Ensemble forecasts for Sochi-2014 Olympics: development of COSMO-based ensemble systems and their application

Elena Astakhova, Andrea Montani, Dmitry Alferov, Dmitry Kiktev, Anatoly Muravev, Gdaly Rivin, Inna Rozinkina, Chiara Marsigli, Tiziana Paccagnella
XXII Winter Olympic Games were held in Sochi, Russia from 7 to 23 February 2014

XI Winter Paralympic Games were held in Sochi, Russia from 7 to 16 March 2014

An ensemble of Sochi-2014 mascots
Coastal and mountain clusters of Sochi-2014
Goals:

• Improve and exploit forecasts in complex terrain
  – High-resolution forecasts
  – Ensemble forecasts
  – Nowcasts of high impact weather phenomena

• Improve understanding of physics of high impact weather phenomena in the region

• Deliver forecasts in real time to Olympic forecasters and decision makers
WWRP FDP/RDP projects for Winter Olympics

SNOW-V10 ➔ FROST-2014 ➔ ?

Russian national meteorological service (ROSHYDROMET) is a member of the COSMO consortium

After Athens (Summer 2004) and Turin (Winter 2006), for the third time in a decade the Olympic Games were hosted by a COSMO-country.

COSMO Priority Project CORSO
(Consolidation of Operation and Research results for the Sochi Olympic Games)
(project leaders Gdaly Rivin and Inna Rozinkina)

was initiated to coordinate Olympic-related activity within the consortium and is considered as a COSMO contribution to the FROST-2014 project

E. Astakhova, A. Montani et al. EMS-2014, Prague.
1. High-resolution modeling

2. Downscaling/postprocessing and applications

3. Development and adaptation of COSMO EPSs for the Sochi region

**CORSO Project**

**FDP:**
Adaptation of COSMO LEPS 7 km to the Sochi region and to specific requirements of winter Olympics.

Operational ensemble forecasts during the Trials and Olympics

**RDP:**
Development and verification of high-resolution EPS for the Sochi region

**COSMO-S14-EPS**

**COSMO-Ru2-EPS**

E. Astakhova, A. Montani et al. EMS-2014, Prague.
Ensemble organization

ECMWF-EPS
Globe
T779L61 ($\Delta x \sim 30$ km)
M51, fc+14d
ECMWF computer

COSMO-S14-EPS
SOCHI DOMain
$\Delta x \sim 7$km, L40
M10, fc+72h
ECMWF computer

COSMO-Ru2-EPS
Sochi region
$\Delta x \sim 2.2$ km, L51
M10, fc+48h
RHMC computer

E. Astakhova, A. Montani et al.  EMS-2014, Prague.
Meteorological support for Sochi Olympics (products operationally delivered to Sochi forecasters in February-March 2014)

**COSMO-S14-EPS (7km):**
- Probability fields (T2m max&min, wind gusts 10m, precip, etc)
- Epsgrams (box-and-whiskers + plumes)
- Ensemble mean&spread (on Google maps)

**COSMO-Ru2-EPS (2.2 km):**
- Epsgrams (box-and-whiskers + plumes) with T corrected using prognostic lapse rate included

**Web-site:** frost2014.meteoinfo.ru + e-mail directly to forecasters

E. Astakhova, A. Montani et al. EMS-2014, Prague.
EPSs operational products

On-line comparison with other models and observations !!
### FROST-2014 Ensemble Prediction systems: resolution 7-11 km (convection parameterized)

<table>
<thead>
<tr>
<th>System Name / Origin</th>
<th>Forc ini time (UTC)</th>
<th>Forc length/data freq</th>
<th>Spatial resolution and grid</th>
<th>Ens size</th>
<th>Period of data available</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMO-S14-EPS / COSMO / ARPA-SIMC (Italy)</td>
<td>00 12</td>
<td>72 hr / 3 hr</td>
<td>7km, native rotated model grid</td>
<td>10</td>
<td>21.12.2011-28.05.2014</td>
</tr>
<tr>
<td>GLAMEPS / HIRLAM-ALADIN / Metno (Norway)</td>
<td>06 18</td>
<td>54 hr / 3 hr</td>
<td>~ 11 km, native rotated model grid</td>
<td>54</td>
<td>22.10.2012-31.03.2014</td>
</tr>
<tr>
<td>LAEF / ALADIN/ ZAMG (Austria)</td>
<td>00 12</td>
<td>72 hr / 3 hr</td>
<td>interpolated from native ~11km grid to Lon-Lat 7 km grid</td>
<td>17</td>
<td>17.09.2013-09.04.2014</td>
</tr>
<tr>
<td>NMMB-EPS / NOAA / NCEP (USA)</td>
<td>00 12</td>
<td>72 hr / 3 hr</td>
<td>7 km, Lon-Lat grid</td>
<td>7</td>
<td>19.02.2013-9.06.2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.09.2013-25.03.2014</td>
</tr>
</tbody>
</table>
FROST-2014 Ensemble Prediction systems: resolution 2-3 km (convection-permitting)

<table>
<thead>
<tr>
<th>System Name / Origin</th>
<th>Forc ini time (UTC)</th>
<th>Forc length/ data freq</th>
<th>Spatial resolution and grid</th>
<th>Ens size</th>
<th>Period of data available</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMO-Ru2-EPS/COSMO/ RHMC (Russia)</td>
<td>00 12</td>
<td>48 hr / 1 hr</td>
<td>2.2 km, native rotated model grid</td>
<td>10</td>
<td>01.01.2013-28.02.2013 12.11.2013-27.05.2014</td>
</tr>
<tr>
<td>HARMON-EPS /HIRLAM-ALADIN/ Metno (Norway)</td>
<td>06 18</td>
<td>36 hr / 3 hr</td>
<td>2.5 km, Lambert conformal projection</td>
<td>13</td>
<td>15.01.2014 - 31.03.2014</td>
</tr>
</tbody>
</table>

Coding: mainly Grib1, NMMB-EPS changed to Grib2 since Jan 15, 2014

Data location: mainly on FROST-2014 server (password protected access), COSMO-Ru2-EPS on RHMC server

Additionally (at selected points, in xml format):
- GLAMEPS calibrated (T2m, wind speed 10m, precipitation)
- GLAMEPS 1h-updated (T2m)

E. Astakhova, A. Montani et al. EMS-2014, Prague.
Different orography of coarse-resolution EPSs in the Sochi region

7km

COSMO-S14-EPS

GLAMEPS

7km

NMMB-EPS

LAEF

11 km Interpol to 7 km
Detalization of orography in high-resolution EPSs in the Sochi region

- COSMO-S14-EPS (7km)
- GLAMEPS (11km)
- COSMO-Ru2-EPS (2.2km)
- HARMON-EPS (2.8km)
Ensemble products available at FROST-2014 site

LAEF Meteograms: T2m, 3h precip, 10m and 850hPa wind, low clouds, snowfall level

GLAMEPS Meteograms: T2m, 3h precip, H500, 10m gusts, pmsl
### Subjective Evaluation of FROST EPS technologies

<table>
<thead>
<tr>
<th>Model Grid mesh size</th>
<th>Overall usefulness</th>
<th>Forecast accuracy</th>
<th>Visualization (appearance)</th>
<th>Timelines and reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMO-S14-EPS 7 km</td>
<td>2.1</td>
<td>2.0 2.0 2.0 2.0</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>ALADIN LAEF 11 km</td>
<td>2.0</td>
<td>1.8 1.8 2.0 2.0</td>
<td>2.5</td>
<td>2.7</td>
</tr>
<tr>
<td>GLAMEPS 11 km</td>
<td>1.5</td>
<td>1.8 1.8 1.8 2.0</td>
<td>2.3</td>
<td>2.7</td>
</tr>
<tr>
<td>GLAMEPS calibr 11 km</td>
<td>2.0</td>
<td>2.0 2.0 2.0 2.0</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>NMMB-EPS 7 km</td>
<td>2.1</td>
<td>2.0 2.0 1.3 2.0</td>
<td>1.7</td>
<td>2.2</td>
</tr>
</tbody>
</table>

- **COSMO-S14-EPS 7 km**
  - Precip reasonable. Good tendencies. Wind poor. Was available well before the Olympics that was helpful to get used to this information.

- **ALADIN LAEF 11 km**
  - Good Wind, including Vmax. Nice plots.

- **GLAMEPS 11 km**
  - Informative tendencies. Issues with absolute values.

- **GLAMEPS calibr 11 km**
  - Interesting and helpful.

- **NMMB-EPS 7 km**
Subjective Evaluation of FROST EPS technologies (continued)

0 – not useful  1 – partly useful  2 – useful  3 - excellent

<table>
<thead>
<tr>
<th>Model Grid mesh size</th>
<th>Overall usefulness</th>
<th>Forecast accuracy</th>
<th>Visualization (appearance)</th>
<th>Timeliness and reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMO-Ru2-EPS 2.2 km</td>
<td>1.7</td>
<td>1.3 1.7 1.7 2.0</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>HarmonEPS 2.5 km</td>
<td>1.3</td>
<td>1.5 1.3 1.3 1.3</td>
<td>2.2</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Experimental

In general good in T and Precip, but there were problems with T in anticyclones and Foehn

During the Sochi Olympics COSMO model was the most popular (both deterministic and ensemble forecasts) !!

E. Astakhova, A. Montani et al.  EMS-2014, Prague.
### Most interesting cases during the Olympics/ Paralympics

<table>
<thead>
<tr>
<th>Date</th>
<th>Process \ phenomenon</th>
<th>Models’ behavior</th>
<th>Impact on competitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Febr, 07</td>
<td>Foehn</td>
<td>Poor T by most models at 1500-2300 m</td>
<td></td>
</tr>
<tr>
<td>Febr, 16</td>
<td>Low visibility</td>
<td></td>
<td>Postponed competitions at Laura and Extreme Park</td>
</tr>
<tr>
<td>Febr, 18</td>
<td>Cold front</td>
<td>Good precipitation forecast by most models</td>
<td></td>
</tr>
<tr>
<td>Febr, 22</td>
<td>Foehn</td>
<td>Poor T by most models</td>
<td></td>
</tr>
<tr>
<td>Mar, 11</td>
<td>Cold front &amp; Low visibility</td>
<td>$T_{\text{max}}$ forecast not good by most models</td>
<td>Postponed skiing competitions at Roza Khutor</td>
</tr>
<tr>
<td>Mar, 13</td>
<td>“Weak” process</td>
<td>Poor precipitation by most models above 1500 m</td>
<td></td>
</tr>
<tr>
<td>Mar, 17</td>
<td>Cold front</td>
<td>Poor $V_{\text{max}}$ forecast by most models at altitude above 1500 m</td>
<td></td>
</tr>
</tbody>
</table>

*List is prepared by T. Dmitrieva*
Tropospheric foehn. February 7, 2014

At 1500 - 2300 m
- Low humidity
- No diurnal variations of T
- Higher T than usual
- E and SE winds

RKHU1, 2320 m

Relative humidity (%)
Temperature (°C)
Tropospheric foehn
February 7, 2014

RKHU4, 1580 m

Only GLAMEPS calibrated gave right T
No EPS forecasted low RH
Cosmo-Ru2-EPS excellently predicted 10 m wind direction
Verification problems

Nearest point approach:
• One model grid-point may be the nearest to several stations
• The nearest grid-point can be in different valley, at different slope, or at different height with respect to the station
• Differentiation by height decreases the sample considerably

Several-km domain:
• Stations in the domain can be at different heights, slopes, etc. and can be characterized by various meteorological regimes

All approaches:
• Need for better observation data control
• Need for forecast data control (especially for hi-res!)
• The more observations the better

Legend:
Light-blue squares: COSMO-S14-EPS grid-points
Dark-blue stars: COSMO-RU2-EPS grid-points

E. Astakhova, A. Montani et al. EMS-2014, Prague.
Verification of EPS results

• Verification for all FROST EPSs was performed against the AMS observations.
• RHMC verification package based on R was used.

Period: 15 January – 15 March 2014
Elements: 3-h prec, T2m, wind speed
Method: nearest point
Domain: Mountain cluster
  13 mountain stations:
    the lowest was Krasnaya Polyana, H=564 m

Diagnostic analysis was performed for individual stations:
  histograms, quantile-quantile plots, diagnostic diagram, ME, MAE, RMSE were prepared

Probabilistic scores (Brier and its components, ROC, reliability diagrams with frequency histograms) were calculated for a group of 13 mountain stations
**Distribution analysis: histograms, q-q plot and diagnostic diagram**

Parameter: T2m, Location: Biathlon Stadium (1455 m),
Verification Period: 15.1.2014-15.3.2014, Verification approach: Nearest point

All forecasts starting from 00 UTC and 12 UTC analyses

Q-Q plots are used to test whether the samples are from the same distribution
Distribution analysis: histograms, q-q plot and diagnostic diagram

Parameter: T2m, Location: Biathlon Stadium (1455 m),
Verification Period: 15.1.2014-15.3.2014,
Verification approach: Nearest point

Lead=0

All forecasts starting from 00 UTC and 12 UTC analyses

Q-Q plot

COSMO-Ru2-EPS

Diagnostic diagram

Necessary but not sufficient condition: Q-Q points near F=O line for perfect forc

E. Astakhova, A. Montani et al. EMS-2014, Prague.
Role of spatial resolution

Parameter: T2m, Location: Biathlon Stadium (1455 m), Verification Period: 15.1.2014-15.3.2014, Verification approach: Nearest point

Lead=48

7km grid spacing

2.2 km grid spacing

Hi-res ensemble forecasts: better pdfs, higher variability but poorer ensemble mean scores
<table>
<thead>
<tr>
<th>Station</th>
<th>BIAS (for 6/12/18hr lead time)</th>
<th>Mean Absolute Error (for 6/12/18hr lead time)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COSMO-S14-EPS</td>
<td>COSMO-RU2-EPS</td>
</tr>
<tr>
<td>Sledge (~700m)</td>
<td>-1.3 / -2.0 / -1.4</td>
<td>0.2 / -1.9 / -0.1</td>
</tr>
<tr>
<td>Freestyle (~1000m)</td>
<td>-2.0 / -1.8 / -1.9</td>
<td>0.3 / -0.7 / 0.0</td>
</tr>
<tr>
<td>Biathlon Stadium (~1500m)</td>
<td>-1.4 / -1.3 / -1.4</td>
<td>0.9 / 0.0 / 0.5</td>
</tr>
<tr>
<td>Mountain Skiing (start) (~2000m)</td>
<td>1.6 / 2.2 / 1.6</td>
<td>0.6 / 0.2 / 0.1</td>
</tr>
</tbody>
</table>

Green – better for all lead times

- **T2m:** Some positive effect of downscaling from 7 to 2 km resolution
- **Wind Speed:** No positive effect of dynamical downscaling was found

E. Astakhova, A. Montani et al. EMS-2014, Prague.
Comparison with other FROST2014 ensembles
Precip > 0.01 mm/3h

COSMO-S14-EPS – red
COSMO-RU2-EPS – orange
LAEF – brown
NMMB-EPS – black
HARMON-EPS – blue
GLAMEPS – green

13 mountain stations in the area of Krasnaya Polyana

COSMO-S14-EPS, NMMB-EPS and COSMO-RU2-EPS look most informative

But! Only preliminary ranking of models can be performed for the lack of statistical significance assessments

E. Astakhova, A. Montani et al. EMS-2014, Prague.
Comparison with other FROST2014 ensembles

Precip > 5 mm/3h


COSMO-S14-EPS – red
COSMO-RU2-EPS – orange
LAEF-EPS – brown
NMMB-EPS – black
HARMON-EPS – blue
GLAMEPS – green

For higher Precip threshold (w.r.t. the lower threshold):
• COSMO-S14-EPS, COSMO-Ru2-EPS, NMMB-EPS, and HARMON-EPS become worse.
• in contrast, LAEF and GLAMEPS become better.

Only preliminary results are presented, verification results should be analyzed further!
Conclusions for COSMO-based EPSs

• The COSMO-based EPS systems developed for Sochi Olympics (COSMO-S14-EPS and COSMO-Ru2-EPS) demonstrated high skill for T2m, wind, and precipitation.

• The hi-res system provided more detailed forecasts and added value for some parameters. It is slightly more skillful for T2m, but worse for wind. However, diagnostics and summary performance measures do not give ground for categorical conclusions!

• Both systems provided a good support to Sochi forecasters and were highly appreciated.

• Verification activity should be continued, including application of new approaches and observations, comparison with other FROST2014 ensembles.

• The archived information on forecasts, IC&BCs, and observations is valuable and new experiments can be performed within the Sochi testbed. Within a new COSMO PT CORSO-A the forecast archive will be reorganized following TIGGE-LAM standards.

E. Astakhova, A. Montani et al. EMS-2014, Prague.
Acknowledgements

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Anastasia Bundel (RHMC, Russia) for help in verification and discussion of results

Cosmo Consortium for a chance to present the results at EMS2014
Thank you for your attention!