Initial fields of snow cover characteristics preparation for COSMO-Ru

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1 Introduction

Use of present-day mesoscale atmospheric models allows getting more and more realistic forecast information. High grid resolution (several km) of a mesoscale atmospheric model provides higher quality of weather elements forecasting in comparison with traditional use of global atmospheric models with grid sizes of about tens of km. It is well-known that success of mesoscale modeling strongly depends on accuracy of initial fields, as they either remain constant during the whole period or change much slower than atmospheric characteristics.

Initial fields for COSMO-model are prepared with the help of GME-model and standard meteorological observations assimilation. Initial fields have information about snow water equivalent and snow density. Snow depth measurements are determined by snowstake once a day and are included in the list of standard meteorological observations. In Russia snow density and snow water equivalent measurements are also carried out, yet they are held once in 5-10 days on several hydrological stations and can't be used in data assimilation cycles.

Technologies of obtaining of snow depth initial data with its possible following conversion into snow water equivalent in different meteorological centers could be varied, yet in these technologies, as a rule, station measurements of snow depth and satellite information about snow boundary are used ([3], [4], [5]).

Data assimilation systems are also created in Russian Hydrometeocenter ([2], [13]). However they are basically oriented on the use in global atmospheric models.

In weather forecast tasks and while doing applied researches it is necessary to have not only information about snow depth, but also about snow water equivalent. Up to date satellite information has discrepancies with land data ([10], [11]), so obtaining of more reliable values of snow water equivalent according to remote sensing data needs further development of satellite equipment.

In case of cloudy conditions satellite images with high spatial resolution received from synthetic aperture radar are increasingly used for surface characteristics determination ([7]). Yet currently such a data is provided only commercially.

Recently the only use of remote sensing data is insufficient for realistic representation of snow cover, especially for weather and climate forecast tasks and other applied researches. So the common method is to use satellite data as a snow 'mask' in snow models (for example, [6], [9]), which could work independently or be coupled with atmospheric models. Most of such snow models contain rather detailed description of processes in snow cover, as they are designed for solving of specific problems for small territories (for example, for avalanche forming forecasting). As a result - calculation of snow cover characteristics fields requires rather substantial time, that significantly obstruct the use of such models operationally for weather forecast creation.

In winter period different services (utilities, road services, railway services, power station operation, planning of winter competition holding, emergency forecasting and so on) are required adequate information about snow cover characteristics. During snow melting snow equivalent data and information about snow boundary are needed for runoff calculations, prevention of emergencies and agricultural work carrying out.

All the above mentioned determined the need of development of a method for snow cover characteristics initial fields formation for atmospheric models, based on standard meteorological observations at stations in SYNOP-code and satellite data with high resolution. In this article the example of its successful application with the use of mesoscale model COSMO-Ru is given.

2 Materials and Methods

Preparation of initial fields of snow cover characteristics for mesoscale model (the authors made a research taking mesoscale model COSMO-Ru ([12], [14]) with 2.2 km resolution as an example) needs standard observational data done on HMS net and transmitted in SYNOP-code. Scheme of the algorithm for initial fields of snow density and snow water equivalent and surface temperature (covered or not by snow, measured on HMS) construction is shown on figure 1.

Snow density and snow water equivalent values are calculated with the help of the developed snow model SMFE (Snow Model Finite Element) during the whole snow period for stations, where measurements are done, with their further interpolation on regular grid cells using technologies of combination with first guess fields and satellite data.

SMFE algorithm is represented in paper [8]. It should be noted that the model is oriented only on the use of standard observations from HMS. Snow density and snow water equivalent calculation is done with discrecity equal to snow depth measurements carrying out, i.e. once a day for the Russian territory. Snow density is calculated due to equations from [15], which link it with Young's module.

When fresh snow falling its density is calculated in SMFE according to [1] in dependence on air temperature.

The following snow processes are taken into account in SMFE: snow depth acceleration due to dry/wet snow falling and snow depth reduction due to slump, as well as snow melting, percolation and melted water runoff, the process of 'snow blowing' and evaporation/condensation from snow surface.

Remote sensing data are used for snow boundary accurate definition. When stations are densely situated, composite satellite images with 4-km resolution located on NOAA site are employed, which are processed and moved to COSMO-Ru grid cells with the help of special program (authors - U. Alfereov, V. Kopeykin). The field obtained in this way which reflects the space distribution of snow cover is used for correction of snow cover characteristics fields.

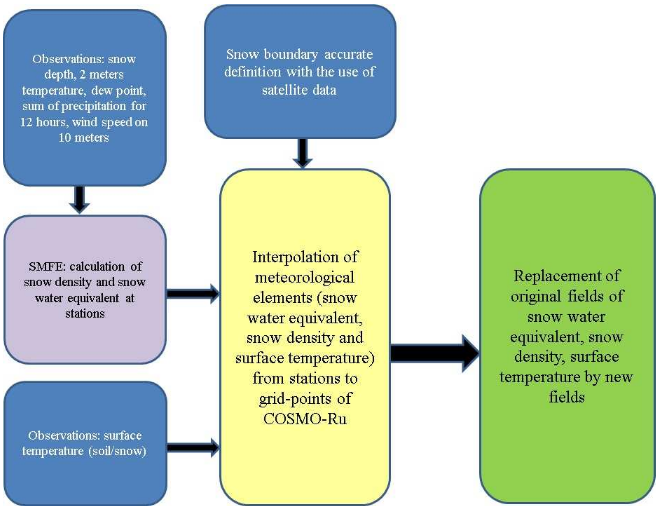

Figure 1: Scheme of the algorithm for initial fields of snow cover characteristics construction (COSMO-Ru as an example model).

In a region with a complicated relief (North-Caucasian region) initial fields replacement requires using composite satellite images with 250-meters special resolution obtained as a result of MODIS data processing, as the use of composite satellite image with 4-km resolution results in gross errors while defining snow cover presence, especially in valleys.

The algorithm based on the use of first guess fields is applied for atmospheric model initial fields construction. Original (operational) fields of snow cover characteristics from GME, which are modified with optimal interpolation method, with the combination of snow cover values from SMFE are used as such fields. Field correction can be done with the use of coefficients, obtained after comparison between operational and modified fields.

Original values of snow cover characteristics (snow density and snow water equivalent) and surface temperature are replaced by modified values in file containing initial fields for mesoscale model. Forecasts with original and modified initial fields of snow cover characteristics were calculated for some days during snow period on the European part of Russia in 2012-2013 with the help of mesoscale model COSMO-Ru. The model was integrated with initial fields prepared for 00 UTC. Experiments were done for two computational areas - Central and North-Caucasian regions.

3 Results and Discussion

Completed numerical experiments show that setting of realistic initial fields of snow cover characteristics lead to forecast quality improvement. It is connected with the fact that snow cover takes part in heat and moisture exchange with the overlying air and influences the heat budget forming. The example of snow water equivalent initial field for mesoscale model COSMO-Ru for Central region territory is shown on fig.2: original (operational) and modified (experiment) versions.

Snow water equivalent values for several stations at 10 April 2013 according to observational data, COSMO-Ru forecasts on 12 hours based on original and modified data are shown in Table 1. As can be seen from this table and fig 2, there is an improvement of initial fields and forecasts of the model COSMO-Ru. Thus, there is an improvement in snow water equivalent forecasting for stations situated on the north of the computational area (Bologoe, Privolzhsk, Buy) when modifying initial data of snow cover characteristics. Snow boundary is in good agreement with observational data. For example, at station Voznesenskoe snow cover was present according to observations, the same result is observed for experiment unlike operational model variant. The similar result is obtained for station Verhov'e, where snow cover has already melted, what was predicted by COSMO-Ru with the use of modified initial data.

For some stations (Spas-Demensk, Karachev) modifications in initial data don't influence forecasting of snow water equivalent, what may be explained as that: in case of presence of snow cover with snow water equivalent value averaged for the region original and modified initial fields may differ from each other too little. Maximum differences between original and modified fields are indicated for maximum values of snow water equivalent (i.e. in the north) as well as on snow boundary.

Feedback from changes in initial fields of snow cover characteristics is observed when calculating forecasts of other meteorological elements. Some changes in low cloudiness were distinguished. Differences between surface albedo forecasts are observed in the region of snow boundary. It's well-known that snow boundary is the zone of maximum contrasts of meteorological elements. As presence/absence of snow cover defines the contribution to surface heat budget, maximum differences between operational version and experiment are observed in 2 meters temperature fields. Let's study stations which were situated in the zone of snow boundary lying.

According to Table 2, there is an improvement of 2 meters temperature forecasts at stations Efremov, Volovo, Verhov'e both for day and nocturnal hours. On stations Unecha and Temnikov changes in initial fields of snow cover characteristics lead to degradation of 2 meters temperature forecasts, yet it is connected with approach to parameterization of 2 meters temperature used in mesoscale COSMO-mode: when snow is present, overlying temperature could be equal to values close to $0^{o}C$. It should be noted that in modified initial fields these stations occurred to be covered with snow, what led to wrong calculations of 2 meters temperature by the model. The derived result indicates that it's necessary to make changes in computational algorithm of 2 meters temperature in COSMO-model.

At station Fatezh there is also some deterioration of forecast of 2 meters temperature. It is connected with the fact that values of snow cover characteristics are used for the previous day for initial data preparation because of snow cover measurements at stations in Russia which are done once a day (at 03 or 06 UTC). At station Fatezh on 9th April snow cover was observed, and on 10th April it has already melted. By virtue of such an observational discrecity some discrepancies in 2 meters calculation for several stations in the zone of snow boundary can be found in case of modified fields of snow cover characteristics using.

Station	Observations	Operational variant	Experiment	Absolute error I	Absolute error II
Bologoe	154	200	139	46	15
Privolzhsk	150	171	167	21	17
Buy	137	196	128	59	9
Kolomna	51	106	68	55	17
Mozhaysk	127	138	110	11	17
Plavsk	86	49	36	37	50
Spas-Demensk	114	106	106	8	8
Suhinichi	102	91	94	11	8
Belgorka	96	118	107	22	11
Karachev	48	37	37	11	11
Poniry	46	15	44	31	2
Voznesenskoe	62	0	32	62	30
Verhov'e	0	16	0	16	0
Mean absolute error				30	15

Table 1: Snow water equivalent (mm) on 10^{th} April 2013 according to observational data, COSMO-Ru forecasts on 12 hours with original and modified initial data. Note. I - difference between observations and operational variant, II - difference between observations and experiment.

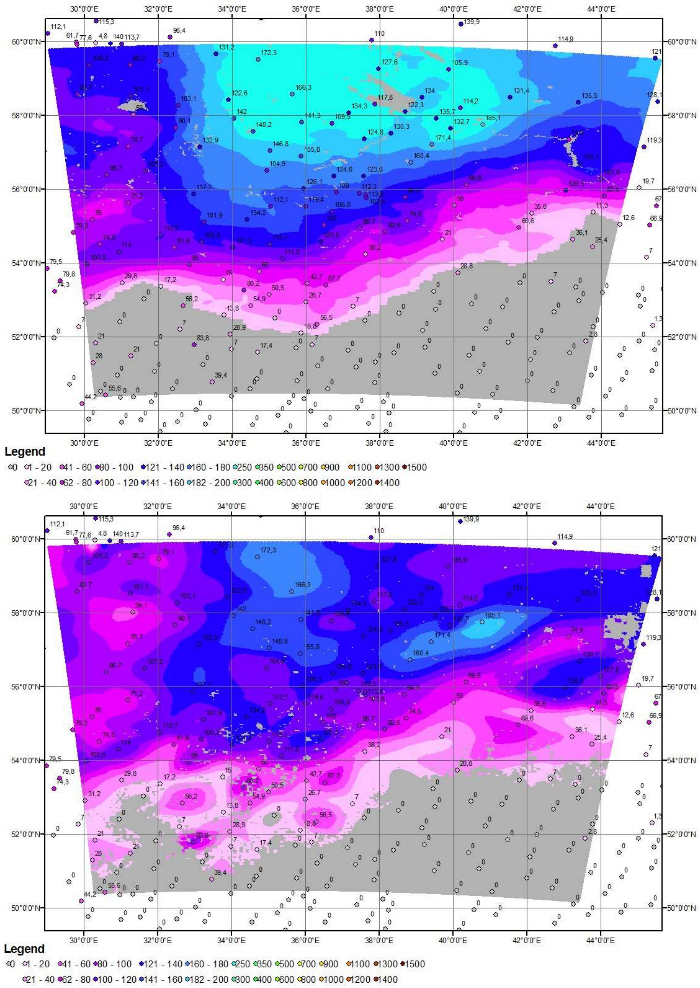

Figure 2: Initial field of snow water equivalent (mm) prepared for mesoscale model COSMO-Ru for Central region: operational variant (top) and experiment (bottom). 00 UTC 10 April 2013.

Station	10 April 2013, 12 UTC			11 April 2013, 00 UTC		
	Observations	Operational variant	Experiment	Observations	Operational variant	Experiment
Efremov	8.0	4.3	6.6	-0.4	-0.5	-0.9
Volovo	6.9	0.6	5.7	-1.1	-3.6	-2.1
Verhov'e	7.0	1.2	6.0	0.8	-1.2	-0.2
Unecha	7.2	6.2	0.6	0.2	0.7	0.0
Fatezh	7.1	6.6	1.3	1.0	0.4	-0.3
Temnikov	8.1	5.6	1.1	-1.5	-3.0	-4.9

Table 2: 2 meters temperature (^{o}C) at day (12 hours) and nocturnal (00 hours) hours according to observations and forecasts on 12 and 24 hours of mesoscale model COSMO-Ru (operational variant and experiment).

Example of snow water equivalent forecast on 12 hours obtained by mesoscale model COSMO-Ru with original and modified initial data for North-Caucasian region, is shown on fig.3, from which is followed that the proposed method makes it possible to get more realistic ant detailed initial field of snow water equivalent and its forecast, respectfully.

The use of modified initial fields in mesoscale model COSMO-Ru could improve 2-meters temperature in valleys. The example for station Teberda is shown in Table 3. According to this table, forecast values obtained during the experiment are in good accordance with station observations, while operational model version using doesn't provide realistic forecasting of diurnal variation of 2 meters temperature.

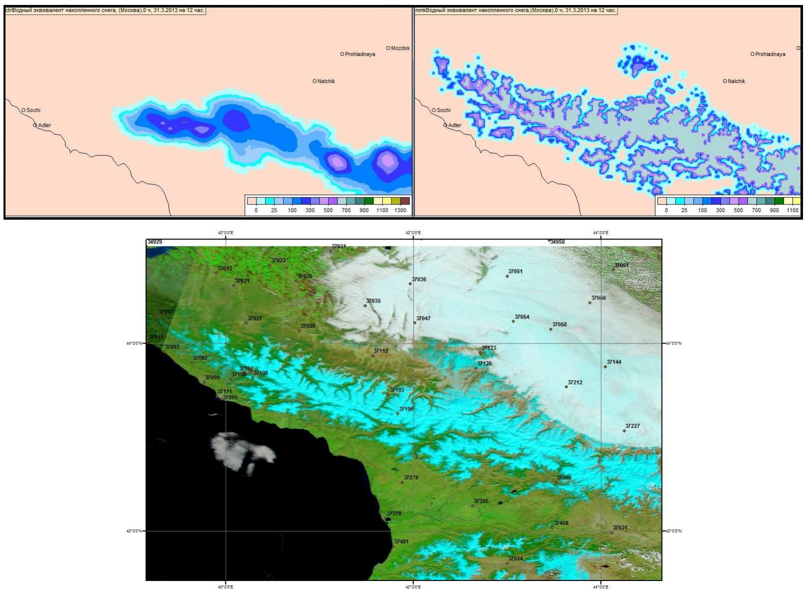

Figure 3: Forecast of snow water equivalent (mm) 12 hours by mesoscale model COSMO-Ru: operational variant (left) and experiment (right). Start - 00 UTC 31 March 2013. Fragment of computational area - the North Caucasus. Bottom - MODIS data with 250-meters resolution for 30 March 2013, snow cover is shown in blue.

Hour	Observations	Operational variant	Experiment
3	3.8	2.3	2.8
6	11.0	3.2	5.9
9	17.0	4.0	10.5
12	16.5	6.3	12.6
15	11.3	5.2	8.8
18	6.9	4.1	5.5
21	6.1	4.5	5.1
0	5.1	5.3	5.7

Table 3: 2 meters temperature (^oC) at station Teberda according to observational data and forecasts of mesoscale model COSMO-Ru (operational variant and experiment). 31 March 2013.

4 Conclusion

So, during the following research it was determined that:

- the proposed method makes it possible to prepare realistic fields of snow cover characteristics;
- changing of initial fields of snow cover characteristics leads to their further more corrective forecast by the mesoscale model;
- the most sensitive to changes in initial fields of surface characteristics is the zone of snow boundary lying;
- changes in initial fields of snow cover characteristics influence on changes in forecast of other meteorological elements (2 meters temperature, low cloudiness, surface albedo).

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