



Final Verification Report: 4DWxCube – Sub-regional MET prototypes

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Abstract

This document describes the verification exercise results of the Sub-regional Meteorological (MET) prototypes of the MET Domain System "4DWxCube" (11.02.01-D31) and it is focus on the Sub-regional operational user environment. It follows the planned verification exercises described in 11.02.02-D18 (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 Sub-regional MET prototypes developed in SESAR 1 project.

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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 Sub-regional Meteorological (MET) prototypes of the MET Domain System “4DWxCube”. It is focused on the Sub-regional 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 Sub-regional 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.

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1 Introduction

1.1 Purpose of the document

This document provides the verification report of the Sub-regional MET of the MET Domain System (DS) “4DWxCube”. It describes the results of verification exercises defined in 11.02.02-D18, Verification Plan (VP) – Sub-regional OUE [8] and how they have been conducted. The verification activities are focussed on requirements of MET technical specifications expressed in 11.02.02-D14 [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 Sub-regional 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 Sub-regional operations and WP8 Information Management.

Any OFA contributing to the Sub-regional 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 03.03.01 and its contributing operational and technical projects;
- OFA 03.03.02 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	Proposed by WP11.02, 11.02.01 D31 TAD

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Term	Definition	Source
	SWIM compliant “MET-GATE”.	
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

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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-D14 [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-D18 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-TER1.0001: consistency of MET information
Leading organization	EUMETNET EIG
Verification exercise objectives	OBJ-11.02.02-VP-TER1.1001
Rationale	The purpose of this exercise is to verify that the Sub-regional MET prototypes produce consistent MET products.
Verification Technique	Inspection
Dependent Verification Exercises	-

Table 3: Objectives verified in EXE-11.02.02-VP-TER1.0001

Verification Exercise ID and Title	EXE-11.02.02-VP-TER1.0002: Use of latest science for MET information
Leading organization	EUMETNET EIG
Verification exercise objectives	OBJ-11.02.02-VP-TER1.1002
Rationale	The purpose of this exercise is to verify that the Sub-regional 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-TER1.0002

Verification Exercise ID and Title	EXE-11.02.02-VP-TER1.0003: MET parameter properties
Leading organization	EUMETNET EIG
Verification exercise objectives	OBJ-11.02.02-VP-TER1.1007
Rationale	The purpose of this exercise is to verify that the Sub-regional 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-TER1.0003

Verification Exercise ID and Title	EXE-11.02.02-VP-TER1.0004: MET information accuracy
Leading organization	EUMETNET EIG
Verification exercise objectives	OBJ-11.02.02-VP-TER1.1008
Rationale	The purpose of this exercise is to verify that the Sub-regional MET prototypes produce high accuracy MET products.
Verification Technique	Test
Dependent Verification Exercises	-

Table 6: Objectives verified in EXE-11.02.02-VP-TER1.0004

Verification Exercise ID and Title	EXE-11.02.02-VP-TER1.0005: MET product production
Leading organization	EUMETNET EIG
Verification exercise objectives	OBJ-11.02.02-VP-TER1.1003 OBJ-11.02.02-VP-TER1.1004 OBJ-11.02.02-VP-TER1.1005
Rationale	The purpose of this exercise is to verify the production of the MET products from Sub-regional MET prototypes.
Verification Technique	Inspection
Dependent Verification Exercises	-

Table 7: Objectives verified in EXE-11.02.02-VP-TER1.0005

Verification Exercise ID and Title	EXE-11.02.02-VP-TER1.0007: MET data reliability
Leading organization	EUMETNET EIG
Verification exercise objectives	OBJ-11.02.02-VP-TER1.1009
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-TER1.0007

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-D14 Technical Specifications [7] and are expressed in detail in 11.02.02-D18 Verification Plan [8].

Verification objective ID	Verification objective title	Success criterion
OBJ-11.02.02-VP-TER1.1001	Inspection of consistency of MET information	MET information is consistent in the specified area.
OBJ-11.02.02-VP-TER1.1002	Inspection of the use of latest science in the MET prototypes	Latest science is used in the MET prototypes
OBJ-11.02.02-VP-TER1.1003	ICAO regulated MET information production inspection	ICAO regulated MET information is produced by the Regulatory MET prototype.
OBJ-11.02.02-VP-TER1.1004	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-TER1.1005	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-TER1.1007	MET products properties inspection	MET products fulfil the requirements expressed in TS 11.02.02-D14.
OBJ-11.02.02-VP-TER1.1008	MET products properties test	MET parameters fulfil the accuracy requirements expressed in TS 11.02.02-D14.
OBJ-11.02.02-VP-TER1.1009	MET data reliability test	MET data is reliable when provided by certified MET provider and access to data is successful.

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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 (VP) [8].

2.2.3 Verification Exercises List and Dependencies

The exercise EXE-11.02.02-VP-TER1.0007 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].

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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-TER1.0001	Inspection of consistency of MET information	01/10/2015	10/12/2015	01/12/2015	15/12/2015
EXE-11.02.02-VP-TER1.0002	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-TER1.0003	Inspection of MET parameter properties	01/10/2015	10/12/2015	01/12/2015	15/12/2015
EXE-11.02.02-VP-TER1.0004	Test of MET information accuracy	01/01/2014	10/12/2015	01/12/2015	15/12/2015
EXE-11.02.02-VP-TER1.0005	Inspection of MET product production	01/01/2014	10/12/2015	01/12/2015	15/12/2015
EXE-11.02.02-VP-TER1.0007	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.

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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-TER1.0001	OBJ-11.02.02-VP-TER1.1001	Verify by inspection the consistency of MET information	CRT-11.02.02-VP-TER1.1001	MET information is consistent in the specified area.	It is verified that Sub-regional MET prototypes provide consistent MET information in a specific geographic domain depending on the kind of MET information.	OK
EXE-11.02.02-VP-TER1.0002	OBJ-11.02.02-VP-TER1.1002	Verify by inspection the use of latest science in the available MET prototypes	CRT-11.02.02-VP-TER1.1002	Latest science is used in the MET prototypes	It is verified that Sub-regional MET prototypes provide MET information based on the latest science.	OK
EXE-11.02.02-VP-TER1.0003	OBJ-11.02.02-VP-TER1.1007	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-D14.	CRT-11.02.02-VP-TER1.1007	MET products fulfil the requirements expressed in TS 11.02.02-D14	It is verified that Sub-regional MET prototypes provide MET products fulfilling the MET product properties requirements, depending on the MET parameter.	OK
EXE-11.02.02-VP-TER1.0004	OBJ-11.02.02-VP-TER1.1008	Verify by test that the accuracy of MET information fulfil the requirements expressed in TS 11.02.02-D14.	CRT-11.02.02-VP-TER1.1008	MET products fulfil the accuracy requirements expressed in TS 11.02.02-D14	It is verified that the Sub-regional MET prototypes provide MET products fulfilling the MET product accuracy requirements	OK
EXE-11.02.02-VP-TER1.0005	OBJ-11.02.02-VP-TER1.1003	Verify by inspection of the production of MET products by the Regulatory	CRT-11.02.02-VP-TER1.1003	ICAO regulated MET information is produced by the Regulatory MET prototype.	It is verified that ICAO regulated MET information is	OK

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Verification Exercise ID	Verification Objective ID	Verification Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Verification Objective Analysis Status
		MET prototype.			produced by the Regulatory MET prototype.	
EXE-11.02.02-VP-TER1.0005	OBJ-11.02.02-VP-TER1.1004	Verify by inspection the production of MET products by the Nominal MET prototype.	CRT-11.02.02-VP-TER1.1004	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-TER1.0005	OBJ-11.02.02-VP-TER1.1005	Verify by inspection the production of MET products by the Significant MET prototype.	CRT-11.02.02-VP-TER1.1005	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.	OK
EXE-11.02.02-VP-TER1.0007	OBJ-11.02.02-VP-TER1.1009	Verify by test that the MET information is reliable.	CRT-11.02.02-VP-TER1.1009	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-TER1.0001, EXE-11.02.02-VP-TER1.0002, EXE-11.02.02-VP-TER1.0003, EXE-11.02.02-VP-TER1.0004, EXE-11.02.02-VP-TER1.0005 and EXE-11.02.02-VP-TER1.0007 are verified 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-D14 TS [7] and their verification results.

Identifier	Description	Verification Method	Verification Exercise	Verification result
REQ-11.02.02-TS-TER2.0001	The Regulatory MET prototype shall produce the following common <ul style="list-style-type: none"> - SIGMET - AIRMET - area forecasts for low level flights - METAR - TREND - SPECI - TAF - VAA - TCA - Radioactive material as SIGMET - meteorological satellite images - ground-based radar images products according to ICAO Annex 3 templates (contents and if not otherwise specified accuracy) and ICAO Doc 7754 (issue time/update rate).	Inspection	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.1101	The Nominal MET prototype shall provide observation products for <ul style="list-style-type: none"> - wind speed aloft - wind direction aloft - temperature aloft - air pressure (QNH) with instantaneous availability / update rate of 10 minutes (wind).	Inspection	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.1102	The X2.1 MET prototype shall produce observation products for <ul style="list-style-type: none"> - wind speed aloft - wind direction aloft - headwind aloft - crosswind aloft - temperature 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-TER1.0003	Fulfilled
REQ-11.02.02-TS-TER2.1201	The Nominal MET prototype shall provide deterministic forecast products for <ul style="list-style-type: none"> - wind speed aloft - wind direction aloft - temperature aloft - air pressure (QNH) - dew point aloft - air density aloft 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.	Inspection	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0004 EXE-11.02.02-VP-TER1.0005	Fulfilled

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Identifier	Description	Verification Method	Verification Exercise	Verification result
REQ-11.02.02-TS-TER2.1202	The Nominal MET prototype (X2.1) shall produce forecast products for <ul style="list-style-type: none"> - wind speed aloft - wind direction aloft - headwind aloft - crosswind aloft - temperature for an area of minimum 10 NM 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 NM and an update rate of 10 minutes.	Test	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.1301	The Nominal MET prototype shall produce probability forecast products on air pressure (QNH) with minimum time horizon as well as higher time resolution and update rate according to ICAO Annex 3 templates.	Inspection	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.1302	The X1.3 MET prototype shall produce a seamless prediction of ensemble forecast products for <ul style="list-style-type: none"> - 2m temperature - 2m relative humidity - 10m wind speed - 6hour precipitation accumulation in a high spatial and temporal resolution covering GER-FR-UK territory.	Test	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.1303	The X1.8 MET prototype shall produce ensemble forecast products for <ul style="list-style-type: none"> - wind speed aloft - wind direction aloft - temperature aloft probabilistic information in a high spatial and temporal resolution with a global coverage.	Test	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.2101	The Significant MET prototype shall produce observation products on <ul style="list-style-type: none"> - significant weather - convective activity - turbulence - icing - wind shear with higher spatial and temporal resolution than in ICAO Annex 3.	Inspection	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled

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Identifier	Description	Verification Method	Verification Exercise	Verification result
REQ-11.02.02-TS-TER2.2102	The Significant MET Prototype shall send on observed Information on observed significant weather conditions immediately after detection.	Test	EXE-11.02.02-VP-TER1.0007	Fulfilled
REQ-11.02.02-TS-TER2.2103	The X1.1 MET prototype shall produce observation products for - convective activity information - lightning information for an area of minimum 120NM around the airport with an update frequency according the received information.	Test	EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.2201	The Significant MET prototype shall produce deterministic products on significant weather with an accuracy at least as in and with higher spatial and time resolution than in ICAO Annex 3	Inspection	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0004	Fulfilled
REQ-11.02.02-TS-TER2.2202	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-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.2203	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-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.2204	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-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled

Identifier	Description	Verification Method	Verification Exercise	Verification result
REQ-11.02.02-TS-TER2.2301	The Significant MET prototype shall produce probabilistic products on - significant weather - turbulence - icing with accuracy at least as high as in and with higher spatial and time resolution than in ICAO Annex 3.	Inspection	EXE-11.02.02-VP-TER1.0003 EXE-11.02.02-VP-TER1.0004 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.2302	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-TER1.0003 EXE-11.02.02-VP-TER1.0005	Fulfilled
REQ-11.02.02-TS-TER2.9001	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-TER1.0001	Fulfilled
REQ-11.02.02-TS-TER2.9002	The MET prototypes shall produce MET products based on latest science in observation and forecasting techniques.	Review of design	EXE-11.02.02-VP-TER1.0002	Fulfilled
REQ-11.02.02-TS-TER2.9003	The MET prototypes shall produce reliable (not corrupted) MET products.	Inspection	EXE-11.02.02-VP-TER1.0007	Fulfilled
REQ-11.02.02-TS-TER2.9004	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-TER2.1001	The Nominal MET prototype shall produce individual - wind - temperature products with accuracy better than 10kt / 10° and combined error less than 15kt (it is assumed that 1kt error = 1°error).	Inspection	EXE-11.02.02-VP-TER1.0004	Fulfilled
REQ-11.02.02-TS-TER2.1002	The Nominal MET prototype shall use for MET observations aloft, the most accurate source (ground based observations, airborne observation or merge of ground based and airborne observations).	Inspection	EXE-11.02.02-VP-TER1.0004	Fulfilled

Identifier	Description	Verification Method	Verification Exercise	Verification result
REQ-11.02.02-TS-TER2.1003	The Nominal MET prototype shall produce observation and forecast products in an area - at least 100-120 NM around the airport - or for trajectories with higher spatial and temporal resolution than in ICAO Annex 3.	Review of Design	EXE-11.02.02-VP-TER1.0003	Fulfilled

Table 12: Sub-regional 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-TER2.9004 (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 be verified 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.

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 Sub-regional MET Prototypes has been verified successfully for limited geographical areas. The Sub-regional MET prototypes provide consolidated and translated MET information based on the latest science. The Sub-regional 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 Sub-regional 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 Sub-regional MET prototypes and made available by the involved METSPs. The same applies for deterministic and probabilistic forecasts.

5.2 Recommendations

The Sub-regional 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 Sub-regional MET prototypes is necessary to ensure they will always be based on the latest science. The verification exercises focus on the consolidated Sub-regional MET prototypes. Due to the few accuracy requirements and the specific consolidated and translated MET prototypes developed within this programme the accuracy has only been verified following those few requirements for the developed consolidated, translated MET prototypes.

The verification objectives have been verified successfully for all MET prototypes. The MET products are available in respect to the specified areas and can be provided to the users. The MET-GATE prototype is the technical system to give access to this MET information.

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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-TER1.0001	Yes
	EXE-11.02.02-VP-TER1.0002	Yes
	EXE-11.02.02-VP-TER1.0003	Yes
	EXE-11.02.02-VP-TER1.0004	Yes
	EXE-11.02.02-VP-TER1.0005	Yes
Nowcasting of convection	EXE-11.02.02-VP-TER1.0001	Yes
	EXE-11.02.02-VP-TER1.0002	Yes
	EXE-11.02.02-VP-TER1.0003	Yes
	EXE-11.02.02-VP-TER1.0004	Yes
	EXE-11.02.02-VP-TER1.0005	Yes
Super-ensemble mesoscale forecast of convection	EXE-11.02.02-VP-TER1.0001	Yes
	EXE-11.02.02-VP-TER1.0002	Yes
	EXE-11.02.02-VP-TER1.0003	Yes
	EXE-11.02.02-VP-TER1.0004	Yes
	EXE-11.02.02-VP-TER1.0005	Yes
Icing forecast	EXE-11.02.02-VP-TER1.0001	Yes
	EXE-11.02.02-VP-TER1.0002	Yes
	EXE-11.02.02-VP-TER1.0003	Yes
	EXE-11.02.02-VP-TER1.0004	Yes
	EXE-11.02.02-VP-TER1.0005	Yes
Turbulence forecast	EXE-11.02.02-VP-TER1.0001	Yes
	EXE-11.02.02-VP-TER1.0002	Yes
	EXE-11.02.02-VP-TER1.0003	Yes
	EXE-11.02.02-VP-TER1.0004	Yes
	EXE-11.02.02-VP-TER1.0005	Yes
MET support to 4D trajectory planning	EXE-11.02.02-VP-TER1.0001	Yes
	EXE-11.02.02-VP-TER1.0002	Yes
	EXE-11.02.02-VP-TER1.0003	Yes
	EXE-11.02.02-VP-TER1.0004	Yes
	EXE-11.02.02-VP-TER1.0005	Yes
MODE-S EHS derived MET information	EXE-11.02.02-VP-TER1.0003	Yes

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	EXE-11.02.02-VP-TER1.0005	Yes
E-AMDAR MET information	EXE-11.02.02-VP-TER1.0003	Yes
	EXE-11.02.02-VP-TER1.0005	Yes

Table 13: Verification of MET prototypes

The EXE-11.02.02-VP-TER1.0007 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-TER1.0001 Report

6.1.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-TER1.0001, 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 Sub-regional MET prototypes are addressed in this verification exercise. It is checked whether the requirement REQ-11.02.02-TS-TER1.9001 [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 Sub-regional operational user environment (OUE) and therefore part of the Sub-regional 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.

6.1.2.2 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 Sub-regional 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.

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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 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.

7: 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 Sub-regional 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-TER1.9001 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.

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5: Inspection of CAT information

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

6: 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.

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.

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 Sub-regional 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-TER1.0002 Report

6.2.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-TER1.0002, 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 Sub-regional MET prototypes. It is checked whether the requirement REQ-11.02.02-TS-TER1.9002 [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 Sub-regional OUE and therefore part of the Sub-regional 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.

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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 Sub-regional 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 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.

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7: 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 Sub-regional MET prototypes provide MET information based on the latest science. Considering the current limited areas the requirement 11.02.02-TS-TER1.9002 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 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.

7: 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

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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 Sub-regional 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-TER1.0003 Report

6.3.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-TER1.0003, MET product properties, is an inspection of the properties of consolidated and translated MET information. The Sub-regional 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 Sub-regional OUE and therefore part of the Sub-regional 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 Sub-regional 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

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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 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

7: 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

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Forecast horizon: T+[12 15 18 21 24 27 30 33 36 39 42 45 48]

Update rate: 6 hours

8: 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

9: 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

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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 Sub-regional 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 Sub-regional 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 Sub-regional MET prototypes fulfil all requirements concerning the involved kind of MET parameter. The Sub-regional MET prototypes 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.

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 Sub-regional MET prototypes and could be extended to the general available Sub-regional 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-TER1.0004 Report

6.4.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-TER1.0004, 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 Sub-regional 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.

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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 Sub-regional OUE and therefore part of the Sub-regional 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.

6.4.2.2 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 Sub-regional 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.

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

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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 runways. Runways 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 (7) 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 Sub-regional 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-TER1.1201, REQ-11.02.02-TS-TER1.2201 and REQ-11.02.02-TS-TER1.2301 are fulfilled naturally by any METSP involved in WP11.02. The REQ-11.02.02-TS-TER1.1001 and REQ-11.02.02-TS-TER1.1002 have also been verified successfully.

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-TER1.0005 Report

6.5.1 Verification Exercise Scope

EXE-11.02.02-VP-TER1.0005, 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 Sub-regional 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-D14, TS, Sub-regional OUE [7].

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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...)
- VIII 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 Sub-regional 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 Sub-regional 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 Sub-regional MET prototypes have been conducted between September 2014 and March 2015. The verification runs were completed with new requirements from the 11.02.02-D14, Updated TS, Sub-regional 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, Sub-regional OUE [7] in December 2015. The answers were analysed by the Sub-regional 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 (not sub-regional)	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)

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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 Sub-regional 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-D14, TS, Sub-regional OUE [7] are available from the involved NMS's.

6.5.3.2 Analysis of Verification Exercise Results

Sub-regional 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 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.

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

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

8. 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.

9. 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.

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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 Sub-regional 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-TER1.0007 Report

6.6.1 Verification Exercise Scope

The exercise EXE-11.02.02-VP-TER1.0007, 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.

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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 Sub-regional MET prototypes”, 11.02.02-D14, Ed. 00.01.00, October 2015
- [8] MET Information Systems Development Verification & Validation (11.02.02), “Updated Verification Plan – 4DWxCubes – Sub-regional prototypes”, 11.02.02-D18, 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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