W O R L D   M E T E O R O L O G I C A L   O R G A N I Z A T I O N
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ANNUAL JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA-PROCESSING AND FORECASTING SYSTEM (GDPFS) INCLUDING NUMERICAL WEATHER PREDICTION (NWP) RESEARCH ACTIVITIES FOR 2017

TABLE OF CONTENTS

Introduction

[National Contributions and/or Consortia]

1. Summary of highlights

- COMET designated as Regional Specialized Meteorological Centre (RSMC) for Limited Area Deterministic Numerical Weather Prediction and Limited Area Ensemble Numerical Weather Prediction (http://www.meteoam.it/international_activities)
- Increase of resolution of the deterministic and probabilistic operational NWP system.
- Initial migration towards IBL Visual Weather for the whole batch maps production and Civil Aviation weather warnings production and delivery.

2. Equipment in use at the Centre

- ***GTS management***:
  Message Switching System (MSS):
  - IBL Moving Weather
  - Computer type: cluster of 2 HP ProliantDL380g8
  - OS Red Hat Enterprise Linux 6.5
- ***WIS (WMO Information System):***
  DCPC (RTH function):
  - IBL Discover Weather
  - Computer type: cluster of 2 HP Proliant DL380g8
  - OS Red Hat Enterprise Linux 6.5
  - IBL Moving Weather bc/dr
  - Computer type: cluster of 2 Virtual Machines
  - OS Red Hat Enterprise Linux 6.5

  DCPC (Mediterranean Data Collection & Production Centre for Marine Meteorology and Oceanografy) and RSMC (Regional Specialized Meteorological Centre):
  - IBL Discover Weather
  - Computer type: cluster of 2 HP Proliant DL380g8
  - OS Red Hat Enterprise Linux 6.5

- ***Data collecting and processing system:***
  The data collecting and processing system consists of 2 main areas dedicated to perform specific tasks.

  The first one is being used for filtering, collecting and processing data for daily operational activity. A 12 member Linux cluster is being used for this task. It is composed of

- o 2 HP DL385G2 each with 2 processors (dual-core AMD Opteron 2218)
- o 4 HP DL380G5 each with 2 processors (dual-core Intel Xeon 5160)
- o 6 Virtual Machines each with 4vCPU (AMD Opteron Processors 6234) and 8Gb vMem on a VMware High Availability ESXi cluster

In addition:

- o Virtual Machine with 4vCPU and 16Gb vMem is being used on a VMware High Availability ESXi cluster.
- o Virtual Machine with 4vCPU and 8GB vMem is being used on a VMware High Availability ESXi cluster.

An additional Virtual Machine with 4vCPU and 16Gb vMem is being used on a VMware High Availability ESXi cluster.

The second one is being used for collecting weather data when they become aged for daily operational activity and are made available for climatological studies/requests. It's a High Availability 2 member cluster (fail-over) LAMP platform based, composed of

- o 2 HP DL585 G7 each with 2 processors (8-core AMD Opteron 2GHz)

with a 6 modular smart-array storage (each with 12 disk SATA 1 TB – 7200 RPM). The operating system in use is Red Hat Enterprise Linux Server release 6.3 (Santiago).

In addition, there are also 6 HP HPProliant DL140 - G3, 4 with 2 DualCore and 2 with 2 QuadCore Intel Xeon

Since October 2009 a non-convetional observations collecting system is in pre-operational mode. The focus is to extend the number of observations provided to the data assimilation system. The equipment in use is composed of

- o 1 HP Server with 2 Intel Xeon 5310 4 cores processors;

  The operating system in use is Suse SLE 10.3 and the database is mysql.

An operative G.I.S. system is hosted on

- o 2 HP Server with 2 Intel Xeon 5310 4 cores processors each;

Windows environment:

- o 3 Virtual Machine with 2 cores (AMD Opteron Processors 6234) and 8GB RAM. Role: web server
- o 2 Virtual Machines with 8 cores (AMD Opteron Processors 6234) and 32 GB RAM each. Role: Base maps caching an Geo Processing Server
- o 4 Virtual Machine with 8 cores (AMD Opteron Processors 6234) and 64 GB RAM each. Role: Map Server
- o 1 Virtual Machine with 4 cores (AMD Opteron Processors 6234) and 24 GB RAM. Role: DB Server

Linux environment:

- o 4 Virtual Machines with 8 cores and 32 GB RAM
- o 1 Virtual Machine with 2 core and 8 GB RAM

A Weather Prediction Editing System (WePES) supporting various warning activities is operational since November of 2015 and it is hosted on the Cloud System infrastructure (VMware High Availability ESXi cluster) as follow:

- 1 Virtual Machines with 8 cores (AMD Opteron Processors 6234) and 4 GB RAM.

There is a backup for WePES; it is hosted on a different Cloud System infrastructure (VMware High Availability ESXi cluster) as follow:

- 1 Virtual Machines with 8 cores (AMD) and 4 GB RAM.

A system to pre-process observation messages for their use in Numerical Weather Prediction (NWP), called SAPP (Scalable Acquisition and Pre-Processing) has been installed and configured for pre-operational use. The software has been developed by the European Centre for Medium-Range Weather Forecasts (ECMWF).

The functions of the SAPP processing chain are:

- Acquire observations from multiple sources
- Decode these formats (for example, BUFR, GRIB, HDF, netCDF, ASCII)
- Apply quality control algorithms to the process
- Convert to a consolidated format (BUFR) before use in data assimilation (DA)

The SAPP has been adapted to process also data from not-GTS observational networks in order to evaluate their quality for the operational use in the data assimilation system.

- ***GRIDDED data collecting system:***

The task is accomplished by a software application named GRI.D[2] (GRIB DISTRIBUTION). It works as a FRONT-END for GRIB format data file reception and as BACK-END for GRIB format data file processing and re-distribution to final users. The application is hosted on the Cloud System infrastructure as follow:

- 2 Virtual Machines with 24 cores (AMD Opteron Processors 6234) and 32 GB RAM each.

Planned improvement of GRI.D2 system that will be called WHIP2 (Weather High level Intermediate Post-processing). Some major new features will be:

- NetCDF elaboration.
- Derived fields calculation.
- Single point forecasts in ASCII format elaboration.

- ***High Performance Computing Resources:***

At the moment there are 2 High Performance Computing Facilities:

- HPC PORDOI
- HPC HAL

The first one, Pordoi, was released at the Italian Air Force Operational Centre for Meteorology (COMET, formerly managed by CNMCA, Italian Air Force National Centre for Meteorology and Climatology) for operations in December 2009. The computing facility is a 194 nodes Hewlett Packard Linux Cluster arranged in three different groups; the first group consists of 128 nodes each of them with two quad-core Intel Harpertown 3.16 GHz onboard. The amount of volatile memory for a single node in this case is 8 GB. The second group consists of 64 dual-processor nodes with the 2.6 GHz AMD Opteron and in this case the amount of volatile memory is 4 GB, The third group is made up by two control nodes in High Availability configuration assisting the whole set of 192 computing nodes. The overall peak performance of the Computing Facility is 12,6 Teraflops.

The second one, HAL, has been deployed since November 2015 and during the 2016 the ICT Support Squadron for Meteorology (G.S.I.M.) has been working to set up the new High Performance Computing Cluster (H.P.C.C.). It has became operational on June 2016.
HAL H.P.C.C. is composed by 76 DL380G9 computing nodes and 2 DL380G9 management nodes.
Each computing node has an innovative hybrid CPU-GPU unit that consists of:

- 2 CPU Intel E5-2680v3 2.5GHz with 12 cores (10 nodes with 2 CPU E5-2680 2.40GHz and 14 cores for socket);
- 2 GPU NVIDIA K80 with 24GB of dedicated RAM;
- 64GB RAM.

Nevertheless, it has been planned been planned a RAM upgrade: all computing nodes will be equipped with 128GB of RAM.
Each management node consists of 2 CPU Intel XEON 5450 3.0GHz Quad-Core with 64GB RAM. Management nodes are in High Availability configuration and they assist the whole set of computing nodes.
The overall peak performance of the RESIA H.P.C.C. is currently about 300 TFLOPS, but this value is going to rise when the RAM will be upgraded.
It must be observed that Italy is one of the first countries which is taking advantage of the hybrid CPU-GPU technology for the elaboration of meteorological models. The best thing that comes from this hybrid technology is that it is possible to obtain peak performances with low energy consumption.
Current activities are mainly devoted to the optimisation of EPS models.

- **Graphics and numerical post-elaboration resources:**
  12 odes cluster:

  - 2 nodes DL 385 G2, 4 cores AMD OPTERON 2218 2.6GHz (2 x 4 cores) and 8 GB RAM
  - 4 nodes DL 380 G5, 4 cores INTEL XEON 5160 3GHz (4x4 cores) and 8 GB RAM
  - 6 Virtual Machines each with 4vCPU (AMD Opteron Processors 6234) and 8Gb vMem on a VMware High Availability ESXi cluster

  Server for trajectories production with FLEXTRA software:

  - 1 Virtual Machine with 4vCPU and 16Gb VMem on a VMware High Availability ESXi cluster

3. Data and Products from GTS in use

Data received from GTS:

- AIREP
- AMDAR/ACAR
- BUOY
- PILOT

- SHIP
- SYNOP
- TEMP,TEMP-SHIP and 4D-TEMP
- PROFILER

BUFR from EUMETCAST network:

- AMSU-A/MHS from NOAA/METOP
- NPPATMS from NPP
- AMV from EUMETSAT
- wind scatterometer from METOP
- IASI retrievals

Local Area observations and MODE-S from private FTP server:

- GRIB from ECMWF : Global model, EPS model, Wave model
- GRIB from ECMWF : Boundary Condition

4. Forecasting system

The operational short-range numerical forecasting system is composed of :

- Ensemble Kalman Filter (EnKF) Data Assimilation System based on the COMET-LETKF algorithm and the High-resolution non-hydrostatic model COSMO integrated over the Mediterranean-European region with a resolution of 7km and 49 vertical levels (10 km, 45 vertical levels up to september 2017);
- High-resolution non-hydrostatic model COSMO-ME integrated over the Mediterranean-European region with a resolution of 5km and 45 vertical levels (7 km, 40 vertical levels up to end of may 2017);
- Very high-resolution non-hydrostatic model COSMO-IT integrated over the Italian region at 2.2km resolution (2.8 km up to November 2017).

Along with the standard LETKF analysis, a control state LETKF (deterministic) analysis is computed using the standard Kalman gain and a control forecast, instead of the background ensemble mean. COSMO-ME is initialised by the control state of the Italian Air Force Operational Centre for Meteorology–COMET data assimilation cycle and driven by IFS boundary conditions. COSMO-IT is nested into COSMO-ME.

4.1 System run schedule and forecast ranges

The schedule of the short range forecasting system, based on LETKF Analysis, is the following:

	0000 UTC	**0600 UTC**	**1200 UTC**	**1800 UTC**
Cut-off	**2h 30m**	**2h 30m**	**2h 30m**	**2h 30m**
LETKF analysis end	**03.20 UTC**	**09.20 UTC**	**15.20 UTC**	**21.20 UTC**

The high resolution forecasting system has the following schedule:

	0000 UTC	**0600 UTC**	**1200 UTC**	**1800 UTC**

COSMO-ME range	**72h**	**48h**	**72h**	**48h**
COSMO-ME output time step	**1h**	**1h**	**1h**	**1h**
COSMO-ME end	**04.20 UTC**	**10.20 UTC**	**16.20 UTC**	**22.20 UTC**

	0000 UTC	**0600 UTC**	**1200 UTC**	**1800 UTC**
COSMO-IT range	**48h**	**30h**	**48h**	**30h**
COSMO-IT output time step	**0.25h**	**0.25h**	**0.25h**	**0.25h**
COSMO-IT end	**05.00 UTC**	**10.40 UTC**	**17.00 UTC**	**22.40 UTC**

4.2 Medium range forecasting system (4-10 days)

4.2.1 Data assimilation, objective analysis and initialization

4.2.1.1 In operation

None

4.2.1.2 Research performed in this field

No research performed in this field

4.2.2 Model

4.2.2.1 In operation

The ECMWF O1280L137 operational deterministic model is being used at COMET and CNMCA. Surface and upper air fields of the 00Z and 12Z runs are routinely downloaded via RMDCN on 0.1° horizontally spaced mesh for surface fields and on a 0.5° horizontally spaced mesh for upper air fields. A bi-dimensional pictorial representation of such fields is being used for operational meteorological support worldwide within 90° N and 89°S. The same data are being used for text and pictorial representation for single site forecasts within the same area. All the upper air fields refer to pressure levels from 1000 HPa up to 10 HPa. The possibility to reduce the time step to 3 hours is being considered and applied if allowed by the available bandwidth.

4.2.2.2 Research performed in this field

None

4.2.3 Operationally available Numerical Weather Prediction (NWP) Products

The following field parameters are operationally available. Most of them are pictorially represented in the form of statically produced bidimensional lat-lon maps while some are published via G.I.S. services
Moreover the same parameters are also available for all forecasters by ecCharts, the operationally supported web based service to explore and visualise ECMWF graphical forecast products; it allows tailored products in own dash-board.

ECMWF O1280L137 deterministic atmospheric model from 00Z and 12Z runs:

Analysis products

Surface parameters:
1. Mean sea level pressure;
2. 10 meters wind;
3. 2 meters temperature;
4. 2 meters dew point.

Upper Air parameters:
1. Geopotential Height at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa,300 HPa;
2. Temperature at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa,300 HPa;
3. Vertical Velocity at 700 HPa;
4. Vorticity at 500 HPa;
5. Potential Vorticity at 300 HPa.

Forecast products

Surface parameters:
1. 6 hours integrated total and convective precipitation;
2. 12 hours integrated total and convective precipitation;
3. 2 meters air temperature;
4. 2 meters max air temperature in the last 6 hour period;
5. 2 meters min temperature in the last 6 hours period;
6. 2 meters dew point temperature;
7. Mean sea level pressure;
8. Surface Pressure;
9. Weather impacts on specific activities determined by threshold values set on meteorological impact parameters;
10. Vertical Velocity at 700 HPa;
11. 10 meters wind;
12. Total cloud cover, Low cloud cover, High cloud cover, Medium cloud cover;
13. 10 meters wind max gust;
14. Cloud base height;
15. Composite cloud;
16. 6h integrated total snow precipitation;

Upper air parameters:
1. Geopotential height at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa;
2. Temperature at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa;
3. Wind at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa;
4. Relative Humidity at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa;
5. Wet bulb potential temperature at 850 HPa;
6. Vorticity at 500 HPa;
7. Isoentropic potential vorticity IPV = 2 at 300 HPa;
8. Dynamic tropopause;
9. Freezing level;
10. Wind 200 hpa;

ECMWF WAM wave model from 00Z and 12Z runs:

Forecast Products:

1. Significant wave height;
2. Mean direction of significant wave height;
3. Mean period of significant wave height;

4. Sea state.

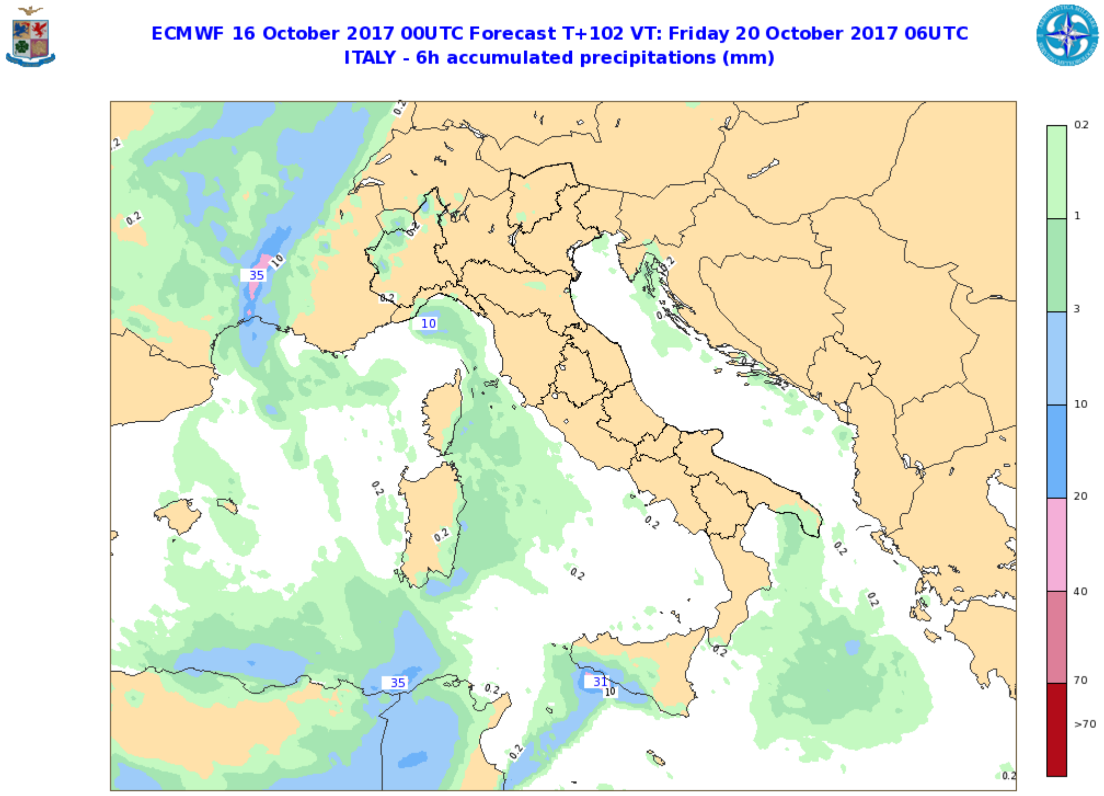


Fig.1 Example of pictorial representation of 6 hours time interval integrated precipitation from ECMWF operational model.

4.2.4 Operational techniques for application of NWP products (MOS, PPM, KF, Expert Systems, etc.)

4.2.4.1 In operation

None

4.2.4.2 Research performed in this field

None

4.2.5 Ensemble Prediction System (EPS) (Number of members, initial state, perturbation method, model(s) and number of models used, number of levels, main physics used,perturbation of physics, post-processing: calculation of indices, clustering)

4.2.5.1 In operation

The ECMWF EPS system is being used at COMET and CNMCA.

4.2.5.2 Research performed in this field

None

4.2.5.3 Operationally available EPS Products

Products and maps from ECMWF EPS, like EPSgrams, probability maps and plumes.

4.3 Short-range forecasting system (0-72 hrs)

4.3.1 Data assimilation, objective analysis and initialization

4.3.2.1 In operation

The operational data assimilation cycle (Bonavita, Torrisi and Marcucci, Q.J.R.M.S. 2008, 2010) is based on the Ensemble Kalman Filter (EnKF) approach, in particular the LETKF version (Hunt et al.2007) has been chosen. The COMET-LETKF data assimilation is running on the Mediterranean-European domain with 40 ensemble members plus a deterministic run, having a 0.0625° grid spacing (~7 km) and 49 vertical levels. The control state LETKF analysis is computed using the standard Kalman gain and a control run, instead of the background ensemble mean. The COSMO-ME deterministic run is initialized from the LETKF control state analysis.

Temperature, wind and specific humidity on model levels and surface pressure are provided as analysis fields.

The main characteristics of the operational atmospheric data assimilation system are reported in the following table:

Assimilated obs.	**SYNOP, SHIP, BUOY, RAOB (also 4D), SHIP, PILOT, WIND-PROFILER/RADAR, AIREP, AMDAR,/ACAR, MODE-S, MSG3-MET7 AMV, MetopA-B scatt. winds, NOAA-Metop A-BAMSUA/MHS and NPP ATMS radiances**
Assimilation cycle	**6 hours**
Analysis method	**LETKF**
First guess	**6 hours COSMO forecasts**
Coverage	**Mediterranean European region (Fig)**
Horizontal resolution	**0.0625 ° x 0.0625 °**
Vertical resolution	**49 model levels**
Model and sampling error	**“Relaxation-to-prior spread”multiplicative inflation method according to Whitaker et al. 2010** **Additive noise from scaled ECMWF EPS pertubations**
Lateral and surface BCs perturbation	**Lateral Boundary conditions from the most recent IFS deterministic run perturbed using ECMWF EPS** **Climatologically perturbed SST**

A 3 hourly intermittent data assimilation cycle using a multivariate three dimensional variational scheme (3D-VAR) – physical space analysis system (PSAS) with first guess at right time (FGAT) (*Bonavita and Torrisi, Meteorol. Atmos. Phys. 8, 2005*) and 1.5 h cutoff is mainly run to support the synoptic production of weather rooms (Euro Atlantic maps, etc). Temperature, wind and specific humidity on 45 model levels and surface pressure are provided on the Euro-Atlantic domain (14 km, Fig.1).

The main characteristics of the 3DVAR atmospheric data assimilation system are reported in the following table:

Assimilated obs.	**SYNOP, SHIP, BUOY, RAOB (also 4D), SHIP, PILOT, WIND-PROFILER/RADAR, AIREP, AMDAR, ACAR, MSG3-MET7 AMV, MetopA-B scatter. winds .**
Assimilation cycle	**3 hours**
Analysis method	**3D Multivariate FGAT PSAS analysis**
First guess	**3 hours COSMO forecasts**
Coverage	**Euro-Atlantic area**
Horizontal resolution	**0.125° x 0.125°**
Vertical resolution	**45 model levels**

The IFS snow analysis masked with the snow LAND-SAF product along with the IFS sea surface temperature are used once a day.

4.3.2.2 Research performed in this field

Recent developments are:

- Monitoring of GPS zenith total delay
- Monitoring of non-GTS local observations (temperature, wind, pressure, precipitation, humidity) from regional high-resolution networks;
- Implementation of ASCAT-HSAF soil moisture assimilation in LETKF and test on experimental suite;
- Forecast sensitivity to observation evaluation according to Kalnay et al. 2012.

Current development activities comprise:

- Pre-operational runs of KENDA-LETKF to initialise 2.2 km COSMO-IT
- Continue investigation of model error representation (covariance localization, stochastic physics, bias correction, etc);
- Further investigation of assimilation of soil moisture in the KENDA-LETKF system;
- Implementation and test of 3h COMET-LETKF data assimilation cycle;
- Test of DACE-3DVAR code

4.3.2 Model

4.3.2.1 In operation

Non-Hydrostatic Modeling

The non-hydrostatic modelling area is based on a COSMO model. COSMO-ME is integrated over the Euro-Mediterranean area with a 5km grid spacing (fig. 2) and 45 vertical levels using COMET-LETKF control analysis as initial state and IFS forecast fields as lateral boundary conditions. The main features of the operational implementations of the COSMO-ME are summarized in the following table:

COSMO-ME

Domain size	**1083x 559**
Grid spacing	**0.045° (5km)**
Number of layers / top	**45 / ~22 Km**
Time step and integration scheme	**60 sec Runge-kutta HE-VI time-splitting**
Forecast range	**72/48 hrs**
Initial time of model run	**00/06/12/18 UTC**
Lateral boundary conditions	**IFS**
L.B.C. update frequency	**3 hrs**
Initial state	**COMET-LETKF deterministic analysis**
Initialization	**None**
External analysis	**snow cover,SST**
Special features	**Filtered topography**
Status	**Operational**
Hardware	**HP Cluster Linux (COMET)/ CRAY (ECMWF)**

COSMO-IT is the very high resolution configuration of COSMO Model integrated over the Italian domain (Fig.3) using COSMO-ME fields as boundary conditions.

COSMO-IT

Domain size	**576x 701**
Grid spacing	**0.02° (2.2 km)**
Number of layers / top	**65 / ~22 Km**
Time step and integration scheme	**25 sec Runge-KuttaHE-VI time-splitting**

Forecast range	**48/30 hrs**
Initial time of model run	**00/06/12/18 UTC**
Lateral boundary conditions	**COSMO-ME**
L.B.C. update frequency	**1 h**
Initial state	**Nudging**
Initialization	**None**
External analysis	**None**
Special features	**Filtered topography**
Status	**Operational**
Hardware	**HP Cluster Linux (COMET)/CRAY (ECMWF)**

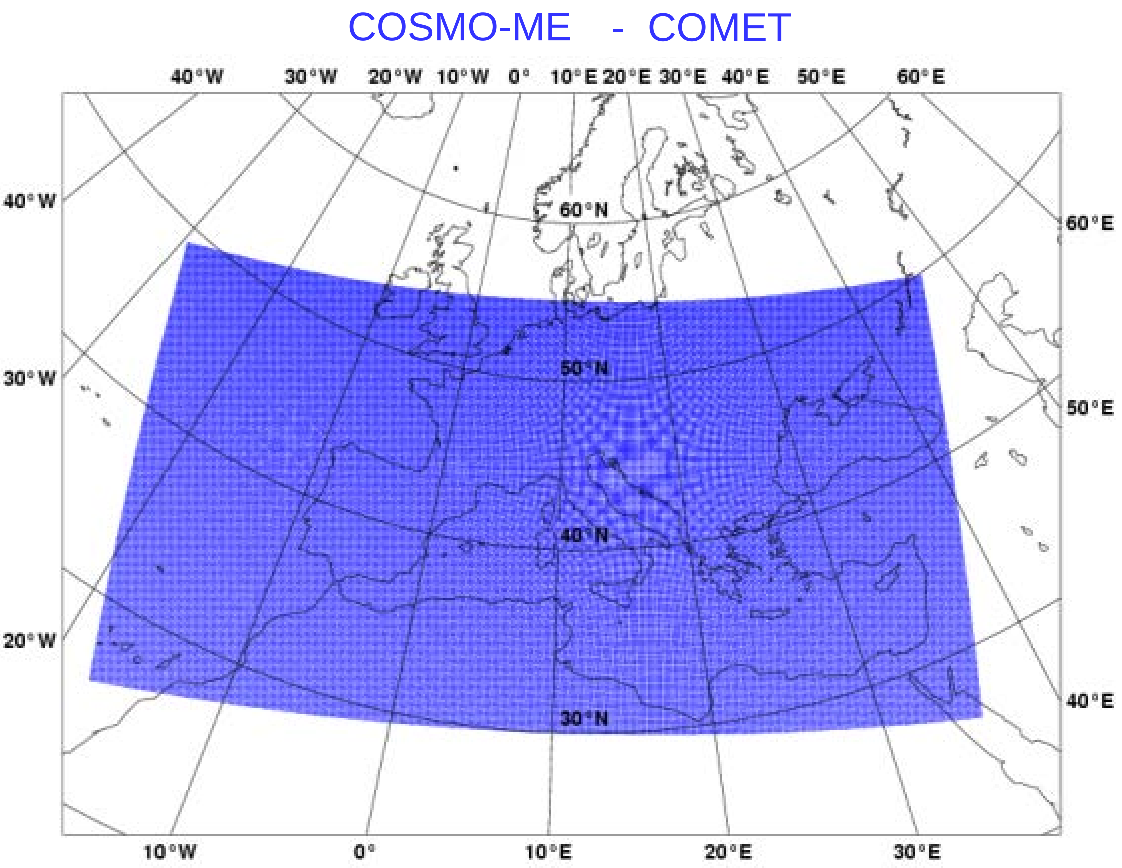


Fig. 2: Integration domain for the COSMO-ME non-hydrostatic model implementation.

4.3.2.2 Research performed in this field

- test of new physical parameterizations (e.g. marine surface layer, Bechtold convection scheme) in COSMO models;
- test of COSMO-IT rapid update cycle;
- deterministic post-processing of COSMO-IT fields;
- development of a new set of products (COSMO-IT) to support operational aeronautical activities (turbulence, icing, fog and thunderstorm detection, lighting, etc.) ;

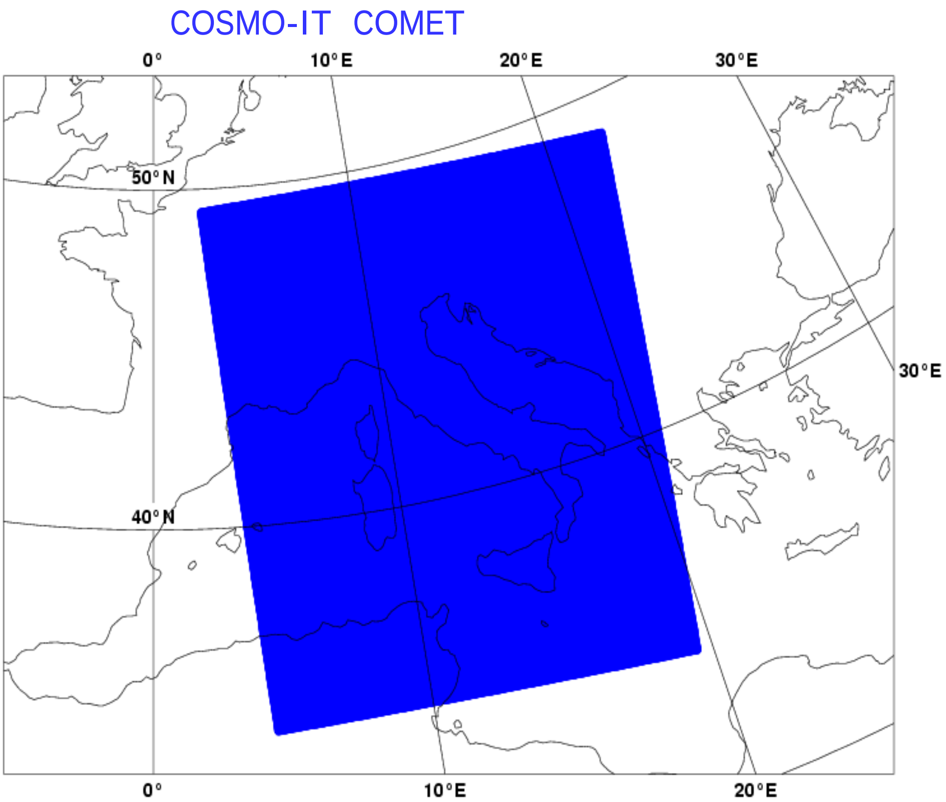


Fig. 3: Integration domain for the COSMO-IT non-hydrostatic model implementation.

4.3.3 Operationally available NWP products

COSMO-ME deterministic atmospheric model:
Analysis Products:

Surface parameters:
1. Mean sea level pressure;
2. 2 meters temperature;
3. 2 meters dew point temperature;
4. 10 meters wind;

Upper air parameters:
1. Geopotential height at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa, 200 HPa, 100 HPa;

2. Air temperature at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa, 200 HPa, 100 HPa;
3. Horizontal wind at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa, 200 HPa, 100 HPa;
4. Rel Humidity at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa, 200 HPa, 100 HPa.

Forecast Products:

Surface parameters:

1. Mean sea level pressure;
2. 2 meters air temperature;
3. 2 meters max and min air temperature;
4. 2 meters dew point temperature;
5. 10 meters wind;
6. 10 meters max gust;
7. Total cloud cover, low cloud cover, medium cloud cover, high cloud cover;
8. Base height and top height of convective clouds;
9. 6-hours integrated precipitation;
10. 6-hours convective precipitation;
11. 2 meters relative humidity;
12. Composite cloud;
13. Convection available potential energy;
14. 3-hours integrated precipitation;
15. 12-hours integrated precipitation;
16. 3-hours integrated snow precipitation;
17. 6-hours integrated snow precipitation;
18. Supercell index;
19. 2 meters air temperature – 24h trend;
20. 2 meters max air temperature variation in 48h.

Upper air parameters:

1. Geopotential height at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa, 200 HPa, 100 HPa.
2. Air temperature at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa, 200 HPa, 100 HPa.
3. Wind at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa, 200 HPa, 100 HPa.
4. Relative Humidity at 1000 HPa, 925 HPa, 850 HPa, 700 HPa, 500 HPa, 300 HPa, 200 HPa, 100 HPa.
5. Freezing level

A selected sub-set of products is also available on WIS-DCPC according to the requirements of the Regional Specialized Meteorological Centre (RSMC) for Limited Area Deterministic Numerical Weather Prediction (http://www.meteoam.it/international_activities/product_dissemination/deterministic_wis)
Deterministic NWP products available on WIS-DCPC are:

1. Geopotential height at 925 HPa, 850 HPa, 700 HPa, 500 HPa, 250 HPa;
2. Air temperature at 925 HPa, 850 HPa, 700 HPa, 500 HPa, 250 HPa;
3. Wind at 925 HPa, 850 HPa, 700 HPa, 500 HPa, 250 HPa;
4. Relative Humidity at 925 HPa, 850 HPa, 700 HPa, 500 HPa, 250 HPa;

5. Divergence and vorticity at 925 HPa, 850 HPa, 700 HPa, 500 HPa;
6. Mean sea level pressure;
7. 2 meters air temperature;
8. 2 meters dew point temperature;
9. 10 meters wind;
10. 6-hours integrated precipitation.

All fields are provided at the 0.25°x0.25° resolution, every 6 hours up to +72hours, two times a day (00UTC and 12UTC).

COSMO-IT not-hydrostatic deterministic atmospheric model:

Forecast Products:

1. Convection available potential Energy
2. Supercell index
3. 3-hours integrated precipitation
4. 6-hours integrated precipitation
5. 10 meters wind
6. 10 meters max wind 1h

VERTICAL PROFILES.

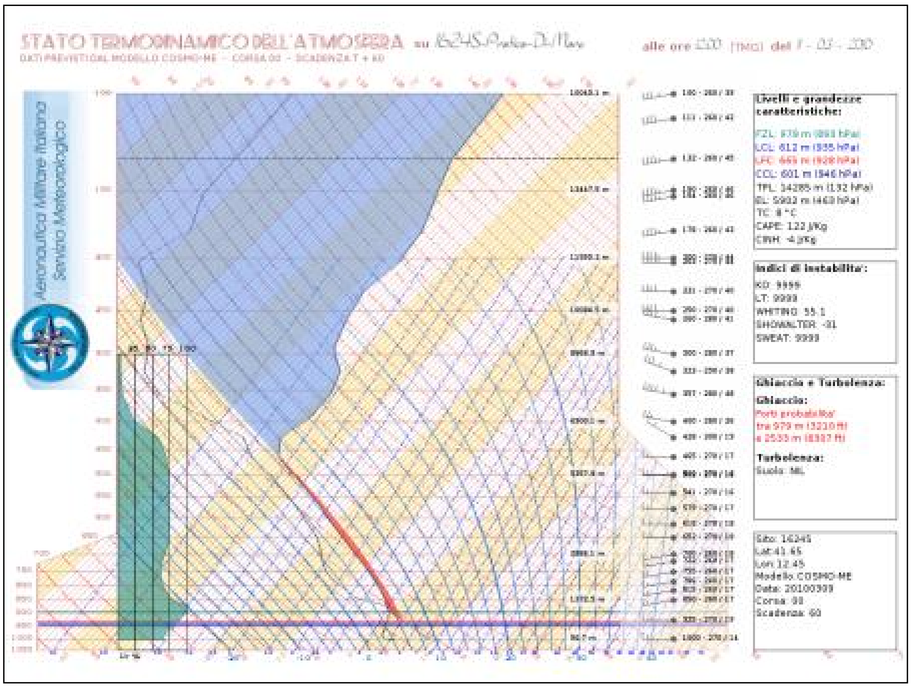


Fig. 4: Example of Vertical profile product from COSMO-ME model fields

A new pictorial representation of vertical profiles has been developed, validated and made operational since summer 2009. In this context an Herloffson diagram is being operationally used. It is an exact digital replica of the paper version used in the past by the Italian Met Service personnel to plot upper air observations. It is used both for observations and forecasts plotting.

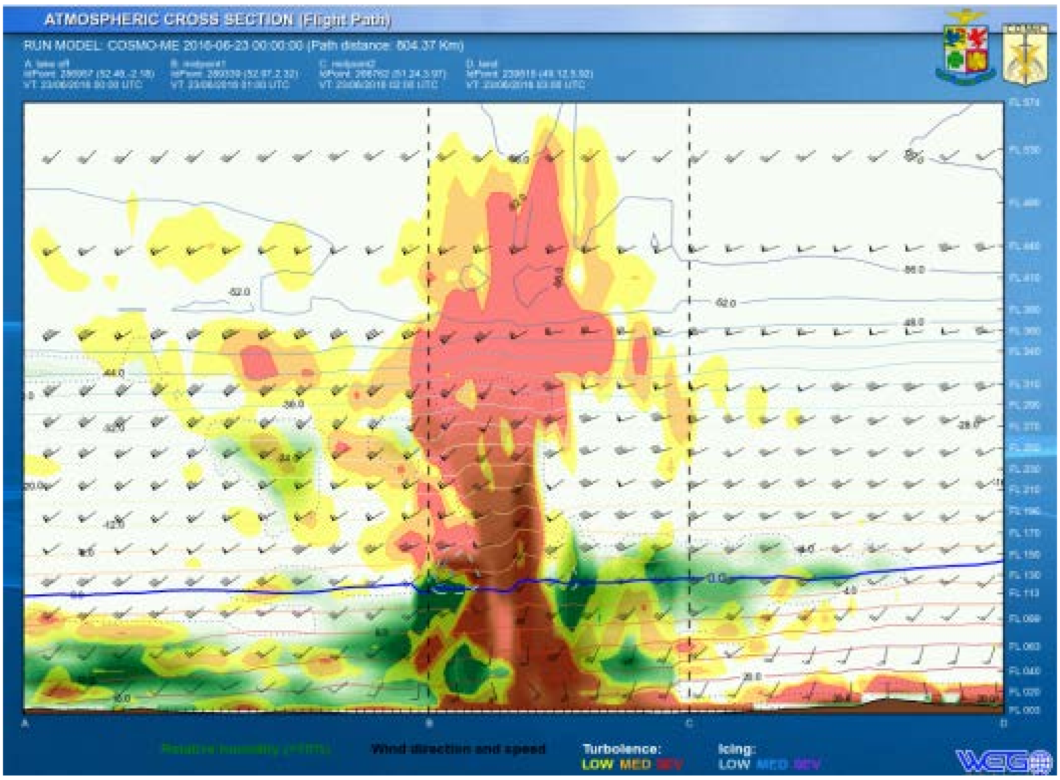


Fig. 5: Example of a vertical cross section along a flight route dynamically produced by the means of the G.I.S. system being used at COMET.

METGRAMS.

A massive production of metgrams is being operational at the Italian Met Service. Every day more than 3000 metgrams are being produced and delivered to final users on the Italian Met Service web site via “http” and “ftp” protocols. A thematic criteria is used to produce different kind of metgrams. Aeronautical metgrams are conceived for example in terms of a set of meteorological parameters specific for aeronautical use like ceiling and top of convective clouds, convective and large scale precipitation discriminating rain from snow, low, medium and high cloud coverage, mean sea level pressure and QNH. General purpose metgrams are instead conceived in terms of more general meteorological parameters such as mean sea level pressure, 2m temperature, 2m relative humidity, 10 m horizontal wind. Besides new thematic metgrams are being developed. Among them it is important to point out the “transport theme” which will include all the meteorological parameters related to surface transports (railways, highways, and maritime routing).

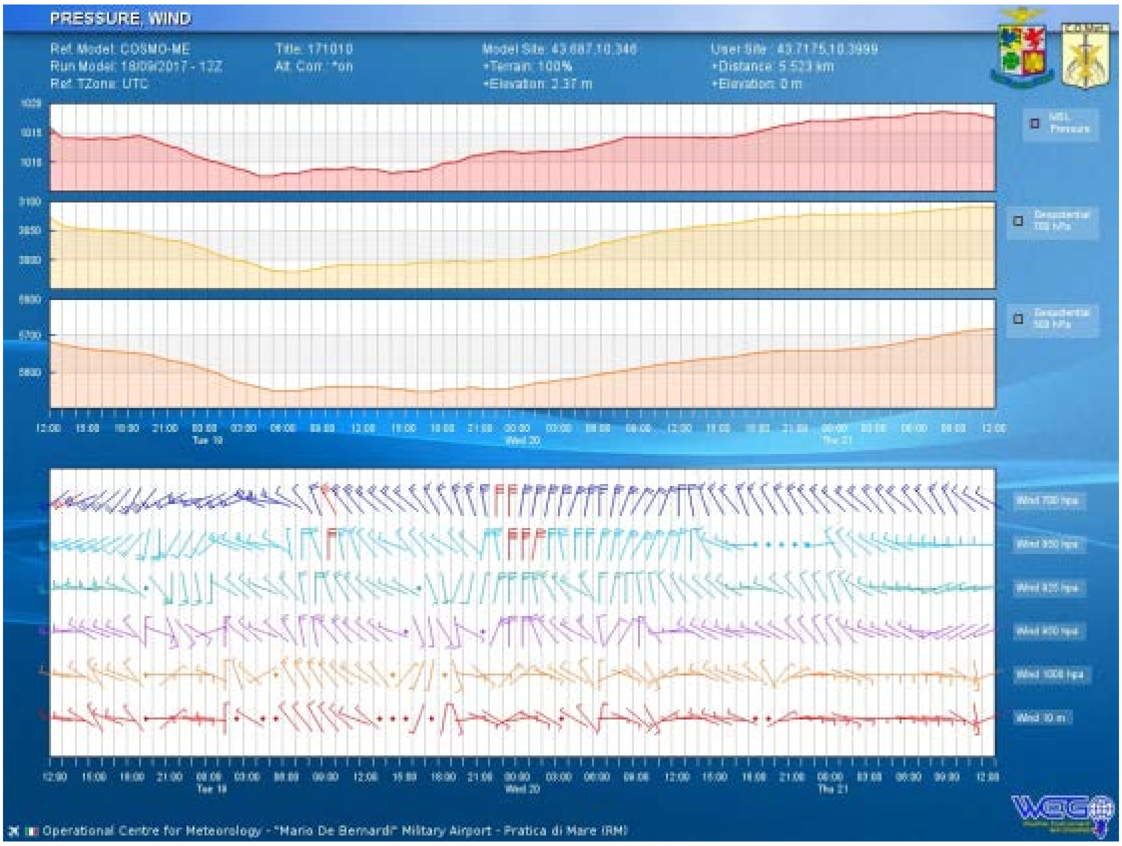


Fig. 6: Example of a meteogram product from COSMO-ME model fields

SYNTHETIC SATELLITE IMAGES

A process-based modelling approach is used to generate synthetic satellite images from COSMO-ME outputs. The method is based on the radiative transfer model code RTTOV (Fig.7).

Fig. 7: Example of a synthetic satellite simulated image usingCOSMO-ME model outputs

AWI

A deterministic post-processing package of the COSMO-ME model fields known as Automatic Weather Interpretation (AWI) is in use at COMET and CNMCA. A series of multi-parameter decisional tree allows the determination of weather phenomena (drizzle, rain, snow, thunderstorms, fog, etc.) as well as of the cloud type, the risk of icing, strong wind or heat waves. Details are given in Ciciulla (*Workshop on Statistical and Dynamical Adaptation, 5–6 May 2003, Wien,* http://srnwp.met.hu/). An example of AWI product (referring to significant weather phaenomena) is given in Fig. 8. Current work is focused on the improvement of thealgorithms used in AWI.

LOCAL FORECASTS.

The full set of weather parameters from COSMO-ME model and derived variables from Automated Weather Interpreter is daily being retrieved for a collection of about 1200 sites and then encoded both in extended SYNOP-like message and XML format for further applications.

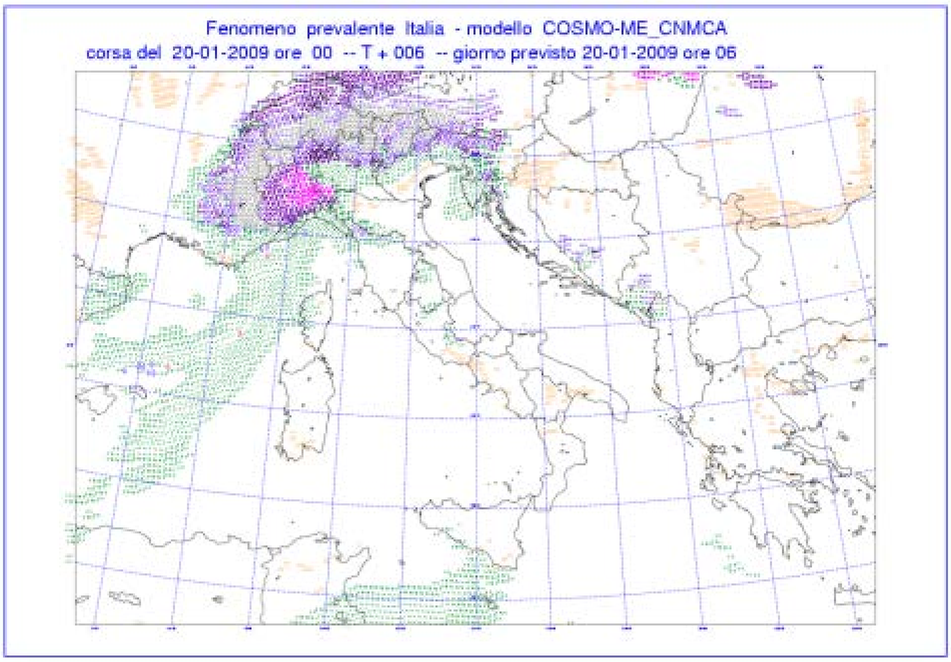


Fig. 8: Example of AWI product from post-processed COSMO-ME model fields.

REGIONAL FORECASTS.

As the reader may be aware, the Italian territory is divided into 20 regional bodies called "***Regioni***" from the administrative point of view. For these bodies a specific weather forecast at COMET is daily being prepared and issued 24/7 twice a day. To prepare these product the forecaster is presented a synthetic icon representation inferred from the single point forecasts related to all the grid points pertaining each region up to 48 hours. At each point a set of weather parameters is taken from COSMO-ME model and the weather phenomena insisting on that point is inferred through the set of AWI post-processing algorithms. The synthetic icon representation and its spatial range representativeness is performed by an algorithm set up in cooperation with operational forecasters.

The synthetic icon representation is moreover being furtherly developed with the aim of producing an automated behaviour in Google Earth software where significant icons are displayed while the geographical detail associated to zooming increases.

G.I.S.

Our Geospatial Information System offer an interactive interface to retrieve, generate, represent, manipulate and overlap forecast and observational information with reference to geographic location data. The meteorological information can be elaborated to represent a local information, i. e. a vertical profile, or area information, i. e. 2 m temperature shading over the whole model domain or a vertical cross section along a flight route.

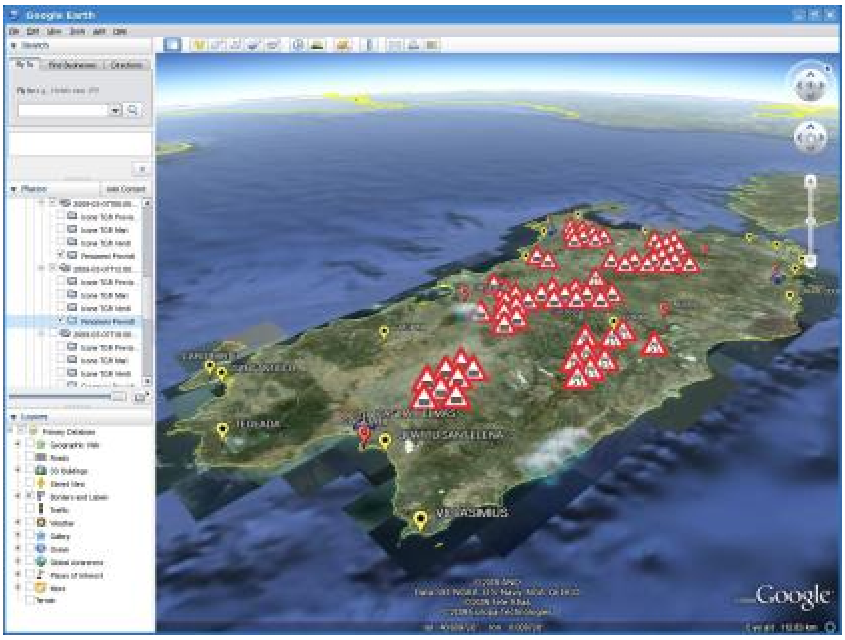


Fig. 9: Example of the pictorial AWI post-processing for the Regional Forecast production provided by COMET and being used at CNMCA.

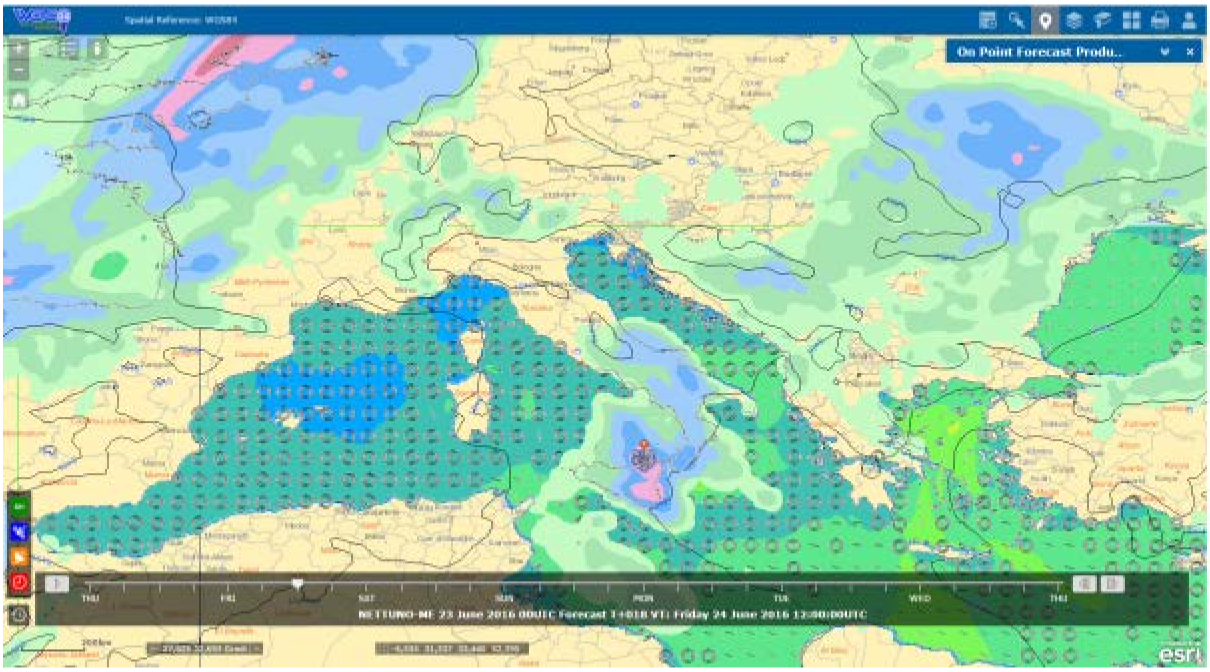


Fig. 10: A snapshot of the G.I.S. Interface at COMET with point and area data overlapped

WEATHER WARNINGS AND FORECAST REPORTS

COMET is responsible to provide meteorological watch for general aviation purposes over the Flight Information Regions (FIRs) of competence, as well as weather watch for sea basins surrounding Italy; in that respect, based on nowcasting and model products described above, specific task is the issue of the following contents when needed:

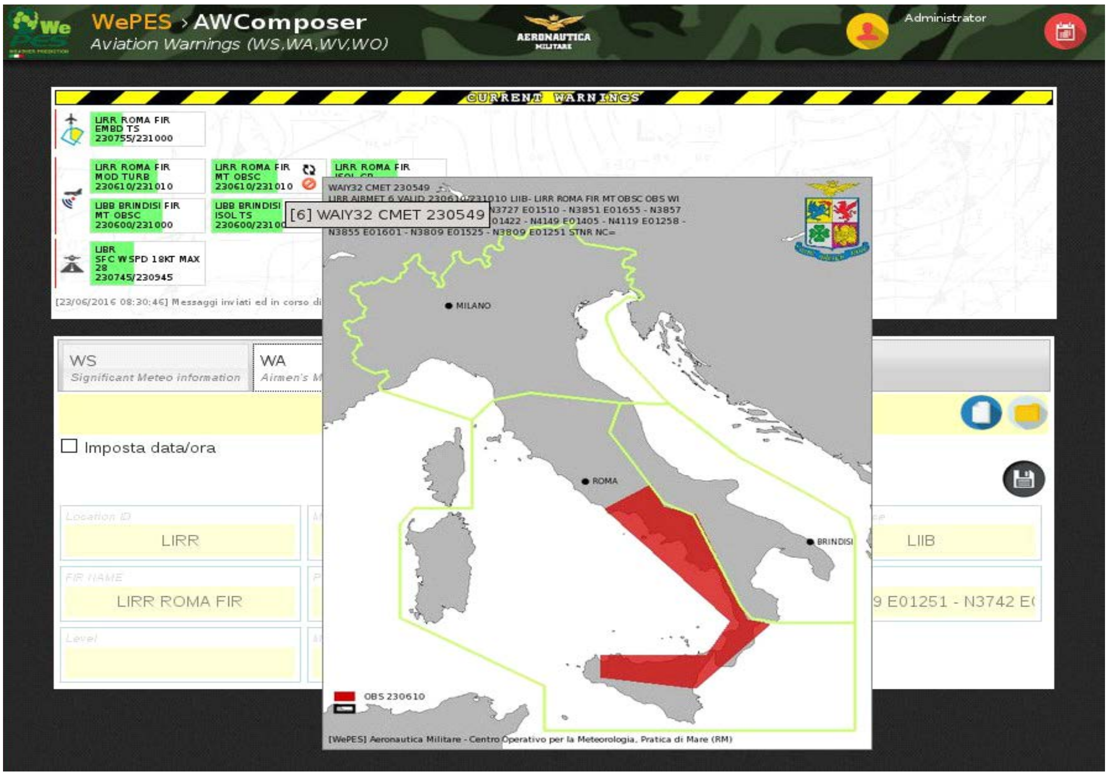
- Sigmets;
- Volcanic Ash Sigmets;
- Airmets;
- Aerodrome Warnings;
- Terminal Aerodrome Forecasts,

and

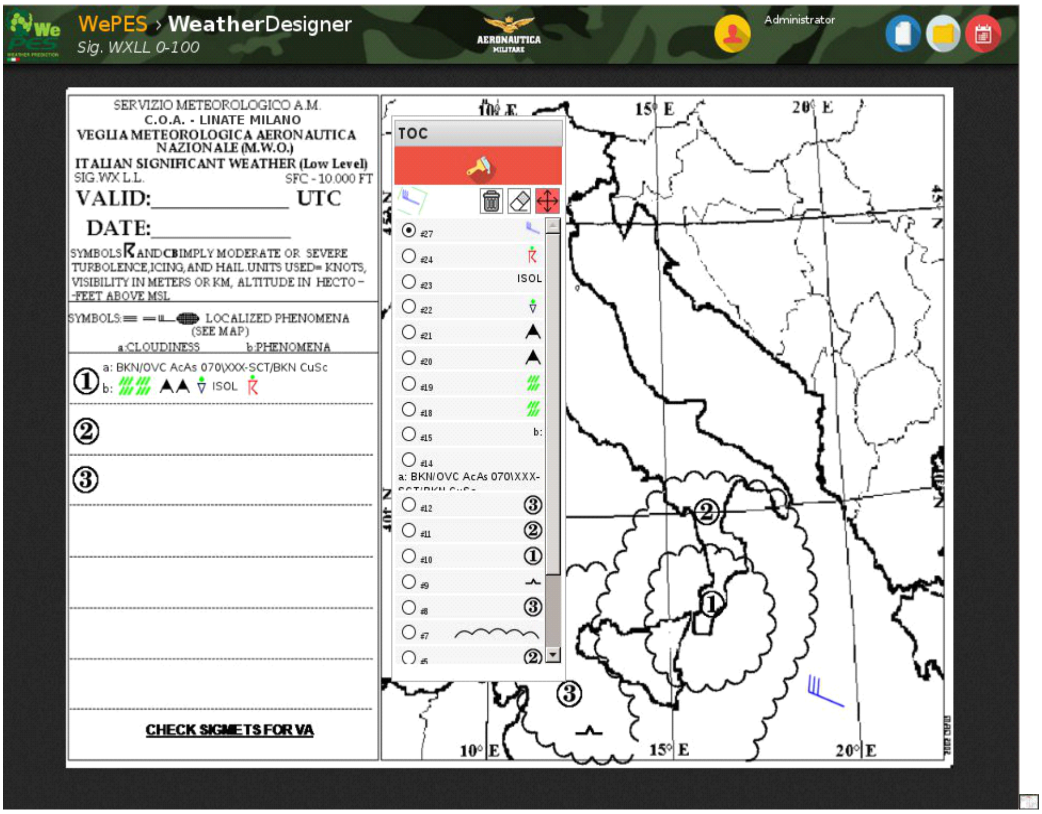
- Gale Warnings;
- Weather Forecasts over Mediterranean Sea;

WePES system is the web-based operational workstation available for COMET and CNMCA forecasters. Specific tools has been designed to cover all the operational meteorological content of information required, generating both graphic formats as well as alphanumeric formats. Tools has also been tailored for depicting Significant Weather Low Level Charts (SWLL), editing of alerts, warnings and weather forecast maps and messages even detailed at regional scale, provisions of severe weather warnings in the Meteoalarm framework.

Started migration towards IBL Visual Weather system for the Civil Aviation weather warnings production and delivery. Conclusion by the end of 2018.



A snapshot regarding WePES system and the editing activity for SWLL prognostic charts required as Aviation Weather Centre.



A snapshot regarding WePES system and the editing activity for SWLL prognostic charts required asAviation WeatherCentre.

4.3.4 Operational techniques for application of NWP products (MOS, PPM, KF, Expert Systems, etc..)

4.3.4.1 In operation

None

4.3.4.2 Research performed in this field

None

4.3.5 Ensemble Prediction System (Number of members, initial state, perturbation method, model(s) and number of models used, perturbation of physics, post-processing: calculation of indices, clustering)

4.3.5.1 In operation

The atmospheric short-range ensemble prediction system (COSMO-ME EPS) based on the COMET-LETKF analysis and the COSMO model is running operationally at COMET (pre-operational since July 2013).
The relevant characteristics of the atmospheric COSMO-ME EPS are:

- Domain and resolution: COSMO model is integrated 40 times on the same domain of the COMET-LETKF system.
- IC and BC: initial conditions are derived from the COMET-LETKF system;lateral boundaries conditions are from the ECMWF-EPS system.
- Model error: stochastics physics perturbation tendencies.

- Forecast range: 72 hours at 00/12 UTC.

4.3.5.2 Research performed in this field

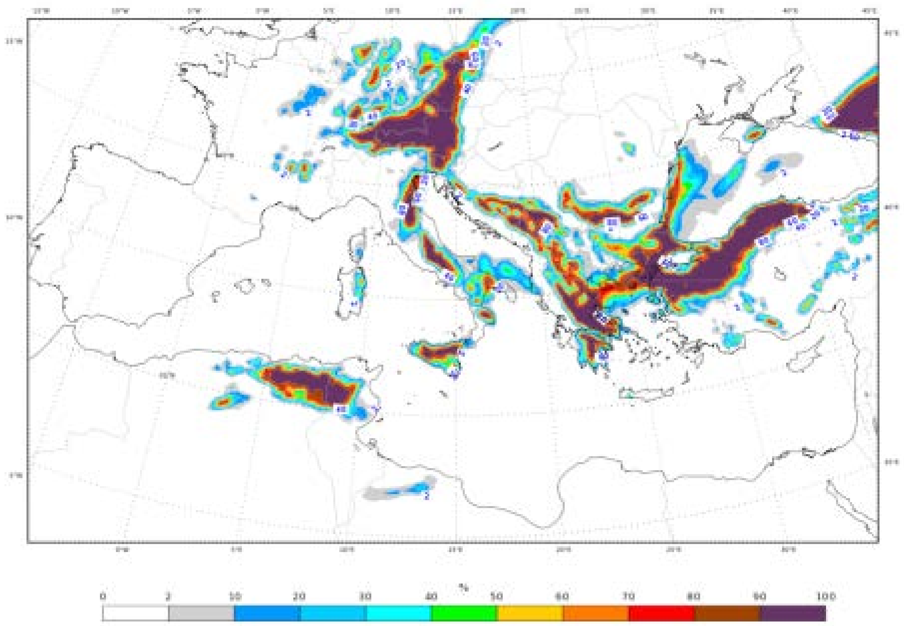
A further work of calibration and tuning of the system is planned to release operationally a full set of probabilistic products from COSMO-ME EPS for most important towns. A convection permitting EPS system based on KENDA-LETKF system and COSMO-IT model (COSMO-IT EPS) has been testing in cooperation with ARPA-Emilia Romagna and ARPA Piemonte.

In the framework of EUMETNET SRNWP-EPS Phase II project, a tool for the probabilistic forecast of fog and thunderstorm is under development.

4.3.5.3 Operationally available EPS products

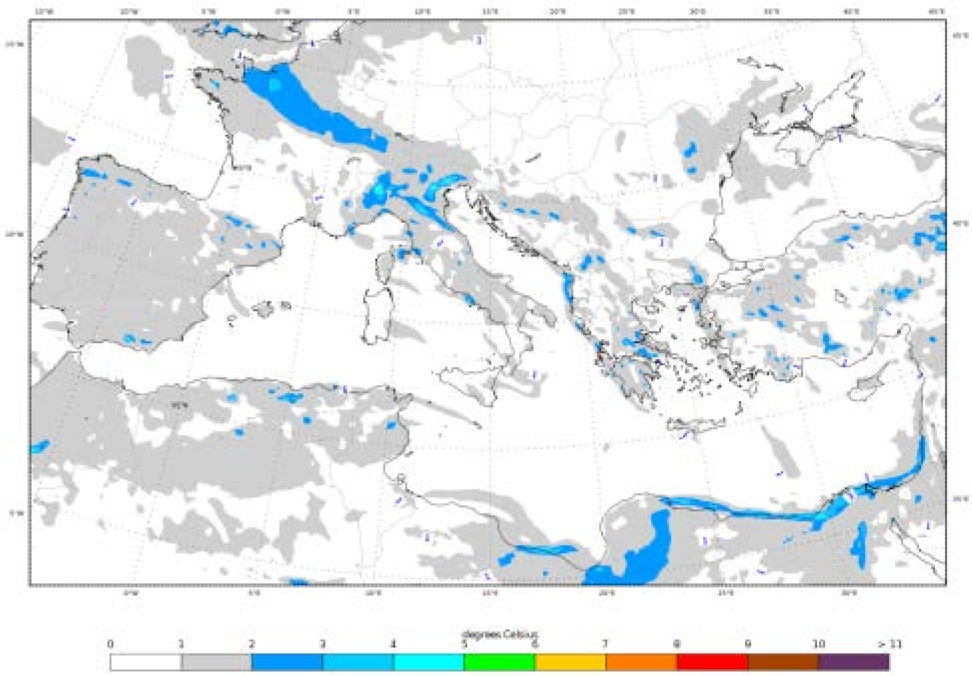
1. uncertainty of 2m temperature
2. uncertainty of 10m wind
3. 6h integrated total precipitation > 0.2 mm
4. 6h integrated total precipitation > 10 mm
5. 6h integrated total precipitation > 20 mm
6. 6h integrated total precipitation > 30 mm
7. 6h integrated total precipitation > 40 mm
8. 24h integrated total precipitation > 100 mm
9. 24h integrated total precipitation > 20 mm
10. 24h integrated total precipitation > 40 mm
11. 6h integrated total snow precipitation > 0.2 cm
12. 6h integrated total snow precipitation > 10 cm
13. 6h integrated total snow precipitation > 20 cm
14. 6h integrated total snow precipitation > 5 cm
15. 24h integrated total snow precipitation > 10 cm
16. 24h integrated total snow precipitation > 20 cm
17. 24h integrated total snow precipitation > 40 cm
18. Max 2m temperature > 32°C
19. Max 2m temperature > 35°C
20. Max 2m temperature > 38°C
21. Min 2m temperature < 5°C
22. Min 2m temperature < 0°C
23. Min 2m temperature < -5°C
24. Min 2m temperature < -10°C
25. Wind gust > 21 kt
26. Wind gust > 33 kt
27. Wind gust > 55 kt

COSMOME_EPS 31 December 2014 00UTC Forecast T+6 VT: Wednesday 31 December 2014 06UTC
6h Snowfall (convective + stratiform) probability > 0.2 mm



Meteograms over about 9000 italian cities are also produced including the probability of precipitation.

COSMOME_EPS 04 January 2015 00UTC Forecast T+6 VT: Sunday 04 January 2015 06UTC
2 m Temperature uncertainty (2 x Standard Deviation) degrees Celsius



A selected sub-set of products is also available on WIS-DCPC according to the requirements of the Regional Specialized Meteorological Centre (RSMC) for Limited Area Ensemble Numerical Weather Prediction

(http://www.meteoam.it/international_activities/ensemble_wis)

Ensemble NWP products available on WIS-DCPC are:

1. Ensemble mean and uncertainty of mean sea level pressure;
2. Ensemble mean and uncertainty of 10m wind;
3. Ensemble mean and uncertainty of geopotential height at 500hPa;
4. Probability of Wind gust > 11 m/s
5. Probability of Wind gust > 17 m/s
6. Probability of Wind gust > 28.5 m/s
7. Probability of 6h integrated total precipitation > 0.2 mm
8. Probability of 6h integrated total precipitation > 10 mm
9. Probability of 6h integrated total precipitation > 20 mm
10. Probability of 6h integrated total precipitation > 30 mm
11. Probability of 24h integrated total precipitation > 100 mm
12. Probability of 24h integrated total precipitation > 20 mm
13. Probability of 24h integrated total precipitation > 40 mm

All fields are provided at the 0.5°x0.5° resolution, every 6 hours up to +72hours, at 00UTC.

4.4 Nowcasting and Very Short-range Forecasting Systems (0-12 hrs)

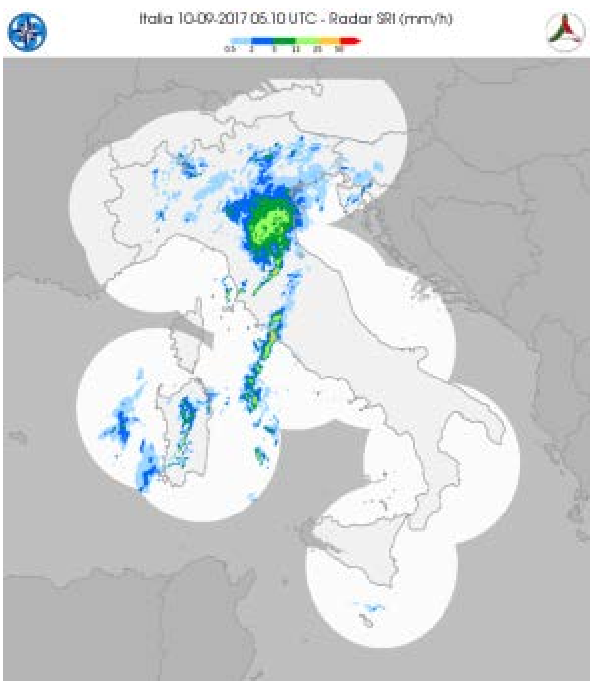
4.4.1 Nowcasting system

The Nowcasting activities is based on the management of special observation retrieved from RADAR and LIGHTINING network and satellite data.

4.4.1.1 In operation

RADAR system:

- SRI composite of radar data collected from the Italian Air force station in (Capo Caccia, regional meteorological services, National Agency for Civil Aviation, National Department for Civil Protection and few foreign country sites (France, Switzerland, Slovenia) is produced every 10 minutes, as in figure.



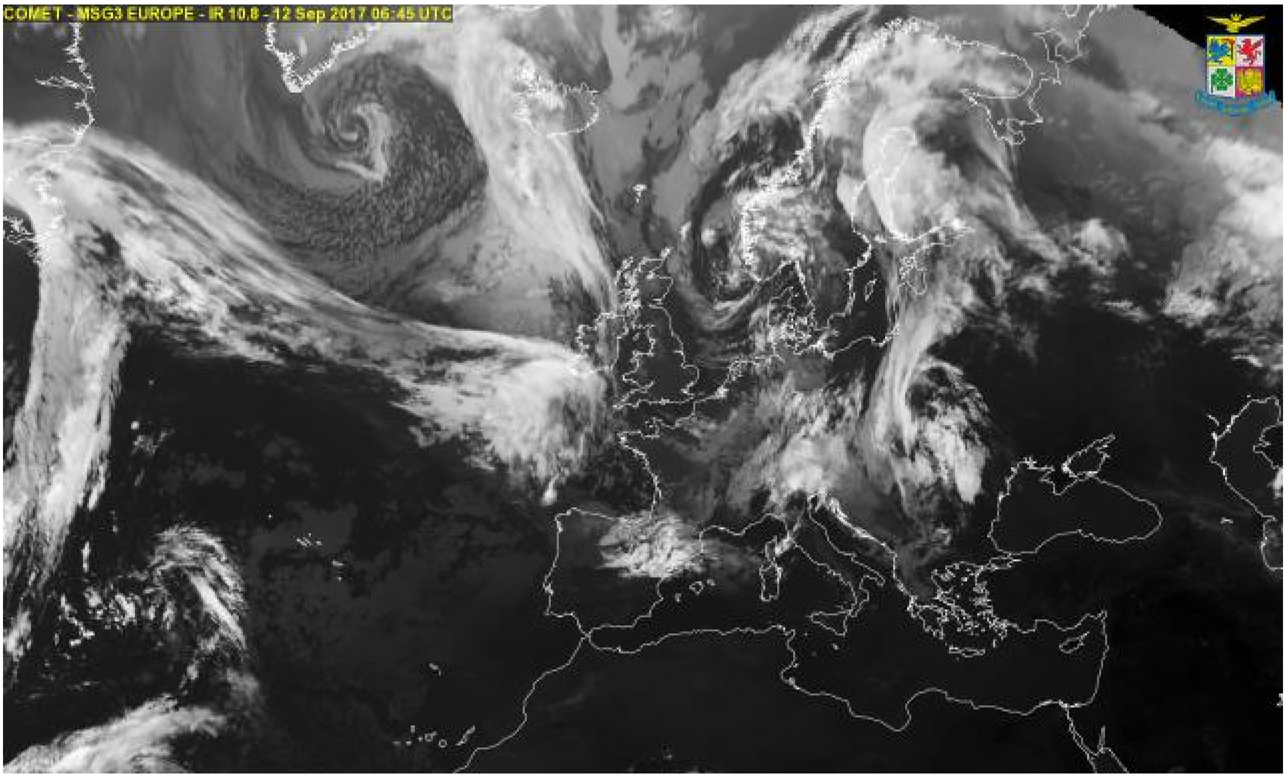
SATELLITE Systems:

The satellite area receives data via EUMETCAST system and from polar satellites (METOP, POESS, FY, TERRA and AQUA, NPP). The satellite branch elaborates data in the visible and infrared bands to produce image in b/w and rgb composite. Products of 2nd level are designed for an easy use of satellite information. In 2009 the integration of different sources has been implemented to supply an overview to decision makers about the critical parameters.

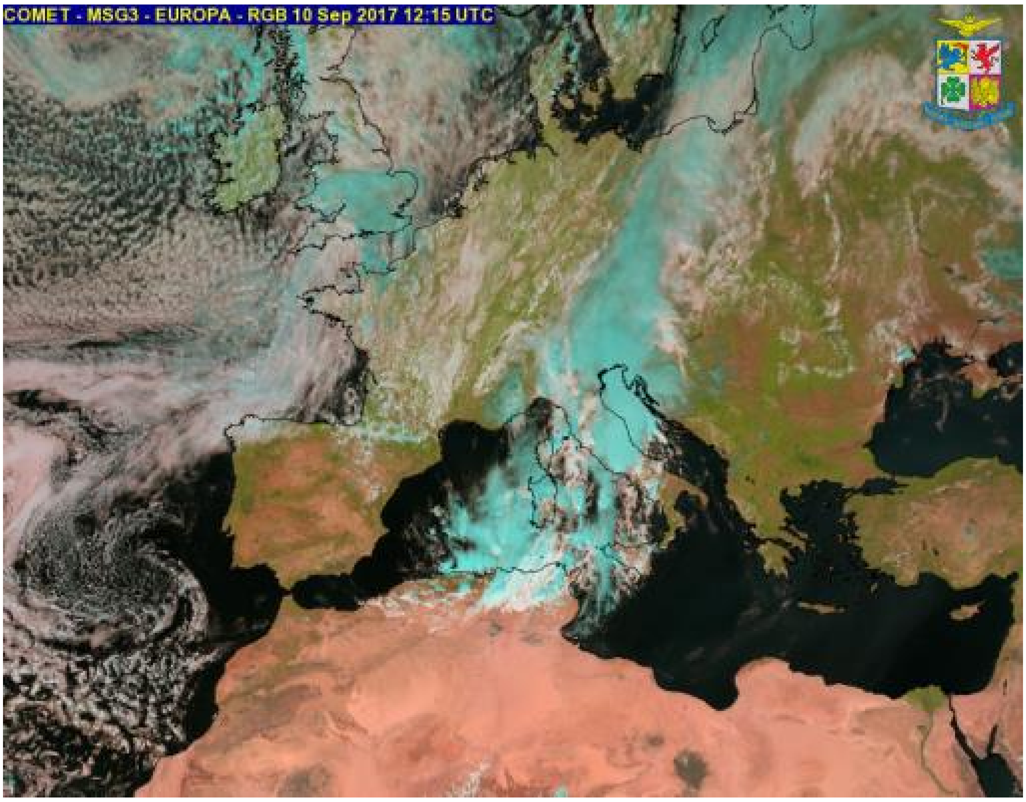
The service runs on European and Asiatic areas, but on demand, the service can be exported on area of interest.

The physical parameters managed from Italian Met Service are most of available channels to retrieve the parameters summarized in the following table:

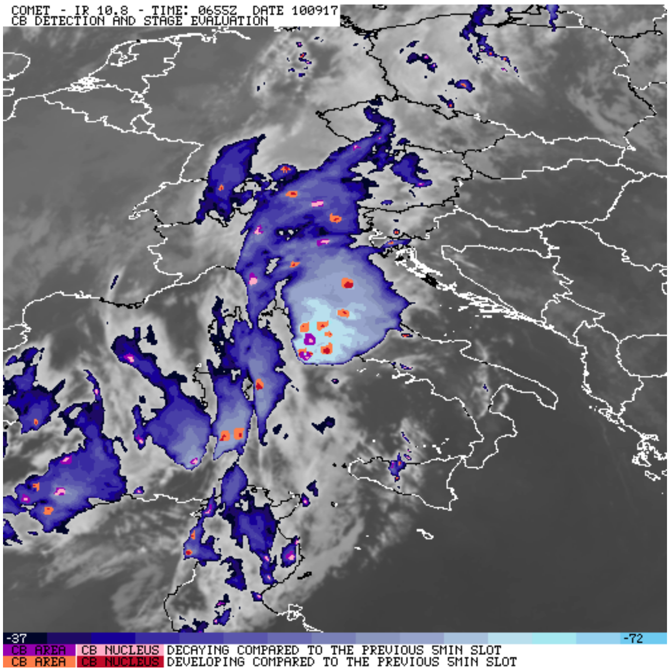
Parameters	**sensor**	**Area**
Cloud Type	SEVIRI	Full disk 0° and IODC
CTH	SEVIRI	Full disk 0°
CTT	SEVIRI	Full disk 0°
CTP	SEVIRI	Full disk 0°
Convective Clouds	SEVIRI	Europe, Full disk 0°
LST	SEVIRI	Europe
SST	SEVIRI	Mediterranean, North Atlantic region
Rain Rate	AMSU/DMSP	Full disk 0°
Accumulated Rain	AMSU/DMSP/SEVIRI	Full disk 0°
Volcanic Asch	SEVIRI/AVHRR	Europe/Italy
Fire- probability of detection	SEVIRI	Italy



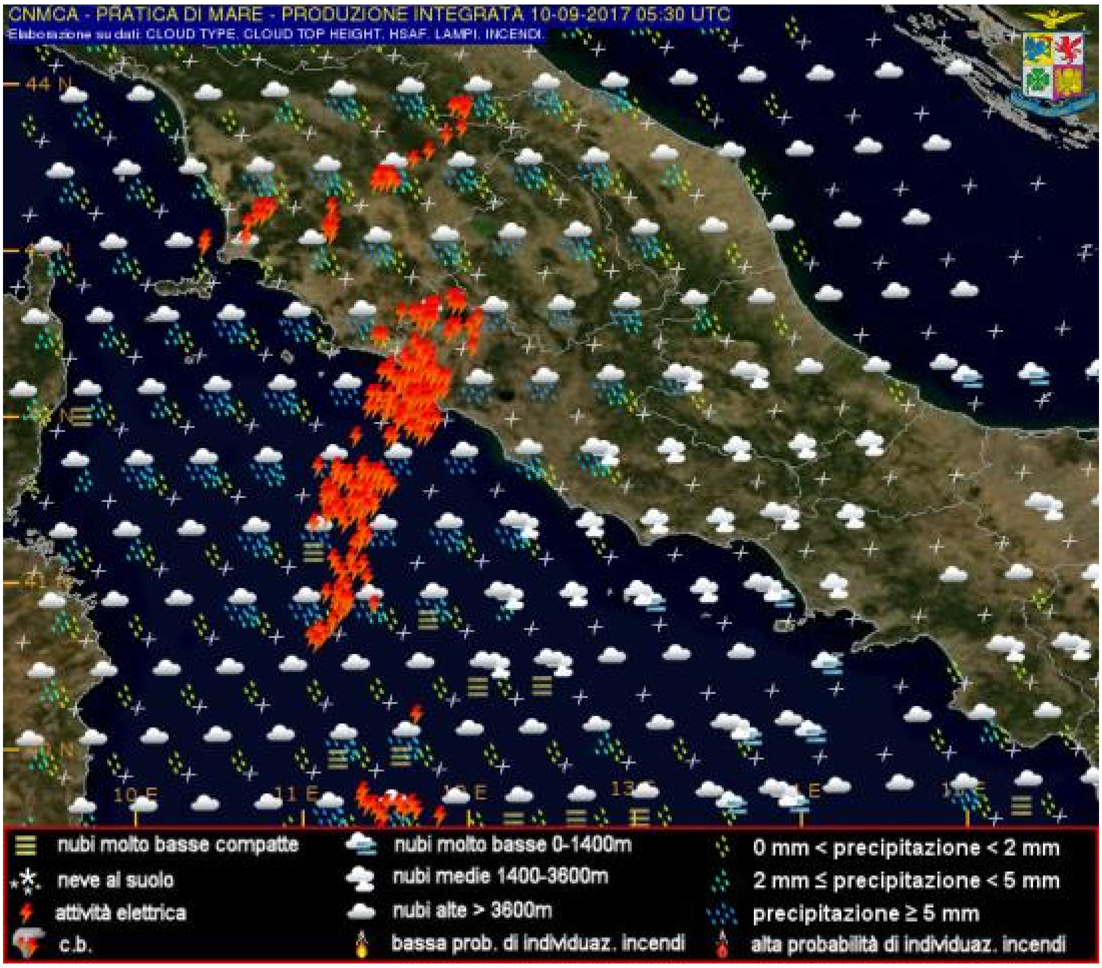
Example of infrared picture on European area.



- Example of   RGB picture on European area.



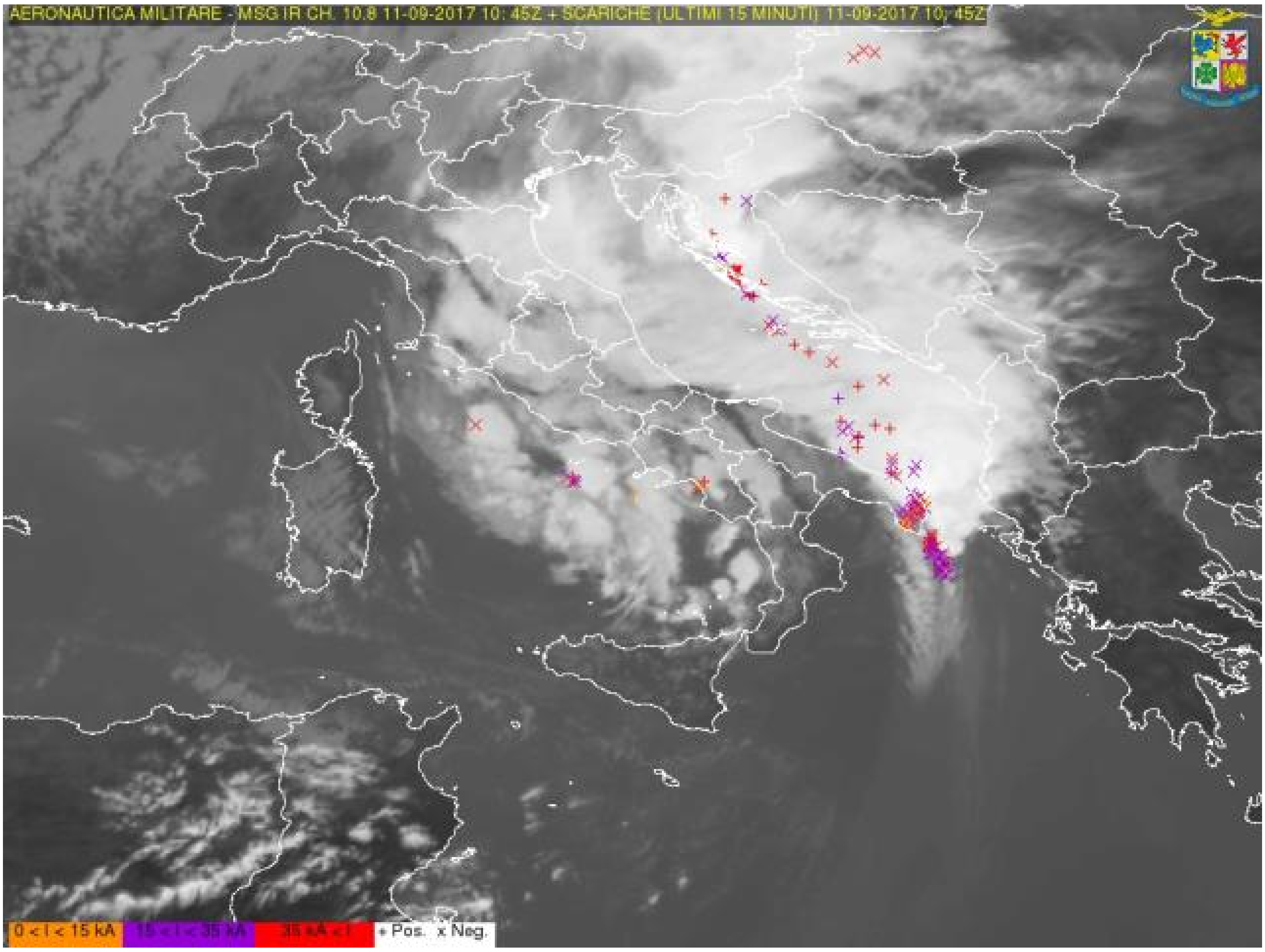
- Example of 2nd level product to recognize and very short range forecasts of stormy cells.



- Example of INTEGRATED INFORMATION TO SUPPORT DECISION MAKERS. The pictures visualizes only the presence of parameters showed and the bottom of the figure. The image summarize a lot of parameters retrieved from different sources.

LIGHTNING DETECTION system:

Italian Air Force Operational Met Centre- COMET has realized a national network for the location of electrical discharge, available every 5 minutes



4.4.1.2 Research performed in this field

None

4.4.2 Models for Very Short-range Forecasting Systems

4.4.2.1 In operation

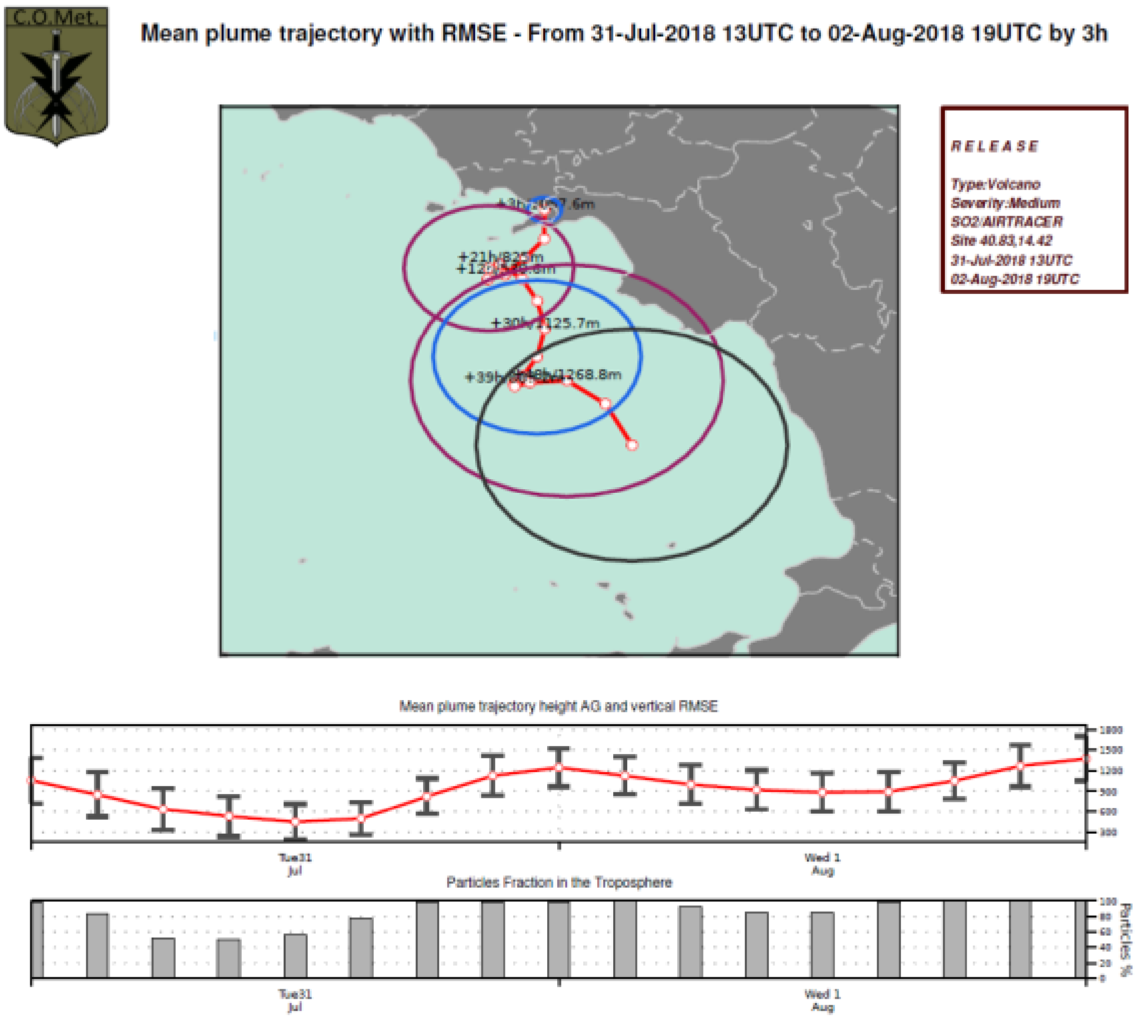
None

4.4.2.2 Research performed in this field

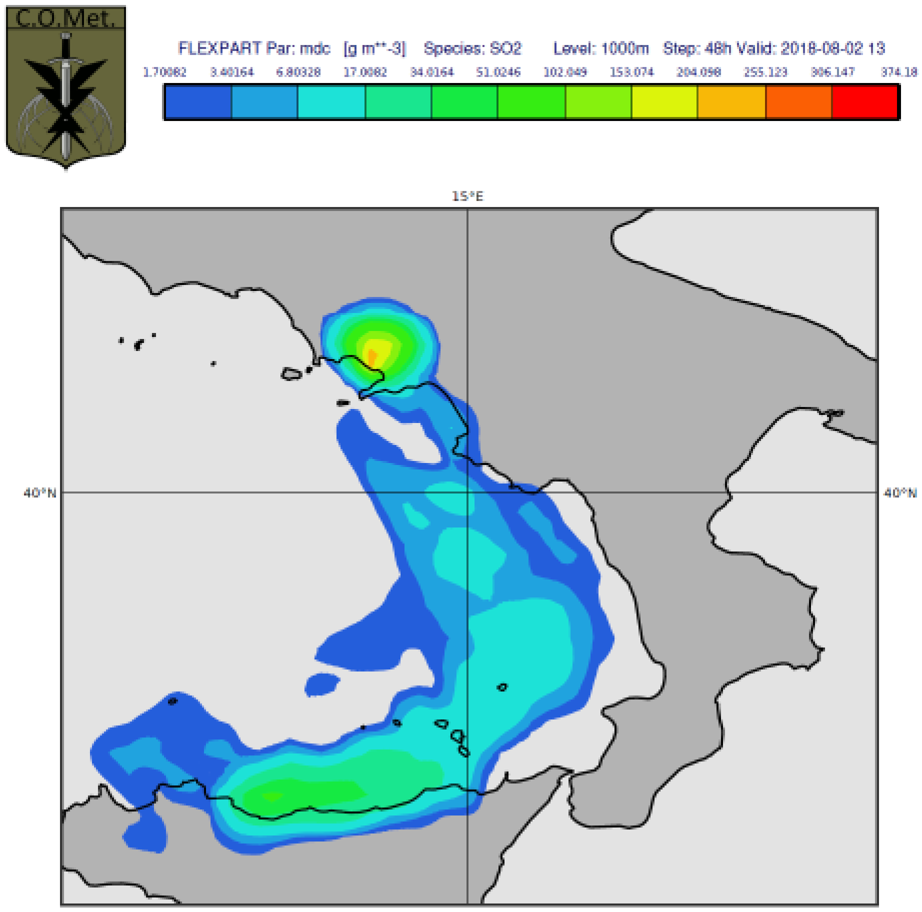
None

4.5 Specialized numerical predictions (on sea waves, storm surge, sea ice, marine pollution transport and weathering, tropical cyclones, air pollution transport and dispersion, solar ultraviolet (UV) radiation, air quality forecasting, smoke, sand and dust, etc.)

- The ECMWF O1280L137 fields referring to wind, relative and specific humidity, temperature, pressure, cloudiness, radiation, sensible heat flux, precipitation and soil characteristics are being used to generate information related to the identification and tracking of the dispersion areas of potentially contaminating chemical, nuclear and biological substances, in particular to:
  - provide meteorological forcing to the Lagrangian dispersion model FLEXPART.



Example of air particles mean trajectory based on ECMWF and FLEXPART model



Example of single level air particles concentration based on ECMWF forecast fields and FLEXPART model

- The ECMWF O1280L137 wind speed, temperature and relative humidity fields are also used to infer heat index and windchill factor.
- From DWD Global Model, UV forecasts are routinely downloaded in text format and pictorially represented within the framework of a population protection program.

In cooperation with CNR-ISMAR institute a sea state forecast system, named NETTUNO, has been implemented in 2008.
In cooperation with INGV-Bologna a high-resolution oceanic model driven by COSMO-ME model is under development.

4.5.1 Assimilation of specific data, analysis and initialization (where applicable)

4.5.1.1 In operation
None

4.5.1.2 Research performed in this field

None

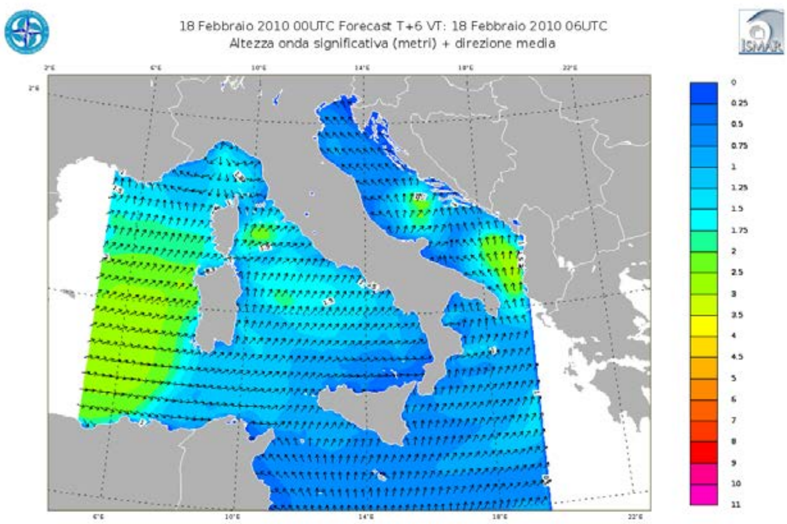
4.5.2 Specific models (as appropriate related to 4.5)

4.5.2.1 In operation

NETTUNO system is based on the ECMWF version of WAM model integrated over the whole Mediterranean basin which is driven by COSMO-ME forecast winds. It was developed in cooperation with the ISMAR-CNR institute of Venice.
Forecast fields (mean wave period and direction, significant wave height) are given every 3 hrs up to 72 hrs.
A brief summary of NETTUNO-ME features is given in the following table:

Domain size	**846X321**
Grid spacing	**0.05°**
Time step	**120 s**
Forecast range	**72 hrs**
Initial time of model run	**00/12 UTC**
N° frequencies/directions	**30/36**
Atmospheric model wind	**COSMO-ME**
Wind update frequency	**1 hr**
Initial state	**Previous run**
Status	**Operational**
Hardware	**HP Cluster Linux (COMET)/Cray (ECMWF)**

A high resolution (1’) WAM model, named NETTUNO-IT, driven by COSMO-IT wind forecast and nested in the NETTUNO-ME is operational over the Italian domain.



Example of map of NETTUNO-IT (1’)

4.5.2.2 Research performed in this field

A two-way coupling between the WAM and COSMO-ME model was tested in collaboration with ISMAR-CNR

4.5.3 Specific products operationally available

None

4.5.4 Operational techniques for application of specialized numerical prediction products (MOS, PPM, KF, Expert Systems, etc.) (as appropriate related to 4.5)

4.2.4.1 In operation

None

4.2.4.2 Research performed in this field

None

4.5.5 Probabilistic predictions (where applicable)

4.5.5.1 In operation

In the framework of MyWAVE project a “sea state” EPS based on the NETTUNO system (Bertotti and Cavaleri 2009) and the COSMO-ME EPS has been implemented and tested in collaboration with ISMAR-CNR.

The sea state probabilistic forecast is obtained driving the wave model using the hourly COSMO-ME EPS wind forecast members. The NETTUNO-EPS consists of 40+1 members, that are integrated at 00 UTC up to 48 hour forecast in the Mediterranean basin.

4.5.5.2 Research performed in this field

Improvement in this field are linked to the COSMO-ME EPS system progress.

4.5.5.3 Operationally available probabilistic prediction products

Probability maps for sea state field at different threshold are produced.

4.6 Extended range forecasts (10 days to 30 days) (Models, Ensemble, Methodology)

4.6.1 In operation

None

4.6.2 Research performed in this field

None

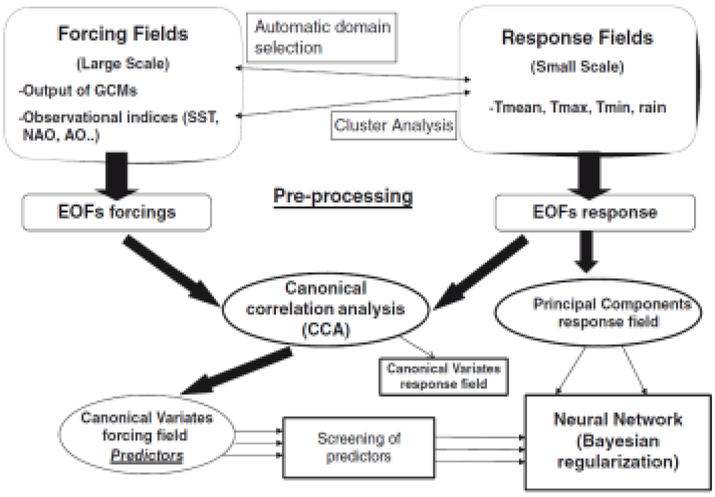
4.6.3 Operationally available EPS products

None

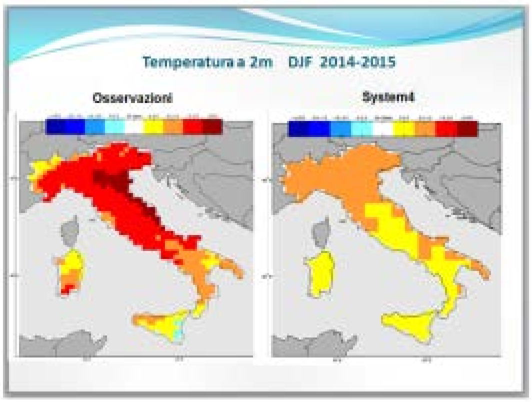
4.7 Long range forecasts (30 days up to two years) (Models, Ensemble, Methodology)

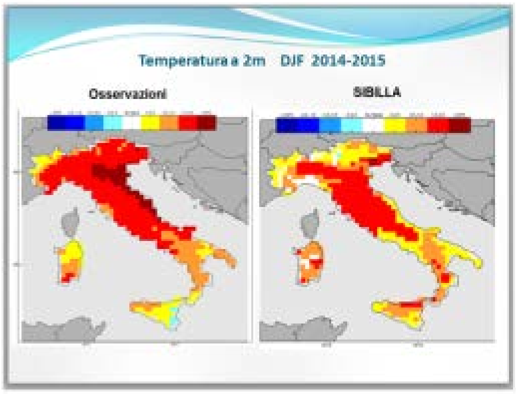
4.7.1 In operation

The Italian Air Force Met Service operates a neural network MOS-like statistical system called SIBILLA (Statistical Integrated Bayesian Information System for Large to Local area Analysis) to post-process the ECMWF seasonal forecasting system fields, in order to get a downscaling of the projections over the Italian area and correct possible systematic errors of the father numerical model. The following figures show the general operating scheme of the system and just an example of System4 and SIBILLA output maps.



A general scheme of the SIBILLA downscaling system.





An example of System4 and SIBILLA output maps

4.7.2 Research performed in this field

None

4.7.3 Operationally available products

None

5. Verification of prognostic products

5.1 Annual verification summary

Quality Control of forecast products through the unified system named VERSUS (VERification System Unified Survey) based on RDBMS system and a web-based GUI are carried out routinely at COMET. The development of a complete Conditional and Standard Verification Tool has been the first priority and outcome of the VERSUS project exploited in the COSMO consortium framework (started in 2006 and currently in Project Phase 7).

From a more general point of view the main purpose of VERSUS is the systematic evaluation of model performances in order to reveal, in a way different from the usual classical verification tools, model weaknesses. It is able to provide information providing hints which could be the causes of model deficiencies that can usually be seen in the operational verification.
The typical approach to Conditional Verification consist of the selection of one or several forecast products and one or several mask variables or conditions, which would be used to define for example thresholds for the product verification (e.g. verification of T_{2M} only for grid points with zero cloud cover in model and observations). Through the development of VERSUS software a unified, flexible and customizable tool – able to perform operational standard verifications, operational conditional verifications along with experimental standard and conditional verifications, in batch and interactive mode – has been achieved.

Statistical scores and scores plots are routinely produced at COMET for the following NWP models, in operation at COMET: COSMO-ME, COSMO-I7, for both surface and upper air parameters; COSMO-IT and ECMWF, only for surface parameters.
The basic verified weather parameters for all the models are:

- 2m temperature;
- 10m wind-speed and direction;
- 6h,12h,24h cumulated precipitation;
- MSLP;
- 2m dew point temperature;
- total cloud cover

along with forecasted upper air parameters:

- temperature;
- geopotential;
- wind-speed and direction;
- relative humidity and/or dew point.

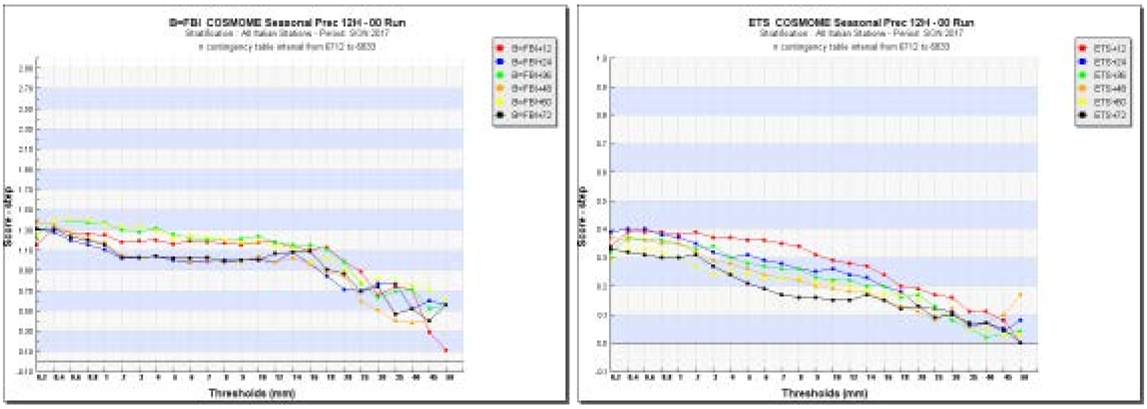
These datasets are regularly available every 3 hours (6 or 12 hours for upper-air) for all the Italian Meteorological stations. A set of stratifications in time are routinely performed as follows:

- Monthly mean
- Quarterly mean
- Yearly mean (mainly for the calculation of a Global quality index)

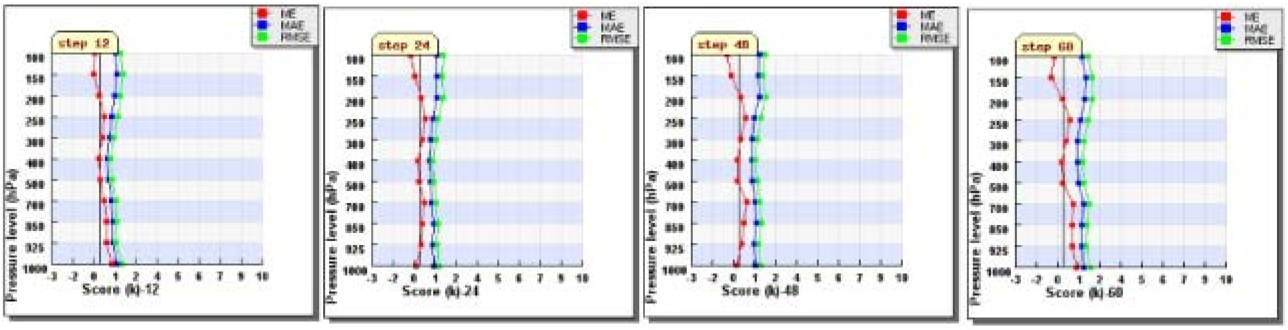
The scores can be also morphologically (or geographically) stratified in coastal, valley and mountain stations or Northern, Central and Southern Italy, all over Italy and so on.
The scores produced for continuous variable are: Mean Error, Mean Absolute Error, Root Mean Squared Error and their respective Skill Scores for accuracy. As reference scores both persistence, random chance and climatology can be used.
Scores produced for categorical events (e.g. precipitation) are computed from a 2x2 contingency table showing the frequency of “yes” and “no” forecasts and corresponding

observation. These contingency tables can be computed for different thresholds values. There are a quite large number of measure that can come out from such a table and all of them can be computed through the use of VERSUS software. Among these: frequency bias, probability of detection, false alarm ratio, equitable threat score, odds ratio.

In the following figures some verification plots are shown as an example for COSMO-ME model 00UTC run, for 12h cumulated precipitation and upper air temperature fields for period SON 2017.



12h cumulated precipitation FBI and ETS for SON 2017 (all Italian Stations)



Upper-air Temperature verifications for COSMO-ME model 00UTC run - SON 2017 (All Italian TEMP stations)

5.2 Research performed in this field

At present not all types of observations can be processed in VERSUS software, for example satellite and radar observations. In future release, it has been planned to include the use of non conventional observation datasets (e.g. raingauges, radar, satellite) and gridded observations (e.g. precipitation analysis).In parallel with the operational verification tasks, the research activities of the Italian Meteorological Service in this field are coordinated within the Working Group on “Verification and Case Studies” of the COSMO Consortium *(http://www.cosmo-model.org/content/tasks/workGroups/wg5/default.htm)*.

6. Plans for the future (next 4 years)

6.1 Development of the GDPFS

6.1.1 Major changes in the operational DPFS which are expected in the next year

6.1.2 Major changes in the operational DPFS which are envisaged within the next 4 years

6.2 Planned Research Activities in NWP, Nowcasting, Long-range Forecasting and Specialized Numerical Predictions

6.2.1 Planned Research Activities in NWP

Calibration of the COSMO EPS short range ensemble prediction system.
Improvement of convection permitting model forecast up to 1km grid spacing.

6.2.2 Planned Research Activities in Nowcasting

6.2.3 Planned Research Activities in Long-range Forecasting

For the near future our plans are: to train SIBILLA starting from the new ECMWF seasonal forecasting system (SEAS5) datasets; to calibrate the system not only by means of observational data but also using reanalysis data; to analyze the feasibility of a filtering, during the training and the operational post-processing phases, of seasonal forecasting ensemble members making use of monthly forecasts; to broaden the number and type of predictors and predictands currently used.

6.2.4 Planned Research Activities in Specialized Numerical Predictions

7. Consortium

7.1 System and/or Model

COSMO, the Consortium for Small-scale Modelling, consists of the weather services of Germany (DWD), Greece (HNMS), Israel (IMS), Italy (ReMet), Poland (IMGW-PIB), Romania (NMA), Russia (Roshydromet), and Switzerland (MeteoSwiss).

The COSMO modelling system supports three main applications, namely, regional numerical weather prediction (NWP) including data assimilation (DA), regional climate scenario calculations (CLM), and air quality (chemical weather) simulations (ART).

The *COSMO Model* (http://cosmo-model.org/content/model/general/default.htm) is a nonhydrostatic limited-area atmospheric prediction model. It has been designed for both operational numerical weather prediction (NWP) and various scientific applications on the meso-β and meso-γ scale. The COSMO Model is based on the primitive thermo-hydrodynamical equations describing compressible flow in a moist atmosphere. The model equations are formulated in rotated geographical coordinates and a generalized terrain following height coordinate. A variety of physical processes are taken into account by parameterization schemes.

Besides the forecast model itself, a number of additional components such as data assimilation, interpolation of boundary conditions from a driving model, and postprocessing utilities are required to run the model in NWP mode, climate mode or for case studies.

7.1.1 In operation

Country	Deterministic System Grid spacing (km)	Ensemble DA System Grid spacing (km) / number of members	Ensemble Pred. System Grid spacing (km) / number of members
Germany	2.8	2.8 / M40 (operational at DWD since 03/2017)	2.8 / M20

Switzerland	6.6 and 1.1	2.2 / M21	2.2 / M21
Italy	5.0 and 2.2	7.0 / M41 2.2 / M21 (pre-operational)	7.0 / M40
Greece	7.0 and 2.2	-	-
Poland	7.0 and 2.8	-	2.8 / M20
Romania	7.0 and 2.8	-	-
Russia	13.2, 7.0, 2.2 and 1.1	-	-
Israel	7.0 and 2.8	-	-

Table 1: Overview of the operational regional NWP systems at the COSMO members (Dec. 2017)

COSMO running on hybrid HPC architectures

Over the course of seven years, an extension of the COSMO model which is capable of running on hybrid HPC architecture with accelerators (NVIDIA GPUs) has been developed in the framework of the priority project POMPA.

Since spring 2016, MeteoSwiss operates its COSMO models on a novel GPU-based supercomputer (Piz Kesch) on 192 GPUs. With this system, COSMO demonstrates the capability of its modelling system to provide highest-resolution forecasts (a 1.1 km mesh-size model is among the highest-resolved operational NWP models in Europe; https://www.geosci-model-dev-discuss.net/gmd-2017-230/) on moderately-priced emerging hardware architectures. This is the worldwide first application of such a hybrid technology for operational weather forecasts.

COMet is also working on implementing COSMO operationally on a GPU-based supercomputer. The new priority project CEL-ACCEL started to extend new COSMO-EULAG dynamical core on modern supercomputing architectures (GPU and manycore CPUs).

The GPU version of COSMO model is now being introduced in the official COSMO version providing the possibility to run COSMO flexibly either on conventional or on hybrid technology with accelerators.

7.1.2 Research performed in this field

There is a number of important ongoing priority projects (PP) and priority tasks (PT).

PP KENDA-O (Km-Scale Ensemble-Based Data Assimilation for High-Resolution Observations) continues to further improve the convective-scale data assimilation system to allow for its fully operational implementation and to further improve and extend the system for the use of new observation types including direct radar, satellite and aircraft data.

PP CDIC (Comparison of the dynamical cores of ICON and COSMO) continues testing dynamical cores of ICON and COSMO according to the decision tree for dynamical cores within the COSMO strategy of harmonization with ICON.

PP CELO (COSMO-EULAG Operationalization) continues work on implementing to the COSMO model the compressible EULAG dynamical core developed within the ECMWF PantaRhei project and coupling it with COSMO-ICON common physics.

PP $T^2(RC)^2$ (Revised Cloud Radiation Coupling) continues improvement of the cloud-radiation coupling while aiming at a better representation of aerosol and subgrid-scale clouds and at improving the computational efficiency of the code.

PP CALMO-MAX (CALibration of COSMO MOdel) continues development and evaluation of objective tuning methodology for COSMO model at the convection-permitting regime with 2.2 and 1.1 km horizontal grid spacings.

PP INSPECT (Intercomparison of Spatial Verification Methods for COSMO Terrain) continues testing and evaluation of new spatial verification methods, especially for convection-permitting EPS products, in close link with the international MesoVICT (Mesoscale Verification Inter-Comparison over Complex Terrain) project.

PP CEL-ACCEL is aimed at implementing the consistent anelastic/compressible COSMO-EULAG dynamical core (DC) within the C++ dynamical core framework of COSMO. The main deliverable is the high-resolution forecasting system ready for pre-operational testing on modern supercomputing architectures (GPU, manycore CPUs).

PP POMPA (Performance on Massively Parallel Architectures) succeeded in operational implementation of the COSMO model on the GPU-based computer architecture at MeteoSwiss and aims at merging of the GPU capability with the official model trunk containing new ICON physics packages.

PP SPRED (Studying Perturbations for the Representation of modeling uncertainties in Ensemble Development) continues work on improvement of spread/skill relation especially in the near-surface layer including development of methodologies for perturbations of surface parameters.

PT ConSAT (Consolidation of Surface to Atmosphere Transfer and its part 4) succeeded in implementation of the improved ICON version of the turbulence parametrisation to the COSMO model and continues its further development as well as the revision and improvement of the surface to atmosphere transfer scheme.

PT TERRA Nova is testing the new version of the soil module TERRA to provide better understanding of the strength and limitations of the latest release of the TERRA module.

PT SAINT (Snow cover Atmosphere INTeractions) continues to improve the current multi-layer snow cover scheme. The PT is expected to deliver a well validated, stable version, of an improved multilayer snow cover scheme included into the official versions of COSMO and ICON models.

PT AEVUS (Analysis and Evaluation of TERRA_URB Scheme) is aimed at testing the TERRA_URB scheme by means of evaluation and comprehensive verification of the performance of the code and at improving the calibration of the namelist parameters.

PT CIAO (implementation of the Bechtold Convection scheme In COSMO model: deterministic And ensemble-mOde tests) assess the sensitivity of COSMO forecast skill, in both deterministic and ensemble mode, to the use of newly implemented Bechtold convection scheme.

7.2 System run schedule and forecast ranges

See section 4.1

7.3 List of countries participating in the Consortium

Currently, the following national meteorological services are COSMO members:

Germany	DWD	Deutscher Wetterdienst
Switzerland	MCH	MeteoSchweiz
Italy	ReMet	Aeronautica Militare-Reparto per la Meteorologia
Greece	HNMS	Hellenic National Meteorological Service

Poland	IMGW	Institute of Meteorology and Water Management
Romania	NMA	National Meteorological Administration
Russia	RHM	Federal Service for Hydrometeorology and Environmental Monitoring
Israel	IMS	Israel Meteorological Service

The following regional and military services within the member states are also participating:

Germany	AGeoBw	Amt für GeoInformationswesen der Bundeswehr
Italy	CIRA	Centro Italiano Ricerche Aerospaziali
Italy	ARPAE-SIMC	ARPAE Emilia Romagna
Italy	ARPA Piemonte	Agenzia Regionale per la Protezione Ambientale Piemonte

In 2017 the COSMO model has been used *operationally* under license agreement by the national meteorological services of the United Arab Emirates (NCMS), Brazil (IMET), Oman (DGMAN), Botswana (BMS) and Namibia (NMS), as well as by the Brazilian Navy (DHN) and Turkmenistan (Turkmen Gidromet).

The annual licence fee for the *operational* usage of the COSMO model is 20,000 € per service, but is not charged for developing countries. This allows e.g. Burkina Faso, Egypt, Georgia, Indonesia, Kenya, Madagascar, Malawi, Mozambique, Nigeria, Philippines, Rwanda, Sudan, Tanzania, Ukraine, Vietnam and Zimbabwe to use the COSMO model free of charge.

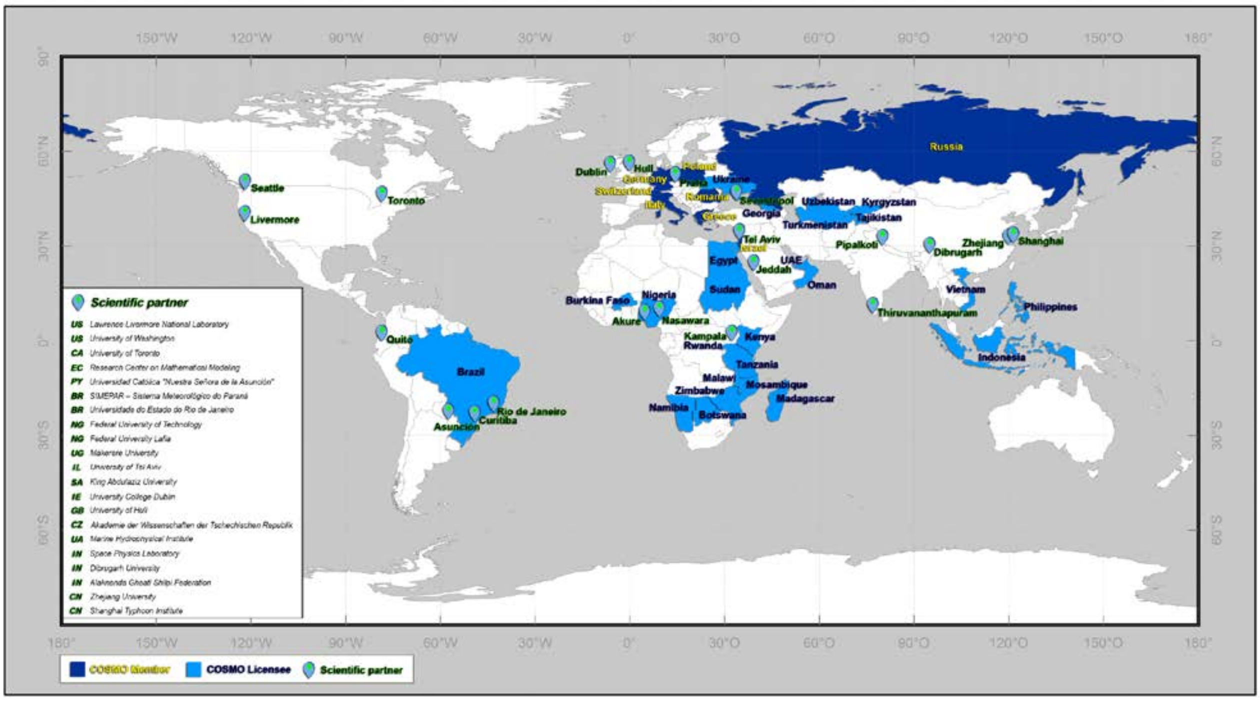
Besides the COSMO Licensees already running the COSMO-Model in daily production, there are a few weather services evaluating usage of our model system. Among them are the national weather services of Armenia, Azerbaijan, Pakistan and South Africa. They have a scientific license at the moment.

All services receive tailored lateral boundary data from DWD's global model ICON up to four times per day.

The funds acquired from license fees are used to promote collaboration between COSMO partners within the working groups (WG) and scientific projects (PP/PT), trainings of the service staff (ICON and COSMO-CLM/ART Training Courses) as well as to support science dissemination during the annual ICCARUS User Seminar and other external scientific meetings and conferences.

Scientific cooperation

In addition to the national weather services there is a long list of research partners at universities or research institutes. Their interest in the COSMO-Model is manifold, for example:
- doing simulations for special domains and weather situations,
- investigating and further developing physical parameterizations,
- developing extra components for the model system,
- running data assimilation.



Map of the COSMO members and licensees
as well as scientific partners (only for non-COSMO member countries) in 2017.

7.4 Data assimilation, objective analysis and initialization

7.4.1 In operation

The data assimilation system for the COSMO model is based on the observation nudging technique. The variables nudged are the horizontal wind, temperature, and humidity at all model layers, and pressure at the lowest model level. The other model variables are adapted indirectly through the inclusion of the model dynamics and physics in the assimilation process during the relaxation. At present, radiosonde, aircraft, wind profiler, surface synoptic, ship, and buoy data are used operationally. For model configurations at the convection-permitting scale, radar-derived precipitation rates are included additionally via the latent heat nudging method. If nudging is used for data assimilation, an extra initialization is not required. Separate two-dimensional analysis schemes based on the successive correction technique are deployed for the depth of the snow cover and the sea surface temperature, and a variational scheme for the soil moisture.

Gradually, the default data assimilation system based on nudging technique is being replaced with Local Ensemble Transform Kalman Filter (LETKF, see section 7.4.2).

As for COSMO-LEPS, the following initialization is performed: the upper-level initial conditions of the individual members are interpolated from the ECMWF EPS elements providing the boundaries. On the other hand, the initialization at the lower boundary is performed by taking the surface fields of COSMO-EU, including soil temperature and humidity, and blending them with those provided by ECMWF.

On January 20 2017 the global numerical weather prediction system ICON run at DWD introduced hybrid combination (En-Var) of an Ensemble-Kalman Filter (EnKF) with the variational 3D-Var scheme, which allows for using the Ensemble-based information of flow-dependent error covariance matrices in the deterministic analysis. In the result ICON model forecasts used as an initial and boundary conditions for several COSMO model operational setups has substantially improved.

7.4.2 Research performed in this field

The focus of research efforts lies on the development of a novel data assimilation scheme based on the Local Ensemble Transform Kalman Filter (LETKF) technique in the frame of the KENDAO priority project. Its main purpose is to deliver perturbed initial conditions for convection-permitting ensemble prediction systems as well as initial conditions for such deterministic systems. For more information, see

http://www.cosmo-model.org/content/tasks/priorityProjects/kendaO/default.htm.

Following encouraging test results, including comparison with nudging, the project aims at operationalization and further development of the LETKF assimilation system. The current research includes, in between,:

- use of remote sensing data (3D radar radial velocity, satellite soil moisture analysis, SEVIRI radiance, GNSS slant total delay) and observations related to the boundary layer, humidity, cloud and precipitation, and surface
- algorithmic developments and extensions of the system, including multi-scale multi-step approaches, and particle filters (PF)
- work started for implementing KENDA in ICON-LAM
- exploratory research towards hybrid extensions of the system LETKF-PF

After pre-operational testing, the system was already implemented for operational use in MeteoSwiss in 2016 and implemented preoperational at DWD , ARPAE-SIMC and COMET.

7.5 Operationally available Numerical Weather Prediction (NWP) Products

See section 4.3.3.

As for COSMO-LEPS, the available operational products include the following:

- “deterministic products”, different weather scenarios (one per member) for the model variables, at several forecast ranges
- “probabilistic products”, probability of exceedance of user-defined thresholds for the different model variables, at several forecast ranges
- “pointwise products”, meteograms over station points in terms of the main model variables.

7.6 Verification of prognostic products

See section 5 in reports of COSMO members.

7.7 Plans for the future (next 4 years)

7.7.1 Major changes in operations

See section 6.1 in reports of COSMO members

7.7.2 Research performed in this field

The COSMO Science Plan (http://www.cosmo-model.org/content/consortium/reports/sciencePlan_2015-2020.pdf) calls for harmonization of developments of COSMO and ICON models in the time horizon of 2020. ICON refers to the nonhydrostatic ICON Modelling Framework, jointly developed in recent years by DWD and Max-Planck-Institute for Meteorology. In 2016 the first phase of the process aiming at the unification of ICON and COSMO physics packages was accomplished with an approval for preparation of a new COSMO model version V5.05 including the complete set of the ICON versions of the physical-process parameterization schemes. Version this is planned for an offcial release in 2018. Note however, that some differences between the ICON and COSMO version of parameterization schemes remain, and will probably ever be present, because of the difference in the code structure of the two models and (importantly) because of the difference in resolution at which the models are run. The utilization of the ICON parameterization schemes allows COSMO to benefit from the new developments already implemented in ICON and their further improvements, and allows using more efficiently the limited COSMO human resources for further developments. That accomplishment paves the way for the next unification step aiming at the evaluation of ICON-LAM (Limited Area Mode of ICON).

The ICON model code is almost ready to be used for limited-area mode numerical weather prediction. The main missing component is the integration of various forward operators needed for the high-resolution ensemble data assimilation system KENDA. In addition, the KENDA system itself requires substantial further development to be adapted to the ICON data structures.

At the ICON Training Course 2017, representatives from IMGW, IMS, NMA, ReMet and Roshydromet have been able to perform their first simulations with ICON-LAM. Preliminary comparisons of ICON-LAM and COSMO in hindcast mode at DWD show comparable or even improved scores for ICON-LAM. The boundary conditions currently used by the COSMO members for the COSMO-model, namely ICON or IFS, can also be used for ICON-LAM. A major advantage of ICON-LAM compared to the COSMO-model is the two-way nesting capability. This means that the grid spacing can be locally refined within one simulation. The boundary data are then provided from the original coarser grid. Using the optional two-way interaction, information from the finer resolved grid is also transferred to the original coarse grid.

COSMO strategy calls also for a unified software framework for data assimilation utilizing innovative ensemble KENDA system developed by COSMO in recent years. The operational implementations of KENDA at MeteoSwiss since 2016 as well as at DWD since March 2017 constitute a milestone and a significant achievement in implementing this strategy. In Italy two different configurations of KENDA are pre-operational: the 2.2km one is running at regional agency ARPAE since May 2017 and COMet (the operational centre of ReMet) since September 2017 and the 7km one is running at COMet (10km from September 2016 to November 2017), in order to substitute the COMet-LETKF system, operational since 2011.

With the fast development of COSMO software, the consortium develops dedicated tools and standards to ensure high quality of its codes and to control and coordinate their further developments. These efforts are supported by a purchase of a new COSMO web server and further development of COSMO web pages to allow for better exchange of information for COSMO scientists and its governing bodies.

8. References: Give references to the sources where more detailed descriptions of different components of the data processing and forecasting system can be found, including WEB sites addresses.