OFFSHORE WIND ENERGY DEVELOPMENT IN THE ADRIATIC SEA: THE P.O.W.E.R.E.D. PROJECT AS PLANNING POLICY

Università Politecnica delle Marche, Ancona, May 2013

"Attività di modellistica numerica previsionale meteorologica al Servizio IdroMeteoClima di ARPA Emilia-Romagna"

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Organization:
ARPA SIMC

REGIONE MARCHE

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Cross Border Cooperation 2007 2013

POWERED
green energy in Adriatic sea

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7. Some Applications
8. Future developments

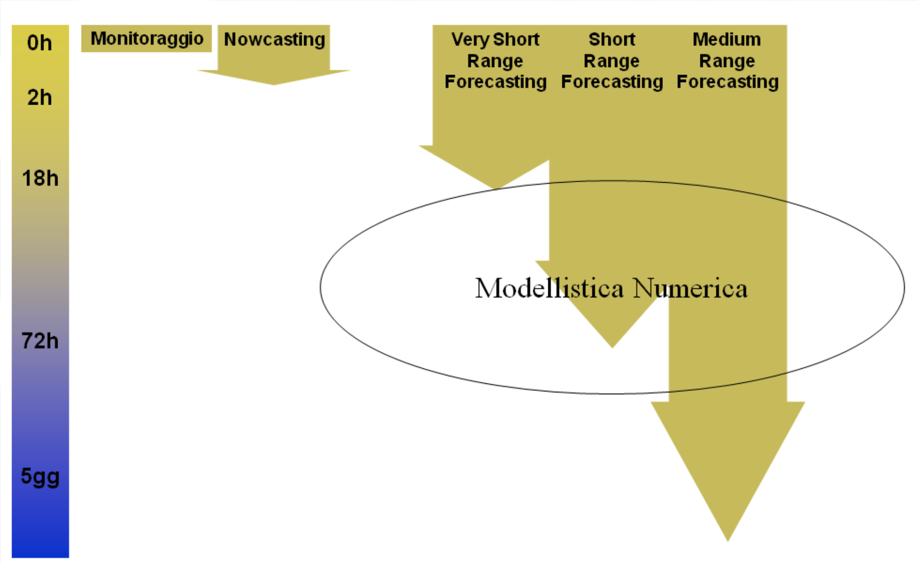
Numerical Weather Prediction Models

Weather forecasting, beyond the few hours range of nowcasting, is completely based on the support given by Numerical Weather Prediction Models. Such models are based on the numerical translation of the physical equations describing atmospheric motions and processes.

- continuity equation $\frac{\partial \rho}{\partial t} = -\nabla.(\rho \tilde{V})$
- momentum equation $\frac{d\tilde{V}}{dt} = -2\tilde{\Omega}\times\tilde{V} - \alpha\nabla p - g\tilde{k} + \tilde{\tau}$
- thermodynamic equation

$$c_p \frac{dT}{dt} = Q + \frac{RT}{p}\omega$$

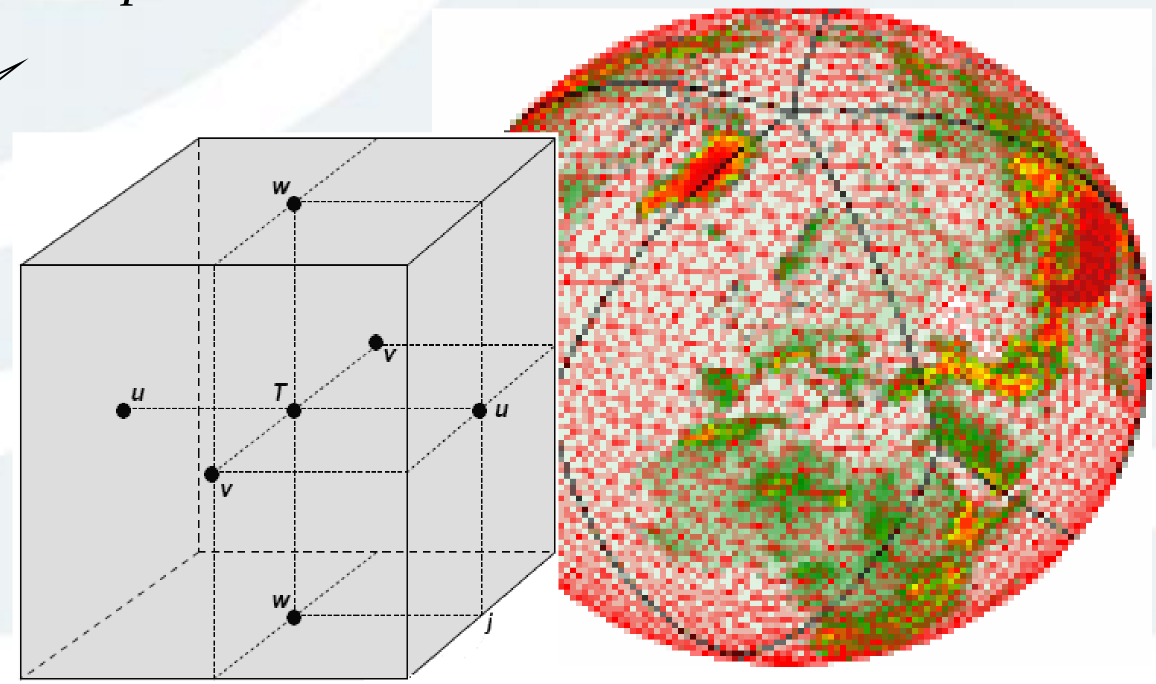
- humidity equation *dq/dt = evaporation – precipitation*
- surface equations *soil temperature and moisture*



When the "conservation" equations are discretized over a given grid size (typically a few km to several hundred km) it is necessary to add "sources and sinks" terms due to small scale physical processes that occur at scales that cannot be explicitly resolved by the models. As an example, the equation for water vapor conservation on pressure coordinates is typically written as

$$\frac{\partial \bar{q}}{\partial t} + \bar{u}\frac{\partial \bar{q}}{\partial x} + \bar{v}\frac{\partial \bar{q}}{\partial y} + \bar{\omega}\frac{\partial \bar{q}}{\partial p} = \bar{E} - \bar{C} + \frac{\partial \overline{\omega' q'}}{\partial x}$$

It is customary to call the left-hand side of the equation, the "dynamics" of the model which is computed explicitly



Numerical Weather Prediction Models

Numerical weather prediction models are usually divided in two major categories:

- **Global Circulation Models (GCM)**

  usually operated by the biggest Meteorological Centres, as ECMWF, DWD Germany, UK MetOffice, Meteo France, NCEP Washington

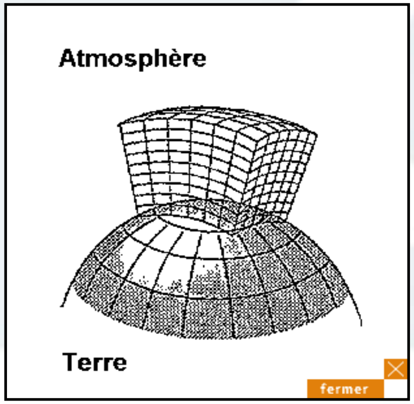
  GCMs integrate the models equations over the entire globe with a high vertical extension due to the necessity of describing also stratosphere/troposphere interaction.

  The global coverage of GCM induces a limit in the attainable horizontal resolution; this limit is given by the available computer resources.

The task of describe weather evolution with greater local accuracy, is usually committed to national weather services which have implemented national modelling operational suites based on

- **Limited area Models (LAM)**

  LAM integrate the model equations , with higher horizontal resolution,over a limited geographical domain.



Initial Conditions

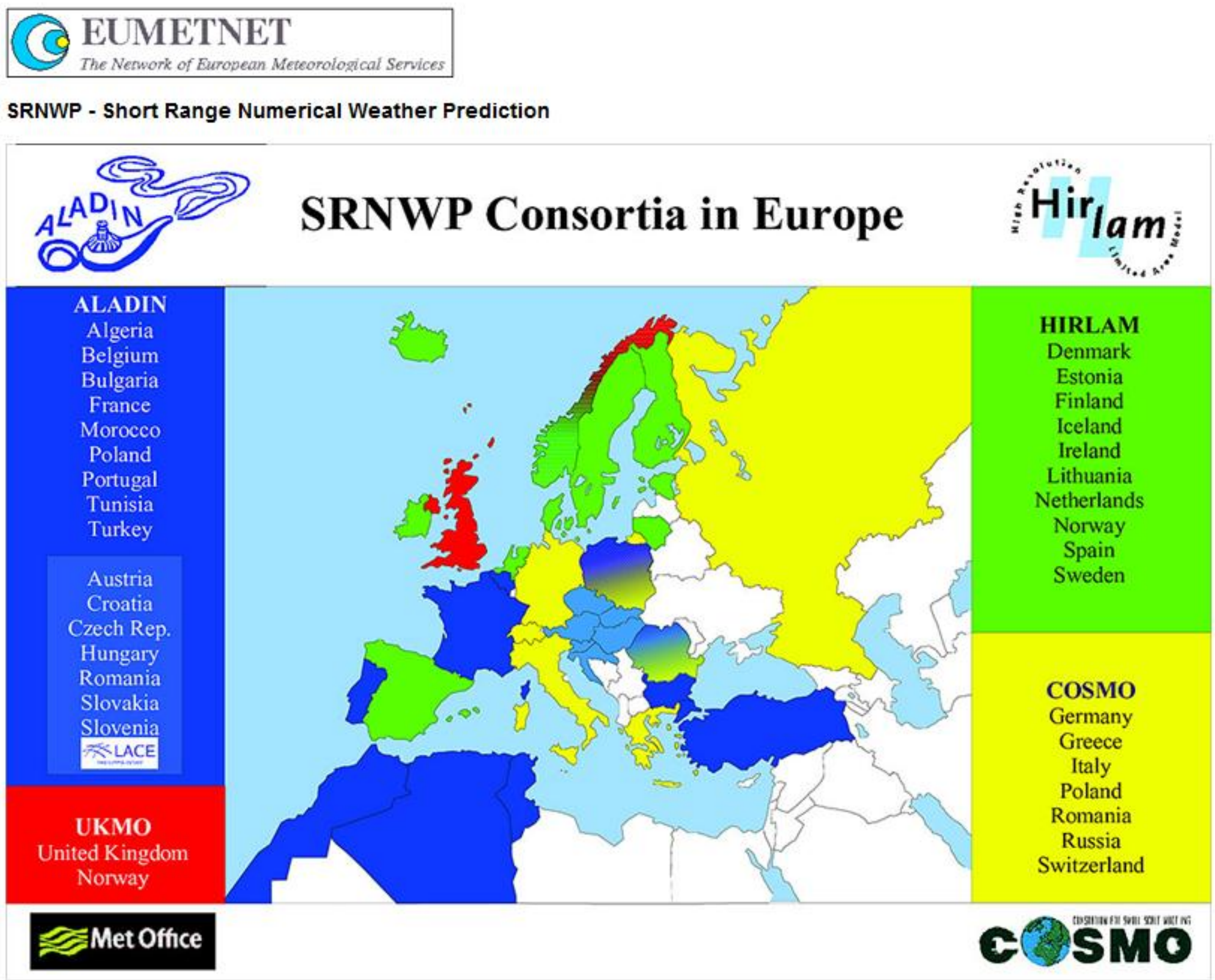
<u>Both GCM and LAM need an Initial Condition</u> (the state of the atmosphere at a specified time) to start the numerical integration of model equations.

The procedure to generate this initial condition is complicate as the forecast model itself and the former definition of Analysis has been now replaced by the concept of <u>Data Assimilation</u> procedure.

IC is defined on the base of sparse non/homogeneous meteorological observations coming from conventional networks (e.g. surface synop observations, upper air soundings from TEMP) and non convention data like those coming from satellite.

<u>The initial state</u>, obtained through the DA cycle, <u>must be "suitable"</u> to be properly interpreted by the model. The model is just a truncated and approximated representation of the atmosphere and inconsistencies can lead to "strange" <u>non physical model reactions</u> corrupting model forecast for the first part of the model integration.

NUMERICAL WEATHER PREDICTION IN EUROPE



EUMETNET/SRNWP AND NWP IN ITALY

Italy joined the COSMO Consortium with an international agreement signed USAM, the National Airforce Weather Service

www.cosmo-model.org

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Consortium for Small-scale Modeling

created: 1998

The Consortium for Small-scale Modeling (COSMO) was formed in October 1998. It's general goal is to develop, improve and maintain a non-hydrostatic limited-area atmospheric model, to be used both for operational and for research applications by the members of the consortium. Moreover, within a licence agreement, the COSMO model may be used for operational and research applications by other national (hydro-)meteorological services, universities and research institutes.

Participating national meteorological services

Today, the consortium, has as members these national meteorological services (presented in date-of-join order) :

DWD MCH USAM HNMS IMGW NMA RHM

Germany	DWD	Deutscher Wetterdienst
Switzerland	MCH	MeteoSchweiz
Italy	USAM	Ufficio Generale Spazio Aereo e 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

Other major members

Additionally, these regional and military services within the member states are also participating:

AGeoBw CIRA ARPA-SIMC ARPA Piemonte

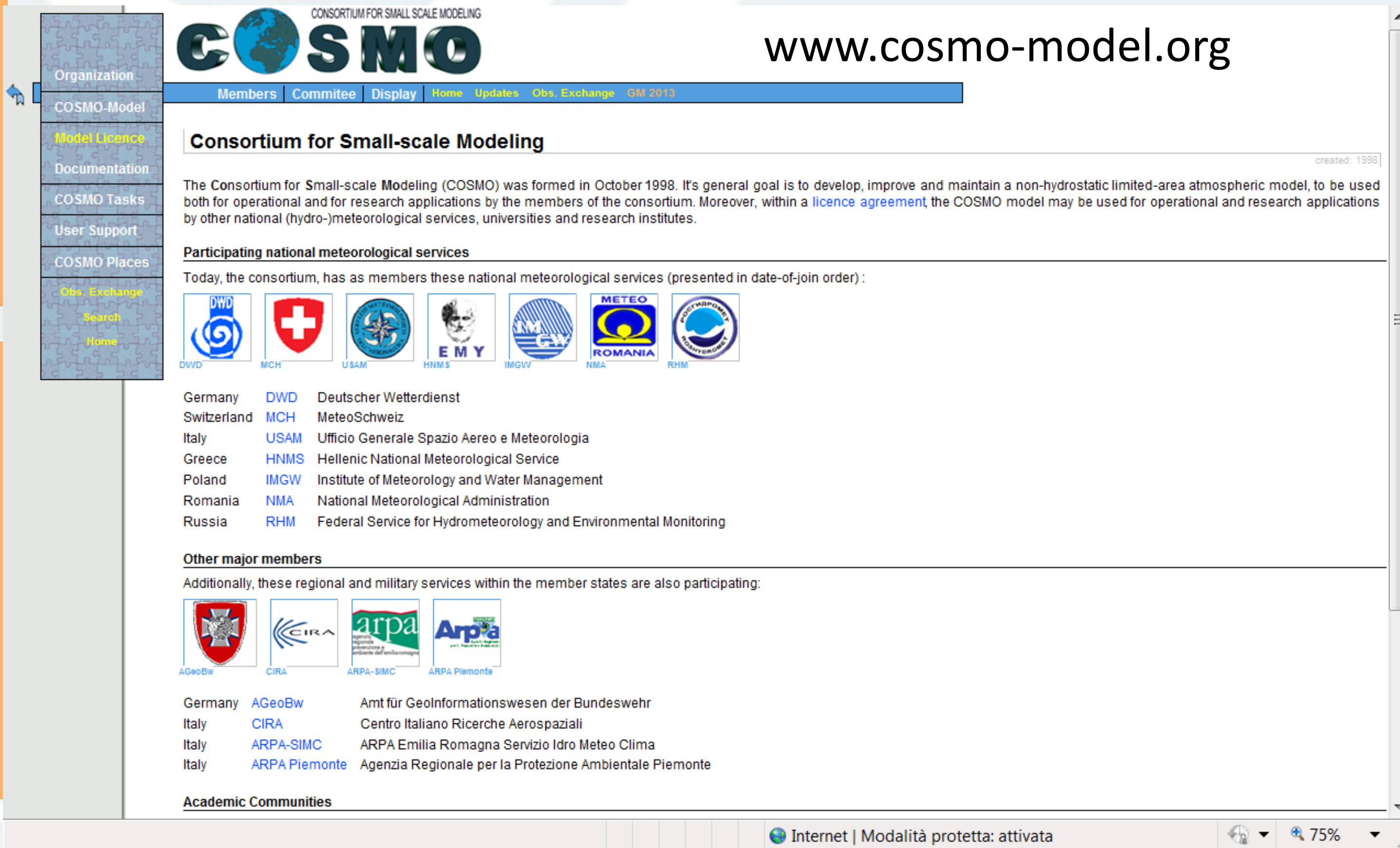
Germany	AGeoBw	Amt für GeoInformationswesen der Bundeswehr
Italy	CIRA	Centro Italiano Ricerche Aerospaziali
Italy	ARPA-SIMC	ARPA Emilia Romagna Servizio Idro Meteo Clima
Italy	ARPA Piemonte	Agenzia Regionale per la Protezione Ambientale Piemonte

ARPA SIMC and NWP in Italy

Italy joined the COSMO Consortium with an international agreement signed USAM, the National Airforce Weather Service

At National level,
USAM, ARPA SIMC and ARPA Piemonte signed the LAMI agreement to cooperate on the management and on the development of the national NWP operational suites.

Since 2004, LAMI is the official NWP system to support the National Civil Protection activities.
ARPA-SIMC has been included among the Centres of Competence of the National Civil Protection Sytem.



THE COSMO MODEL

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General Description: Model Dynamics and Numerics

see also: basic design | initial and boundary conditions | physical parameterizations | external parameters | code and parallelization | data assimilation
Last updated: September 2011

The COSMO-Model is based on the primitive hydro-thermodynamical equations describing compressible non-hydrostatic flow in a moist atmosphere without any scale approximations. A basic state is subtracted from the equations to reduce numerical errors associated with the calculation of the pressure gradient force in case of sloping coordinate surfaces. The basic state represents a time-independent dry atmosphere at rest which is prescribed to be horizontally homogeneous, vertically stratified and in hydrostatic balance.

The basic equations are written in advection form and the continuity equation is replaced by a prognostic equation for the perturbation pressure (i.e. the deviation of pressure from the reference state). The model equations are solved numerically using the traditional finite difference method. In the following we summarize the dynamical and numerical key features of the COSMO-Model.

Model Equations

- nonhydrostatic, full compressible hydro-thermodynamical equations in advection form
- subtraction of a hydrostatic basic state (reference atmosphere) at rest. Options for
  - a reference atmosphere defined with a constant Δt, with an increasingly negative vertical temperature gradient in the stratosphere and a limit to the vertical model extent.
  - a reference atmosphere based on a temperature profile
    $T_0(z) = T_{00} + \Delta t \, EXP(-z/h\_scal)$,
    approaching an isothermal profile in the stratosphere and no limits of the vertical model extent.

Prognostic Variables

- horizontal and vertical cartesian wind components (u,v,w)
- temperature (t)
- pressure perturbation (p', deviation from the reference state)
- specific humidity (q_v) and specific cloud water content (q_c)
- optionally: cloud ice content (q_i), specific water content of rain (q_r), snow (q_s) and graupel (q_g)
- optionally: turbulent kinetic energy (tke)

Diagnostic Variables

- Total air density
- 2 meter temperature
- 10 meter wind speeds
- maximal wind gust in 10 meter
- precipitation fluxes of rain and snow
- and much more ....

Coordinate System

- rotated geographical (lat/lon) coordinate system horizontally
- generalized terrain-following height-coordinate with user defined grid stretching in the vertical. Options for
  - base-state pressure based height coordinate
  - Gal-Chen height coordinate and
  - exponential height coordinate (SLEVE) according to Schär et al. (2002)

Internet | Modalità protetta: attivata 75%

THE COSMO MODEL

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General Description: Model Physical Parameterizations

see also: dynamics and numerics | initial and boundary conditions | basic design | external parameters | code and parallelization | data assimilation

Last updated: September 2011

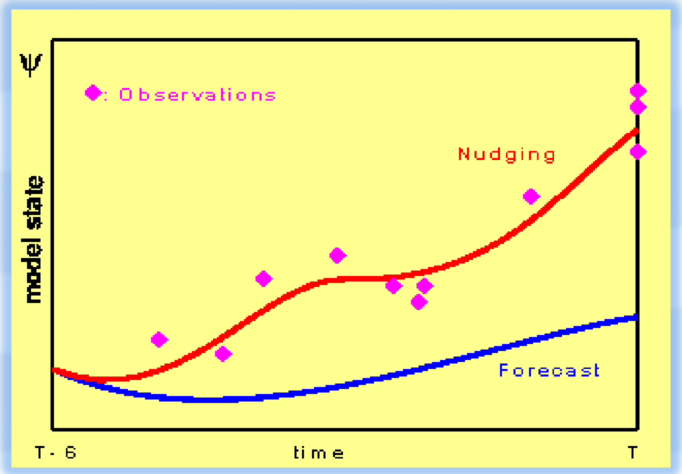
A variety of subgrid-scale physical processes are taken into account by parameterization schemes. Some parts of the present physics package of the COSMO-Model have been adapted from the former operational hydrostatic models EM/DM, but some are based on new developments or have been taken over by GME or the IFS. The following table gives a short overview on the parameterization schemes used operationally and on additional options implemented so far.

Grid-Scale Clouds and Precipitation	• Cloud water condensation and evaporation by saturation adjustment. • Precipitation formation by a bulk microphysics parameterization including water vapour, cloud water, cloud ice, rain and snow with 3D transport for the precipitating phases. • Option for a new bulk scheme including graupel. • Option for a simpler column equilibrium scheme.
Subgrid-Scale Clouds	• Subgrid-scale cloudiness is interpreted by an empirical function depending on relative humidity and height. A corresponding cloud water content is also interpreted. Option for a statistical subgrid-scale cloud diagnostic for turbulence.
Moist Convection	• Tiedtke (1989) mass-flux convection scheme with equilibrium closure based on moisture convergence. Option for a modified closure based on CAPE. • Reduced Tiedtke scheme for shallow convection only.
Radiation	• δ-two stream radiation scheme after Ritter and Geylen (1992) for short- and longwave fluxes (employing eight spectral intervals); full cloud-radiation feedback.
Subgrid-Scale Orography	• Subgrid-scale orography (SSO) scheme by Lott and Miller (1997) which deals explicitly with a low-level flow that is blocked when the subgrid-scale orography is sufficiently high.
Subgrid-Scale Turbulence	• Prognostic turbulent kinetic energy closure at level 2.5 including effects from subgrid-scale condensation and from thermal circulations. • Option for a diagnostic second order K-closure of hierarchy level 2 for vertical turbulent fluxes. • Preliminary option for calculation of horizontal turbulent diffusion in terrain following coordinates (3D Turbulence).
Surface Layer	• A Surface layer scheme (based on turbulent kinetic energy) including a laminar-turbulent roughness layer. • Option for a stability-dependent drag-law formulation of momentum, heat and moisture fluxes according to similarity theory (Louis, 1979).
Soil Processes	• Multi-layer version of the former two-layer soil model after Jacobsen and Heise (1982) based on the direct numerical solution of the heat conduction equation. Snow and interception storage are included. • Option for the (old) two-layer soil model employing the extended force-restore method still included.
Sea Ice Scheme	• Based on work by Mironov and Ritter (DWD)
FLake Model	• A Fresh-water Lake model by Mironov (2008)

Internet | Modalità protetta: attivata 75%

Assimilation by Nudging

Thus, the so-called nudging equation describes a continuous adaptation of the model values towards the observed values during the forward integration of the model (Fig.1).



Analysis of Atmospheric Fields: Nudging-Based Data Assimilation

3.1 Concept and Basic Ideas

Nudging or Newtonian relaxation consists of relaxing the model's prognostic variables towards prescribed values within a predetermined time window. Detailed descriptions of the technique can be found e.g. Anthes (1974), Davies and Turner (1977), and Stauffer and Seaman (1990). In the present scheme, nudging is performed towards direct observations, which is more appropriate for asynoptic data (Stauffer and Bao (1993)) and high-resolution applications than nudging towards 3-dimensional analyses (Stauffer and Seaman (1994)). A relaxation term is introduced into the model equations, and the tendency for the prognostic variable $\psi(\mathrm{x},t)$ is given by

$$\frac{\partial}{\partial t}\psi(\mathrm{x},t) = F(\psi,\mathrm{x},t) + \boxed{G_\psi \cdot \sum_{k_{(obs)}} W_k(\mathrm{x},t) \cdot [\psi_k^{obs} - \psi(\mathrm{x}_k,t)]} \qquad (3.1)$$

F denotes the model dynamics and physical parameterizations, ψ_k^{obs} the value of the k^{th} observation influencing the grid point x at time t, x_k the observation location, G_ψ a constant called nudging coefficient (currently set to $12 \cdot 10^{-4} s^{-1}$ for surface pressure and $6 \cdot 10^{-4} s^{-1}$ for the other assimilated quantities), and W_k an observation-dependent weight. This weight always takes values between 0 and 1 (except for surface pressure, cf. Section

NUMERICAL MODELLING AT ARPA-SIMC

COSMO: International cooperation

LAMI:National cooperation

DPCN: support and coordination through specific agreementsNational

Numerical Modelling
ARPA-SIMC

Deterministic forecasting

COSMO I7 (+72)

COSMO I2 (+48)

Numerical Modelling at ARPA-SIMC

COSMO: International cooperation

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Numerical Modelling ARPA-SIMC

Deterministic forecasting

COSMO I7 (+72)

COSMO I2 (+48)

CINECA Supercomputing resources

ARPA SIMC LINUX cluster

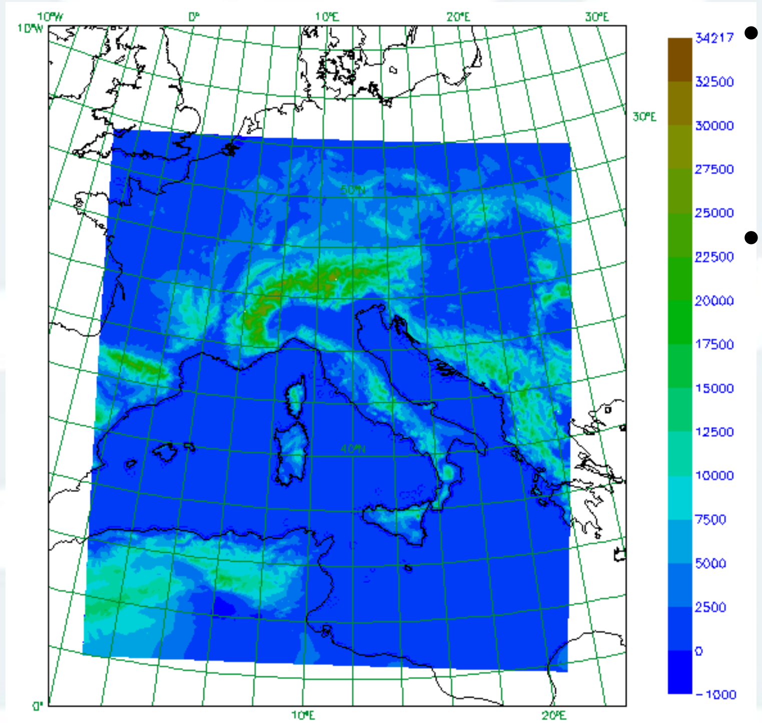
Operational @ CINECA

- Twice per day at 00 and 12 UTC
- Time range + 72 hours
- Horizontal Resolution ~ 7km
- BCs from ECMWF IFS (15 km h.r.); BC frequency 3 hours
- IC through Nudging of observations

Test Suite @ CINECA

Hot Back-up@ CINECA

COSMO I7



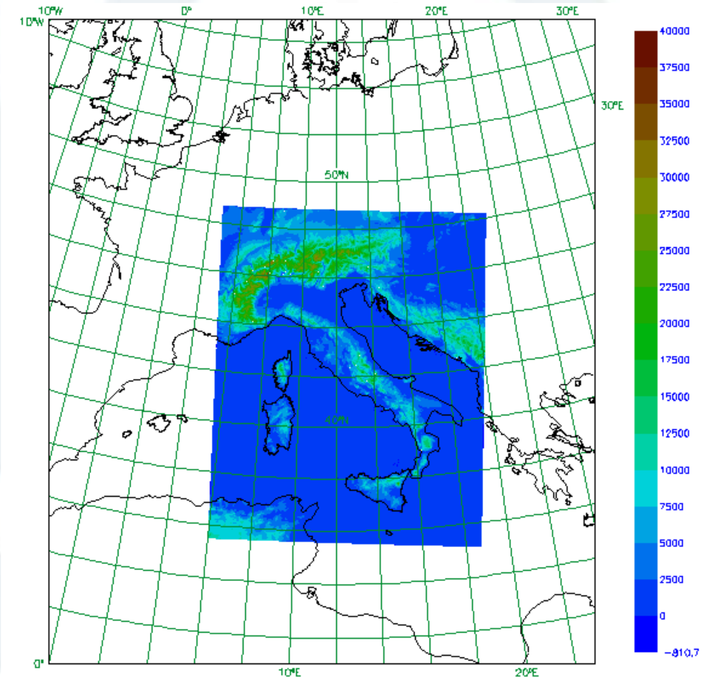
Back-up @SIMC

- Twice per day at 00 and 12 UTC
- Time range + 72 hours
- Horizontal Resolution ~ 7km
- BCs from DWD GME (20 km h.r.); BC frequency 1 hour
- IC through Nudging of observations

Operational @ CINECA

- Twice per day at 00 and 12 UTC
- Time range + 48 hours
- Horizontal Resolution ~ 2.8km
- BCs from COSMO I7; BC frequency 1 hour
- IC through Nudging of observations

COSMO I2



The major difference compared to COSMO I7 is the switch-off of the parametrized convection

Test Suite @ CINECA

Hot Back-up@ CINECA

Numerical Modelling at ARPA-SIMC:
Major Ongoing Developments

Numerical Modelling
ARPA-SIMC

Deterministic forecasting

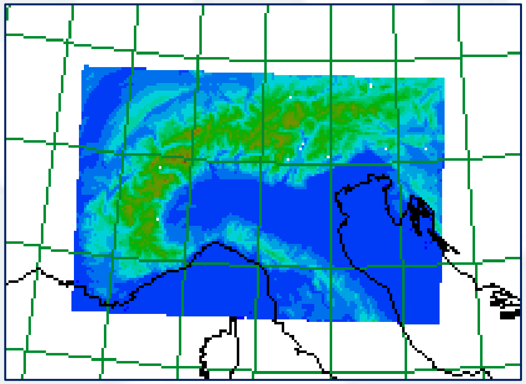
- COSMO I7 (+72)
- COSMO I2 (+48)
- COSMO I2 (+18)

Very short Range
Better support during the monitoring phases related to Civil Protection Alerts

Pre-operational @ SIMC

COSMO RUC

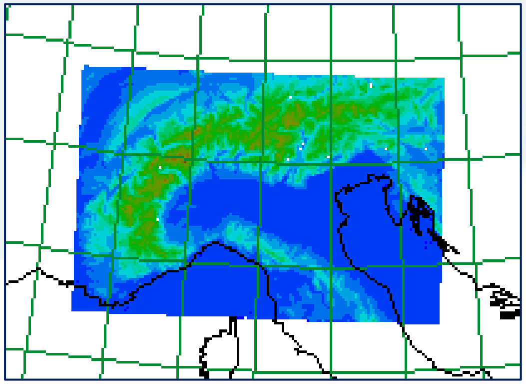
- Eight times per day at 00,03,06,09,12,15,18,21 UTC
- Time range + 18 hours
- Horizontal Resolution ~ 2.8km
- BCs from COSMO I7; BC frequency 1 hour
- IC through Nudging of observations

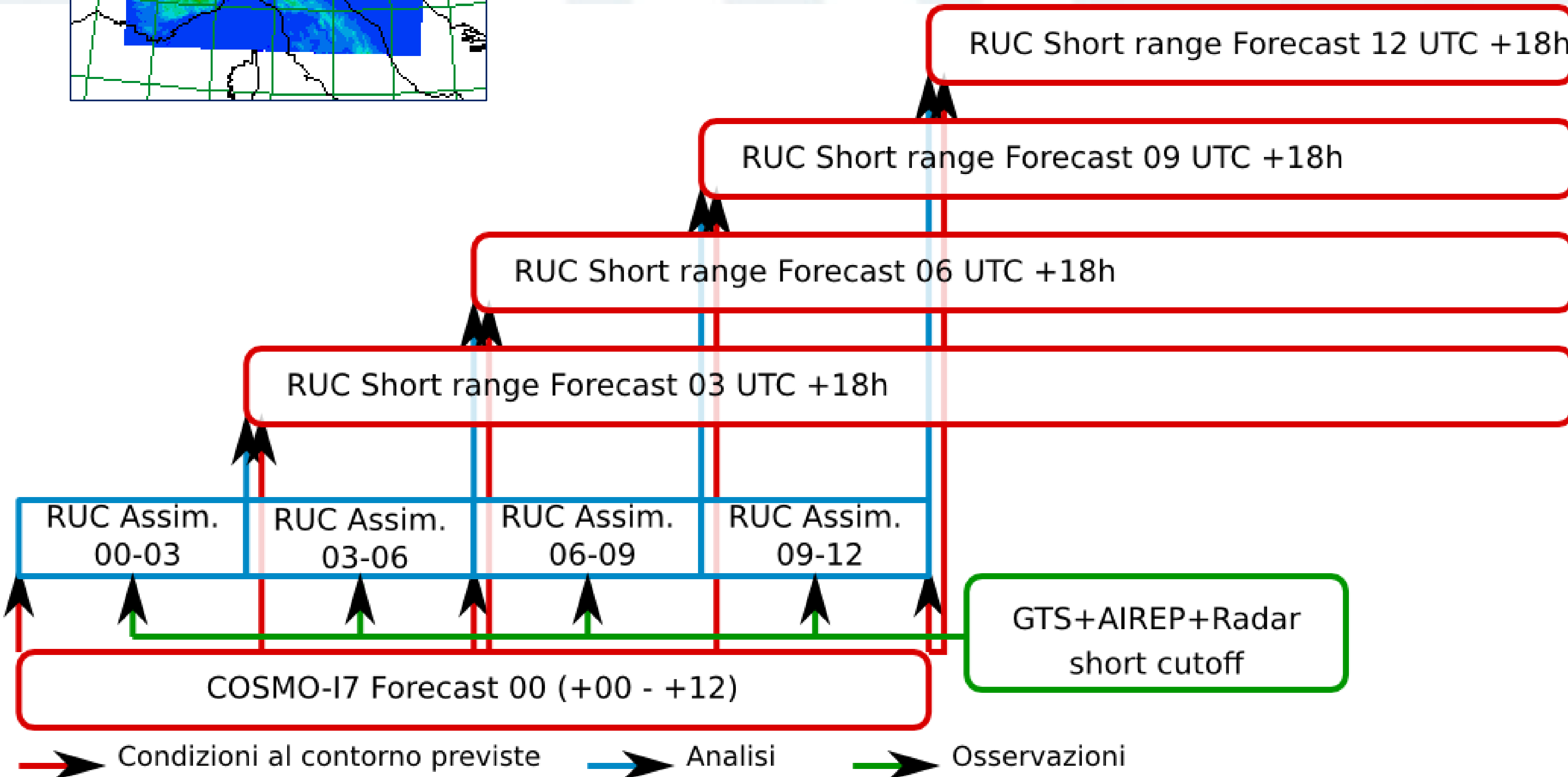


At present the major difference compared to COSMO I2 is assimilation of Radar estimated rain rate by applying the Latent Heat Nudging technique.

Forecasts available (after this trial phase) after two hours from the nominal time of the start of the forecast.

COSMO RUC scheme





NUMERICAL MODELLING AT ARPA-SIMC: MAJOR ONGOING DEVELOPMENTS:

IMPLEMENTATION AND TEST OF THE NEW ENSEMBLE BASED DATA ASSIMILATION SCHEME KENDA

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Priority Project "KENDA"
Km-Scale Ensemble-Based Data Assimilation

Last updated: 6 Jun 2012

Project leader: Christoph Schraff (DWD)

Introduction

SET EDIT ON

The **aim** of the project is to develop a novel ensemble-based data assimilation system for the convective scale (i.e. 1 - 3 km model mesh-size) and to show that it works scientifically and gives a systematic positive impact (compared to nudging), in particular in convective situations, but also for low stratus conditions and near steep orography. The system has to be able to provide the initial conditions for convective-scale ensemble forecasting.

Two approaches have been envisaged at the beginning of the project, that is the Local Ensemble Transform Kalman Filter (**LETKF**, see Hunt et al., 2007) and the Sequential Importance Resampling (**SIR**) filter (van Leeuwen, 2003). The distribution of the resources should depend on the relevance of **non-Gaussianity**. In some preliminary investigation, only moderate deviations from Gaussianity have been found in most observation minus forecast statistics. Therefore, all the resources from the weather services in COSMO are being devoted to the LETKF in view of the fact that for this method, successful meteorological data assimilation applications exist and less practical problems are expected than for the SIR approach. Then, the more basic research required for the latter should rely mainly on resources from cooperating universities and research institutes.

Motivation

Our strategy for (very) short-range NWP in the coming years is to deliver not only deterministic forecasts, but a representation of the probability density function (PDF) for the atmospheric state, e.g. in the form of probabilities assigned to members of an ensemble running at a mesh-size of about 1 - 3 km. Furthermore, the use of indirect observations at high frequency is considered to become more important in the future.

Compared to larger scales, several conditions relevant for data assimilation are much more predominant in the convective scale. These include non-Gaussian PDFs, flow-dependent and poorly-known balance, and strong non-linearity. Therefore, it is considered more appropriate for the future **to develop a separate data assimilation scheme for the convective scale** and use a potentially different (but in practice similar) approach for a generalised system for global and regional modelling. Such a system combining global and regional modelling is being developed in the form of a global non-hydrostatic model with regional grid refinement at DWD and MPI Hamburg in the project ICON. Its analysis component will be based a hybrid 3DVAR (PSAS - physical space analysis system) - LETKF system.

Thus, an alternative data assimilation technique appropriate for the convective scale needs to be developed. However, the problem of convective-scale data assimilation is far from being solved nowadays. The main efforts by other groups and weather services in Europe are directed mainly towards 3D- and 4DVAR, but it is not clear how well this will work on these scales. For sure, developing a new 4DVAR system would require huge efforts. In the light of the human resources in COSMO, which are more limited than within MeteoFrance/HIRLAM/HARMONIE, let alone the UK Met Office, embarking on this approach would imply the risk of always lagging behind the other groups.

More recently, ensemble approaches, and in particular (variants of) the Ensemble Kalman Filter, have received increased attention (above all in USA). They usually require significantly less resources for development. Moreover, they can naturally be used to provide the initial conditions for convective-scale Ensemble prediction systems and are therefore much better suited for forecasting and delivering representations of the PDFs. By embarking on this approach, COSMO can attain a strong position within Europe with a chance for leadership in this area.

COSMO

Accordo “LAMI”
USAM ARPA Piemonte

Attività Modellistica
ARPA-SIM

COSMO I7 (+72)

COSMO I2 (+48)

Previsione Deterministica

COSMO

Accordo “LAMI”
USAM ARPA Piemonte

Attività Modellistica
ARPA-SIM

COSMO I7 (+72)

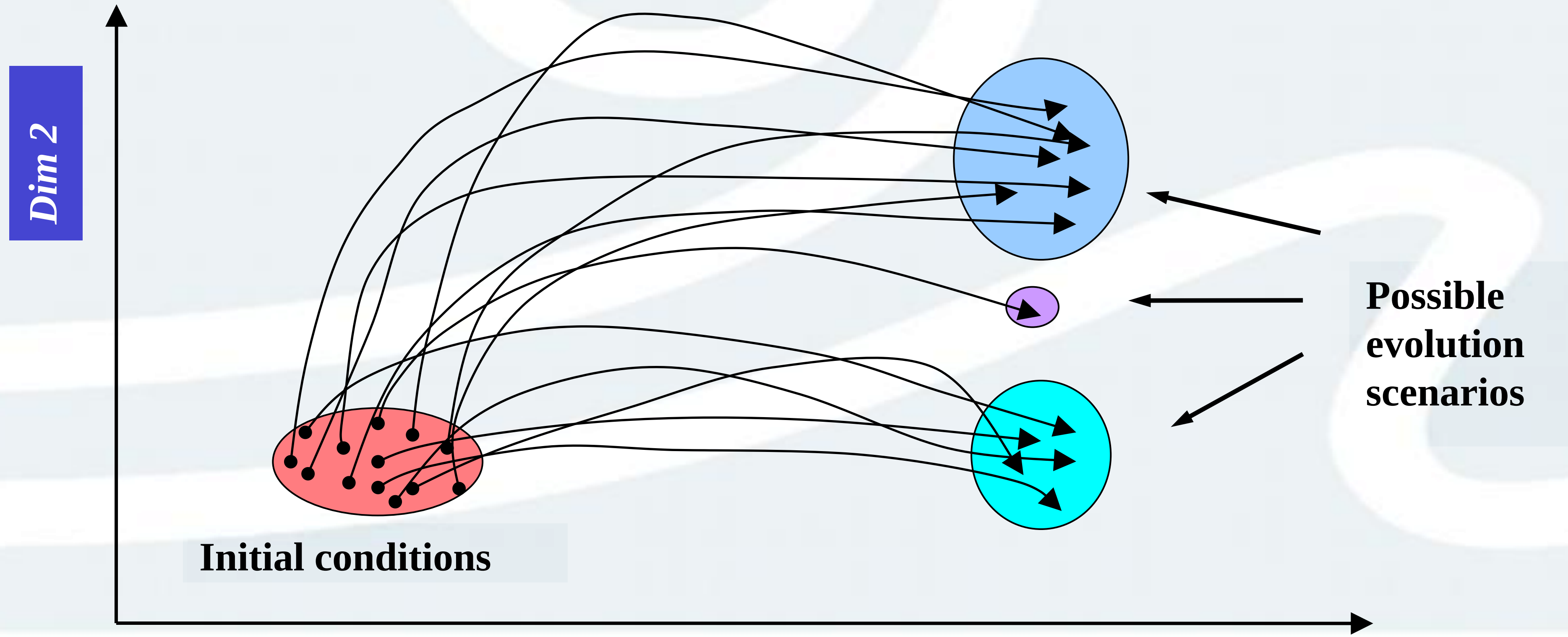
COSMO I2 (+48)

Previsione Deterministica

Ensemble forecasting

COSMO
LEPS (+132)

ENSEMBLE FORECASTING



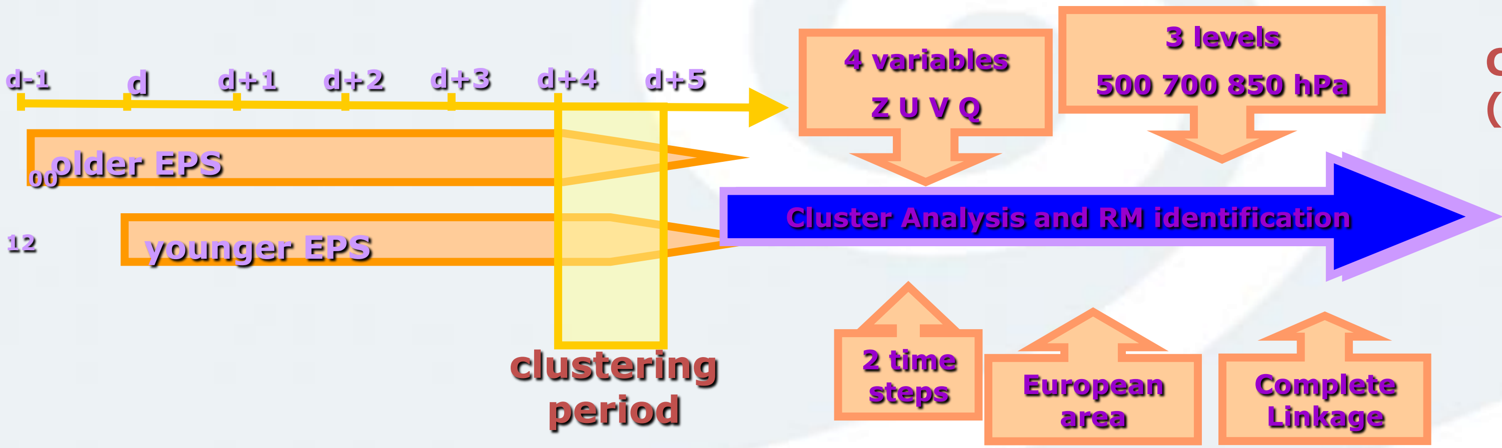
ENSEMBLE FORECASTING

Model Errors

Accounting for uncertainties associated to Numerical Forecast

Analysis Errors

COSMO-LEPS suite @ ECMWF: present status

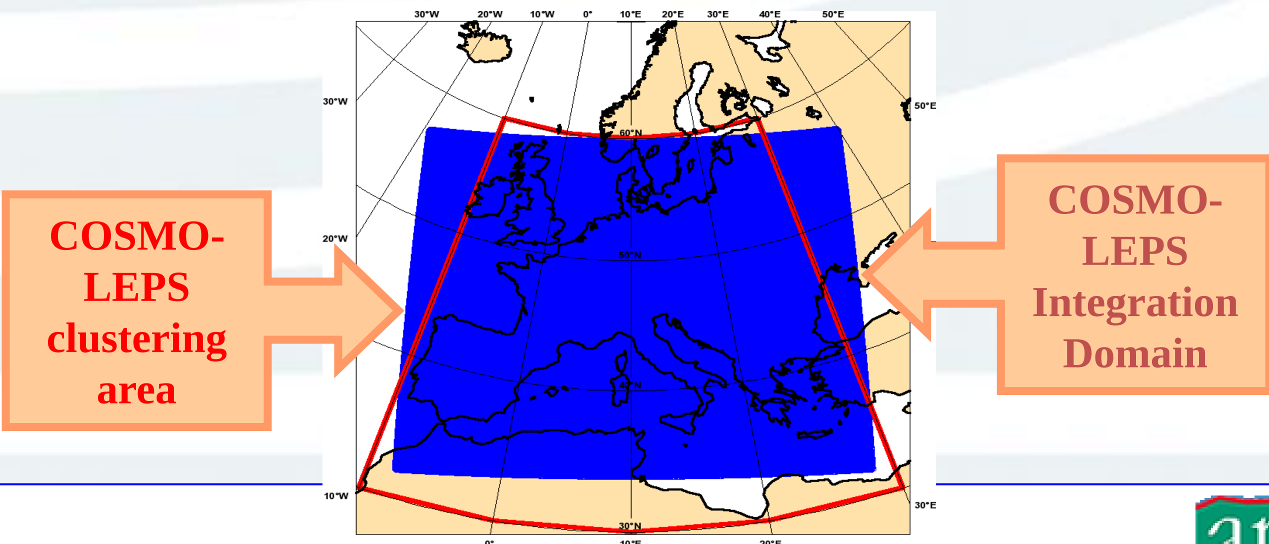


16 Representative Members driving the 16 COSMO-model integrations (weighted according to the cluster populations)

using either Tiedtke or Kain-Fristch convection scheme (members 1-8 T, members 9-16 KF)

+

perturbations in turbulence scheme and in physical parameterisations



- suite runs twice a day (00 and 12UTC) as a "time-critical application" managed by ARPA-SIMC;
- Δx ~ 7 km; 40 ML; fc+132h;
- COSM0 v4.21 since July 2012;
- computer time (30 million BUs for 2012) provided by the ECMWF member states in COSMO.

COSMO-HYBrid Ensemble Prediction System: under test in parallel suite

Generate 20-member hybrid ensemble (COSMO-HYBEPS) , where:

a) 16 members comes from COSMO-LEPS,

b) 1 member is nested on IFS (uses Tiedtke scheme),

c) 1 member is nested on IFS (uses Kain-Fritsch scheme),

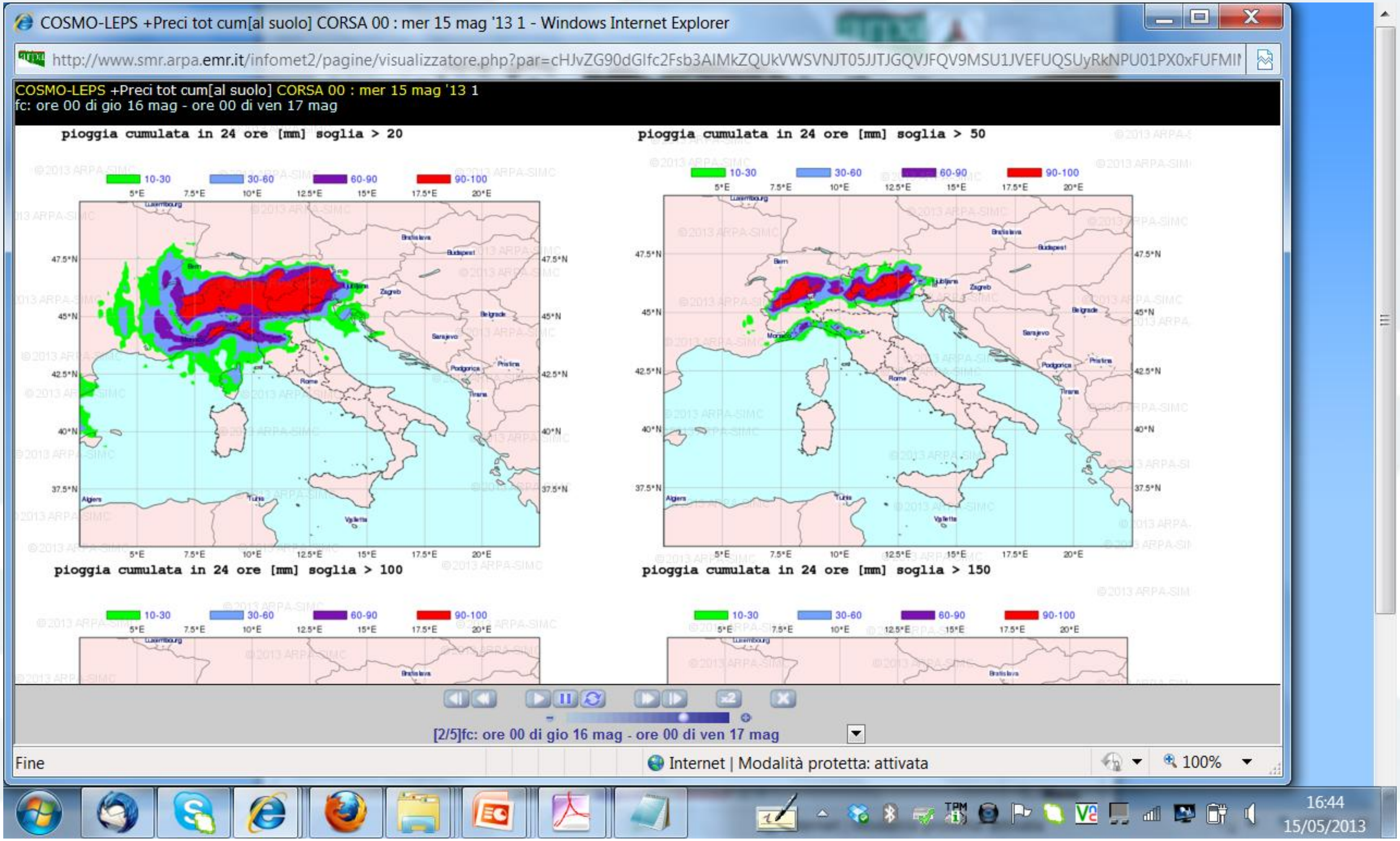
d) 1 member is nested on GME,

e) 1 member is nested on GFS.

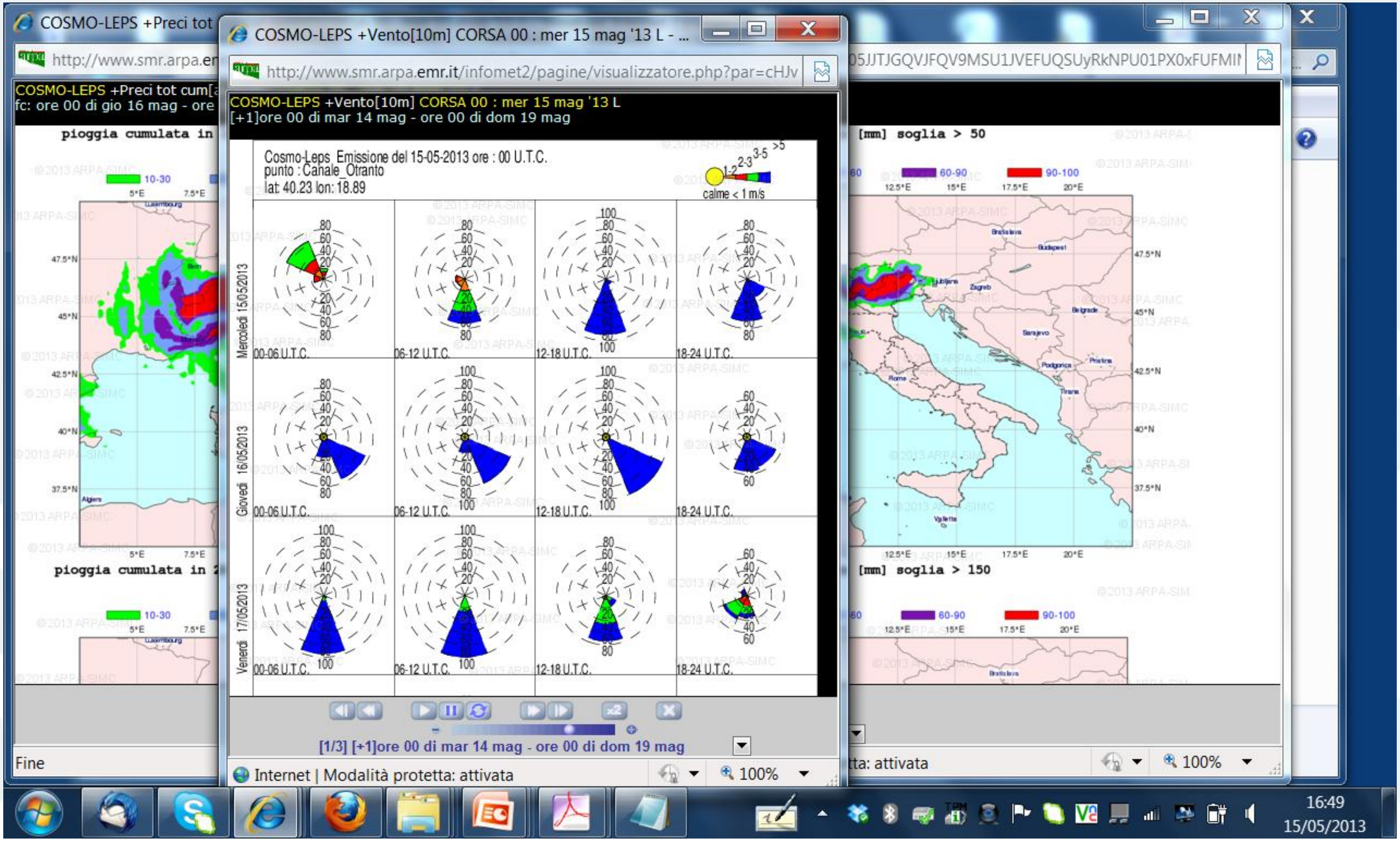
All members have **Δx ~ 7 km; 40 ML; fc+132h;**

Product visualization

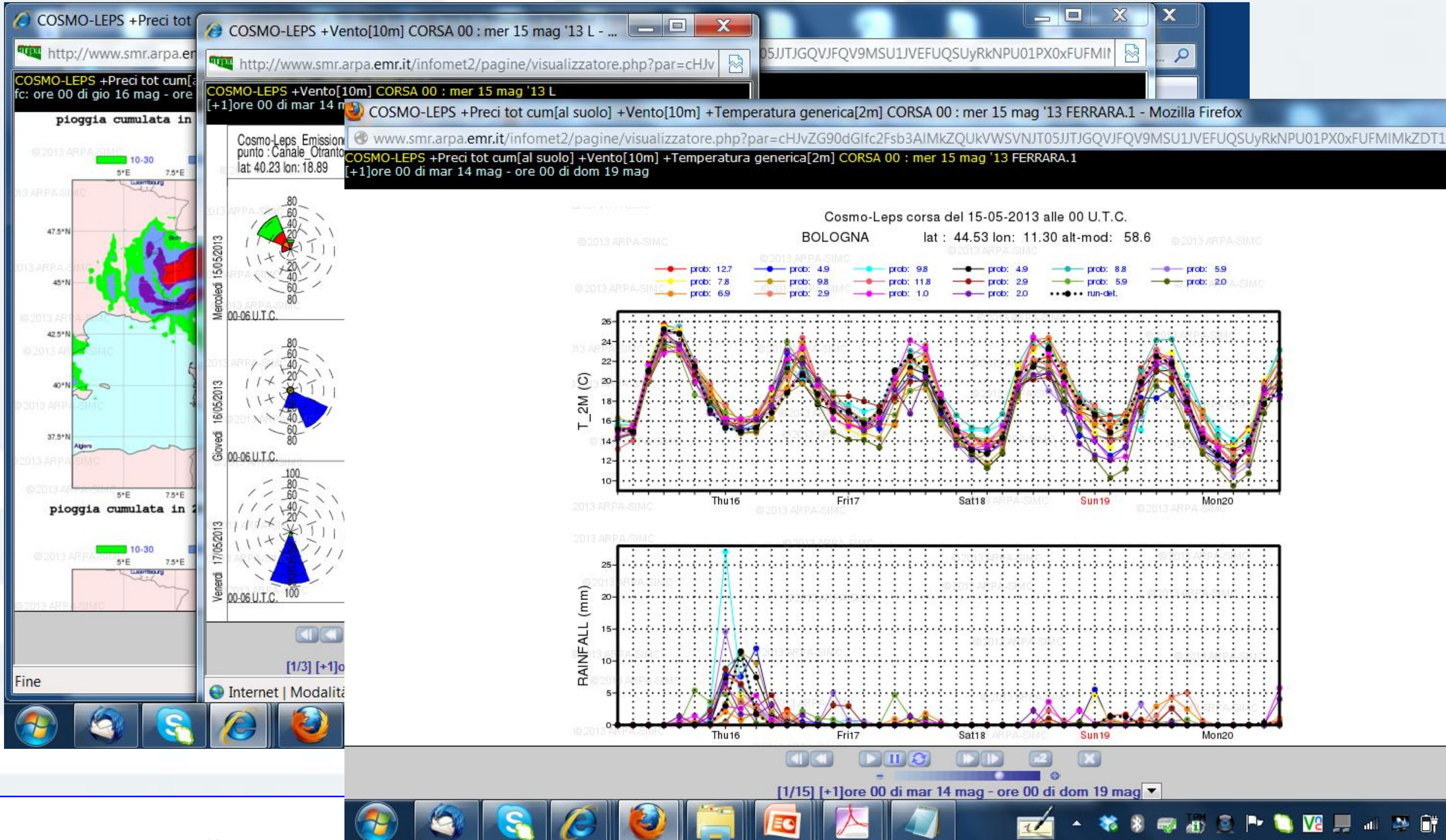
Product visualization



Product visualization



Product visualization



ENSEMBLE FORECASTING: DEVELOPMENTS

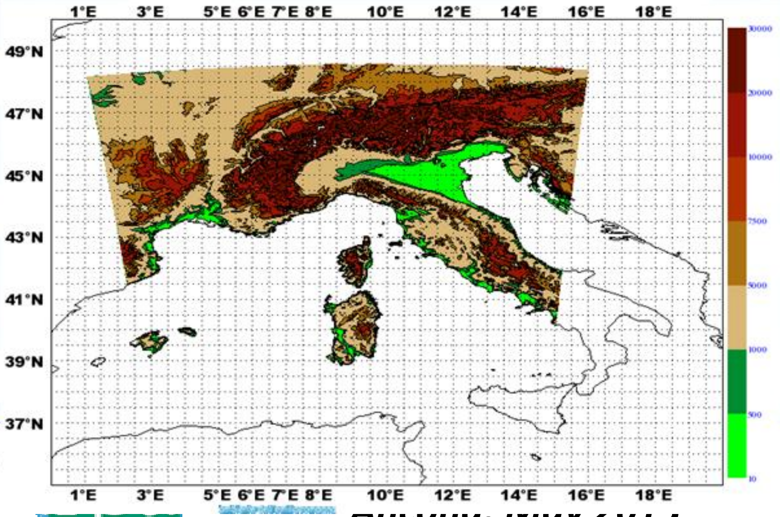
1. Revision of the Ensemble Reduction Technique to select Bopundary conditions out of a coarser EPS

ENSEMBLE FORECASTING: DEVELOPMENTS

1. Revision of the Ensemble Reduction Technique to select Bopundary conditions out of a coarser EPS
2. Design and testing of a 2.8 km ensemble

Hymex implementation

- Hymex SOP: 6th Sept – 5th Nov 2012
- Many models available, among which AROME-EPS 2.5km
- Many observations available (and many deployed on IOPs)
- COSMO-H2-EPS set-up:
  - 2.8 km, 50 levels
  - 10 members
  - IC and BC COSMO-LEPS
  - 1 run daily at 12 UTC
  - 36h forecast range



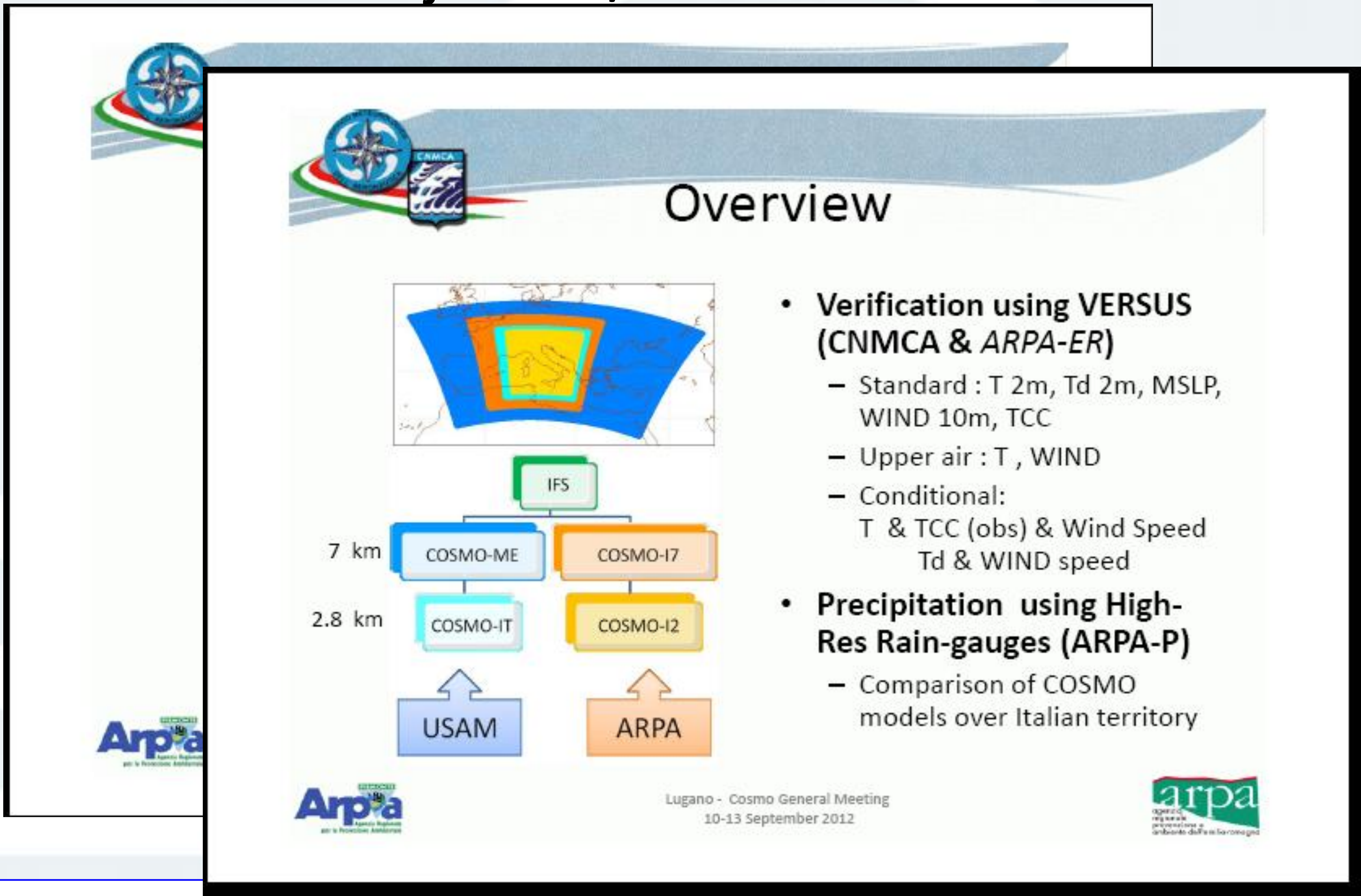
ENSEMBLE FORECASTING: DEVELOPMENTS

1. Revision of the Ensemble Reduction Technique to select Bopundary conditions out of a coarser EPS
2. Design and testing of a 2.8 km ensemble
3. Implementation and testing of a LETKF to provide smaller scale perturbations on Initial conditions

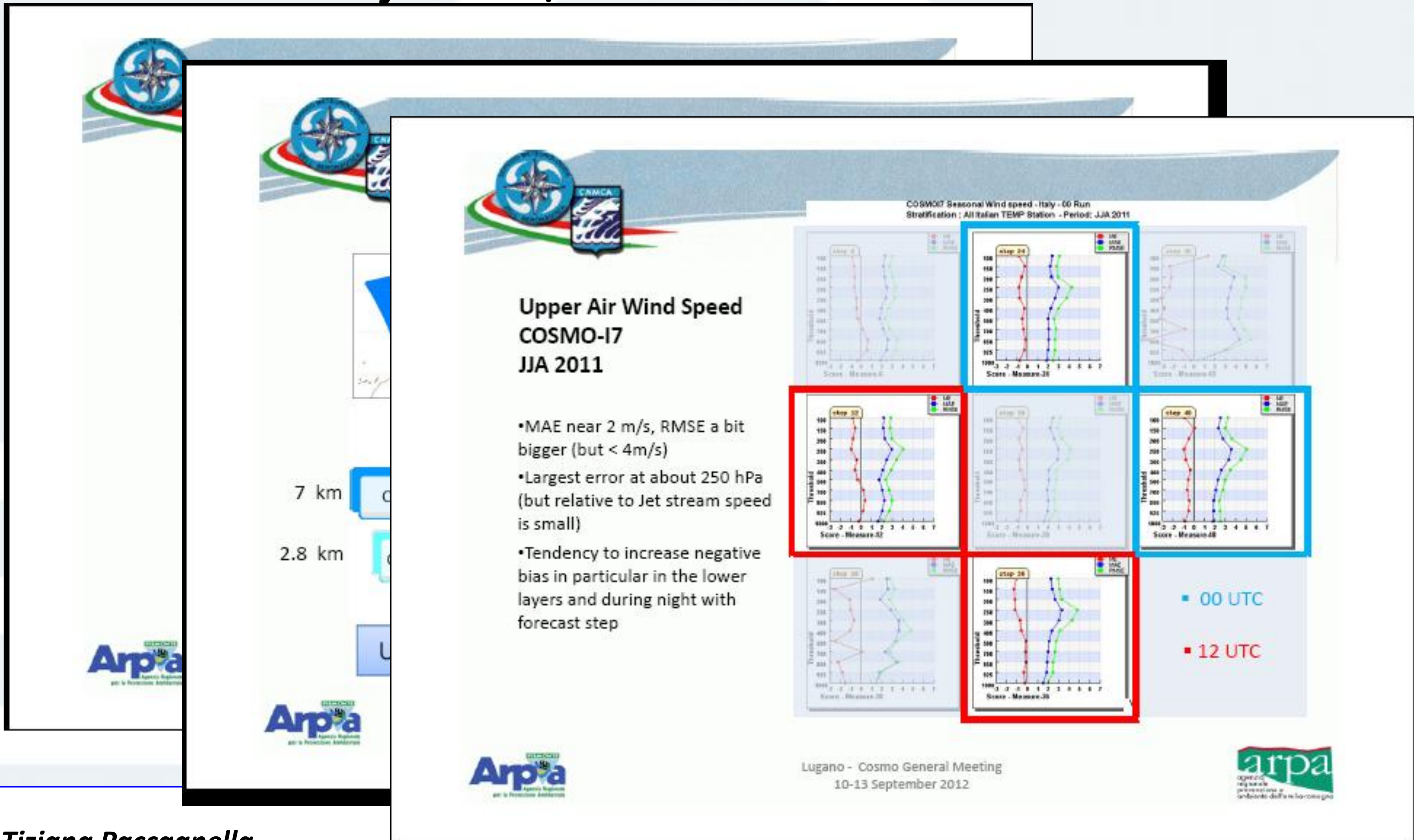
Objective/statistical verification

http://www.cosmo-model.org/content/consortium/generalMeetings/general2012/wg5-versus.htm

Objective/statistical verification



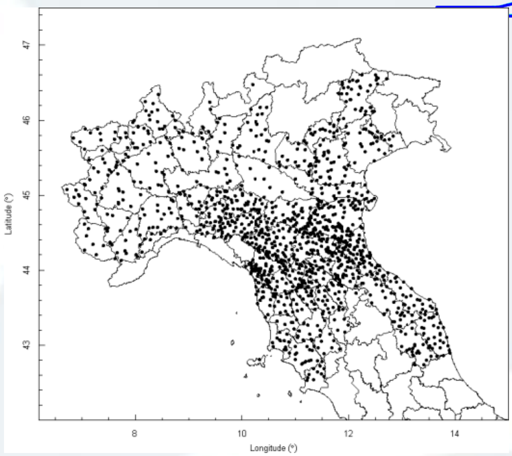
Objective/statistical verification



HIGH RESOLUTION QPF VERIFICATION

Very high resolution ⇨ Low predictability at the pixel scale

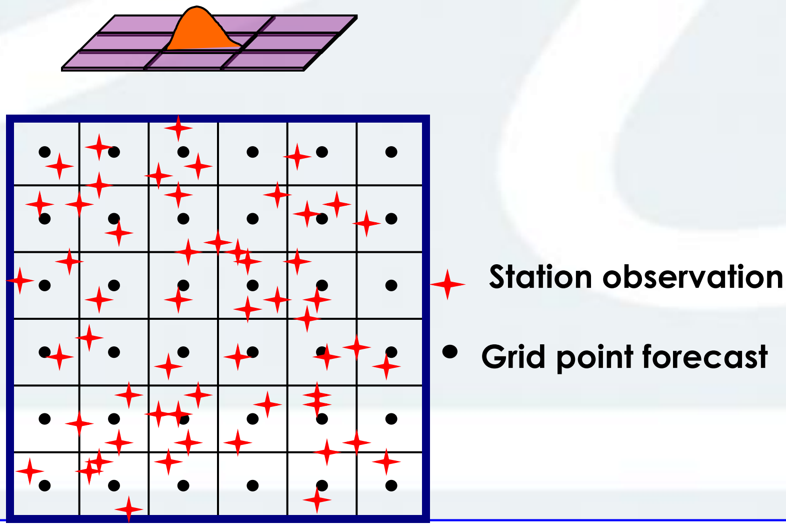
Verification of the single pixels ⇨ Verification of the statistical properties over areas including more pixels



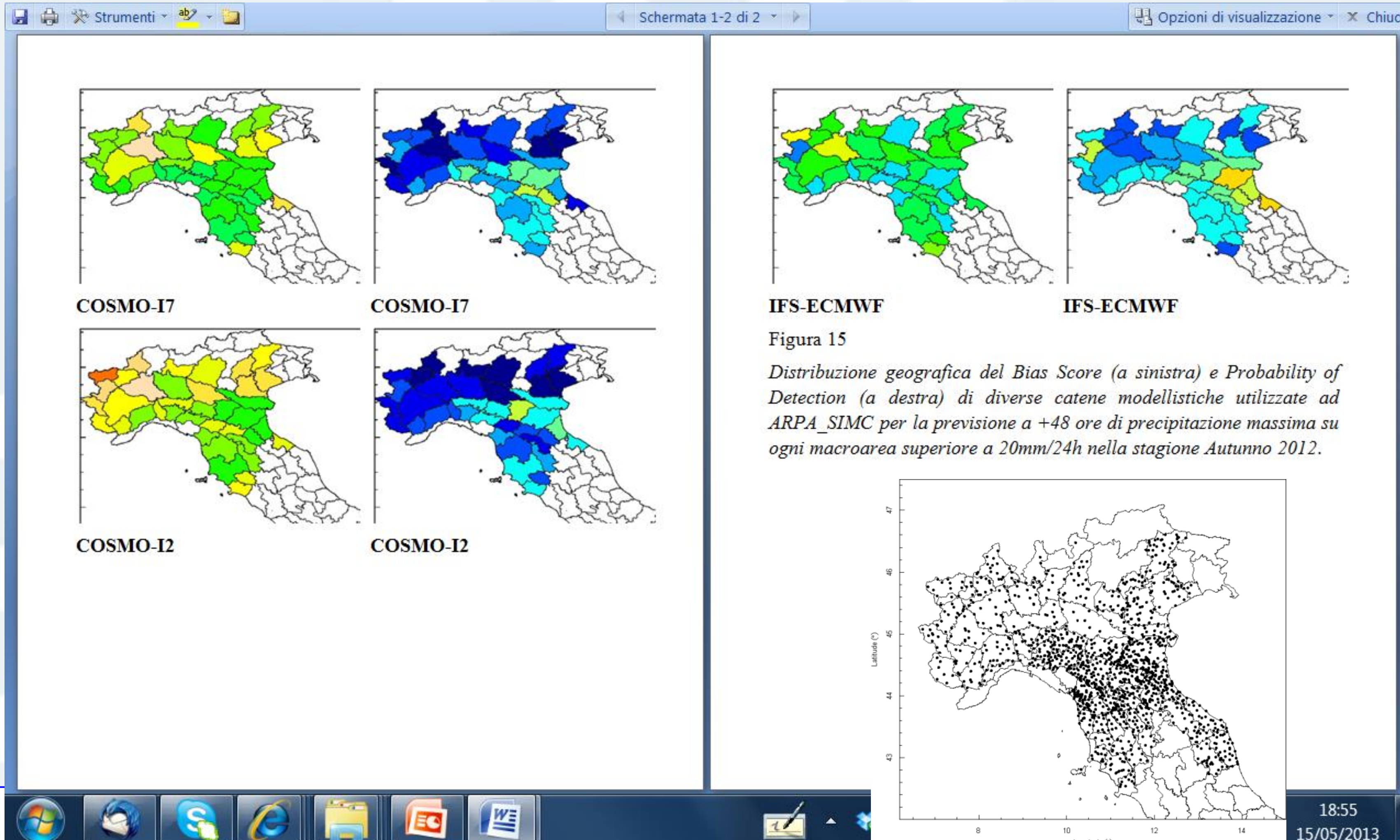
Verification made in terms of:

- **Average value**
- **Maximum value**
- **50th percentile (median)**
- **90th percentile**

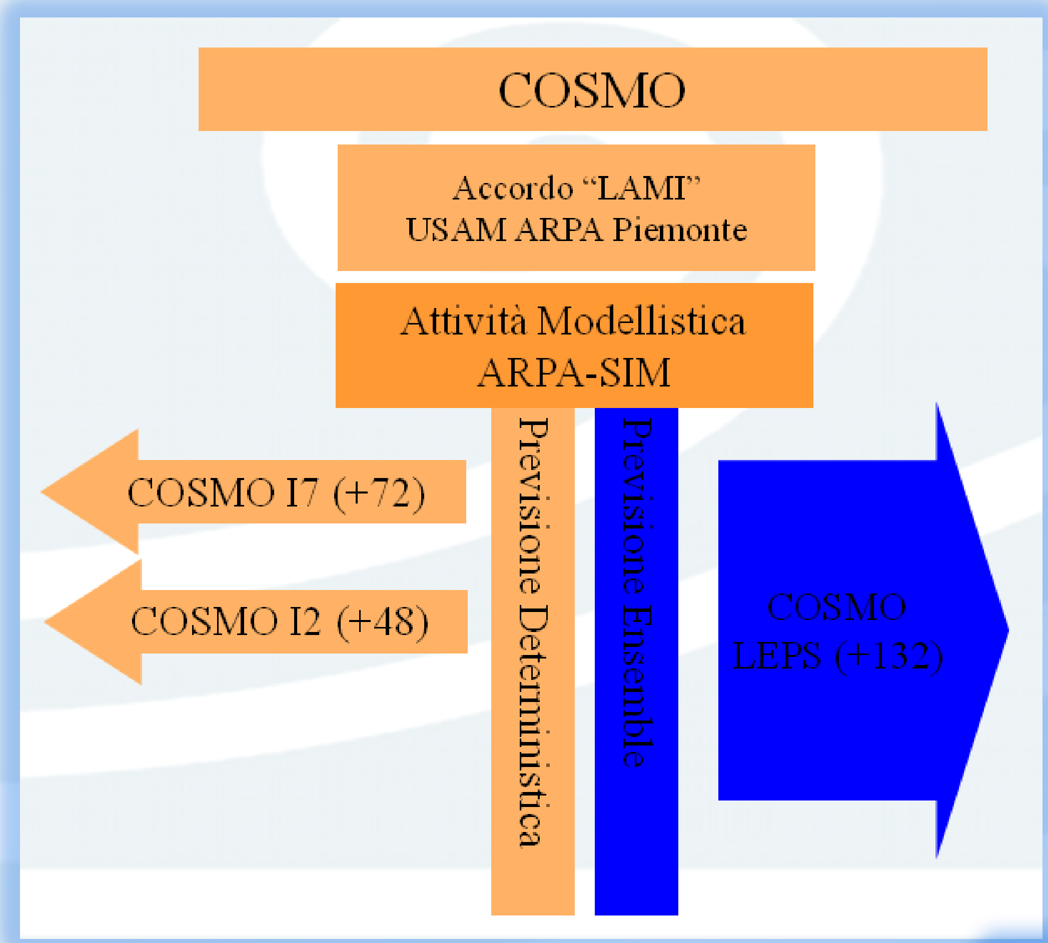
in a box including more pixels



Verification of Precipitation: an example



Users and Applications



Marine
modelling and applications

Air quality
modelling and applications

Hydrological
modelling and applications

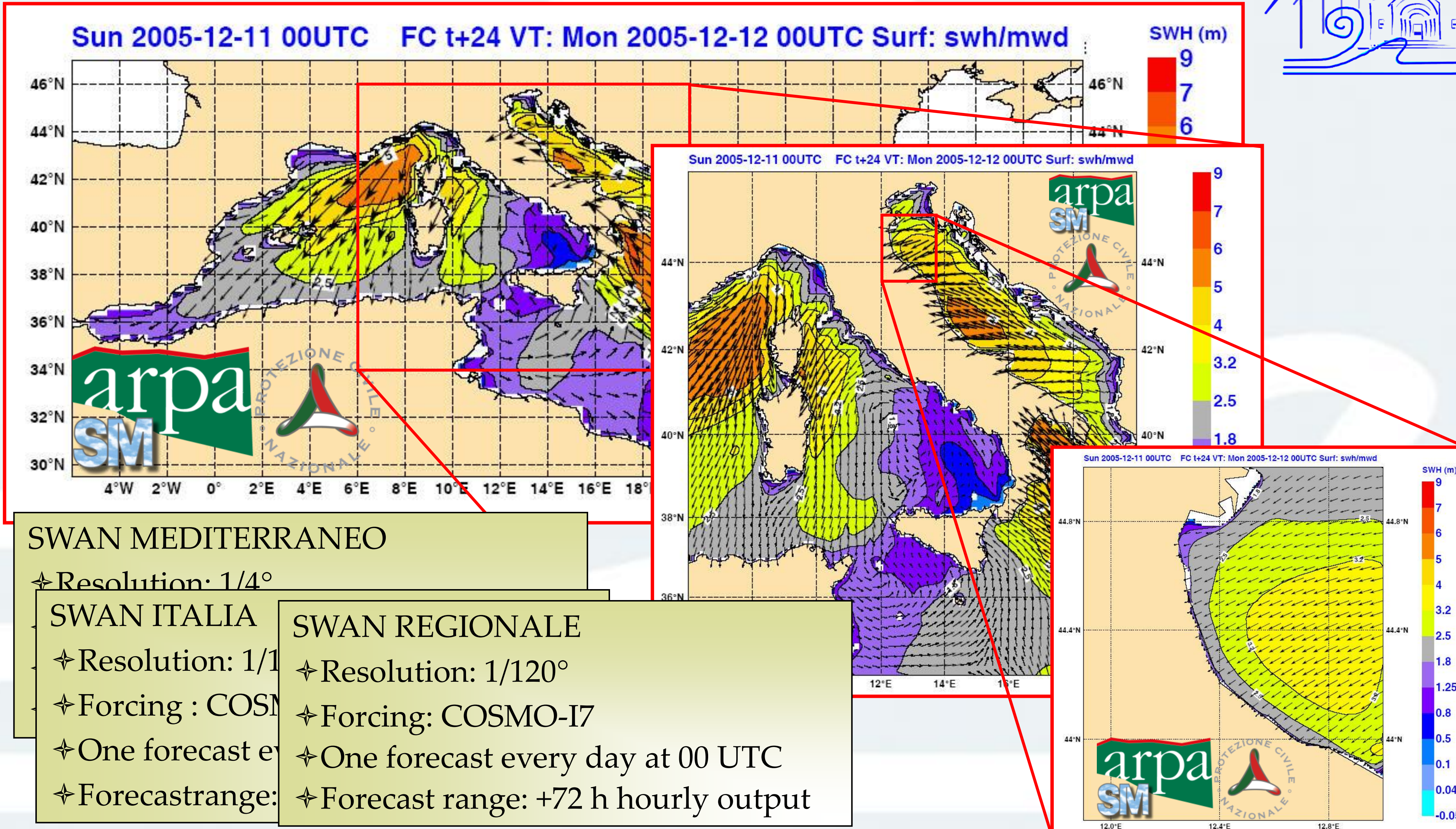
ENERGY

Civil Protection system

Forecasters and direct users

Other services, etc. etc.

SWAN MED-ITA-RE

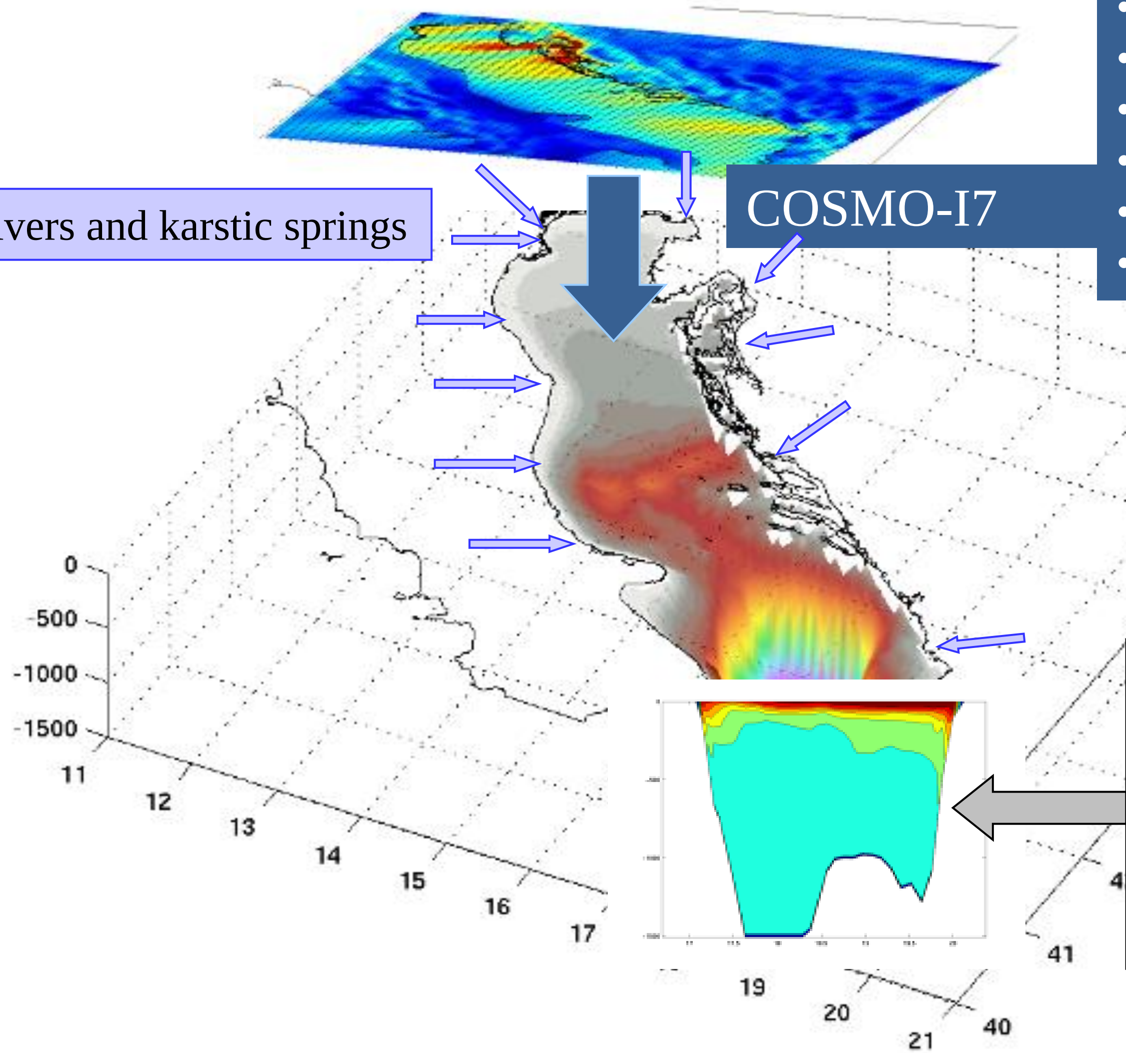


SWAN MEDITERRANEO
- ✧Resolution: 1/4°

SWAN ITALIA
- ✧Resolution: 1/1
- ✧Forcing : COSM
- ✧One forecast e
- ✧Forecastrange:

SWAN REGIONALE
- ✧Resolution: 1/120°
- ✧Forcing: COSMO-I7
- ✧One forecast every day at 00 UTC
- ✧Forecast range: +72 h hourly output

AdriaROMS



48 rivers and karstic springs

COSMO-I7

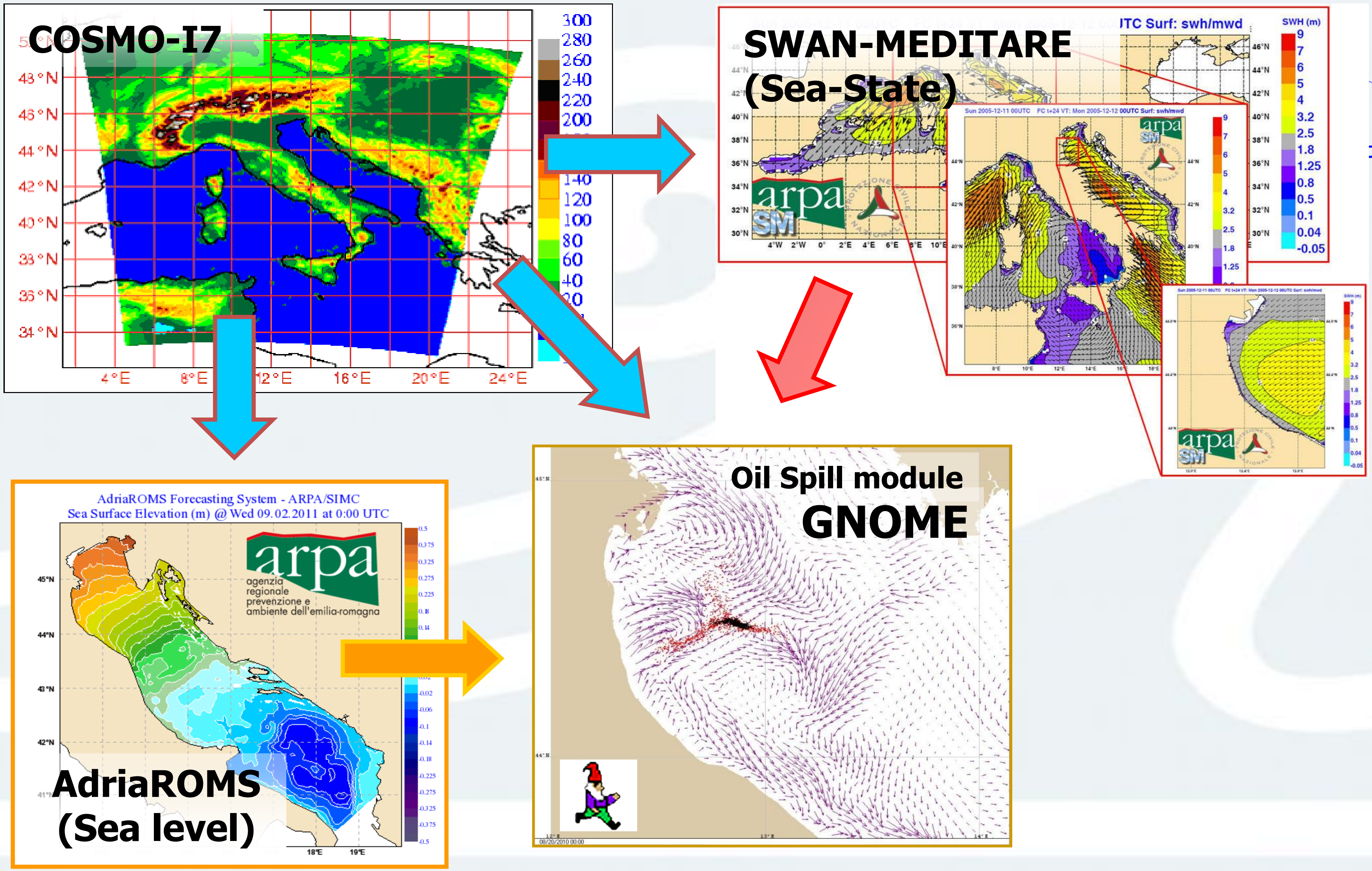
- 10 m wind
- sea level pressure
- 2 m air temperature
- 2m dewpoint temperature
- precipitation
- net solar radiation
- total cloud cover

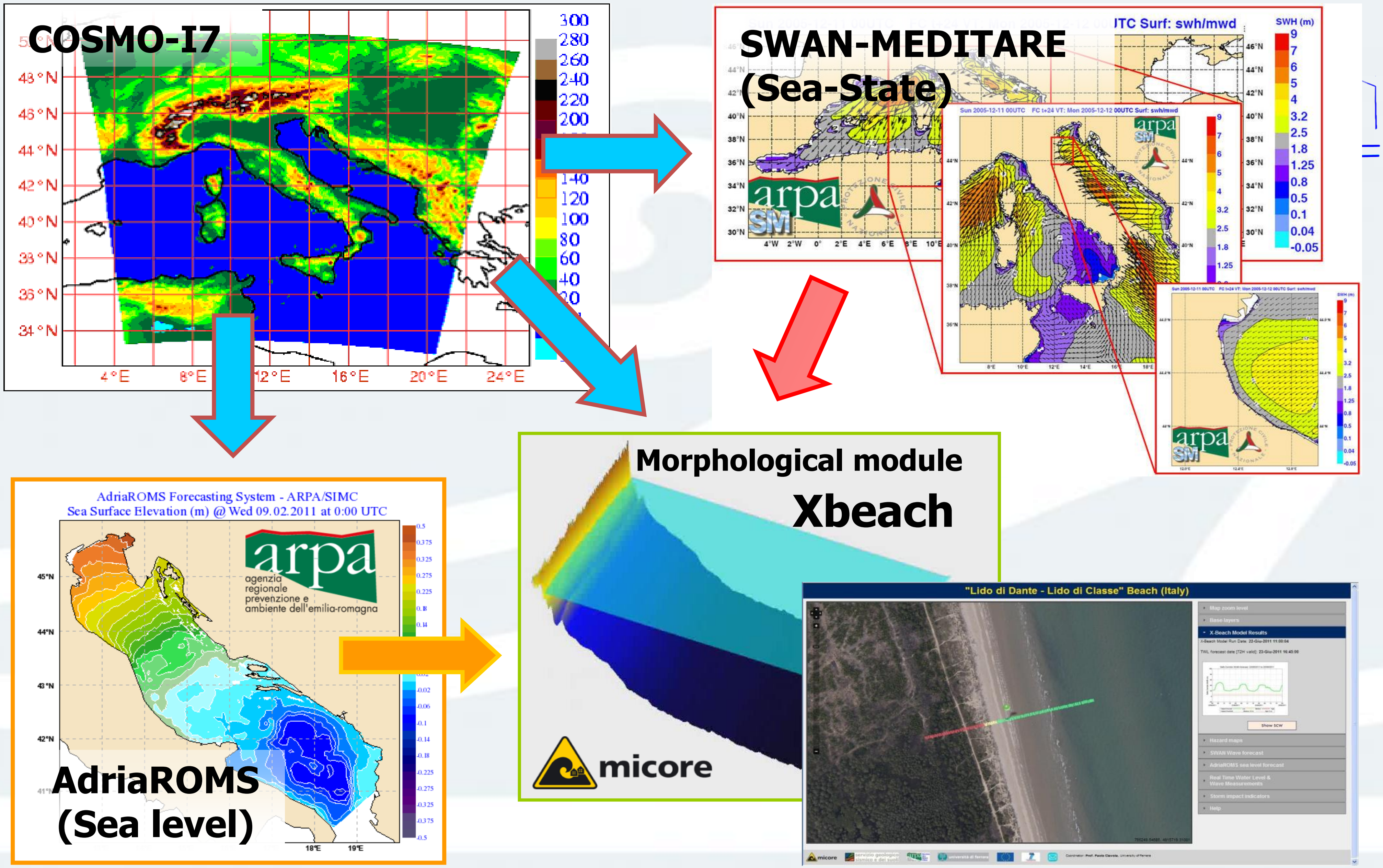
BCs at Otranto strait

4 harmonic components (M2, S2, O1, K1) by the Oregon State University (OSU) model and software.

Mediterranean Forecasting System (MFS)

→ 2km: U,V, SSH,T, S (…myOCEAN…)


COSMO-I7
SWAN-MEDITARE
(Sea-State)
AdriaROMS Forecasting System - ARPA/SIMC
Sea Surface Elevation (m) @ Wed 09.02.2011 at 0:00 UTC
AdriaROMS
(Sea level)
Oil Spill module
GNOME



COSMO-I7
SWAN-MEDITARE
(Sea-State)
Morphological module
Xbeach
micore
"Lido di Dante - Lido di Classe" Beach (Italy)
AdriaROMS Forecasting System - ARPA/SIMC
Sea Surface Elevation (m) @ Wed 09.02.2011 at 0:00 UTC
AdriaROMS
(Sea level)

CONCLUDING REMARKS

Thanks to the COSMO and LAMI cooperation, and to the support of National Civil Protection, ARPA SIMC is managing and further developing state-of-the-art numerical modelling systems.

The future of Limited Area Modelling is toward the km scale. Even if Numerical weather prediction has made very big progresses in the last decades, the intrinsic low predictability of small scale processes still implies big challenges.

Models must be improved in their capability to better represent small scale processes; data assimilation systems should be developed in such a way to use at best the huge amount of information coming from the new observation capabilities.

CONCLUDING REMARKS

The awareness of our limits brought to the development of probabilistic prediction based on Ensemble Forecasting.

Big efforts are being doing by the scientific community to improve these systems in such a way to have a proper link between the estimate of the uncertainty in the forecast and the actual forecast errors.

How to use probabilities is a big issue and it should be matter of cooperation between Meteorologists and users.

OFFSHORE WIND ENERGY DEVELOPMENT IN THE ADRIATIC SEA: THE P.O.W.E.R.E.D. PROJECT AS PLANNING POLICY

Università Politecnica delle Marche, Ancona, May 2013

Thank you!