# Final Verification Report: 4DWxCube – Network MET prototypes

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***Abstract***

This document describes the verification exercise results of the Network Meteorological (MET) prototypes of the MET Domain System "4DWxCube" (11.02.01-D31) and it is focus on the Network operational user environment. It follows the planned verification exercises described in 11.02.02-D20 (Verification Plan) based on consolidated MET capabilities as joint effort of European National Meteorological Services members of EUMETNET. This document is the update of the Initial Verification Report and is final version of verification results for Network MET prototypes developed in SESAR 1 project.

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# Document History

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# Intellectual Property Rights (foreground)

This deliverable consists of SJU foreground and EUMETNET Consortium background. The NWP models and used to support the described prototypes, belong to the respective National Meteorological Service.

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# Executive summary

This document describes the verification exercise results of the Network Meteorological (MET) prototypes of the MET Domain System “4DWxCube”. It is focused on the Network operational user environment (OUE). The verification activities were performed by collaboration between the different national MET Service Providers (METSPs) involved in WP11.2 which provide MET information to the users of the Network OUE via the 4DWxCube. The main focus was to verify the consistency and harmonisation of MET information and that MET information is based on the latest science to provide the users with a common view of MET and the highest performance of information possible.

This verification report includes six exercises. The first two exercises focus on the consistency, harmonisation and the use of the latest science. In the next two exercises, the properties and accuracy of the consolidated and translated MET information was inspected. Additional verification activities demonstrate the verification of the availability of MET Information and the reliability of MET Information which was tested within the verification exercises of the MET-GATE.

This report shows satisfactory results. Recommendations and limitations are given to each specific verification exercise analysis, if necessary.

# 1 Introduction

## 1.1 Purpose of the document

This document provides the verification report of the Network MET of the MET Domain System (DS) "4DWxCube". It describes the results of verification exercises defined in 11.02.02-D20, Verification Plan (VP) – Network OUE [8] and how they have been conducted. The verification activities are focussed on requirements of MET technical specifications expressed in 11.02.02-D15 [7] based on consolidated MET capabilities developed as joint effort of European National Meteorological Services members of EUMETNET EIG. The verification activities were performed by collaboration between the different National MET Service (NMS) partners involved in WP11.2 who provide MET information to the users of the network OUE via the 4DWxCube. The main focus was to verify the consistency and harmonisation of MET information and that MET information is based on the latest science to provide the users with a common view of MET and the highest performance of information possible.

The verification report informs the reader about the features of MET information that is made available for aviation stakeholders in Europe.

## 1.2 Intended readership

The intended readership of the verification report is equal to the readership envisaged for the verification plan.

This document is mainly intended for project partners and related projects which need MET Information in support of their conceptual and operational activities. The intended audience of this document are initially the WP11.2 projects to support suitable validation exercises. Operational work packages (OPS WPs) and Operational Focus Areas (OFAs) that might be interested in the results are primarily project partners within WP7 Network operations and WP8 Information Management.

Any OFA contributing to the Network OUE as well as their related projects needing MET Information in support of their operational concepts is envisaged as intended audience. In particular, the following OFAs are identified as interested audience:

- OFA 05.03.07 and its contributing operational and technical projects;
- OFA 03.01.03 and its contributing operational and technical projects.

## 1.3 Structure of the document

The document is structured as follows:

Chapter 1 introduces the document and describes the intended readership and terminology;
Chapter 2 provides background information and summarizes verification exercises and objectives;
Chapter 3 defines the conduct of verification exercises;
Chapter 4 provides the verification exercise results and analysis;
Chapter 5 includes conclusions and recommendations;
Chapter 6 includes the verification exercise reports

## 1.4 Glossary of terms

Table 1: List of terms

| Term | Definition | Source |
|---|---|---|
| **4DWxCube** | The 4DWxCube is a (virtual) repository of shared consistent and translated meteorological information, produced by multiple METSPs and made available to ATM stakeholders via its SWIM compliant "MET-GATE". | Proposed by WP11.02, 11.02.01 D31 TAD |

| Term | Definition | Source |
|---|---|---|
| **MET product** | MET information that are provided to the MET-GATE | Proposed by P11.02.02 |
| **MET-GATE** | The "MET-GATE" is a SWIM node enabling the discovery, access and retrieval of consistent and translated MET information, tailored to the ATM stakeholders' needs, from the 4DWxCube via SWIM compliant web services. | Proposed by WP11.02, 11.02.01 D31 TAD |

## 1.5 Acronyms and Terminology

Table 2: List of acronyms

| Term | Definition |
|---|---|
| **4DWx** | 4 dimensional weather data |
| **AMDAR** | Aircraft Meteorological Data Relay |
| **ATM** | Air Traffic Management |
| **CAT** | Clear Air Turbulence |
| **DS** | Domain System |
| **DWD** | National Weather Service of Germany |
| **E-AMDAR** | EUMETNET-AMDAR |
| **EUMETNET** | European Meteorological Network |
| **(Mode-S) EHS** | (Mode-S) Enhanced Surveillance |
| **FB** | Functional Block |
| **FMI** | National Weather Service of Finland |
| **ICAO** | International Civil Aviation Organization |
| **KNMI** | National Weather Service of the Netherlands |
| **Météo-France** | National Weather Service of France |
| **MET** | Meteorology or Meteorological |
| **MET-GATE** | MET information services Generation, ATM Tailoring and Exchange |
| **Met Norway** | National Weather Service of Norway |
| **METSP** | MET Service Provider |
| **MO (Met Office)** | National Weather Service of United Kingdom |

| Term | Definition |
|---|---|
| **Mode-S** | Mode-Selective |
| **NMS** | National Meteorological Service |
| **NOP** | Network Operation Plan |
| **NWP** | Numerical Weather Prediction |
| **OFA** | Operational Focus Area |
| **OPS-WP** | Operational Work Package |
| **OUE** | Operational User Environment |
| **QoS** | Quality of Service |
| **SESAR** | Single European Sky ATM Research Programme |
| **SESAR Programme** | The programme which defines the Research and Development activities and Projects for the SJU. |
| **SJU** | SESAR Joint Undertaking (Agency of the European Commission) |
| **SMHI** | National Weather Service of Sweden |
| **SUT** | System Under Test |
| **SWIM** | System Wide Information Management |
| **TAD** | Technical Architecture Description |
| **TS** | Technical Specification |
| **VP** | Verification Plan |
| **VR** | Verification Report |

# 2 Context of the Verification

The verification activities analyse the features of MET information that is made available for ATM and airspace users in Europe. It is focussed on MET TSs expressed in 11.02.02-D15 [7] based on consolidated and translated MET prototypes. This report describes the results of the conducted verification exercises which are specified in 11.02.02-D20 VP [8].

## 2.1 System Overview

The Verification Plan provides detailed information about the developed MET prototypes. There has been no specific system under test used for the verification exercises. The MET information have been scientifically tested or inspected and analysed manually.

The tables below summarize the conducted exercises.

| Verification Exercise ID and Title | EXE-11.02.02-VP-NET1.0001: consistency of MET information |
|---|---|
| Leading organization | EUMETNET EIG |
| Verification exercise objectives | OBJ-11.02.02-VP-NET1.1001 |
| Rationale | The purpose of this exercise is to verify that the Network MET prototypes produce consistent MET products. |
| Verification Technique | Inspection |
| Dependent Verification Exercises | - |

Table 3: Objectives verified in EXE-11.02.02-VP-NET1.0001

| Verification Exercise ID and Title | EXE-11.02.02-VP-NET1.0002: Use of latest science for MET information |
|---|---|
| Leading organization | EUMETNET EIG |
| Verification exercise objectives | OBJ-11.02.02-VP-NET1.1002 |
| Rationale | The purpose of this exercise is to verify that the Network MET prototypes are produced on the knowledge of latest science. |
| Verification Technique | Inspection |
| Dependent Verification Exercises | - |

Table 4: Objectives verified in EXE-11.02.02-VP-NET1.0002

| Verification Exercise ID and Title | EXE-11.02.02-VP-NET1.0003: MET parameter properties |
|---|---|

| | |
|---|---|
| **Leading organization** | EUMETNET EIG |
| **Verification exercise objectives** | OBJ-11.02.02-VP-NET1.1007 |
| **Rationale** | The purpose of this exercise is to verify that the Network MET prototypes produce MET products with the requested properties. |
| **Verification Technique** | Inspection |
| **Dependent Verification Exercises** | - |

Table 5: Objectives verified in EXE-11.02.02-VP-NET1.0003

| **Verification Exercise ID and Title** | **EXE-11.02.02-VP-NET1.0004: MET information accuracy** |
|---|---|
| **Leading organization** | EUMETNET EIG |
| **Verification exercise objectives** | OBJ-11.02.02-VP-NET1.1008 |
| **Rationale** | The purpose of this exercise is to verify that the Network MET prototypes produce high accuracy MET products. |
| **Verification Technique** | Test |
| **Dependent Verification Exercises** | - |

Table 6: Objectives verified in EXE-11.02.02-VP-NET1.0004

| **Verification Exercise ID and Title** | **EXE-11.02.02-VP-NET1.0005: MET product production** |
|---|---|
| **Leading organization** | EUMETNET EIG |
| **Verification exercise objectives** | OBJ-11.02.02-VP-NET1.1003<br>OBJ-11.02.02-VP-NET1.1004<br>OBJ-11.02.02-VP-NET1.1005 |
| **Rationale** | The purpose of this exercise is to verify the production of the MET products from Network MET prototypes. |
| **Verification Technique** | Inspection |
| **Dependent Verification Exercises** | - |

Table 7: Objectives verified in EXE-11.02.02-VP-NET1.0005

| Verification Exercise ID and Title | EXE-11.02.02-VP-NET1.0007: MET data reliability |
|---|---|
| **Leading organization** | EUMETNET EIG |
| **Verification exercise objectives** | OBJ-11.02.02-VP-NET1.1009 |
| **Rationale** | The purpose of this exercise is to verify the reliability of MET products. |
| **Verification Technique** | Test/Analysis |
| **Dependent Verification Exercises** | EXE-11.02.02-VP-4DWC.0007 |

Table 8: Objectives verified in EXE-11.02.02-VP-NET1.0007

## 2.2 Summary of Verification Exercise/s

### 2.2.1 Summary of Verification Objectives and Success Criteria

The verification objectives have been derived from the requirements of the 11.02.02-D15 Technical Specifications [7] and are expressed in detail in 11.02.02-D20 Verification Plan [8].

| Verification objective ID | Verification objective title | Success criterion |
|---|---|---|
| OBJ-11.02.02-VP-NET1.1001 | Inspection of consistency of MET information | MET information is consistent in the specified area. |
| OBJ-11.02.02-VP-NET1.1002 | Inspection of the use of latest science in the MET prototypes | Latest science is used in the MET prototypes |
| OBJ-11.02.02-VP-NET1.1003 | ICAO regulated MET information production inspection | ICAO regulated MET information is produced by the Regulatory MET prototype. |
| OBJ-11.02.02-VP-NET1.1004 | Inspection of production of forecasts and observations of key meteorological parameters at surface and aloft. | Requested meteorological parameters are made available by the Nominal MET prototype. |
| OBJ-11.02.02-VP-NET1.1005 | Inspection of production of forecasts and observations of significant weather parameters. | Significant weather parameters are produced by the Significant MET prototype. |
| OBJ-11.02.02-VP-NET1.1007 | MET products properties inspection | MET products fulfil the requirements expressed in TS 11.02.02-D15. |
| OBJ-11.02.02-VP-NET1.1008 | MET products properties test | MET parameters fulfil the accuracy requirements expressed in TS 11.02.02-D15. |

| Verification objective ID | Verification objective title | Success criterion |
|---|---|---|
| OBJ-11.02.02-VP-NET1.1009 | MET data reliability test | MET data is reliable when provided by certified MET provider and access to data is successful. |

Table 9: Summary of verification objectives and success criteria

### 2.2.2 Choice of methods and techniques

No changes regarding verification methods and techniques as compared to the Verification Plan [8].

### 2.2.3 Verification Exercises List and Dependencies

The exercise EXE-11.02.02-VP-NET1.0007 MET data reliability is dependent on the MET-GATE verification process by T11.02.02.02. It has been verified within EXE-11.02.02-VP-4DWC.0007 [11] and detailed results are published in the 4DWxCube-MET-GATE verification report [12].

# 3 Conduct of Verification Exercises

## 3.1 Verification Exercises Preparation

The preparatory activities are described in the VP. There are no differences to be identified.

## 3.2 Verification Exercises Execution

| Exercise ID | Exercise Title | Actual Exercise execution start date | Actual Exercise execution end date | Actual Exercise start analysis date | Actual Exercise end date |
|---|---|---|---|---|---|
| EXE-11.02.02-VP-NET1.0001 | Inspection of consistency of MET information | 01/10/2015 | 10/12/2015 | 01/12/2015 | 15/12/2015 |
| EXE-11.02.02-VP-NET1.0002 | Inspection of the use of latest science for in the MET prototypes | 01/09/2014 | 01/03/2015 | 01/02/2015 | 13/03/2015 |
| EXE-11.02.02-VP-NET1.0003 | Inspection of MET parameter properties | 01/10/2015 | 10/12/2015 | 01/12/2015 | 15/12/2015 |
| EXE-11.02.02-VP-NET1.0004 | Test of MET information accuracy | 01/01/2014 | 10/12/2015 | 01/12/2015 | 15/12/2015 |
| EXE-11.02.02-VP-NET1.0005 | Inspection of MET product production | 01/01/2014 | 10/12/2015 | 01/12/2015 | 15/12/2015 |
| EXE-11.02.02-VP-NET1.0007 | Test of MET data reliability | 01/12/2014 | 30/04/2015 | 15/02/2015 | 31/05/2015 |

Table 10: Verification Exercises execution/analysis dates

## 3.3 Deviations from the Planned Activities

N/A

### 3.3.1 Deviations with Respect to the Verification Strategy

N/A: a verification strategy was not produced.

### 3.3.2 Deviations with Respect to the Verification Plan

There are limited deviations from the plan where the low visibility conditions in X1.6 refer only to winter weather conditions as the prototype has focussed its functionality on prediction of winter conditions and the availability of probability of sand/dust storms were only partly fulfilled dependent on the specific type of probability data. In addition confidence factors for MET forecast are not available though probabilistic forecast can be used instead.

# 4 Verification exercises Results

## 4.1 Summary of Verification Exercises Results

| Verification Exercise ID | Verification Objective ID | Verification Objective Title | Success Criterion ID | Success Criterion | Exercise Results | Verification Objective Analysis Status |
|---|---|---|---|---|---|---|
| EXE-11.02.02-VP-NET1.0001 | OBJ-11.02.02-VP-NET1.1001 | Verify by inspection the consistency of MET information | CRT-11.02.02-VP-NET1.1001 | MET information is consistent in the specified area. | It is verified that Network MET prototypes provide consistent MET information in a specific geographic domain depending on the kind of MET information. | OK |
| EXE-11.02.02-VP-NET1.0002 | OBJ-11.02.02-VP-NET1.1002 | Verify by inspection the use of latest science in the available MET prototypes | CRT-11.02.02-VP-NET1.1002 | Latest science is used in the MET prototypes | It is verified that Network MET prototypes provide MET information based on the latest science. | OK |
| EXE-11.02.02-VP-NET1.0003 | OBJ-11.02.02-VP-NET1.1007 | Verify by inspection that the MET prototypes produce MET products with the properties (such as update rate, area of interest, time resolution) specified in the requirements expressed in TS 11.02.02-D15. | CRT-11.02.02-VP-NET1.1007 | MET products fulfil the requirements expressed in TS 11.02.02-D15 | It is verified that Network MET prototypes provide MET products fulfilling the MET product properties requirements , depending on the MET parameter. | OK |
| EXE-11.02.02-VP-NET1.0004 | OBJ-11.02.02-VP-NET1.1008 | Verify by test that the accuracy of MET information fulfil the requirements expressed in TS 11.02.02-D15. | CRT-11.02.02-VP-NET1.1008 | MET products fulfil the accuracy requirements expressed in TS 11.02.02-D15 | It is verified that the Network MET prototypes provide MET products fulfilling the MET product | OK |

| Verification Exercise ID | Verification Objective ID | Verification Objective Title | Success Criterion ID | Success Criterion | Exercise Results | Verification Objective Analysis Status |
|---|---|---|---|---|---|---|
| | | | | | accuracy requirements | |
| EXE-11.02.02-VP-NET1.0005 | OBJ-11.02.02-VP-NET1.1003 | Verify by inspection of the production of MET products by the Regulatory MET prototype. | CRT-11.02.02-VP-NET1.1003 | ICAO regulated MET information is produced by the Regulatory MET prototype. | It is verified that ICAO regulated MET information is produced by the Regulatory MET prototype. | OK |
| EXE-11.02.02-VP-NET1.0005 | OBJ-11.02.02-VP-NET1.1004 | Verify by inspection the production of MET products by the Nominal MET prototype. | CRT-11.02.02-VP-NET1.1004 | Requested meteorological parameters are produced by the Nominal MET prototype. | It is verified that observations and deterministic and probabilistic forecasts of nominal MET information are produced. | OK |
| EXE-11.02.02-VP-NET1.0005 | OBJ-11.02.02-VP-NET1.1005 | Verify by inspection the production of MET products by the Significant MET prototype. | CRT-11.02.02-VP-NET1.1005 | Requested significant weather parameters produced by the Significant MET prototype | It is verified that observations and deterministic forecasts of most significant MET information are produced, but probabilistic forecasts are not produced for a few MET parameters. | NOK |
| EXE-11.02.02-VP-NET1.0007 | OBJ-11.02.02-VP-NET1.1009 | Verify by test that the MET information is reliable. | CRT-11.02.02-VP-NET1.1009 | MET data is reliable when provided by certified MET provider and access to data is successful via MET-GATE. | It is verified that MET information was reliable when being delivered through the MET-GATE | OK |

Table 11: Summary of Verification Exercises Results

## 4.2 Analysis of Verification Exercises Results

EXE-11.02.02-VP-NET1.0001, EXE-11.02.02-VP-NET1.0002, EXE-11.02.02-VP-NET1.0003, EXE-11.02.02-VP-NET1.0004 and EXE-11.02.02-VP-NET1.0007 are verified successfully. EXE-11.02.02-VP-NET1.0005 is verified partially successfully.

Further details can be found in the specific Verification Exercise Report in chapter 6 and in the following table (Table 12) consisting of Technical specification requirements expressed in 11.02.02-D15 TS [7] and their verification results.

| Identifier | Description | Verification Method | Verification Exercise | Verification result |
|---|---|---|---|---|
| REQ-11.02.02-TS-NET2.0001 | The Regulatory MET prototype shall produce the following common<br>- SIGMET<br>- METAR<br>- SPECI<br>- TAF<br>- TREND<br>- VAA<br>- TCA<br>- Radioactive material as SIGMET<br>- meteorological satellite images<br>- ground-based radar images<br>products with issue time, update rate, accuracy and templates in accordance to ICAO Annex 3 and ICAO Doc 7754. | Inspection | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-NET2.1101 | The Nominal MET prototype shall provide observation products for<br>- wind speed aloft<br>- wind direction aloft<br>- temperature aloft<br>- air pressure (QNH)<br>- dew point aloft<br>- air density aloft<br>by taken aircraft observations into account and covering NAT tracks and the ECAC area. | Inspection | EXE-11.02.02-VP-NET1.0005 | Fulfilled |

| Identifier | Description | Verification Method | Verification Exercise | Verification result |
|---|---|---|---|---|
| REQ-11.02.02-TS-NET2.1102 | The X2.1 MET prototype shall produce observation products for<br>- wind speed aloft<br>- wind direction aloft<br>- headwind aloft<br>- crosswind aloft<br>- temperature<br>for an area of minimum 10 nautical miles around the airport extending from the surface up to 5000ft, with vertical resolution of 500ft up to 2000ft and 1000ft up to 5000ft, slant resolution of 0,5 nautical miles and an update rate of 10 minutes. | Test | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-NET2.1201 | The Nominal MET prototype shall provide deterministic forecast products for<br>- wind speed aloft<br>- wind direction aloft<br>- temperature aloft<br>- air pressure (QNH)<br>- dew point aloft<br>- air density aloft<br>by taken aircraft observations into account with a higher spatial and temporal resolution than and at least an accuracy and update rate as high as in ICAO Annex 3 covering NAT tracks and ECAC area.. | Inspection | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0004<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-NET2.1301 | The Nominal MET prototype shall provide probabilistic forecast products for<br>- air pressure (QNH)<br>- dew point aloft<br>- air density aloft<br>with a higher spatial and temporal resolution than and at least an accuracy and update rate as high as in ICAO Annex 3 covering NAT tracks and the ECAC area. | Inspection | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0004<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |

| Identifier | Description | Verification Method | Verification Exercise | Verification result |
|---|---|---|---|---|
| REQ-11.02.02-TS-NET2.1302 | The X1.3 MET prototype shall produce a seamless prediction of ensemble forecast products for<br>- 2m temperature<br>- 2m relative humidity<br>- 10m wind speed<br>- 6hour precipitation accumulation<br>in a high spatial and temporal resolution covering GER-FR-UK territory. | Test | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-NET2.1303 | The X1.8 MET prototype shall produce ensemble forecast products for<br>- wind speed aloft<br>- wind direction aloft<br>- temperature aloft<br>probabilistic information in a high spatial and temporal resolution with a global coverage. | Test | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-NET2.2101 | The Significant MET prototype shall provide observation products for<br>- convective activity information<br>- lightning information<br>- turbulence information<br>- icing information<br>- jet stream information<br>- temperature inversion<br>- volcanic ash information<br>- tropical cyclone information<br>- radioactive cloud information<br>- mountain wave information<br>- dust storm information<br>- sandstorm information<br>- information on widespread snow<br>- information on widespread precipitation<br>- space weather<br>with a higher spatial and temporal resolution than and at least an accuracy and update rate as high as in ICAO Annex 3 covering NAT tracks and the ECAC area. | Inspection | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0004<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |

| Identifier | Description | Verification Method | Verification Exercise | Verification result |
|---|---|---|---|---|
| REQ-11.02.02-TS-NET2.2102 | The X1.1 MET prototype shall produce observation products for<br>- convective activity information<br>- lightning information | Test | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-NET2.2103 | The X1.6 MET prototype shall produce observation products of<br>- severity level and occurrence of de-icing conditions in classes of: no icing, light, moderate, severe and extreme.<br>- severity level and occurrence of low visibility conditions in classes of no LVC, CATI, CATII, CATIIIa, CATIIIb & CATIIIc.<br>based on pre-defined stakeholder thresholds for one location representative for the whole airport with an update rate of 30 minutes. | Test | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |

| Identifier | Description | Verification Method | Verification Exercise | Verification result |
|---|---|---|---|---|
| REQ-11.02.02-TS-NET2.2201 | The Significant MET prototype shall provide deterministic forecast products for:<br>- significant weather information<br>- convective activity information<br>- lightning information<br>- turbulence information<br>- icing information<br>- jet stream information<br>- temperature inversion<br>- volcanic ash information<br>- tropical cyclone information<br>- radioactive cloud information<br>- mountain wave information<br>- dust storm information<br>- sandstorm information<br>- information on widespread snow<br>- information on widespread precipitation with accuracy at least as high as in and with higher spatial and time resolution than in ICAO Annex 3 covering NAT tracks and the ECAC area | Inspection | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0004<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-NET2.2202 | The X1.2 MET prototype shall produce convective activity information forecast products for GER-FR-UK territories with an update frequency of 15 minutes. | Test | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-NET2.2203 | The X1.4 MET prototype shall produce a seamless forecast of icing conditions in severity levels (no icing, light, moderate, severe) with higher spatial and temporal resolution than in ICAO Annex 3. | Test | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-NET2.2204 | The X1.5 MET prototype shall produce a seamless forecast of clear air turbulence in four severity levels (no turbulence, light, moderate, severe) with higher spatial and temporal resolution than in ICAO Annex 3. | Test | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |

| Identifier | Description | Verification Method | Verification Exercise | Verification result |
|---|---|---|---|---|
| REQ-11.02.02-TS-NET2.2205 | The X1.6 MET prototype shall produce forecast products of<br>- severity level and occurrence of de-icing conditions in classes of: no icing, light, moderate, severe and extreme.<br>- severity level and occurrence of low visibility conditions in classes of no LVC, CATI, CATII, CATIIIa, CATIIIb & CATIIIc<br>based on stakeholder thresholds for one location representative for the whole airport with an update rate of 30 minutes. | Test | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0005 | Partially fulfilled<br><br>(low visibility forecasts only in winter precipitation) |
| REQ-11.02.02-TS-NET2.2301 | The Significant MET prototype shall provide probabilistic forecast products for:<br>- significant weather information<br>- lightning information<br>- turbulence information<br>- icing information<br>- jet stream information<br>- temperature inversion<br>- volcanic ash information<br>- tropical cyclone information<br>- radioactive cloud information<br>- mountain wave information<br>- dust storm information<br>- sand storm information<br>- information on widespread snow<br>- information on widespread precipitation with a higher spatial and temporal resolution than and at least an accuracy and update rate as high as in ICAO Annex 3 covering NAT tracks and the ECAC area. | Inspection | EXE-11.02.02-VP-NET1.0003<br><br>EXE-11.02.02-VP-NET1.0004<br><br>EXE-11.02.02-VP-NET1.0005 | Partially fulfilled<br><br>(probabilistic forecasts for mountain waves, dust and sand storm are not produced operationally) |

| Identifier | Description | Verification Method | Verification Exercise | Verification result |
|---|---|---|---|---|
| REQ-11.02.02-TS-NET2.2302 | The X1.3 MET prototype shall produce a seamless ensemble forecast product for convective activity (depending on the received parameter) to enable probabilistic information in a high spatial and temporal resolution covering GER-FR-UK territory. | Inspection | EXE-11.02.02-VP-NET1.0003<br>EXE-11.02.02-VP-NET1.0005 | Fulfilled |
| REQ-11.02.02-TS-TER2.2104 | The Significant MET Prototype shall send on observed Information on observed significant weather conditions immediately after detection. | Analysis | EXE-11.02.02-VP-NET1.0007 | Fulfilled |
| REQ-11.02.02-TS-NET2.9006 | The MET products produced by the MET prototypes shall be approved by authorized organisation for aviation usage (e.g. by EASA). | Inspection | N/A | N/A |
| REQ-11.02.02-TS-NET2.9003 | The MET prototypes shall produce reliable (not corrupted) MET products. | Inspection | EXE-11.02.02-VP-NET1.0007 | Fulfilled |
| REQ-11.02.02-TS-NET2.9004 | The MET prototypes shall produce<br>- statistical MET forecast products<br>- case analysis of MET products<br>with a time horizon up to 3 months on request of a network stakeholder. | Analysis | EXE-11.02.02-VP-NET1.0003 | Fulfilled |
| REQ-11.02.02-TS-NET2.9005 | The MET prototypes shall produce confidence factors in relation to the generated MET forecast products. | Review of Design | EXE-11.02.02-VP-NET1.0007 | Not Fulfilled |
| REQ-11.02.02-TS-NET2.9001 | The MET prototypes shall produce MET products consistent in time and across the different Operational User environments. | Review of design | EXE-11.02.02-VP-NET1.0001 | Fulfilled |
| REQ-11.02.02-TS-NET2.9002 | The MET prototypes shall produce MET products based on latest science in observation and forecasting techniques. | Review of design | EXE-11.02.02-VP-NET1.0002 | Fulfilled |

| Identifier | Description | Verification Method | Verification Exercise | Verification result |
|---|---|---|---|---|
| REQ-11.02.02-TS-NET2.9007 | The MET Prototypes shall produce MET forecast products with a time horizon:<br>- up to 3 months (statistical forecast)<br>- up to 5-7 days ahead for a wide area (general forecast)<br>- up to 3 days ahead for dedicated areas (more specific forecast)<br>- up to 1 day ahead (detailed forecast). | Review of Design | EXE-11.02.02-VP-NET1.0003 | Fulfilled |

Table 12: Network Technical Specification [7] requirements and verification results from verification exercises

Many METSP provide ICAO Annex 3 products and forecasts though they also have available improved forecasts that are above and beyond the minimum requirements of ICAO Annex 3. As this data is available, customers should be able to access the higher performance data as it will give improved resolution, data availability and timeliness which will assist in decision making, risk management and planning over all time scales.

REQ-11.02.02-TS-NET2.9006 (The MET products produced by the MET prototypes shall be approved by authorized organisation for aviation usage (e.g. by EASA).) was not able to verify as it covers Aviation Authorities which are not part of the SESAR programme. Many aspects of aviation are highly regulated and require over seeing bodies to ratify changes in working practice and minimum requirements.

The requirement about the confidence factors of the MET products REQ-11.02.02-TS-NET2.9005 (The MET prototypes shall produce confidence factors in relation to the generated MET forecast products) could not been verified during the described exercises because the required confidence factors have not been defined and clearly specified by the users to be considered in the verification exercise. Probabilistic data could be used instead as they also give advice about confidence of the MET information.

### 4.2.1 Unexpected Behaviours/Results

There are no further unexpected behaviours or results identified which have not been addressed in the section above (4.2).

# 5 Conclusions and recommendations

## 5.1 Conclusions

Consistency of consolidated and translated MET products produced by Network MET Prototypes has been verified successfully for limited geographical areas. The Network MET prototypes provide consolidated and translated MET information based on the latest science. The Network MET prototypes provide MET products according to the requested MET information properties depending on the specific kind of MET parameter. The consolidated and translated MET products produced by the Network MET prototypes fulfil the MET information requirements considering accuracy. ICAO regulated MET information is made available. The availability of consolidated and translated MET information is verified successfully in limited areas. The production of MET information as specified in the requirements is mostly verified successfully. All observations of nominal and significant meteorological parameters are produced by the Network MET prototypes and made available by the involved METSPs. The same applies for deterministic and probabilistic forecasts, besides a few exceptions: probabilistic forecasts for mountain waves, dust and sand storms information. This information is not predicted on a regular basis as they are very computing power intensive and therefore very expensive and the significant events occur only occasionally. On occasion the information can be calculated and predicted for the respective geographical areas.

## 5.2 Recommendations

The Network MET prototypes are currently available only in limited geographical areas. Therefore, only validation exercises within these areas can be supported with the respective MET information. The ongoing advancement of the Network MET prototypes is necessary to ensure they will always be based on the latest science. The verification exercises focus on the consolidated Network MET prototypes Due to the few accuracy requirements and the specific consolidated and translated MET prototypes developed within this programmes the accuracy has only be verified following those few requirements for the developed consolidated, translated MET prototypes.

Most of the verification objectives have been verified successfully for all MET prototypes. The MET products except the specified parameters for probabilistic information (mountain waves and sand/dust storms) are available in respect to the specified areas and can be provided to the users. The unavailability of some probabilistic data did not prevent the validation to take place as they were available as deterministic forecasts for use is aviation as they already are in a pre-SESAR context. No validation exercise has requested this type of MET information as probabilistic data anyway. It would be expected in the near furore that probabilistic forecast of mountain waves and sand/dust storms would be available to users. The MET-GATE prototype is the technical system to give access to this MET information.

# 6 Verification Exercises reports

The following table (Table 13) summarizes which MET prototypes have been verified in which specific verification exercise:

| MET prototype | Verification exercise | Conducted: yes/no |
|---|---|---|
| Radar composite of 3D convection | EXE-11.02.02-VP-NET1.0001 | Yes |
| | EXE-11.02.02-VP-NET1.0002 | Yes |
| | EXE-11.02.02-VP-NET1.0003 | Yes |
| | EXE-11.02.02-VP-NET1.0004 | Yes |
| | EXE-11.02.02-VP-NET1.0005 | Yes |
| Nowcasting of convection | EXE-11.02.02-VP-NET1.0001 | Yes |
| | EXE-11.02.02-VP-NET1.0002 | Yes |
| | EXE-11.02.02-VP-NET1.0003 | Yes |
| | EXE-11.02.02-VP-NET1.0004 | Yes |
| | EXE-11.02.02-VP-NET1.0005 | Yes |
| Super-ensemble mesoscale forecast of convection | EXE-11.02.02-VP-NET1.0001 | Yes |
| | EXE-11.02.02-VP-NET1.0002 | Yes |
| | EXE-11.02.02-VP-NET1.0003 | Yes |
| | EXE-11.02.02-VP-NET1.0004 | Yes |
| | EXE-11.02.02-VP-NET1.0005 | Yes |
| Icing forecast | EXE-11.02.02-VP-NET1.0001 | Yes |
| | EXE-11.02.02-VP-NET1.0002 | Yes |
| | EXE-11.02.02-VP-NET1.0003 | Yes |
| | EXE-11.02.02-VP-NET1.0004 | Yes |
| | EXE-11.02.02-VP-NET1.0005 | Yes |
| Turbulence forecast | EXE-11.02.02-VP-NET1.0001 | Yes |
| | EXE-11.02.02-VP-NET1.0002 | Yes |
| | EXE-11.02.02-VP-NET1.0003 | Yes |
| | EXE-11.02.02-VP-NET1.0004 | Yes |
| | EXE-11.02.02-VP-NET1.0005 | Yes |
| Winter weather conditions forecast at airports | EXE-11.02.02-VP-NET1.0001 | Yes |
| | EXE-11.02.02-VP-NET1.0002 | Yes |
| | EXE-11.02.02-VP-NET1.0003 | Yes |
| | EXE-11.02.02-VP-NET1.0004 | Yes |
| | EXE-11.02.02-VP-NET1.0005 | Yes |
| MET support to Network Capacity | EXE-11.02.02-VP-NET1.0001 | No |

| | | |
|---|---|---|
| reduction forecast (available prototype used) | EXE-11.02.02-VP-NET1.0002<br>EXE-11.02.02-VP-NET1.0003<br>EXE-11.02.02-VP-NET1.0004<br>EXE-11.02.02-VP-NET1.0005 | Yes<br>Yes<br>No<br>Yes |
| MET support to 4D trajectory planning | EXE-11.02.02-VP-NET1.0001<br>EXE-11.02.02-VP-NET1.0002<br>EXE-11.02.02-VP-NET1.0003<br>EXE-11.02.02-VP-NET1.0004<br>EXE-11.02.02-VP-NET1.0005 | Yes<br>Yes<br>Yes<br>Yes<br>Yes |
| MODE-S EHS derived MET information | EXE-11.02.02-VP-NET1.0003<br>EXE-11.02.02-VP-NET1.0005 | Yes<br>Yes |
| E-AMDAR MET information | EXE-11.02.02-VP-NET1.0003<br>EXE-11.02.02-VP-NET1.0005 | Yes<br>Yes |

Table 13: Verification of MET prototypes

The EXE-11.02.02-VP-NET1.0007 has been performed by the MET-GATE and uses Regulatory MET products as well as existing MET forecast products due to the capabilities of the 4DWxCube - MET-GATE prototype.

# 6.1 Verification EXE-11.02.02-VP-NET1.0001 Report

## 6.1.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-NET1.0001, Consistency of MET information is an inspection of the input data and processing methods of consolidated and translated MET products where consistent MET information is currently available. The Network MET prototypes are addressed in this verification exercise. It is checked whether the requirement REQ-11.02.02-TS-NET1.9001 [7] is met or not.

## 6.1.2 Conduct of Verification Exercise

### 6.1.2.1 Verification Exercise Preparation

The MET capabilities developed within P11.02.02 applicable for the network operational user environment (OUE) and therefore part of the Network MET prototypes are used for this verification exercise. The addressed MET information is listed in the respective exercise procedure described in the Verification Plan. There is no specific configuration necessary for conducting this exercise because the inspection is performed manually.

### 6.1.2.2 Verification Exercise execution

It will be evaluated where consistent and harmonised MET information is currently available. This verification exercise is run eight times, once for each MET capability belonging to the Network MET prototypes.

Each verification execution is a manual inspection of the processed input data and method applied to compute consolidated MET information. It is evaluated where consistent MET information is available.

An actual detailed timing cannot be given for each verification run. The consistency inspection is performed at the late stage of prototype development for those which have been further developed after the initial verification exercise, mostly between October 2015 and December 2015.

1: Inspection of radar composite of 3D convection information

Radar scans from the French and UK radar network are ingested in the consolidation tool which produces 3D gridded multi radar reflectivity products currently on two domains (400kmx400kmx12km) centred on London Heathrow and Paris Charles-de-Gaulle airports.

2: Inspection of Nowcasting of convection information

The national convection Nowcasting tools from Météo-France, Met Office and DWD are translated into harmonised convection warning levels. For safety reasons the maximum warning level available is chosen in the overlap regions during consolidation process which produces a consistent output covering the three national territories.

3: Inspection of super-ensemble mesoscale forecast of convection information

Output MET parameter from the contributing ensemble weather prediction systems of Météo-France, Met Office and DWD are processed to compute probability maps of weather events. This MET capability focuses on convection indicators which are consolidated at the national model edges without unphysical discontinuity. Therefore consistent probability information of predictors of convective activity is computed over the geographical area covered by the contributing systems.

4: Inspection of icing forecast information

The national icing forecast products from Météo-France, Met Office and DWD are translated into harmonised icing warning levels. For consolidation the Pepe & Thomson [9] method is applied to produce consistent icing information within the geographical domain covered by the contributing systems.

5: Inspection of CAT information

The national turbulence forecast products from Météo-France, Met Office and DWD are translated into harmonised turbulence warning levels on a standardised domain. For consolidation the Pepe & Thomson [9] method is applied to produce consistent turbulence information within the geographical domain covered by the contributing systems.

6: Inspection of winter conditions forecast at airports information

The winter weather prototype consists of several different kinds of MET information to forecast winter weather conditions at airports. The surface conditions forecast is computed by FMI's friction algorithm on the basis of SMHI's numerical weather prediction data including the amount of water, snow and ice on the surface. De-icing weather classes based on thresholds received from de-icing local agents are analysed and predicted based on many different kinds of MET information such as weather radar data, METAR observations and high resolution NWP model output. The application of a standardised method to forecast winter weather conditions at different airports by using consistent input data as weather radar composites, METARs and the same NWP system concludes in a consistent winter weather forecast for several airports. Though, it needs to be considered that the local stakeholders may provide different thresholds which leads to inconsistency in the warning levels if thresholds are applied.

7: Inspection of MET information forecast to support 4D trajectories

This MET capability develops ensemble forecast of wind and temperature conditions that are most valuable for the trajectory planning. The main goal is to fulfil the needs of the users for validation exercises. The MET information is provided by Met Office and Météo-France and is based on their ensemble prediction systems. The provided MET information is not consolidated as it is in the nature of ensembles to determine varieties in forecasts to determine different options. Each provided ensemble member MET information is consistent per se.

8: Inspection of MET information forecast for network capacity reductions due to weather across Europe

Ensemble inputs were assessed but with a lack of consistency between different models and minimal data test methods against. Suggestions were made for how this could be addressed but as this prototype was not represented in the user requirements, no further development was made for this exercise.

#### 6.1.2.3 Deviation from the planned activities

There is no deviation from the planned activities.

The MET prototype for MET support of network capacity reduction prediction could not be used for verification as it had been described in the verification plan.

### 6.1.3 Verification exercise Results

#### 6.1.3.1 Summary of Verification exercise Results

It is verified that Network MET prototypes provide consistent MET information in a specific geographical domain depending on the kind of MET information. Considering the currently limited areas the requirement 11.02.02-TS-NET1.9001 has been verified successfully.

#### 6.1.3.2 Analysis of Verification Exercise Results

1: Inspection of radar composite of 3D convection information

Consistent 3D radar information is available and verified in two domains of a size of 400km x 400km x 12km centred on London Heathrow and Paris Charles-de-Gaulle airports.

2: Inspection of Nowcasting of convection information

Consistent convection Nowcasting information is available and verified covering Germany, France and the United Kingdom plus Ireland.

3: Inspection of super-ensemble mesoscale forecast of convection information

Consistent super-ensemble information for convection is available and verified covering the ensemble prediction system domains provided by Météo-France, Met Office and DWD.

4: Inspection of icing forecast information

Consistent icing forecast information is available and verified covering Europe.

5: Inspection of CAT information

Consistent turbulence forecast information is available and verified covering Europe in the upper altitudes.

6: Inspection of winter conditions forecast at airports information
Winter weather conditions forecast is available for European airports and is verified to be consistent for Luleå/Sweden airport.

7: Inspection of MET information forecast to support 4D trajectories

The MET information is provided by Met Office and Météo-France and is based on their probabilistic prediction systems over their meso-scale domains. The provided MET information is not consolidated as it is in the nature of ensembles to determine varieties in forecasts to determine different options. Each provided ensemble member MET information is consistent per se.

8: Inspection of MET information forecast for network capacity reductions due to weather across Europe

General verification results against thresholds are available for UK airports in the Met Office ensemble prediction system domain, but no verification was done with the other models or using a consistent approach over the larger European area.

#### 6.1.3.2.1 Unexpected Behaviours/Results

N/A

## 6.1.4 Conclusions and recommendations

### 6.1.4.1 Conclusions

The verification exercise was successful for all mature prototypes. The consistency of the Network MET prototypes is limited to the specified domains and to those prototypes that have been developed to a sufficiently mature state.

### 6.1.4.2 Recommendations

The domain should be extended to whole ECAC domain in the future.

# 6.2 Verification EXE-11.02.02-VP-NET1.0002 Report

## 6.2.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-NET1.0002, Use of latest science for MET information is an inspection of the processed data and techniques applied to consolidate and translate MET information for MET products provided by the Network MET prototypes. It is checked whether the requirement REQ-11.02.02-TS-NET1.9002 [7] is fulfilled.

## 6.2.2 Conduct of Verification Exercise

### 6.2.2.1 Verification Exercise Preparation

The MET capabilities developed within P11.02.02 applicable for the Network OUE and therefore part of the Network MET prototypes are used for this verification exercise. The addressed MET information is listed in the respective exercise procedure described in the Verification Plan [8]. There is no specific configuration necessary for conducting this exercise because the inspection is performed manually.

### 6.2.2.2 Verification Exercise execution

It will be evaluated if the MET products are produced on the basis of the latest science. This verification exercise is run eight times, once for each MET capability belonging to the Network MET prototypes.

Each verification execution is a manual inspection of the processed input data and method applied to compute consistent MET information. It is evaluated whether the techniques correspond to the latest knowledge of science available.

An actual detailed timing cannot be given for each verification run. The inspection of applied techniques was performed as soon as the first prototype was available, mostly between September 2014 and March 2015. The MET Prototypes have been in the late stage of their development since the initial Verification Report so no major structural changes that could affect the use of latest science have emerged. New inspection was therefore unnecessary.

1: Inspection of radar composite of 3D convection information

Radar scans from the French and UK radar network are ingested in the consolidation tool which produces 3D gridded multi radar reflectivity products. The radar used operationally by NMSs are the most advanced radar systems for meteorological needs and are replaced successively when enhanced measurements systems are developed. The computation of a three dimensional radar product based on two dimensional radar measurements is a very advanced technique based on the latest science.

2: Inspection of nowcasting of convection information

The convection nowcasting tools from Météo-France, Met Office and DWD use high quality measurements of weather radars, lightning detection systems and satellites as well as data from NWP systems which are enhanced continuously based on the latest science. Improving the performance of nowcasting tools is an ongoing development process by including the most advanced knowledge of science.

3: Inspection of super-ensemble mesoscale forecast of convection information

Ensemble weather prediction is an enhanced technique beyond deterministic NWP. The consolidated MET information ingests EPSs from Météo-France, Met Office and DWD, all of which are enhanced continuously based on the latest science. The method ensures a smooth transition without any unphysical discontinuity at the model domain boundaries, nor a loss of quality, thereby producing consistent high-resolution MET information over a large geographical area based on the latest state of the art.

4: Inspection of icing forecast information

The icing forecast products from Météo-France, Met Office and DWD are based on NWP systems which are enhanced continuously based on the latest science. The Pepe & Thomson [9] method is the chosen technique considering the latest knowledge of science to consolidate the forecasts of the contributing NMSs to reach a consistent icing forecast with the best performance possible.

5: Inspection of CAT forecast information

The CAT forecast products from Météo-France, Met Office and DWD are based on NWP systems which are enhanced continuously based on the latest science. The Pepe & Thomson [9] method is the chosen technique considering the latest knowledge of science to consolidate the forecasts of the contributing NMSs to reach a consistent CAT forecast with the best performance possible.

6: Inspection of winter conditions forecast at airports information

The winter weather condition forecast prototype ingests MET parameter from SMHI's or FMI's NWP systems which are both enhanced continuously based on the latest science. The performance of the FMI's friction algorithm is verified continuously for every new implemented module. The De-icing weather classes are predicted based on weather radar among others which are the most advanced radar systems for meteorological needs and are replaced successively when enhanced measurements systems are developed.

7: Inspection of MET information forecast for network capacity reductions due to weather across Europe

Initial developments on Net Work Capacity did demonstrate some potential when using the Met Offices ensemble system in the development of new scientific methodology. However as this was not developed fully this exercise is only partly fulfilled.

8: Inspection of MET information forecast to support 4D trajectories

This MET prototype ingests ensemble wind and temperature forecasts which is an enhanced technique beyond deterministic NWP. In parallel to the ongoing development process of NWPs the configuration of an ensemble prediction system (EPS) is modified accordingly to determine the most suitable and enhanced varieties in forecast.

#### 6.2.2.3 Deviation from the planned activities

There is no deviation from the planned activities, except that MET prototypes for the support of network capacity reduction prediction was not further developed so could not be fully used for verification.

### 6.2.3 Verification exercise Results

#### 6.2.3.1 Summary of Verification exercise Results

It is verified that Network MET prototypes provide MET information based on the latest science. Considering the current limited areas the requirement 11.02.02-TS-NET1.9002 has been verified successfully.

#### 6.2.3.2 Analysis of Verification Exercise Results

1: Inspection of radar composite of 3D convection information

The consolidated 3D radar information is based on the latest science.

2: Inspection of nowcasting of convection information

The consolidated nowcasting of convection information is based on the latest science.

3: Inspection of super-ensemble mesoscale forecast of convection information

The consolidated super-ensemble information for convection is based on the latest science.

4: Inspection of icing forecast information

The consolidated icing forecast information is based on the latest science.

5: Inspection of CAT forecast information

The consolidated CAT forecast information is based on the latest science.

6: Inspection of winter conditions forecast at airports information

The winter weather conditions forecast is based on the latest science.

7: Inspection of MET information forecast for network capacity reductions due to weather across Europe

The limited use of forecast data from the Met Office showed that network capacity planning could be possible over Europe, and as it is based on NWP model output the prototype would be based on the latest science.

8: Inspection of MET information forecast to support 4D trajectories

The 4D trajectory forecast information is based on the latest science for ensembles.

#### 6.2.3.2.1 Unexpected Behaviours/Results

N/A

### 6.2.4 Conclusions and recommendations

#### 6.2.4.1 Conclusions

The verification exercise was successful for all mature prototypes.

#### 6.2.4.2 Recommendations

The ongoing advancement of the Network MET prototypes is necessary to ensure they will always be based on the latest science, relying on high Research & Development capacity of the METSPs.

## 6.3 Verification EXE-11.02.02-VP-NET1.0003 Report

### 6.3.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-NET1.0003, MET product properties, is an inspection of the properties of consolidated and translated MET information. The Network MET prototypes are addressed in this verification exercise. It is checked whether the requirements addressing properties of MET information are met or not.

## 6.3.2 Conduct of Verification Exercise

### 6.3.2.1 Verification Exercise Preparation

The MET capabilities developed within P11.02.02 applicable for the Network OUE and therefore part of the Network MET prototypes are used for this verification exercise. The addressed MET information is listed in the respective exercise procedure described in the Verification Plan [8]. There is no specific configuration necessary for conducting this exercise because the inspection is performed manually.

### 6.3.2.2 Verification Exercise execution

The properties of the consolidated MET information will be evaluated. This verification exercise is run ten times, once for each MET capability belonging to the Network MET prototypes.

Each verification execution is a manual inspection of the metadata of the MET information. It is evaluated if the MET properties of the available consolidated and translated MET information met the features specified in the TS requirements.

An actual detailed timing cannot be given for each verification run. The MET properties inspection is performed at the late stage of prototype development, mostly between October 2015 and December 2015.

1: Inspection of the properties of 3D radar composite convection information

Geographical coverage: two areas of 400km x 400km one centred on London Heathrow airport and the other on Paris Charles-de-Gaulle airport

Horizontal resolution: 1km²

Vertical resolution: 500m (up to 12 km)

Temporal resolution: none, (observation)

Forecast horizon: none (observation)

Update rate: 5 minutes

2: Inspection of properties of the nowcasting of convection information

Geographical coverage: Germany, France and United Kingdom including Ireland

Horizontal resolution: ~ 1.1km x 1.1km

Vertical resolution: 2D, plus cloud top height

Temporal resolution: 15 minutes

Forecast horizon: T+1 hour

Update rate: 15 minutes

3: Inspection of the properties of the super-ensemble mesoscale forecast of convection information

Geographical coverage: Germany, France, extending domain covering United Kingdom including Ireland under development

Horizontal resolution: 2.2 x 2.2 km (0.027° x 0.022° grid)

Vertical resolution: specific vertical pressure levels

Temporal resolution: 1 hour

Forecast horizon: T+24 hours

Update rate: 24 hours

4: Inspection of the properties of icing forecast information

Geographical coverage: Europe

Horizontal resolution: approx. 5 x 5 km

Vertical resolution: 1000hPa, 950hPa, 925hPa, 900hPa, 850hPa, 800hPa and four more levels above

Temporal resolution: 3 hours
Forecast horizon: T+24 hours
Update rate: 6 hours

5: Inspection of CAT forecast information
Geographical coverage: Europe
Horizontal resolution: 0.1° x 0.1° grid (approx. 10 x 10 km)
Vertical resolution: 400hPa, 300hPa, 250hPa, 200hPa, 150hPa
Temporal resolution: 3 hours
Forecast horizon: T+30 hours
Update rate: 6 hours

6: Inspection of the properties of winter conditions forecast information
Harmonized MET airport parameter, e.g. air temperature, runway surface temperature, relative humidity, dew point temperature, precipitation are available with the following properties:
Geographical coverage: Helsinki and Stockholm (specific TMAs in FIN-SWE-NOR territory)
Horizontal resolution: 500m²
Vertical resolution: none (2D information)
Temporal resolution: 15 minutes
Forecast horizon: T+3 hours
Update rate: 1 hour

7: Inspection of the properties of MET information forecast for network capacity reductions due to weather across Europe
Geographical coverage: European airports (currently limited to UK airports and one case study using Paris Charles de Gaulle)
Horizontal resolution: Site-specific data
Vertical resolution: Surface conditions
Temporal resolution: 1 hourly
Forecast horizon: T+30 hours
Update rate: 12 hours

8: Inspection of the properties of MET information forecast to support 4D trajectories
Geographical coverage: Global
Horizontal resolution: 0.5*0.5
Vertical resolution: u wind, v wind, Temperature at [100, 150, 180, 200, 230, 250, 270, 300, 350, 400, 500, 600, 700, 850]hPa
Temporal resolution: 3 hourly
Forecast horizon: T+[ 0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48]
Update rate: 6 hours

9: Inspection of the properties of MODE-S EHS derived MET information
Mode-S EHS observations (wind speed, wind direction, temperature)
Quality: wind speed: 1,5m/s;
wind direction: 10-15°
temperature: 1-2K
Formats: BUFR, WMO7, NetCDF, ASCII

Time: since 1st January 2013 till present
Geographic coverage: MUAC air space
Temporal resolution: 15 minutes batches
Latency: approx. 10 min.

Case studies.
With HIRLAM:
Semi operational since 2014
Geographical coverage: France, Germany, United Kingdom and South of Norway
SW corner: 50.5°N and 1.5°E
Horizontal resolution: 0.1° x 0.1° grid (approx. 10 x 10 km)
Vertical resolution: 40 levels
Temporal resolution: 10min up to 6 hours, afterwards 1hour
Forecast horizon: 24hours (improvements up to 15 hours)
Update rate: 1 hour

With HARMONIE:
Case study covers period from 18th November to 31st December 2013
Geographical coverage: from NE corner 48,5°N / 8,2°E to 58,8°N / 22,2°E
Horizontal resolution: 2,5km x 2,5km
Vertical resolution: 65 levels
Temporal resolution: 1 hour
Forecast horizon: 24hours (improvements up to 6 hours)
Update rate: 3 hours

10: Inspection of the properties of E-AMDAR MET information
Case study covers period from 1st March to 31st May 2011
Exemplary number of AMDAR humidity measurements: 15,390 by 40 aircraft (30th March)
Geographical coverage: Eastern US, 100°W / 29°N to 70°W/ 43°N
Horizontal resolution: 7km x 7km
Vertical resolution: 40 layers, resolution decreasing by height
Temporal resolution: 6 hourly
Forecast horizon: T+78h for 00 and 12 UTC, T+48h for 06 and 18 UTC
Update rate: 6 hours

#### 6.3.2.3 Deviation from the planned activities

N/A

### 6.3.3 Verification exercise Results

#### 6.3.3.1 Summary of Verification exercise Results

It is verified that Network MET prototypes provide MET information fulfilling the MET information properties requirements depending on the kind of MET parameter. The geographical coverage expands from single TMAs to consistent MET information covering Europe. The horizontal resolution

varies between several hundreds of meters to a few kilometres. The vertical resolution of the 3D MET information ranges from 100m to only a few representative, specific pressure levels. The temporal resolution differs between 15 minutes for very short term forecast and 3 hours for short term forecasts. The forecast horizon lies between 1 hour and 24 hours. The Network MET prototypes based on observations have an update rate of 5 minutes while nowcasting tools in small areas are updated every 15 minutes. The ensemble forecast has the longest update rate with 24 hours.

#### 6.3.3.2 Analysis of Verification Exercise Results

The consolidated and translated MET information of the Network MET prototypes fulfil all requirements concerning the involved kind of MET parameter. The Network MET prototypes developed in SESAR WP11.2 do not cover the medium term planning phase beyond 48 hours though some could be extended by degrading the temporal resolution and/or the update rate.

The verification exercise has not been performed yet for MET information outside the consolidated MET information as WP11.2 development is focussed on this kind of MET information. The MET parameters that have not been verified successfully are mountain waves, dust and sand storm information which are not available for probabilistic forecasts. The X1.6 requirements are fulfilled partially as the low visibility is predicted within this prototype for winter resp. snowfall conditions.

##### 6.3.3.2.1 Unexpected Behaviours/Results

The consolidated MET information developed for the support of network capacity reduction decisions was not further developed so could not be used for verification.

### 6.3.4 Conclusions and recommendations

#### 6.3.4.1 Conclusions

The requirements concerning MET parameter properties addressed in the Technical Specification [7] have been verified successfully for consolidated and translated MET information. The verification exercise was successful for all mature prototypes.

#### 6.3.4.2 Recommendations

The verification exercise focuses on the consolidated Network MET prototypes and could be extended to the general available Network MET information from NMS's to verify the kind of MET information that are not included in the consolidated MET information.

## 6.4 Verification EXE-11.02.02-VP-NET1.0004 Report

### 6.4.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-NET1.0004, Accuracy of MET products is tested for each MET capability involved in the consolidation and translation development process. The output data of consolidated and translated MET information is verified. The Network MET prototypes are addressed in this verification exercise. It is checked whether the requirements concerning the accuracy of MET information are met by the consolidated and translated MET information or not.

### 6.4.2 Conduct of Verification Exercise

#### 6.4.2.1 Verification Exercise Preparation

The MET capabilities developed within P11.02.02 applicable for the Network OUE and therefore part of the Network MET prototypes are used for this verification exercise. The addressed MET information is listed in the respective exercise procedure described in the Verification Plan [8]*[6]*. There is no specific configuration necessary for conducting this exercise because the inspection is performed manually.

### 6.4.2.2 Verification Exercise execution

It will be evaluated if the accuracy of consolidated and translated MET information meets the specified requirements. This verification exercise is run eight times, once for each MET capability belonging to the Network MET prototypes.

Each verification execution is a manual test of the processed output data of the consolidated MET information. An actual detailed timing cannot be given for each verification run. The accuracy test is performed after the first prototype was available and repeated for each development status to ensure to apply the most appropriate consolidation method to achieve the best performance result. Most work was conducted between September 2014 and March 2015 and continued at the late or final stage of Met capability development between October 2015 and December 2015.

The current available requirements only request an accuracy that at least meets that required by ICAO Annex 3 (REQ-11.02.02-TS-NET1.2201, REQ-11.02.02-TS-NET2.0001).

Detailed list of all respective MET prototypes (X1.1 – X1.6 + X1.8, X2.1+X2.2)

1: Inspection of the properties of 3D radar composite convection information

Parameter: a high resolution 3D radar mosaic and 2D radar products indicative of convective storm severity: 45 dBZ echo tops (TOP45), Vertically Integrated Liquid (VIL), maximum reflectivity (ZMAX) and height of maximum reflectivity HZmax

Accuracy: The root mean square error (RMSE) is around 2 +/-1dB below 10km and increases rapidly above. The bias ranges from 0dB at 0.5km to 5 dB at 12km. An increasing bias for the schemes with height also means with distance from the radars. The UKM bias tends to be more homogeneous with height than the FRM one. The UKM methods overestimates the reflectivity by 2dB above 2km while FRM methods starts by underestimating the reflectivity by up to 2dB below 2km and overestimates the reflectivity by up to 3 dB above 4km. Both schemes largely overestimate the reflectivity above 10 km.

2: Inspection of properties of the Nowcasting of convection information

Parameter: Convection severity class

Accuracy: The verification results of the national tools are good and very similar in comparison to each other. The absolute values are quite low for probability of detection and high for the false alarm rates due to the very strict verification method. The British input to the consolidated Nowcasting of convection product shows strong over warning (highest false alarm rate). Therefore its usage has been limited to the British domain. In the overlap regions with the two other model domains the highest warning level of the German and French domain has been used for the consolidated product to ensure safety.

3: Inspection of the properties of the super-ensemble mesoscale forecast of convection information

Parameter: 2m-temperature, 2m-relative humidity, 10m-wind speed, 6h- precipitation accumulation

Accuracy: The super-ensemble concept appears to be feasible. The meteorological quality of the super-ensemble is generally slightly superior to all national systems in the overlap regions. In non-overlap regions, the super-ensemble is equivalent to using the local national ensemble. The national ensembles have varying forecast performance, but the super-ensemble tends to either beat all of them or be similar to the best. It means that it can be a bad idea to ditch a model because it is not as good as another: model diversity brings substantial user value (at least when all considered models have comparable performance, such as here).

4: Inspection of the properties of icing forecast information

Parameter: Consolidated icing forecast parameter (intensity)

Accuracy: All national models perform nearly identical in the case of icing yes/no. The consolidated icing product shows the highest accuracy by combining all three models in a deterministic poor-man ensemble: the ratio of probability of detection to false alarm rate is then the highest.

5: Inspection of CAT forecast information

Parameter: Consolidated turbulence forecast parameter (intensity)

Accuracy: The consolidated turbulence product for Europe combines the national models which support the highest accuracy score in the verification exercise. The same method applies on the model for the European + Eastern North Atlantic domain shows same results: a combination of single national models increases in a poor-man ensemble of deterministic forecasts the accuracy score of the consolidated product.

6: Inspection of the properties of winter conditions forecast information

Parameter: Harmonized MET airport parameter, e.g. air temperature, runway surface temperature, relative humidity, dew point temperature, precipitation

Accuracy: Friction is not an easy parameter to verify. Maintenance operations (snow ploughing and especially chemical spreading) have a very strong impact for the runaways. Runaways may be clear of ice and snow when model assumes that there is still ice and snow remaining. However, the verification results, probability of detection and false alarm rate are good (approx. 0,85 and 0.40). In the maintenance point of view it is typically more important to overestimate than underestimate the expected slipperiness. It has been noticed that the used numerical model underestimates the friction in case of snow on the surface.

8: Inspection of the properties of MET information forecast to support 4D trajectories

Parameter: u wind, v wind components and temperature for various height levels

Accuracy: It has been shown that all ensemble prediction systems considered (ECMWF, MOGEPS and PEARP) are capable of capturing specific nominal weather events observed from AMDAR measurements 36 hours before take-off time, with a ROC curve score ranging from 0.82 to 0.93 amongst the models at a lead time of +36 hours.. It has also been shown that the Met Performance can be further improved by combining the different ensemble models to form a multi-model ensemble.

9: Inspection of the properties of MODE-S EHS derived MET information

Parameter: Mode-S EHS observations, model parameter (esp. wind, temperature)

Accuracy: The findings of assimilation of Mode-S EHS are that the HARMONIE model with Mode-S EHS scores better on short-range forecast (up to 6 hours into the forecast) when verified against independent wind and temperature observations. Improvement in wind speed for T+6h in 875 hPa 1%, in 400 hPa 2%.

10: Inspection of the properties of E-AMDAR MET information

Parameter: Model forecast of icing conditions based on E-AMDAR observations

Accuracy: The case study has shown that the probability of detection for icing conditions increases by including AMDAR humidity measurements in the data assimilation of numerical weather prediction systems. The probability of detection decreases which means that the no icing conditions have been predicted less often correct, the false alarm rate increases slightly.

#### 6.4.2.3 Deviation from the planned activities

There is no deviation from the planned activities, except that MET prototypes for the support of network capacity reduction prediction was not further developed so could not be used for verification.

### 6.4.3 Verification exercise Results

#### 6.4.3.1 Summary of Verification exercise Results

It is verified that Network MET prototypes fulfil the accuracy requirements.

#### 6.4.3.2 Analysis of Verification Exercise Results

As the NMS's are bound to follow ICAO Annex 3 standards, requirement REQ-11.02.02-TS-NET1.2001 and REQ-11.02.02-TS-NET1.3001 are fulfilled naturally by any METSP involved in WP11.02.

##### 6.4.3.2.1 Unexpected Behaviours/Results

N/A

### 6.4.4 Conclusions and recommendations

#### 6.4.4.1 Conclusions

The requirements concerning MET information addressed in the TS [7] have been verified successfully for consolidated and translated MET information. The verification exercise was successful for all mature MET prototypes. The two requirements are fulfilled by all NMSs for any MET information provided for aviation purposes.

#### 6.4.4.2 Recommendations

The accuracy requirements need to be specified in more detail and extended to further parameters of MET information to represent and show the accuracy and other performance features of the consolidated and translated MET information.

## 6.5 Verification EXE-11.02.02-VP-NET1.0005 Report

### 6.5.1 Verification Exercise Scope

EXE-11.02.02-VP-NET1.0005, MET product production is an inspection of the involved NMS's MET product portfolio of the availability of deterministic and probabilistic forecasts and observations of meteorological parameters at the surface and aloft. The availabilities of Network MET prototypes are also addressed in this verification exercise. It is checked what MET information is produced to which area/location.

### 6.5.2 Conduct of Verification Exercise

#### 6.5.2.1 Verification Exercise Preparation

A questionnaire was circulated to find out what MET information is currently available in each actively involved stakeholder's NMS (MO, DWD, Météo-France, FMI, Met Norway, KNMI). The questionnaire includes the requirements from the 11.02.02-D15, TS, Network OUE [7].

The questionnaire was divided into 11 parts:

I Availability of ICAO products

II Performance of ICAO products

III Availability of MET parameters (airport, surface)

IV Availability of MET parameters aloft (nominal weather)

V Availability of MET parameters aloft (significant weather)

VI MET Expert activity => out of scope as it addresses operations needs

VII MET parameter details (accuracy, update rate, granularity...)

VII MET aloft parameter details (accuracy, update rate, granularity...)

IX MET nominal weather parameter details (accuracy, update rate, granularity...)

X MET significant weather parameter details (accuracy, update rate, granularity...)

XI Safety issues

Parts I, IV and V are the ones concerning the MET information availability so they were addressed in this verification exercise.

### 6.5.2.2 Verification Exercise execution

First, it will be evaluated if Network MET prototypes, including consolidated and translated MET information, are currently available. This verification exercise is run eight times, once for each MET capability belonging to the Network MET prototypes.

Secondly, it will be evaluated what MET products are currently produced by each involved stakeholder's NMS. This verification exercise was run only once.

The verification runs for Network MET prototypes have been conducted between September 2014 and March 2015. The verification runs were completed with new requirements from the 11.02.02-D15, Updated TS, Network OUE [7] between October 2015 and December 2015.

The survey to determine the involved NMS's product portfolio for production of MET information was conducted between March 2nd and March 30th 2015. The survey was completed with new requirements from the updated TS, Network OUE [7] in December 2015. The answers were analysed by the Network OUE leader to determine if all availability requirements are currently fulfilled.

Detailed list of all respective MET prototypes (X1.1 – X1.8, X2.1 +X2.2)

| Ref | Prototype Name | Availability |
|---|---|---|
| X1.1 | Radar composite for 3D convection | Available (Met Office, Météo-France) |
| X1.2 | Nowcasting of Convection | Available (DWD) |
| X1.3 | Super-ensemble mesoscale forecast of convection | Available (Météo-France) |
| X1.4 | Forecast of Icing | Available (DWD) |
| X1.5 | Forecast of CAT | Available (Met Office) |
| X1.6 | Winter weather | Available (FMI, SMHI) |
| X1.7 | Network capacity | Not available (Met Office) |
| X1.8 | 4D Trajectory | Partly available (Met Office, Météo-France) |
| X2.1 | Mode-S EHS observations of wind/temp and enhanced NWP | Available (KNMI) |
| X2.2 | E-AMDAR | Available (DWD) |

### 6.5.2.3 Deviation from the planned activities

N/A

## 6.5.3 Verification exercise Results

### 6.5.3.1 Summary of Verification exercise Results

It is verified that all the MET information included in the Network MET prototypes are available with specific properties depending on the kind of MET parameter.

It is concluded that at the moment not all required MET parameters expressed in 11.02.02-D15, TS, Network OUE [7] are available from the involved NMS's.

### 6.5.3.2 Analysis of Verification Exercise Results

*Network MET Prototypes inspection:*

1: Inspection of availability of radar composite of 3D convection information:

Consistent 3D radar information is available in two domains centred on London Heathrow and Paris Charles-de-Gaulle airports.

2: Inspection of availability of consolidated nowcasting of convection information

Consistent convection nowcasting information is available covering Germany, France and United Kingdom including Ireland.

3: Inspection of availability of super-ensemble mesoscale forecast of convection information

Consistent super-ensemble information for convection is available covering the ensemble prediction system domains provided by Météo-France, Met Office and DWD.

4: Inspection of availability of consolidated icing forecast information

Consistent icing forecast information is available covering Europe.

5: Inspection of availability of consolidated CAT forecast information

Consistent CAT information is available covering Europe.

6: Inspection of availability of harmonised winter conditions forecast at airports information

Winter weather conditions forecast is available for Helsinki and Stockholm airports.

7: Inspection of availability of MET information forecast for network capacity reductions due to weather across Europe

MET information to support Network capacity was not developed completely to take to verification.

8: Inspection of availability of MET information forecast to support 4D trajectories

MET information to support 4D trajectories is available to cover European trajectories.

9. MODE-S EHS data and MODE-S EHS enhanced forecasts

MODE-S EHS observations and enhanced forecasts are available for MUAC airspace and a larger model domain covering this airspace.

10. E-AMDAR

Case study to show the benefit for MET forecast products by including on board measurements of humidity data in the NWP models, no prototype for validation produced.

*General MET information inspection by questionnaire:*

The inspection of involved NMS's product portfolio by questionnaire revealed that the availability of ICAO products (part I of questionnaire) is compliant. All observations and deterministic forecasts of nominal and significant meteorological parameters are made available by the involved NMS's. However, all probabilistic forecasts of MET aloft parameters are not available at the moment and all but convective activity information and probability of thunderstorm are missing from either ensemble or probabilistic forecasts from the NMS's product portfolio.

#### 6.5.3.2.1 Unexpected Behaviours/Results

The consolidated and translated MET information developed for the support of network capacity reduction decisions was not further developed so could not be used for verification.

### 6.5.4 Conclusions and recommendations

#### 6.5.4.1 Conclusions

The verification exercise was successful for all mature prototypes. The MET products of the Network MET prototypes are available as requested in the specified areas.

#### 6.5.4.2 Recommendations

The inspection of the NMS's product portfolio could be extended to further EUMETNET EIG members across Europe (there are 31 European National Meteorological and Hydrological Services represented by EUMETNET EIG).

## 6.6 Verification EXE-11.02.02-VP-NET1.0007 Report

### 6.6.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-NET1.0007, MET data reliability was conducted as part of the EXE-11.02.02-VP-4DWC.0007 described in Updated Verification Plan: 4DWxCube – MET-GATE [11]. The results of the verification are published in Final Verification Report: 4DWxCube – MET-GATE [12].

### 6.6.2 Conduct of Verification Exercise

#### 6.6.2.1 Verification Exercise Preparation

N/A

#### 6.6.2.2 Verification Exercise execution

The preferred verification methods were inspection and design review. The verified requirements include aspects of data reliability and technical safety.

#### 6.6.2.3 Deviation from the planned activities

N/A: There is no deviation from the planned activities.

### 6.6.3 Verification exercise Results

#### 6.6.3.1 Summary of Verification exercise Results

It is verified that MET products are reliable and immediate access to incoming data is successful. The reliability requirements originated from TS and IRS are satisfied by the MET-GATE.

#### 6.6.3.2 Analysis of Verification Exercise Results

The aspect of the immediate availability of incoming data could be verified in this group related to the MET-GATE verification test component 'reliabComponent'. It could be verified successfully that incoming data is made available to requesting HTTP clients by the MET-GATE Prototype instance shortly afterwards (delay of few seconds due to internal processing of the non-operational system).
The MET products provided by certified MET Service provider could be accessed uncorrupted and are therefore classified as safe and reliable.

#### 6.6.3.2.1 Unexpected Behaviours/Results

N/A

## 6.6.4 Conclusions and recommendations

### 6.6.4.1 Conclusions

The verification exercise was successful for the set of verification objectives which could be a priori verify at all. The index mechanism was only analysed with regards to its implementation. Bulk tests confirming also its suitability in high-performance cases were not yet implemented.

The verification exercise was successful by accessing reliable MET information immediate on demand.

### 6.6.4.2 Recommendations

N/A

# 7 References

## 7.1 Applicable Documents

**[1]** Template Toolbox 03.00.00
https://extranet.sesarju.eu/Programme%20Library/SESAR%20Template%20Toolbox.dot

**[2]** Requirements and V&V Guidelines 03.00.00
https://extranet.sesarju.eu/Programme%20Library/Requirements%20and%20VV%20Guidelines.doc

**[3]** Templates and Toolbox User Manual 03.00.00
https://extranet.sesarju.eu/Programme%20Library/Templates%20and%20Toolbox%20User%20Manual.doc

**[4]** European Operational Concept Validation Methodology (E-OCVM) - 3.0 [February 2010]

**[5]** EUROCONTROL ATM Lexicon
https://extranet.eurocontrol.int/http://atmlexicon.eurocontrol.int/en/index.php/SESAR

## 7.2 Reference Documents

The following documents provide input/guidance/further information/other:

**[6]** Requirements for MET Information (11.02.01), “MET Technical Architecture Description (TAD)”, 11.02.01 – D31, Ed. 00.02.00, October 2015

**[7]** MET Information Systems Development Verification & Validation (11.02.02), “Updated Technical Specification – 4DWxCube Network MET prototypes”, 11.02.02-D15, Ed. 00.01.00, October 2015

**[8]** MET Information Systems Development Verification & Validation (11.02.02), “Updated Verification Plan – 4DWxCubes – Network prototypes”, 11.02.02-D20, Ed 00.01.00, October 2015

**[9]** Pepe, M.S. and Thompson, M.L., 2000, Combining diagnostic test results to increase accuracy, Biostatistics 1,2, pp. 123 – 140

**[10]** ICAO Annex 3

**[11]** MET Information Systems Development Verification & Validation (11.02.02), “Updated Verification Plan: 4DWxCube – MET-GATE”, 11.02.02-D29, Ed 00.01.00, October 2015

**[12]** MET Information Systems Development Verification & Validation (11.02.02), “Final Verification Report: 4DWxCube – MET-GATE”, 11.02.02-D30, Ed 00.01.00, February 2016

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