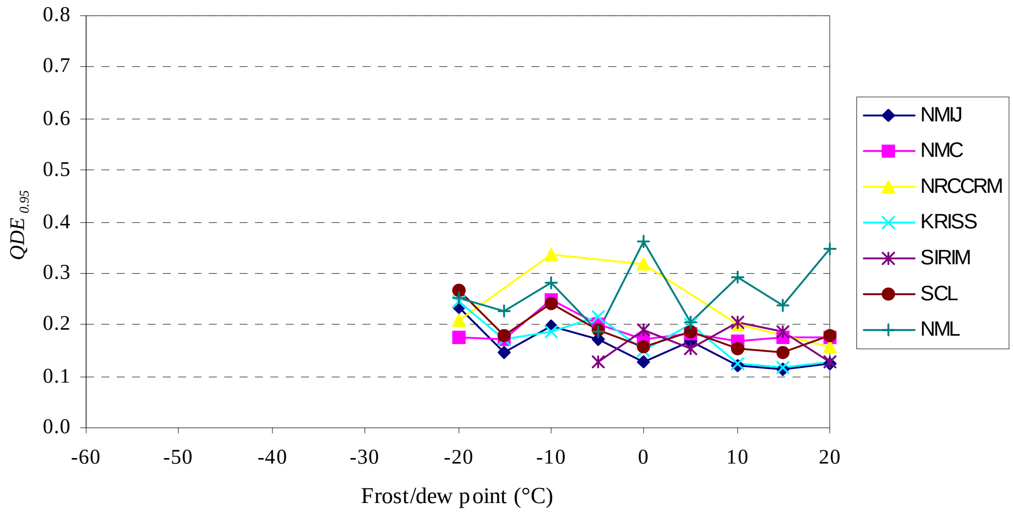
SIRIM 2nd PRT



CMS M4RS232



CMS 2nd PRT



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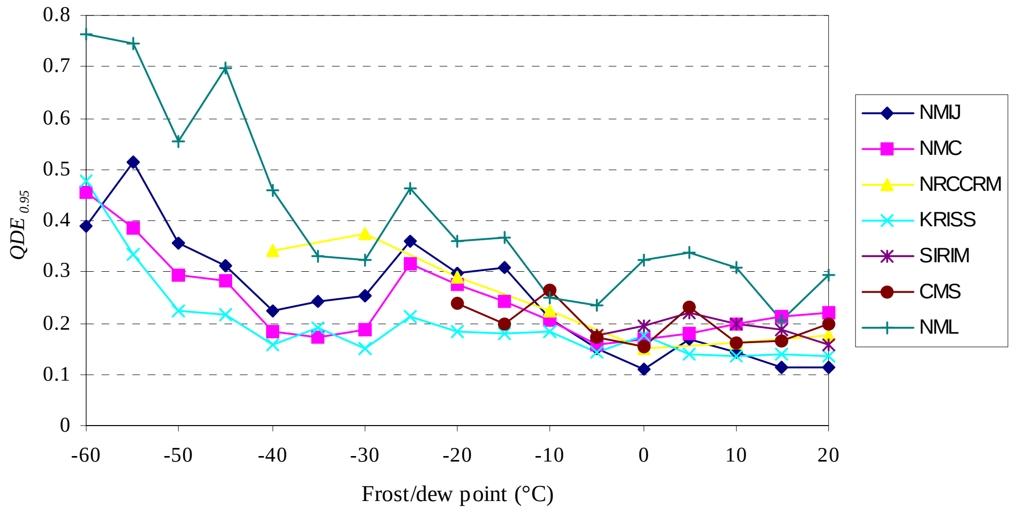

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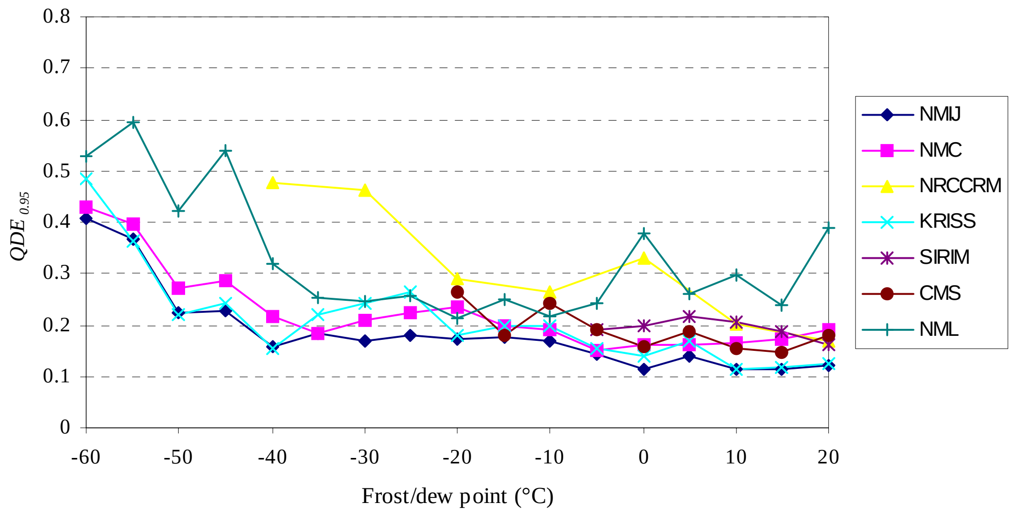
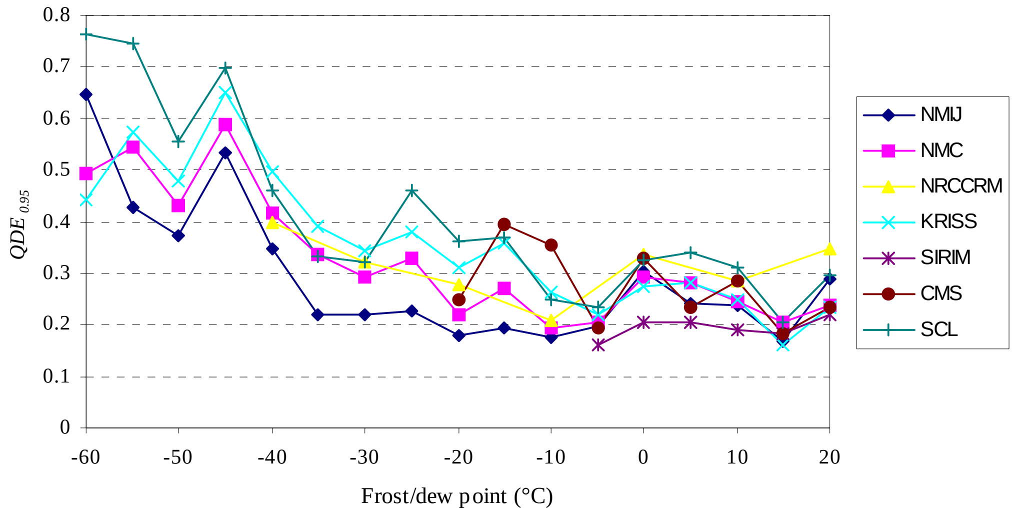


NML M4RS232



NML 2nd PRT