Snow water equivalent analysis based on modeling as Synop observation operator:

experience of COSMO-Ru technology

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Motivation

- NWP models need a fields of current values of Snow water equivalent (SWE) and of Snow Depth as initial information
- A great sensitivity of T2m model forecasts to the SWE accuracies near snow boundary was detected. The error of T2m can reach more 10°
- Serious inaccuracies of initial fields of SWE arriving from global model systems to COSMO-Ru are detected for large regions of long snow period for snowy years (till 100% and 1 m)
- Now the SWE as COSMO product doesn't use in spring flood calculations for regions with rare observation network

The regional system of correction of SWE fields arriving from global modelling& DAS could improve the situation

Challenges

No direct operational observations of SWE and of Snow Density (SD);

reliable satellite technologies for determination of SWE, in particular for northern regions are in progress and plan to provide reliable information only after few years

SWE and SD values depend on whole previous weather winter history, the use of constants and aging functions for SD for long periods can lead to wrong results

The continuous modeling of SWE/SD into atmospheric models-DAS cycles (actually way) lead to accumulation of errors

But: The operational Snow Depth values arriving from operational Synop data and the operational data of Snow mask based satellites are realistic!

Motivation

The regional system of correction of SWE fields arriving from global modelling& DAS could improve the situation

The operational Snow Depth values arriving from operational Synop data

the operational data of Snow mask based satellites are realistic

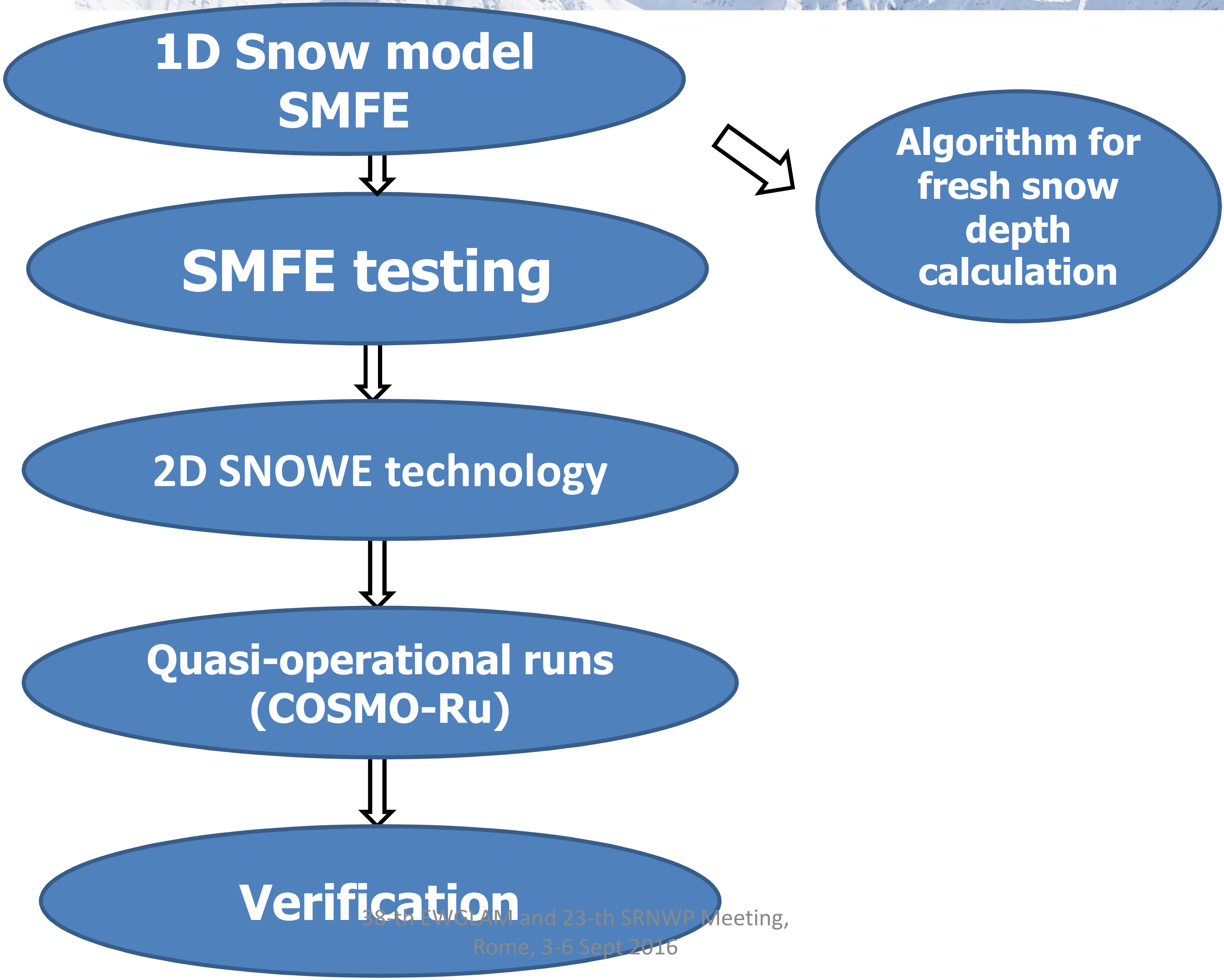
Snow-analysis schemes into ICON-DAS provide the realistic values of snow depth and of snow mask

SWE and SD values depend on whole previous weather winter history

The standalone continuous modeling of SWE operated the SYNOP measurements is realistic way to obtain the daily SWE values

Order of the realization

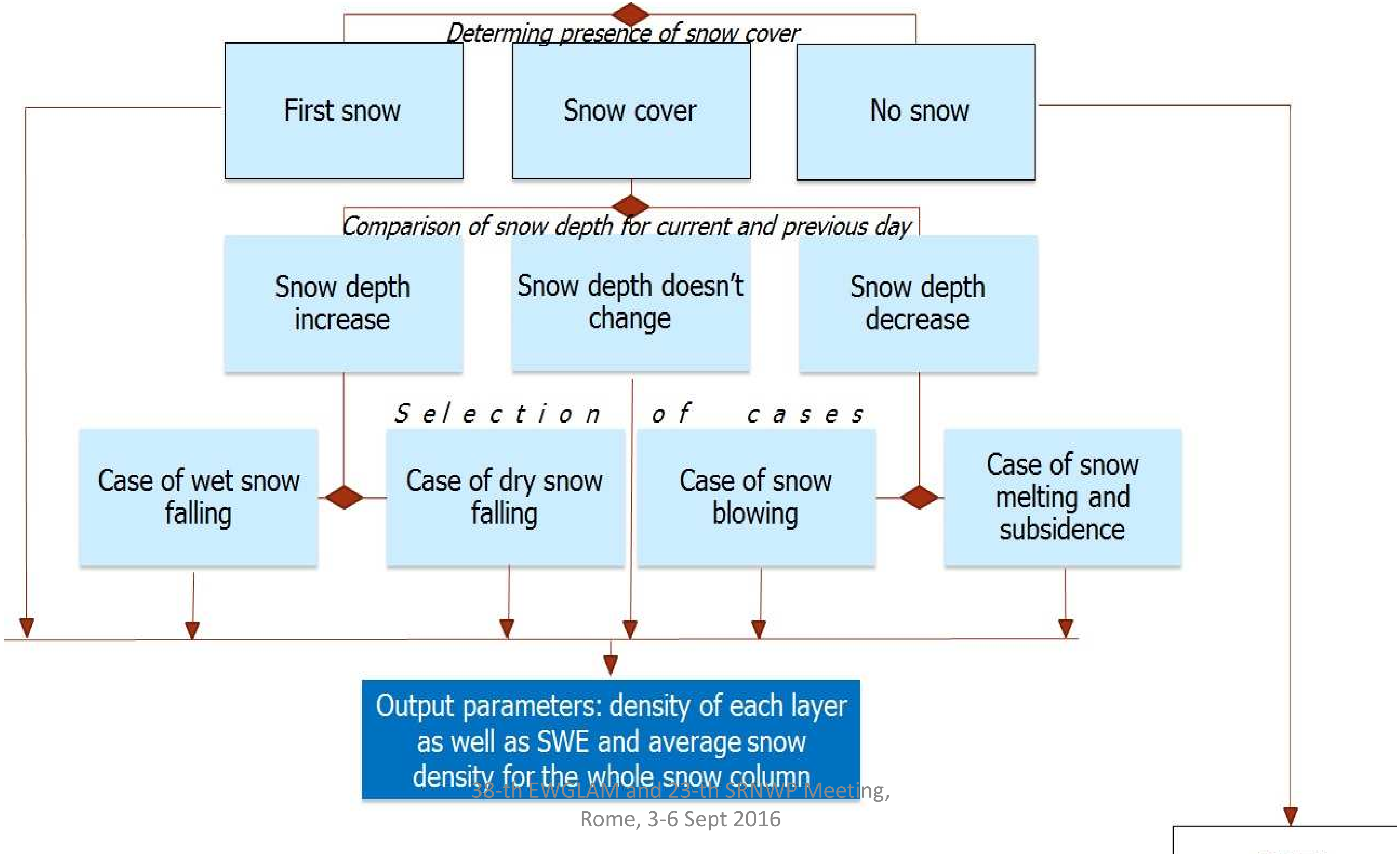
SNOW HYSTORy



SNOWFALLs

Multi-layer snow model SMFE

SYNOP data: Snow Depth, T2m, Td2m, W10m, Prec (after QC)



About SMFE

- 1d model (data operator) SMFE use only standard meteorological observations (SYNOP)
- Runs of SMFE produce snow cover characteristics for every day
- Model SMFE includes simplified description of the basic processes in snow cover

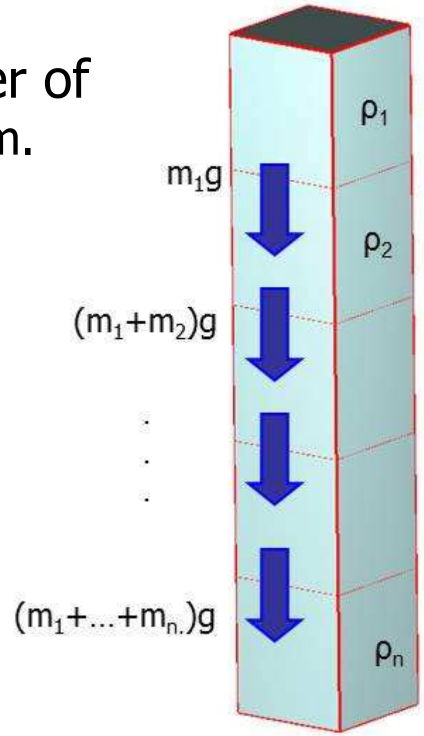
Multi-layer snow model SMFE (Snow Model Finite Element)

- Snow is represented as a number of layers («elements»). The number of elements depends on snow depth H. Each element has a height of h=1 cm.

- Each time step (equal to 1 day) the number of new elements is determined in dependence on snow depth changing ΔH :

$$N(t_k) = N(t_{k-1}) + \Delta N \qquad \Delta N = \Delta H / h$$

- If $\Delta N > 0$ (case of snow falling), then density of fallen upper layers (fresh snow with a depth of ΔH) is calculated in dependence on average daily air temperature according to [Bartlett, MacKay, Verseghy, 2006].



For «settled» snow (except «fresh-fallen» layers) each time step changing of element's densities is determined $\Delta\rho_n(t_k) = \rho_n(t_{k-1}) + \Delta\rho$ (where $n(t_k) = 1,\ldots, N(t_k)$ is a serial number of an element), if $\Delta N \neq 0$

$$\Delta\rho = \rho' + \rho'' + \rho'''$$

ρ' - Case of snow compression due to new elements $\Delta N > 0$

ρ'' - Case of snow compression due to snow blowing $\Delta N < 0$

ρ''' - Case of snow column compression due to snow subsidence or melting (water percolation and freezing) $\Delta N < 0$

Multi-layer snow model SMFE

- If $\Delta N > 0$,then density of each element $\rho_n(t_k) = \rho_n(t_k)\left(T_n(t_{\tilde{k}}),\ \sum_{m=n(t_k)}^{N(t_k)} \rho_m(t_k) \right)$ is a function depending on air temperature $T_n(t_{\tilde{k}})$ in time moment $t_{\tilde{k}}$, when snow was falling, and amount of layers, which affected it from above (case of snow depth increase, density of these layers is calculated according to [Yosida, Huzioka, 1954] and [Epifanov, Osokin, 2010 (in Russian)]).

- If snow depth doesn't change for one day and, respectfully, the number of elements $\Delta N = 0$ then SWE and snow density don't change upon the condition that there were no precipitation; otherwise equal amount of moisture is added to each element.

- Decreasing of snow depth ($\Delta N < 0$) is determined as: melting takes place when positive air temperatures are observed during a day, snow blowing – when there are negative temperatures in case of significant decrease of snow depth, in other cases – there is snow compression (subsidence).

- Each day SWE is calculated as a sum of SWE of all the layers, and snow column density as a mean value of densities of all the layers

Algorithm for fresh snow depth calculation

For small time intervals (up to 12 hours) calculation of fresh snow density can be led based on formula from [*Barltett, MacKay, Verseghy* , 2006], which is used in CLASS-model :

$$\rho_{s,f} = 67.92 + 51.25 e^{\frac{T_a}{2.59}}, \ T_a \le 0^0 C; \ \rho_{s,f} = \min(200; 119.2 + 20T_a), T_a > 0^0 C$$

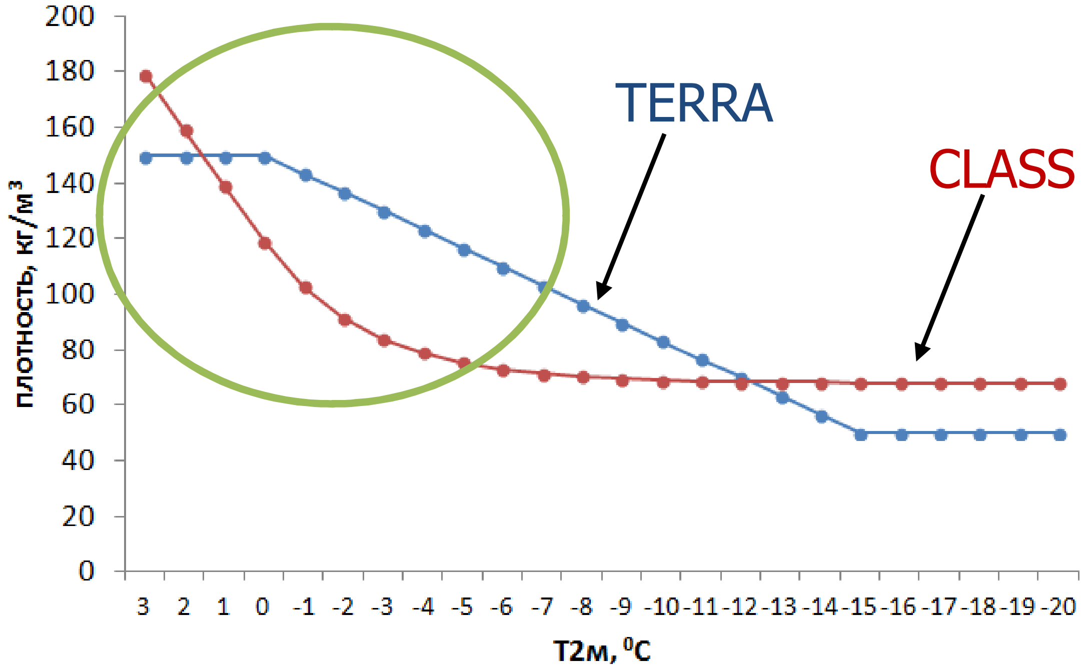
Fresh snow depth is calculated as :

$$h_{s,f} = \frac{p_s \cdot \rho_w}{\rho_{s,f}}$$

$h_{s,f}$ - fresh snow depth (mm),

p_s - precipitation sum (mm),

$\rho_w = 1000 \ kg/m^3$ - density of water

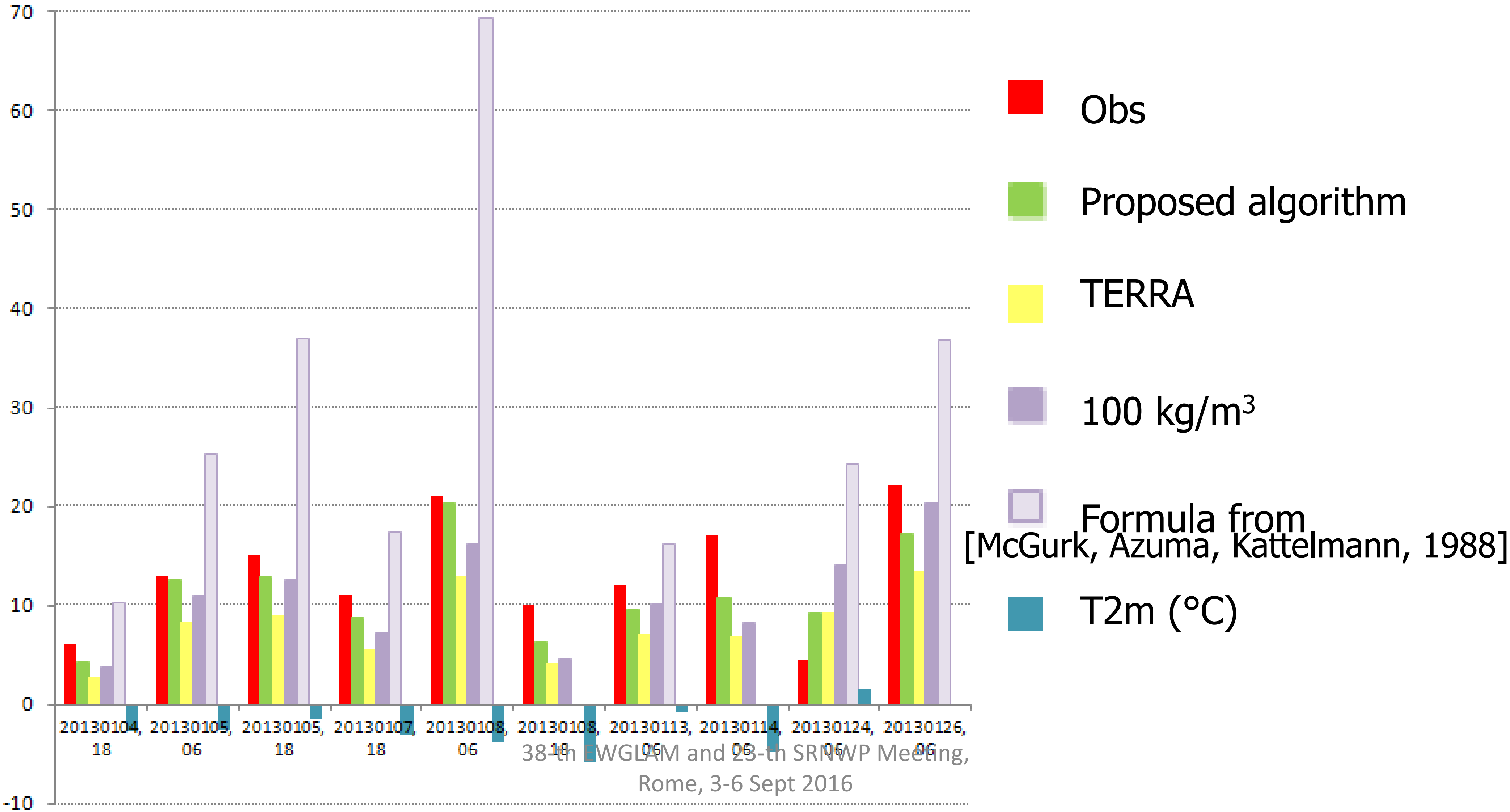


In TERRA-model in COSMO fresh snow density is equal to:

$$\rho_{s,f} = 50 + 100 \cdot \frac{T_{low} - 258.16}{15.0}$$

T_{low} – temperature of the lowest model atmospheric level (K)

Fresh snow depth (cm): measurements and calculated values according to different algorithms (station Gornaya Karusel', January 2013)



Precipitation sums (mm) at station Zugspitz (2960 m a.s.l., Bavaria) and SWE values (mm) according to SMFE calculations for snow accumulation period 2009/2010

Month	X	XI	XII	I	II	III	IV
Precipitation sums (according to SYNOP)	**241**	**335**	**520**	**629**	**717**	**859**	**965**
SWE (according to SMFE)	**245**	**298**	**506**	**629**	**715**	**902**	**968**
Mean Relative error, %	**1,6**	**12,5**	**2,6**	**0**	**0,2**	**4,8**	**0,4**

Mean relative error of SWE values is 2,4%

$$MRE = \frac{1}{n}\sum_{i=1}^{n}\frac{|f_i - o_i|}{o_i}\cdot 100\%$$

- Mean relative error

Snow accumulation period is reproduced realistically by the model SMFE

Statistical characteristics for SWE (mm) for four seasons (2009/10, 2010/11, 2011/12, 2012/13)

Centre

name	RMSE(мм)	MRE(%)
Anna	1,4	23,5
Bologoe	1,5	14,9
Buzuluk	1,9	24,7
Buy	2,0	14,4
Vetluga	2,5	26,0
Gotnya	1,3	21,3
Dmitrov	1,9	16,4
Inza	4,7	46,3
Karachev	4,6	36,1
Kolomna	1,3	12,0
Michurinsk	2,4	26,8
Mozhga	3,6	19,0
Morshansk	1,6	17,6
Poniry	2,6	21,4
Radischevo	3,7	19,6
Rybinsk	5,3	26,1
Rilsk	1,6	24,2
Spas-Demensk	1,9	17,7

mean: 2,7mm; 20,4%

North

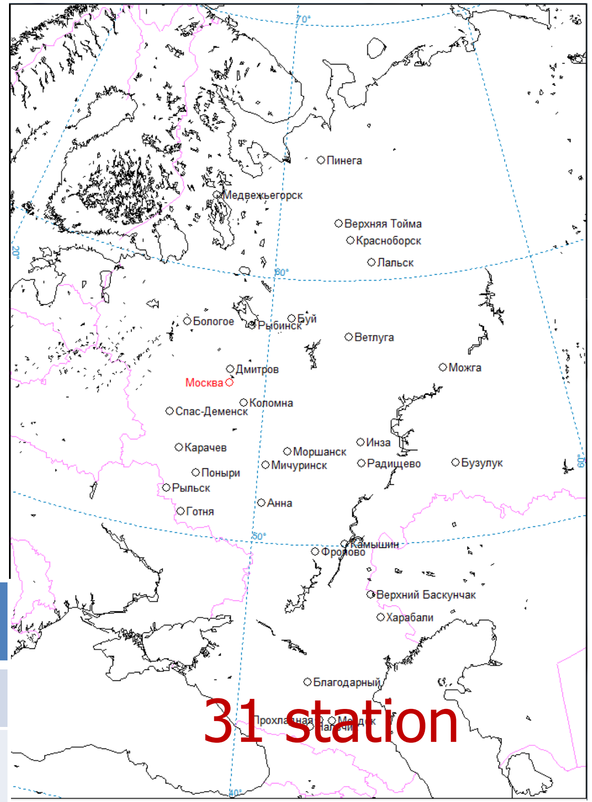
name	RMSE(мм)	MRE(%)
Verhnaya Toyma	2,6	14,2
Krasnoborsk	2,1	17,6
Lal'sk	3,4	26,6
Pinega	3,5	23,0

mean: 2,9mm; 20,4%

South

name	RMSE(мм)	MRE(%)
Blagodarniy	2,1	70,7
Verhny Baskunchak	2,1	48,3
Kamishin	4,4	45,4
Karabulak	3,6	23,3
Mozdok	3,0	28,8
Nal'chik	1,8	43,6
Prohladnaya	2,2	30,7
Frolovo	1,6	41,3
Harabaly	1,8	22,5

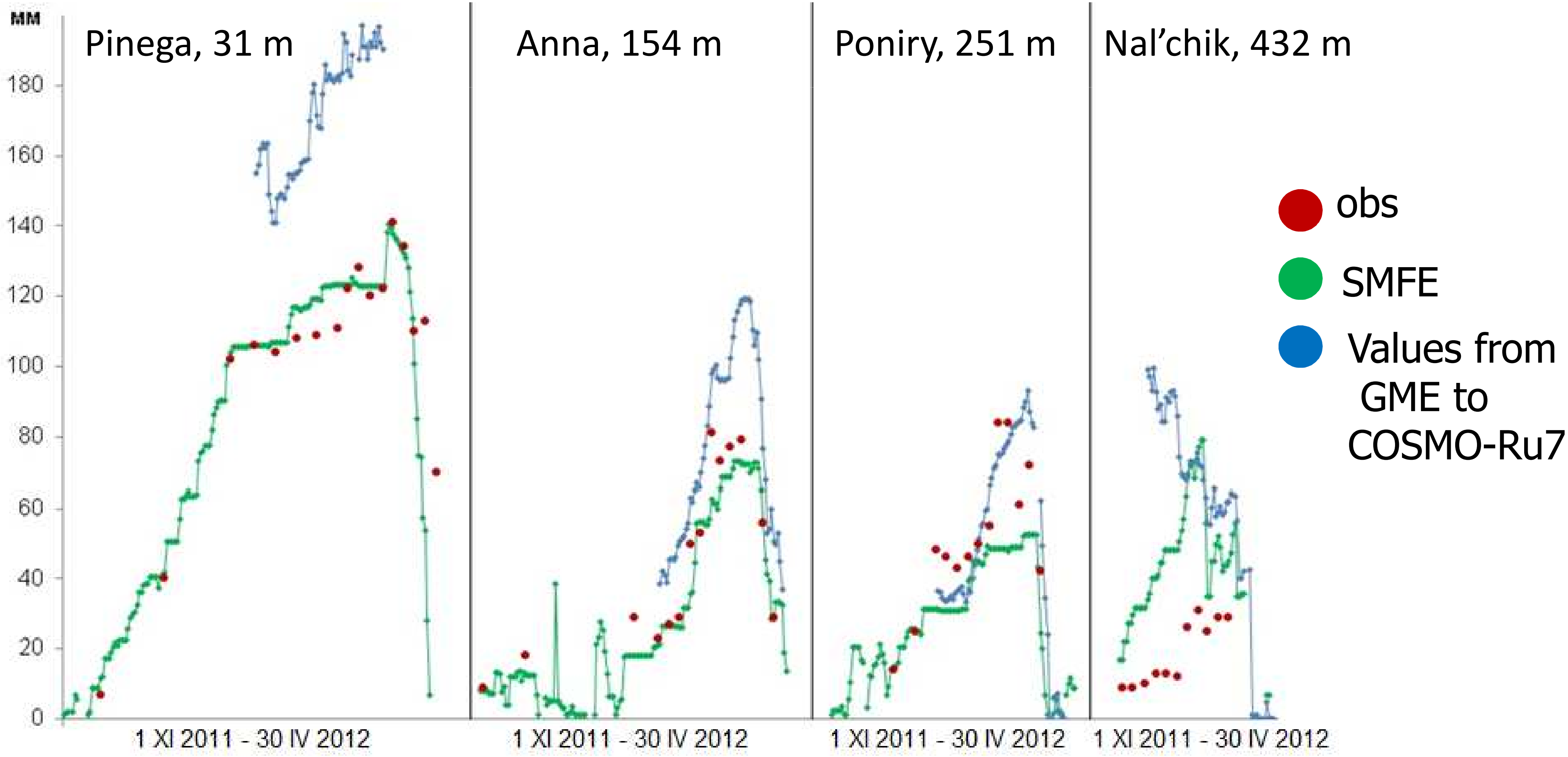
mean: 2,3 mm; 39,4%



31 station

124 cases

SWE (mm) for stations situated at the European part of Russia (snow season 2011/2012)



SNOWE technology: OA of snow cover characteristics for NWP model (exemplifying COSMO-Ru)

Observations: HSNOW, T2m, DPT, prec, 10m wind → SMFE: calculation of SWE and snow density values at stations

Satellite data (for improvement of positioning of snow boundary) → Finding of proportions between original FG and calculated fields at stations and interpolation of relations to grid-points of COSMO-Ru

First guess (FG) of SWE and snow density for COSMO-Ru → FG change due to its division on the relations

→ Replacement of original fields of SWE and snow density by modified fields

In quasi-operational regime since 1 December 2014

For COSMO-Ru versions with 7 km (COSMO-Ru7, ETR) and 2.2 km (COSMO-Ru2, CFO) resolution.

Since 1 March 2016 – for COSMO-ENA (13.2 km)

About SMFE and SNOWE

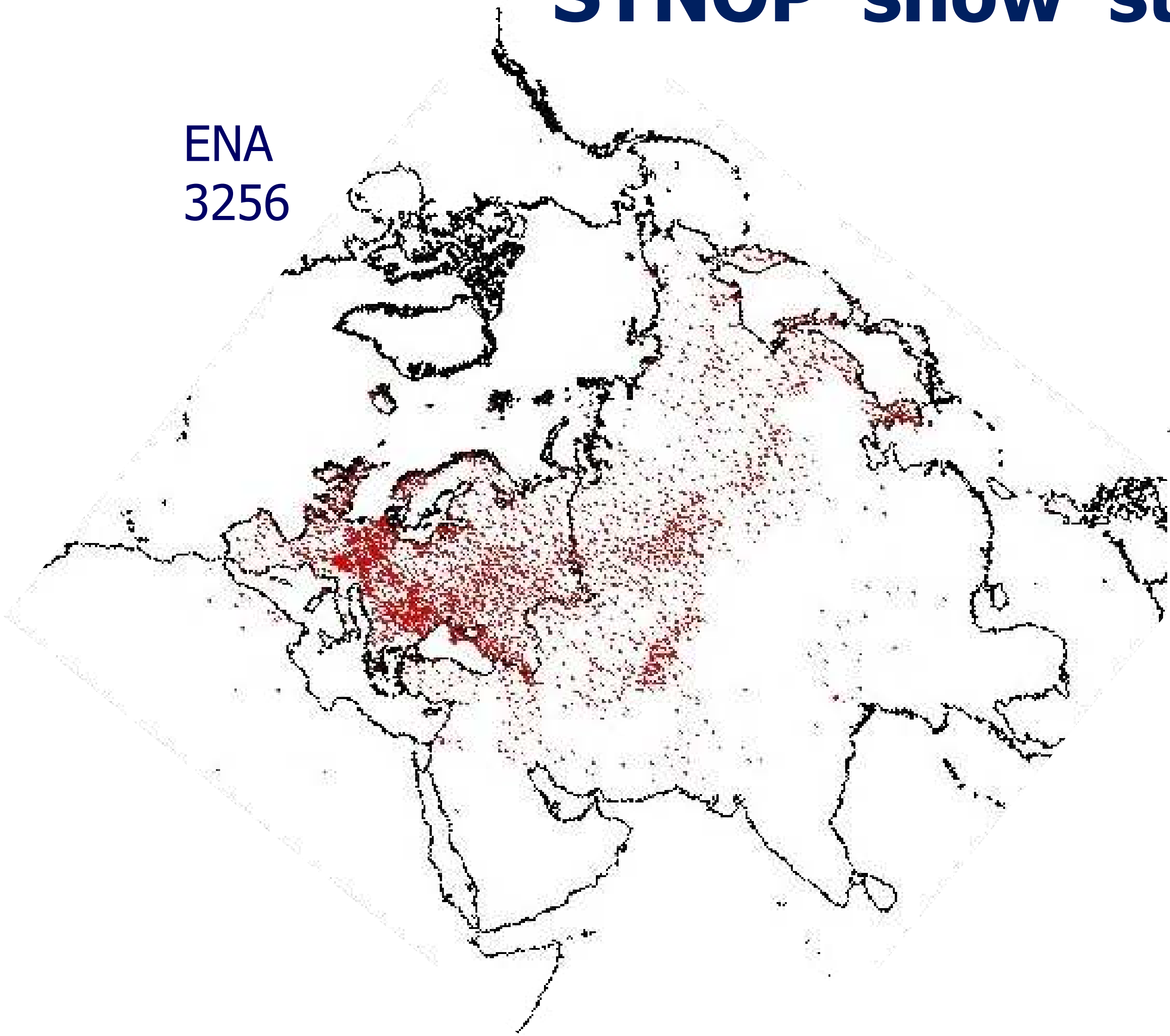
- 1D-model (data operator) SMFE can be executed either directly for SYNOP stations (their further interpolation and using of COSMO first guess) as for at COSMO-grid point

- With coupling with first guess (FG) of mesoscale model, it is possible to form fields of snow cover characteristics for large areas, including ones with rare observational net

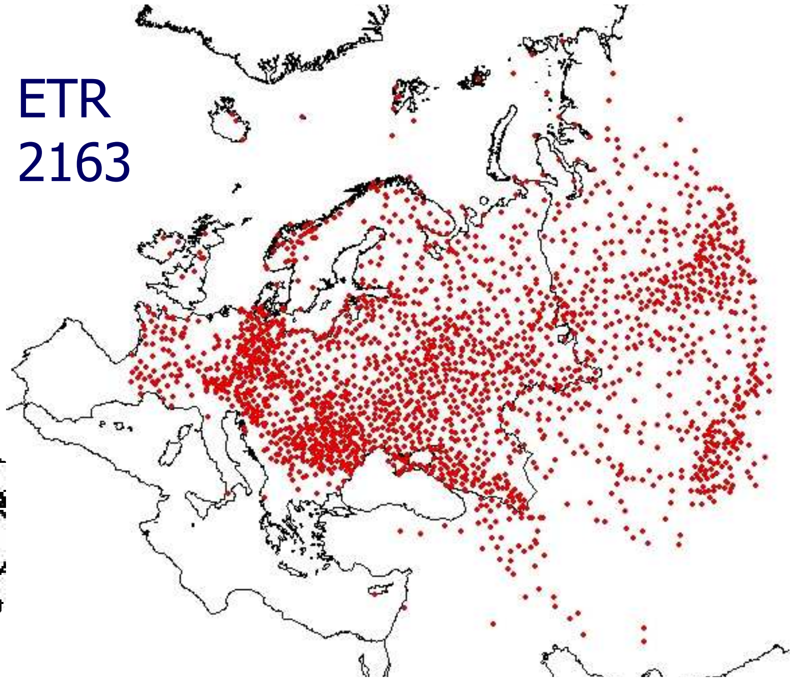
- Codes: Fortran 90, is being prepared for users

SYNOP 'snow' stations

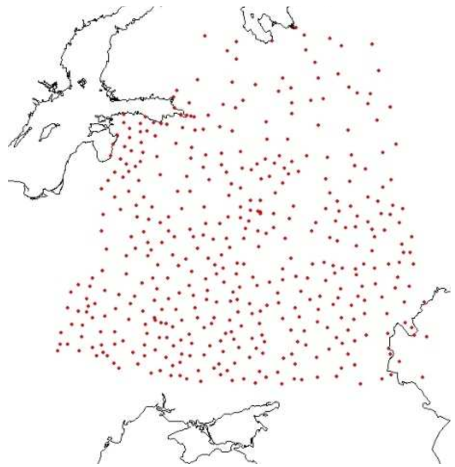
ENA
3256



ETR
2163

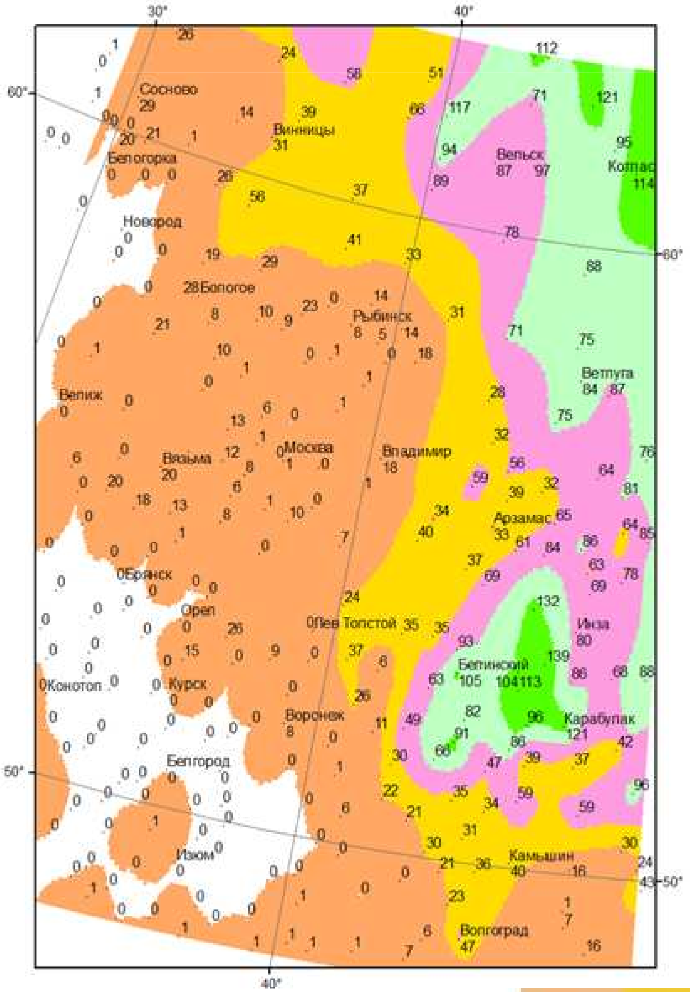


CFO
436

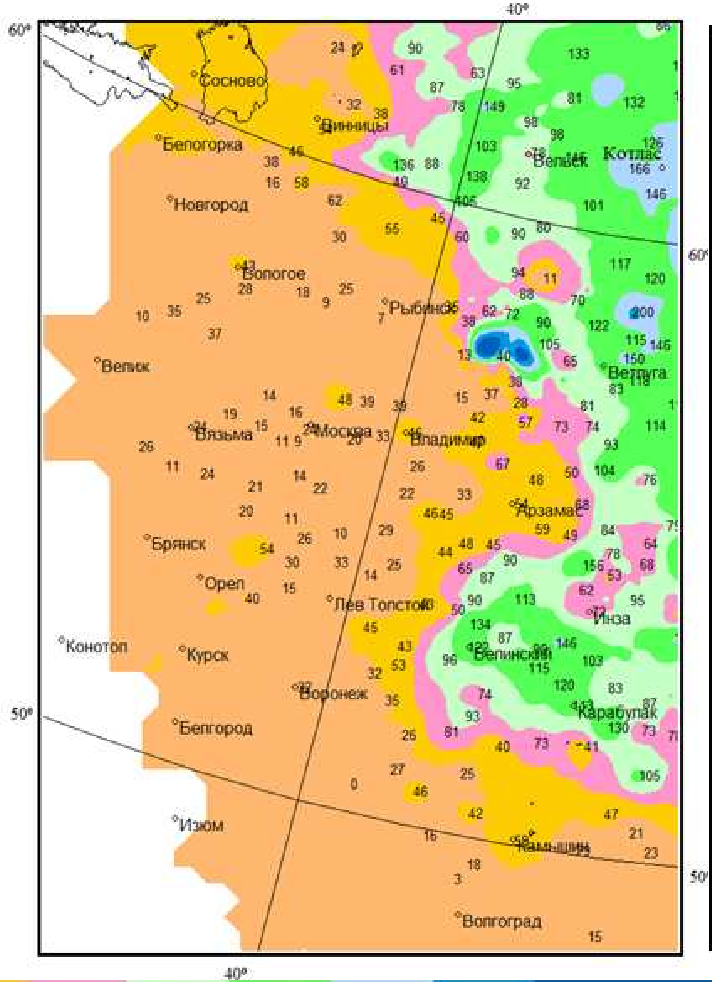


Maps of SWE (mm) 28 February 2014

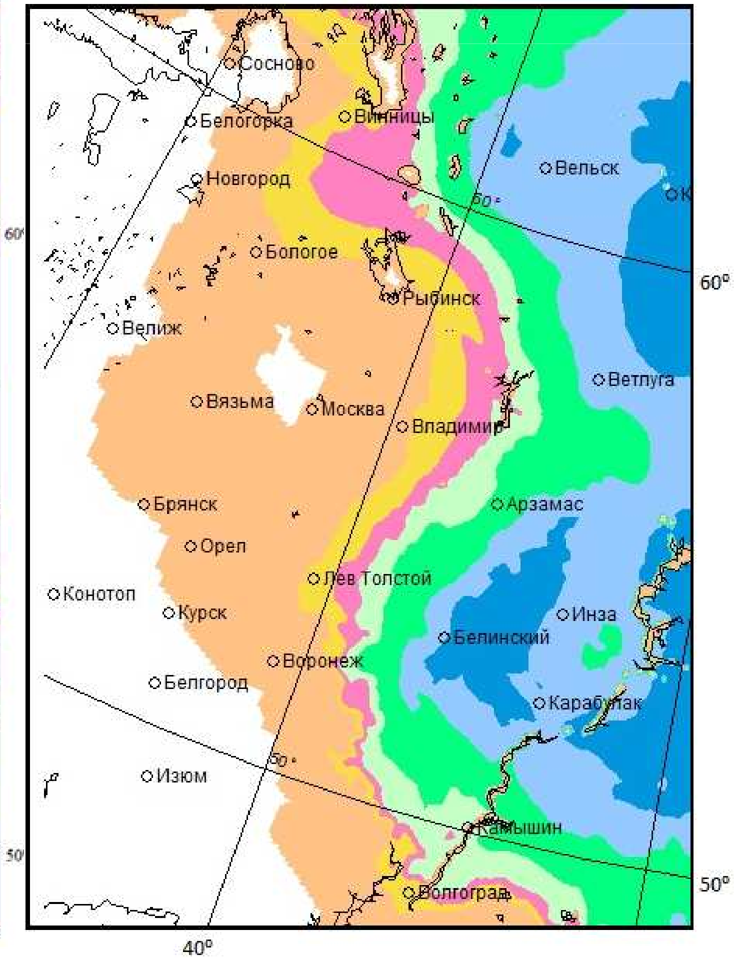
SMFE analysis

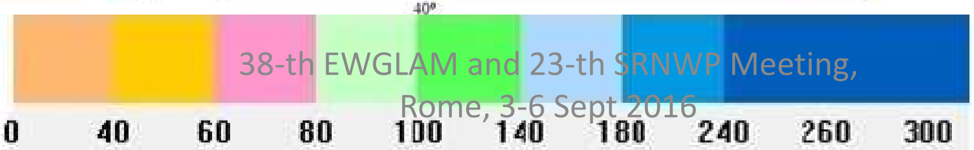


Hydrological obs

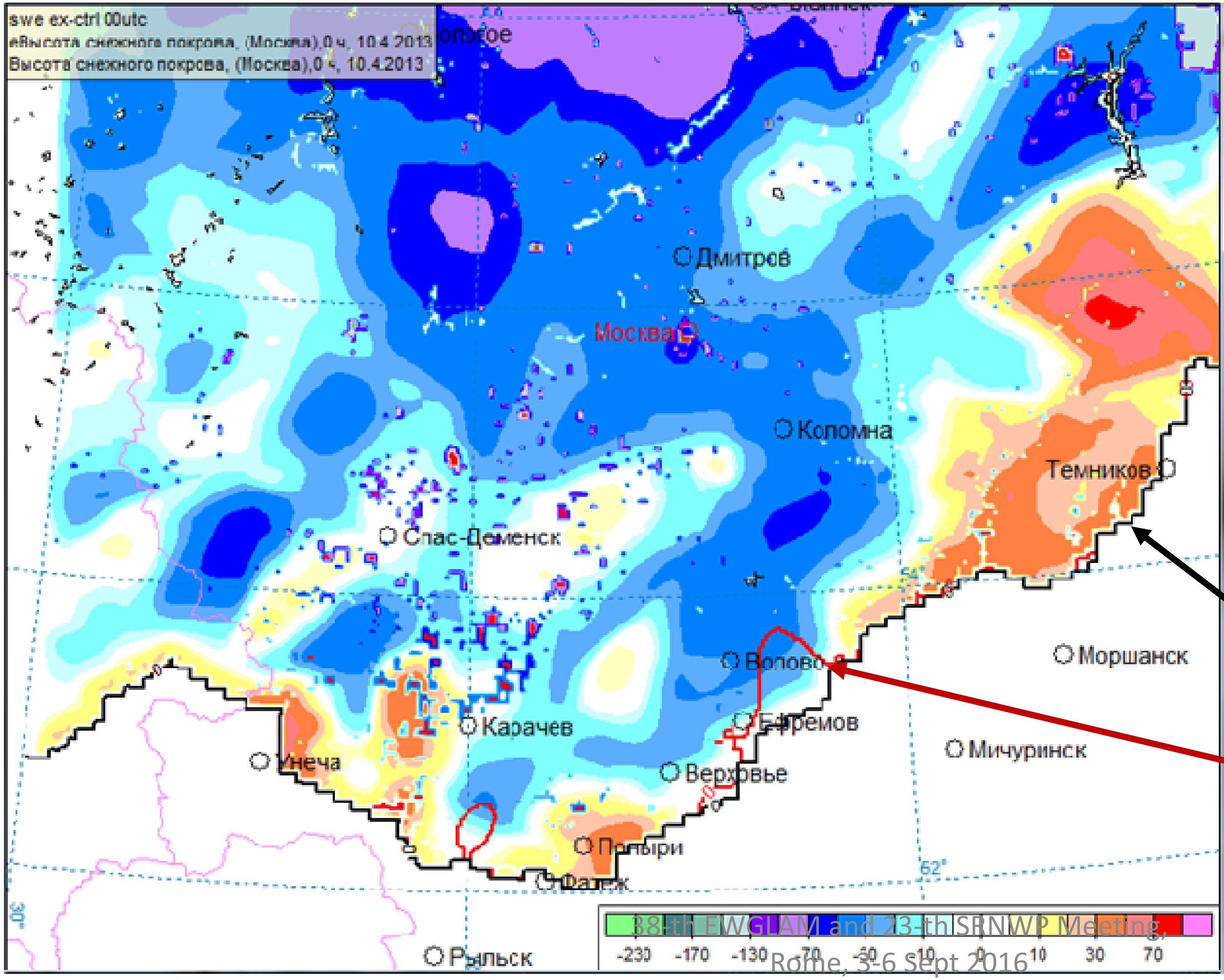


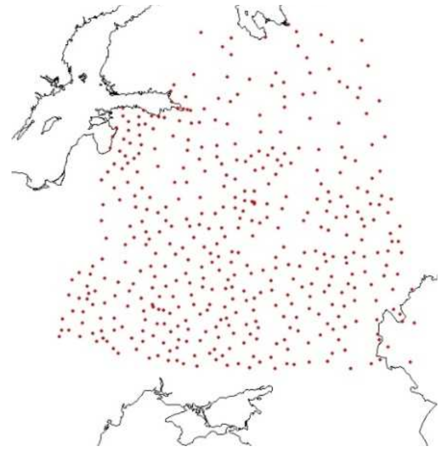
Initial field from GME to COSMO-Ru7





Difference in initial fields of SWE (mm, SNOWE technology-operational run) for COSMO-Ru2. Start – 00 UTC 10 April 2013



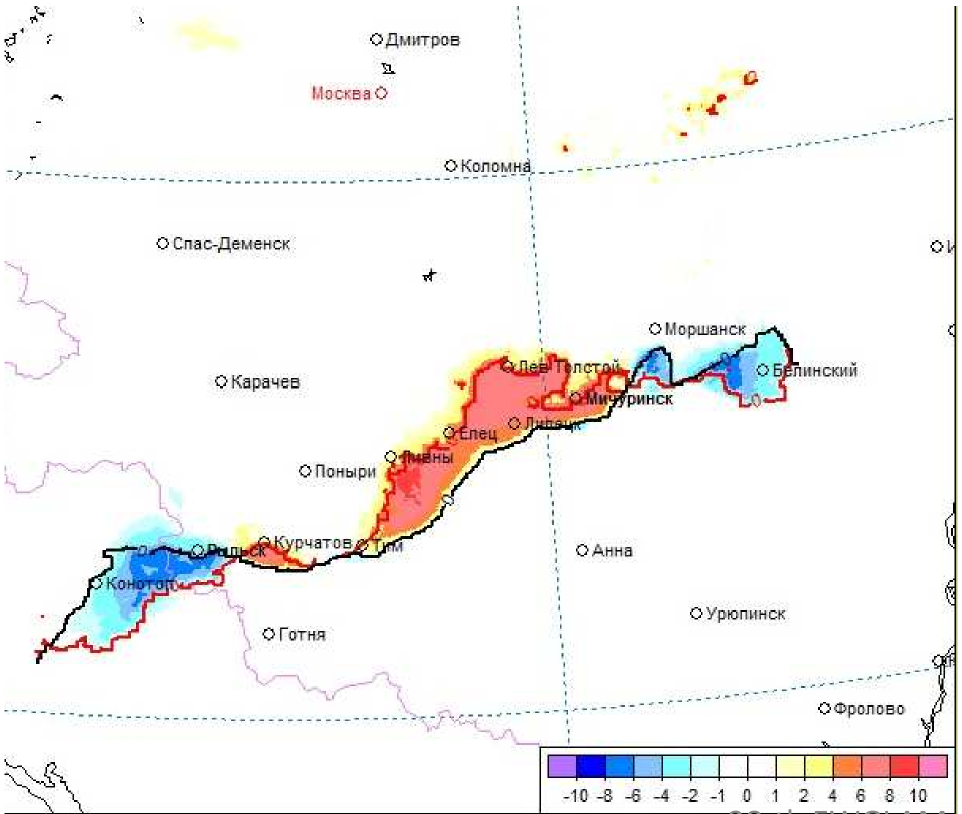


Lines – initial snow boundary disposition (**red** – SNOWE technology, **black** – operational run)

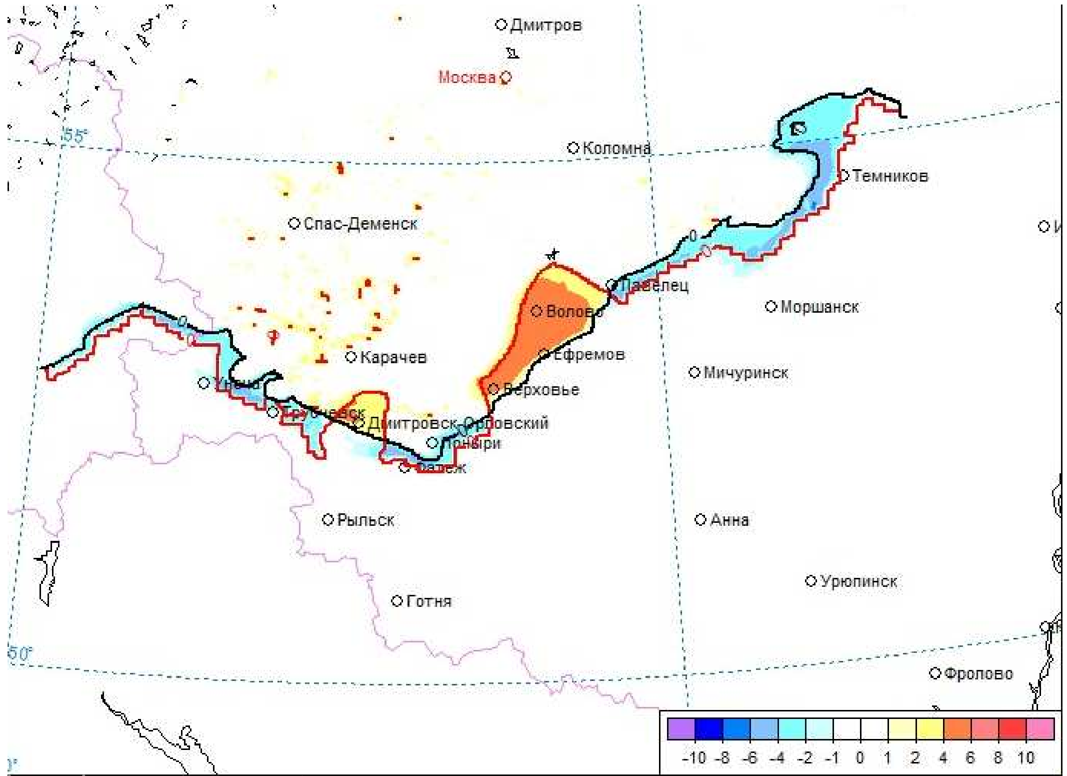
Difference in T2m forecasts (°C, SNOWE technology-operational run) of COSMO-Ru2. Start – 00 UTC 5 and 10 April 2013

Lines – forecasts of snow boundary disposition for 12 h:
black– operational run, **red** – SNOWE technology

5 April 2013



10 April 2013

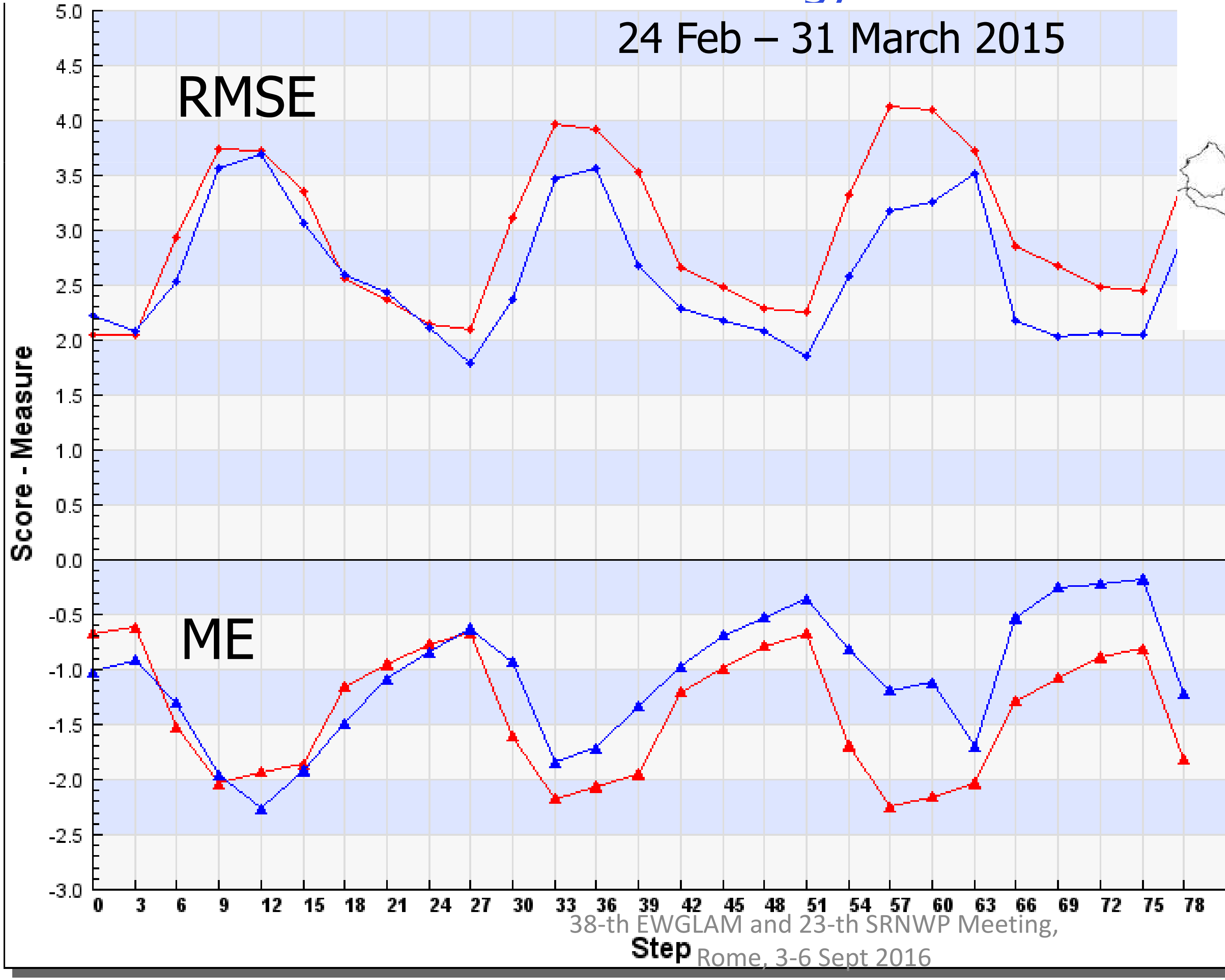


Estimates of T2m forecasts (°C) for stations close to the snow boundary zone

Station	10 April 2013, 12 UTC		
	Obs, t°C	Operational run, t°C/ Abs error, °C/ Accuracy%	SNOWE technology t°C/ Abs error,°C/ Accuracy%
Efremov	8,0	4,3 /3,7/0	6,6/1,4/100
Volovo	6,9	0,6/6,3/0	5,8/1,1/100
Verhov'e	7,0	1,2/5,8/0	6,0/1,0/100
Dmitrovsk-Orlovskiy	7,2	1,1/6,1/0	4,9/2,3/100
Temnikov	7,2	6,2/1,0/100	5,6/1,6/100
Unecha	7,1	6,6/0,5/100	5,4/1,7/100
Fatezh	8,1	5,6/2,5/100	6,7/1,4/100
Trubchevsk	7,0	7,0/0,0/100	5,5/1,5/100
Pavelets	7,8	3,8/4,0/0	0,8/7,0/0
	Mean a	3,3°/44%	2,1°/89%

Synop stations in domain of COSMO-Ru7

Conditional verification of T2m forecasts for operational run and SNOWE technology of COSMO-Ru7



Comparison of positive air temperatures

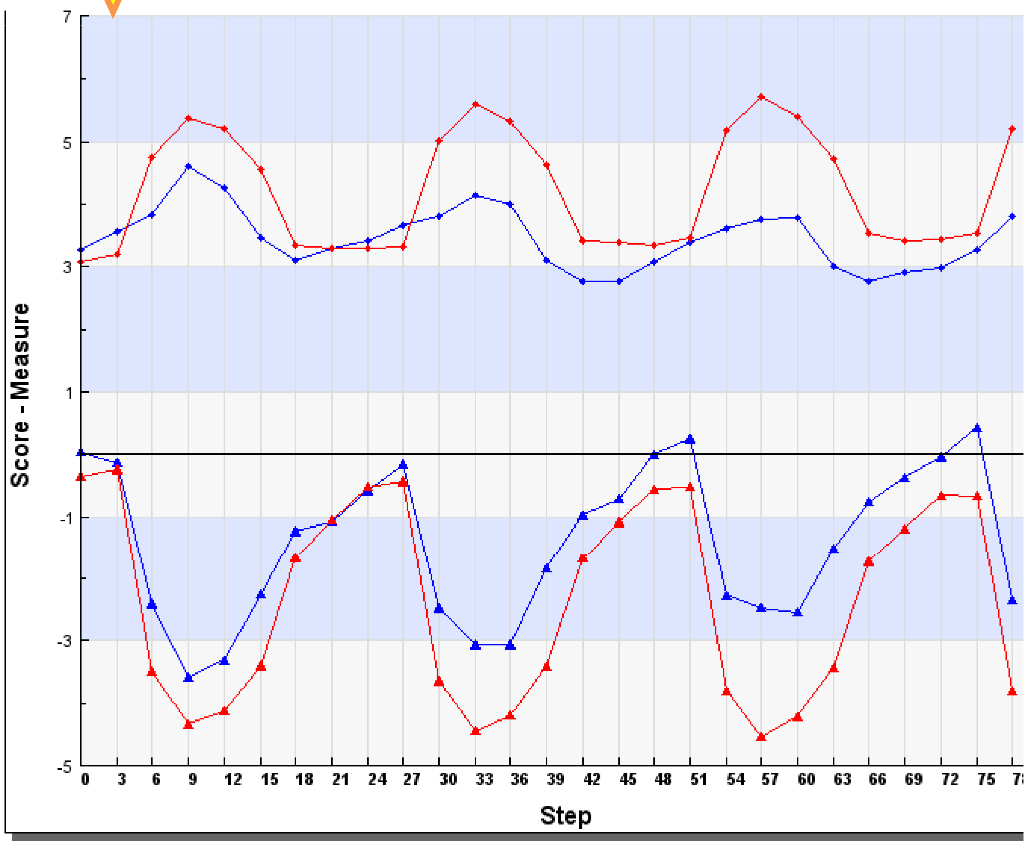
$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(f_i - o_i)^2}$$

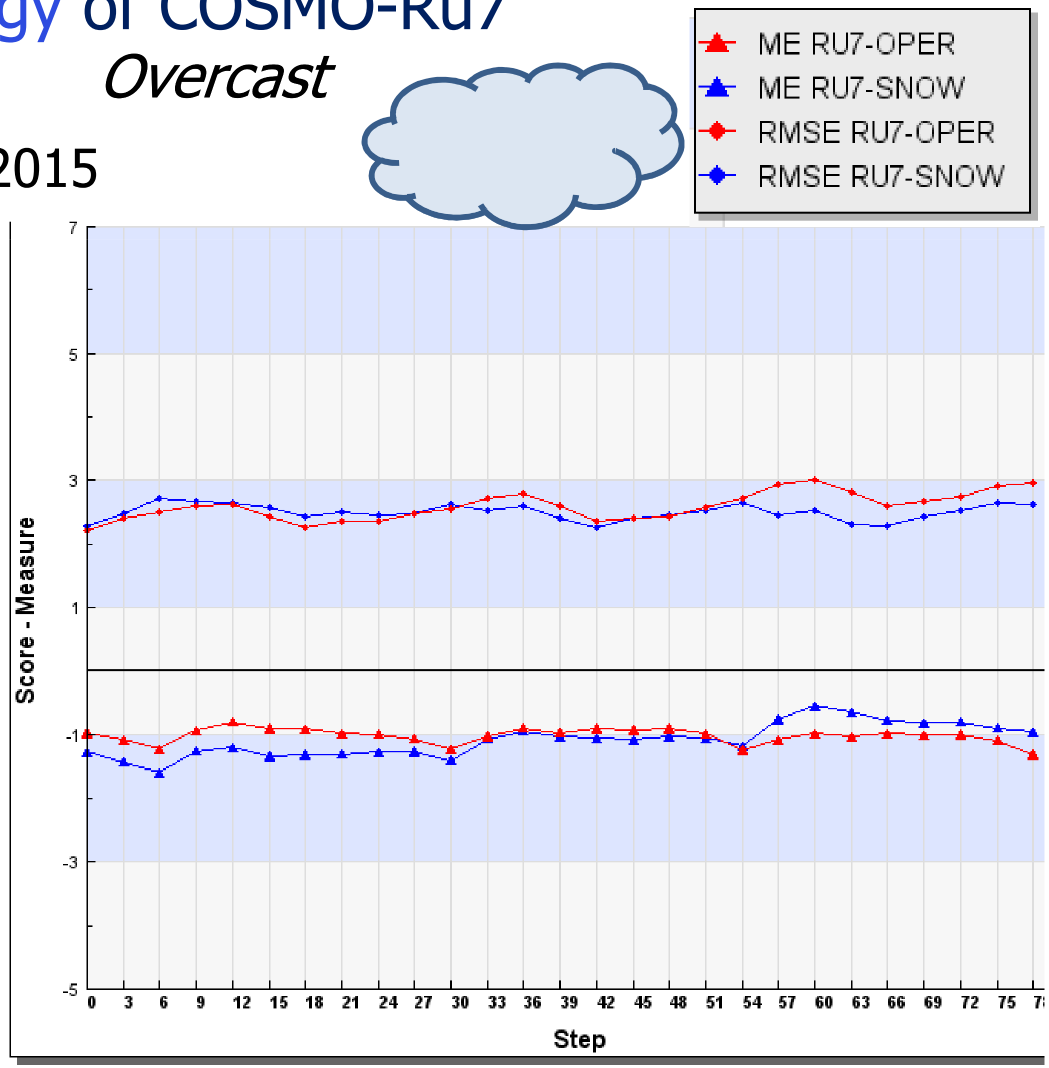
$$ME = \frac{1}{n}\sum_{i=1}^{n}(f_i - o_i)$$

Conditional verification of T2m forecasts for operational run and SNOWE technology of COSMO-Ru7

Clear sky *Overcast*

24 Feb – 31 March 2015





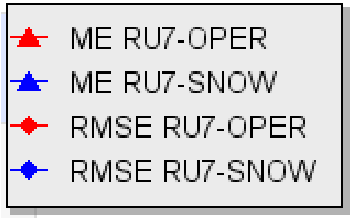
Condition: prognostic and observed total cloud cover≤ 25%

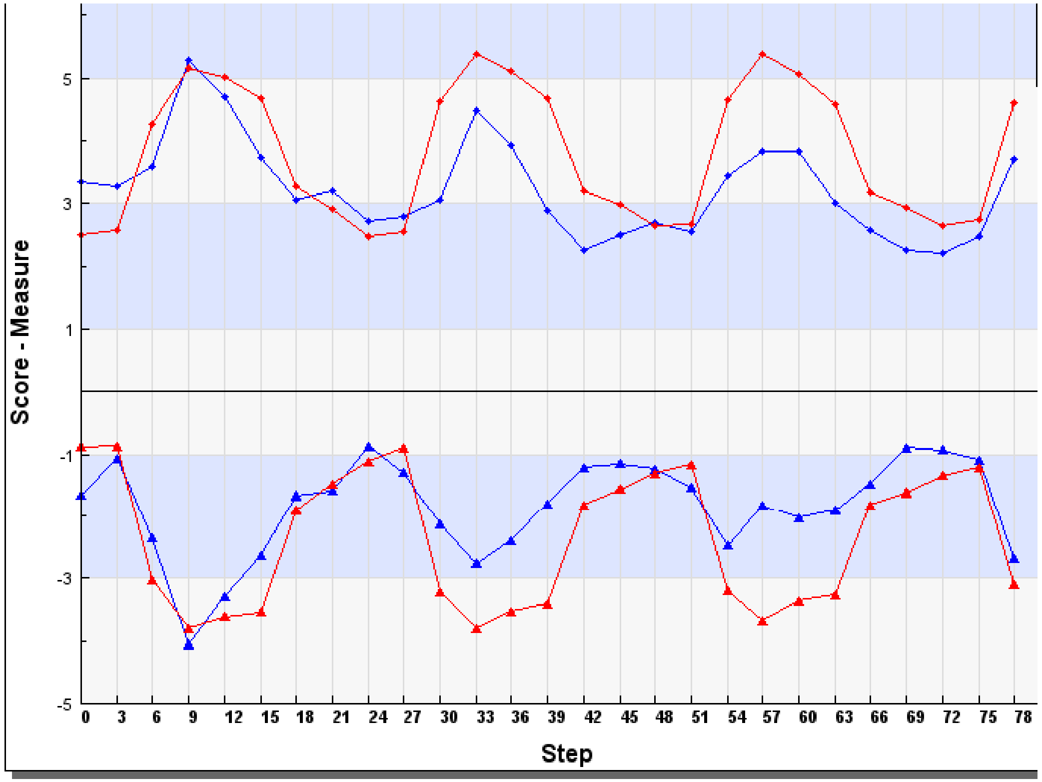
Condition: prognostic and observed total cloud cover ≥ 75%

Conditional verification of T2m forecasts for operational run and SNOWE technology of COSMO-Ru7

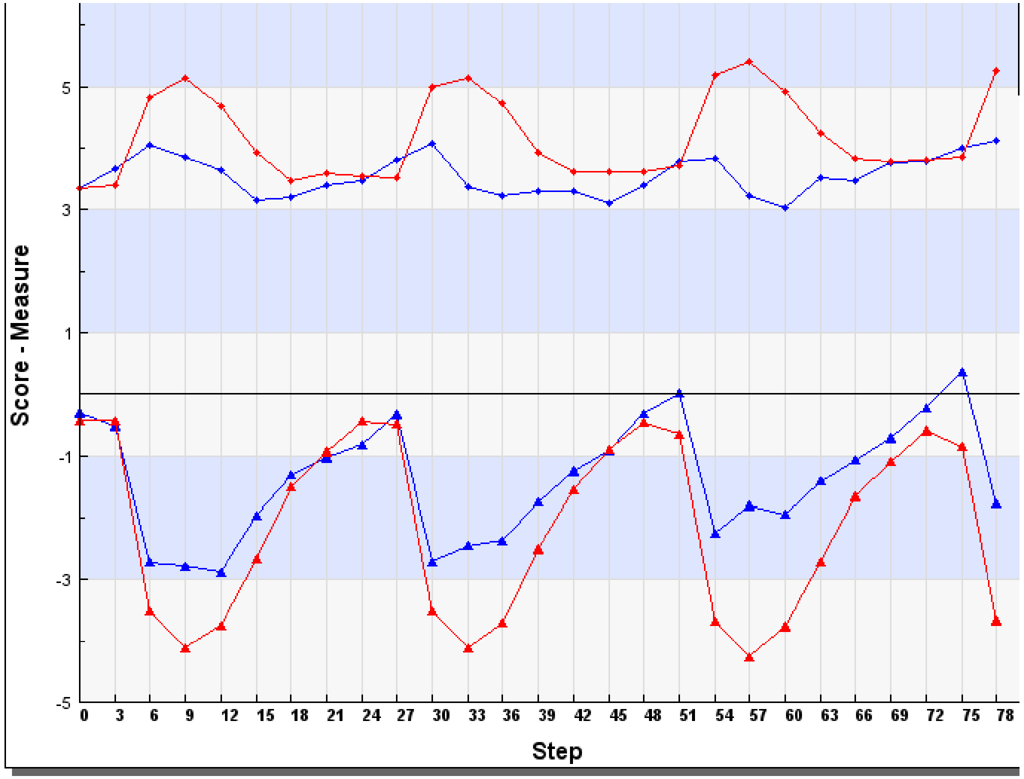
Clear sky conditions

24 Feb – 31 March 2015



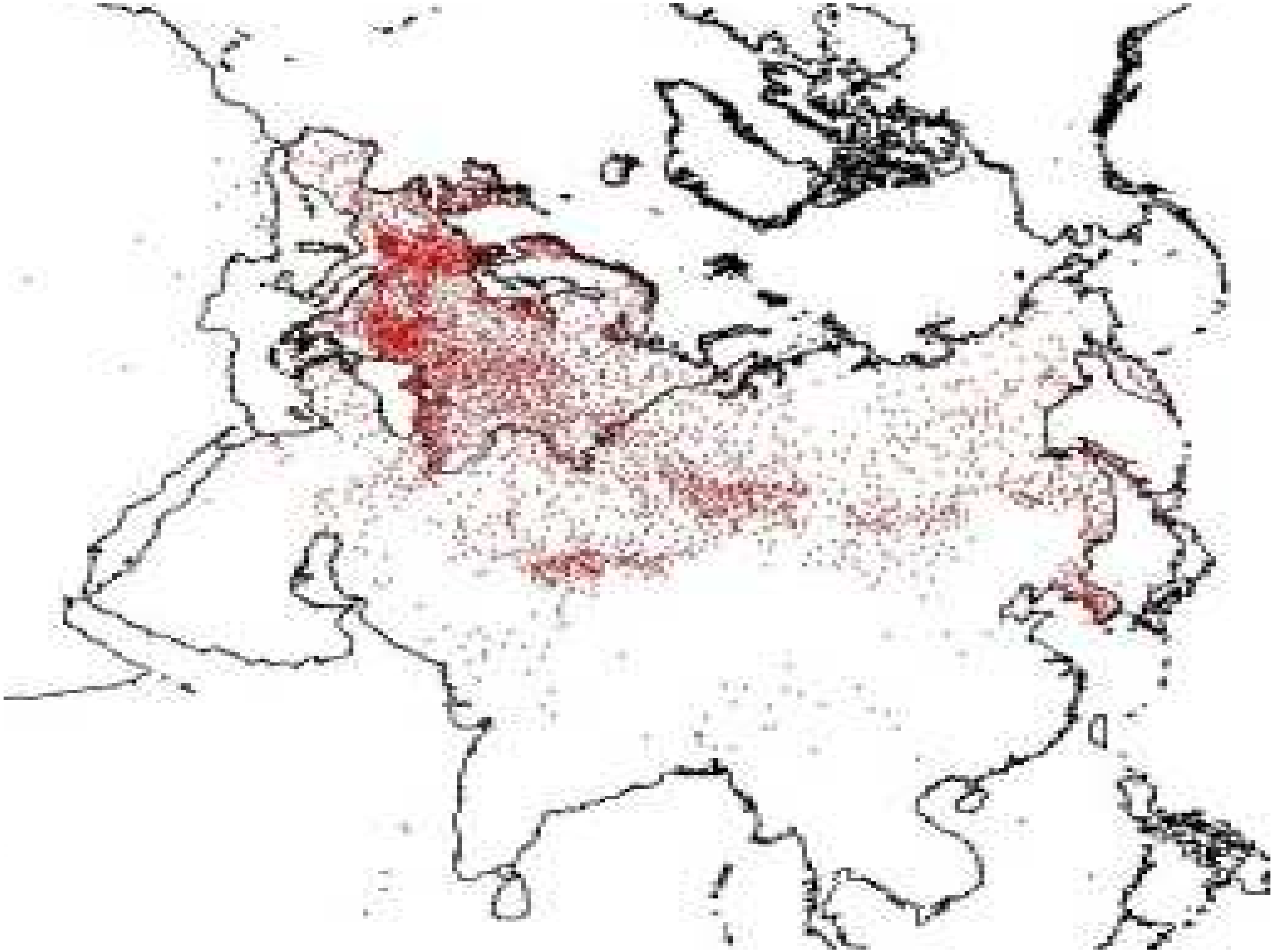


Condition: prognostic total cloud cover≤ 25% + positive observed air temperatures

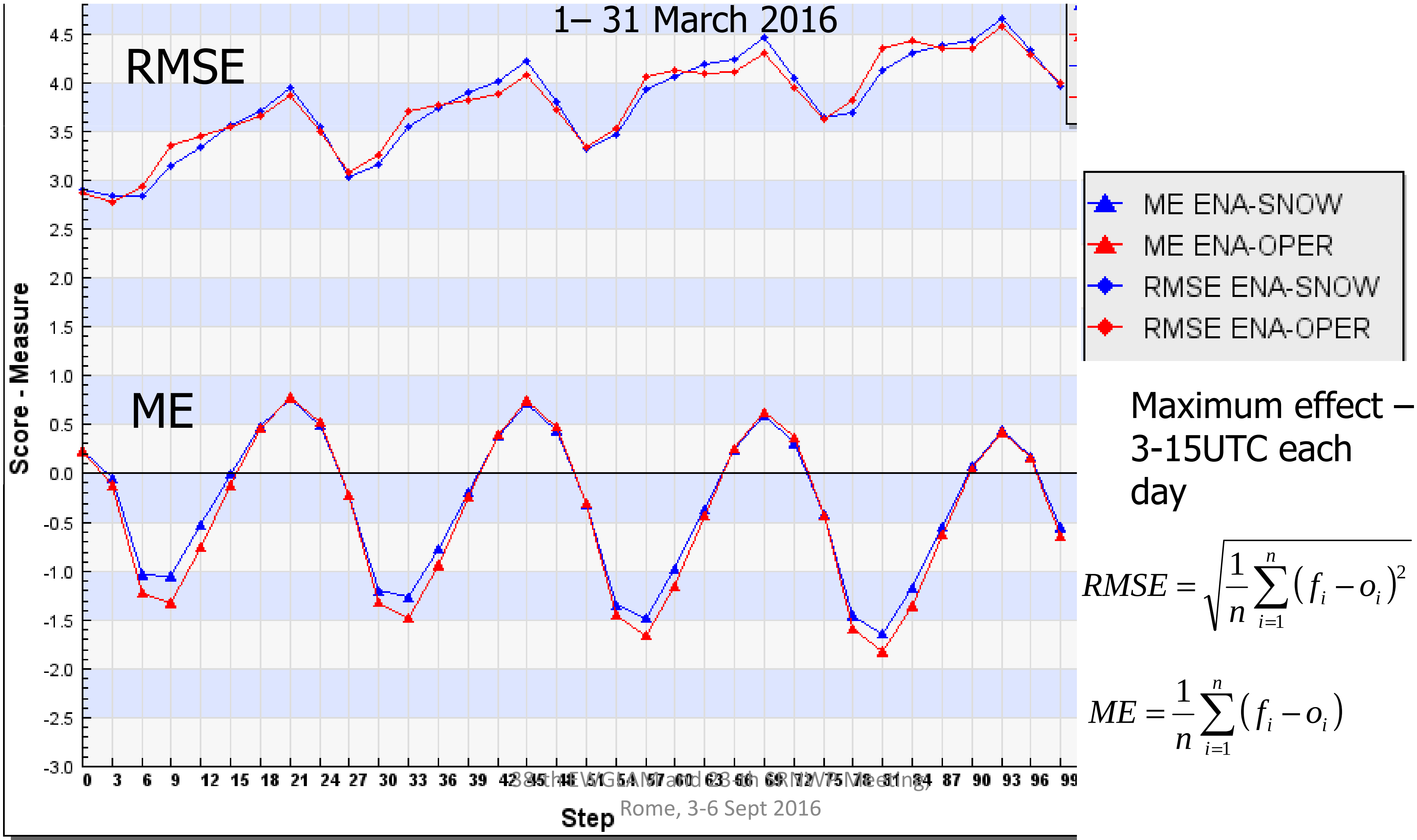


Condition: prognostic total cloud cover ≤ 25% + negative observed air temperatures

Synop stations in domain of COSMO-Ru-ENA



Conditional verification of T2m forecasts for operational run and SNOWE technology of COSMO-RuENA



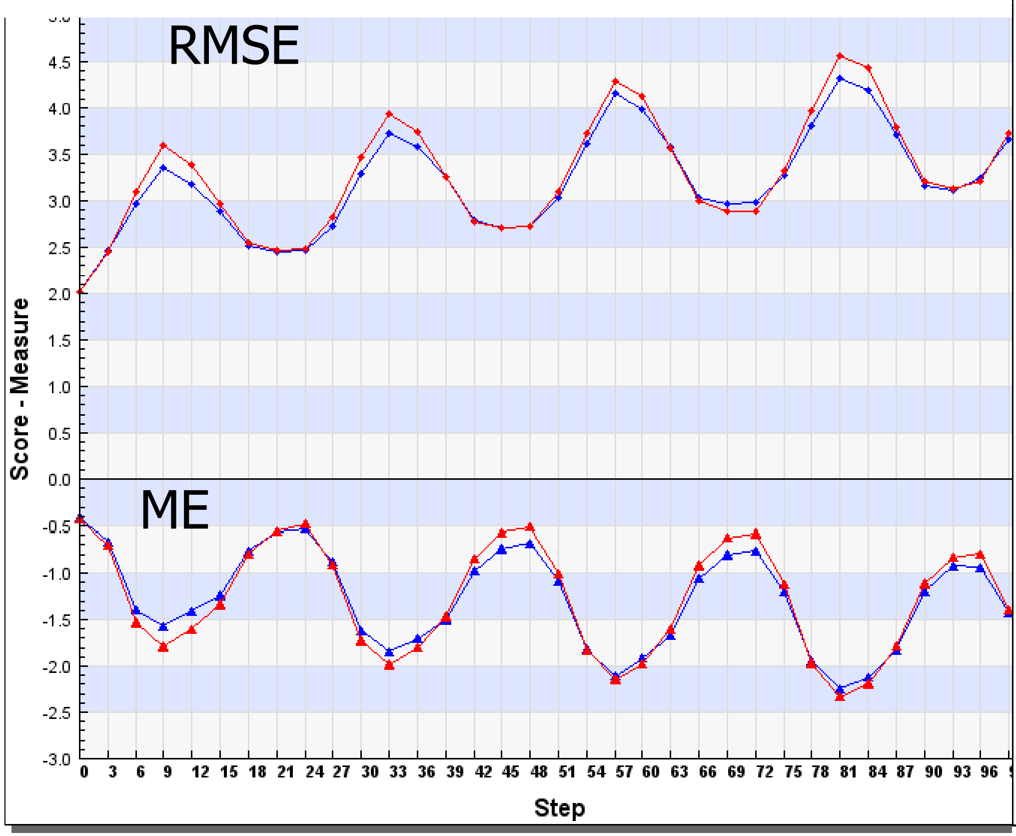
Maximum effect – 3-15UTC each day

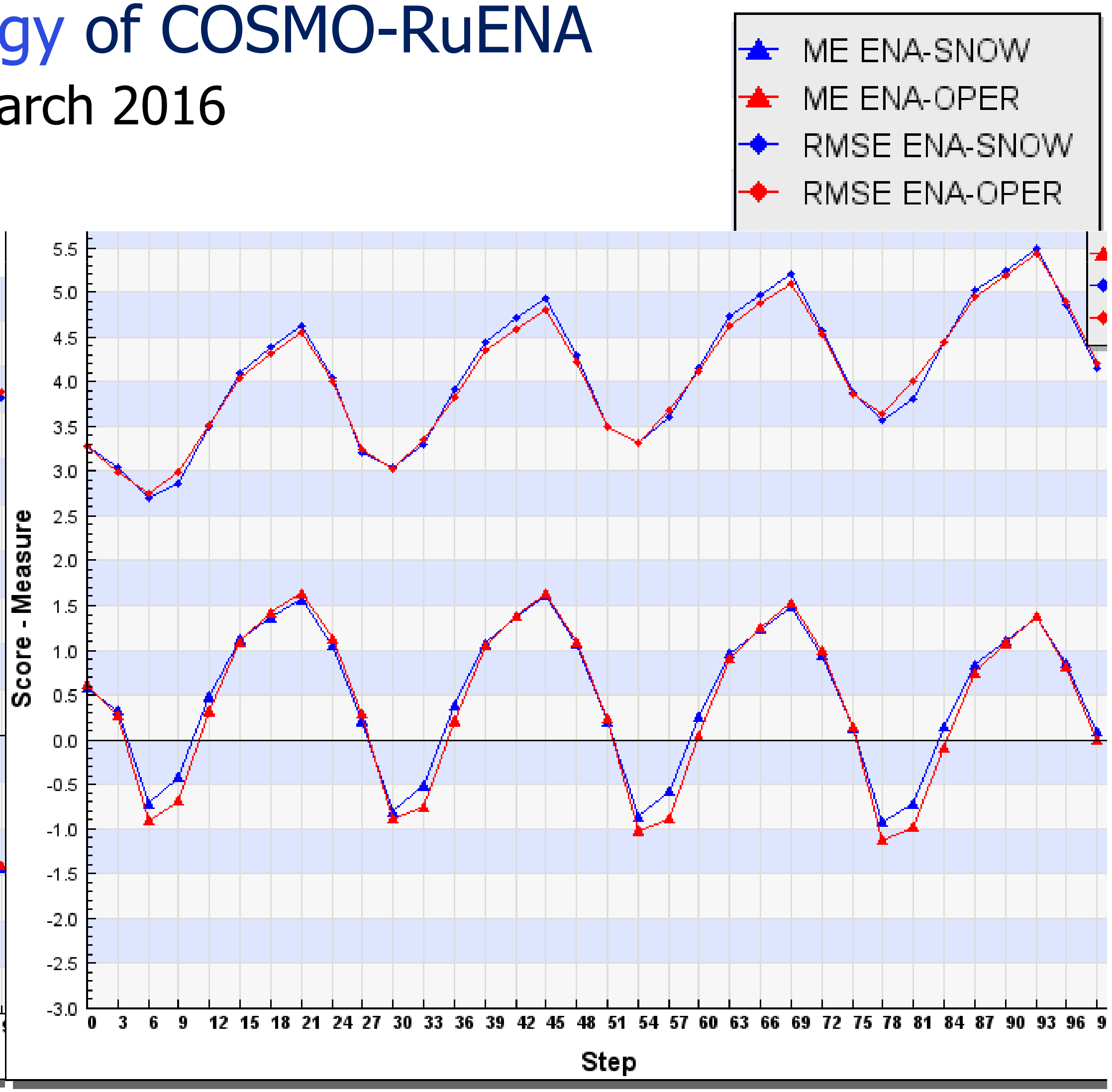
$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(f_i - o_i)^2}$$

$$ME = \frac{1}{n}\sum_{i=1}^{n}(f_i - o_i)$$

Conditional verification of T2m forecasts for operational run and SNOWE technology of COSMO-RuENA

1– 31 March 2016





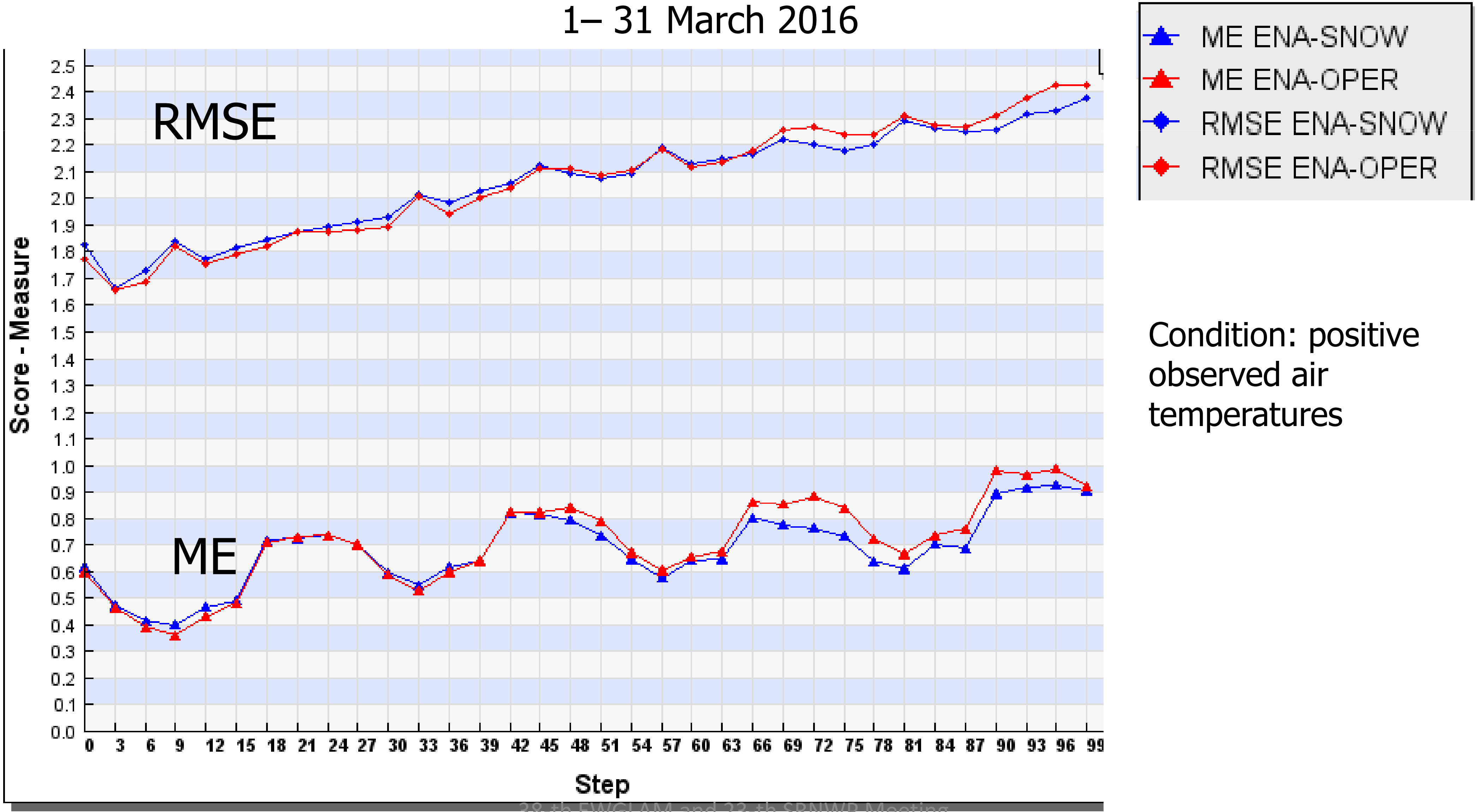
Comparison of positive air temperatures

Comparison of negative air temperatures

Total cloud cover didn't affect T2m forecasts during this period

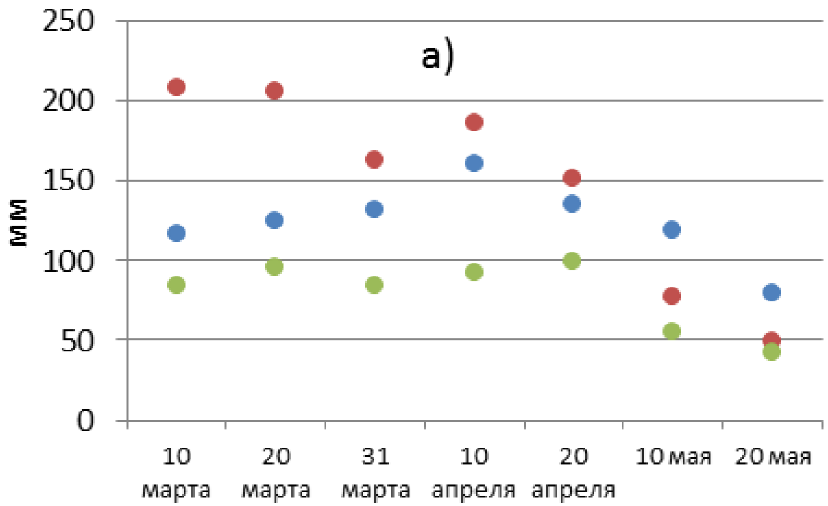
Conditional verification of WindSpeed10m forecasts for operational run and SNOWE technology of COSMO-RuENA

1– 31 March 2016



Condition: positive observed air temperatures

SWE for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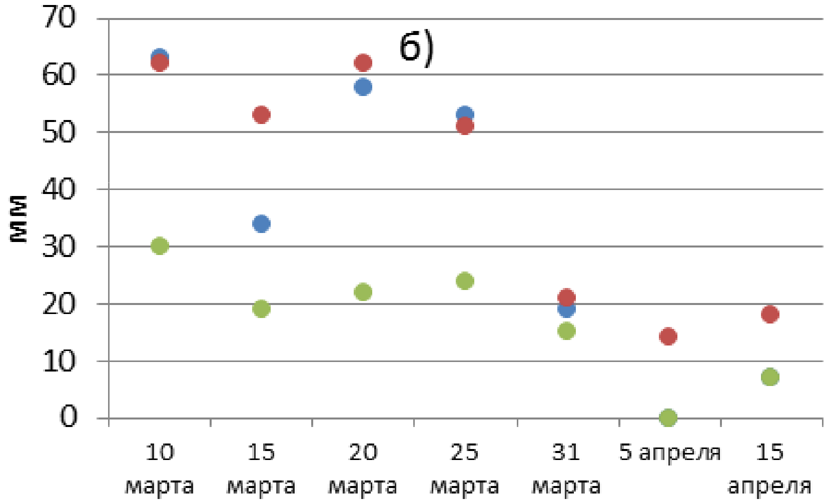
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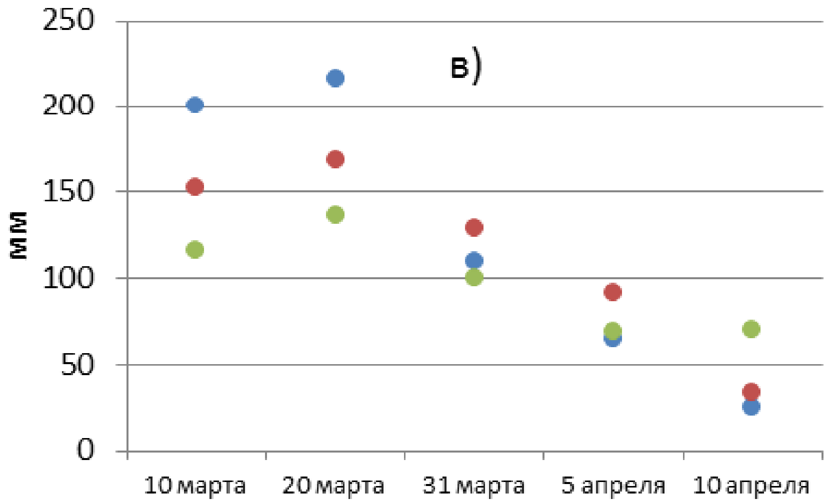
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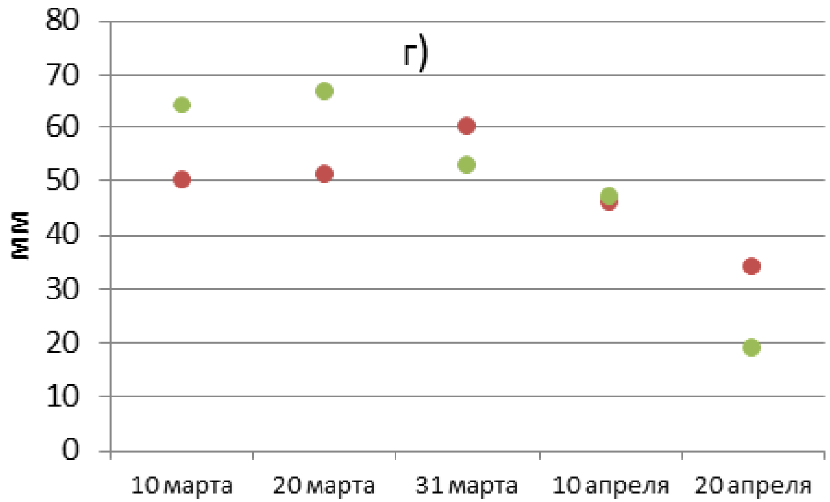
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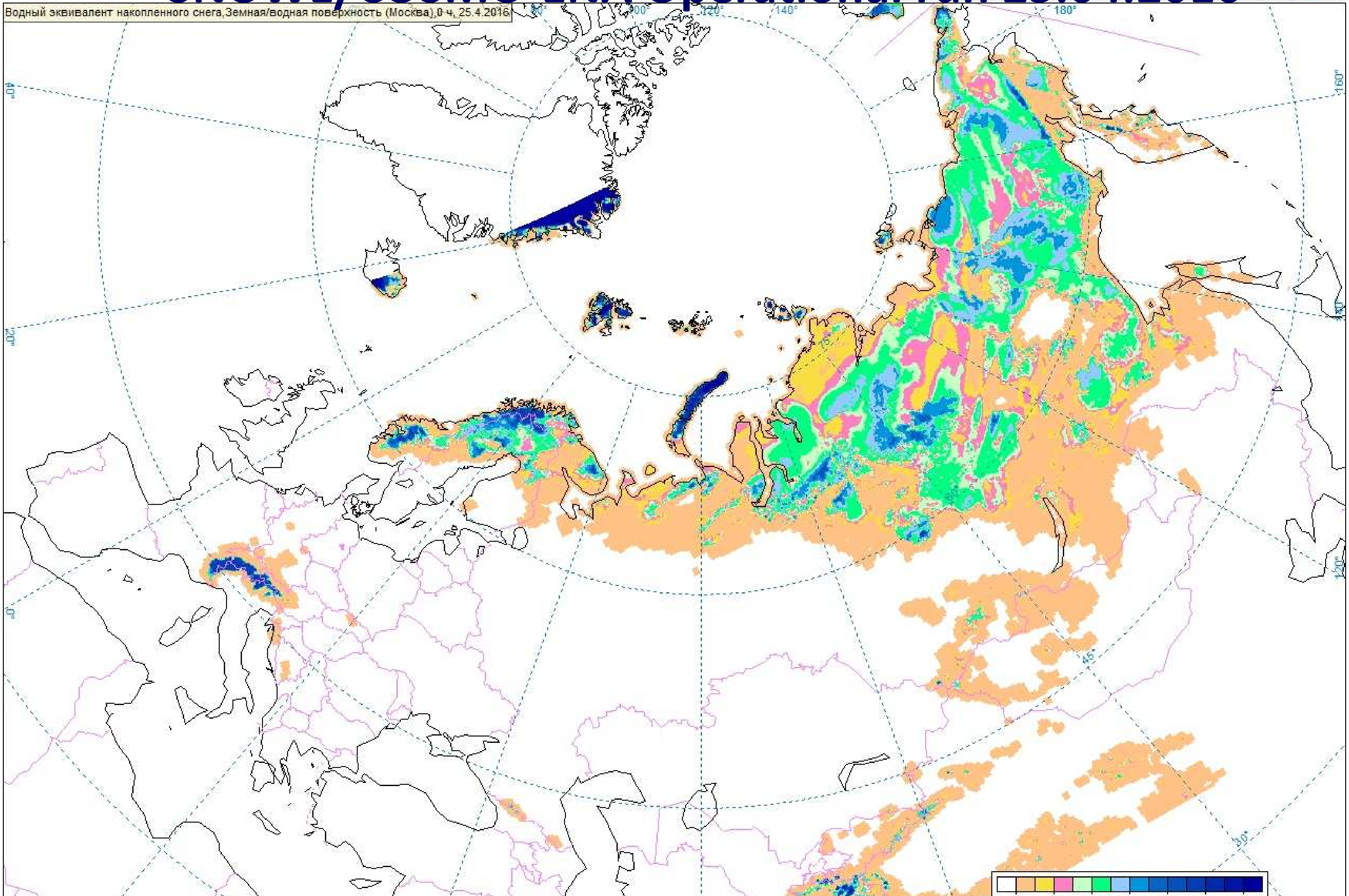
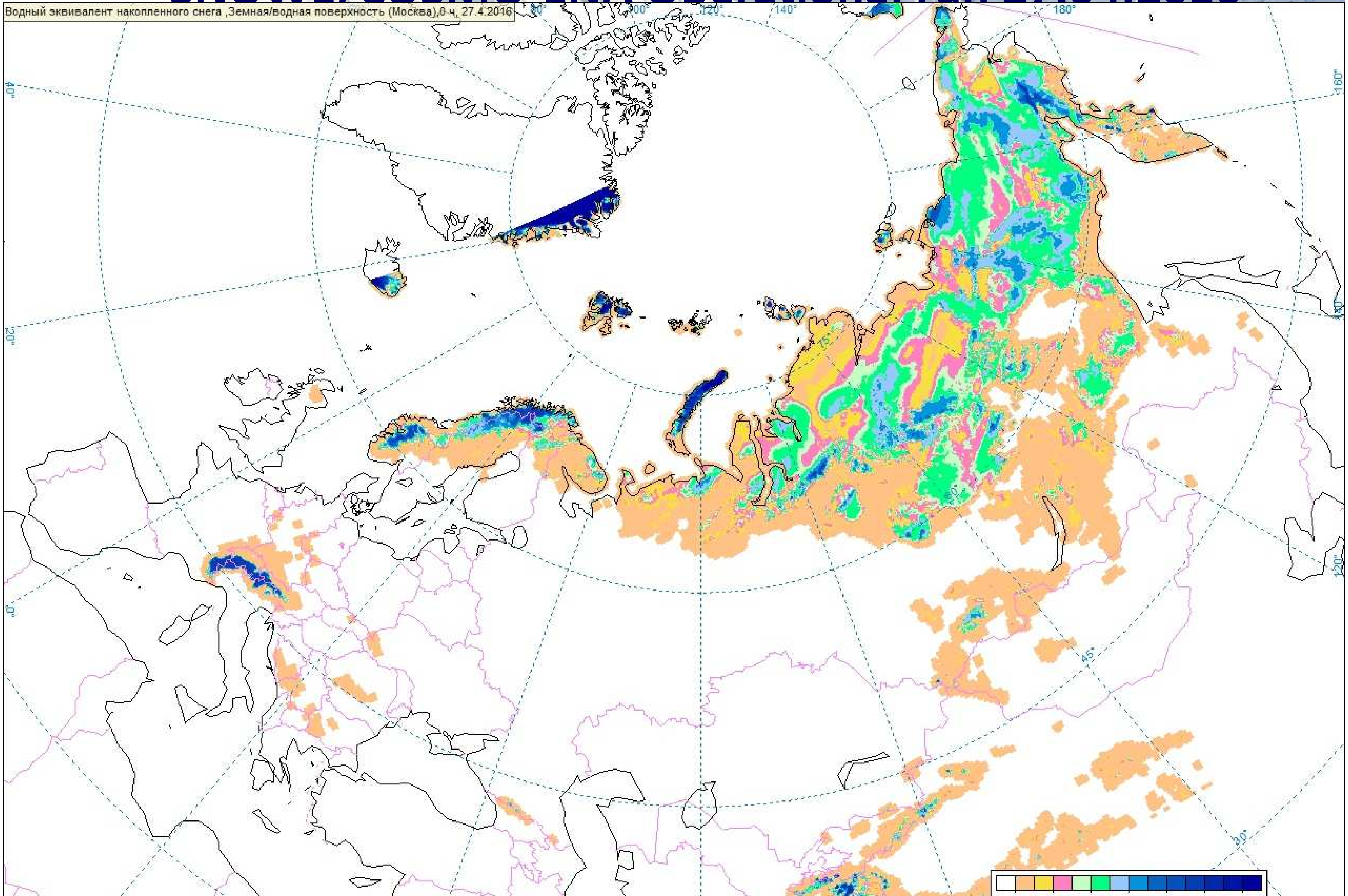
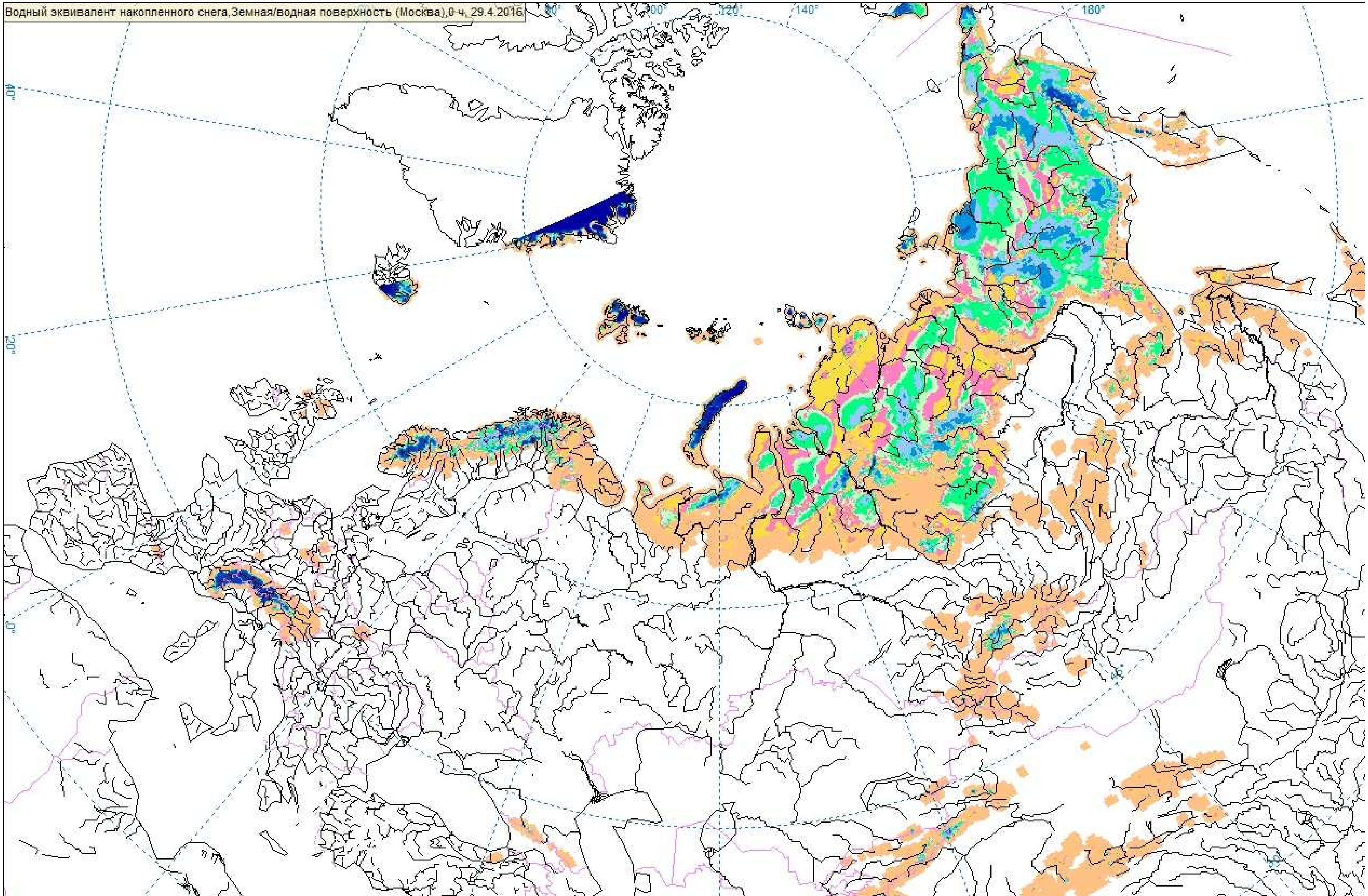
SNOWE/COSMO-ENA Operational run 25.04.2016



SNOWE/COSMO-ENA Operational run 27.04.2016



SNOWE/COSMO-ENA Operational run 29.04.2016



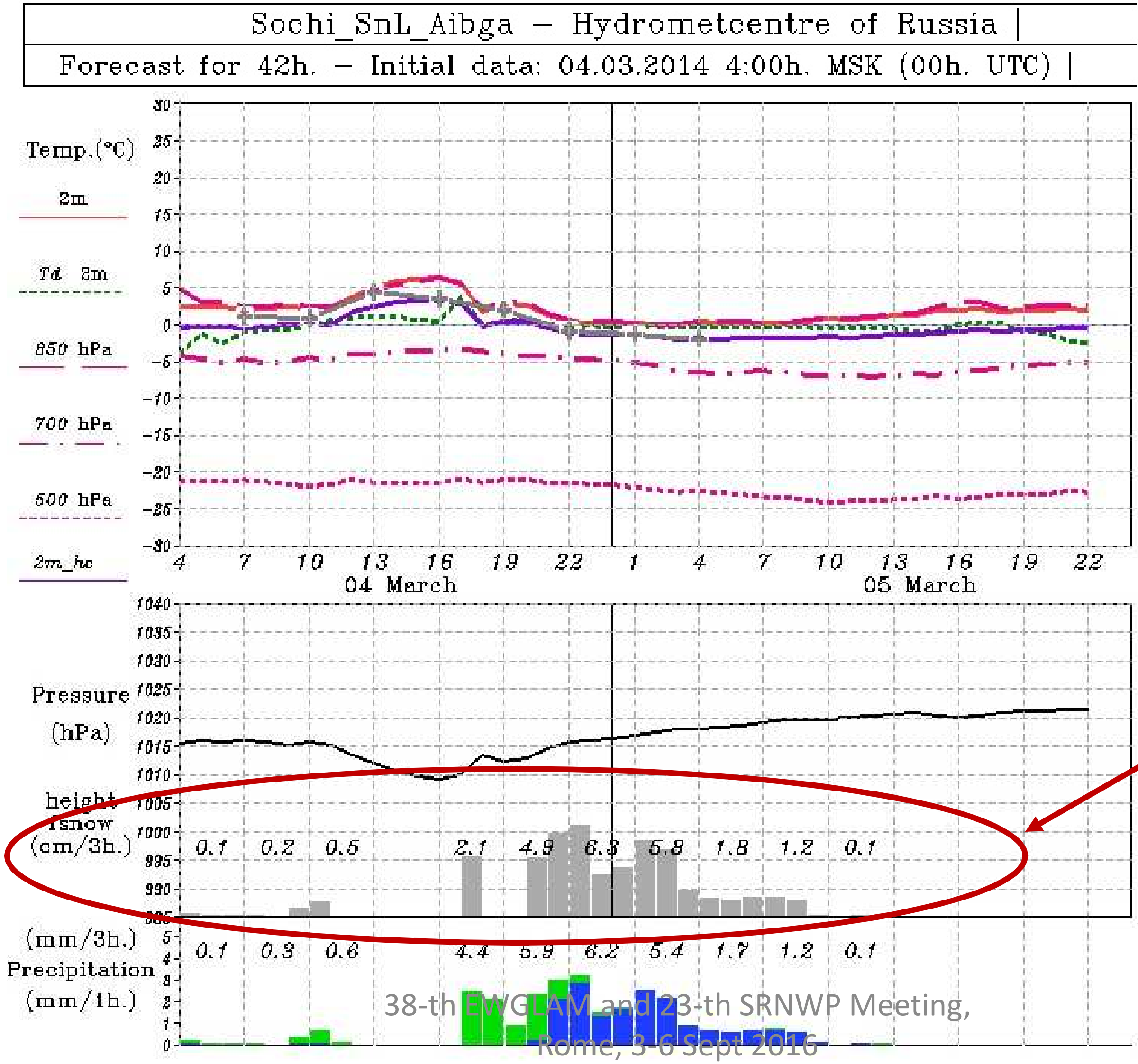
SMFE using

SMFE

Initial fields of snow cover characteristics for NWP mesoscale models

Maps of SWE for vast areas (as reference material)

Example of meteogramm for station Aibga obtained by using COSMO-Ru2. Start – 00 UTC 4 March 2014



1h sums of fresh snow, numbers at the top– its 3h sums

Conclusions

- **A Multi-layer 1-D Snow model SMFE is proposed. It daily produces SWE and of Snow density as operator of SYNOP measurements of Snow Depth, T2m, R2m, V10m, Prec. on all previous days of snow period**
- **2-D SNOWE technology for provide the Initial fields of SWE realized and coupled with COSMO-Ru with use the results of analysis of Snow Depth. Quasi-operational tests during 2013/14, 14/15, 15/16 showed the accuracy about 15- 25% of modelled SWE values**
- **SNOWE as corrector of initial fields of COSMO-Ru permitted to reduce RMSE of T2m forecasts near snow boundary in spring on 0,5-1,5°C and up to 7°C for several points**
- **SNOWE coupled with COSMO-Ru-ENA permits to obtain daily values of SWE for l Northern and Siberian areas of Russia and can begin the important source of information for flood calculations for the regions of rare hydrological network**

- Algorithm for fresh snow depth calculation based on precipitation sums and air temperature was tested and implemented in FieldExtra [URL: http://www.cosmo-model.org/content/support/software/default.htm] and COSMO-Ru

- A system of calculation of current snow water equivalent (SWE) fields is proposed and realized for the most part of Europe and of the Northern and Central Asia. This system produces the initial data of snow density and of SWE for COSMO-model runs (since the convenient direct observations of SWE measurements are not available for the regions mentioned above). This system is based on the modeling of snow state history during the whole cold period using only SYNOP measurements data: T2m, V10m, snow depth.
- The main block of this system is the 1-d multilayer model of snow “SNOWE”. SNOWE runs daily during cold period with 12/24h time steps and allows to obtain the SWE values for the points of SYNOP measurements. The value of snow density at each layer is determined considering snow falls, accumulation, melting and wind transport.
- For obtain the initial 2d fields of SWE and snow density, within COSMO-technology the first guess fields of named parameters (from DAS of DWD global modeling) are corrected by SNOWE results.
- The proposed technology after detailed tests was modified to use SNOWE for each COSMO model cell using the initial fields of T2m, V10m, snow (generated by DAS with good quality), instead of using data of measurements in the points.

Thank you for your attention!

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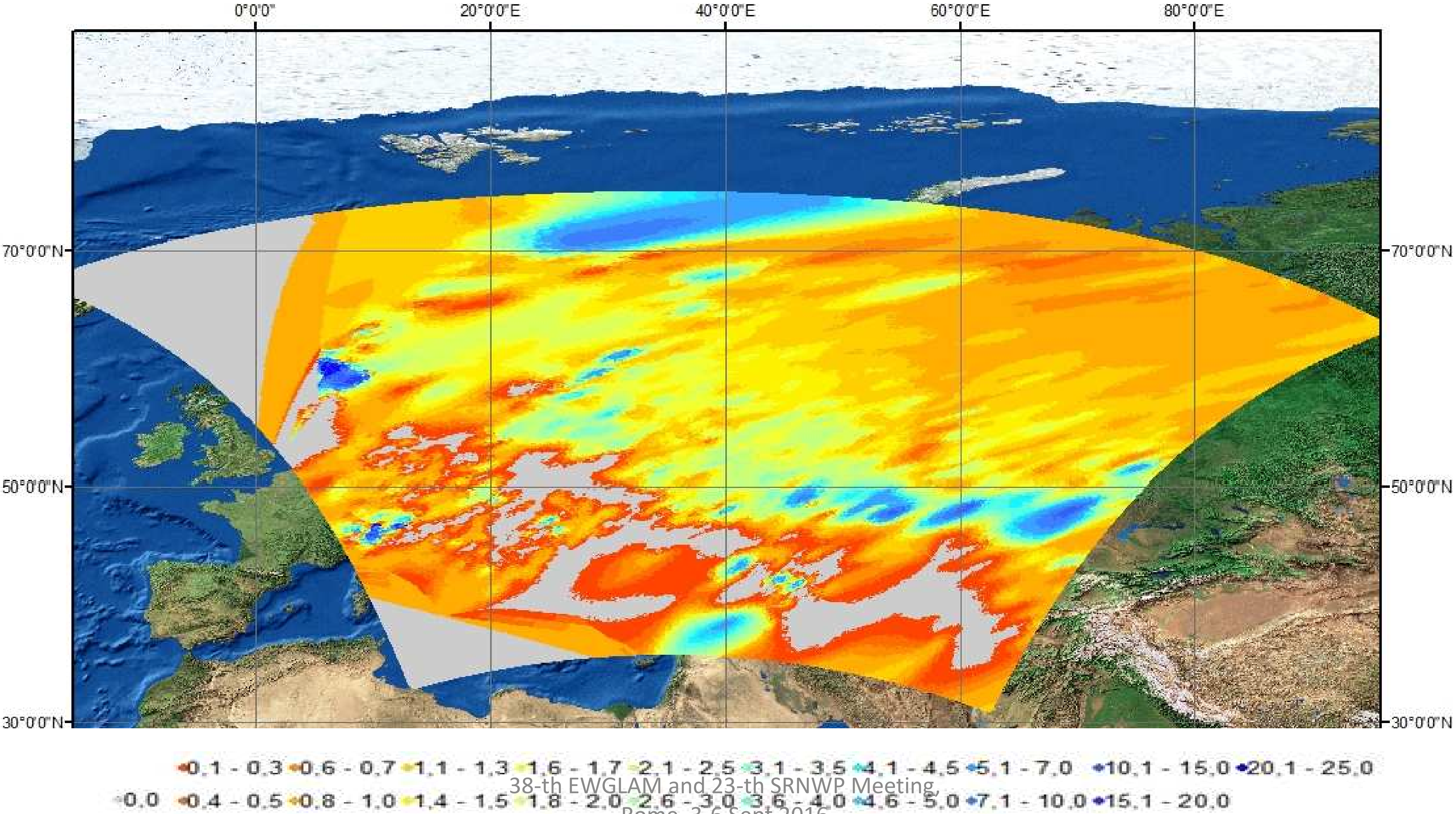
Interpolated discrepancies between COSMO-Ru7 initial SWE fields and SMFE calculations. 26 January 2015



Interpolated discrepancies between COSMO-Ru7 initial RHO fields and SMFE calculations. 26 January 2015