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Report on the Results of the Comparison on the Luminous Intensity, Luminance and Chromaticity

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19NRM02 RevStdLED

Abstract

Six LED-based standard light sources, two for luminous intensity and three coloured and one white for luminance, were prepared by PTB and TechnoTeam for this purpose. The aim of this comparison piloted by TUBITAK was to compare the different abilities of the participants in respect to spectral correlations. However, due to the Covid pandemic and the war in Ukraine, the schedule was completely corrupted, so that the comparison had to be carried out independently and with fewer partners than originally planned. Due to time constraints, only TechnoTeam, Jeti, candelTec, CSIC, LNE, TUBITAK, NMISA and PTB could take part. In addition, spectral correlations were only taken into account with respect to the correlation of the chromaticity coordinates. Nevertheless there was still a novelty, as with this intercomparison the results of the chromaticity coordinates of the LED lamps and their uncertainties were determined by TUBITAK with the help of TechnoTeam for the first time not only according to the classical GUM, (JCGM 100:2008), as independent coordinates, but correctly taken as multivariate quantities (JCGM 102:2011), to which an approach for determining the 2-dimensional Degree of Equivalence (DoE) was provided in the Python Toolbox. Unfortunately a more detailed examination of the results was no longer possible due to time constraints of the project.

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D4: Report on the Results of the Comparison on the Luminous Intensity, Luminance and Chromaticity

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Partners	**TUBITAK**, PTB, TechnoTeam, JETI, CandelTech, IO-CSIC, DTU, Aalto, NCS-IM, IPQ, LNE, NMISA, KIT
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1. Introduction

This Report is about measurement analyses in the context of the comparison carried out in Work Package 2 of the EMPIR 19NRM02 Project. This comparison of luminous intensity, luminance and chromaticity is part of the agreed protocol for EMPIR project 19NRM02 RevStdLED [1].

The comparison was made by the measurement of two groups of transfer standards. PTB provided two of the transfer standards developed in 15SIB07 PhotoLED for luminous intensity and TechnoTeam provided three chromatic LED-Based L³ standards (red, green and blue) and one white L³ standard for chromaticity / luminance.

The comparison was conducted in accordance with the Technical Protocol, which was prepared by the TÜBİTAK and approved by the participants.

The measurement partners have submitted their results to TÜBİTAK. The luminance, intensity, and chromaticity results have been evaluated using conventional methods. Additionally, the chromaticity results have been analysed as multidimensional data. The comparison report was prepared by TÜBİTAK .Following this, the partners have made contributions by reviewing the report as requested. The analysed results were then revised in accordance with the comments provided by TT and PTB.

2. Participants of the Comparison

2.1. Participant List

List of participating laboratories is given in Table 1.

Table 1. List of participating laboratories

Acronym of Institute	Country	Contact Person	Shipping Address
TÜBİTAK	Türkiye	Zühal Alpaslan Kösemen zuhal.kosemen@tubitak.gov.tr Tel: +90 262 679 50 00 (Ext. 3302)	TÜBİTAK Ulusal Metroloji Enstitüsü TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TÜRKIYE
PTB	Germany	Thorsten Gerloff Thorsten.Gerloff@ptb.de +49 5315924128	Physikalisch-Technische Bundesanstalt (PTB) Working Group 4.15 Bundesallee 100 38116 Braunschweig Germany
LNE	France	Jimmy Dubard jimmy.dubard@lne.fr	LNE-CNAM 61 rue du Landy 93210 La Plaine St Denis France
TechnoTeam	Germany	Benjamin Ruggaber Benjamin.ruggaber@technoteam.de	Werner-von-Siemens-Straße 5, 98693 Ilmenau, Germany
JETI GmbH	Germany	Steffen Görlich steffen.goerlich@jeti.com	JETI Technische Instrumente GmbH Göschwitzer Straße 48

Acronym of Institute	Country	Contact Person	Shipping Address
			07745 Jena
IO-CSIC	Spain	Alejandro Ferrero alejandro.ferrero@csic.es +34 91 561 6800 (ext 940242) Joaquin Campos joaquin.campos@csic.es +34 915616800	Instituto de Optica “Daza de Valdes” C/. Serrano, 144. 28006 Madrid Spain
CandelTech	Spain	Teresa Molina-Jiménez tmolina@candeltec.es +34960079566	Pol. Ind. L’Horta Vella, Calle 8, Nave 6, 46117 Bétera (Valencia), Spain
NMISA	South Africa	Pieter du Toit pdutoit@nmisa.org +27128412156 +27794845045	National Metrology Institute of SA Building 5 CSIR Campus Meiring Naudé Road, Brummeria, Pretoria, 0182, South Africa
[1]MIKESopell-Aalto	Finland	Ville Mantela ville.mantela@aalto.fi	Aalto University Metrology Research Institute (MIKES-Aalto) P.O. Box 15500 00076 AALTO Finland
[1]IPQ	Portugal	Olivier Pellegrino opellegrino@ipq.pt	Instituto Português da Qualidade Laboratório Nacional de Metrologia Rua António Gião 2 PT-2829-513 Caparica, Portugal
[1]DTU	Denmark	Anders Thorseth andt@fotonik.dtu.dk +45 26444841	Technical University of Denmark Frederiksborgvej 399 4000 Roskilde, Denmark,
[2]NCS-IM	Ukraine	Mykola Huriev nickgurev@gmail.com +38 0637935165	42 Mironositskaya Str., UA-61002 Kharkov, Ukraine
[3]KIT	Germany	Klaus Trampert klaus.trampert@kit.edu	Kaiserstraße 12, DE-76131 Karlsruhe, Germany

[1]MIKESopell-Aalto, IPQ and DTU did not send their comparison reports and they withdrew from the comparison.

[2]NCS-IM could not make measurements because of the war. They withdrew from the comparison.

[3]KIT could not make measurements. They withdrew from the comparison.

2.2. Pilot Institute

This comparison was piloted by TÜBİTAK UME. Pilot laboratory is responsible for preparing the technical protocol, calculating the results and preparing the comparison report.

2.3. The time schedule

The time schedule for the comparison is given in the Table 2.

Table 2. Circulation Time Schedule

Institute	Country	Starting Date	Time for Measurement and Transportation
PTB	GERMANY	November 2021	30 days
TT	GERMANY	November 2021	30 days
JETI	GERMANY	Feb.-March 2022	45 days
CandelTec	SPAIN	March-April 2022	21 days
IO-CSIC	SPAIN	April-May 2022	45 days
DTU	DENMARK	May-June 2022	45 days
AALTO	FINLAND	June-July 2022	45 days
IPQ	PORTUGAL	August 2022	30 days
LNE	FRANCE	September 2022	30 days
TÜBİTAK	TÜRKIYE	February 2023	30 days
NMISA	S.AFRICA	May 2023	14 days
PTB	GERMANY	July 2023	30 days
TT	GERMANY	September 2023	10 days

2.4. Unexpected events

During the course of the comparison, some delays have occurred in the planed schedule due to severe customs and transport delays, COVID-19 pandemic and the war between Ukraine and Russia were contributing factors.

2.5. Travelling Standard

Two of the travelling standards are supplied by PTB for luminous intensity measurements. Four of the travelling standards are supplied by TT for colour coordinate measurements. The traveling standards are shown in Figure 1.

The Model and Serial No of travelling standards are given in Table 3.

PTB Standards

TT Standard

Figure 1. Travelling standards

Table 3. The model and serial number of travelling standards

	Model No	Serial No
PTB1	OS40003A	LIS-A #1
PTB2	OS40003A	LIS-A #2
TT1	LB W5SM	AC4X6TJI
TT2	LW W5SM	AC54AFIH
TT3	LT W5SM	AC55OCVT
TT4	LR W5SM	AC52SLQZ

3. Measurement Instructions

The measurement instructions, of the travelling standard and its configuration required were given in the Technical Protocol.

4. Quantities Measured

The measured quantities are luminous intensity, luminance and chromaticity coordinates.

5. Measurement Results of Participants

Table 4. The participant results (x_i), and their uncertainties ($U(x_i)$, for xy colour coordinates

Lamp	Measurement Parameter	NMI	Participant Result	
			x_i (-)	$U(x_i)$ (-)
LT W5SM	x	TT	0.1934	0.0062
		TÜBİTAK	0.1968	0.0028
		CandelTech	0.1923	0.0030
		CSIC	0.1953	0.0014
		JETI	0.1952	0.0094
		NMISA	0.1926	0.0010
		LNE	0.1969	0.0050
		PTB	0.1939	0.0026
	y	TT	0.7267	0.0004
		TÜBİTAK	0.7180	0.0030
		CandelTech	0.7260	0.0035
		CSIC	0.7302	0.0035
		JETI	0.7258	0.0014
		NMISA	0.7253	0.0046
		LNE	0.7238	0.0082
		PTB	0.7263	0.0002
LR W5SM	x	TT	0.7018	0.0014
		TÜBİTAK	0.6982	0.0030
		CandelTech	0.7002	0.0036
		CSIC	0.7024	0.0019
		JETI	0.7020	0.0020
		NMISA	0.7012	0.0017
		LNE	0.7029	0.0050
		PTB	0.7019	0.0006
	y	TT	0.2981	0.0014
		TÜBİTAK	0.2996	0.0028
		CandelTech	0.2980	0.0038
		CSIC	0.2974	0.0011
		JETI	0.2974	0.0020
		NMISA	0.2985	0.0006
		LNE	0.2980	0.0015
		PTB	0.2981	0.0006

Table 4. The participant results (x_i), and their uncertainties ($U(x_i)$, for xy color coordinates (Continue)

Lamp	Measurement Parameter	NMI	Participant Result	
			x_i (-)	$U(x_i)$ (-)
LB W5SM	x	TT	0.1253	0.0022
		TÜBİTAK	0.1262	0.0028
		CandelTech	0.1263	0.0040
		CSIC	0.1237	0.0005
		JETI	0.1252	0.0026
		NMISA	0.1261	0.0007
		LNE	0.1240	0.0024
		PTB	0.1255	0.0009
	y	TT	0.0754	0.0052
		TÜBİTAK	0.0794	0.0028
		CandelTech	0.0768	0.0040
		CSIC	0.0764	0.0006
		JETI	0.0771	0.0068
		NMISA	0.0755	0.0012
		LNE	0.0763	0.0018
		PTB	0.0761	0.0021
LW W5SM	x	TT	0.3046	0.0018
		TÜBİTAK	0.3049	0.0028
		CandelTech	0.3032	0.0018
		CSIC	0.3074	0.0006
		JETI	0.3054	0.0014
		NMISA	0.3044	0.0010
		LNE	0.3067	0.0036
		PTB	0.3054	0.0008
	y	TT	0.2854	0.0016
		TÜBİTAK	0.2872	0.0028
		CandelTech	0.2848	0.0017
		CSIC	0.2885	0.0009
		JETI	0.2865	0.0018
		NMISA	0.2862	0.0016
		LNE	0.2888	0.0040
		PTB	0.2868	0.0008

Table 5. The participant results (x_i), and their corresponding uncertainties $U(x_i)$ for luminous intensity

Lamp	Measurement Parameter	NMI	Participant Result	
			x_i (cd)	$U(x_i)$ (cd)
LISA-1	Luminous Intensity	PTB	239.12	1.73
		TÜBİTAK	240.85	4.82
		CandelTech	235.40	5.00
		CSIC	235.15	1.48
		JETI	239.81	4.80
		LNE	239.50	3.10
LISA-2	Luminous Intensity	PTB	237.57	1.73
		TÜBİTAK	239.65	4.79
		CandelTech	233.90	5.00
		CSIC	233.96	1.47
		JETI	237.43	4.84
		LNE	238.50	3.10

Table 6. The participant results (x_i), and their corresponding uncertainties $U(x_i)$ for luminance

Lamp	NMI	Participant Result	
		x_i (cd/m2)	$U(x_i)$ (cd/m2)
LT W5SM	TT	6785.0	130.0
LT W5SM	TÜBİTAK UME	6730.0	121.1
LT W5SM	CandelTech	6810.0	148.0
LT W5SM	CSIC	6656.8	41.5
LT W5SM	JETI	6740.6	285.8
LT W5SM	NMISA	6852.9	130.2
LT W5SM	LNE	6814.5	126.7
LT W5SM	PTB	6867.0	75.0
LR W5SM	TT	4033.0	160.0
LR W5SM	TÜBİTAK UME	4110.0	74.0
LR W5SM	CandelTech	4120.0	90.0
LR W5SM	CSIC	4034.7	27.7
LR W5SM	JETI	3873.7	227.8
LR W5SM	NMISA	4057.8	73.0
LR W5SM	LNE	4160.4	77.4
LR W5SM	PTB	4076.0	86.0
LB W5SM	TT	2519.0	110.0
LB W5SM	TÜBİTAK	2460.0	44.3
LB W5SM	CandelTech	2402.0	52.0

LB W5SM	CSIC	2399.7	17.4
LB W5SM	JETI	2525.1	195.9
LB W5SM	NMISA	2565.7	46.2
LB W5SM	LNE	2493.1	46.4
LB W5SM	PTB	2539.0	65.0
LW W5SM	TT	7043.0	60.0
LW W5SM	TÜBİTAK	7080.0	127.4
LW W5SM	CandelTech	7163.0	154.0
LW W5SM	CSIC	7003.7	44.1
LW W5SM	JETI	6979.5	146.6
LW W5SM	NMISA	7162.9	128.9
LW W5SM	LNE	7131.9	132.7
LW W5SM	PTB	7165.0	56.0

6. The Comparison Reference Value (CRV)

The Comparison Reference Values (x_{CRV}) were calculated for each measurement point using the weighted mean [2], [3]. To reach result x_i a normalised weight w_i was attributed, given by;

$$w_i = C \times \frac{f_{pi}}{u(x_i)^2} \tag{1}$$

f_{pi} is the flag indicating if the result of participant is taken into account in the calculation of x_{CRV} or not. It takes the values 1 or 0. For the first attempt, f_{pi} is set to 1 for all participants.

The normalising factor, C, is given by:

$$C = \frac{1}{\sum_1^N \frac{f_{pi}}{u(x_i)^2}} \tag{2}$$

The x_{CRV} is given by:

$$x_{CRV} = \sum_{i=1}^{N} w_i \times x_i = \frac{\sum_1^N f_{pi} \frac{x_i}{u(x_i)^2}}{\sum_1^N \frac{f_{pi}}{u(x_i)^2}} \tag{3}$$

and the uncertainty of the Comparison Reference Values (x_{CRV}) was calculated by:

$$u(x_{CRV}) = \sqrt{C} = \sqrt{\frac{1}{\sum_1^N \frac{f_{pi}}{u(x_i)^2}}} \tag{4}$$

The expanded uncertainty of the Comparison Reference Values (x_{CRV}) was calculated by:

$$U(x_{CRV}) = 2 \times u(x_{CRV}) \quad (5)$$

A chi-square test was applied to carry out a consistency check of the results [3]. The test consists in comparing the values of $F_N\,(x_i)$ calculated by Equation (6) with the value of the chi-square distribution calculated for υ = N – 1 degrees of freedom at probability 0.05.

$$F_N\,(x_i) = \sum_{1}^{N} f_{pi} \times \frac{(x_i - x_{CRV})^2}{u(x_i)^2} \quad (6)$$

x_{CRV} and N measurement results x_i were regarded as consistent if;

$$F_N\,(x_i) \leq \chi^2_{(N-1;\,0.05)} \quad (7)$$

N : The number of participants

$F_N\,(x_i)$: The sum of squares function constitutes the sum of N contributions

$\chi^2_{(N-1;\,0.05)}$: Chi-squared distribution for υ = N – 1 degrees of freedom at probability 0.05

Where chi-square test was failed for the full set (N contributions), the Comparison Reference Value (x_{CRV}) was calculated the weighted mean of a largest consistent subset, contains as many as possible of those results of participants that are consistent with the weighted mean of that subset by using Equation (8). The result of participant with the largest E_n was excluded from the Comparison Reference Value by f_p is set to 0 and then chi-square test was again applied. This process of excluding the result with the largest E_n from contributing to the weighted mean was iterated until statistical consistency was reached.

$$F_r\,(x_i) = \sum_{1}^{r} f_{pi} \times \frac{(x_i - x_{CRV})^2}{u(x_i)^2} \quad (8)$$

x_{CRV} and r measurement results x_i were regarded as consistent if;

$$F_r\,(x_i) \leq \chi^2_{(r-1;\,0.05)} \quad (9)$$

r : The number of participants for the largest consistent subset

$F_r\,(x_i)$: The observed Chi-squared value, the sum of squares function constitutes the sum of r contributions, χ^2_{obs}

$\chi^2_{(r-1;\,0.05)}$: Chi-squared distribution for υ = r – 1 degrees of freedom at probability 0.05

The results presented in Table 7 show that the chi-squared distributions ($F_N\,(x_i')$ & $F_r\,(x_i')$), observed Chi-square values ($\chi^2_{(N-1;\,0.05)}$ & $\chi^2_{(r-1;\,0.05)}$), the result of the consistency test, if the consistency test

was failed, the outlier(s) which its result was excluded from the Comparison Reference Value and the Comparison Reference Values (x_{CRV}) and corresponding uncertainties ($U(x_{CRV})$).

Table 7. Results of chi-square test and the Comparison Reference Values

Lamp	Meas. Parameter	N	$F_N(x_i)$	$\chi^2_{(N-1;\,0.05)}$	Consistency/ Outlier(s)	r	$F_r(x_i)$	$\chi^2_{(r-1;\,0.05)}$	Consistency	x_{CRV}	$U(x_{CRV})$
xy Color Coordinates (-) and Luminance (cd·m^{-2})											
LT W5SM	x	8	17.1	14	No	7	10.8	13	Yes	0.1933	0.0008
	y	8	40.4	14	No	7	8.7	13	Yes	0.7264	0.0002
	Luminance	8	6.6	14	Yes	8	6.6	14	Yes	6781.6	39.7
LR W5SM	x	8	7.9	14	Yes	8	7.9	14	Yes	0.7018	0.0005
	y	8	5.2	14	Yes	8	5.2	14	Yes	0.2982	0.0004
	Luminance	8	7.9	14	Yes	8	7.9	14	Yes	4080.7	14.2
LB W5SM	x	8	36.5	14	No	7	3.9	13	Yes	0.1257	0.0005
	y	8	7.2	14	Yes	8	7.2	14	Yes	0.0763	0.0005
	Luminance	8	18.2	14	No	7	11.1	13	Yes	2458.3	10.7
LW W5SM	x	8	46	14	No	7	7.6	13	Yes	0.3049	0.0005
	y	8	22.4	14	No	7	7.7	13	Yes	0.2864	0.0006
	Luminance	8	8.6	14	Yes	8	8.6	14	Yes	7085.0	16.0
Luminous Intensity (cd)											
LISA-1	Intensity	6	12.3	11	No	5	2.9	9	Yes	239.11	1.33
LISA-2	Intensity	6	11.5	11	No	5	3.3	9	Yes	237.63	1.33

7. Degree of Equivalences (D_i) and Normalised Errors (E_n)

The results of the comparison are reported as the degrees of equivalence and the normalised error between a participant's result and the Comparison Reference Values (x_{CRV}).

The degree of equivalence of each participant (D_i), was calculated as:

$$D_i = x_i - x_{CRV} \tag{10}$$

where x_i is the result of the participants and x_{CRV} is the Comparison Reference Value.

The expanded uncertainty of the degree of equivalence for a participant's result ($U(D_i)$), was calculated as:

$$U(D_i) = \sqrt{U(x_i)^2 + U(x_{CRV})^2} \tag{11}$$

$$U(D_i) = \sqrt{U(x_i)^2 - U(x_{CRV})^2} \tag{12}$$

where $U(x_i)$ is the expanded uncertainty of the results of each participant and $U(x_{CRV})$ is the expanded uncertainty of the Comparison Reference Value. Equation (11) was used where the participant result does not contribute to the Comparison Reference Value. Equation (12) was used where the participant result contributes to the Comparison Reference Value.[2,3]

For each participant's result, the normalised errors (E_n) were calculated as.

$$E_n = \frac{x_i - x_{CRV}}{\sqrt{U(x_i)^2 - U(x_{CRV})^2}} = \frac{D_i}{U(D_i)} \tag{13}$$

$$E_n = \frac{x_i - x_{CRV}}{\sqrt{U(x_i)^2 + U(x_{CRV})^2}} = \frac{D_i}{U(D_i)} \tag{14}$$

Equation (13) was used for the results which contribute to the Comparison Reference Value. Equation (14) was used for the participant results which are excluded from the Comparison Reference Value.

The participant results were regarded as satisfactory if $|E_n| \leq 1$.

The degree of equivalences and the normalised errors are presented in Appendix I and Appendix II in tables and in graphs respectively.

The bilateral degree of equivalence between the results of the participant i and the participant j, was calculated as:

$$D_{ij} = x_i - x_j \tag{15}$$

where x_i is the result of the participant i and x_j is the result of the participant j.

The expanded uncertainty of the bilateral degree of equivalence between the results of the participant i and the participant j, was calculated as:

$$U(D_{ij}) = \sqrt{U(x_i)^2 + U(x_j)^2} \tag{16}$$

where $U(x_i)$ is the expanded uncertainty of the results of the participant i and $U(x_j)$ is the expanded uncertainty of the results of the participant j.

The normalised errors (E_n) between the results of the participant i and the participant j, were calculated as.

$$E_n = \frac{x_i - x_j}{\sqrt{U(x_i)^2 + U(x_j)^2}} = \frac{D_{ij}}{U(D_{ij})} \tag{17}$$

The degree of equivalences between the results of the participant i and the participant j and the normalised errors are presented in Appendix III in tables.

8. Chromaticity Coordinates Comparison Evaluation as a Multidimensional Quantities

8.1. Reference Value Determination

For Multidimensional values ,comparison reference value is a weighted average

$$\bar{x} = \sum_{i=1}^{n} W_i x_i \text{ with } \sum_{i=1}^{n} W_i = I. \quad (18)$$

The formal extension of this principle to the multivariate case leads to with the inverse covariance matrices as weights.[4]

$$\overline{x_W} = V_T^{-1} \sum_{i=1}^{n} V_i^{-1} x_i \quad V_T = \sum_{i=1}^{n} V_i^{-1} \quad (19)$$

V_i is the (m × m) covariance matrix

x_i is measured value of laboratories I=1,2,3,4…….

To determine the uncertainty value of Comparison reference value, the value's covariance matrix shall be derived. For these results general weights in

$$V_{\bar{x}} = \sum_{i=1}^{n} W_i V_i W_i' \quad (20)$$

From the general expression (20)

$$V_{\bar{x}} = V_T^{-1} \quad (21)$$

8.2. Degree of Equivalences (D_i) and Normalised Errors (E_n) for multidimensional Quantities

In the multivariate case the degree of equivalence d_i is a vector with dimension m and the uncertainty is described by a m × m covariance matrix [5]. For chromaticity coordinates two laboratories differences can be show

$$d_i = \begin{bmatrix} x_A \\ y_A \end{bmatrix} - \begin{bmatrix} x_B \\ y_B \end{bmatrix} \quad (22)$$

The covariance matrix that results from subtracting the bivariate normal distribution must be calculated.

$$V_{d_i} = \begin{bmatrix} u^2(x_A) & r \cdot u(x_A) \cdot u(y_A) \\ r \cdot u^2(x_A) \cdot u(y_A) & u^2(y_A) \end{bmatrix} + \begin{bmatrix} u^2(x_B) & r \cdot u(x_B) \cdot u(y_B) \\ r \cdot u^2(x_B) \cdot u(y_B) & u^2(y_B) \end{bmatrix} \quad (23)$$

covariance matrix is obtained by assuming an underlying m-variate normal distribution a confidence region is described by an m-dimensional elliptical contour centered around d_i

$$(x - d_i)' V_{d_i}^{-1} (x - d_i) = \chi^2_{m,\alpha} \quad (24)$$

In this work evaluations were done by Python based codes which were developed by project group [6].

9. Conclusions

The comparison measurements within the scope of the 19NRM02 project was carried out with the participation of project partners. In the Chromaticity comparison, the values of participants who did not declare their correlation coefficient values were assumed to be 0, and the results were evaluated accordingly. Color coordinates, which represent a multidimensional quantity, were evaluated as multidimensional data by taking correlation effects into account using the Monte Carlo method. In addition, classic comparison methods were employed for evaluation. All results are presented in Appendix I. Due to the large number of participants and some unaccepted delays in customs and in sending the participants reports, the comparison has took longer time.

The comparison reference value has been determined based on the weighted mean of participant results that survived outlier detection. Cut-off values were determined for luminous intensity and luminance values comparison [7].

Table 8. Statistics on Normalized Error Values

Lamp	Meas. Point	Number of Results	Number of Results for $\lvert E_n \rvert > 1$
LT W5SM	x	8	3
	y	8	2
	Luminance	8	0
LR W5SM	x	8	1
	y	8	0
	Luminance	8	0
LB W5SM	x	8	1
	y	8	1
	Luminance	8	1
LW W5SM	x	8	1
	y	8	1
	Luminance	8	0
LISA-1	Luminous Intensity	6	1
LISA-2	Luminous Intensity	6	1

10. References

[1] JCGM 100, "Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM)", 2008.

[2] Cox M. G., “The evaluation of key comparison data”, 2002 Metrologia **39**, 589-595.

[3] Cox M. G., “The evaluation of key comparison data: determining the largest consistent subset”, 2007 Metrologia 44 187.

[4] Ruggaber B,Vollrath T.,Krüger U.,Blattner P.,Gerloff T. DEGREE OF EQUIVALENCE OF TRISTIMULUS VALUES OF LEDS UNDER CONSIDERATION OF MEASUREMENT UNCERTAINTY AND CORRELATION, Conference CIE 2021 September 27 - 29, 2021

[5] Zeier, M: ON THE ANALYSIS OF MULTIDIMENSIONAL QUANTITIES IN MEASUREMENT COMPARISONS. Conference on Precision Electromagnetic Measurements, 9 to 14 July 2006, Torino, Italy; Conf. Digest p. 458-459, DOI: 10.1.1.513.2806

[6] https://github.com/empir19nrm02

[7] Guidelines for CCPR Key Comparison Report Preparation CCPR Working Group on Key Comparisons CCPR-G2 Rev.4 –2019

Appendix I: Degrees of Equivalence and Normalised Errors

Table 9. The DoEs and their expanded uncertainties and the normalised errors (E_n) for xy color coordinates

NMI	D_i (-)	$U(D_i)$ (-)	E_n	D_i (-)	$U(D_i)$ (-)	E_n
	LT W5SM x			**LT W5SM y**		
TT	0,0001	0,0061	0,0	0,0003	0,0004	0,8
TÜBİTAK	0,0035	0,0027	**1,3**	-0,0085	0,0030	**-2,8**
CandelTech	-0,0010	0,0029	-0,3	-0,0004	0,0035	-0,1
CSIC	0,0021	0,0017	1,2	0,0038	0,0035	**1,1**
JETI	0,0019	0,0094	0,2	-0,0006	0,0014	-0,4
NMISA	-0,0006	0,0006	**-1,1**	-0,0011	0,0046	-0,2
LNE	0,0036	0,0049	0,7	-0,0026	0,0082	-0,3
PTB	0,0006	0,0025	0,3	-0,0001	0,0001	-0,7
	LR W5SM x			**LR W5SM y**		
TT	0,0000	0,0013	0,0	-0,0001	0,0014	0,0
TÜBİTAK	-0,0036	0,0030	**-1,2**	0,0015	0,0028	0,5
CandelTech	-0,0016	0,0035	-0,4	-0,0002	0,0037	0,0
CSIC	0,0007	0,0018	0,4	-0,0008	0,0010	-0,8
JETI	0,0002	0,0019	0,1	-0,0008	0,0020	-0,4
NMISA	-0,0005	0,0016	-0,3	0,0003	0,0005	0,7
LNE	0,0011	0,0050	0,2	-0,0002	0,0015	-0,1
PTB	0,0001	0,0004	0,4	-0,0001	0,0005	-0,1
	LB W5SM x			**LB W5SM y**		
TT	-0,0004	0,0021	-0,2	-0,0009	0,0052	-0,2
TÜBİTAK	0,0004	0,0028	0,1	0,0031	0,0028	**1,1**
CandelTech	0,0006	0,0040	0,1	0,0005	0,0039	0,1
CSIC	-0,0020	0,0007	**-2,9**	0,0001	0,0004	0,3
JETI	-0,0005	0,0026	-0,2	0,0008	0,0068	0,1
NMISA	0,0003	0,0005	0,7	-0,0009	0,0011	-0,8
LNE	-0,0017	0,0023	-0,7	0,0000	0,0018	0,0
PTB	-0,0002	0,0007	-0,3	-0,0002	0,0020	-0,1
	LW W5SM x			**LW W5SM y**		
TT	-0,0003	0,0017	-0,2	-0,0010	0,0015	-0,6
TÜBİTAK	-0,0001	0,0028	0,0	0,0009	0,0027	0,3
CandelTech	-0,0017	0,0017	-1,0	-0,0015	0,0016	-0,9
CSIC	0,0025	0,0008	**3,1**	0,0021	0,0011	**1,9**
JETI	0,0005	0,0013	0,4	0,0001	0,0017	0,1
NMISA	-0,0005	0,0009	-0,6	-0,0002	0,0015	-0,1
LNE	0,0018	0,0036	0,5	0,0024	0,0040	0,6
PTB	0,0005	0,0006	0,8	0,0004	0,0006	0,7

Table 10. The degree of equivalences (D_i), its expanded uncertainties ($U(D_i)$) and the normalised errors (E_n) for luminous intensity

NMI	LISA-1			LISA-2		
	D_i (-)	$U(D_i)$ (-)	E_n	D_i (-)	$U(D_i)$ (-)	E_n
PTB	0,000	0,006	0,01	-0,0003	0,0060	-0,1
JETI	0,003	0,019	0,15	-0,0009	0,0193	0,0
CandelTech	-0,016	0,020	-0,78	-0,0158	0,0200	-0,8
CSIC	-0,017	0,011	**-1,52**	-0,0155	0,0110	**-1,4**
LNE	0,002	0,011	0,15	0,0036	0,0113	0,3
TÜBİTAK	0,007	0,019	0,38	0,0084	0,0191	0,4

Table 11. The degree of equivalences (D_i), its expanded uncertainties ($U(D_i)$) and the normalised errors (E_n) for luminance

NMI	D_i (-)	$U(D_i)$ (-)	E_n
	LT W5SM		
TT	0,0005	0,0234	0,02
TÜBİTAK	-0,0060	0,0442	-0,14
CandelTech	0,0042	0,0256	0,16
CSIC	-0,0184	0,0187	-0,98
JETI	0,0049	0,0230	0,21
NMISA	-0,0076	0,0222	-0,34
LNE	0,0105	0,0235	0,45
PTB	0,0126	0,0191	0,66
	LR W5SM		
TT	-0,0117	0,0417	-0,28
TÜBİTAK	-0,0507	0,0574	-0,88
CandelTech	0,0096	0,0264	0,36
CSIC	-0,0113	0,0210	-0,54
JETI	0,0195	0,0240	0,81
NMISA	0,0072	0,0232	0,31
LNE	-0,0056	0,0229	-0,25
PTB	-0,0012	0,0255	-0,05
	LB W5SM		
TT	0,0247	0,0496	0,50
TÜBİTAK	0,0272	0,0826	0,33
CandelTech	-0,0229	0,0293	-0,78
CSIC	-0,0238	0,0256	-0,93
JETI	0,0142	0,0284	0,50
NMISA	0,0007	0,0276	0,03
LNE	0,0437	0,0314	**1,39**

PTB	0,0328	0,0342	0,96
	LW W5SM		
TT	-0,0059	0,0148	-0,40
TÜBİTAK	-0,0149	0,0233	-0,64
CandelTech	0,0110	0,0244	0,45
CSIC	-0,0115	0,0148	-0,78
JETI	0,0066	0,0217	0,30
NMISA	-0,0007	0,0210	-0,03
LNE	0,0110	0,0213	0,52
PTB	0,0113	0,0150	0,75

Appendix II: Graphs of Degrees of Equivalence (DoE)

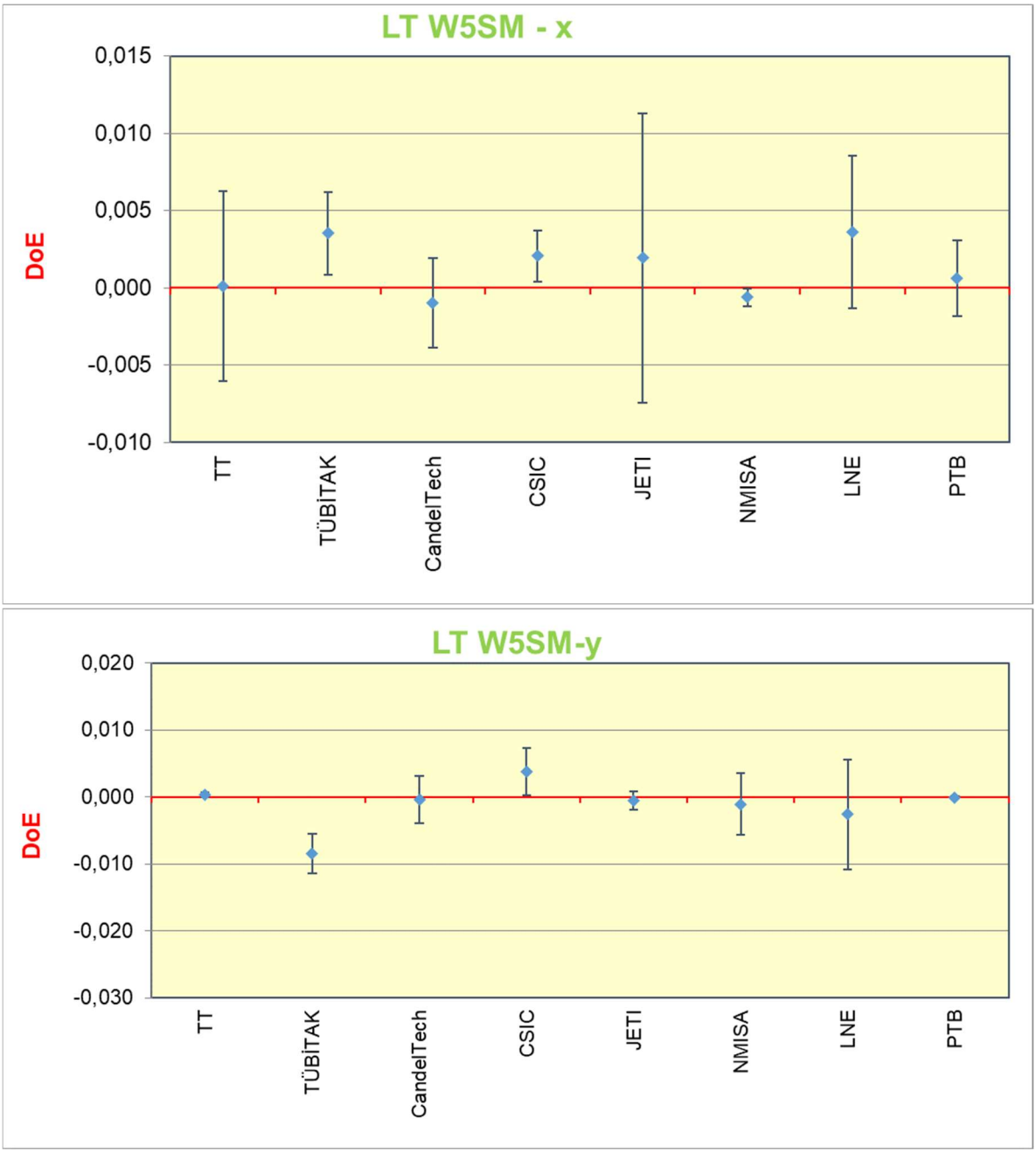

Figure 2. Graphs of Degrees of Equivalence (DoE) for LTW5SM

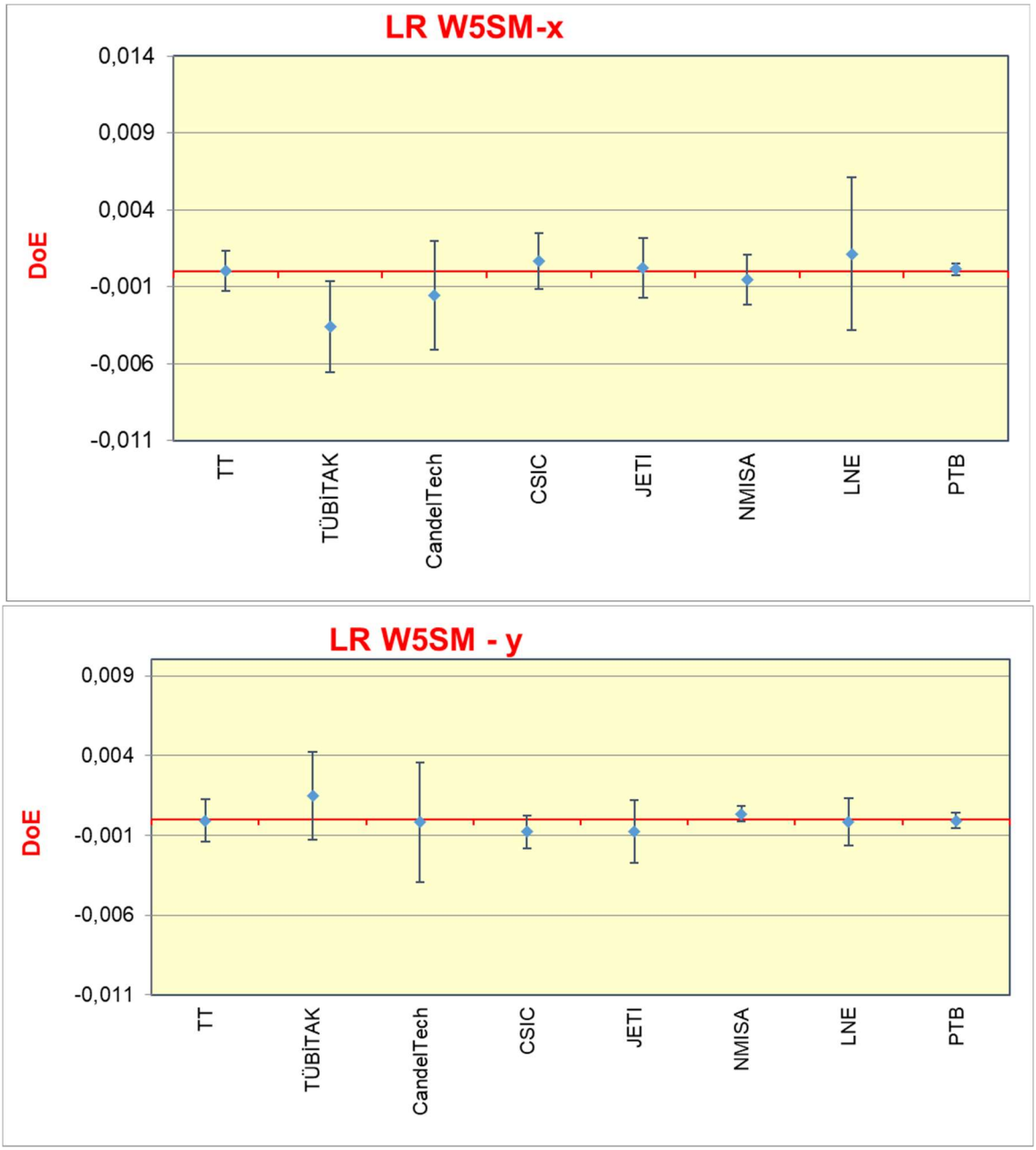

Figure 3. Degrees of Equivalence (DoE) for LRW5SM chromacity measurements

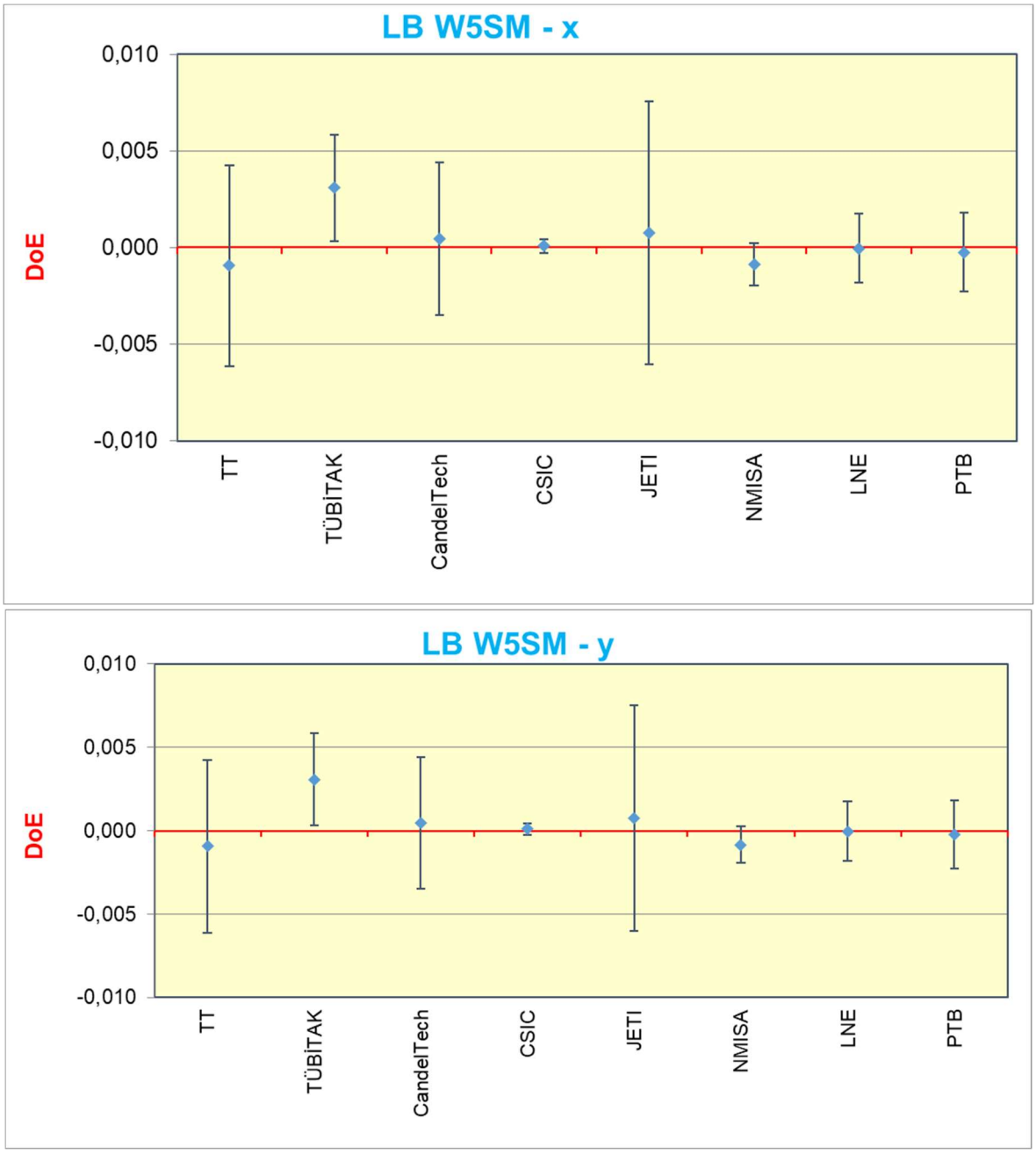

Figure 4. Degrees of Equivalence (DoE) for LBW5SM chromacity measurements

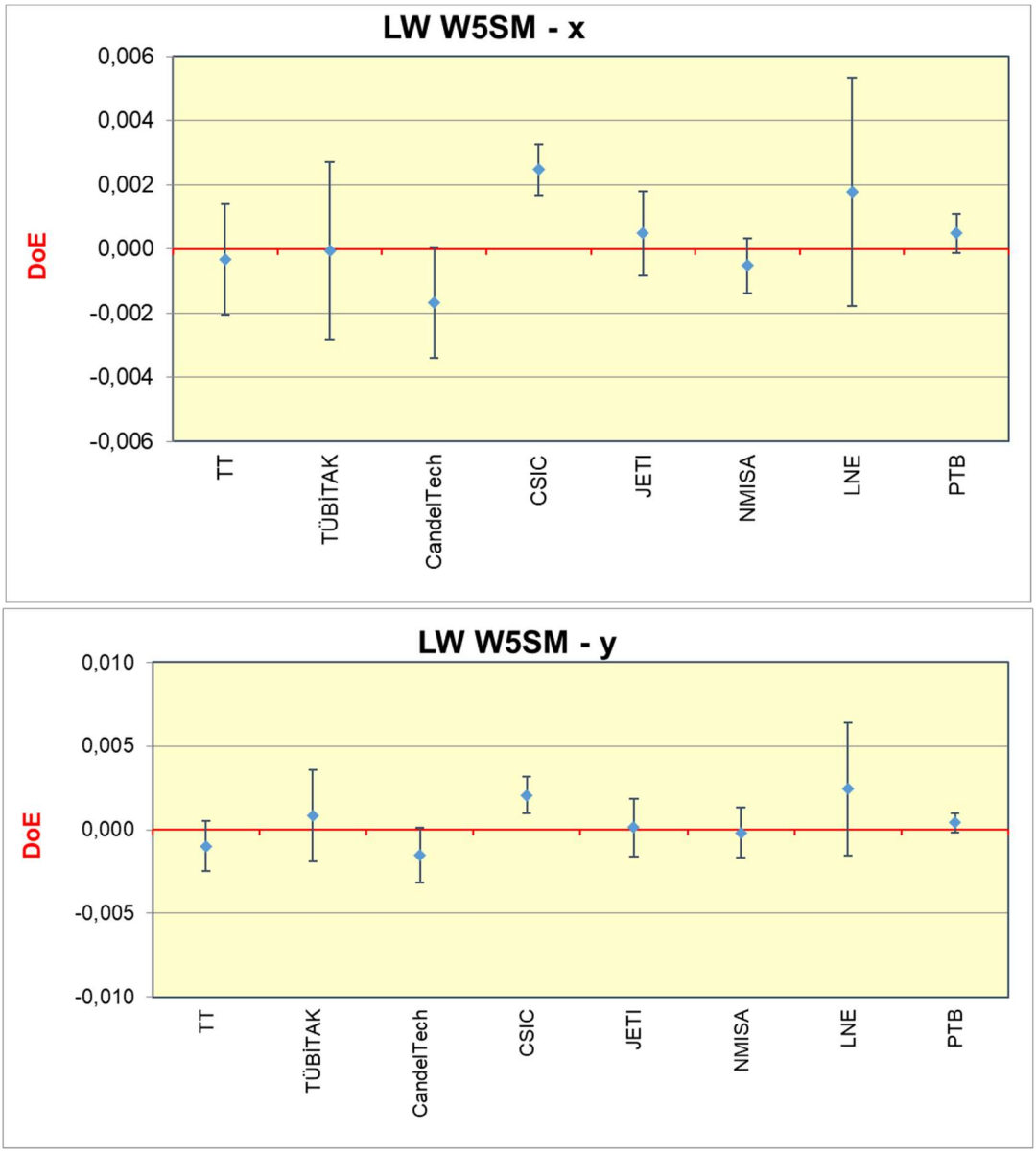

Figure 5. Degrees of Equivalence (DoE) for LWW5SM chromacity measurements

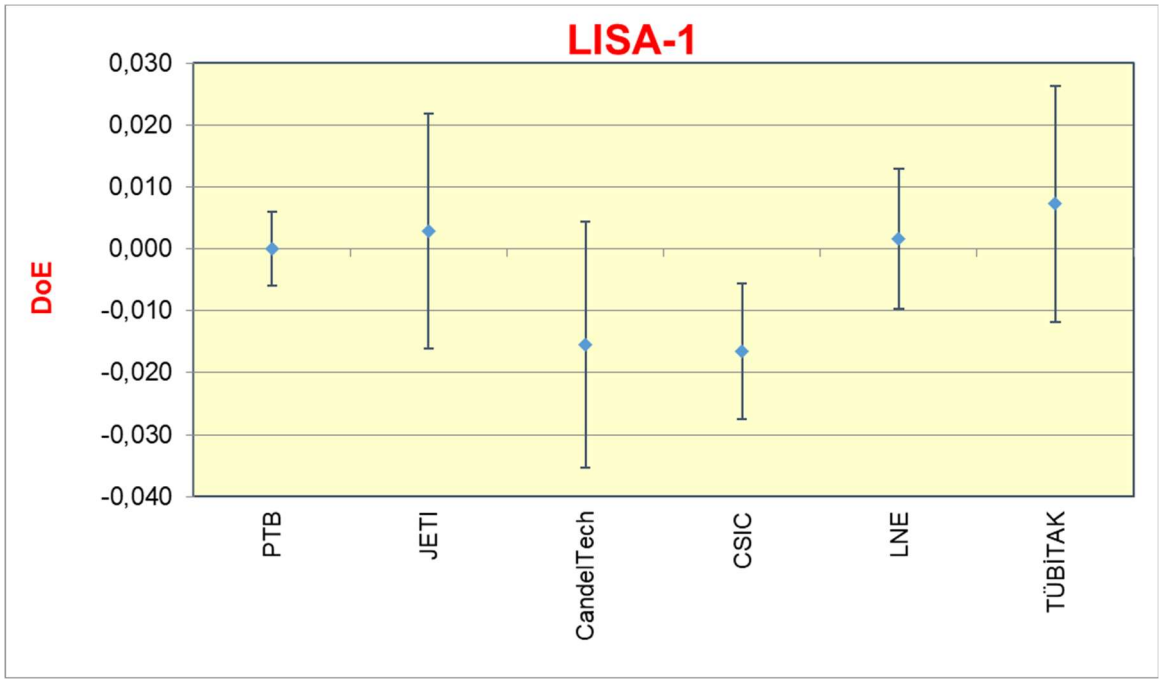

Figure 6. Degrees of Equivalence (DoE) for LISA-1 luminous intensity measurements

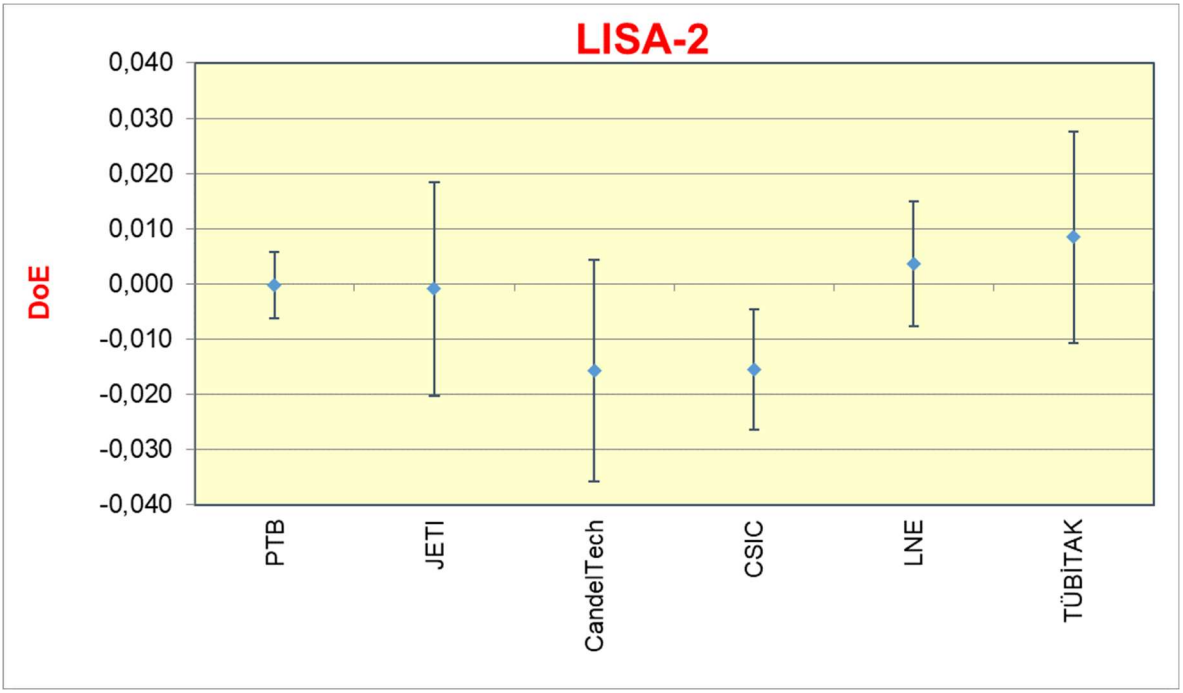

Figure 7. Degrees of Equivalence (DoE) for LISA-2 luminous intensity measurements

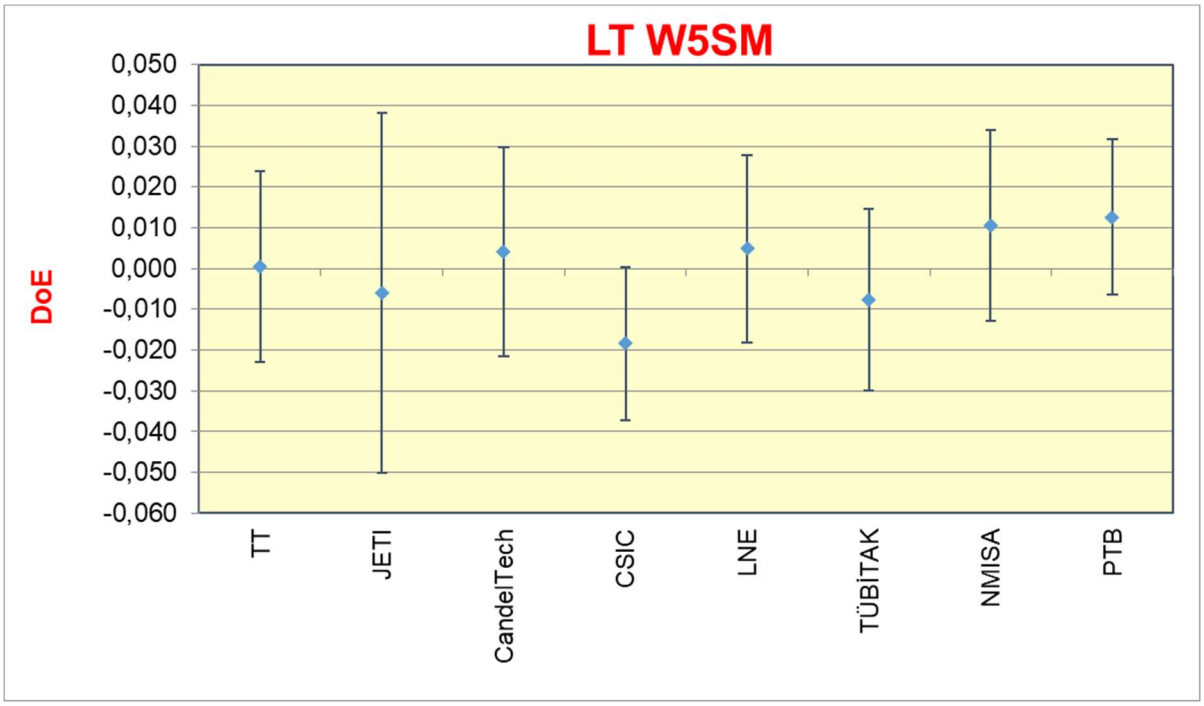

Figure 8. Degrees of Equivalence (DoE) for LT W5SM luminance measurements

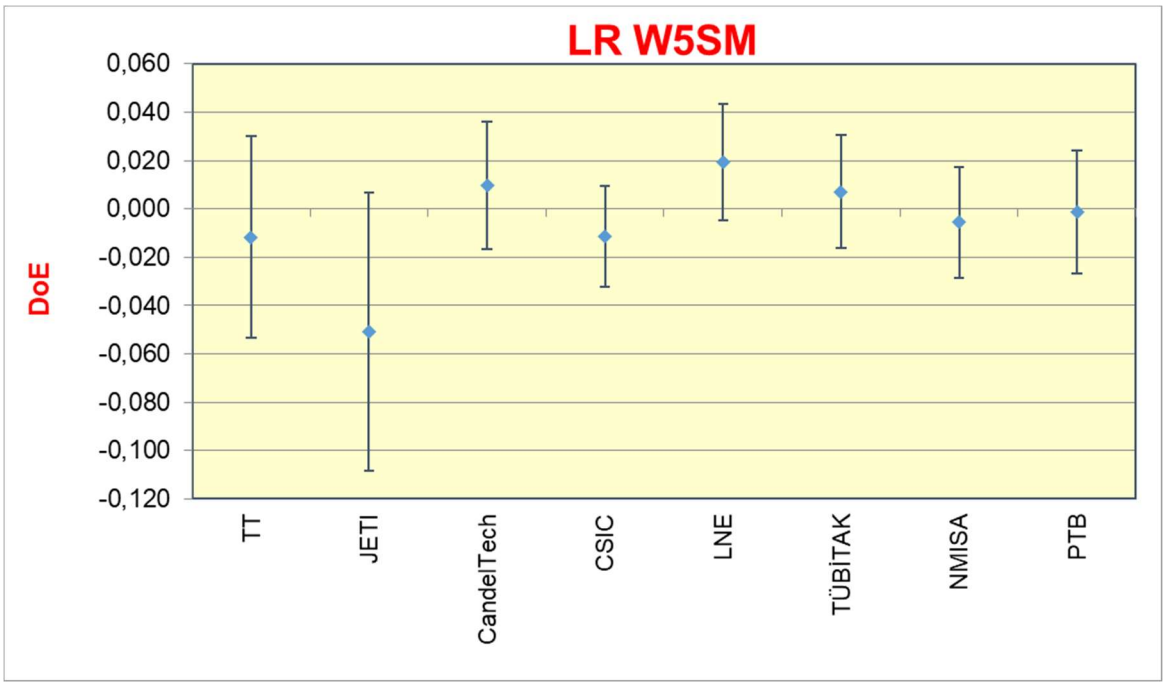

Figure 9. Degrees of Equivalence (DoE) for LR W5SM luminance measurements

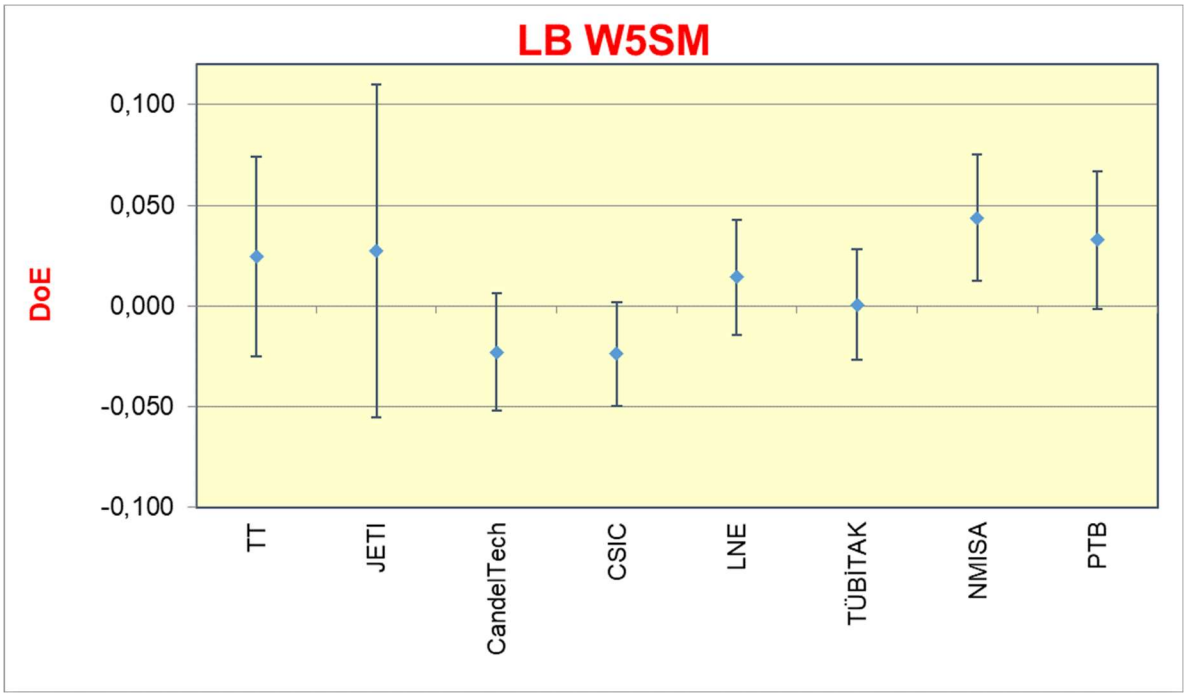

Figure 10. Degrees of Equivalence (DoE) for LB W5SM luminance measurements

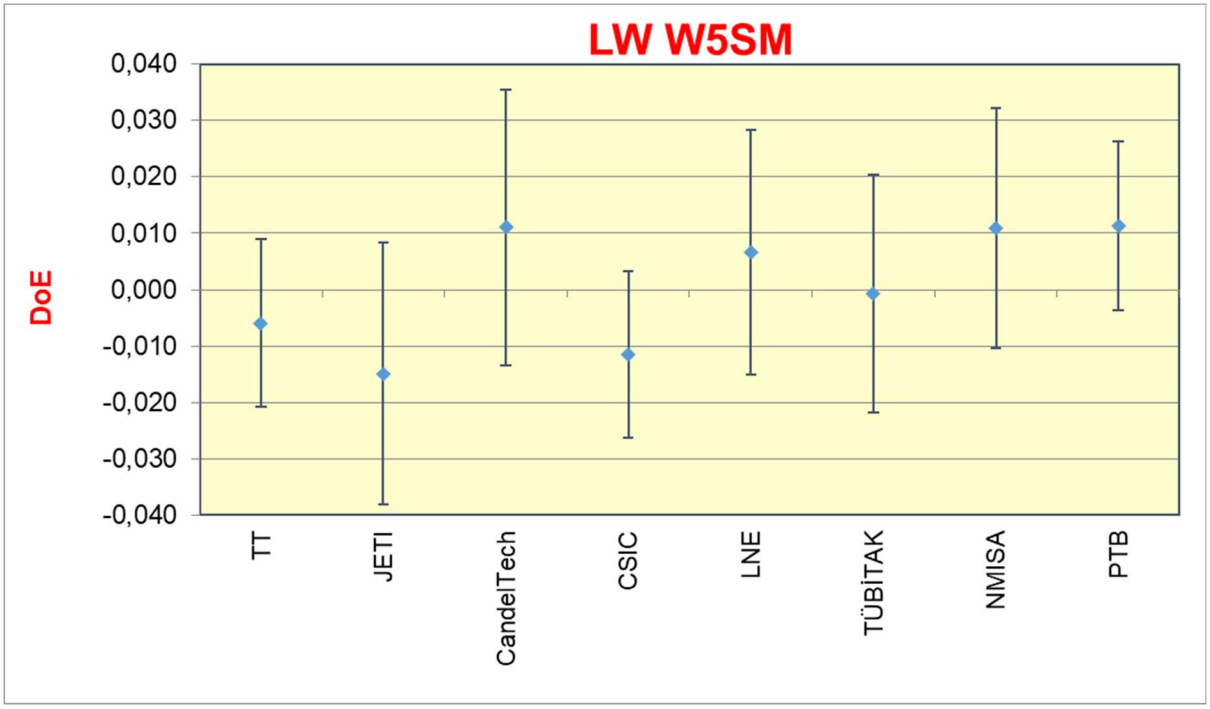

Figure 11. Degrees of Equivalence (DoE) for LW W5SM luminance measurements

Appendix III: The bilateral DoEs between the results of the participant i and the participant j

Table 12. The bilateral DoEs between the results of the participant for LT W5SM chromacity measurements

LT W5SM – x								
	TT	TÜBİTAK UME	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0000	-0,0034	0,0011	-0,0019	-0,0018	0,0021	-0,0035	-0,0005
TÜBİTAK	-0,0034	0,0000	0,0045	0,0015	0,0016	0,0055	-0,0001	0,0029
CandelTech	0,0011	-0,0045	0,0000	-0,0030	-0,0029	0,0010	-0,0046	-0,0016
CSIC	-0,0019	-0,0015	0,0030	0,0000	0,0001	0,0040	-0,0016	0,0014
JETI	-0,0018	-0,0016	0,0029	-0,0001	0,0000	0,0039	-0,0017	0,0013
NMISA	0,0021	-0,0055	-0,0010	-0,0040	-0,0039	0,0000	-0,0056	-0,0026
LNE	-0,0035	0,0001	0,0046	0,0016	0,0017	0,0056	0,0000	0,0030
PTB	-0,0005	-0,0029	0,0016	-0,0014	-0,0013	0,0026	-0,0030	0,0000
LT W5SM – y								
	TT	TÜBİTAK UME	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0000	0,0088	0,0007	-0,0035	0,0009	0,0014	0,0029	0,0004
TÜBİTAK	0,0088	0,0000	-0,0081	-0,0123	-0,0079	-0,0073	-0,0059	-0,0084
CandelTech	0,0007	0,0081	0,0000	-0,0042	0,0002	0,0007	0,0022	-0,0003
CSIC	-0,0035	0,0123	0,0042	0,0000	0,0044	0,0049	0,0064	0,0039
JETI	0,0009	0,0079	-0,0002	-0,0044	0,0000	0,0005	0,0020	-0,0005
NMISA	0,0245	-0,0157	-0,0238	-0,0280	-0,0236	-0,0000	-0,0216	-0,0241
LNE	0,0029	0,0059	-0,0022	-0,0064	-0,0020	-0,0015	0,0000	-0,0025
PTB	0,0004	0,0084	0,0003	-0,0039	0,0005	0,0010	0,0025	0,0000

Table 13. The bilateral DoEs between the results of the participant for LR W5SM chromacity measurements

LR W5SM – x								
	TT	TÜBİTAK UME	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0000	0,0036	0,0016	-0,0006	-0,0002	0,0092	-0,0011	-0,0001
TÜBİTAK	0,0036	0,0000	-0,0020	-0,0042	-0,0038	0,0056	-0,0047	-0,0037
CandelTech	0,0016	0,0020	0,0000	-0,0022	-0,0018	0,0076	-0,0027	-0,0017
CSIC	-0,0006	0,0042	0,0022	0,0000	0,0004	0,0098	-0,0005	0,0005
JETI	-0,0002	0,0038	0,0018	-0,0004	0,0000	0,0094	-0,0009	0,0001
NMISA	0,0092	-0,0056	-0,0076	-0,0098	-0,0094	0,0000	-0,0103	-0,0093
LNE	-0,0011	0,0047	0,0027	0,0005	0,0009	0,0103	0,0000	0,0010
PTB	-0,0001	0,0037	0,0017	-0,0005	-0,0001	0,0093	-0,0010	0,0000
LR W5SM – y								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0000	-0,0015	0,0001	0,0007	0,0007	-0,0074	0,0001	0,0000
TÜBİTAK	-0,0015	0,0000	0,0016	0,0023	0,0022	-0,0059	0,0016	0,0015
CandelTech	0,0001	-0,0016	0,0000	0,0006	0,0006	-0,0075	0,0000	-0,0001
CSIC	0,0007	-0,0023	-0,0006	0,0000	0,0000	-0,0081	-0,0006	-0,0007
JETI	0,0007	-0,0022	-0,0006	0,0000	0,0000	-0,0081	-0,0006	-0,0007
NMISA	-0,0074	0,0059	0,0075	0,0081	0,0081	0,0000	0,0075	0,0074
LNE	0,0001	-0,0016	0,0000	0,0006	0,0006	-0,0075	0,0000	-0,0001
PTB	0,0000	-0,0015	0,0001	0,0007	0,0007	-0,0074	0,0001	0,0000

Table 14. The bilateral DoEs between the results of the participant for LB W5SM chromacity measurements

LB W5SM – x								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0000	-0,0009	-0,0010	-0,0010	0,0001	-0,0033	0,0013	-0,0002
TÜBİTAK	-0,0009	0,0000	-0,0001	-0,0001	0,0010	-0,0024	0,0022	0,0007
CandelTech	-0,0010	0,0001	0,0000	0,0000	0,0011	-0,0023	0,0023	0,0008
CSIC	0,0016	-0,0024	-0,0026	-0,0026	-0,0015	-0,0049	-0,0003	-0,0018
JETI	0,0001	-0,0010	-0,0011	-0,0011	0,0000	-0,0034	0,0012	-0,0003
NMISA	-0,0033	0,0024	0,0023	0,0023	0,0034	0,0000	0,0046	0,0031
LNE	0,0013	-0,0022	-0,0023	-0,0023	-0,0012	-0,0046	0,0000	-0,0015
PTB	-0,0002	-0,0007	-0,0008	-0,0008	0,0003	-0,0031	0,0015	0,0000
LB W5SM – y								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0000	-0,0040	-0,0014	-0,0010	-0,0017	0,0002	-0,0009	-0,0007
TÜBİTAK	-0,0040	0,0000	0,0026	0,0030	0,0023	0,0042	0,0031	0,0033
CandelTech	-0,0014	-0,0026	0,0000	0,0004	-0,0003	0,0016	0,0005	0,0007
CSIC	-0,0010	-0,0030	-0,0004	0,0000	-0,0007	0,0012	0,0001	0,0003
JETI	-0,0017	-0,0023	0,0003	0,0007	0,0000	0,0019	0,0008	0,0010
NMISA	0,0002	-0,0042	-0,0016	-0,0012	-0,0019	0,0000	-0,0011	-0,0009
LNE	-0,0009	-0,0031	-0,0005	-0,0001	-0,0008	0,0011	0,0000	0,0002
PTB	-0,0007	-0,0033	-0,0007	-0,0003	-0,0010	0,0009	-0,0002	0,0000

Table 15. The bilateral DoEs between the results of the participant for LW W5SM chromacity measurements

LW W5SM – x								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0000	-0,0003	0,0014	-0,0028	-0,0008	-0,0026	-0,0021	-0,0008
TÜBİTAK	-0,0003	0,0000	0,0016	-0,0025	-0,0005	-0,0023	-0,0018	-0,0005
CandelTech	0,0014	-0,0016	0,0000	-0,0042	-0,0022	-0,0040	-0,0035	-0,0022
CSIC	-0,0028	0,0025	0,0042	0,0000	0,0020	0,0002	0,0007	0,0020
JETI	-0,0008	0,0005	0,0022	-0,0020	0,0000	-0,0018	-0,0013	0,0000
NMISA	-0,0026	0,0023	0,0040	-0,0002	0,0018	0,0000	0,0005	0,0018
LNE	-0,0021	0,0018	0,0035	-0,0007	0,0013	-0,0005	0,0000	0,0013
PTB	-0,0008	0,0005	0,0022	-0,0020	0,0000	-0,0018	-0,0013	0,0000
LW W5SM – y								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0000	-0,0018	0,0006	-0,0031	-0,0011	-0,0069	-0,0034	-0,0014
TÜBİTAK	-0,0018	0,0000	0,0024	-0,0012	0,0007	-0,0051	-0,0016	0,0004
CandelTech	0,0006	-0,0024	0,0000	-0,0036	-0,0017	-0,0075	-0,0040	-0,0020
CSIC	-0,0031	0,0012	0,0036	0,0000	0,0020	-0,0038	-0,0003	0,0017
JETI	-0,0011	-0,0007	0,0017	-0,0020	0,0000	-0,0058	-0,0023	-0,0003
NMISA	-0,0069	0,0051	0,0075	0,0038	0,0058	0,0000	0,0035	0,0055
LNE	-0,0034	0,0016	0,0040	0,0003	0,0023	-0,0035	0,0000	0,0020
PTB	-0,0014	-0,0004	0,0020	-0,0017	0,0003	-0,0055	-0,0020	0,0000

Table 16. The bilateral DoEs between the results of the participant for LISA-1 Luminous Intensity measurements

LISA-1						
	PTB	JETI	CandelTech	CSIC	LNE	TUBITAK
PTB	0,0000	-0,0029	0,0158	0,0169	-0,0016	-0,0072
JETI	-0,0029	0,0000	0,0187	0,0198	0,0013	-0,0043
CandelTech	0,0156	-0,0184	0,0000	0,0011	-0,0171	-0,0226
CSIC	0,0166	-0,0194	-0,0011	0,0000	-0,0182	-0,0237
LNE	-0,0016	-0,0013	0,0174	0,0185	0,0000	-0,0056
TUBITAK	-0,0072	0,0043	0,0232	0,0242	0,0056	0,0000

Table 17. The bilateral DoEs between the results of the participant for LISA-2 Luminous Intensity measurements

LISA-2						
	PTB	JETI	CandelTech	CSIC	LNE	TUBITAK
PTB	0,0000	0,0006	0,0157	0,0154	-0,0039	-0,0087
JETI	0,0006	0,0000	0,0151	0,0148	-0,0045	-0,0093
CandelTech	0,0154	-0,0149	0,0000	-0,0003	-0,0193	-0,0240
CSIC	0,0152	-0,0146	0,0003	0,0000	-0,0190	-0,0237
LNE	-0,0039	0,0045	0,0197	0,0194	0,0000	-0,0048
TUBITAK	-0,0088	0,0094	0,0246	0,0243	0,0048	0,0000

Table 18. The bilateral DoEs between the results of the participant for LT W5SM Luminance measurements

LT W5SM	**TT**	**JETI**	**CandelTech**	**CSIC**	**LNE**	**TUBITAK**	**NMISA**	**PTB**
TT	0,0000	0,0066	-0,0037	0,0193	-0,0043	0,0082	-0,0099	-0,0119
JETI	0,0065	0,0000	-0,0102	0,0126	-0,0108	0,0016	-0,0164	-0,0184
CandelTech	-0,0037	0,0103	0,0000	0,0230	-0,0007	0,0119	-0,0063	-0,0083
CSIC	0,0189	-0,0124	-0,0225	0,0000	-0,0231	-0,0109	-0,0286	-0,0306
LNE	-0,0043	0,0110	0,0007	0,0237	0,0000	0,0126	-0,0056	-0,0076
TUBITAK	0,0081	-0,0016	-0,0117	0,0110	-0,0124	0,0000	-0,0179	-0,0200
NMISA	-0,0100	0,0167	0,0063	0,0295	0,0056	0,0183	0,0000	-0,0020
PTB	-0,0121	0,0188	0,0084	0,0316	0,0077	0,0204	0,0021	0,0000

Table 19. The bilateral DoEs between the results of the participant for LR W5SM Luminance measurements

LR W5SM	TT	JETI	CandelTech	CSIC	LNE	TUBITAK	NMISA	PTB
TT	0,0000	0,0411	-0,0211	-0,0004	-0,0306	-0,0187	-0,0061	-0,0105
JETI	0,0395	0,0000	-0,0598	-0,0399	-0,0689	-0,0575	-0,0454	-0,0496
CandelTech	-0,0216	0,0636	0,0000	0,0211	-0,0097	0,0024	0,0153	0,0108
CSIC	-0,0004	0,0416	-0,0207	0,0000	-0,0302	-0,0183	-0,0057	-0,0101
LNE	-0,0316	0,0740	0,0098	0,0312	0,0000	0,0123	0,0253	0,0207
TUBITAK	-0,0191	0,0610	-0,0024	0,0187	-0,0121	0,0000	0,0129	0,0083
NMISA	-0,0062	0,0475	-0,0151	0,0057	-0,0247	-0,0127	0,0000	-0,0045
PTB	-0,0107	0,0522	-0,0107	0,0102	-0,0203	-0,0083	0,0045	0,0000

Table 20. The bilateral DoEs between the results of the participant for LB W5SM Luminance measurements

LB W5SM	TT	JETI	CandelTech	CSIC	LNE	TUBITAK	NMISA	PTB
TT	0,0000	-0,0024	0,0487	0,0497	0,0104	0,0240	-0,0182	-0,0079
JETI	-0,0024	0,0000	0,0512	0,0523	0,0128	0,0265	-0,0158	-0,0055
CandelTech	0,0464	-0,0488	0,0000	0,0010	-0,0365	-0,0236	-0,0638	-0,0540
CSIC	0,0474	-0,0497	-0,0010	0,0000	-0,0375	-0,0245	-0,0647	-0,0549
LNE	0,0103	-0,0127	0,0379	0,0389	0,0000	0,0135	-0,0283	-0,0181
TUBITAK	0,0234	-0,0258	0,0241	0,0251	-0,0133	0,0000	-0,0412	-0,0311
NMISA	-0,0185	0,0161	0,0682	0,0692	0,0291	0,0430	0,0000	0,0105
PTB	-0,0079	0,0055	0,0570	0,0580	0,0184	0,0321	-0,0104	0,0000

Table 21. The bilateral DoEs between the results of the participant for LW W5SM Luminance measurements

LW W5SM	TT	JETI	CandelTech	CSIC	LNE	TUBITAK	NMISA	PTB
TT	0,0000	0,0091	-0,0168	0,0056	-0,0125	-0,0052	-0,0167	-0,0170
JETI	0,0090	0,0000	-0,0256	-0,0035	-0,0214	-0,0142	-0,0256	-0,0259
CandelTech	-0,0170	0,0263	0,0000	0,0227	0,0044	0,0117	0,0000	-0,0003
CSIC	0,0056	0,0035	-0,0222	0,0000	-0,0180	-0,0108	-0,0222	-0,0225
LNE	-0,0126	0,0218	-0,0043	0,0183	0,0000	0,0073	-0,0043	-0,0046
TUBITAK	-0,0053	0,0144	-0,0116	0,0109	-0,0073	0,0000	-0,0116	-0,0119
NMISA	-0,0170	0,0263	0,0000	0,0227	0,0043	0,0117	0,0000	-0,0003
PTB	-0,0173	0,0266	0,0003	0,0230	0,0046	0,0120	0,0003	0,0000

Appendix IV: The bilateral E_n values, between the results of the participant i and the participant j

Table 22. The bilateral E_n values, between the results of the participants for LT W5SM chromacity measurement

LT W5SM - x								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0.0	-0.5	0.2	-0.3	-0.2	0.1	-0.4	-0.1
TÜBİTAK	-0.5	0.0	1.1	0.5	0.2	1.4	0.0	0.8
CandelTech	0.2	-1.1	0.0	-0.9	-0.3	-0.1	-0.8	-0.4
CSIC	-0.3	-0.5	0.9	0.0	0.0	1.5	-0.3	0.5
JETI	-0.2	-0.2	0.3	0.0	0.0	0.3	-0.2	0.1
NMISA	0.1	-1.4	0.1	-1.5	-0.3	0.0	-0.8	-0.4
LNE	-0.4	0.0	0.8	0.3	0.2	0.8	0.0	0.5
PTB	-0.1	-0.8	0.4	-0.5	-0.1	0.4	-0.5	0.0
LT W5SM – y								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0.0	2.9	0.2	-1.0	0.6	0.3	0.4	0.8
TÜBİTAK	2.9	0.0	-1.7	-2.6	-2.4	-1.3	-0.7	-2.8
CandelTech	0.2	1.7	0.0	-0.8	0.1	0.1	0.2	-0.1
CSIC	-1.0	2.6	0.8	0.0	1.2	0.8	0.7	1.1
JETI	0.6	2.4	-0.1	-1.2	0.0	0.1	0.2	-0.4
NMISA	0.3	1.3	-0.1	-0.8	-0.1	0.0	0.2	-0.2
LNE	0.4	0.7	-0.2	-0.7	-0.2	-0.2	0.0	-0.3
PTB	0.8	2.8	0.1	-1.1	0.4	0.2	0.3	0.0

Table 23. The bilateral E_n values, between the results of the participants for LR W5SM chromacity measurement

LR W5SM – x								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0.0	1.1	0.4	-0.3	-0.1	0.3	-0.2	-0.1
TÜBİTAK	1.1	0.0	-0.4	-1.2	-1.1	-0.9	-0.8	-1.2
CandelTech	0.4	0.4	0.0	-0.6	-0.4	-0.3	-0.4	-0.5
CSIC	-0.3	1.2	0.6	0.0	0.2	0.5	-0.1	0.3
JETI	-0.1	1.1	0.4	-0.2	0.0	0.3	-0.2	0.0
NMISA	0.3	0.9	0.3	-0.5	-0.3	0.0	-0.3	-0.4
LNE	-0.2	0.8	0.4	0.1	0.2	0.3	0.0	0.2
PTB	-0.1	1.2	0.5	-0.3	0.0	0.4	-0.2	0.0
LR W5SM – y								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0.0	-0.5	0.0	0.4	0.3	-0.3	0.0	0.0
TÜBİTAK	-0.5	0.0	0.3	0.8	0.7	0.4	0.5	0.5
CandelTech	0.0	-0.3	0.0	0.2	0.1	-0.1	0.0	0.0
CSIC	0.4	-0.8	-0.2	0.0	0.0	-0.9	-0.3	-0.6
JETI	0.3	-0.7	-0.1	0.0	0.0	-0.5	-0.2	-0.3
NMISA	-0.3	-0.4	0.1	0.9	0.5	0.0	0.3	0.5
LNE	0.0	-0.5	0.0	0.3	0.2	-0.3	0.0	-0.1
PTB	0.0	-0.5	0.0	0.6	0.3	-0.5	0.1	0.0

Table 24. The bilateral E_n values, between the results of the participants for LB W5SM chromacity measurement

LB W5SM – x								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0	-0,2	-0,2	-0,4	0,0	-0,3	0,4	-0,1
TÜBİTAK	-0,2	0,0	0,0	0,0	0,3	0,0	0,6	0,2
CandelTech	-0,2	0,0	0,0	0,0	0,2	0,1	0,5	0,2
CSIC	0,7	-0,9	-0,6	-3,7	-0,6	-2,7	-0,1	-1,7
JETI	0,0	-0,3	-0,2	-0,4	0,0	-0,3	0,3	-0,1
NMISA	-0,3	0,0	-0,1	-0,2	0,3	0,0	0,8	0,5
LNE	0,4	-0,6	-0,5	-0,9	-0,3	-0,8	0,0	-0,6
PTB	-0,1	-0,2	-0,2	-0,8	0,1	-0,5	0,6	0,0
LB W5SM – y								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0	-0,7	-0,2	-0,2	-0,2	0,0	-0,2	-0,1
TÜBİTAK	-0,7	0,0	0,5	1,0	0,3	1,3	0,9	0,9
CandelTech	-0,2	-0,5	0,0	0,1	0,0	0,3	0,1	0,2
CSIC	-0,2	-1,0	-0,1	0,0	-0,1	0,7	0,1	0,2
JETI	-0,2	-0,3	0,0	0,1	0,0	0,2	0,1	0,1
NMISA	0,0	-1,3	-0,3	-0,7	-0,2	0,0	-0,4	-0,3
LNE	-0,2	-0,9	-0,1	-0,1	-0,1	0,4	0,0	0,1
PTB	-0,1	-0,9	-0,2	-0,2	-0,1	0,3	-0,1	0,0

Table 25. The bilateral E_n values, between the results of the participants for LW W5SM chromacity measurement

LW W5SM – x								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0	-0,1	0,5	-1,5	-0,4	0,1	-0,5	-0,4
TÜBİTAK	-0,1	0,0	0,5	-0,9	-0,2	0,2	-0,4	-0,2
CandelTech	0,5	-0,5	0,0	-2,2	-0,9	-0,6	-0,9	-1,1
CSIC	-1,5	0,9	2,2	0,0	1,3	2,5	0,2	2,0
JETI	-0,4	0,2	0,9	-1,3	0,0	0,6	-0,3	0,0
NMISA	0,1	-0,2	0,6	-2,5	-0,6	0,0	-0,6	-0,8
LNE	-0,5	0,4	0,9	-0,2	0,3	0,6	0,0	0,4
PTB	-0,4	0,2	1,1	-2,0	0,0	0,8	-0,4	0,0
LW W5SM – y								
	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0	-0,6	0,2	-1,7	-0,5	-0,3	-0,8	-0,8
TÜBİTAK	-0,6	0,0	0,7	-0,4	0,2	0,3	-0,3	0,1
CandelTech	0,2	-0,7	0,0	-1,8	-0,7	-0,6	-0,9	-1,0
CSIC	-1,7	0,4	1,8	0,0	1,0	1,2	-0,1	1,3
JETI	-0,5	-0,2	0,7	-1,0	0,0	0,1	-0,5	-0,2
NMISA	-0,3	-0,3	0,6	-1,2	-0,1	0,0	-0,6	-0,3
LNE	-0,8	0,3	0,9	0,1	0,5	0,6	0,0	0,5
PTB	-0,8	-0,1	1,0	-1,3	0,2	0,3	-0,5	0,0

Table 26. The bilateral E_n values, between the results of the participants for LISA-1 Luminous Intensity measurements

LISA-1						
	PTB	JETI	CandelTech	CSIC	LNE	TUBITAK
PTB	0,0	-0,1	0,7	1,3	-0,1	-0,3
JETI	-0,1	0,0	0,6	0,9	0,1	-0,2
CandelTech	0,7	-0,6	0,0	0,0	-0,7	-0,8
CSIC	1,3	-0,9	0,0	0,0	-1,2	-1,1
LNE	-0,1	-0,1	0,7	1,2	0,0	-0,2
TUBITAK	-0,3	0,2	0,8	1,1	0,2	0,0

Table 27. The bilateral E_n values, between the results of the participants for LISA-2 Luminous Intensity measurements

LISA-2						
	PTB	JETI	CandelTech	CSIC	LNE	TUBITAK
PTB	0,0	0,0	0,7	1,2	-0,2	-0,4
JETI	0,0	0,0	0,5	0,7	-0,2	-0,3
CandelTech	0,7	-0,5	0,0	0,0	-0,8	-0,8
CSIC	1,2	-0,7	0,0	0,0	-1,2	-1,1
LNE	-0,2	0,2	0,8	1,2	0,0	-0,2
TUBITAK	-0,4	0,3	0,8	1,1	0,2	0,0

Table 28. The bilateral En values, between the results of the participants for LT W5SM luminance measurements

LT W5SM	TT	TÜBİTAK UME	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0	0,3	-0,1	0,9	0,1	0,9	-0,2	-0,5
TÜBİTAK	0,3	0,0	-0,4	0,6	0,0	0,7	-0,5	-1,0
CandelTech	-0,1	0,4	0,0	1,0	0,2	1,0	0,0	-0,3
CSIC	0,9	-0,6	-1,0	0,0	-0,3	0,3	-1,2	-2,5
JETI	0,1	0,0	-0,2	0,3	0,0	0,4	-0,2	-0,4
NMISA	0,9	-0,7	-1,0	-0,3	-0,4	0,0	-1,1	-1,6
LNE	-0,2	0,5	0,0	1,2	0,2	1,1	0,0	-0,4
PTB	**-0,5**	**1,0**	**0,3**	**2,5**	**0,4**	**1,6**	**0,4**	**0,0**

Table 29. The bilateral En values, between the results of the participants for LR W5SM luminance measurements

LR W5SM	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0	-0,4	-0,5	0,0	0,6	-1,5	-0,7	-0,2
TÜBİTAK	-0,4	0,0	-0,1	1,0	1,0	-1,7	-0,5	0,3
CandelTech	-0,5	0,1	0,0	0,9	1,0	-1,5	-0,3	0,4
CSIC	0,0	-1,0	-0,9	0,0	0,7	-3,0	-1,5	-0,5
JETI	0,6	-1,0	-1,0	-0,7	0,0	-1,8	-1,2	-0,8
NMISA	-1,5	1,7	1,5	3,0	1,8	0,0	1,3	1,9
LNE	-0,7	0,5	0,3	1,5	1,2	-1,3	0,0	0,7
PTB	-0,2	-0,3	-0,4	0,5	0,8	-1,9	-0,7	0,0

Table 30. The bilateral En values, between the results of the participants for LB W5SM luminance measurements

LB W5SM	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0	0,5	1,0	1,1	0,0	0,5	0,2	-0,2
TÜBİTAK	0,5	0,0	0,8	1,2	-0,3	0,1	-0,5	-1,0
CandelTech	1,0	-0,8	0,0	0,0	-0,6	-0,7	-1,3	-1,6
CSIC	1,1	-1,3	0,0	-0,1	-0,6	-0,8	-1,9	-2,1
JETI	0,0	0,3	0,6	0,6	0,0	0,3	0,2	-0,1
NMISA	0,5	-0,1	0,7	0,8	-0,3	0,0	-0,5	-0,9
LNE	0,2	0,5	1,3	1,8	-0,2	0,5	0,0	-0,6
PTB	-0,2	1,0	1,6	2,0	0,1	0,9	0,6	0,0

Table 31. The bilateral En values, between the results of the participants for LW W5SM luminance measurements

LW W5SM - X	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0,0	-0,3	-0,7	0,5	0,4	-0,5	-0,6	-1,5
TÜBİTAK	-0,3	0,0	-0,4	0,6	0,5	-0,2	-0,3	-0,6
CandelTech	-0,7	0,4	0,0	1,0	0,9	0,2	0,2	0,0
CSIC	0,5	-0,6	-1,0	0,0	0,2	-0,7	-0,9	-2,3
JETI	0,4	-0,5	-0,9	-0,2	0,0	-0,7	-0,8	-1,2
NMISA	-0,5	0,2	-0,2	0,7	0,7	0,0	-0,1	-0,3
LNE	-0,6	0,3	-0,2	0,9	0,8	0,1	0,0	-0,2
PTB	-1,5	0,6	0,0	2,3	1,2	0,3	0,2	0,0

Appendix V: Chromaticity Comparison Results as a Multidimensional data

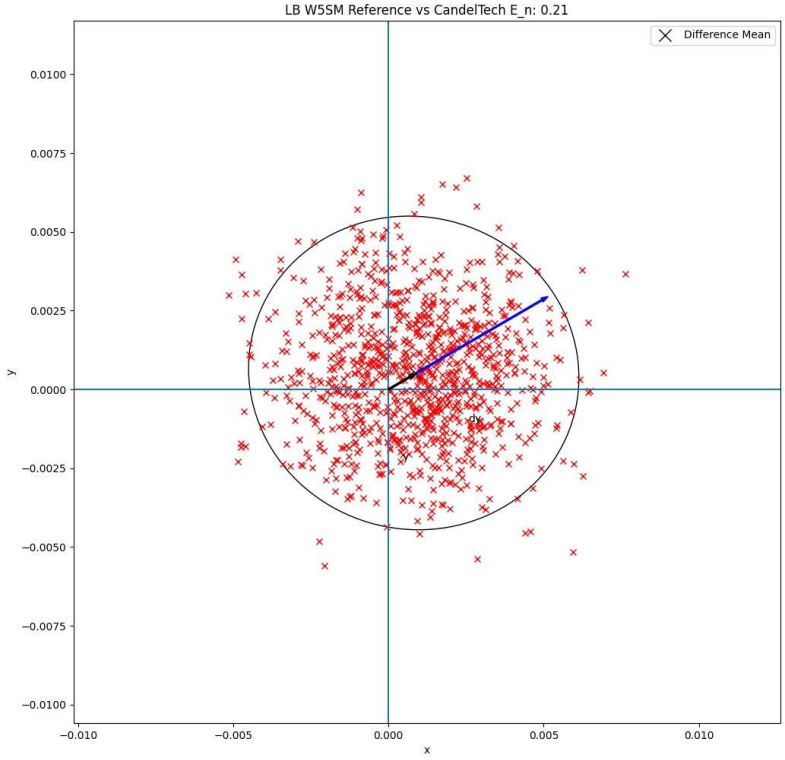

Figure 12. Distribution of the difference with reference value and CandelTech for LBW5SM

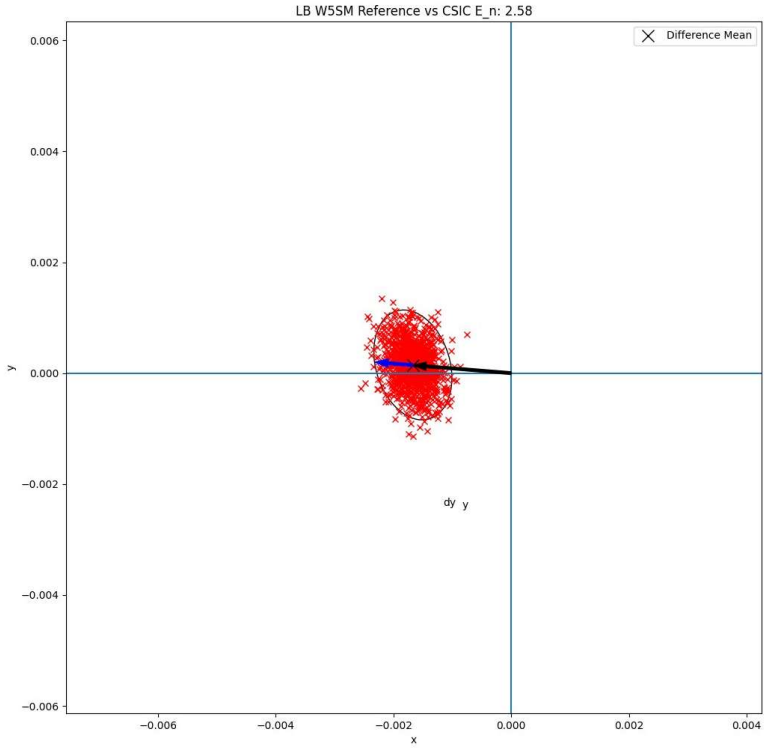

Figure 13. Distribution of the difference with reference value and CSIC for LBW5SM

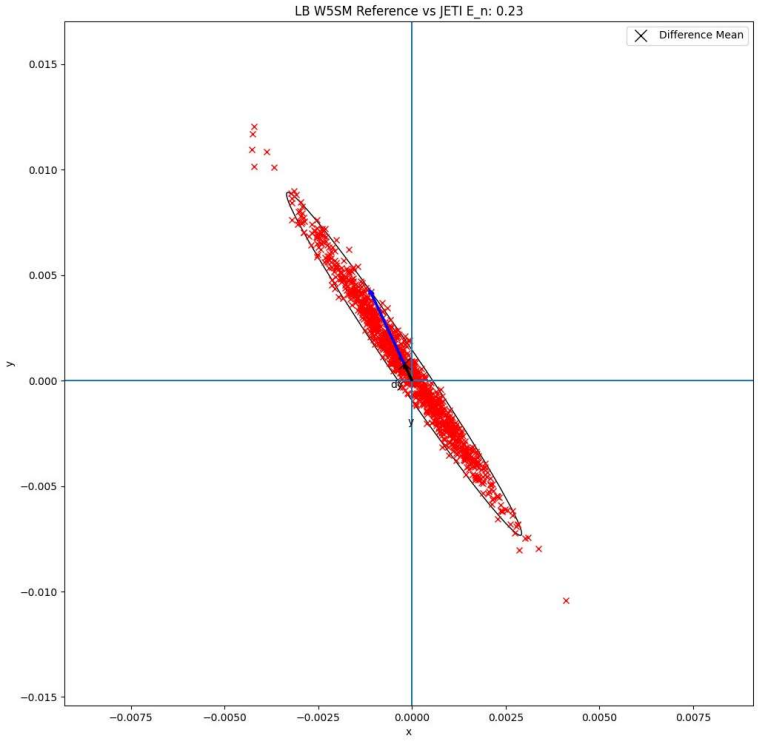

Figure 14. Distribution of the difference with reference value and JETI for LBW5SM

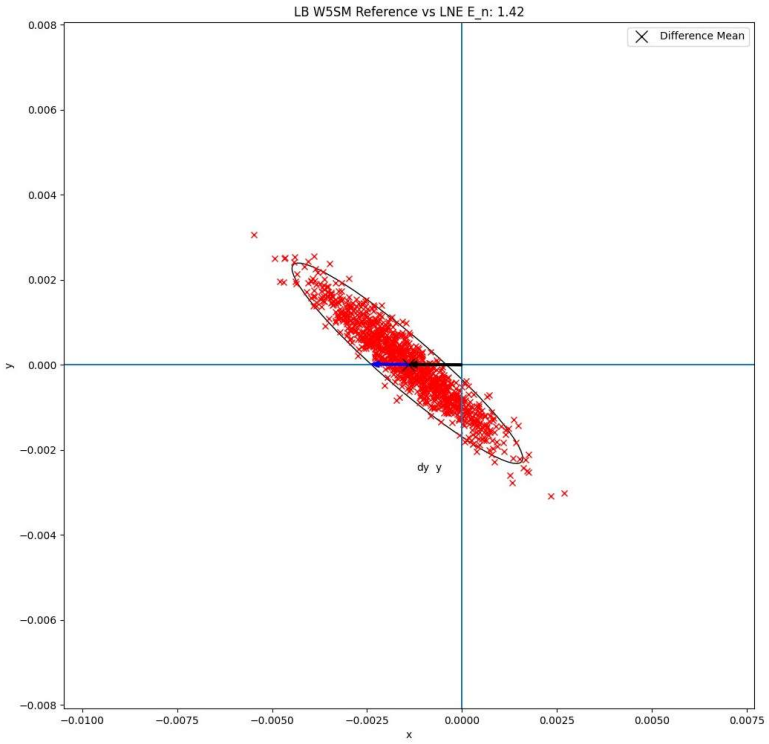

Figure 15. Distribution of the difference with reference value and LNE for LBW5SM

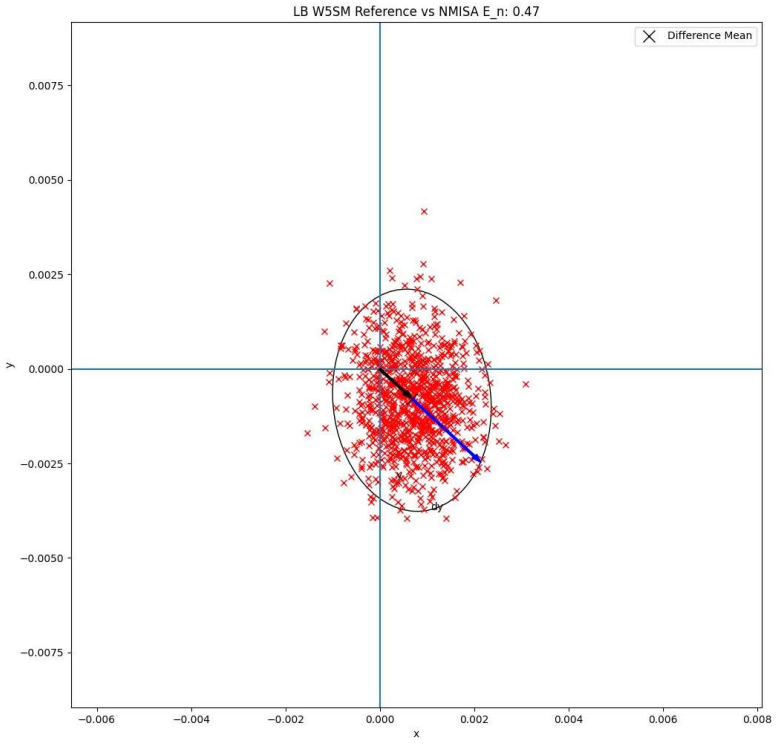

Figure 16. Distribution of the difference with reference value and NMISA for LBW5SM

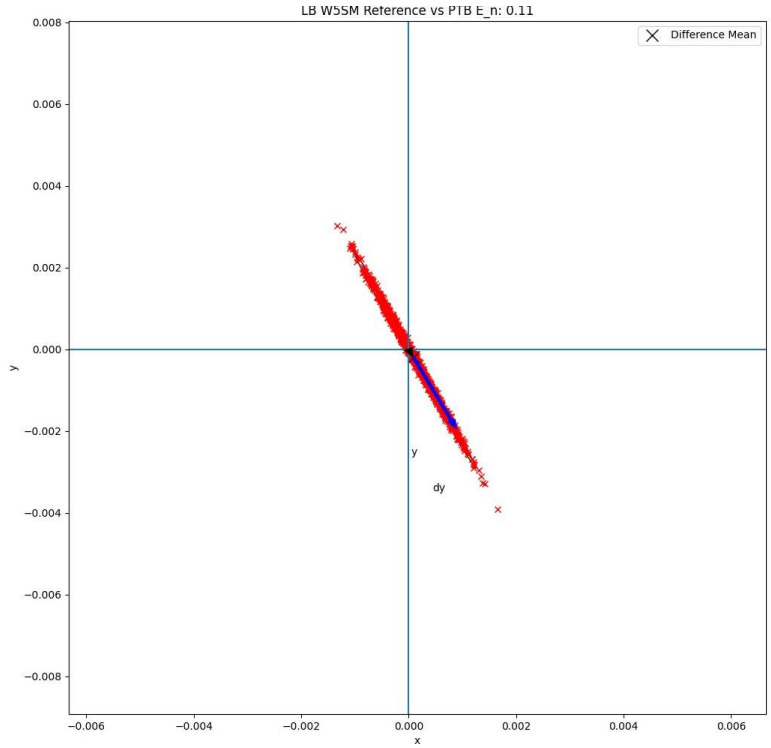

Figure 17. Distribution of the difference with reference value and PTB for LBW5SM

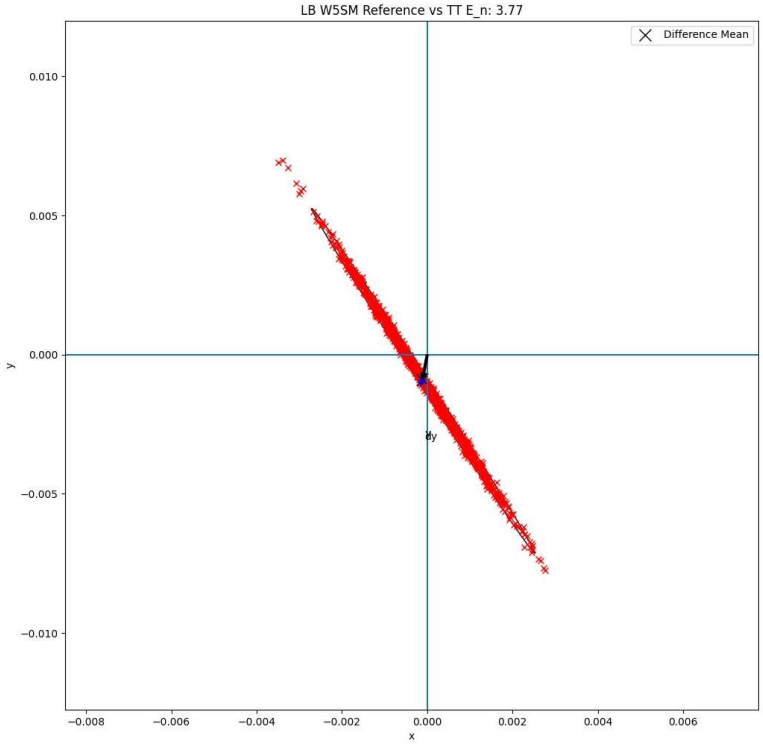

Figure 18. Distribution of the difference with reference value and TT for LBW5SM

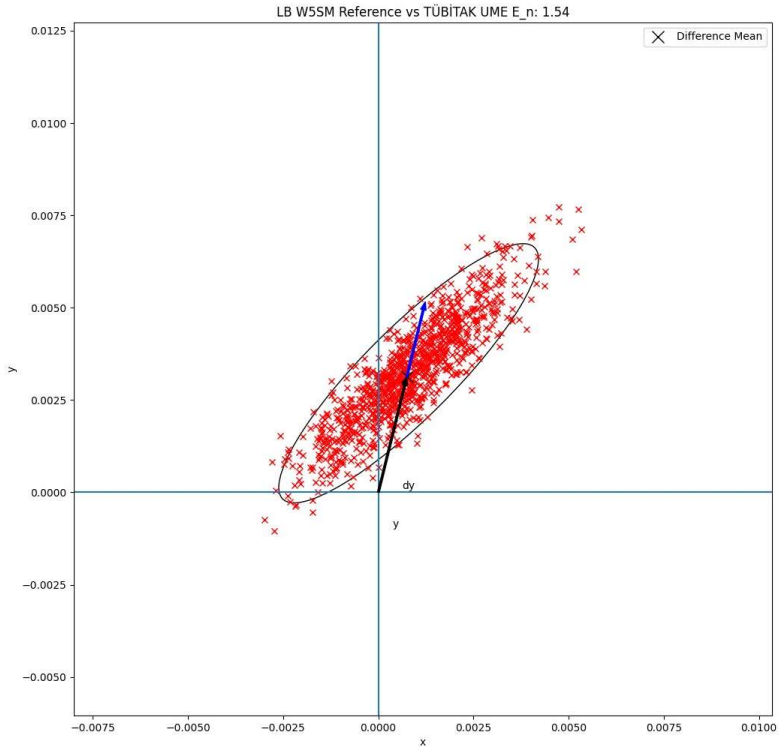

Figure 19. Distribution of the difference with reference value and TÜBITAK UME for LBW5SM

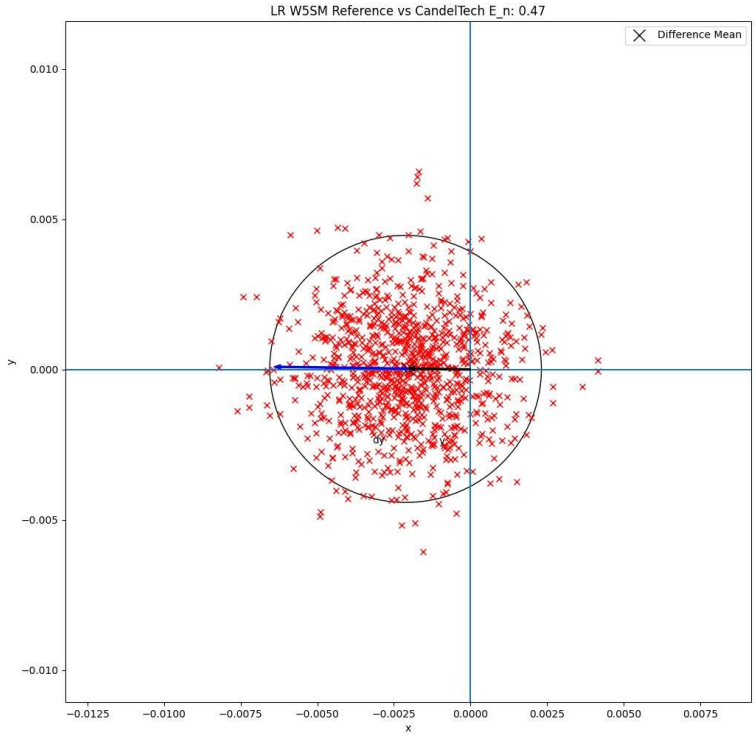

Figure 20. Distribution of the difference with reference value and CandelTech for LRW5SM

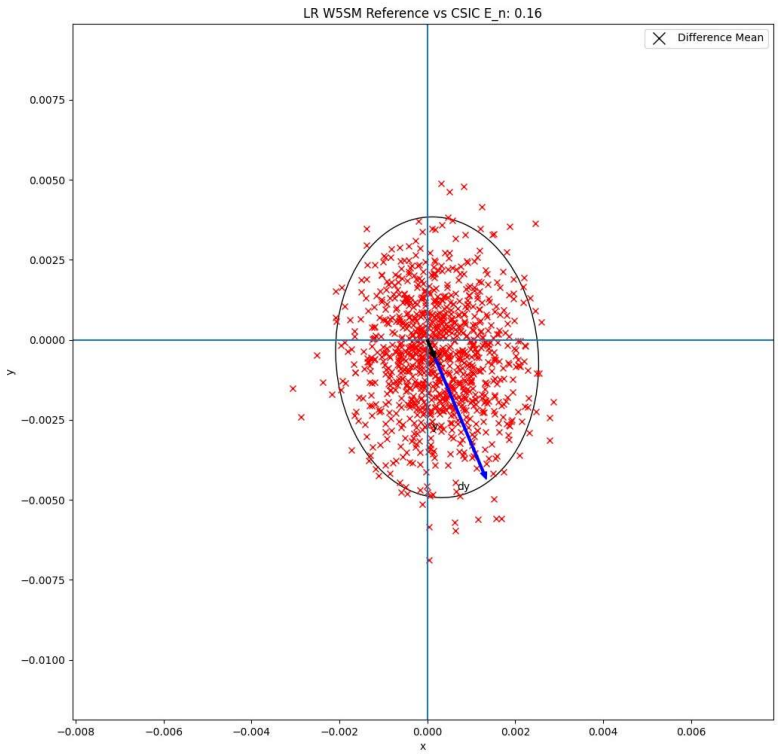

Figure 21. Distribution of the difference with reference value and CSIC for LRW5SM

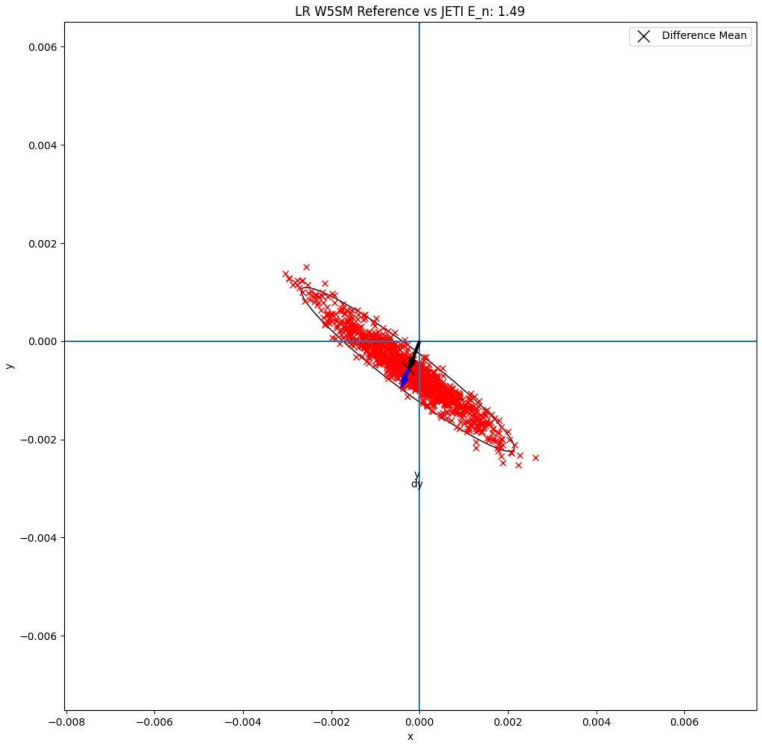

Figure 22. Distribution of the difference with reference value and JETI for LRW5SM

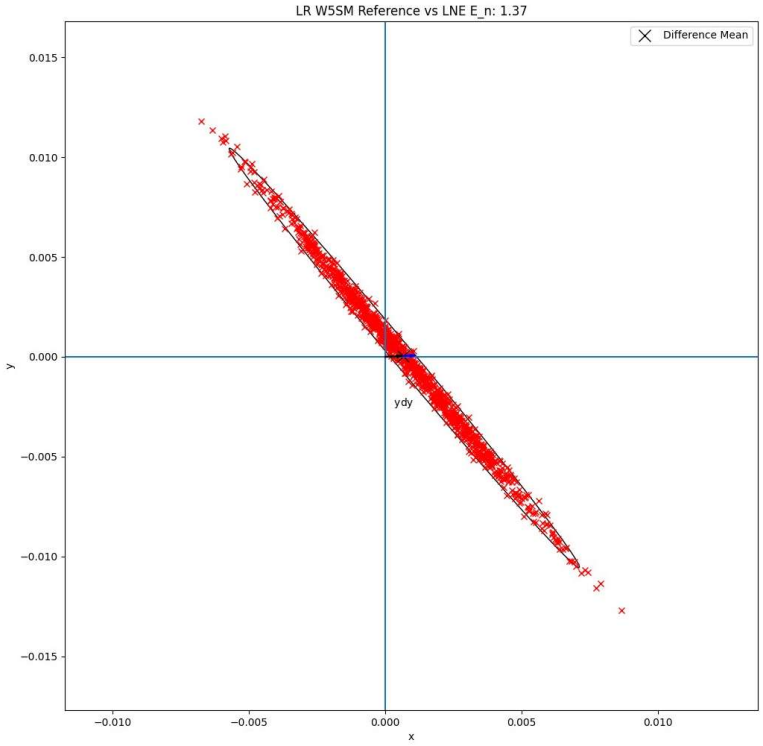

Figure 23. Distribution of the difference with reference value and LNE for LRW5SM

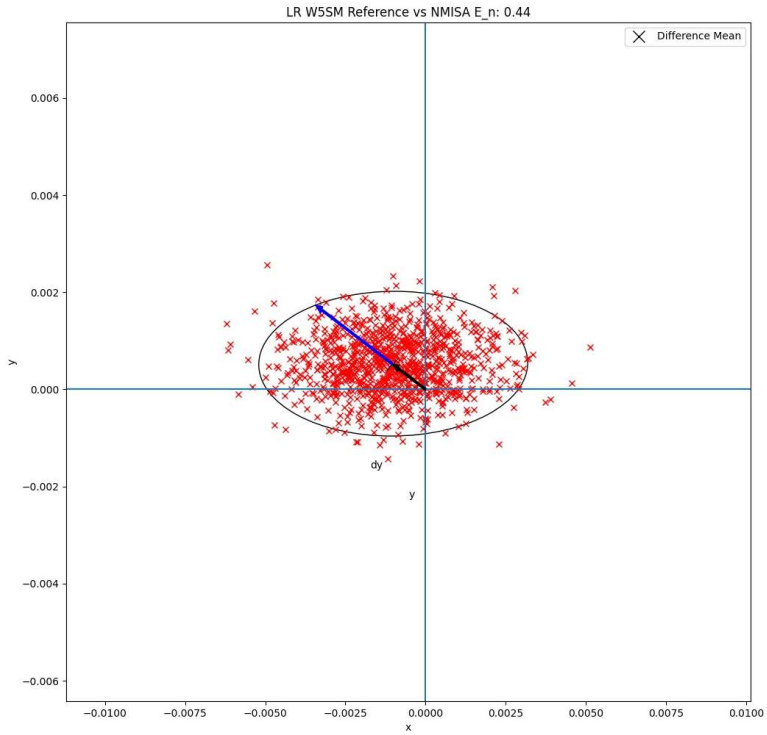

Figure 24. Distribution of the difference with reference value and NMISA for LRW5SM

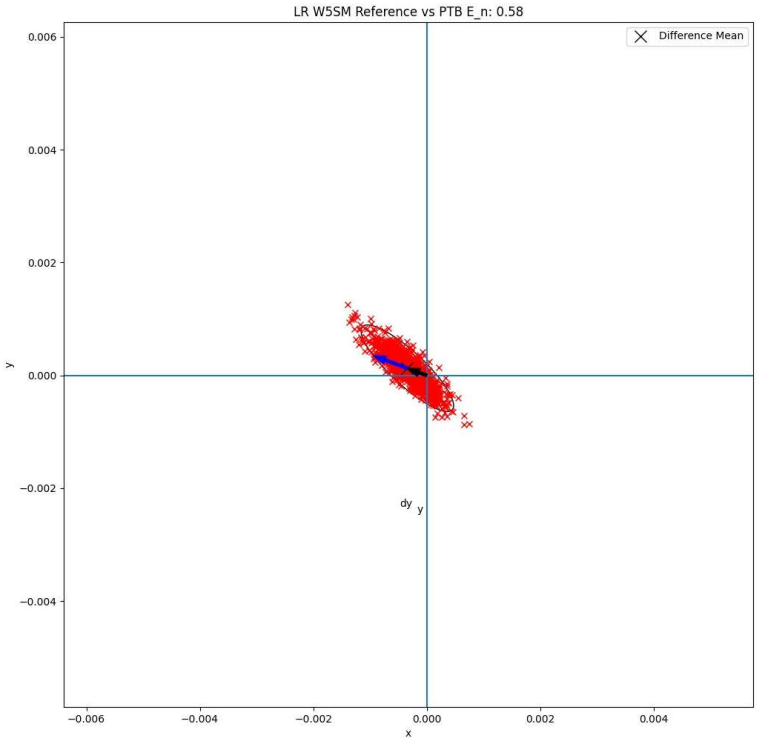

Figure 25. Distribution of the difference with reference value and PTB for LRW5SM

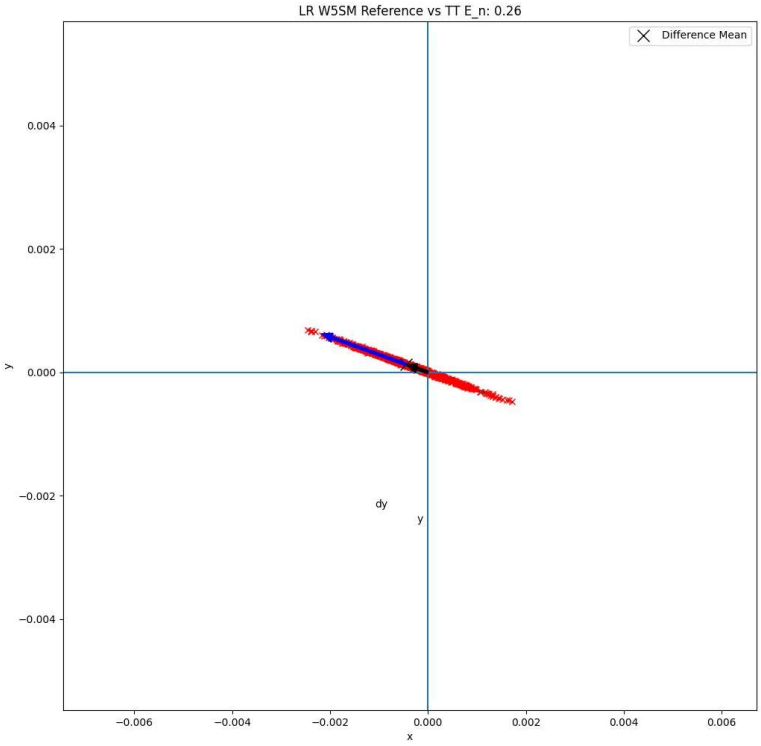

Figure 26. Distribution of the difference with reference value and TT for LRW5SM

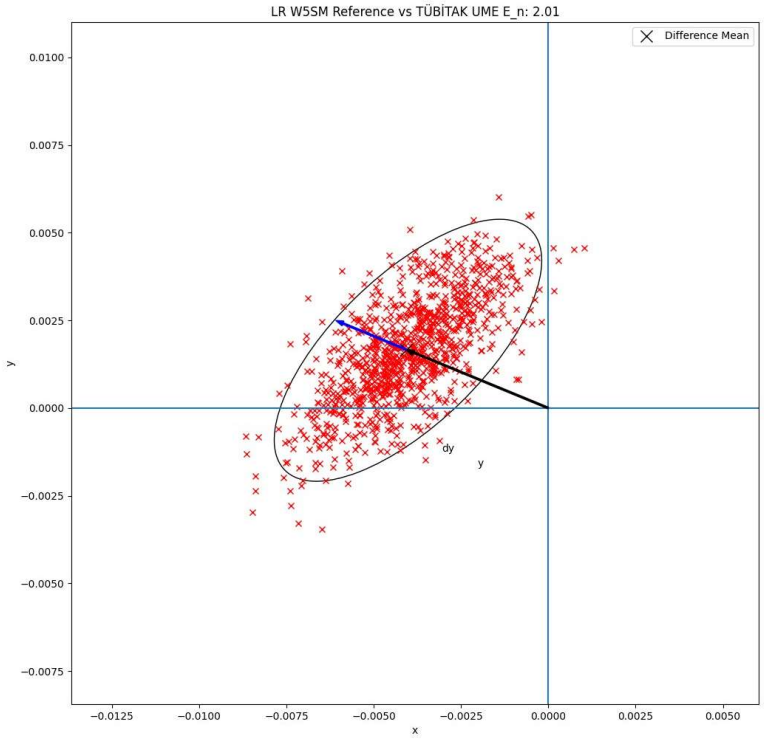

Figure 27. Distribution of the difference with reference value and TÜBITAK UME for LRW5SM

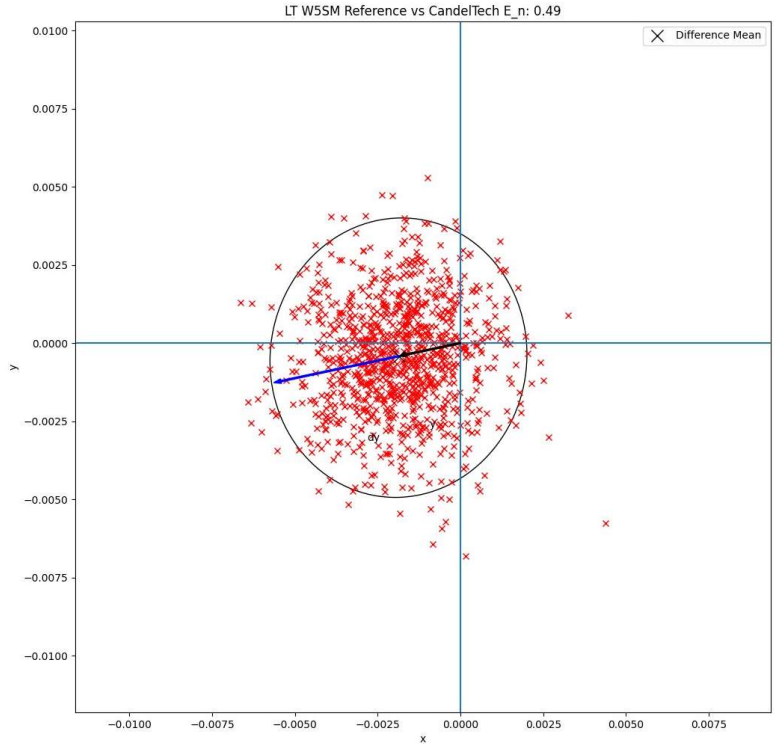

Figure 28. Distribution of the difference with reference value and CandelTech for LTW5SM

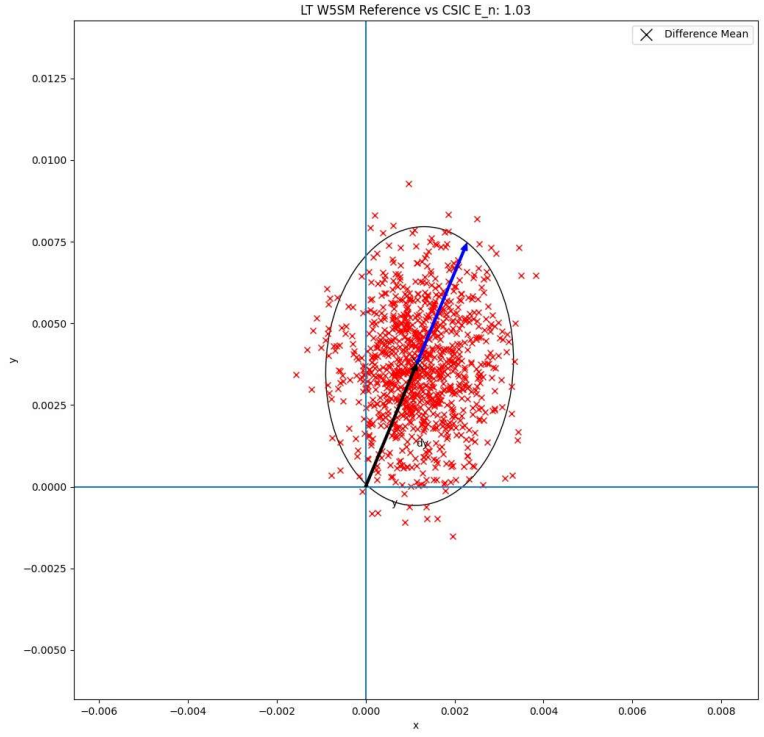

Figure 29. Distribution of the difference with reference value and CSIC for LTW5SM

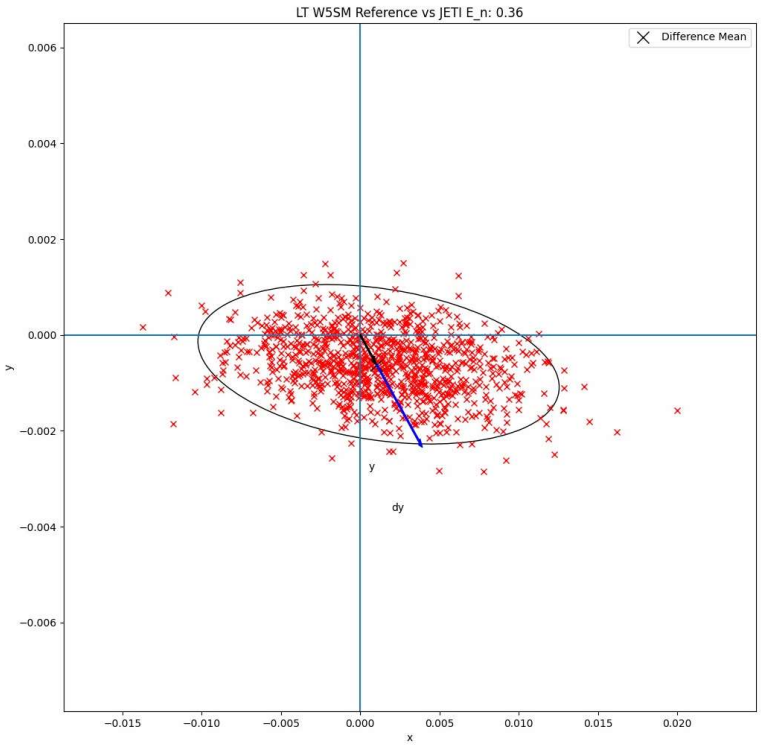

Figure 30. Distribution of the difference with reference value and JETI for LTW5SM

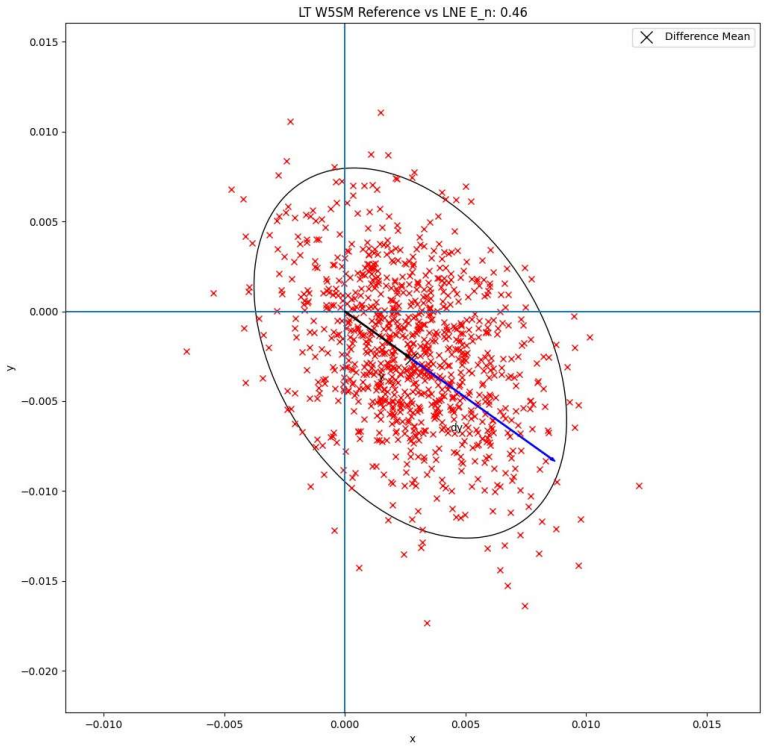

Figure 31. Distribution of the difference with reference value and LNE for LTW5SM

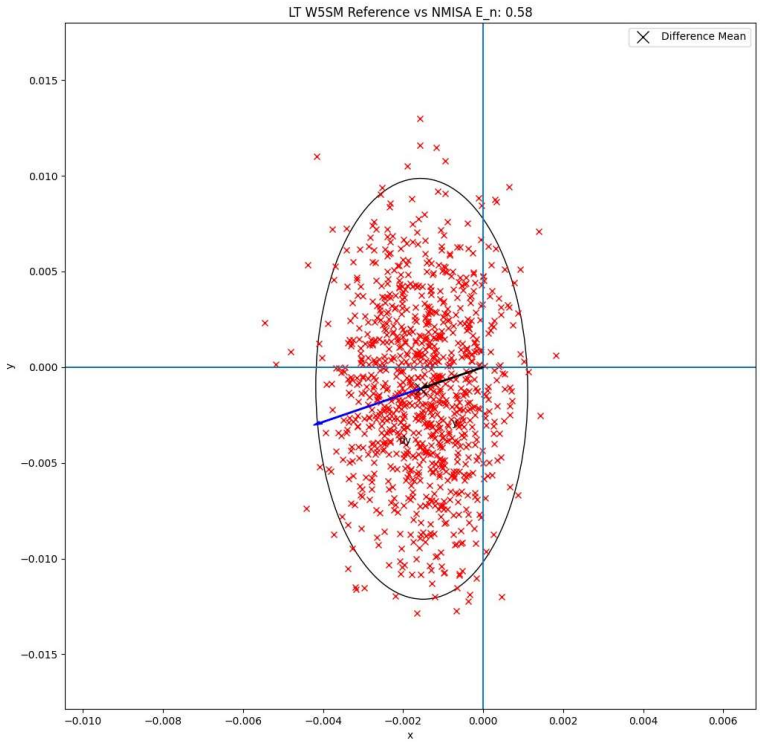

Figure 32. Distribution of the difference with reference value and NMISA for LTW5SM

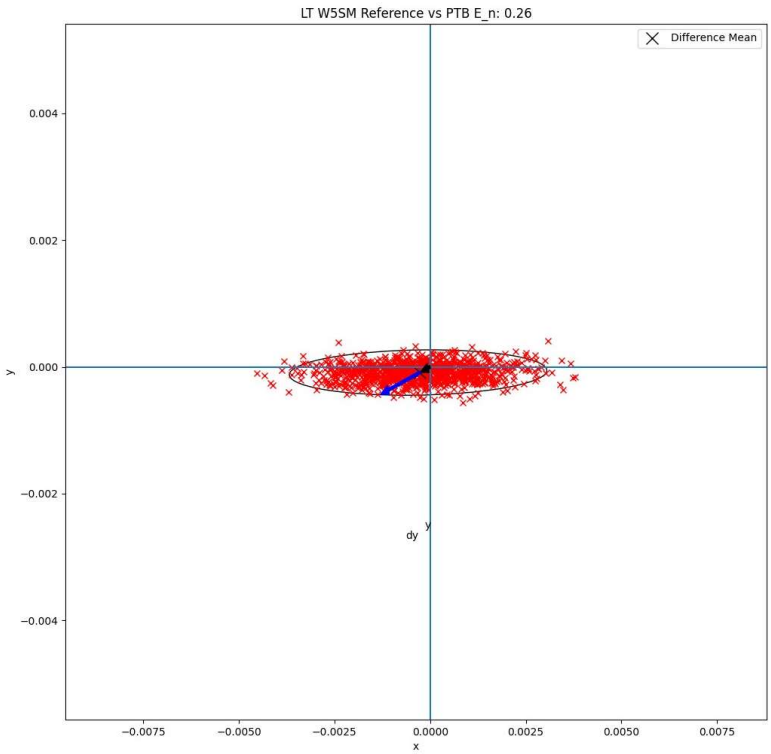

Figure 33. Distribution of the difference with reference value and PTB for LTW5SM

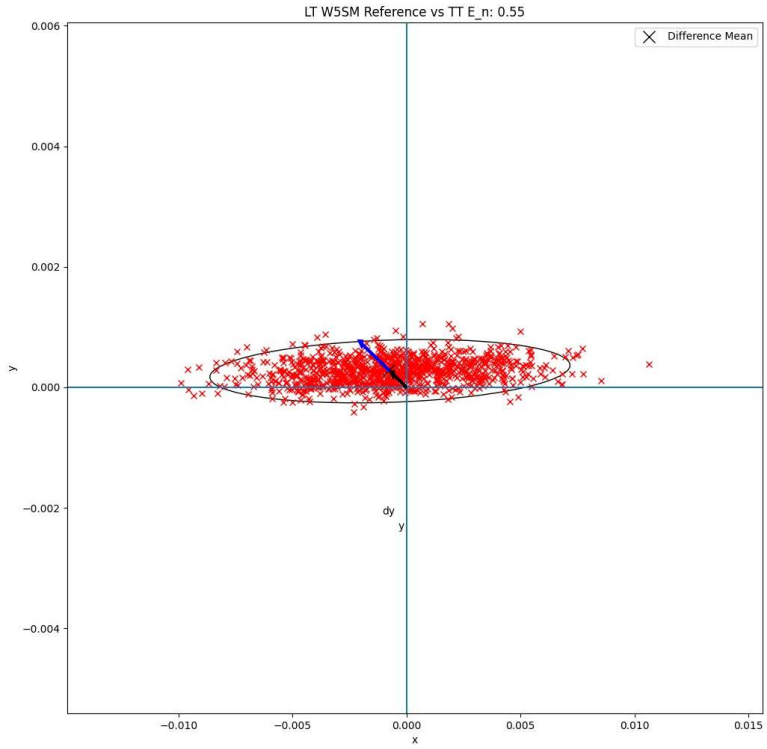

Figure 34. Distribution of the difference with reference value and TT for LTW5SM

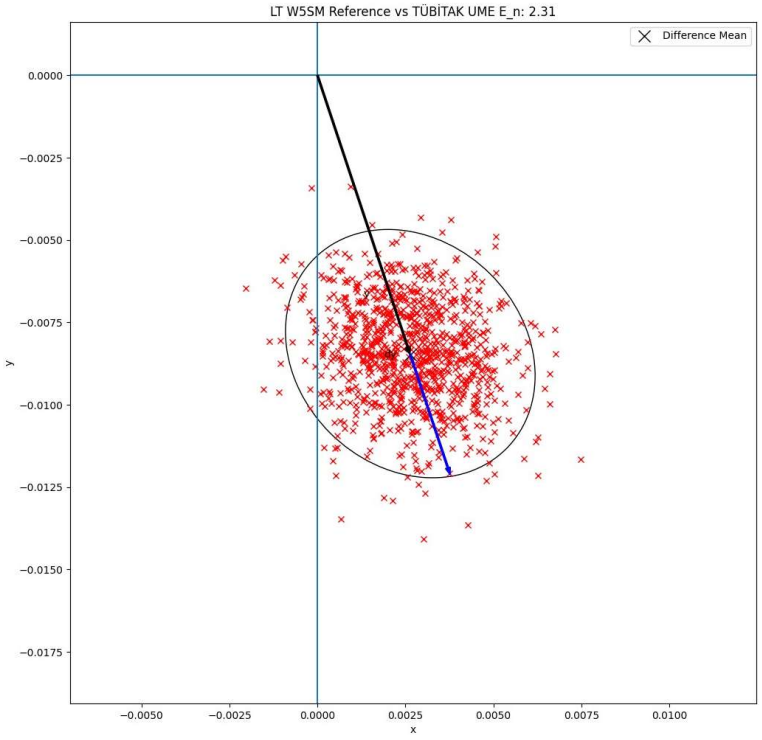

Figure 35. Distribution of the difference with reference value and TÜBITAK UME for LTW5SM

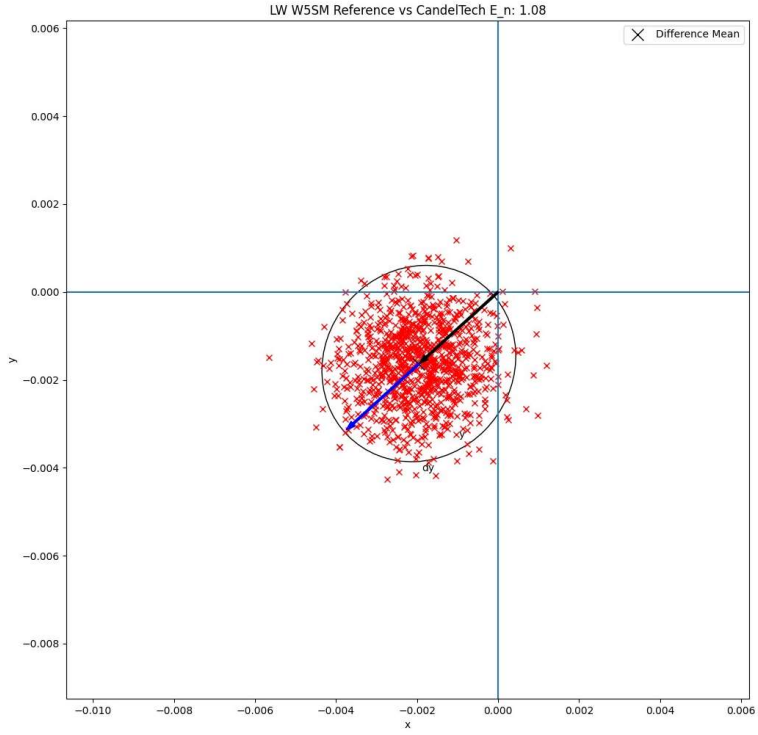

Figure 36. Distribution of the difference with reference value and CandelTech for LWW5SM

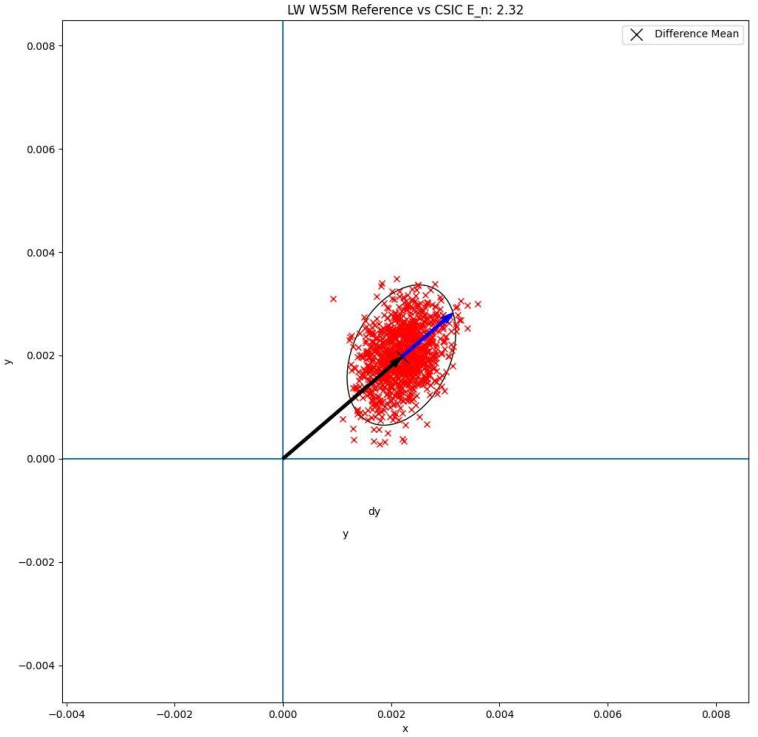

Figure 37. Distribution of the difference with reference value and CSIC for LWW5SM

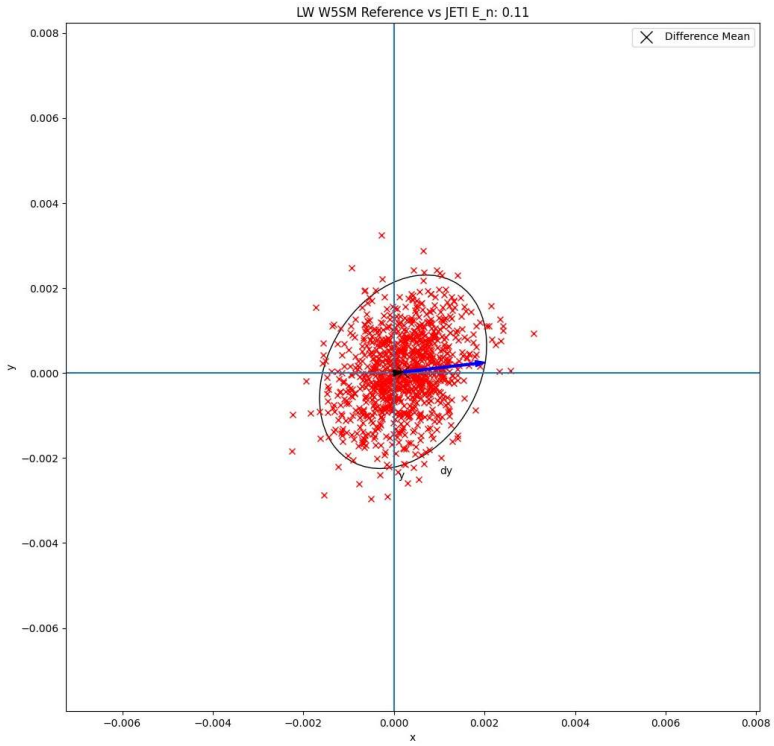

Figure 38. Distribution of the difference with reference value and JETI for LWW5SM

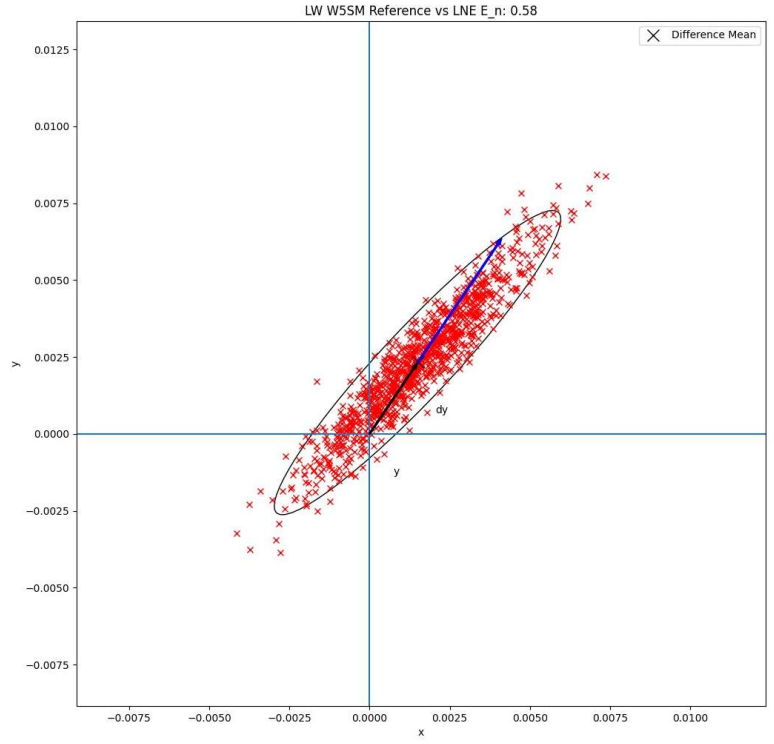

Figure 39. Distribution of the difference with reference value and LNE for LWW5SM

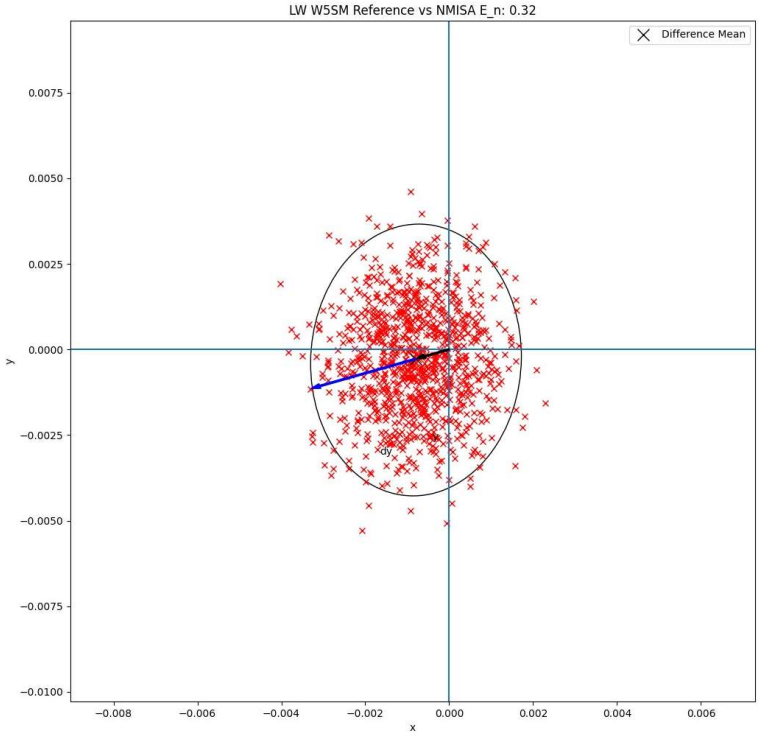

Figure 40. Distribution of the difference with reference value and NMISA for LWW5SM

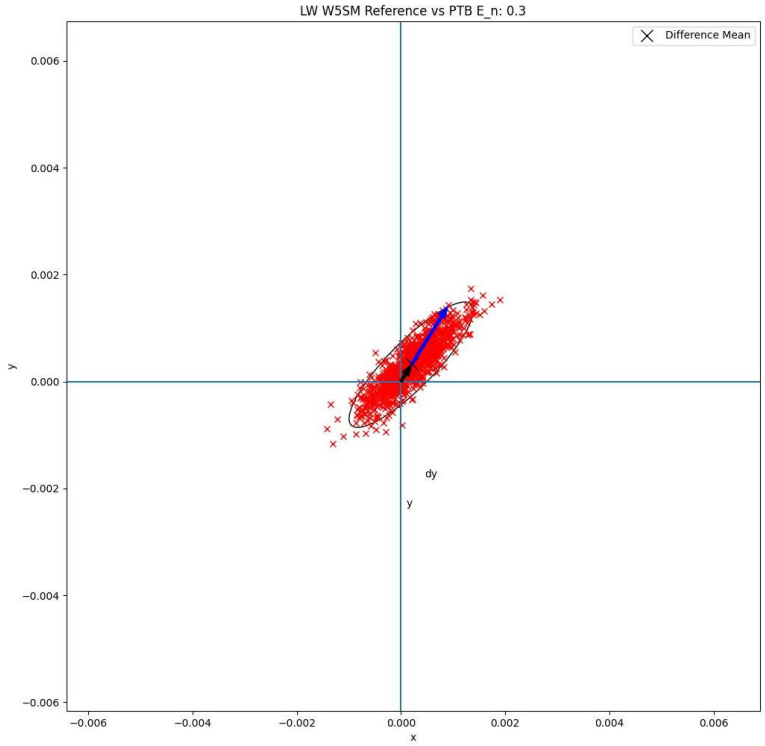

Figure 41. Distribution of the difference with reference value and PTB for LWW5SM

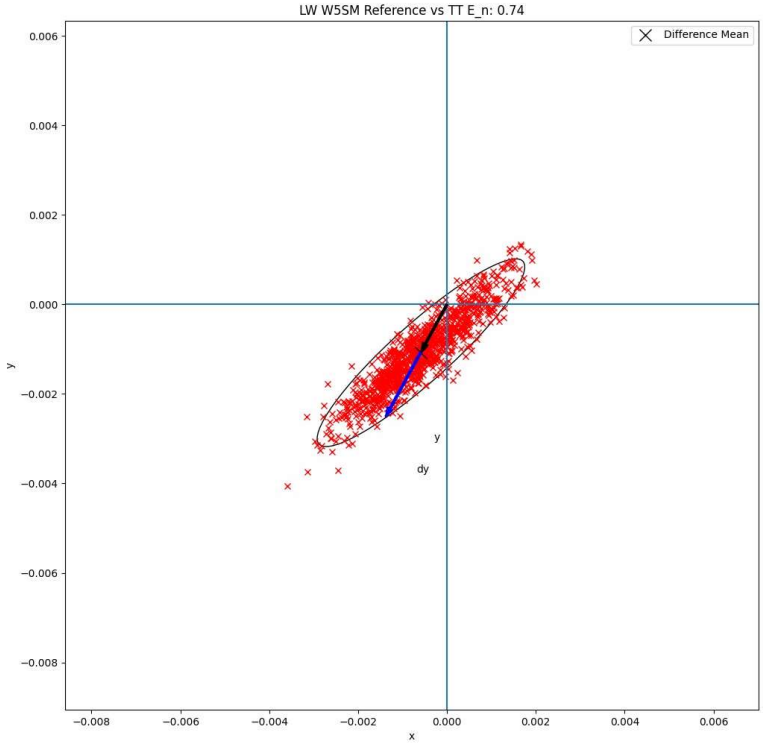

Figure 42. Distribution of the difference with reference value and TT for LWW5SM

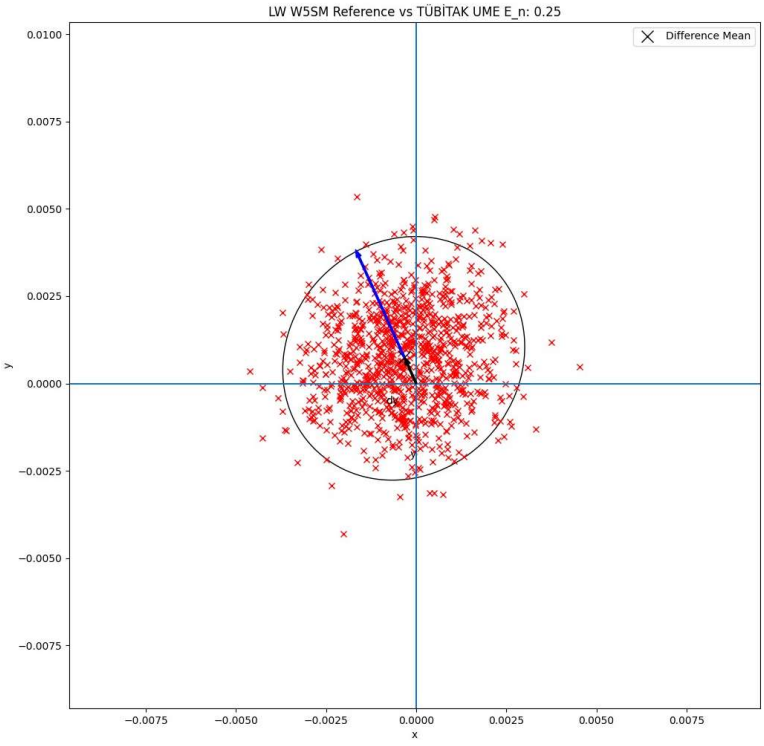

Figure 43. Distribution of the difference with reference value and TUBITAK UME for LWW5SM

Table 32. En values, between the participants and reference value, calculated by using multidimensional data method

	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
LT W5SM	0.55	2.31	0.49	1.03	0.36	0.58	0.46	0.26
LR W5SM	0.26	2.01	0.47	0.16	1.49	0.44	1.37	0.58
LB W5SM	3.77	1.54	0.21	2.58	0.23	0.47	0.42	0.11
LW W5SM	0.74	0.25	1.08	2.32	0.11	0.32	0.58	0.30

Table 33. The bilateral En values, between the results of the participants for LT W5SM by using by using multidimensional data method

LT W5SM	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0.00	2.37	0.21	0.84	0.51	0.16	0.42	0.69
TÜBİTAK	2.37	0.00	1.61	2.16	1.95	1.15	0.58	2.29
CandelTech	0.21	1.61	0.00	1.01	0.24	0.09	0.65	0.34
CSIC	0.84	2.16	1.01	0.00	0.95	0.99	0.59	0.97
JETI	0.51	1.95	0.24	0.95	0.00	0.23	0.22	0.31
NMISA	0.16	1.15	0.09	0.99	0.23	0.00	0.65	0.34
LNE	0.42	0.58	0.65	0.59	0.22	0.65	0.00	0.45
PTB	0.69	2.29	0.34	0.97	0.31	0.34	0.45	0.00

Table 34. The bilateral En values, between the results of the participants for LR W5SM by using by using multidimensional data method

LR W5SM	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0.00	1.43	0.34	0.27	0.82	0.28	0.71	0.09
TÜBİTAK	1.43	0.00	0.54	1.29	1.21	0.79	0.78	1.67
CandelTech	0.34	0.54	0.00	0.46	0.37	0.20	0.54	0.39
CSIC	0.27	1.29	0.46	0.00	0.13	0.36	0.24	0.27
JETI	0.82	1.21	0.37	0.13	0.00	0.49	0.85	1.04
NMISA	0.28	0.79	0.20	0.36	0.49	0.00	0.33	0.29
LNE	0.73	0.78	0.54	0.24	0.85	0.33	0.00	1.63
PTB	0.09	1.67	0.39	0.27	1.04	0.29	1.63	0.00

Table 35. The bilateral En values, between the results of the participants for LB W5SM by using by using multidimensional data method

LB W5SM	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0.00	0.64	0.32	1.64	1.12	0.41	0.45	3.80
TÜBİTAK	0.64	0.00	0.47	0.86	0.41	1.10	0.82	0.82
CandelTech	0.32	0.47	0.00	0.52	0.20	0.23	0.44	0.21
CSIC	1.64	0.86	0.52	0.00	2.13	1.33	0.10	2.40
JETI	1.12	0.41	0.20	2.13	0.00	0.25	0.74	0.21
NMISA	0.41	1.10	0.23	1.33	0.25	0.00	0.63	0.30
LNE	0.45	0.82	0.44	0.10	0.74	0.63	0.00	0.83
PTB	3.80	0.82	0.21	2.40	0.21	0.30	0.83	0.00

Table 36. The bilateral En values, between the results of the participants for LW W5SM by using by using multidimensional data method

LW W5SM	TT	TÜBİTAK	CandelTech	CSIC	JETI	NMISA	LNE	PTB
TT	0.00	0.47	0.44	1.38	0.38	0.22	0.84	0.89
TÜBİTAK	0.47	0.00	0.70	0.78	0.24	0.22	0.34	0.21
CandelTech	0.44	0.70	0.00	2.34	0.91	0.47	0.77	1.15
CSIC	1.38	0.78	2.34	0.00	2.13	1.29	0.53	1.66
JETI	0.38	0.24	0.91	1.23	0.00	0.34	0.46	0.13
NMISA	0.22	0.22	0.47	1.29	0.34	0.00	0.48	0.40
LNE	0.84	0.34	0.77	0.53	0.46	0.48	0.00	0.49
PTB	0.89	0.21	1.15	1.66	0.13	0.40	0.49	0.00