SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Investigation of case studies during Sochi Olympic Games using COSMO-based ensemble prediction systems.
Computer Project Account:	spcoleps
Start Year - End Year :	2015 - 2017
Principal Investigator(s)	Montani Andrea
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Other Researchers (Name/Affiliation):	

July 2018

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The project objectives can be summarised as follows:

- set-up, implementation and maintenance of a limited-area ensemble prediction system based on COSMO model and targeted for the area around Sochi, Russia, where past winter Olympic and Paralympic Games took place (7-23 February and 7-16 March 2014). This system (named COSMO-S14-EPS) was aimed at increasing the probabilistic prediction of high-impact weather for the outdoor activities at the Olympic Games, with special focus on precipitation, temperature and wind;
- use COSMO-S14-EPS to provide initial and boundary conditions for a convection permitting EPS (COSMO-RU2-EPS), also experimented during the Olympic Games:
- perform a comparison between COSMO-S14-EPS and other systems providing forecasts for the Olympic Games.

Summary of problems encountered

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

It is difficult to know the disk space occupation related to a special project (it would be useful to have a command similar to "acct_status spcoleps", but for the disk space).

Experience with the Special Project framework

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

The SP framework is fine. I am not sure whether the final report should be a sort of cut-and-paste of the SP interim reports of the past years.

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.)

The main achievements can be summarised as follows:

1. positive impact of using convection-permitting ensembles with respect to the convection-parametrized ones
2. added value of multi-model ensemble systems for surface verification.

More details are provided in the attached scientific report.

List of publications/reports from the project with complete references

Astakhova E.D., Montani A., Alferov D.Yu., 2014. Ensemble prediction systems for sochi region based on cosmo model: development of methods and provision of probabilistic forecasts for XXII Winter Olympics, Proceedings of Hydrometcentre of Russia. 2014. Vol. 352. 21-36

Astakhova E.D., Montani A., Alferov D. Yu., 2015. Ensemble forecasts for Sochi--2014 Olympic Games}, Russ. Meteorol.Hydro., 40, 531-539.

Kiktev D., Joe P., Isaac G.A., Montani A., Frogner I.-L., Nurmi P., Bica B., Milbrandt J., Tsyrulnikov M., Astakhova E., Bundel A., Bélair S., Pyle M., Muravyev A., Rivin G., Rozinkina I., Paccagnella T., Wang Y., Reid J., Nipen T., Ahn K.-D., 2017. FROST-2014: The Sochi Winter Olympics International Project, Bull. Amer. Meteor. Soc, 98, 1908-1929. doi: 10.1175/BAMS-D-15-00307.1

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.)

It was submitted a new special project (computer account: SPCOLEPS) dealing with the investigation of case studies using different model configurations, but not necessarily related to the Sochi Olympics event. The new project should last from 2018 to 2020.

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

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1 Motivation and introduction

The last winter Olympic/Paralympic Games were held in February-March 2014 in Sochi, Russia. The Russsian Meteorological Service (Roshydromet) initiated a special international project FROST-2014 (FROST - Forecast and Research in the Olympic Sochi Testbed) related to these Games; it got a status of WMO World Weather Research Programme (WWRP) blended Forecast Demonstration and Research and Development Project (Kiktev et al., 2015a; Kiktev et al., 2015b).
The COSMO activity in FROST-2014 was integrated within a consortium Priority Project "Consolidation of Operation and Research results for the Sochi Olympic Games" (PP CORSO) (Rivin and Rozinkina, 2013). PP CORSO finished in 2014. Its results included a successful experience of high-resolution modeling in mountainous areas, improved downscaling/postprocessing procedures for the Sochi region, regular provision of probabilistic forecasts during the Games as well as research in ensemble modeling with different resolutions.
It was realized in 2014 that some additional work was necessary to implement CORSO achievements to COSMO practice and to enable their better usage. That is why the priority task CORSO-A followed PP CORSO. Here only the ensemble component of CORSO and CORSO-A activity will be described.

2 Ensemble prediction systems developed in the framework of CORSO project

Two ensemble prediction systems (EPS) were developed within PP CORSO: COSMO-S14-EPS with a 7-km resolution and COSMO-Ru2-EPS with a 2.2 km resolution (Montani et al, 2013, 2014, 2015). COSMO-S14-EPS (S14 stands for Sochi2014) was created at ARPA-SIMC (Montani et al, 2013) and was a version of COSMO-LEPS system (Montani et al, 2011) displaced from the European area to the Sochi region. The system was driven by the ECMWF EPS, namely, by its most representative prognostic realizations which were selected by a clustering procedure. The lower boundary condition was a result of COSMO model run in hindcast mode (a short-range forecast nested on ECMWF analyses).
The model-related uncertainties were taken into account in COSMO-S14-EPS by using two different convection parameterization schemes (Tiedtke or Kain-Fritsch, random choice) in different members and also by varying tuning coefficients in parameterizations of sub-grid scale processes (in particular, turbulent). The most essential differences between COSMO-S14-EPS and COSMO-LEPS systems were integration domains (Sochi region or Europe) and ensemble sizes (10 and 16 members, respectively). The system with a 2.2-km grid size named COSMO-Ru2-EPS ran at Roshydromet and performed a dynamical downscaling of COSMO-S14-EPS increasing the resolution both in horizontal (from 7 to 2.2 km) and in vertical (from 40 to 50 levels). No additional perturbations were introduced neither to

initial and boundary conditions nor to the model. The ensemble has the same size as in COSMO-S14-EPS and was composed of 10 perturbed members with no control. Both EPSs ran operationally during the Olympics/Paralympics, their results were provided to Sochi forecasters and proved to give a valuable support to them. More precisely, the entire length of parallel runs of COSMO-S14-EPS and COSMO-Ru2-EPS was longer than the period of the Games and covered December 2013-April 2014. The forecast results were archived on Roshydromet servers along with initial and boundary conditions generated by COSMO-S14-EPS and later used by COSMO-Ru2-EPS.

3 CORSO-A necessity and goal

It is worth noticing that COSMO ensemble forecasts can be considered a part of the more extensive FROST-2014 archive that included the results of four more ensemble prediction systems (Kiktev et al, 2015; Astakhova et al, 2015). Two systems, GLAMEPS and HarmonEPS, were presented to FROST-2014 by the Norwegian Meteorological Institute, while ALADIN-LAEF and NMMB-EPS came from the Central Institution for Meteorology and Geodynamics (ZAMG), Austria, and the National Centers for Environmental Prediction (NCEP), USA, respectively. The complete list of the participant ensemble systems is reported in Table 1.

Table 1: 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

The EPS resolution ranged from 7 to 11 km except for the convection permitting HarmonEPS with its 2.5 km horizontal step; the ensemble size varied from 7 to 54. Additionally, deterministic forecasts by 9 different systems, nowcasts from 6 systems, and a variety of observational data of different types, including station, radar, profiler data, operational meteorological bulletins, camera snapshots, etc., were aggregated at the FROST-2014 server and available via the project web-site `http://frost2014.meteoinfo.ru` . By no doubt, this huge amount of forecast and observation data could be very useful for research in the field of short-range limited-area deterministic and ensemble prediction. Remember that the Sochi area is a very complex region with steep mountains lying near the warm Black Sea and forecasting in mountainous regions is still a challenge for numerical weather prediction models. However, it became clear after the Olympic Games, that in research tasks it would be quite difficult and problematic to use the forecast data in the form presented on the FROST-2014 server because of different coding and organization of data files transferred to Roshydromet by various data providers. The application of the archive would be much easier if the forecast data were organized following some standard rules. A good idea is to follow TIGGE-LAM project and to prepare a Sochi unified archive using the coding standards and user interfaces adopted in TIGGE-LAM (Paccagnella et al., 2012). TIGGE and TIGGE-LAM data portals are well known and very popular in scientific community and a lot of research has been done using the data presented there. That is why one of CORSO-A goals was to implement a unified archive of COSMO ensemble forecasts (with 7 and 2.2 km resolutions) for the Sochi area. The archive was expected to be accompanied by the data on initial and boundary conditions for high-resolution ensembles and by a list of important weather events during Olympics and Paralympics.

4 Performance of the ensemble systems

As described in Kiktev et al. (2017) and in Table 1, two convection-permitting systems (i.e., systems with explicitly simulated deep convection), COSMO-Ru2-EPS and HarmonEPS, were tested in research mode while the coarser resolution EPSs were operational. All forecasts were issued twice a day, starting from 00 and 12 UTC with the exception for the HIRLAM systems that started at 06 and 18 UTC. The Games area was within the operational domains of ALADIN-LAEF and GLAMEPS, whereas the other systems were specifically set up for FROST-2014. The EPSs generated a set of probabilistic products, including ensemble mean and ensemble standard deviation for several near-surface and upper-air variables, probability of exceeding a specified threshold, as well as ensemble meteograms for selected points. Additionally, pointwise calibrated and hourly updated GLAMEPS forecasts were produced. The impact of calibration on the skill of COSMO-based ensembles will be investigated in forthcoming studies. The ensemble products were systematically presented at the FROST-2014 site and widely applied and appreciated by the Sochi forecasters.

After the Games the project research was mainly focused on possible advantages of high-resolution convection-permitting and multi-model ensembles as well as on the effects of calibration. Figure 1 presents the Continuous Ranked Probability Score (CRPS; the lower the better) (WMO 2008) for ECMWF EPS, GLAMEPS, calibrated GLAMEPS, and HarmonEPS forecasts, three systems having quite different resolutions. While ECMWF EPS and GLAMEPS had a comparable number of ensemble members (51 and 54, respectively), HarmonEPS had only 13 members. The most striking feature in the figure is the effect of calibration producing much better scores for temperature and wind, and slightly better for precipitation for most lead times. Running an EPS is expensive, while calibration is much cheaper in terms of computational cost and thus appears to be a highly beneficial approach.

Other FROST-related developments after the Games were calibration and an enrichment of the ensemble. As for the latter, Figure 2 illustrates the potential of multi-model approach using the FROST-2014 EPSs. The areas under the relative operating characteristic (ROC) curves for individual EPSs (Wilks, 1995) and their combined multi-model ensemble are shown. The scores for convection-parameterized (left) and convection-permitting (right) EPSs are given as functions of forecast lead time for 6-h precipitation exceeding 1 mm. All FROST-2014 EPSs exhibited quite high and, on average, comparable ROC values. It can be noticed that the scores of the multi-model ensemble are consistently higher than those of its constituents for all forecast ranges, indicating a better ability of the system to predict this type of events.

The role of spatial resolution for EPS performance is demonstrated in Figure 3. Here, the debiased RPSS (Ranked Probability Skill Score) was selected as it makes ensembles with differing sizes comparable. In general, the higher-resolution ensembles with an explicit treatment of convection performed better than the convection-parameterized systems (COSMO-Ru2 and HarmonEPS vs. COSMO-Ru7 and GLAMEPS, respectively).

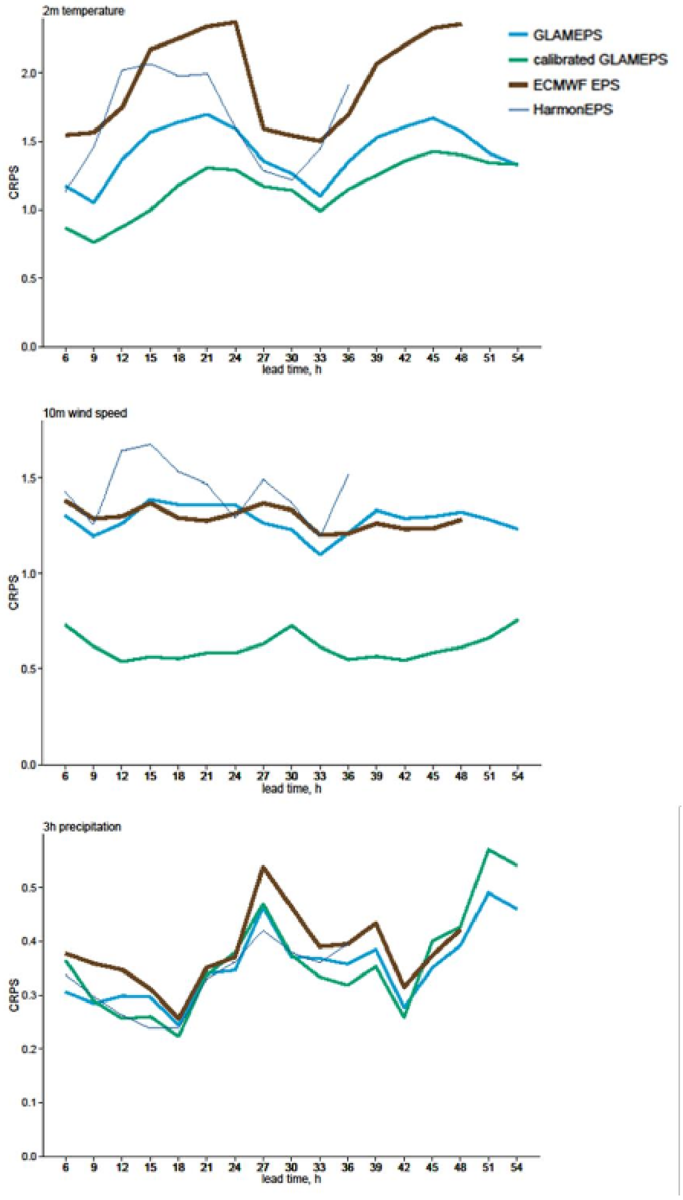

Figure 1: CRPS for ECMWF EPS, GLAMEPS, calibrated GLAMEPS, and HarmonEPS (the lower the better). Top: T 2m ; Middle: 10-m wind speed; Bottom: 3-h precipitation (from Kiktev et al., 2017).

5 Conclusions

Before the Games, the majority of the local forecasters had a very limited practice in use of ensemble forecast products. The Games experience facilitated the gradual embedding of the probabilistic thinking into their working practices and formed a new need for this kind of numerical guidance. The probabilistic information tended to be more actively used by the forecasters for the second and third forecast days, while the deterministic predictions were preferred for the shorter forecast ranges. In some situations (particularly in the case of low visibility event) the information on forecast uncertainty by the different ensemble systems was conveyed to the sport managers for support of the decision making.

Therefore, the information provided by the different ensemble systems met to a great extent

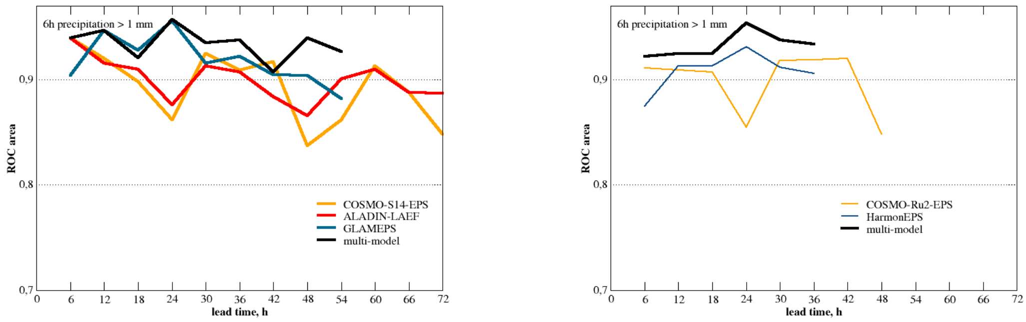

Figure 2: Area under the ROC curve (the higher the better) for forecasts of the event "6-h accumulated precipitation is above 1 mm" aggregated over the stations of the mountain cluster for convection-parameterized (left panel) and convection-permitting (right panel) EPSs as well as for the corresponding multi-model ensembles. Note that about 200 occurrences of the above event were observed during the verification period (from Kiktev et al., 2017).

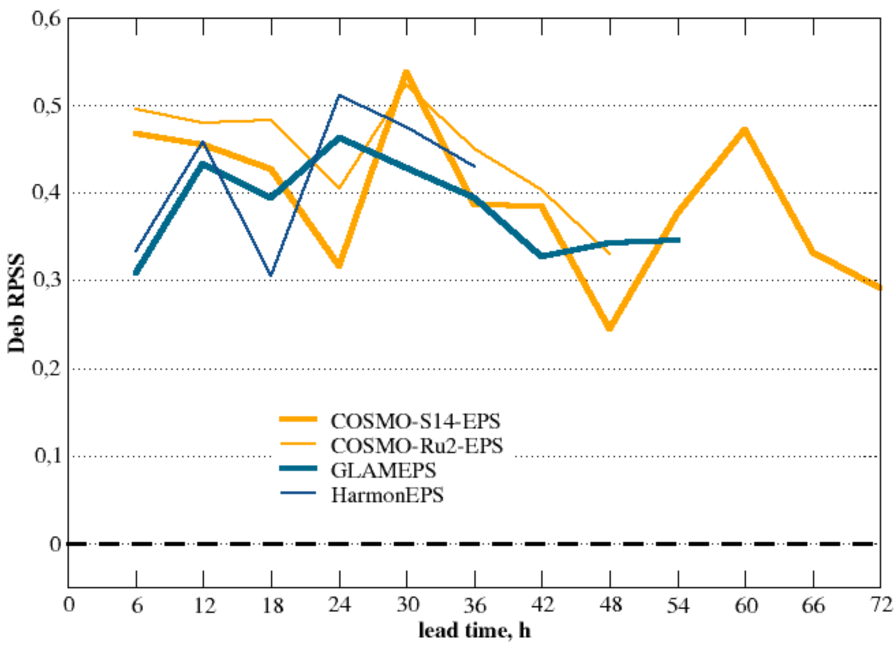

Figure 3: Debiased RPSS (the higher the better) for 6-h accumulated precipitation forecast by two convection-parameterized (COSMO-S14-EPS and GLAMEPS) and two convection-permitting EPSs (COSMO-Ru2-EPS and HarmonEPS), aggregated over the stations of the mountain cluster (from Kiktev et al., 2017).

the forecasters' requirements; it is hoped this type of events will encourage the continuous use of ensemble-based products to address the forcast of high-impact weather in regions with complex topography, where Winter Olympic Games typically take place.

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