SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Implementation of a limited-area ensemble prediction system for Sochi Olympic Games
Computer Project Account:	spcoleps
Start Year - End Year :	2012 - 2014
Principal Investigator(s)	Montani Andrea (Italy)[1] , Majewski Detlev (Germany)[2] , Steiner Philippe (Switzerland)[3]
Affiliation/Address:	[1] ARPA-SIMC Servizio IdroMeteoClima, Viale Silvani 6, 40122 Bologna (Italy) [2] DWD, Frankfurter Strasse 135 63067 Offenbach (Germany) [3] Meteoswiss, Kraehbuehlstrasse 58, 8044 Zurich (Switzerland)
Other Researchers (Name/Affiliation):	Chiara Marsigli (ARPA-SIMC)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The aim of the project was to "clone" COSMO-LEPS system and relocate it over Russia, centring the domain over the Sochi area, thus generating a new limited-area ensemble prediction system based on COSMO model and named COSMO-S14-EPS system.

COSMO-S14-EPS was implemented, developed and ran to provide:

- probabilistic guidance of high-impact weather over complex topography,
- a valuable support to bench forecasters during the Olympic Games,
- initial and boundary condition for a convection-permititng COSMO-based limited-area ensemble.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

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…

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

Progress reporting is often a nuisance, but I perfectly understand that ECMWF needs to have some form of control on how the computer time is used.
It is not clear how the final report should differentiate from the sum of the yearly reports ECMWF has already received.

Summary of results

(This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project.)
……
…

List of publications/reports from the project with complete references

Montani A., Marsigli C., Paccagnella T., 2013. Development of a COSMO-based limited-area ensemble system for the 2014 Winter Olympic Games. Cosmo Newsletter No. 13, 93-99. Available at http://www.cosmo-model.org.
Montani A., Alferov D., Astakhova E., Marsigli C., Paccagnella T., 2014. Ensemble forecast-ing for Sochi-2014 Olympics: the COSMO-based ensemble prediction systems. Cosmo Newsletter No. 14, 88-94. Available at http://www.cosmo-model.org.
Montani A., Alferov D., Astakhova E., Marsigli C., Paccagnella T., 2015. Performance of multi-model ensemble systems during Sochi-2014 Olympics: preliminary studies at ARPA-SIMC. Cosmo Newsletter No. 15, 88-94. Available at http://www.cosmo-model.org.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

A new special project was submitted: “Investigation of case studies during Sochi Olympic Games using COSMO-based ensemble prediction systems”.

Implementation of a limited-area ensemble prediction system for Sochi Olympic Games

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1 Introduction

Past winter Olympics and Paralympic Games took place in Sochi, Russia, in a region characterised by complex topography located in the vicinity of the Black Sea. The Olympic Games took place from 7 to 23 February 2014, while the Paralympic Games from 7 to 16 March 2014 (Kiktev, 2011). In the framework of these events, WMO launched two initiatives: a dedicated WWRP FDP (Forecast Demonstration Project) and a dedicated WWRP RDP Research and Development Project) to improve understanding of nowcasting and short-range prediction processes over complex terrain. A new project named **FROST-2014** (**F**orecast and **R**esearch in the **O**lympic **S**ochi **T**estbed; http://frost2014.meteoinfo.ru/) was set-up at the kick-off meeting held in Sochi from 1 to 3 March 2011. Four Working Groups (WGs) were established to deal with the various components of the project, more specifically:

- WG1: observations and nowcasting;
- WG2: NWP, ensembles and assimilation;
- WG3: IT including graphical tools, formats, archiving and telecommunication;
- WG4: products, training, end user assessment and social impacts.

As for WG2, it was agreed that ensembles with resolution about 7 km or coarser could be involved in the project in forecast and demonstration mode (FDP component), while systems with resolution about 2 km would contribute to the project in research mode (RDP component). Within the former component, one of the main activities deals with the set-up, generation, implementation and maintenance of a limited-area ensemble prediction system based on COSMO model and targeted for the Sochi-area.

2 Scientific plan

In the framework of the FDP, it was decided to clone COSMO-LEPS system and relocate it over Russia, centring the domain over the Sochi area, thus generating COSMO–S14–EPS system. In the past years, COSMO-LEPS (Montani et al., 2011) proved to be a valuable tool for the generation of probabilistic predictions of high-impact weather over complex topography and it is envisaged that COSMO-S14-EPS can provide useful support to bench forecasters during the Olympic Games. Within FROST-2014, the attention was focused on those atmospheric variables which play a major role in the outdoor activities of the Olympic Games. More specifically, the probabilistic prediction of wind, wind-gust, precipitation (in various forms), temperature, humidity and visibility was be required for forecast ranges up to three days, depending on the variable.

2.1 Phase I: set–up of the system

In this phase, which took place in early 2012, a prototype COSMO–S14–EPS system was set–up with a configuration similar to COSMO-LEPS application. In order to save computer time, the ensemble size was initially limited to 10 members and the forecast range to 72 hours. Therefore, the main characteristics can be summarised as follows:

- horizontal resolution: 7 km;
- vertical resolution: 40 model levels;
- number of grid points (NX x NY x NZ) = $365 \times 307 \times 40 = 4.482.200$;
- forecast length: 72 hours;
- ensemble size: 10 members,
- initial conditions: interpolated from selected ECMWF EPS members;
- boundary conditions: interpolated from selected ECMWF EPS members;
- initial times of the run: 00UTC and 12UTC.

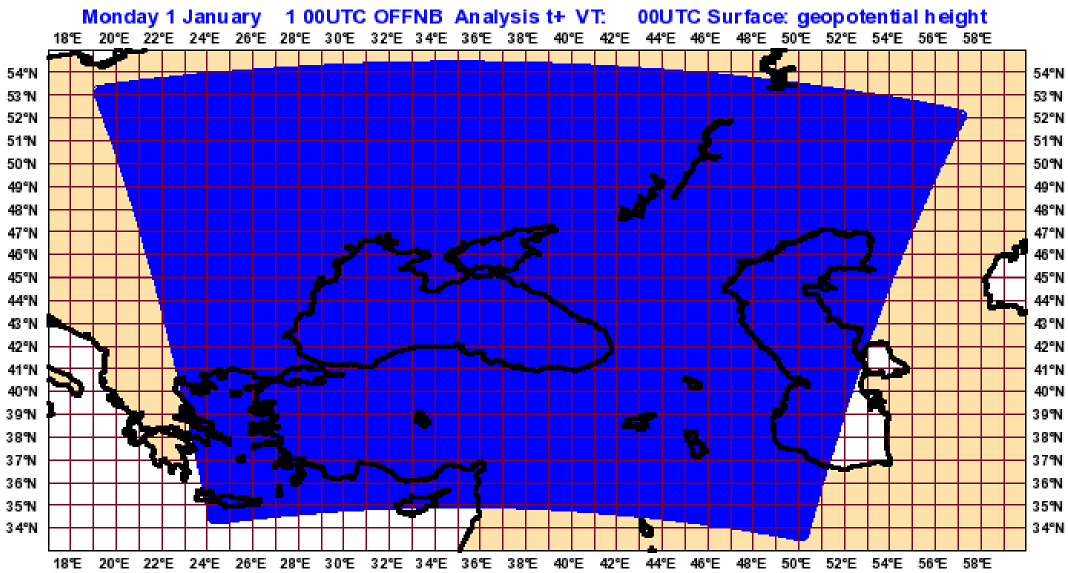

Figure 1: Integration domain for COSMO–S14–EPS

Fig. 1 shows the integration domain of COSMO–S14–EPS. The ECMWF EPS members providing initial and boundary conditions to COSMO–S14–EPS integrations, are selected by means of a clustering analysis / selection of representative members similar to the one used in COSMO-LEPS time-critical application. COSMO–S14-EPS system produces a set of standard probabilistic products (e.g. probability maps, meteograms, . . .) to be delivered in real time to the Met Ops room of the Hydrological and Meteorological Centre of Russia (hereafter, Roshydromet). The generation of the different types of non-graphical products took advantage of Fieldextra, the official COSMO post-processing software, developed at Meteoswiss (for information about Fieldextra, please refer to http://www.cosmo-model.org).

2.2 Phase II: development of the system

This phase covered late 2012 and early 2013: on the basis of the experience gained in Phase I and on the feedback provided by Roshydromet forecasters, the configuration of COSMO–S14–EPS was adapted accordingly; the same applies to the type of products to be generated and delivered. In this phase, the complete transition of the system towards the use of GRIB2 format for COSMO–S14–EPS output files also took place. The set of products to be delivered was consolidated, as well as the procedures of transmission and visualisation.

2.3 Phase III: final implementation of the system

This phase covered the full length of Winter Olympic and Paralympic Games: COSMO–S14–EPS system ran continuously from November 2013 to March 2014. Generation and transfer of products (forecast fields and/or plots) was reliable and a timely delivery was ensured. COSMO–S14–EPS forecasts were used to generate a set of standard probabilistic products, including probability of surpassing a threshold, ensemble mean and ensemble standard-deviation for several surface and upper-air variables. The individual forecast members for a specially defined sub-area were also transferred to the Hydrometcenter of Russia (Roshydromet) where the epsgrams for predetermined points (mainly, locations of outdoor and indoor competitions) were prepared. All these products, delivered in real time to Roshydromet, were used by the Sochi forecasters via the FROST-2014 Web-site (`http://frost2014.meteoinfo.ru/forecast/goomap` and `http://frost2014.meteoinfo.ru/forecast/arpa-new/cosmo-s14-eps-maps`).
It is also ;pointing out that, apart from the ensemble products, COSMO–S14–EPS provided both initial and hourly-boundary conditions (up to t+48h) to Roshydromet for the experimentation with the convection-resolving ensemble COSMO–RU2–EPS, which ran between January and February 2013 as well as from November 2013 to April 2014.

3 Verification results: pre–Olympics phase

In this section, we present the first results relative to the performance of COSMO–S14–EPS. The skill of the mesoscale ensemble is assessed over the period January–March 2012 and compared to that of ECMWF EPS. For both systems, we consider the probabilistic prediction of 12–hour accumulated precipitation exceeding a number of thresholds for several forecast ranges. Table 1 summarises the main properties of COSMO–S14–EPS and ECMWF EPS, indicating the main differences between the two systems.

Table 1: Main features of the verified systems.

	COSMO–S14–EPS	ECMWF EPS
EnsembleSize	10 members	51 members
ForecastLength	72h	240h
InitialTime	12 UTC	12 UTC
HorizontalResolution	7 km	25 km
VerticalResolution	40 ML	62 ML

As for observations, it has been decided to use the data obtained from the SYNOP reports available on the Global Telecommunication System (GTS), since this is recognised to be

Table 2: Main features of the verification configuration.

variable:	12–hour accumulated precipitation (18–06, 06–18 UTC);
period:	from 1 January to 31 March 2012;
region:	40–50N, 35E–45E;
method:	nearest grid–point;
observations:	SYNOP reports;
fcst ranges (h):	6-18, 18-30, 30-42, 42-54, 54-66
thresholds:	1, 5, 10, 15, 25, 50 mm/12h;
scores:	ROC area, BSS, RPSS, OUTL;

a homogeneous and stable dataset throughout the verification period. In the future, it is planned to verify the performance of COSMO–S14–EPS over denser observational datasets. In order to quantify the skill of the system over complex topography, the verification is performed over the domain 40N–50N, 35E–45E. Within this domain, a fixed list of 60 SYNOP stations is considered and the relative reports in terms of total precipitation are used to evaluate the COSMO–S14–EPS and ECMWF-EPS skill. As for the comparison of model forecasts against SYNOP reports, we select the grid–point closest to the observation. Little sensitivity to the results is found when, instead of the nearest grid–point, a bi-linear interpolation using the 4 nearest points to the station location, is used to generate the model forecasts. Therefore, the results shown hereafter will be relative only to the nearest grid–point method. The performance of both systems is examined for 6 different thresholds: 1, 5, 10, 15, 25 and 50 mm/12h.
The following probabilistic scores are computed over the verification period: the Brier Skill Score (BSS), the Ranked Probability Skill Score (RPSS), the Relative Operating Characteristic Curve (ROC) area and the Percentage of Outliers (OUTL). For a description of these scores, the reader is referred to Wilks (1995) and to Marsigli et al. (2008). The main features of the verification exercise are summarised in Table 2.

The skill of the two systems in terms of prediction of 12–hour accumulated precipitation is summarised in Fig. 2, where the Ranked Probability Skill Score (RPSS) is plotted against the forecast range for both COSMO–S14–EPS and ECMWF EPS.

It can be noticed that COSMO-S14–EPS has higher RPSS for all forecast ranges. The difference between the two systems is consistent throughout the full forecast range, with a larger gap for the first day of integration. This implies that, despite the higher ensemble size of ECMWF EPS, the higher resolution of COSMO-S14–EPS contributes to provide more accurate probabilistic predictions of precipitation.
If the attention is now focused on the performance of both systems for a specific event, most of the above comments still hold. As an example, Fig. 3 shows the scores of COSMO-S14–EPS and ECMWF EPS in terms of ROC area for the event "12–hour accumulated precipitation exceeding 10 mm". COSMO-S14–EPS outperforms ECMWF EPS for all forecast ranges, although both systems exhibit a semi–diurnal cycle in the score and tend to provide better guidance for "night–time" precipitation, that is occurring between 18UTC and 6UTC (and corresponding to the ranges 6–18 h, 30–42 h and 54–66 h). As for COMO, this is linked with a too rapid onset of convection, as pointed out by Oberto and Turco (2008) for runs of COSMO in "deterministic mode".

Finally, the attention is focused on the ability of COSMO–S14–EPS to reduce the number of outliers with respect to ECMWF EPS, thanks to the higher resolution and the better description of mesoscale and orographic–related processes. Fig. 4 shows that COSMO–S14–EPS has fewer outliers than the global ensemble, with a clear added value of the mesoscale ensemble for short forecast ranges.

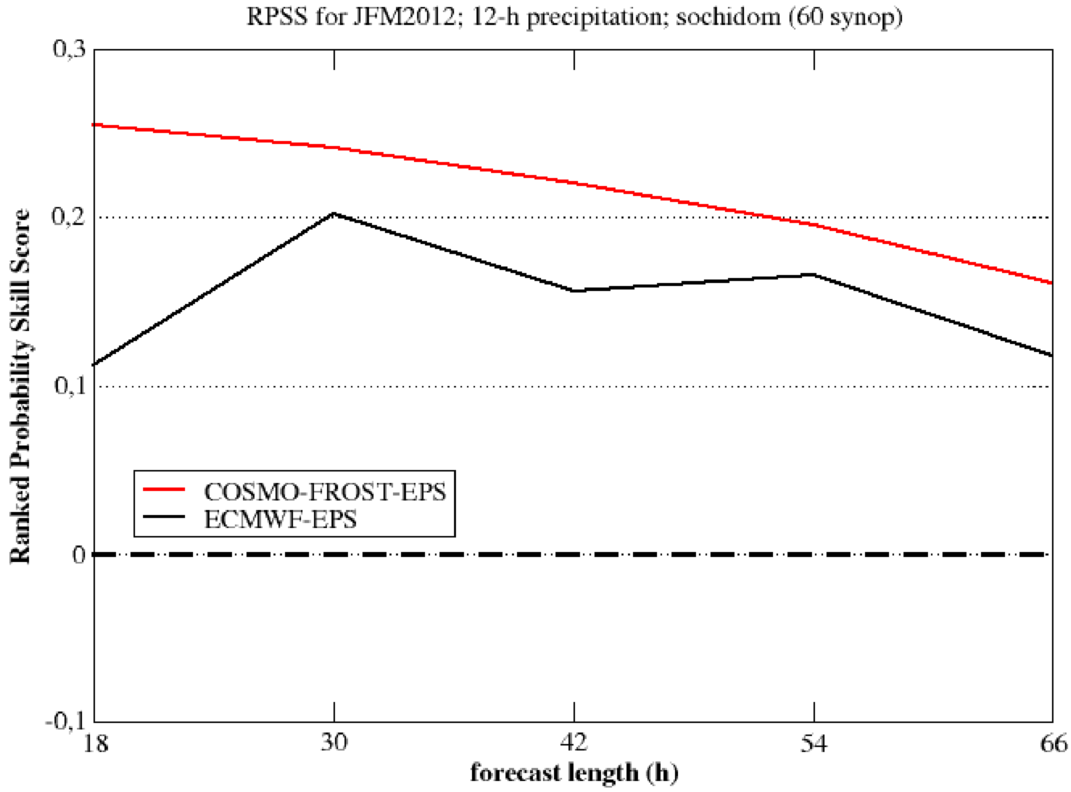

Figure 2: Ranked Probability Skill Score as a function of forecast length for COSMO–S14–EPS (red) and ECMWF EPS (black), calculated over the 3–month period from January to March 2012.

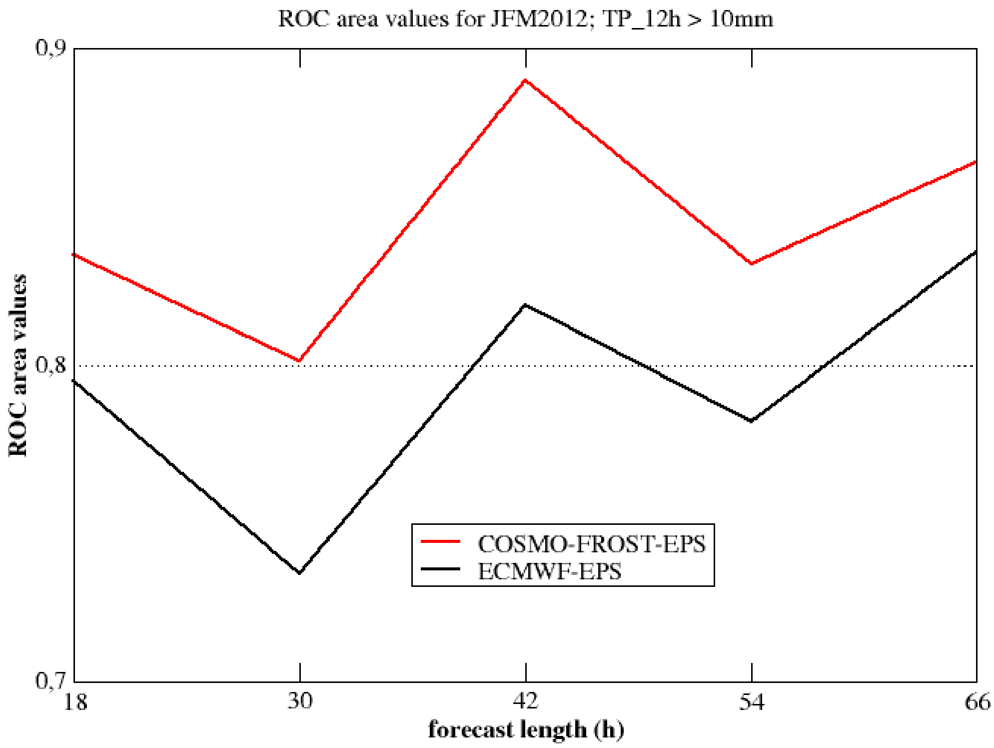

Figure 3: ROC area values for COSMO–S14–EPS (red) and ECMWF EPS (black) relative to the event "precipitation exceeding 10mm in 12 hours" for the forecast ranges of Table 2. Both scores are calculated over the 3–month period from January to March 2012.

According to Talagrand et al. (1999), the value of outliers for a reliable ensemble of size N is given by $2/(N+1)$. These values should not be exceeded. The dashed lines of Fig. 4 indicate these limits for both COSMO–S14–EPS (red, 18%) and ECMWF EPS (black, 4%). Therefore, it looks as if COSMO–S14–EPS approaches the theoretical value to larger extent than ECMWF EPS, which seems to have too many outliers in the short range.

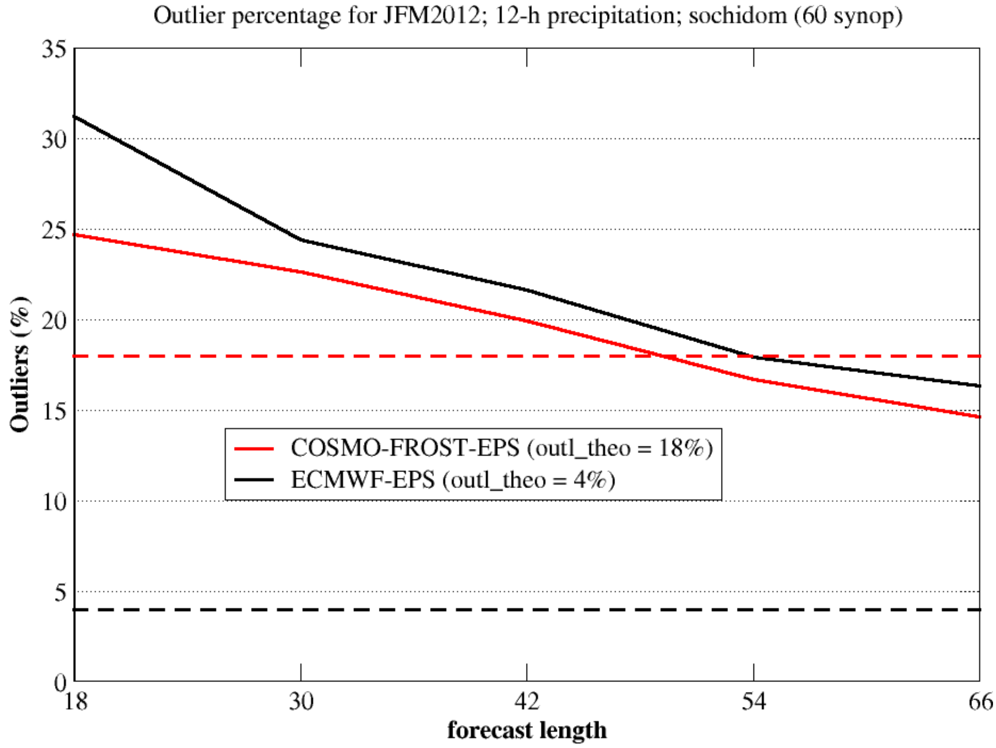

Figure 4: Percentage of Outliers for COSMO–S14–EPS (red) and ECMWF EPS (black), calculated over the 3–month period from January to March 2012. The red (black) dashed line indicates the theoretical limit of outliers for COSMO–S14–EPS (ECMWF EPS).

4 Verification results: post–Olympics phase

In addition to COSMO–S14–EPS, several NWP systems were deployed in the Olympic area. Six different limited-area ensemble prediciton systems were implemented and ran in real time during the Olympic season. While four systems were based on parameterised convection, two of them (namely, COSMO-RU2-EPS and HARMON-EPS) suuported an explicit representation of convection processes. Table 3 reports the main features of the particupating systems, while more details can be found under `http://frost2014.meteoinfo.ru/`.
Among the several post-Olympic activities, an intercomparison of the performance of some participating ensembles was initiated. As a pilot study, COSMO–S14–EPS (Montani et al., 2011 and 2013) and ALADIN-LAEF were selected and intercompared in terms of probabilistic prediction of precipitation. The attention was initially focussed on these two sysyems, because both of them were implemented and ran at ECMWF, the access to the fields to be compared being simpler and faster.

In this section, the preliminary results of the intercomparison exercise are presented. The skills of the different ensemble systems were assessed over the period 15 January – 15 March 2014 (the official verification period of 2014 Olympics). In addition to COSMO-S14-EPS and ALADIN-LAEF, we also verified the performance of the multi-model ensemble (referred to as **"combined"** in Table 3) obtained by pooling together the members of COSMO-S14-

Table 3: Main characteristics of the limited-area ensemble prediction systems paricipating to FROST–2014.

System name	ensemble size	resolution (km)	forecast length (h)	boundary conditions	runs (UTC)
COSMO-S14-EPS	10	7	72	ECMWF ENS	00,12
ALADIN-LAEF	17	11	72	ECMWF ENS	00,12
GLAMEPS	54	11	54	ECMWF ENS	06,18
NMMB	7	7	72	GEFS	00,12
COSMO-RU2-EPS	10	2.8	48	COSMO-S14-EPS	00,12
HARMON-EPS	14	2.5	36	ECMWF ENS	06,18
combined	**27**	**7**	**72**		**12**

EPS and ALADIN-LAEF. This enabled the generation of a 27–member ensemble, whose elements were reinterpolated onto a common 7-km grid. For these three systems, we considered the probabilistic prediction of 12-hour precipitation exceeding a number of thresholds for several forecast ranges. For reason of brevity, only the results relative to the 12UTC runs are reported. As for observations, it was decided to use the data obtained from the SYNOP reports available on the Global Telecommunication System (GTS). This enabled the possibility to assess the performance of the systems over a relatively dense observation dataset (73 stations), since the verification domain was restriced to an area centred over the Olympic venue (40-50N, 35-45E), shown in Fig. 5. As for the comparison of model forecasts against observations, we selected the grid-point closest to the observation.

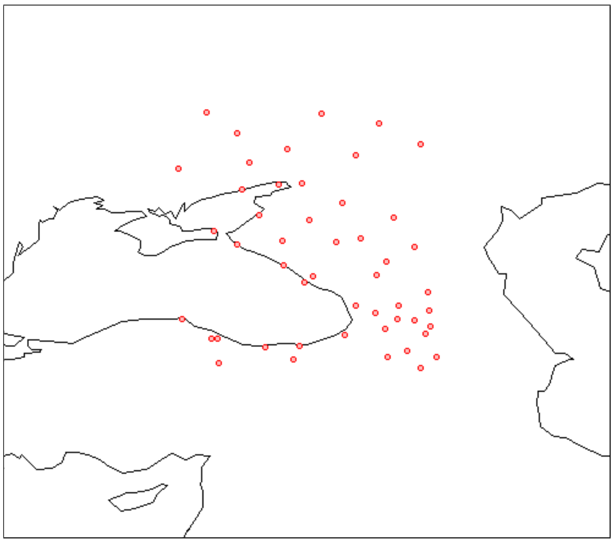

Figure 5: Location of the stations used for the intercomparison exercise between COSMO-S14-EPS, ALADIN-LAEF and "combined".

The skill of the systems was studied for 6 different thresholds: 1, 5, 10, 15, 25 and 50 mm/12h. The following probabiglistic scores were computed: the Brier Skill Score (BSS), the Ranked Probability Skill Score (RPSS), the Relative Operating Characteristic Curve (ROC) area, the Rank Hystograms (RK) and the Percentage of Outliers (OUTL). For a description of these scores, the reader is referred to Wilks (1995). The main features of the intercomparison exercise are also summarised in Table 4.

The performances of COSMO-S14-EPS, ALADIN-LAEF and of the "combined" ensemble

Table 4: Main features of the intercomparison configuration.

variable:	12-hour precipitation (18-06, 06-18 UTC)
starting time:	12 UTC;
period:	from 15 January to 15 March 2014;
region:	40-50N, 35–45 E;
method:	nearest grid–point;
observations:	SYNOP reports (about 73 stations/day);
fcst ranges:	6-18h, 18-30h, 30-42h, 42-54h, 54-66h;
thresholds:	1, 5, 10, 15, 25, 50 mm/12h;
scores:	ROC area, BSS, RPSS, OUTL;
systems:	ALADIN-LAEF, COSMO-S14-EPS, **combined**

are presented in Fig. 6, where we evaluate their ability to predict two different weather events: 12-hour precipitation exceeding 5 mm (left panel) and 10 mm (right panel). The values of the ROC area are plotted against the forecast range for each event.

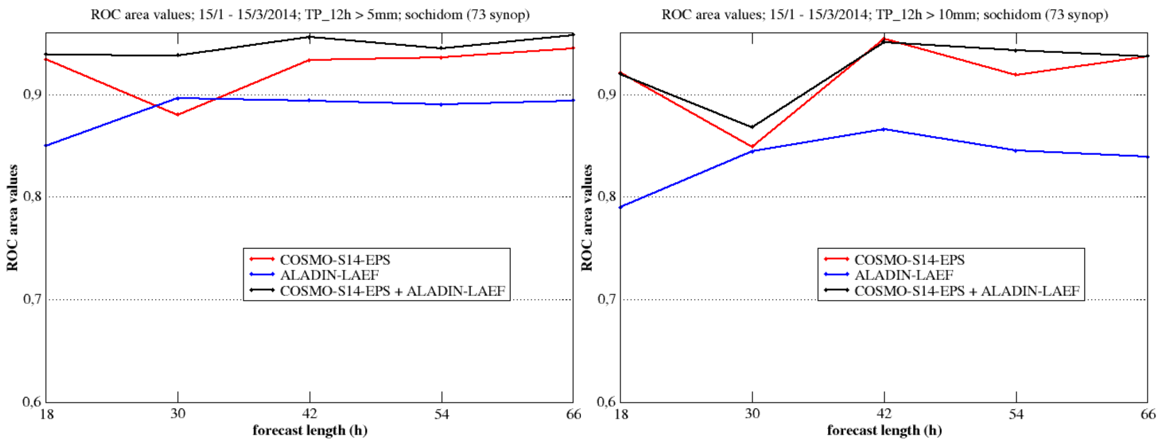

Figure 6: ROC area values as a function of the forecast range for two different weather events: 12-hour precipitation exceeding 5 mm (left) and 10 mm (right). The scores are calculated over the period January-March 2014. Red lines refer to COSMO-S14-EPS, blue lines to ALADIN-LAEF, black lines to the "combined" ensemble.

It can be noticed that the ROC area values are above 0.8 for all systems and for both thresholds, indicating that both COSMO-S14-EPS and ALADIN-LAEF manage to discriminate these events. The skill of ALADIN-LAEF (blue lines) is quite constant with the forecast ranges, while the performance of COSMO-S14-EPS (red lines) varies. The latter ensemble seems to be sligtly superior for most forecast ranges. The combined ensemble (black lines) provides the best scores especially for the lower threshold (left panel of Fig. 6), suggesting the added value of a multi-model approach with respect to the single-model one. The higher skill of the combined ensemble can also be noticed if either lower or higher thresholds are considered (not shown).
The above results are confirmed and even strengthened if the performance of the systems is analysed in terms of "integrated" scores, that is not depending on a particular threshold value. Fig. 7 shows the RPSS and the percentage of outliers (left and right panels, respectively) for the systems under investigation. As for the RPSS, the performance of the two single-model ensembles is very similar. It can be noticed that COSMO-S14-EPS and ALADIN-LAEF exhibit opposite cycles of the score: the former (latter) system has better skill in predicting precipitation which occurs during night-time (day-time). The combined

ensemble (black line) takes the best of both components and provides higher scores with a reduced daily cycle. As for the outliers (right panel in Fig. 7, the added value of the combined ensemble is extremely clear for all forecast ranges, with a 50% reduction of the number of times the analysis is out of the forecast interval spanned by the ensemble members.

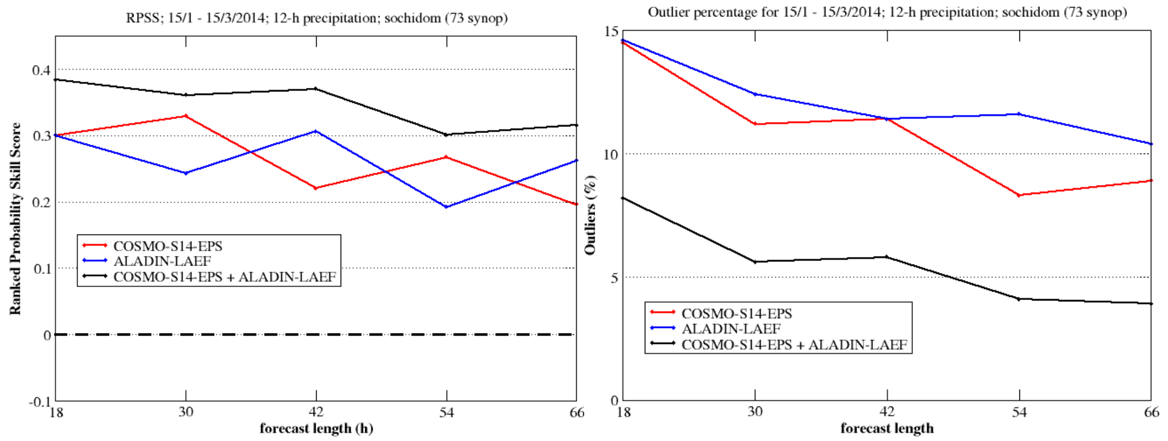

Figure 7: Ranked Probability Skill Score (left panel) and percentage of Ouliers (right panel) as a function of the forecast range. The scores are calculated over the period January-March 2014. Red lines refer to COSMO-S14-EPS, blue lines to ALADIN-LAEF, black lines to the "combined" ensemble.

5 Summary of results

COSMO–S14–EPS is a limited–area ensemble prediction system which supported the probabilistic prediction of high–impact weather events for 2014 winter Olympic Games. The system, based on a relocation of COSMO–LEPS, was shown to provide added value with respect to the driving ensemble (ECMWF EPS) as for the probabilistic prediction of precipitation events. Although these results were not based on a long and statistically significant sample, they already showed the potential of the system, which could provide accurate precipitation forecasts with high spatial detail.

Other important results of the ensemble prediction system experimentation carried out in the framework of SPCOLEPS project can be summarized as follows:

- COSMO–S14–EPS was shown to be able to capture the possible occurrence of intense and localized weather events in the Olympic venues with a few days in advance;
- COSMO–S14–EPS products progressively got more and more used in operational forecasting and the use of probabilistic products among Olympic forecasters increased.
- the COSMO–based ensemble prediction systems, referred to as COSMO–S14–EPS (convection–parameterised) and COSMO–RU2–EPS (convection–permitting), were implemented and run on an operational/quasioperational basis during the pre-Olympic and Olympic seasons;
- a preliminary verification exercise (not shown) was undertaken by assessing the probabilistic skill of both systems in terms of 2–metre temperature during the pre-Olympic season (January-February 2013) over a region centred around Sochi;
- both COSMO–S14–EPS and COSMO–RU2–EPS turned out to have an overall good performance with ability to discriminate different weather events;

- the added value of the higher resolution in COSMO-RU2-EPS was confirmed by the better probabilistic scores obtained by this system;
- although the results presented in Section 4 were based on the combination of only two systems, a great potential was shown for a remarkable gain in predictability by blending different ensemble systems.

References

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