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The COSMO Priority Project CORSO-A

Final Report

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1 Introduction

The PP CORSO (Consolidation of Operation and Research results for the Sochi Olympics) dedicated to development of high-resolution NWP meteosupport of Sochi2014 Olympics held in 2011-2014. PP CORSO was adopted with a goal to enhance and demonstrate the capabilities of COSMO-based systems of NWP in winter conditions for mountainous terrain and to assess the effect of practical use of this information during Sochi-2014 Olympic Games. There were 3 directions of activities concerning the development and implementation of:

a) high-resolution forecasting system (Task1),

b) the means of practical forecasting and down-scaling post-processing (Task2),

c) mesoscale EPS (Task3).

PP CORSO obtained the successful results. The main result of FDP part of PP CORSO was the implementation of high quality NWP system, which the forecasters of Organizing Committee and of sport venues have used as a basic. The COSMO experience and its possibilities were concentrated for obtain the renovated NWP system for SOCHI-2014 region with complex geographical terrain. Due to the cooperation of FDP and RDP activities of PP CORSO, the new level of modeling and of interpretation of results were obtained (The new COSMO-version with step 1.1km, the some down-scaling postprocessing algorithms, knowledge of feed-back from forecasters, the implementation of High-resolution EPS-system 2.2. km for mountain area). Some aspects obtained results could be further researched and could be useful for implementation and investigations in whole COSMO community. The obtained experience, accumulated data of measurements and of forecasts and new numeric experiments permit to adapt & develop and test of the proposed algorithms and technical solutions. The new PT CORSO-After (CORSO-A) should meet these developed challenges for implementation in COSMO technologies and investigations.

1.1 The goal of PT

To prepare the new COSMO tools and practical instructions for be available for COSMO-community related to:

- the implementation of versions COSMO-1km (SubTask1 The guidance of the optimal domain's size selection for 1.1 km resolution of nested COSMO models for the regions with complex mountain relief, TL G.Rivin),
- the realization of down-scaling postprocessing tools for mountain area, (SubTask2, Development of algorithm of subgrid h-correction of T2m (due to the differences between models and real heights) based on COSMO- forecasts of vertical T-gradient , STL I.Rozinkina),
- the development of archive for development of convective-resolution EPS (SubTask3 Preparing of archives of 7 km and 2.2 km EPS forecasts for the Sochi- 2014 modeling area applicable for research aimed at improving COSMO EPS systems and available for community. Their compliance with FROST2014 archives, STL E.Astakhova, A.Montani),

- the preparing of instructions for forecasters for use the results of meso-scale deterministic and EPS results (SubTask4 Preparing of recommendations for forecasters The features of using and interpretation of the results of limited- area meso-scale modeling STL I.Rozinkina).

2 SubTasks, brief description

2.1 SubTask 1 The guidance of the optimal domain's size selection for 1.1 km resolution of nested COSMO models for the regions with complex mountain relief (STL G. Rivin)

2.1.1 Motivation

The development and implementation of COSMO1 were obtained as result of RDP part of PP CORSO. As addition the participants managed to organize the operational runs of COSMO1 for Sochi2014 area during the Olympics 2014, and the positive experience of use of COSMO 1 for Sochi area was gained. The modeling with grid step about 1 km is significantly more realistic for mountain area and as sequence permit to provide for forecasters the additional important products as, e.g. flows of wind in bottom level, that determines the weather in hills and valleys. During the CORSO PP were obtained results shown the strong dependence of the predicted precipitation amount and spatial distribution on the models domain size. This problem need the more attentive examination, because the runs of COSMO1 as part of nested technologies are very expensive in point of view of computing time. The computing resources and the technological requirements of providing forecast by a certain time determine the model run timing. On the other hand it exists the requirements for the quality of the forecasts.

2.1.2 Goal

To formulate and to prove the selection of models domain size for COSMO1 model runs for disseminate this experience for create the similar technologies for detailed calculations on mountain domains in condition of limited computing resources.

2.2 SubTask 2 Development of algorithm of subgrid h-correction of T2m (due to the differences between models and real heights) based on COSMO- forecasts of vertical T-gradient (STL I. Rozinkina)

2.2.1 Motivation

In framework of PP CORSO were realized some approaches for subgrid correction of T2m, as the direct forecasts from COSMO-model of T2m for mountain region were not convenient. There are some causes because it. One of principal causes of this fact for mountain area is the simple discrepancy of local real and averaged of grid cells height. As traditional, T2m can be corrected by use standard adiabatic gradient, but in Sochi2014 region the real temperature profiles can be significantly different including inversions. Because of the variability of the vertical temperature profile depending on a large-scale weather forecasts the implementation of KF or MOS in lot of cases is inefficiently because there are non systematic errors. The CORSO participants proposed the algorithm of correction of local values of T2m for mountains based the COSMO- models forecasts of T-profile of bottoms levels (H-corection). The implementation of this algorithm in meteogram tables permit to obtain the more realistic T2m forecasts for points before the possible subsequent correction tools (KF or MOS), due to improve the limitations of parameterization schemes. This proposed algorithm can be disseminate in two direction of implementation: a) by modified technology of forming of meteograms by including into FieldExtra for calculate the fields of subgrid variations of T2m (for min and max real height of cells).

2.2.2 Goal

To realize the updated software of Fieldextra with including of calculations of subgrid values of T2m based the forecasts of vertical T gradient. To provide the software of 1-D correction of T2m forecasts based the forecasts of vertical T gradient (h-correction).

2.3 SubTask 3 Preparing of archives of 7 km and 2.2 km EPSs forecasts for the Sochi-2014 modelling area applicable for research aimed at improving COSMO EPS systems and available for community (TL E. Astakhova, A. Montani)

2.3.1 Motivation

The two ensemble prediction systems were developed within the PP CORSO: COSMO-S14-EPS with a 7-km resolution and COSMO-Ru2-EPS with a 2.2 km resolution. The results of both ensembles were provided to Sochi forecasters during the Olympics and proved to give a valuable support to them. COSMO-S14-EPS (S14 stands for Sochi-2014) is a relocation of COSMO-LEPS to the area of Olympic Games and was generated rather similarly to COSMO-LEPS but with some changes introduced because of computer-time constraints and the interest towards the short-range. Initial and boundary conditions for COSMO-S14-EPS were taken from ECMWF EPS. The initial ensemble size was reduced to 10 members selected by a clustering procedure (Montani et al., 2011). The lower boundary condition for all COSMO-S14-EPS members was taken from COSMO model run in hindcast mode (short-range forecast nested on ECMWF analyses). COSMO-S14-EPS ran on a regular basis since 19 December 2011 on ECMWF supercomputers. COSMO-S14-EPS generated a set of standard probabilistic products (including probability of surpassing a threshold, ensemble mean, ensemble standard deviation, and ensemble meteograms for several surface and upper-air variables) which were delivered to Sochi forecasters in operational mode. COSMO-Ru2-EPS is a convective-permitting ensemble, based on initial and boundary conditions provided by COSMO-S14-EPS. The system ran on Roshydromet computers. The first winter of its regular runs (2012-2013) and case studies (2011-2013) showed that COSMO-Ru2-EPS gave rather precise and detailed forecasts and therefore could be useful for Sochi forecasters. Following this conclusion, COSMO-Ru2-EPS operationally ran twice a day (00 and 12 UTC) since November 2013 and during the Olympics. In course of CORSO project, the output results of the two EPSs were archived on Roshydromet computers. In total, the results of nearly six months of runs of the COSMO EPSs (both 7 and 2.2 km) are available (November 2013-April 2014). These are forecasts for a very specific area, where mountains with very steep slopes are in close vicinity to the sea and where high-resolution forecasting of high-impact events is a real challenge. The available COSMO-EPS forecasts can be also considered as a part of the FROST2014 archive. Roshydromet suggested that the FROST2014 archive be freely accessible to the entire meteorological community. In addition to the forecasts, available in the FROST2014 archive, the initial and boundary conditions generated by COSMO-S14-EPS were stored at Roshydromet as well. The entire dataset available (COSMO EPSs forecasts + initial and boundary conditions for COSMO high-resolution EPS + FROST forecasts and observations) can be very useful for the international community and especially for COSMO community. Re-forecasts using a modified high-resolution EPS can be done to estimate the influence of different aspects of ensemble generation (e.g. model-related perturbations, soil perturbations, etc.) However, at present there are still some obstacles for using the COSMO-related data:

- there are some gaps in the data;
- the COSMO-Ru2-EPS forecasts are stored on different computers to which there is no external access;
- the entire outputs of COSMO models are stored for COSMO-Ru2-EPS while only a pre-specified set of variables should be archived according to the FROST rules;
- there is no manual;
- the data should be completed by a list of severe events and periods that are worth to examine.

2.3.2 Goal

To prepare an archive of COSMO ensemble forecasts (with 7 and 2.2 km resolutions) for the Sochi area accompanied by initial and boundary conditions for high-resolution ensembles and by a list of important weather events during the period considered. The archive must be provided according to TIGGE-LAM archiving standards, easily accessible and have a clear manual to provide COSMO-community a possibility of experiments over an area where steep mountains are in close vicinity to the sea and high-resolution forecasts of severe events are a challenge.

2.4 SubTask 4. Preparing of recommendations for forecasters The features of using and interpretation of the results of limited- area mesoscale modeling (TL I. Rozinkina)

2.4.1 Motivation

Due to the COSMO PP CORSO and the WMO DP Frost2014 the forecasters of Sochi 2014 region obtained the cascade of model outputs form deterministic and ensemble modern mesoscale NWP technologies at large window of spatial resolutions. The some synoptical trainings for understanding of possible limitations of models are realized d at 2011-2014. Sometime there are not evident forecasting rules for correct interpretation of it output. The study of experience of feedback form forecasters permitted to obtain the experience, useful for disseminate among the forecasters. This practical rules must be based the knowledge of technology and limitations of algorithms for more effective interpretation the main correction.

2.4.2 Goal

To prepare the recommendations for forecasters to formulate and disseminate the experience of feedback and trainings of period before and during the Sochi-2014 concerning the features of interpretation of limited- area mesoscale NWP Systems (based COSMO-Ru technologies).

3 The guidance of the optimal domain's size selection for 1.1 km resolution of nested COSMO models for the regions with complex mountain relief (G. Rivin, M. Shatunova, J. Helmert)

3.1 Introduction

The development and implementation of COSMO model with 1.1 km resolution for the Sochi region was a part of RDP works within the Priority Project CORSO (Consolidation of Operation and Research results for the Sochi Olympics). The RDP results shown the strong dependence of the predicted precipitation amount and its spatial distribution on the models domain size. This problem need the more attentive examination, because the run of COSMO-Ru1 as part of nested technologies is rather expensive in point of view of computational time. The computing resources and the technological requirements of providing forecast by a certain time determine the model run timing. On the other hand, there are requirements for the quality of the forecasts. Factors determining the weather in the region, e.g., predominant direction of air mass transfer, and regional orography define possible location and size of the simulation domain. Forecasts assessment for the area on interest, area of the Sochi Olympics 2014 in our case, allow designate preferable domain. We used data from the observation sites located for the most part near the sports venues in two clusters coastal and mountainous, for verification. Sites of the first cluster are located on the coastline of 95 km and at distance up to 12 km, at an altitude from 2 to 660 m. Mountainous sites are located within the Mzymta river valley and adjoined highlands at an altitude from 560 to 2225 m. Forecast verification was made for the whole region and for mountain valley separately considering distribution of the observation sites.

3.2 Simulation domains

Selection of the simulation domains size and location was made using the results of Subtask 2.2 of PP CORSO Compilation of significant weather climatology for the Sochi region, based on automated weather classification and taking into consideration influence of regional orography. Area of Sochi Olympics and surroundings presented on Fig. 1, where red rectangle indicates location of the Sochi2014 sport venues. Air masses coming from WSW and EN determined weather conditions in the area of Sochi2014 during the winter. Local cyclone formed over the eastern Black Sea basin affects weather also. While western (NW or SW) direction prevails in a large-scale air transport, warm and moisture air mass moves along the local cyclone periphery and along the coast in NE direction, shifts over land and inflows into the mountain valleys. Two mountain ridges Main Caucasian Ridge and East Pontic Mountains are a kind of natural border, preventing the penetration of air masses in the Sochi2014 area from the northeast and southeast. It seems reasonable that simulation domain covered the eastern Black Sea basin and be limited by mentioned mountain ridges. The following three variants were suggested: domain 1 (D1) has 300x300 grid points, domain 2 (D2) has 450x450 and domain 3 (D3) has 450x650, and grid points (see Fig. 2). The results obtained for these three domains were verified by VERSUS. An effect of the simulation domain size and location on precipitation forecast was investigated also for several cases of heavy precipitation. Additional simulations were performed for the one more domain D4 (750x750 grid points) for case studies. COSMO-Ru7 model (7 km grid spacing) provided initial and boundary conditions for COSMO-Ru1.

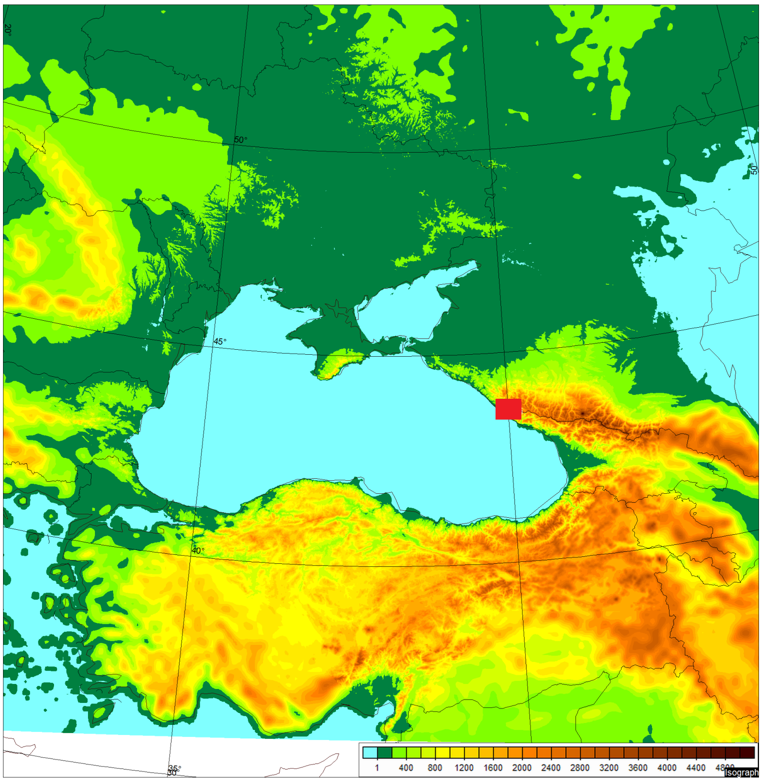

Figure 1: Geographical location of Sochi2014 region (red rectangle).

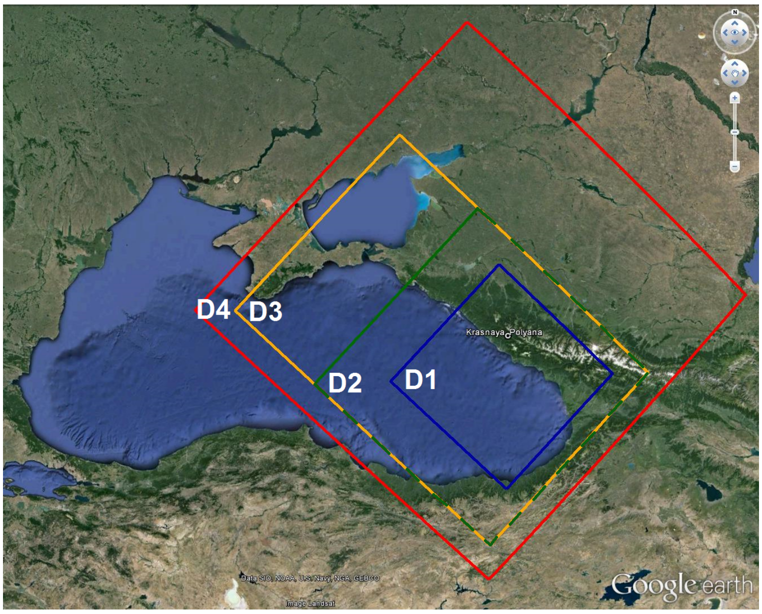

Figure 2: Simulation domains: D1 (blue rectangle) 300 x 300 grid points, D2 (green rectangle) 450 x 450 grid points, D3 (yellow rectangle) 450 x 650 grid points, D4 (red rectangle) 750 x 750 grid points.

3.3 VERSUS verification results

By means of VERSUS, 24 h forecasts for air temperature at 2 m, dew point temperature at 2 m, wind speed at 10 m and 3 h precipitation sum were verified. Two kind of VERSUS stratification were used. The first, Sochi39, includes 56 stations of which half is in the coastal zone and half is in the mountains. The second stratification, Sochi_Mount, includes 25 stations located in the mountain cluster of Sochi2014 within the upper and middle part of the Mzymta river valley. Nearest point 3D optimized method was chosen for verification. During February and March, 2014 local time was equivalent to UTC + 04 h. Verification results mean error (ME) and root mean square error (RMSE) of the 24 h forecast for the different domains are presented on Fig. 3. The results for all domains and two variant of stratification look rather similar but have some features:

- RMSE is less for the D1 for the daytime (04 14 UTC) for air temperature and wind speed forecasts. RMSE difference reaches 0.8 for T2m forecast and 0.3 for wind speed forecast;
- dew point temperature was predicted better for D1 for the most, difference between results for D1 and D2 and D3 became greater after 18 h and at 24 h lead time amounts 0.7-0.9 for mean error.

The difference between results for D2 and D3 is negligible. Thus, the expansion of the simulation domain in the NW direction has not given effect. Average difference between results for D1, D2 and D3 for air temperature is less 0.1 (for ME) and 0.1-0.2 (for RMSE), for dew point temperature is less 0.4 (for ME) and 0.4-0.6 (for RMSE), for wind speed is less 0.1 (for ME) and about 0.1 (for RMSE). Analysis of the results for two stratifications shows that wind speed is slightly better predicted for the mountain cluster, whereas air temperature and dew point temperature forecasts for mountain cluster have lesser score than for the whole assessment area. To assess accumulated precipitation several verification scores described below were calculated using 2x2 contingency table (Table 8) for different thresholds. These scores were calculated for 3h precipitation forecast and for all lead-time (Tables 9-13).

Bias is used to detect whether model overestimated precipitation event or underestimated it (Schirmer, Jamieson, 2015), $bias = (A + B)/(A + C)$.

Critical success index (CSI), also called the threat score (TS), $CSI = A/(A + B + C)$. This score indicates the relative worth of different forecasting techniques (Schaefer, 1990).

True skill statistic (TSS), $TSS = (A \cdot D - B \cdot C)/[(A + C)(B + D)]$; also known as Hanssen-Kuiper skill score is a verification measure of categorical forecast.

Heidke skill score (HSS), $HSS = (A + D - E)/(A + B + C + D - E)$, where E is the correct random forecasts. HSS score used for evaluating rare event forecast is suitable for heavy precipitation forecast assessment.

Equitable Threat Score (ETS), also called Gilbert skill score (GS), $ETS = (A - CH)/(A + B + C - CH)$, where $CH = (A + B)(A + C)/(A + B + C + D)$ is hit due to chance. ETS is commonly used for precipitation verification, in particular because correct no-event forecasts are not considered in this score.

Extremal Dependency Index (EDI), $EDI = (\log F - \log H)/(\log F + \log H)$, where $F = B/(B + D)$ is false alarm rate and $H = A/(A + C)$ is hit rate. EDI is an innovative categorical measured, being independent from base rate $(A+C)/(A+B+C+D)$, used for rare dichotomic events verification.

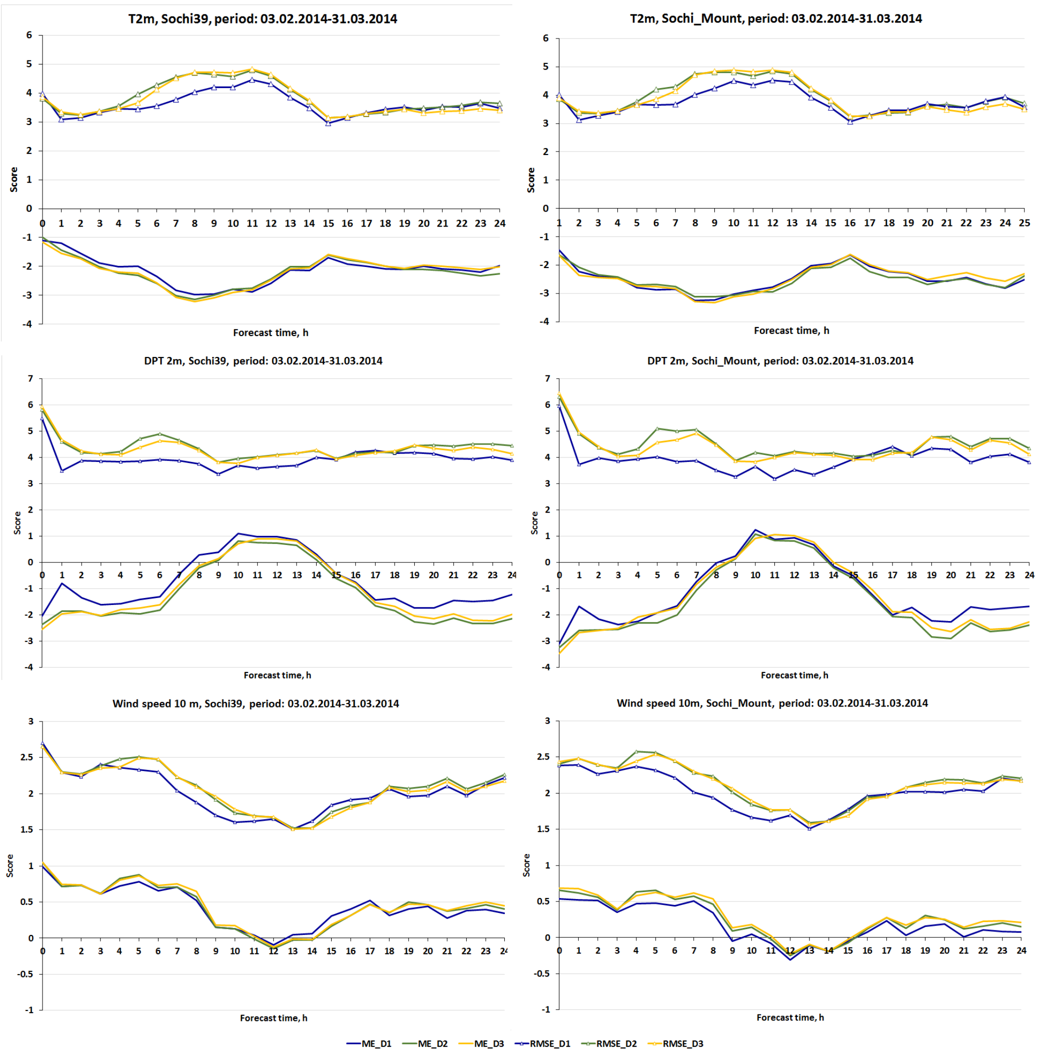

Figure 3: Mean error and RMSE of the air temperature at 2 m, dew point temperature at 2 m and wind speed at 10 m forecasts obtained for three domains.

Precipitation on February and March 2014 in Sochi2014 region usually occurred during daytime, 7-15 h local time (total number of cases indicated at the bottom of the column on Fig. 4). The most cases of heavy precipitation were observed within the 10-16 h local time. Secondary maximum of heavy precipitation (>5 mm/3h) was registered at 22-01 h local time. Bias values for precipitation threshold 0.1 mm/3h for different lead-time (Fig. 5a) show that model overestimates precipitation event for all lead-time regardless of the domain size. For moderate and heavy precipitation (1-5 mm/3h) there is a temporal shift shown on Fig. 5b: while precipitation for the period 9-12 UTC is overestimated, there is underestimation of the event for the previous 3 hours (6-9 UTC). Evaluation of the precipitation with the threshold 3, 5 and 10 mm/3h was made using sample large enough to obtain statistically significant scores.

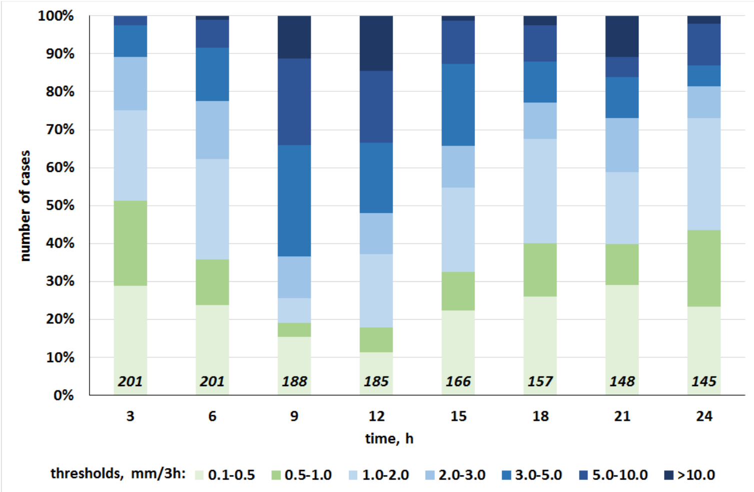

Figure 4: Number of observed precipitation cases for different threshold for 3-hour periods during the day.

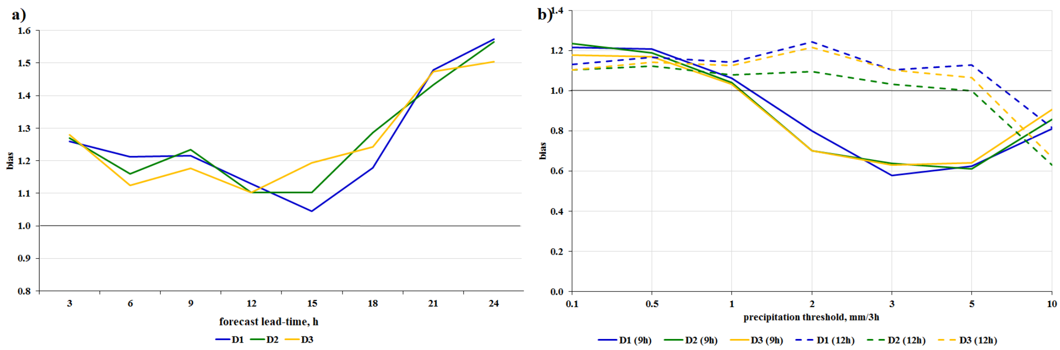

Figure 5: Bias for precipitation threshold 0.1 mm/3h for different lead-time (a) and for different thresholds for lead-time 9 and 12 h (b) for different simulation domains.

Analysis of the scores presented in Tables 9-12 shows that for the first 3 hours period for all domains forecast may be considered no more than satisfactory. Assessment increases for the next periods and for the 9-12 h period forecast has the highest scores for all domains and precipitation thresholds from 0.1 to 5 mm/3h. It is noted that model has rather high scores for forecast precipitation more 10 mm/3h with lead-time 21 h, when secondary maximum of heavy precipitation observed. Comparison of the results for different domains shows that scores for precipitation event forecast (0.1 mm/3h threshold) for D1 are slightly worse than that for D2 and D3. Based on ETS and HSS values that are most suitable for rare event assessment it can be conclude that D1 and D3 have some advantages in heavy precipitation forecasting. It is interesting to note that precipitation forecast for 10 mm/3h threshold is better for D1 for 12 h lead-time, while D3 has some advantages for longer lead-time 21 h. This is also confirmed by the EDI values. Verification by VERSUS shows that small domain can be used for precipitation simulation for the lead-time until 18 h, for greater lead-time it is better to make simulation for larger domain.

3.4 Verification of heavy precipitation event forecast (case studies)

Analysis of the several cases of heavy precipitation was performed to assess the effect of the domain size on the forecast of precipitation amount, its spatial and temporal distribution. The analysis was performed for 12 sites located in the central part of the Sochi2014 area (Fig. 6). Solokh-Aul, Lazarevskoe and Imeretinka are in the coastal cluster, but only the last two are on the seashore. Solokh-Aul is located in the hills at a distance of 12 km from the sea.

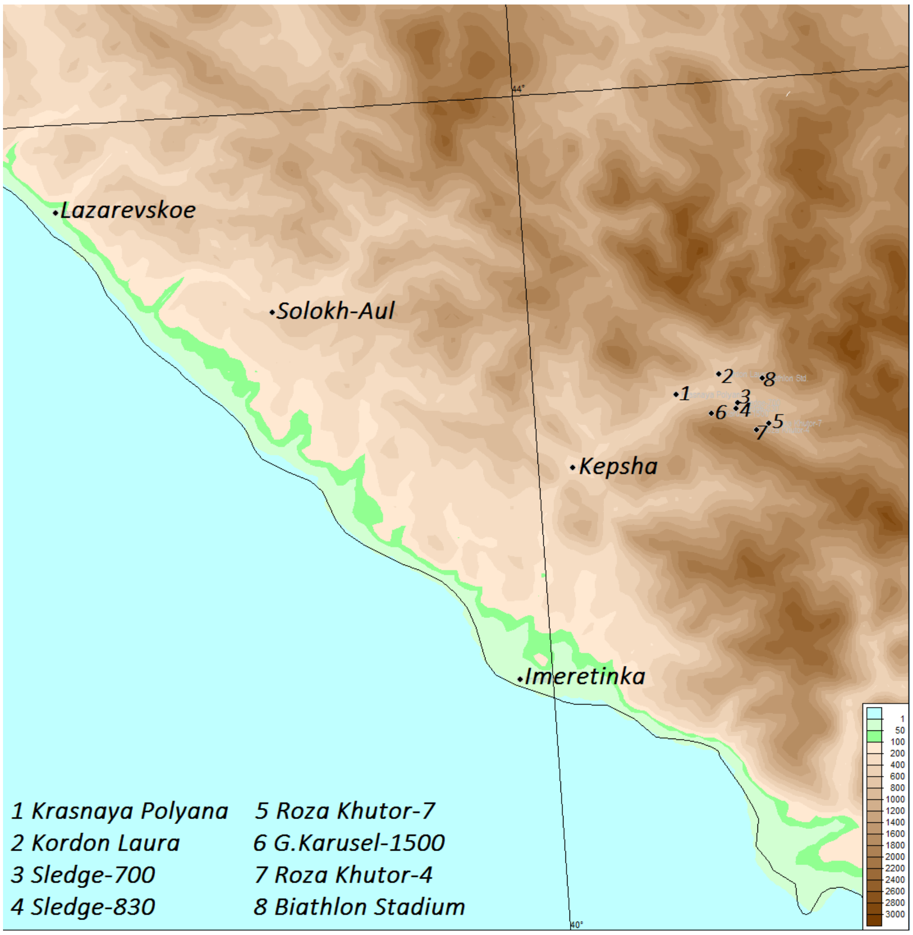

Figure 6: Location of the observation sites used in case studies.

Predicted precipitation daily amount for all domains in comparison with the observations are presented in Tables 1-5. The maximum difference between forecasts was nearly 10 mm/24h. Comparison of the results detects various situations, e.g.:

- results for all domains could be very close to each other and to observation (see Table 3 for G.Karusel-1500);
- difference between forecast and observation could be much greater than difference between forecasts for various domains (see Table 2 for Solokh-Aul);
- for the one domain predicted amount could have good agreement with observations while the difference between forecasts for various domains could be significant (see Table 1 for Kepsha).

Site	Obs.	Forecast			
		750x750	450x650	450x450	300x300
Coastal cluster					
Solokh-Aul	23.0	27.5	28.9	30.5	31.7
Lazarevskoe	19.7	10.8	14.5	7.8	14.2
Imeretinka	9.0	17.0	14.0	17.3	13.3
Mountain cluster (h<1000 m)					
Kepsha	33.5	33.7	29.3	28.6	24.1
Kr. Polyana	29.4	40.0	39.3	38.9	37.1
K. Laura	37.5	41.4	42.4	40.6	40.9
Sledge-700	24.1	28.4	26.8	27.4	25.1
Rosa Khutor-7	32.7	24.6	23.3	26.3	23.1
Sledge-830	24.1	22.8	21.0	22.7	18.4
Mountain cluster (h>1000 m)					
Rosa Khutor-4	38.4	25.9	24.4	26.2	23.1
Biathlon Std.	34.7	30.4	31.2	28.8	30.3
G. Karusel-1500	26.0	22.3	21.0	22.3	19.1

Table 1: Observed and forecasted accumulated precipitation for 24 h on February 18, 2014.

Precipitation temporal distribution presented on Fig. 7 for several sites allows detect domain size influence on the forecast. Variation of the hourly precipitation amount depending on domain could be estimated also. The precipitation on March 17 was caused by convection developed on the cold front and occurred in the morning with peak at 6-7 UTC on coastal sites and at 8-10 UTC on mountainous sites. Maximum hourly amount equal to 12.7 mm was observed at Kepsha. On March 18 precipitation was accompanied by the passage of the rather weak warm front and continued throughout the day. On coastal sites two peaks were observed at 7 and 12 UTC, while within the mountain valley precipitation was more evenly distributed in time. The same forecasted temporal distribution of the precipitation was obtained for all simulation domains. There is shift of the event start time that is about 1-2 hours, predicted precipitation starts earlier than observed. The difference between forecasts for D1-D4 is small for the first 3-5 hours of the forecast. Later it could reach 2-3 mm for hourly-accumulated amount and this was noted both for coastal and mountains sites.

Site	Obs.	Forecast			
		750x750	450x650	450x450	300x300
Coastal cluster					
Solokh-Aul	74.7	37.4	41.5	38.9	41.1
Lazarevskoe	39.0	24.4	26.7	24.6	24.5
Imeretinka	22.7	33.4	31.4	31.8	35.7
Mountain cluster (h<1000 m)					
Kepsha	28.9	31.5	34.4	34.0	35.8
Kr. Polyana	15.1	17.9	20.6	20.7	21.8
K. Laura	17.0	15.3	17.8	17.4	17.2
Sledge-700	15.8	14.2	17.2	16.6	15.3
Rosa Khutor-7	13.8	14.0	16.9	17.0	17.4
Sledge-830	18.8	15.7	16.9	18.8	17.3
Mountain cluster (h>1000 m)					
Rosa Khutor-4	13.9	16.7	19.2	18.9	20.0
Biathlon Std.	11.1	15.0	16.9	16.4	11.6
G. Karusel-1500	20.9	17.0	21.4	21.1	20.3

Table 2: Observed and forecasted accumulated precipitation for 24 h on March 11, 2014

Site	Obs.	Forecast			
		750x750	450x650	450x450	300x300
Coastal cluster					
Solokh-Aul	32.9	26.3	26.2	25.9	26.0
Lazarevskoe	24.2	13.8	15.6	14.7	14.6
Imeretinka	13.4	18.5	19.1	18.3	19.1
Mountain cluster (h<1000 m)					
Kepsha	26.4	17.8	18.3	18.7	18.7
Kr. Polyana	10.4	8.9	9.6	9.7	9.8
K. Laura	15.1	7.6	7.9	7.9	8.4
Sledge-700	12.9	10.6	10.9	10.8	11.5
Rosa Khutor-7	11.7	8.9	9.1	9.0	10.2
Sledge-830	14.2	10.3	10.7	10.6	11.5
Mountain cluster (h>1000 m)					
Rosa Khutor-4	13.8	9.9	10.0	10.1	11.2
Biathlon Std.	15.1	9.4	9.4	9.4	10.1
G. Karusel-1500	15.3	13.5	13.5	13.6	14.5

Table 3: Observed and forecasted accumulated precipitation for 24 h on March 12, 2014

Site	Obs.	Forecast			
		750x750	450x650	450x450	300x300
Coastal cluster					
Solokh-Aul	4.9	14.0	14.8	11.9	12.9
Lazarevskoe	9.2	3.6	3.3	2.5	3.5
Imeretinka	6.6	4.9	5.2	5.1	3.6
Mountain cluster (h<1000 m)					
Kepsha	34.3	29.8	30.4	29.6	31.3
Kr. Polyana	22.5	17.2	17.8	19.6	18.7
K. Laura	18.5	21.5	21.5	23.7	21.7
Sledge-700	14.3	26.8	25.7	25.1	25.3
Rosa Khutor-7	17.3	29.1	27.3	27.7	26.9
Sledge-830	16.7	27.8	26.6	26.8	26.9
Mountain cluster (h>1000 m)					
Rosa Khutor-4	22.2	34.8	32.8	33.3	32.2
Biathlon Std.	9.1	22.6	21.4	20.4	21.5
G. Karusel-1500	22.4	28.8	27.6	26.7	28.8

Table 4: Observed and forecasted accumulated precipitation for 24 h on March 17, 2014

Site	Obs.	Forecast			
		750x750	450x650	450x450	300x300
Coastal cluster					
Solokh-Aul	13.0	10.1	15.8	16.8	19.8
Lazarevskoe	21.3	7.0	15.6	10.3	15.5
Imeretinka	1.2	0.6	19.1	1.4	1.2
Mountain cluster (h<1000 m)					
Kepsha	13.9	4.2	5.5	6.0	7.4
Kr. Polyana	20.8	12.9	14.2	13.1	14.5
K. Laura	24.5	16.4	17.5	17.2	19.7
Sledge-700	15.3	11.0	11.7	11.3	13.6
Rosa Khutor-7	24.8	11.4	12.2	12.2	14.0
Sledge-830	14.3	11.0	11.4	11.0	13.6
Mountain cluster (h>1000 m)					
Rosa Khutor-4	25.6	15.1	16.2	15.7	18.5
Biathlon Std.	16.2	13.9	14.7	14.2	17.1
G. Karusel-1500	19.6	12.1	12.6	11.9	14.4

Table 5: Observed and forecasted accumulated precipitation for 24 h on March 18, 2014

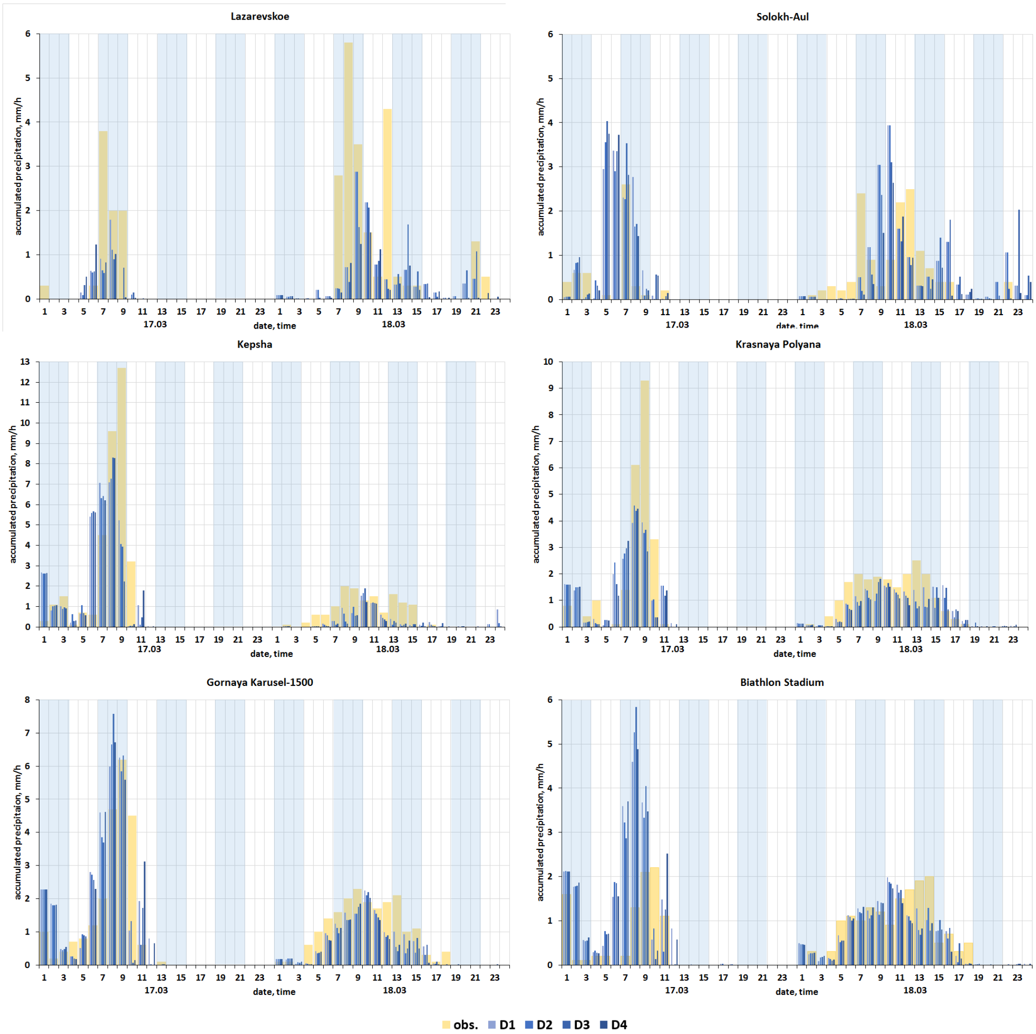

Figure 7: Hourly accumulated precipitation forecasts simulated for various domains in comparison with observation.

The most evident effect of the domain size in precipitation spatial distribution reveals near the domains boundary (Fig. 8 and 10). The difference between forecasts for two domains can reach 10 mm/day. Looking closer on the results for D1-D4 (Fig. 9 and 11), it is noted that the main structure of the precipitation spatial distribution is the same, but there are some variations. In particular, on March 17 precipitation amount increases within the Mzymta river valley (where the Olympic competition took place) with increasing domain size (Fig. 11). Comparison the results for different events shows that changes of the precipitation maximum location and amount could occurred in different direction. The interrelation of the direction of the air mass movement and local orography plays its role here.

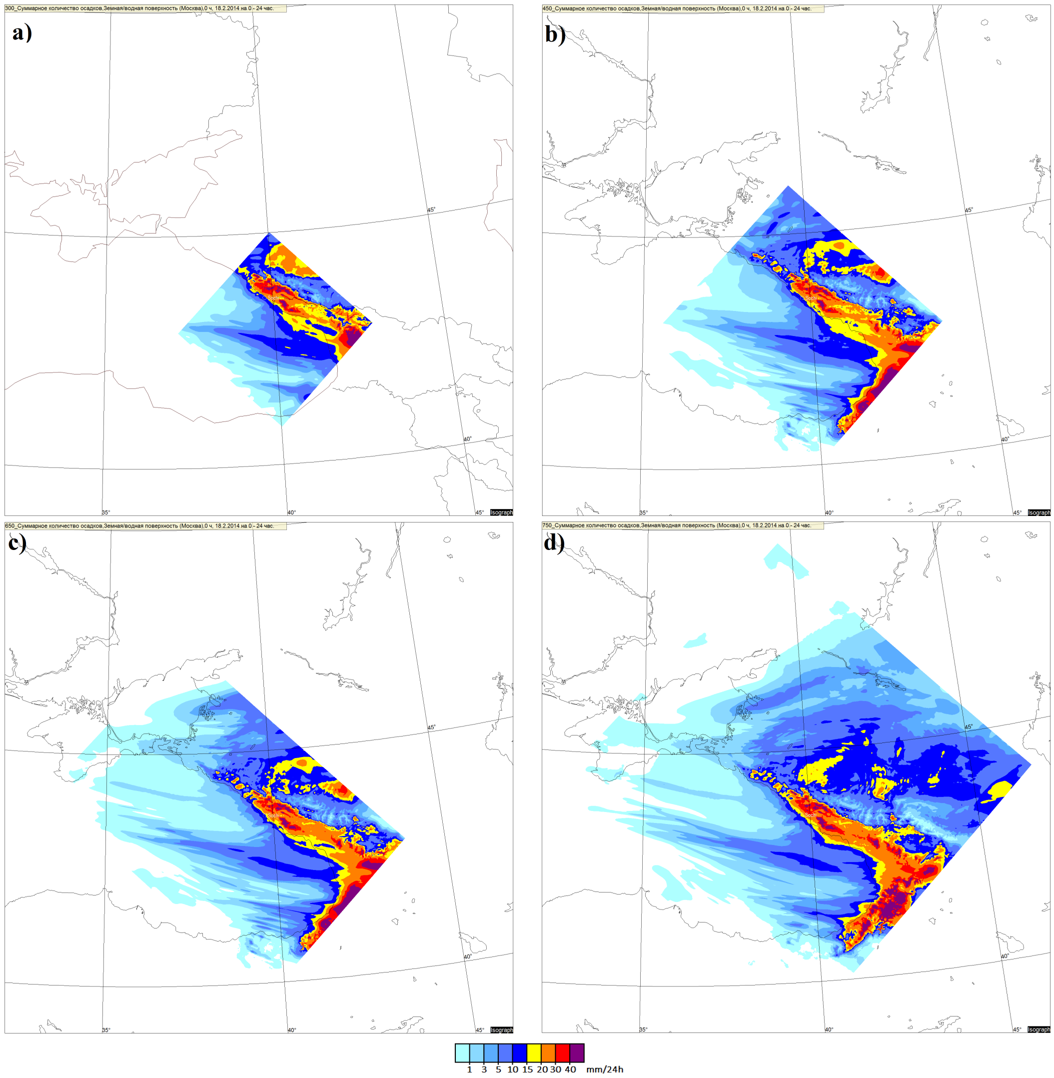

Figure 8: 24 hours accumulated precipitation predicted for various domains: D1 (a), D2 (b), D3 (c), D4 (d). Forecast start 18.02.2014, 00 UTC.

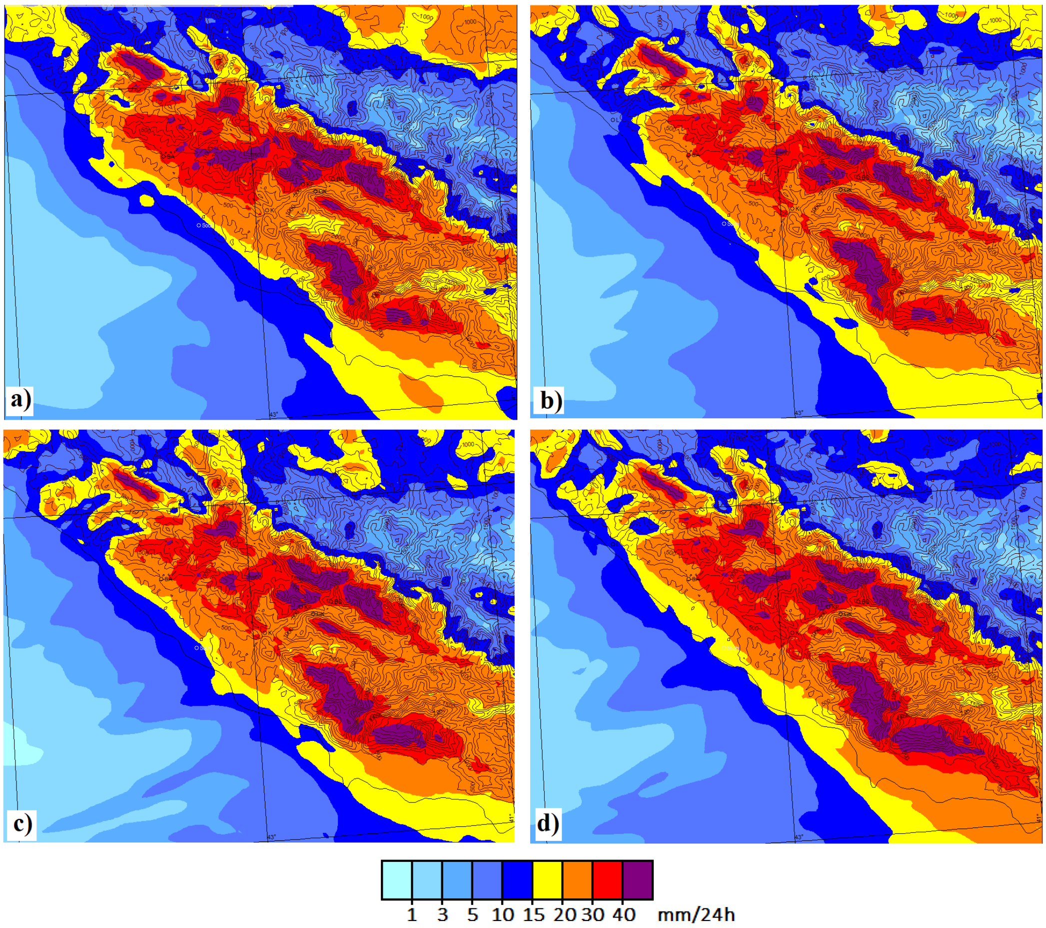

Figure 9: The same as Fig. 8 but for the Sochi region with model orography (isolines).

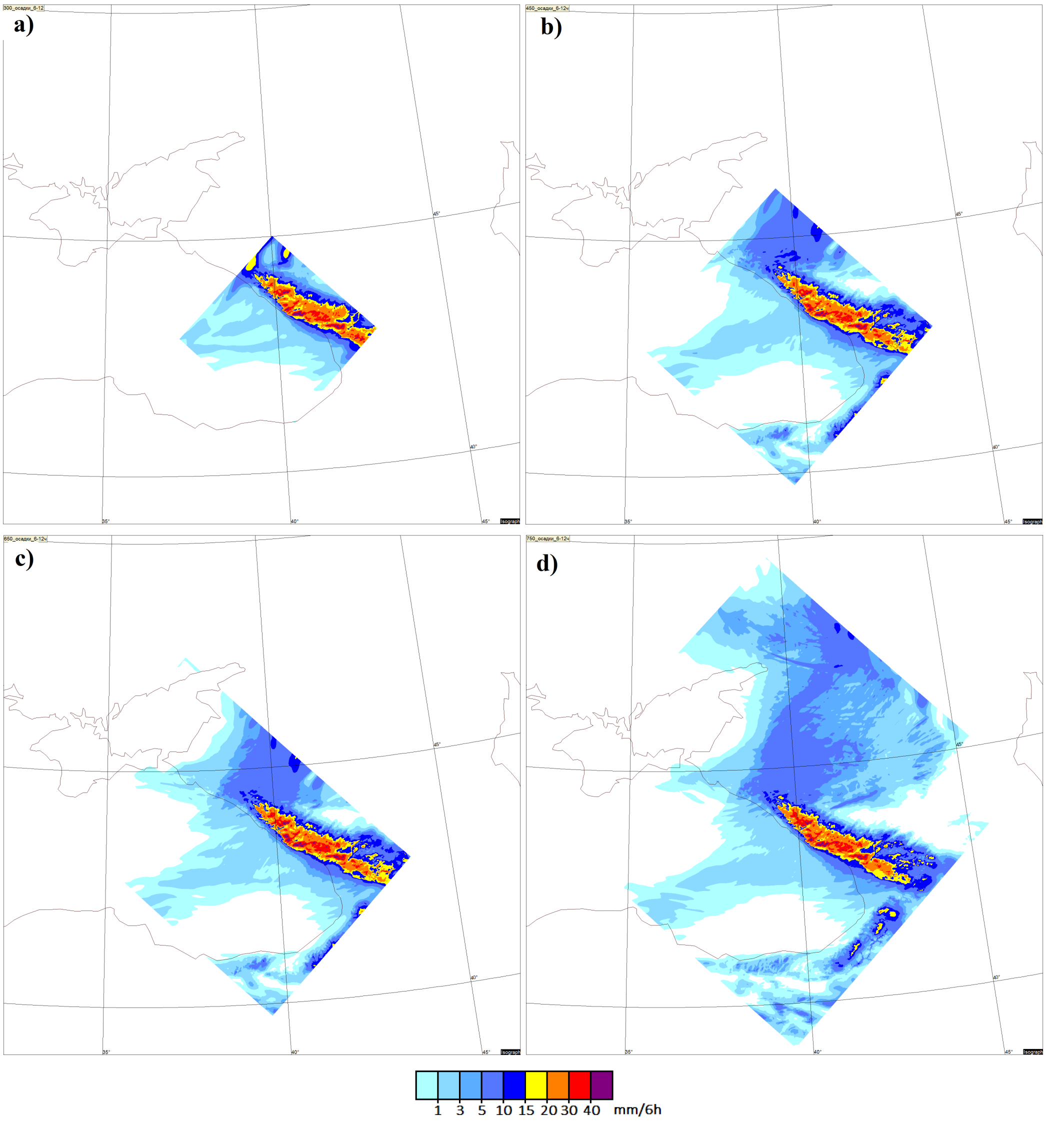

Figure 10: Accumulated precipitation for the period 06-12 UTC predicted for various domains: D1 (a), D2 (b), D3 (c), D4 (d). Forecast start from 17.03.2014, 00 UTC.

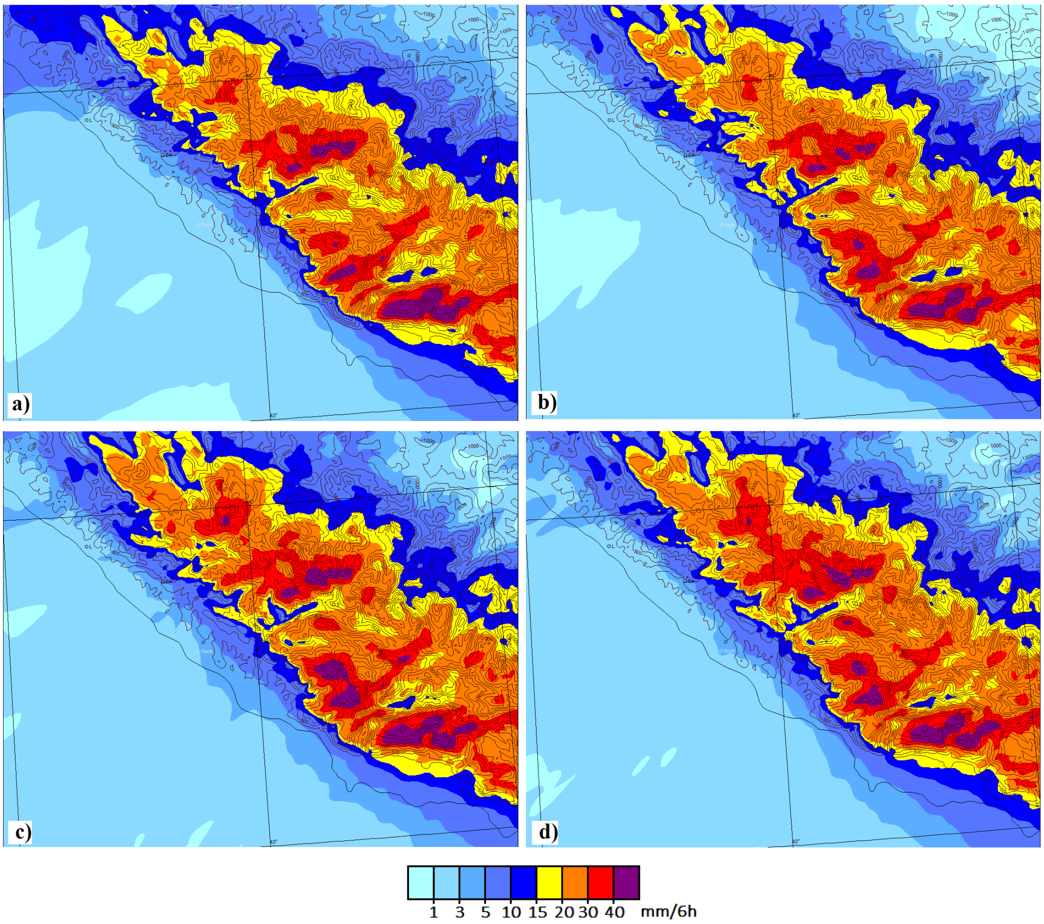

Figure 11: The same as Fig. 10 but for the Sochi region with model orography (isolines).

3.5 Conclusions

COSMO-Ru1 model simulations performed for different domains allow evaluate influence of domain size on the weather elements forecast. A large number of observations provided an assessment period from February 3 to March 31, 2014 for Sochi2014 region. Verification by VERSUS of the forecasts for air temperature at 2 m, dew point temperature at 2 m, wind speed at 10 m shown insignificant variations of the results for chosen domains. Verification shown that model overestimates precipitation event for all lead-time regardless of the domain size and indicated the presence of temporal shift in the forecast of the moderate and heavy precipitation. The difference between forecasts of heavy precipitation amount for various domains can reach 10 mm for daily amount and 2-3 mm for hourly-accumulated precipitation. Verification scores used traditionally for precipitation assessment demonstrate possibility to use rather small simulation domain (300x300 grid points) for the forecasts with lead-time until 18 h without loss of forecast quality.

4 Development of algorithm of subgrid h-correction of T2m for mountains based on COSMO forecasts of local lapse rate (h-correction) (I. Rozinkina, J-M. Bettems, D. Blinov, A. Euripides)

The mail idea of proposed technique is to forecast the lapse-rate of T and Td for the points and make the T2m and TD2m correction based these values. This could be useful in inversia-situations via hight- resolution modeling. In the framework of CORSO-A the proposed algorithm should to be included into FieldExtra.

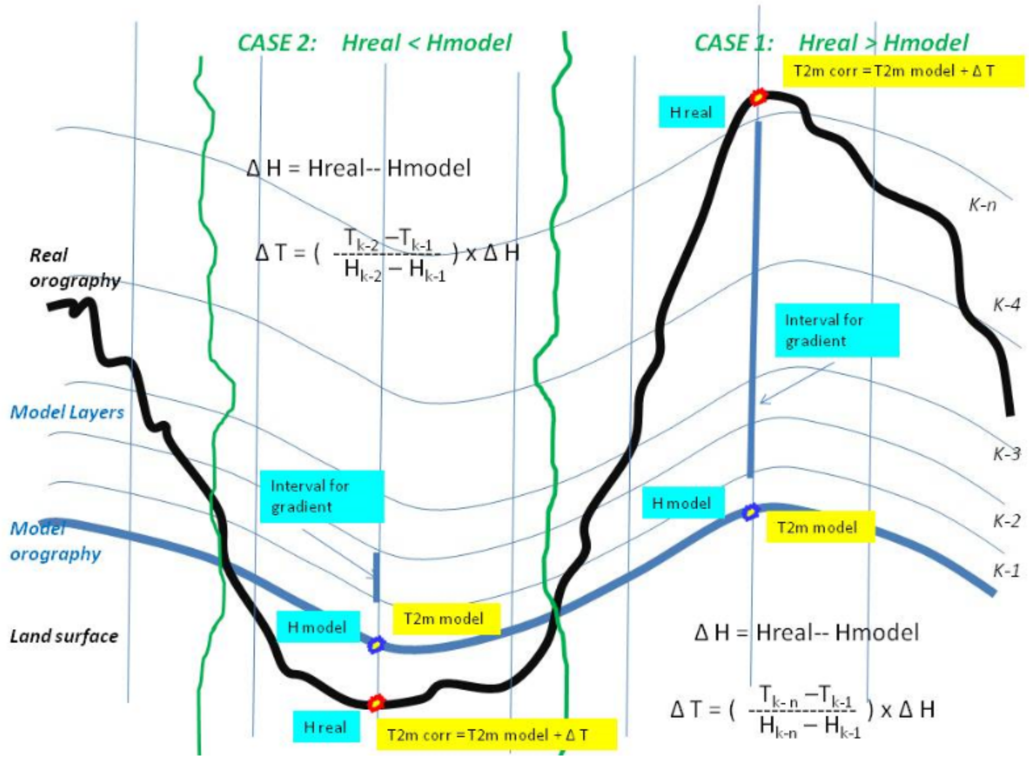

Figure 12: The description of tests and results is given in PP CORSO report.

The description of algorithm and proposals for FieldExtra extension are obtained. The realization of algorithm of FieldEextra (calculation of orography differences for points in FieldExtra and extension of software) + additional testing of 1-D version have been included The algorithm was formulated and included into FieldExtra Software (since 2016, FieldExtra 12.2.0, J-M Bettems).

5 COSMO-BASED ENSEMBLE FORECASTING FOR SOCHI-2014 OLYMPICS: ARCHIVING THE RESULTS (E. Astakhova, A. Montani, D. Kiktev, D. Alferov, A. Smirnov)

5.1 Introduction

The last winter Olympic/Paralympic Games were held in February-March 2014 in Sochi, Russia. The Russian 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 considered. We shall briefly remind CORSO results, overview the goal of CORSO-A, and summarize its results.

5.2 Ensemble prediction systems developed in CORSO

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 or 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 forecast 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. In fact, 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.

5.3 CORSO-A necessity and goal

It is worth to note here that COSMO ensemble forecasts can be considered a part of a more extensive FROST-2014 archive that included the results of four more ensemble prediction systems (Kiktev et al, 2015; Astakhova et al, 2015). The 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 EPS resolution was 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.

5.4 A Unified Sochi archive

The Sochi unified archive covers the period from January 15, 2014 to March 16, 2014. This time interval coincides with the period adopted for verification in FROST-2014 (January 15 - March 15, 2014). The archive contains the ensemble forecasts by COSMO-S14-EPS and COSMO-Ru2-EPS starting at 00 UTC and 12 UTC on the dates within the above-mentioned two-month interval. The prognostic fields for all members are presented with a 3h time frequency on the original COSMO-model rotated latitude-longitude grid with resolutions 7 and 2.2 km for COSMO-S14-EPS and COSMO-Ru2-EPS, respectively. The accumulated parameters (precipitation and wind gusts at 10 m) are not archived at zero time step. The data are in WMO-GRIB2 format. The archived parameters and the corresponding coding information are listed in Table 6. The parameter set is slightly different from the TIGGE-LAM high-priority parameters. The Sochi archive does not contain large-scale precipitation, convective inhibition, and convective available potential energy. As static fields (land-sea mask and orography) did not change during the period, they were written to the archive only once.

Parameter	Abbreviation	Level	Units	GRIB2 specifics
10 meter U-velocity	10u	10m (103,10)	m/s	Instantaneous Product Discipline 0 Parameter Category 2 Parameter number 3 paramId 165
10 meter V-velocity	10v	10m (103,10)	m/s	Instantaneous Product Discipline 0 Parameter Category 2 Parameter number 2 paramId 166
Mean sea level pressure	msl	MSL (101)	Pa	Instantaneous Product Discipline 0 Parameter Category 3 Parameter number 0 paramId 151
Surface air temperature	2t	2m (103,2)	K	Instantaneous Product Discipline 0 Parameter Category 0 Parameter number 0 paramId 167
Surface air dew point temperature	2d	2m (103,2)	K	Instantaneous Product Discipline 0 Parameter Category 0 Parameter number 6 paramId 168
Acc. precipitation (liquid+frozen, convective+ large-scale)	Tp	surface (1)	kg/m^2	Accumulated from the beginning of the forecast Product Discipline 0 Parameter Category 1 Parameter number 52 paramId 228228
10 meter wind gust in the last 3 hours	10fg3	10m (103,10)	m/s	Product Discipline 0 Parameter Category 2 Parameter number 22 typeOfStatisticalProcessing 2 paramId 228028
Orography (geopotential height at the surface)	Orog	surface (1)	gpm	Instantaneous Control run Product Discipline 0 Parameter Category 3 Parameter number 5 paramId 228002
Land-sea mask	lsm	surface (1)	Proportion (0- 1)	Instantaneous Control run Product Discipline 2 Parameter Category 0 Parameter number 0 paramId 172

Table 6: Specification of Sochi archive.

Case	Meteorological process/ phenomenon	Models behavior	Impact on competitions
07.02	Foehn	Poor temperature forecast (underestimated by 1.4 ... 3.7 °C) by most models at Biathlon Stadium	
10-11.02	Dissipated precipitation	Precipitation in the Mountain Cluster predicted by the majority of systems, but not observed actually	
15.02		Poor forecast of maximum wind speed by most models at Krasnaya Polyana (underestimated by 3.5 ... 7 m/s)	
16.02	Low visibility		Postponed competitions at Laura and Extreme Park
18.02	Cold front	Good precipitation forecast by most models	
22.02	Foehn	Poor temperature forecast by most models (negative forecast errors: -2.4 ... -4.4 °C, mostly at 1500 m)	
11.03	Cold front. Low visibility	Bad description of the behavior of maximum temperature (Tmax) by most models (Tmax forecasted at noon, whereas in reality it was observed in the morning)	Postponed skiing competitions at Roza Khutor
13.03		Poor precipitation forecast by most models above 1500 m	
17.03	Cold front	Underestimation of maximum wind speed by most models above 1500 m	

Table 7: The most interesting cases during the Olympics/Paralympics.

The following ensemble meta-data information is included to the GRIB files:

- the ensemble size (GRIB key numberOfForecastsInEnsemble);
- the number of ensemble member (GRIB key perturbationNumber);
- the forecast type (GRIB key dataType = pf/cf, i.e. perturbed/control).

No data for mean sea level pressure is available for COSMO-S14-EPS. Initial and boundary conditions for high-resolution COSMO EPS are available on demand. All other FROST-2014 forecast data (both deterministic and ensemble) in the Sochi unified archive are coded in the same way. The archive is available at http://frost2014.meteoinfo.ru (authorization required). To download the forecasts, you must switch to Forecasts (upper panel) -Export of gridded ensemble forecasts (right panel), and then select the necessary data using the interface similar to that of TIGGE-LAM data portal (Fig. 13). The necessary data will be prepared in compressed form, the corresponding reference will be sent by e-mail, and then the data can be downloaded. In addition to the prognostic fields, point forecasts (mean for ensembles) can be exported in csv format for more than 30 stations in the Sochi region. During the Olympics these forecasts were regularly presented at the multi-system page of the FROST-2014 site along with observation data and were considered very useful both by forecasters and researchers. To prepare these forecasts, the nearest grid-point approach was applied. A Web-tool to export observation data was also developed. For more details, please visit http:/frost2014.meteoinfo.ru, where you will also find a short description of all FROST-2014 numerical weather prediction systems. When research deals with the investigation of the skill of different weather prediction systems and of new ways to improve the forecast, it is important to have information about the synoptic situation in the analyzed domain and to select really essential events for case studies. To facilitate research in the field of short-range forecasting, Sochi forecasters prepared a list of cases recommended for detailed consideration. This list supplements the unified archive and is given in Table 7.

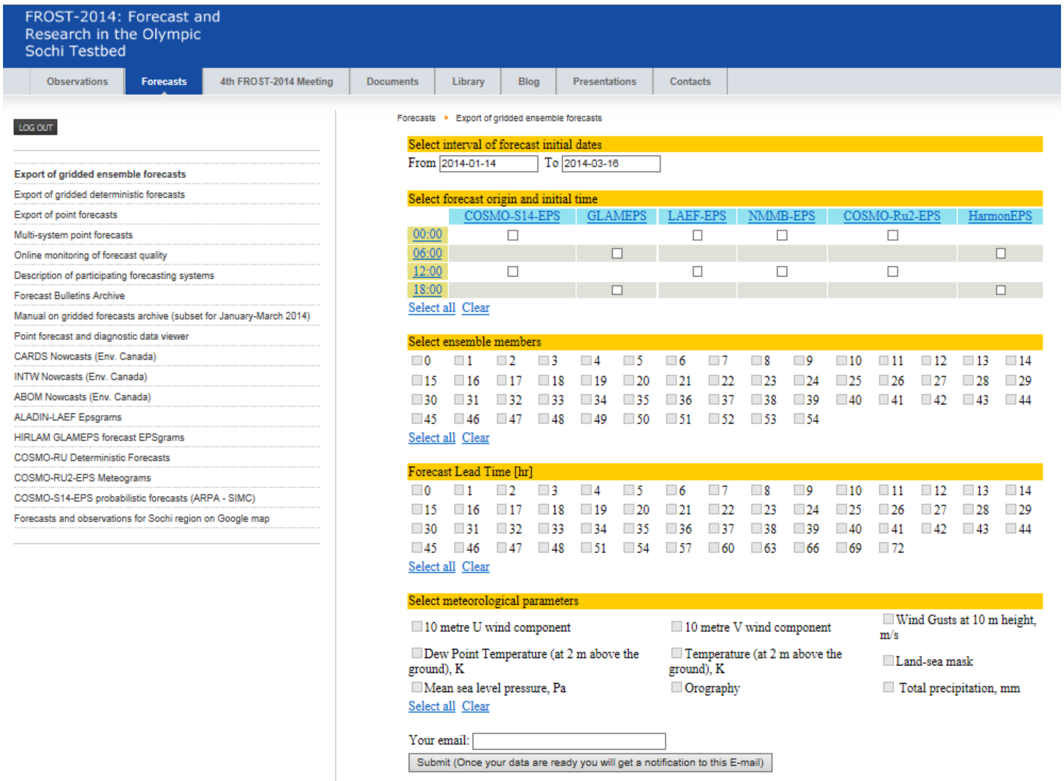

Figure 13: The FROST-2014 Web-interface used to download forecasts from the unified Sochi archive.

5.5 Conclusions

The unified Sochi archive containing forecasts for the area of Olympic Games 2014 for the period from January 15, 2014 to March 16, 2014 was prepared. The forecasts of two COSMO-based ensemble prediction systems, COSMO-S14-EPS and COSMO-Ru2-EPS with resolutions 7 and 2.2 km respectively, are stored in the archive. The Web-tool to download the forecasts and observations as well as the list of interesting cases for research supplement the archive. The archive is organized in TIGGE-LAM style and is available at http://frost2014.meteoinfo.ru.

6 PREPARING OF RECOMMENDATIONS FOR FORECASTERS ABOUT FEATURES OF INTERPRETATION OF THE RESULTS OF MESO- SCALE MODELING (How to use the LAM mesoscale NWP results for mountain terrain) (I. Rozinkina, P. Eckert, G. S. Rivin)

The feed-back from forecasters of Sochi-team in domain of experience of use of numeric mesoscale products was studied. The Some recommendations for improving the further trainings were obtained.

6.1 Introduction

This document summarizes the lessons from experience of meteorological support of Sochi Trials 2011, 2012, 2014), Olympics and Paraolympics (2014), matters of trainings for forecasters team for Sochi2014 meteosupport (2011-2014) in part of use of High resolution NWP products based on COSMO-Ru output, the discussions of experts of the COSMO WG4 sessions during and after period of Sochi-2014 meteosupport and learning exercise. Some examples of NWP output of named learning period were upgraded. The complexity of the Sochi region (steep mountains located in close proximity to the wide warm Black Sea area) justifies the application of the high resolution for short-term numerical weather forecasting. Weather forecast for the "Sochi-2014" is yet a big challenge. This document is focused on the features of using Mesoscale NWP products for mountain terrain on example of COSMO-Ru model with resolution 2.2 km with 1.2 km nested domains. This document is prepared in framework of COSMO PT "CORSO-A" which had the goal to summarize the experience of using results obtained during the realization of Sochi meteosupport for dissemination among the COSMO participating countries. As part, it consists of fixation of certain experience obtained using the products of High-resolution mesoscale model.

6.2 Key definitions

- **Mesoscale atmospheric circulations** - in context of this document it is determined as the atmospheric processes of the spatial scale from several (first tens kilometers) to 100 - 500 km (as distinct from synoptic scale processes - from 100 - 500 to 5000 km). It should be considered that no defined distinction between these scales could be stated as absolute truth. All scales are cross-related and could be determined only specifically in context of specific synoptic situation. In terms of time scale the mesoscale processes could last from minutes to several hours. However these phenomena can generate the synoptic scale events, which could be viable for several days. The cyclones, including tropical cyclones are defined as synoptic objects. The earlier classifications (1970-th) limit the synoptic processes with much more rough scale 2000 km, latter (1980-th) - several hundred km, which partially was related to possibility identifying the circulation objects according the density of observation data.

- **Model grid step** - horizontal distance between the centers of adjacent grids. Size of atmospheric model grid step limits the lower edge of the synoptic objects, which could be identified by the certain model.

- **Resolution of modelled processes** - determines the dimension of reliably circumscribed by the model circulation objects. Normally these objects are of the size of 7 - 10 model grid sells. Accuracy of forecast of atmospheric phenomena related to these objects is of the same scale. For meteorological parameters near the surface, especially at the mountains, the accuracy of the detailed model results could be significantly closer to the size of grid sell due to local limited land surface forcing.

- **Mesoscale atmospheric models** - global or limited area models (LAM) with the grids allowing describe the different atmospheric processes of defined spatial and time intervals (1, 3).

- **Non-hydrostatic atmospheric models** are the models with such spatial resolution when the hydro-static approximation is non-correct, and is required the explicit consideration of vertical motion acceleration (based on vertical component of wind speed), where the hydrostatic approximation can not be used. Non-hydrostatic effects should be taken into account for the grids with the step lesser than 9 - 10 km. This is the typical characteristic of the contemporary models for the limited areas. At the same time, the non-hydrostatic approach is evolved in global modeling aspect.

- **Convective-resolving atmospheric models** - models of the atmosphere allowing (not using parameterizations) describe the large convective systems. Such models have the horizontal grid step of less than 3 km. However, a certain part of convective processes (depending on grid step) will remain in the under-grid scale and should be parameterized. The algorithms of remaining share of convective processes should adequately describe their scale.

6.3 Main statements of use of products of global / Limited area NWP Products for short-range and very-short range forecasting

For short-range weather prediction a forecaster should analyze the output of both kinds of NWP technologies: global and systems of the limited area modeling. The advance of LAMs against the global models is determined by combination of two factors: higher resolution / considering non-hydrostatic effects and the list of available output for forecasters of National meteorological centers, which develop LAM technology. The following statements explain the above.

Purposes for the use of the output of:

a) **Global modeling**

To determine the large-scale weather patterns of atmospheric processes, analyzing and forecasting of generation, evolution and trajectories of the cyclones and anticyclones in short- and medium-range forecasting (in medium-range forecasting the forecasts are based usually on global ensemble modeling). Grid resolution of advances operational global models allows reasonably accurately reproduce the baroclinic zones, jet streams in upper troposphere and stratosphere, processes of cyclones generation, forming and degradation of atmospheric fronts. The grid resolution of global models has a tendency to more and more increasing, and the new generation of Global NWP are usually use non-hydrostatic approach. However, frequently some limitations exist for providing the full sets of products of Global NWP to local users - this is one of serious reasons why the LAM technologies become more and more popular in the National Meteorological Services.

b) **Limited-area modeling**

For forecasting of large variety of phenomena from synoptic to local (depending of dimension of calculation area and dimension/resolution of grid cells. Operational non-hydrostatic LAM might have a large range of grid dimensions - from hundreds meters to several or even first tens of kilometers. They can reasonably adequately reproduce the wide range of meteorological processes in different LAM, often, by "nested" technologies: from large-scale processes (generation, evolution and trajectories of the cyclones) to events of convective nature and/or hazard of appearance of local phenomena (wind gusts, heavy showers, blizzards), fogs, circulation in the mountains and in the coastal areas, influence of the urbanized territories on meteorological characteristics, genesis and development of small-scale, but extremely dangerous polar-lows, etc. Possibility of description of the processes of certain scales is limited to the dimension of LAM grid resolution and form one side and from another - to the dimension of calculation area. Products of LAM operating in the spacious areas of calculation could be used by forecasters along with the products of global systems in analysis of synoptic objects dynamics.

Centers operating the models:

a) **Global NWP models**

Global NWP systems are developed on their own in relatively small number of centers. These global centers have sufficient computational, technological and communicational resources, as well as a proper personnel skills. An important component of the global NWP producing is the development of comprehensive technologies of data assimilation and processing.

b) **Limited-area NWP systems**

The LAM systems are developing in more than 70 National meteorological centers of WMO. LAM systems are developing as a role, both in the centers of global modelling, and in the National meteorological centers, and in some local forecasting centers. LAM "cascade" technologies produce more and more detailed products from initial global model, using the more rough version to LAM versions with each step increasing resolution 3-4 times to hundreds meters comparing with the models, which are used for producing the initial and boundary conditions for LAMs normally having more rough resolution. These systems could be developed for weather forecasting in relatively small areas within the region of responsibility of National (district) meteorological services. Many NGMSs are using LAM models developed in other countries, which relates especially to international consortiums. The LAM systems are based on the operational access to the sets of initial data and boundary conditions for calculation area provided by centers of global NWP via Internet.

Features of Dissemination of NWP products for NHMS WMO weather forecasters

a) **Global NWP products:**

1 Information is provided via WMO WIS in standard code formats on the net - grids in correspondence with WMO regulations (if other is not envisaged by agreement of the country with producers of global forecasts). WMO WIS regulations are oriented on φ/λ grids and standard vertical levels. In the Global models grids of disseminated products are naturally more rough than computational grids. Therefore a part of information of the surface weather produced by global models are often additionally smoothed in the process of transmission of digital information.

2 Via specialized meteorological Internet sites as graphical products. At the same time, lists of the placed products are limited and it is practically impossible to satisfy all requirements connected with detailed visualization and maps design for zone of responsibility of each NHMS.

b) **LAM NWP products:**

Each NHMS can use maximally the LAM output with required details both in computational aspect and visualization for certain region via Internet-technologies.

6.4 Stages of analysis of NWP products for local short- range forecasting

6.4.1 Common recommends

The forecaster analysis of NWP products should have certain stages.

The main idea: To understand the genesis of meteorological processes (following, their properties and potential conditions for severe weather) for identified areas based on combination of synoptic analysis with more detailed data.

The daily operational forecaster discussions (briefing):

The discussion (synoptic briefing) have to be organized to coordinate forecasts for all venues of area of responsibility creating unified concept of understanding of different forecasters and forecasters groups of current and future weather processes. These briefings should be organized firstly in the each forecasters group (e.g. concrete venue or region) and after that via video-conference arranging participation of representatives of all groups at least once a day, but preferably - twice a day, before the issue of morning official forecast and in the evening. The main responsibility takes the main forecaster group, which issues the daily bulletin and controls the Web-site information The discussion have to contain the following items:

1 Analysis of processes from large to local space - scales

2 Proposals for 4-5 Day weather trends based on NWP of large-scale processes for about half/third of Hemisphere

3 Analysis of weather of previous day/night

4 Knowledge of current NWP forecast quality (typical errors for the last several days)

5 Proposals for short-range (from 12 until 72h: tomorrow, after-tomorrow) and very short-range (from 2 until 12 hours: today/tonight)

6 Threat assessment of severe weather events for each forecasting interval.

6.4.2 Experience of large-scale weather types before the analyze of HR products

Each forecasting center or leading forecasting group in specialized meteosupport should have a previous knowledge of relationship between large-scale circulation types and probable local weather phenomena. In framework of development of meteosupport Sochi2014 forecasters from Sochi Black and Azov-seas Branch of North Caucasian Department of Roshydromet prepared the description of typical for rainy/snowy weather situations for mountain cluster of Sochi-2014 area. The typical large-scale processes which lead to the mesoscale circulations with heavy precipitation in Sochi area were described with applicate pictures, examples. The most dangerous hazards for this region are the heavy precipitation events, which can lead to the avalanches, mudslides, floods, traffic jams, damages to electric networks and roads. The previous investigations of weather types were concentrated firstly on the forecasting of probable heavy precipitation and on its phase. Some typical large-scale patterns of processes were identified. In Fig. 14 one of these is shown. This situation can provide a forming of the local cyclones on the South-Eeast of the Black Sea. The cold advection from the North to the western parts of Mediterranean cyclones and cold advection to the central part of Black Sea can amplify the local cyclone forming. These cyclones often could not be well detected in the pressure fields, and sometimes the hazards arrive suddenly for forecasters.

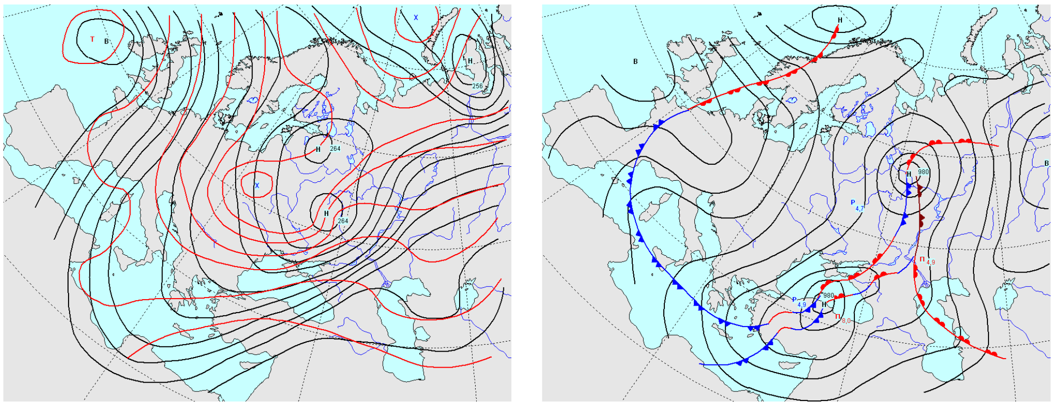

Figure 14: Example of one of typical large-scale situation providing the local cyclogenesis over Southeast of Black sea: H700 and H_{1000}^{500} are on the left, sea level pressure with frontal analysis is on the right.

This forming of little cyclone over the South-eastern coast of Black Sea, providing the transport of wet air to the Sochi mountain valleys in correspondence with orientation of mountain chains. These little cyclonic circulation is well presented on the maps of stream-lines for near-surface level, since the pressure minimums often are not sufficient for draw them. The high resolution information (stream-lines over Black Sea in COSMO realization) helped to detect these situations. The other approach had attempted to be realized for Sochi. Based on COST 733 facilities, the set of synoptic pictures for entire winter period of 2013 was analyzed. Forecasters had a lot of difficulties for join the concrete processes to certain circulation types in provided in COST 733 classifications. It appeared to be easier to do it for the types determined in classification GWT_27 (mainly attachment of every day real synoptic picture to the one of proposed types from GWT_27). It was surprising that the heavy precipitation were probable for a most part of provided large-scale types. It happened to identify only few situations with low probability of precipitation (NN8 and 20, picture 4) and corresponding to heavy rain events in mountain cluster 4 first (Fig. 15, the heavy rains in most cases) as well, 15, 16, 26 (heavy rain are probable in few cases). The formal use of typical patterns from GWT_27, type 4 showed a good correspondence with process shown in Fig. 14, selected in independent mode via only forecasters experience.

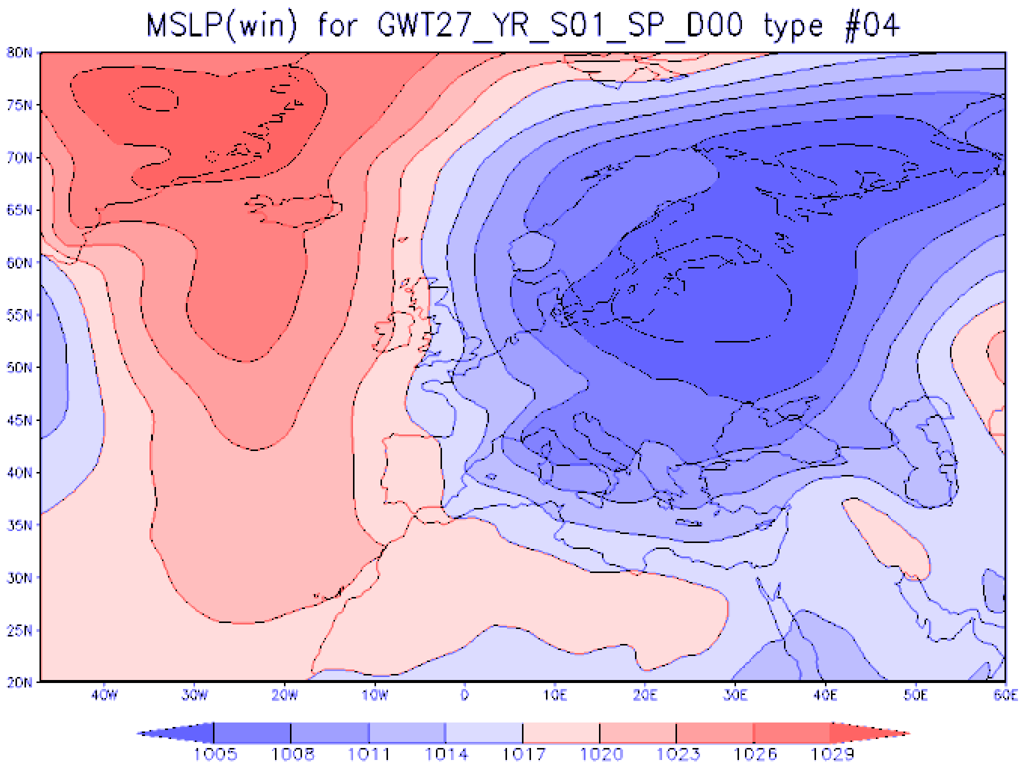

Figure 15: The Pattern N4 from GWT-27. ("wet" with lot of cases of heavy precipitations).

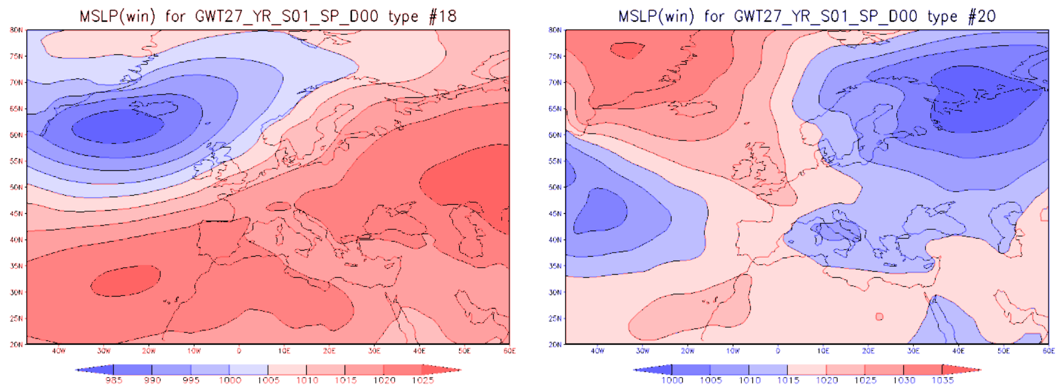

Figure 16: The Pattern N4 (left) and 20 (right) from GWT-27. ("dry" without precipitation).

Note, these "dry" cases are not depended form Ps values, but in both cases the advection of cold air to the middle Black sea is blocked. This below illustrates following conclusions:

- **A large scale synoptic analysis for this region has to establish the factors (cold advection from North or North-East, high humidity flows) to front**

forming near and over the area of forecasters responsibility. For certain days cold advection to the Black Sea has to be detected.

- **The combination with HR results is necessary for notify the forming of the regional circulation or to notify the large-scale synoptic circulation with passing of active fronts with additional advection from North-West.**

6.4.3 Recommended sequence of analysis, design and content of forecasters maps

A view of some - days forecast row of H500 pictures in parallel with P for further 3-4 days

A goal to detect the main atmospheric flow forming advection on area of responsibility, the velocity of processes moving and development, the lapse rates and resemblance to the typical large-scale patterns. The combining of H500 with T2m (or T850) and of P with Middle level clouds and 3-h precipitation amounts is recommended. The printing of these rows of maps is recommended for forecasters for compare the next day old and new forecast rows to discover tendencies of model errors in movement of synoptic objects and front development. The initial part of such forecast row (until 48 hours) by COSMO-Ru7 (step 7 km) is shown at Fig. 17). Figs 18 and 19 present more detailed an example of H500+T2m forecast map design.

Some remarks:

- *The time step for quick large- scale analysis can be 12 hours.*
- *The grid- step of modelling of 15 km is sufficient (If global products with similar grid-step are available, they can be used in similar visualization).*

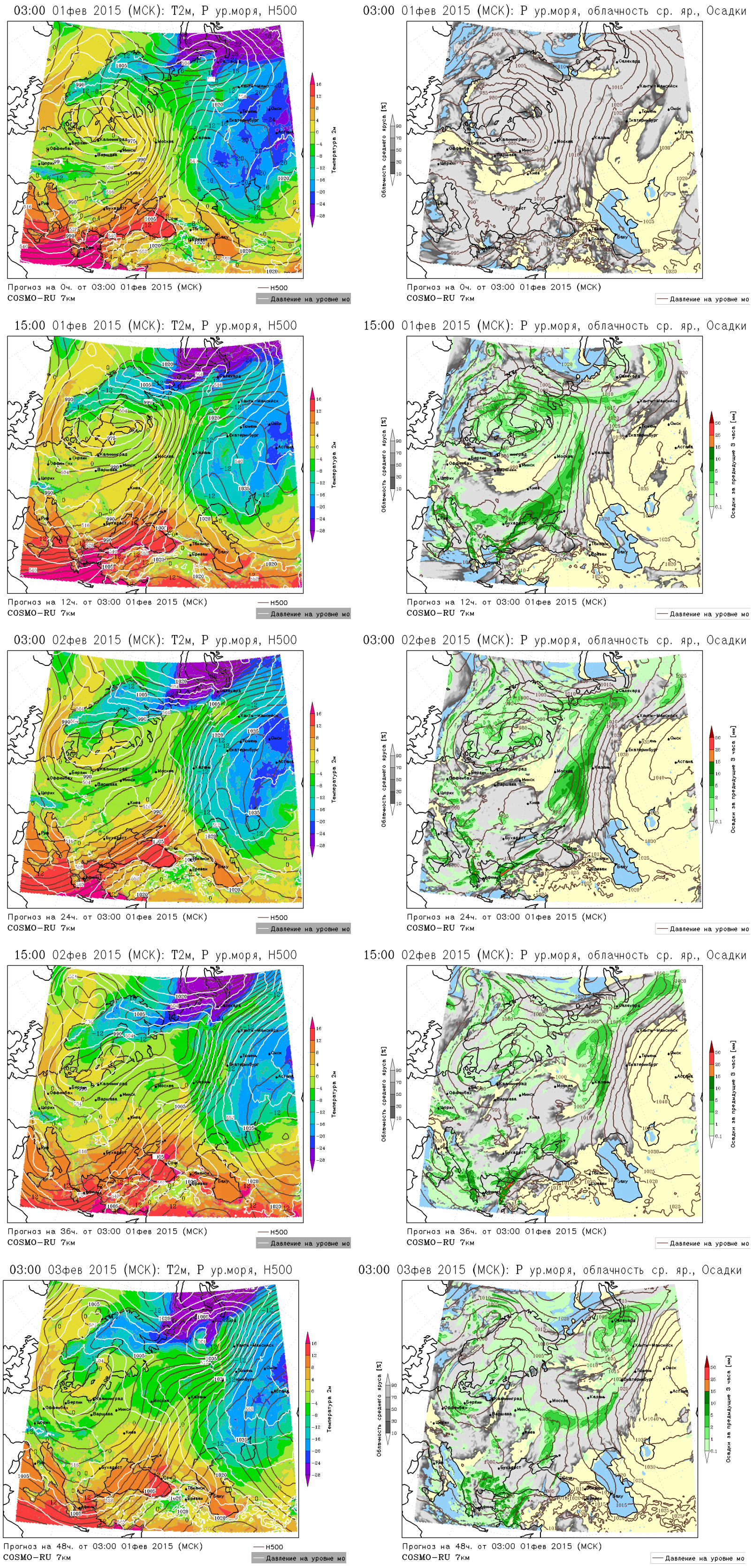

Figure 17: A row of forecasts: H500 and T2m on the left, PMSL, 3h accumulated precipitation and midlevel cloud on the right.

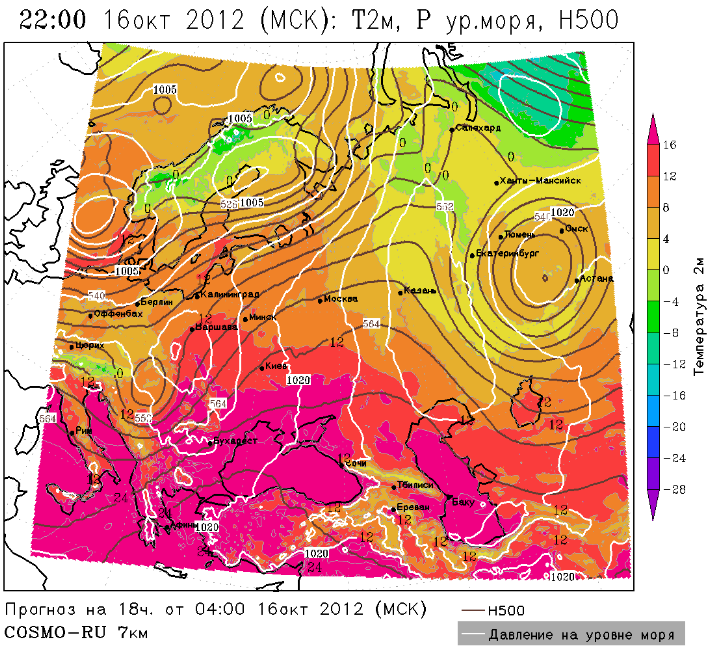

Figure 18: An example map design with H500 and T2m forecast. (Inscription in Russian: (Top) Forecast time and date, forecasted parameters; (Bottom) lead time and forecast start time, model and grid spacing; map legend: color scale for temperature, lines: black- , white: PMSL).

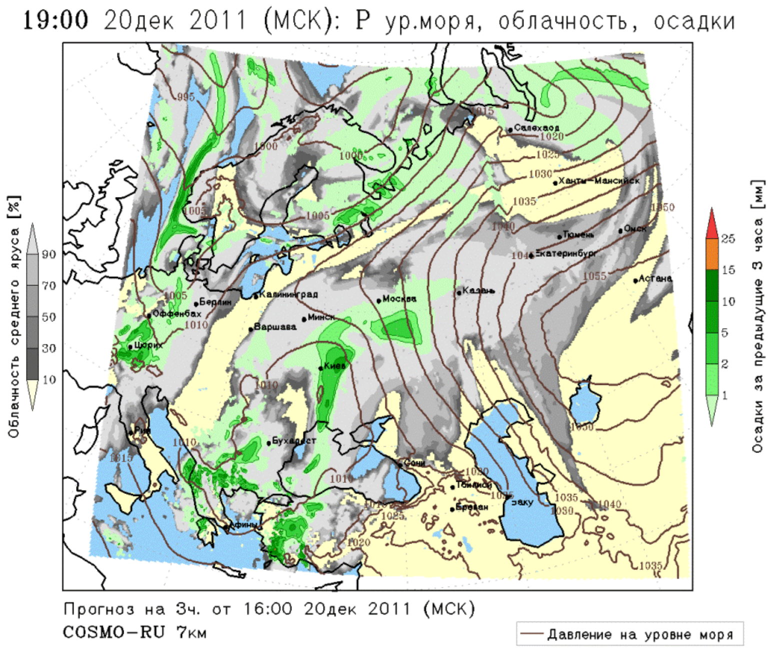

Figure 19: An example map design with PMSL, 3h accumulated precipitation and mid-level cloudiness forecast. (Inscription in Russian: (Top) Forecast time and date, forecasted parameters; (Bottom) lead time and forecast start time, model and grid spacing; map legend: color scale of 3h Precipitation, color scale of Clouds, lines: black: PMSL).

Analysis of maps series of PMSL, Cloudiness, Precipitation with 3h-temporal resolution until 78-84 hours lead time is recommended additionally. This permits to understand the genesis of cyclones and related precipitation. The Mid-level clouds correlate with the frontal area.

Analysis of map series of high- resolution output: COSMO-Ru2 (2.2.km)

Temporal resolution 1 hour, until 48 hours lead time, for entire Caucasian and Eastern Black Sea area:

- Low clouds
- PMSL+ Mid-level Clouds + 3h Precipitation /1h Precipitation (recommended time step of view maps is 3 hours)
- V10m and wing gusts
- T2m + T850
- Fresh snow accumulated for 3 hours and for 24 hours
- Stream lines + Relative humidity at the 900, 800, 750 hPa
- Stream lines + Relative humidity at the 900, 800, 750 hPa

Some design examples are shown in Figs. 20-22.

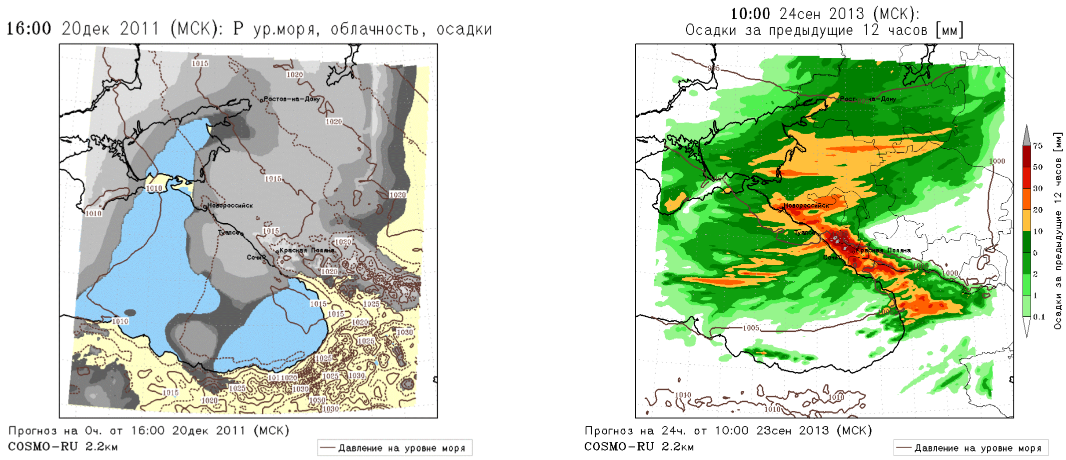

Figure 20: Design of COSMO-Ru2 forecast maps: PMSL, mid-level clouds, 1h precipitation (left) and 12 h accumulated precipitation (right).

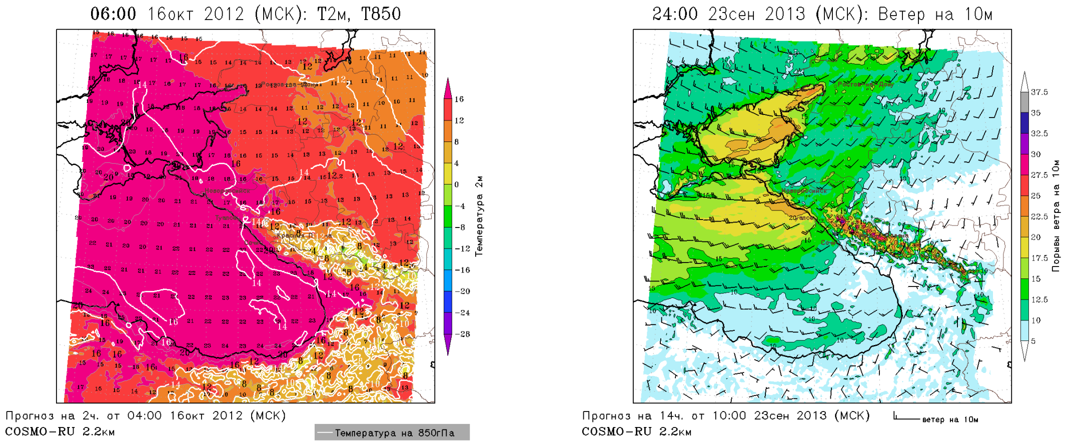

Figure 21: Design of COSMO-Ru2 forecast maps: T2m and T850 (left), wind speed and direction at 10m and wind gusts (right).

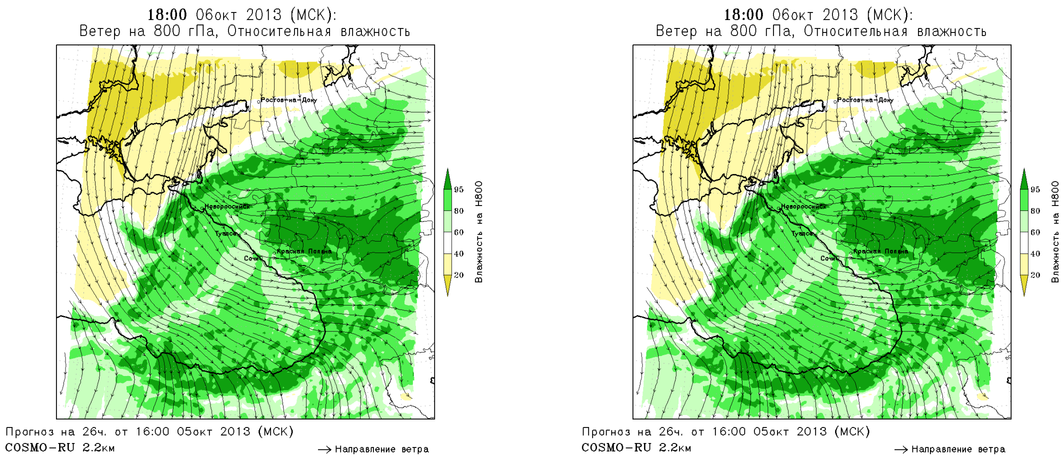

Figure 22: Design of COSMO-Ru2 forecast maps: Streamlines and relative humidity at 800 hPa (left) and at 700 hPa (right).

The Streamlines forecasting maps of HR NWP permits to determine the direction of air movement, the presence of convergence-divergence zones, mesovortices, to specify the time of passage of fronts. The combining with relative humidity helps to determine the change of different air masses (wet-dry), because the relative humidity is the good conservative characteristic of air mass. Sometimes the relative humidity pictures can more clearly indicate the front position (sometimes poorly detected in clouds or wind fields in mountain conditions).

Analysis of rows of maps of high- resolution output: COSMO-Ru1 (1.1.km)

Temporal resolution 1 hour, until 24-36 hours lead time, for Sochi, mountain cluster (minimal area size 200x200 km):

- Low clouds
- Mid-level clouds + 1 h Precipitation
- 12h Precipitation (recommended time step of view maps is 3 hours)

- V10m and wing gusts
- T2m + T850
- Fresh snow accumulated for 3 hours and for 24 hours
- Stream lines + Relative air humidity at the 900, 800, 750 hPa

The products of NWP technology with 1km grid step are the most important kind of NWP information for weather forecasting in the mountains. The most important forecast elements via NWP-1 km are wind and fresh snow fields. The forecasts reflect mountain chains and valleys most accurately (see Fig. 23).

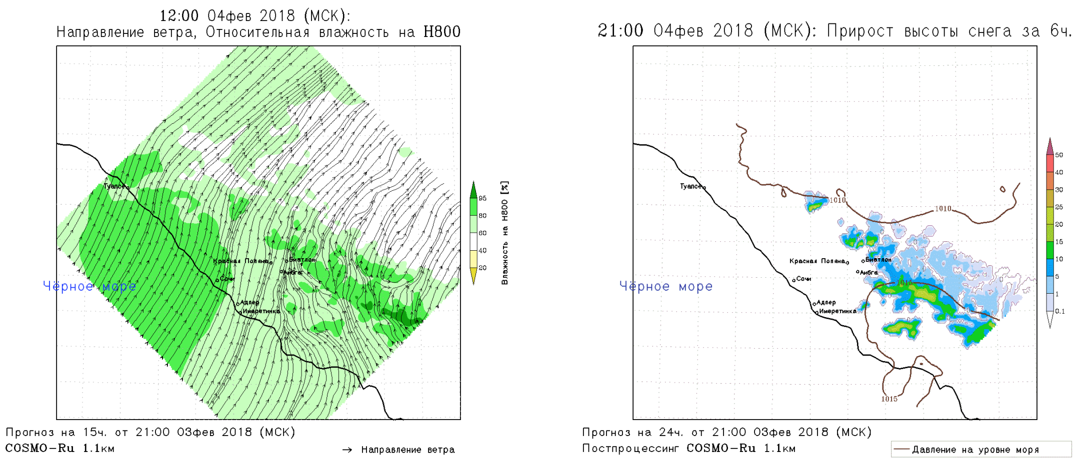

Figure 23: Design of COSMO-Ru1 forecast maps: Streamlines and relative humidity at 800 hPa (left) and fresh snow (right).

6.5 Analysis of Meteograms of deterministic LAM HR NWP

6.5.1 Definitions and goals

Definitions. Meteograms are the graphs, which combine model output (deterministic or ensemble) with form of **time evaluation graphics** of selected meteorological parameters. In case of ensemble forecasting ones are named Ensemble Prediction System meteograms (EPS-grammes). The information of this section relates to **the deterministic high-resolution (HR) model output. Goals and applications.** Meteograms permit to observe time evaluation of key meteorological parameters for selected vertical levels for concrete points. The 1-h (or less) time steps of presenting information (as a rule lesser than for forecasting charts) permits to notify a time of fronts passing, of star-end of weather phenomena, as well of daily temperature extrem time. Another application of meteograms (Fig. 24) is a very quick forecasters complication of meteorological data for big number of points for not large region to receive an information about spatial differences and uncertainties of some parameters. The analysis of NWP matters by forecasters can start by watching of meteograms, as well, it is useful to look at them after analysis of all forecasting maps, after understanding of forecasted synoptic and mesoscale processes. Fig. 24 shows the Meteograms design, which was realized as a result of feed-back from forecasters of Sochi / Hydrometcenter of Russia based on adaptation of DWD variant of COSMO software. The color and placing of picture for forecasts of different parameters are important.

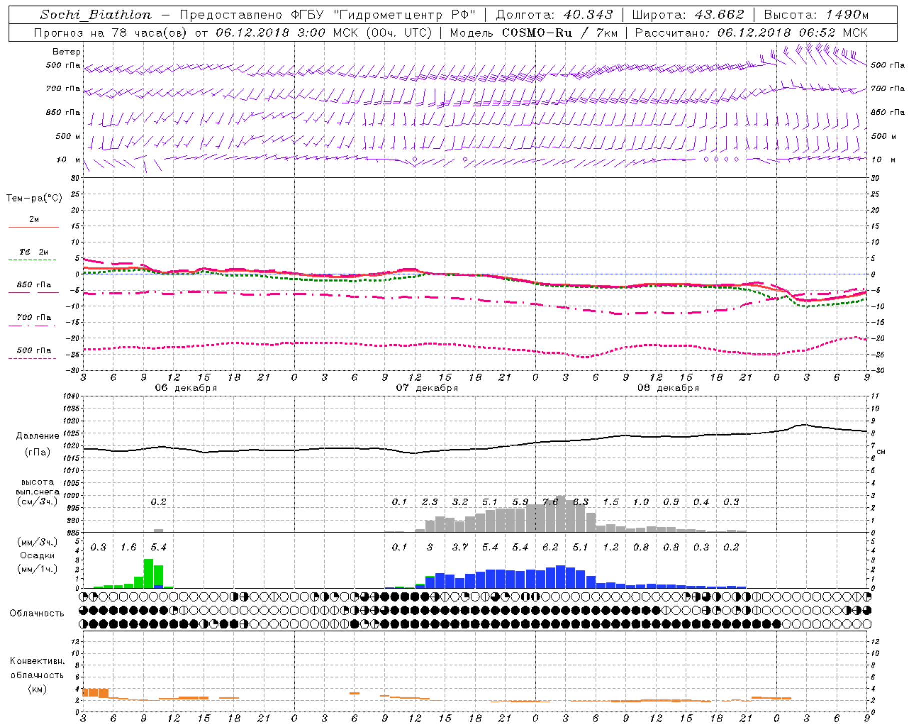

Figure 24: Example of deterministic meteogram for points of Sochi mountain.

6.5.2 Key principles for technology of meteogram forming

- **Meteograms are presented** in some sections of graphics for one point with unified time axe of selected elements adapted to the forecasters expert analysis, e.g. wind, temperature, clouds on several levels, precipitation, etc. The levels for pictures for different elements can be different. A feedback from forecasters for realizing the most efficient pictures design (icluding fast loading of pictures for big number of points on the monitor) is strongly recommended.

- **Meteograms technology has** to provide for quick forecasting analysis the pictures of few-days changes for nominated points of maximal number of important parameters with timestep no more than 1 hour.

- **A severe meteograms around nominated point or inside an area** (a city, a cluster of competitions, etc.) is recommended for more reliable forecasting of random precipitation and of probably hazards.

- **The volume of pictures should be minimal.** This requirement was set up: firstly, to necessity of quick forecasters analysis and comparison of large number of meteograms for different points for one region, secondly, by possible limitations of Internet channels available to forecasters outside on large forecaster centers.

- **Lists of points for meteogram visualization** should be prepared by forecasters/users with indication of Lat/Lon (as rules, there are points of meteostations, towns/cities, important objects, venues of competitions) in stage of forming of meteogram-technology. Systems of forming of meteograms of high resolution modeling such COSMO do not interpolate from the gridded model results to nominated points, and as rules, a nearest model grid-point is automatically selected. In cases of high spatial variability of geographical properties grid- points have to be manually selected based an expert analysis of geographical properties. As an example, Fig. 25 shows grid-points of COSMO-Ru7 (blue) and COSMO-Ru2 (yellow). In the red are shown the points of venues / observing stations. COSMO-Ru2 grid- nodes nearest to the venues have a good concordance with the 2 nominated points (chance coincidence), but a most representative grid-point for the point Krasnaya Polyana should be chosen manually (which has a close high is preferable from 4 nearest grid-nodes).

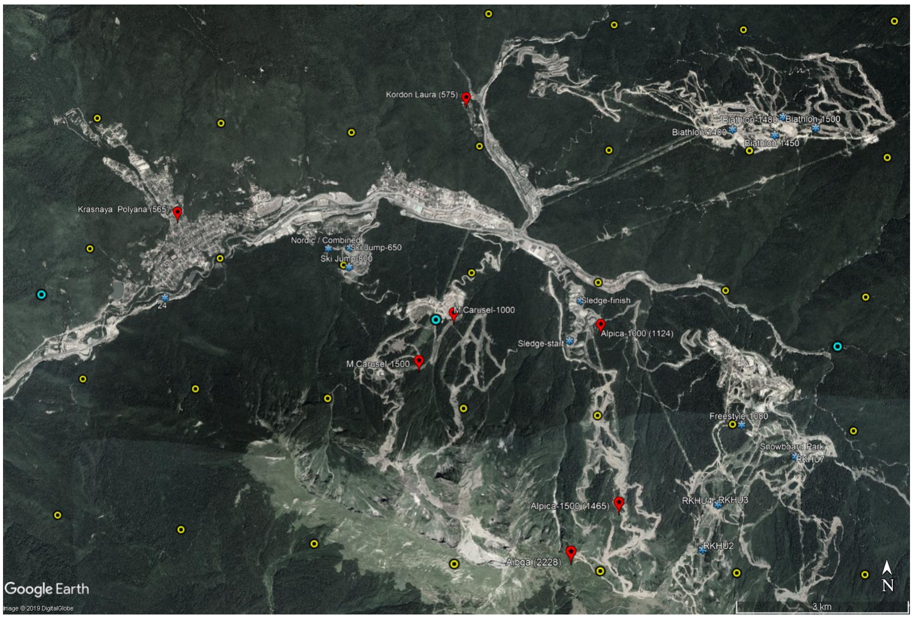

Figure 25: Grid-nodes of COSMO-Ru7 (blue circles) and COSMO-Ru2 (yellow circles) over Earth map for mountain cluster of Sochi region. Red balloons and blue snowflakes indicate the venues locations.

6.5.3 Forecasters analysis based on meteograms

Forecasters should take account that:

- Coordinates of nominated by forecasters points are not same as ones of meteograms (nearest corresponding model grid- points) (see above the previous section) Coordinate values of model meteograms points have be indicated at the top of the picture pages. Forecasters have to compare indicated values with coordinates of real nominated point. In cases of complicate geographical conditions it can lead to the completely wrong forecasts for selected points of local weather conditions (e.g. a land point can be automatically corresponded to a maritime nearest grid point, a point in the valley - to the point at the top of mountain, etc.). In the Fig. 26 grid-point coordinates longitude 40.2E, latitude=43.7N are indicated by red oval. The coordinates of nominated point are 40.1E, 43.6N).
- The real high of nominated point is not same as high of corresponding model grid point (important especially for the mountain cases) High of model grid points is indicated at the top of the picture pages (Fig. 26 at the green oval - 1544m). Forecasters have to

compare these values with ones of real nominated points and to analyze a difference. Some postprocessing technologies calculate the corrected values of T2m and of Td2m based on assumptions of temperature lapse rate. In our example, the real high is only 576m. The results of correction of T2m is shown on the meteogram by violet line, parallel to the red line, corresponding a T2m forecasts from direct model output.

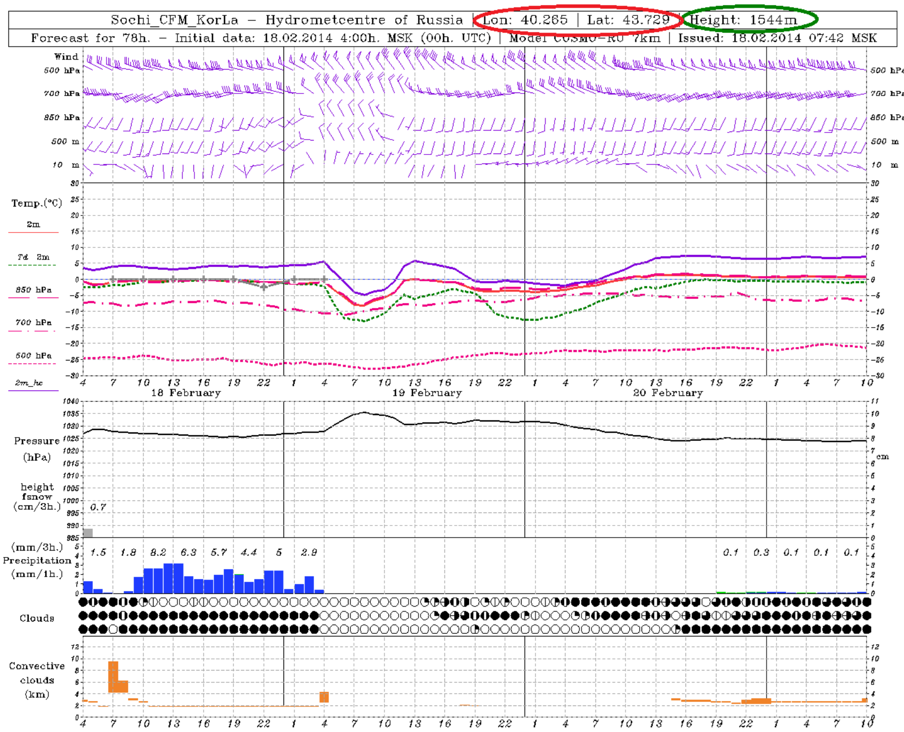

Figure 26: Example of meteogram for Cordon Laura. The coordinates and high of grid- box are circled in ovals (red and green).

There are some features of analysis, important for forecasters:

- *Pressure section:* pressure values and its tendencies, the time interval of minimum due to the rapid cyclone passage
- *Temperature section:*
  - Temperature values and their tendencies at 2, 850 hPa, 700 hPa and 500 hPa can be important for mountain area. Note the inversion state (e.g. if T2m less than T850, in mountains T850 less than T700). (Following special requests, the levels can be other).
  - T850 In mountains regions can be close to the T2m (or underground)
  - An additional T2m values as postprocessing result can be added. Be careful with its analysis.
  - The close and equal values of TD2m and of T2m can indicate the high probability of fog.
- *Precipitation section:*
  - Additional to the vertical columns (1-hour sums) the 3-h sums are written.

  - If the T2m is corrected by postprocessing techniques, the additional control of phase of precipitation is useful. In our case (Fig. 26) after T2m lapse rate correction it was warmer than 0 degrees. So, the predicted snow should be not snow, but in case of continuous heavy rain, forecaster could make a decision himself.
  - In case of short precipitation and/or precipitation of convective origin. It is useful to analyze meteograms for other close grid- points. The radius of probable precipitation is about 3-4 grid- cells!

- *Cloud section:*
  - Middle level clouds are the most important and indicate with high clear-sky or overcast conditions.
  - Low level clouds have a lowest forecasting skill. This is feasible to control based on synoptic knowledge.
  - Convection existing or not can help to understand the origin of clouds.
  - Maximum convection height (yellow columns at the bottom of the page) can indicate the dangerous convective situations in case of extremely high (more than 10 km) of convection level. In these cases the weather hazards of convective origin have a high probability not only for the point of meteogram, but also around this place.

- *Wind section:*
  - Wind direction and speed at 10 m, 500 m, 850, 700, 500 hPa levels are presented. For specialized forecasts the other levels can be required by users.
  - Sharp changes in wind direction at the lower levels can indicate the time of front passage (in our case- at the first hours of forecast and at 3-rd forecast day).
  - Wind speed more than 25 m/s at 500 m altitude can indicate as a threat of squall at the near-surface level.

6.6 Conclusion

In the current document we shoved the key positions of experience of trainings for forecasters for Sochi forecaster team in 2012-2014 years. This experience could be useful for further trainings from one hand, and from other hand should be developed in further.

7 Acknowledgements

This work was carried out within the COSMO PT CORSO-A and WWRP FDP/RDP FROST-2014. The authors are grateful to Tatiana Dmitrieva (Roshydromet) for providing the information on weather cases during the winter 2014 and to Tiziana Paccagnella (ARPAE) for supporting the work.

A Appendix

		Event Observed	
		YES	NO
Event Forecasted	YES	A	B
	NO	C	D

Table 8: 2x2 Contingency Table.

Threshold (mm/3h)	Forecast lead time (h)							
	3	6	9	12	15	18	21	24
	Domain 300 x 300 g.p.							
0.1	0.42	0.62	0.63	0.72	0.58	0.39	0.36	0.49
0.5	0.43	0.66	0.68	0.73	0.62	0.46	0.37	0.42
1	0.35	0.49	0.70	0.77	0.55	0.42	0.33	0.34
2	0.28	0.28	0.59	0.68	0.31	0.38	0.29	0.21
3		0.22	0.44	0.64	0.31	0.51	0.32	
5			0.32	0.55			0.53	
10			0.27	0.26			0.60	
	Domain 450 x 450 g.p.							
0.1	0.42	0.57	0.62	0.66	0.56	0.38	0.38	0.49
0.5	0.43	0.58	0.59	0.70	0.57	0.44	0.37	0.42
1	0.35	0.43	0.62	0.74	0.55	0.39	0.35	0.35
2	0.27	0.25	0.57	0.71	0.39	0.40	0.31	0.18
3		0.20	0.48	0.65	0.34	0.48	0.40	
5			0.32	0.55			0.47	
10			0.26	0.16			0.63	
	Domain 450x 650 g.p.							
0.1	0.42	0.57	0.62	0.66	0.56	0.38	0.38	0.49
0.5	0.43	0.58	0.59	0.70	0.57	0.44	0.37	0.42
1	0.35	0.43	0.62	0.74	0.55	0.39	0.35	0.35
2	0.27	0.25	0.57	0.71	0.39	0.40	0.31	0.18
3		0.20	0.48	0.65	0.34	0.48	0.40	
5			0.32	0.55			0.47	
10			0.26	0.16			0.63	

Table 9: CSI values.

Threshold (mm/3h)	Forecast lead time (h)							
	3	6	9	12	15	18	21	24
	Domain 300 x 300 g.p.							
0.1	0.28	0.51	0.53	0.64	0.50	0.29	0.25	0.38
0.5	0.34	0.59	0.61	0.67	0.56	0.40	0.29	0.33
1	0.29	0.42	0.64	0.72	0.49	0.37	0.27	0.27
2	0.25	0.23	0.53	0.62	0.27	0.35	0.25	0.17
3		0.19	0.39	0.60	0.29	0.49	0.29	
5			0.29	0.52			0.52	
10			0.25	0.24			0.59	
	Domain 450 x 450 g.p.							
0.1	0.29	0.45	0.51	0.58	0.47	0.27	0.27	0.38
0.5	0.34	0.51	0.50	0.63	0.51	0.37	0.29	0.34
1	0.29	0.36	0.55	0.68	0.50	0.33	0.30	0.28
2	0.24	0.21	0.51	0.67	0.36	0.37	0.27	0.14
3		0.17	0.43	0.61	0.32	0.46	0.38	
5			0.29	0.52			0.46	
10			0.25	0.15			0.63	
	Domain 450x 650 g.p.							
0.1	0.29	0.45	0.48	0.59	0.52	0.29	0.27	0.36
0.5	0.34	0.50	0.51	0.62	0.53	0.37	0.28	0.34
1	0.29	0.36	0.58	0.65	0.50	0.33	0.31	0.27
2	0.24	0.22	0.51	0.59	0.38	0.34	0.27	0.15
3		0.20	0.42	0.53	0.37	0.44	0.40	
5			0.28	0.55			0.52	
10			0.24	0.17			0.63	

Table 10: ETS values.

Threshold (mm/3h)	Forecast lead time (h)							
	3	6	9	12	15	18	21	24
	Domain 300 x 300 g.p.							
0.1	0.47	0.72	0.74	0.82	0.68	0.47	0.47	0.67
0.5	0.53	0.77	0.81	0.85	0.74	0.60	0.58	0.62
1	0.48	0.61	0.80	0.88	0.69	0.58	0.48	0.55
2	0.44	0.41	0.64	0.84	0.38	0.57	0.45	0.52
3		0.35	0.47	0.78	0.35	0.68	0.55	
5			0.37	0.73			0.74	
10			0.37	0.35			0.74	
	Domain 450 x 450 g.p.							
0.1	0.49	0.66	0.73	0.76	0.66	0.47	0.50	0.67
0.5	0.54	0.67	0.72	0.81	0.69	0.59	0.56	0.64
1	0.50	0.53	0.72	0.84	0.69	0.53	0.51	0.59
2	0.45	0.33	0.60	0.83	0.49	0.57	0.47	0.47
3		0.29	0.51	0.77	0.39	0.67	0.62	
5			0.37	0.69			0.65	
10			0.37	0.21			0.75	
	Domain 450x 650 g.p.							
0.1	0.49	0.64	0.69	0.77	0.73	0.49	0.51	0.63
0.5	0.52	0.66	0.72	0.80	0.74	0.58	0.54	0.64
1	0.49	0.53	0.75	0.82	0.73	0.54	0.53	0.56
2	0.45	0.35	0.60	0.81	0.52	0.56	0.47	0.49
3		0.32	0.50	0.73	0.46	0.65	0.64	
5			0.37	0.73			0.70	
10			0.37	0.24			0.75	

Table 11: TSS values.

Threshold (mm/3h)	Forecast lead time (h)							
	3	6	9	12	15	18	21	24
	Domain 300 x 300 g.p.							
0.1	0.43	0.68	0.69	0.78	0.67	0.44	0.40	0.55
0.5	0.51	0.74	0.76	0.80	0.72	0.57	0.45	0.49
1	0.45	0.59	0.78	0.84	0.66	0.54	0.42	0.42
2	0.40	0.38	0.69	0.77	0.42	0.51	0.40	0.29
3		0.32	0.56	0.75	0.45	0.66	0.45	
5			0.44	0.69			0.68	
10			0.41	0.39			0.74	
	Domain 450 x 450 g.p.							
0.1	0.45	0.62	0.68	0.73	0.64	0.43	0.43	0.55
0.5	0.51	0.67	0.67	0.77	0.67	0.54	0.45	0.51
1	0.45	0.53	0.71	0.81	0.66	0.49	0.46	0.44
2	0.39	0.35	0.68	0.80	0.53	0.54	0.43	0.25
3		0.29	0.60	0.76	0.48	0.63	0.55	
5			0.45	0.69			0.63	
10			0.40	0.25			0.77	
	Domain 450x 650 g.p.							
0.1	0.45	0.62	0.65	0.74	0.69	0.45	0.43	0.53
0.5	0.50	0.66	0.68	0.76	0.69	0.54	0.44	0.51
1	0.45	0.53	0.74	0.79	0.67	0.49	0.48	0.43
2	0.39	0.36	0.67	0.75	0.55	0.51	0.43	0.25
3		0.33	0.59	0.69	0.54	0.61	0.57	
5			0.44	0.71			0.68	
10			0.38	0.29			0.77	

Table 12: HSS values.

Threshold (mm/3h)	Forecast lead time (h)					
	6	9	12	15	18	21
	Domain 300 x 300 g.p.					
3	0.50	0.70	0.89	0.62	0.83	0.71
5		0.61	0.85			0.87
10		0.64	0.61			0.90
	Domain 450 x 450 g.p.					
3	0.49	0.72	0.88	0.65	0.83	0.78
5		0.62	0.83			0.83
10		0.64	0.48			0.90
	Domain 450x 650 g.p.					
3	0.53	0.71	0.84	0.69	0.81	0.80
5		0.60	0.86			0.89
10		0.63	0.52			0.90

Table 13: EDI values.

Threshold (mm/3h)	Time interval (h)							
	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24
0.1	201	201	188	185	166	157	148	145
0.5	143	153	159	164	129	116	105	111
1	98	129	152	152	112	94	89	82
2	50	76	140	116	75	51	61	39
3	22	45	119	96	57	36	40	27
5	5	17	64	62	21	19	24	19
10	0	2	21	27	2	4	16	3

Table 14: Number of precipitation events of different thresholds for 3-hour intervals.

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COSMO Technical Reports

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COSMO Technical Reports

Issues of the COSMO Technical Reports series are published by the *COnsortium for Small-scale MOdelling* at non-regular intervals. COSMO is a European group for numerical weather prediction with participating meteorological services from Germany (DWD, AWGeophys), Greece (HNMS), Italy (USAM, ARPA-SIMC, ARPA Piemonte), Switzerland (MeteoSwiss), Poland (IMGW), Romania (NMA) and Russia (RHM). The general goal is to develop, improve and maintain a non-hydrostatic limited area modelling system to be used for both operational and research applications by the members of COSMO. This system is initially based on the COSMO-Model (previously known as LM) of DWD with its corresponding data assimilation system.

The Technical Reports are intended

- for scientific contributions and a documentation of research activities,
- to present and discuss results obtained from the model system,
- to present and discuss verification results and interpretation methods,
- for a documentation of technical changes to the model system,
- to give an overview of new components of the model system.

The purpose of these reports is to communicate results, changes and progress related to the LM model system relatively fast within the COSMO consortium, and also to inform other NWP groups on our current research activities. In this way the discussion on a specific topic can be stimulated at an early stage. In order to publish a report very soon after the completion of the manuscript, we have decided to omit a thorough reviewing procedure and only a rough check is done by the editors and a third reviewer. We apologize for typographical and other errors or inconsistencies which may still be present.

At present, the Technical Reports are available for download from the COSMO web site (www.cosmo-model.org). If required, the member meteorological centres can produce hard-copies by their own for distribution within their service. All members of the consortium will be informed about new issues by email.

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