HIRLAM in Sodankylä and at Vatnajökull

Laura Rontu
FMI

1 Introduction

In HIRLAM, new developments aimed at solution of the so called "Nordic temperature problem", have recently taken place. A surface scheme ("newsnow"), accounting for properties of canopy and snow cover, has been suggested by Gollvik and Samuelsson (2006). To validate the new developments, detailed model-observation comparisons are needed. The unique combination of regular soil, snow, surface, boundary layer and upper air observations at the FMI Arctic Research Centre in Sodankylä (26.37 E, 67.63 N, for available data see http://litdb.fmi.fi) offers a good possibility for such comparison. A preliminary analysis of HIRLAM results, compared with Sodankylä observations of January 2007, was presented in a recent NetFAM Toulouse workshop (http://netfam.fmi.fi/CBL07).

Sodankylä represents subarctic boreal forest environment. Very different conditions prevail in Iceland, over Europe's largest glacier Vatnajökull. Results of an extensive observation campaign during the melting period 1996 (Oerlemans et al., 1999), were now utilized for HIRLAM validation (more results to be shown in the ICAM-2007 conference, see http://www.cnrm.meteo.fr/ICAM2007).

Here we report about the main findings of the comparison of observed and simulated surface energy balance in Sodankylä and Vatnajökull, relevant for HIRLAM development and further studies. For the comparisons, validation tools have been developed. Suggestions for improvement of the operational mast verification at http://fminwp.fmi.fi arose during the study.

2 Observations

In Sodankylä, the following types of regular observations are available for model validation studies (see also Atlaskin and Kangas (2006)):

Upper-air PTU-soundings are made twice a day (00 UTC and 12 UTC). The profiles are registered with a temporal resolution of two seconds, corresponding approximately to ten metre vertical resolution.

Automatic weather station provides elements of SYNOP observation with temporal resolution of one minute. Cloud observation is based on interpretation of ceilometer data.

Components of surface radiation balance: down- and upwelling longwave and shortwave (global and diffuse) radiation are measured in a tower at an altitude of 18 m and stored with temporal resolution of one minute.

Profiles of wind, temperature and humidity are obtained from several levels of the 50 m height micrometeorological mast. They are available for 10 min time interval.

Turbulent fluxes of momentum and heat (sensible and latent) fluxes are measured in the micrometerological mast. The main measurement level of the sonic anemometers is at 22 m and data is available as 30-minute averages.

Soil and snow temperatures and the soil heat fluxes are observed in more than 10 levels in soil and snowpack, between -1 m and the level of snow cover (in January 2007, snow depth in Sodankylä was about half a meter). Measurements are available every 10 minutes.

In the present study, all but the PTU sounding data have been used for model-observation comparison.

A detailed description of the Vatnajökull observation campaign is given by (Oerlemans et al., 1999). The aim of the campaign was to provide meteorologically and glaciologically relevant data over the whole melting period. Available data cover the summer 1996 from the last week of May to the first week of September. The measurements have been widely analysed with statistical methods and by case studies, see e.g. the special number of Boun.Lay.Met., 92, (1). However, the data set has evidently not yet been used for validation and development of NWP models.

The data comprise automatic and manual SYNOP observations, radiation and turbulence measurements from 15 automatic weather stations. Most of the stations included a five to ten-meter high mast, that allowed to measure near-surface temperature, humidity and wind profiles plus estimation of the turbulent fluxes. In addition, tethereed balloons were used and upper air soundings made at some stations. Precipitation and ablation measurements completed the glaciologically relevant information. In the present study, data from three AWS from the coast to top along Breidamerkurjökull, a southern outlet glacier of Vatnajökull, were compared with the HIRLAM simulation results.

3 HIRLAM experiments

Setup of the HIRLAM experiments is summarised in Table 1. In both Sodankylä and Vatnajökull cases, nested experiments were performed so that the lateral boundaries and upper air analysis were provided by the host model analyses. In Vatnajökull, double nesting was used with the outer boundaries taken from ERA40 analyses (Uppala et al., 2005). These were downscaled by a mesoscale HIRLAM data-assimilation experiment, run in an Arctic domain (Fig. 1). The finest-resolution HIRLAM experiment used analyses of the arctic domain HIRLAM as lateral boundaries.

A new feature of both experiments was the application of only the surface analysis in the finest resolution experiment (option NOUA). Regular SYNOP observations were included into the surface analysis, which uses the two-metre temperature and humidity for soil temperature and moisture assimilation, and snow and sea surface temperature (SST) observations for analysis of snow cover and SST (the latter is kept constant during the forecast cycles). It was considered that the finest scale experiments would not improve the upper air analysis, when using only the sparse conventional observations. E.g. in Iceland, only the Keflavik sounding far west from Vatnajökull would be available. We did not detect any evident problems in coupling own surface analysis with the external upper air analysis. However, more detailed analysis of this aspect is needed in order to understand the sensitivity of the results to the coupling.

4 Results and findings

An example of near-surface temperatures in Sodankylä 11-15 January, 2007, shows that the "newsnow" (a version based on HIRLAM v.7.1) is able to produce two-metre temperatures, which are close to observed even in the case of strong surface inversion (Fig. 2(a)). However, two-metre temperature practically coincides with the lowest model level temperature, which is too cold (Fig. 2(b)). Consequently, the vertical temperature gradient is incorrect (Fig. 2(c)). A closer look to the temperatures used in the "newsnow" scheme (not shown) reveals that the two-metre temperature also coincides with the snow temperature at the forest floor and with the canopy and canopy snow temperatures. The

Table 1: HIRLAM experiment setup

	Sodankylä	**Vatnajökull**
HIRLAM versions	7.1beta1 and "newsnow"	7.1beta2 and "newsnow"
resolution	11km/60L	2.8km/60L
domain	Northern Europe	Iceland
period	January 2007	June 1996
initial analysis	NOUA	NOUA
boundaries	HIRLAM RCR 22km/40L (an)	HIRLAM beta2 17km/40L (an)
validation	standard + Sodankylä	standard + Vatnajökull
comments	newsnow alpha3 and 7.1	double nesting: ERA40-17km-2.8km

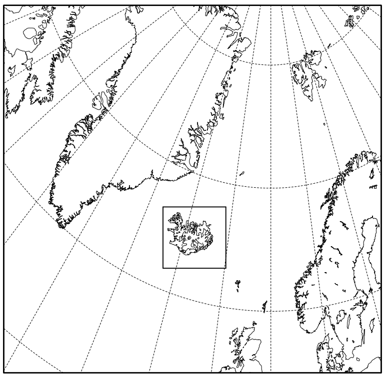


Figure 1: Integration domains of the Vatnajökull experiments: whole area - arctic domain (17km/40L), small box - fine resolution experiments (2.8km/60L)

two-metre temperature and canopy air temperature are identical by definition. In reality, the observed temperature is indeed quite constant from the snow surface to the tree top level, but in the surface inversion cases there is a gradient up to ten degrees or more between the tree top and mast top levels (i.e, between 10 and 50 metres). This discrepancy might be related to the properties of the simulated forest, as the open land snow and surface temperatures are colder in the model. In Sodankylä the real subarctic boreal scotch pine forest, covering the whole grid-box area, is sparse. Thus there is pleanty of space between the trees at all elevations from the surface to the tree tops.

At Vatnajökull, there is no forest or vegetation at all. In HIRLAM, the environment is characterized as bare land of subtype ice. Fig. 3 shows an example of the evolution of the observed and simulated energy balance (sum of net radiation, sensible and latent heat fluxes, that should be balanced by the soil heat flux) during three five-day periods in June 1996 at a station till middle of Breidamerkurjökull slope (station I6, elevation 715 a.m.s.l.). The more the summer advances, the worse becomes the simulation compared to the observation: the model energy balance is at low level compared with the observations, and the diurnal cycle is damped. It turns out that the main reason of this strange behaviour is in the radiation balance, more exactly, in the too large reflected shortwave radiation (not

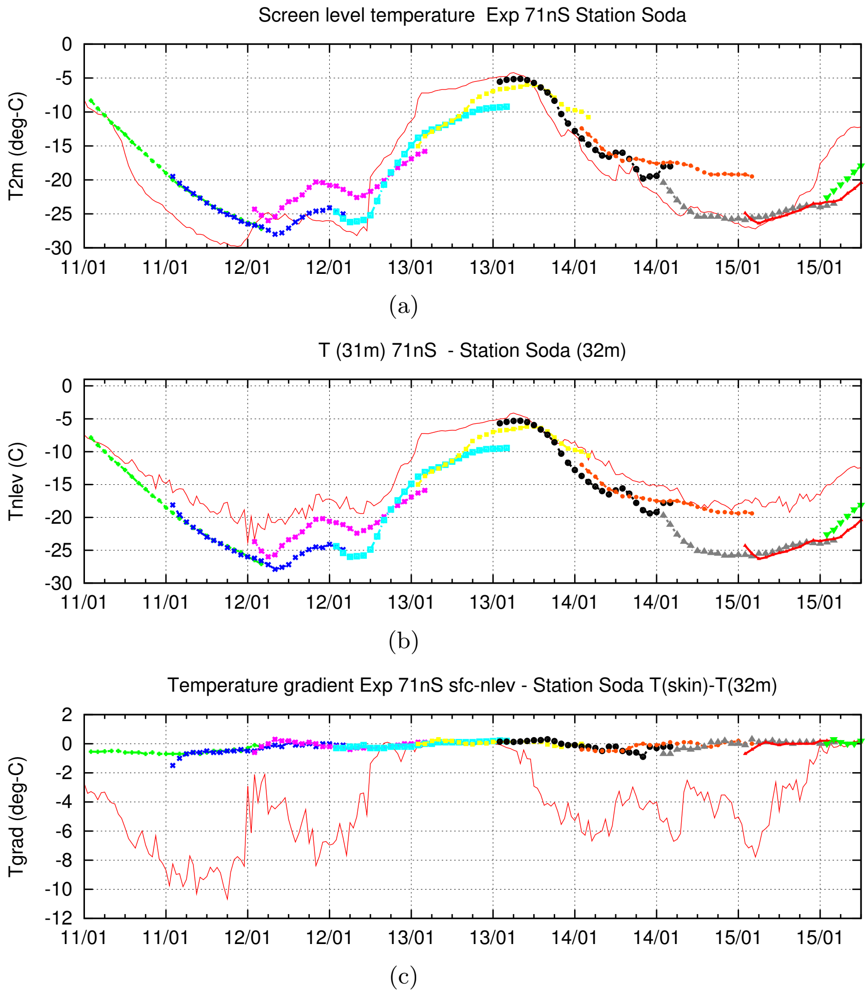
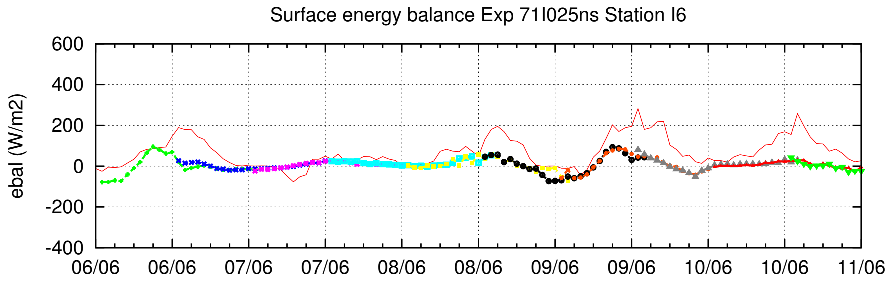


Figure 2: Sodankylä temperatures (y-axis, unit ^{o}C) (a) two-metre T_{2m}, (b) lowest model level T_{nlev}, (c) T_{2m}-T_{nlev} as a function of time (x-axis). Thin solid line: observation, coloured thick lines with markers: HIRLAM "newsnow" forecasts starting 00 UTC and 12 UTC, forecast lead time 27 hours.

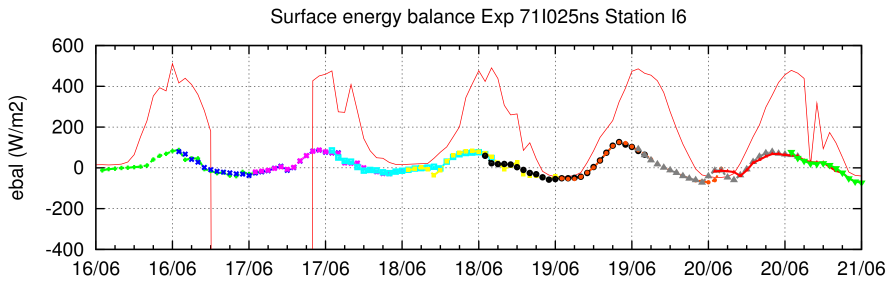
shown). In the beginning of summer, in nature there is snow, which then disappears till mid-June. HIRLAM does not see snow at this station even in the beginning. Instead, the reflected shortwave radiation is determined by the constant value of ice albedo = 0.6 defined in HIRLAM. This is not far from the snow albedo, but after the snow melt, there remains pure ice, whose observed albedo is about 0.2. Such a low value is a specific feature of Iceland, where volcanic ash and dust make the old ice quite dark.

Also the surface temperature is unrealistic, but here the diurnal cycle is too strong (not shown). Instead of staying close to zero on the melting ice, the simulated daily maxima show more than ten degrees warmer values than observed, and night temperatures drop regularly to several degrees below zero (not shown). The only way to relate the underestimated atmospheric net energy flux towards the surface to the too large diurnal temperature cycle, is to assume an overcompensation due to too large soil heat flux. The incorrect heat flux is caused by the incorrect heat conductivity of ice in HIRLAM. Note also, that the incorrect surface temperature leads to incorrect (too big) upwelling long-wave radiation and sensible heat fluxes. These feed errors back to the surface energy balance. The latent heat flux seems to play a minor role both in the simulation and nature.

However, after all these errors of the surface energy balance, the simulated two-metre temperature is somewhat less unrealistic (Fig. 4). This is presumably because HIRLAM is unable to create a vertical gradient between the lowest model level and surface - a problem in Sodankylä, but a virtue on the



(a)



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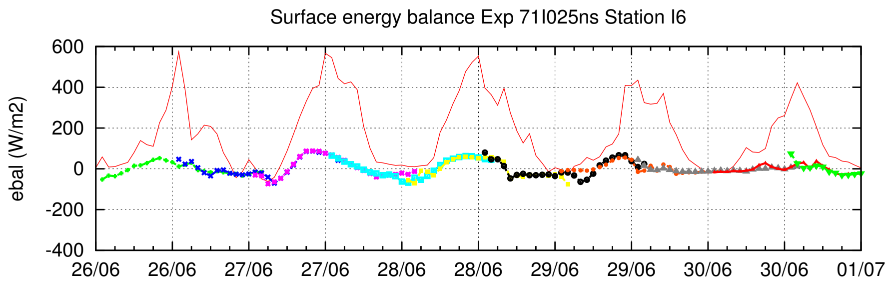

(c)

Figure 3: Vatnajökull energy balance at station I6 (y-axis, unit Wm^{-2}) in the beginning (a), middle (b) and end (c) of June. Lines in figure as in Fig. 2.

glacier? In the Vatnajökull experiment, the synoptic scale features and the fine-scale orography are well described by the model. The good large-scale upper-air analysis, supported by the small-scale surface analysis, even when based on conventional SYNOP observations only, keeps the atmospheric (model level) variables realistic.

At a station at the snow-covered ice cap (U7, 1530 m a.m.s.l), where also HIRLAM knows about the existence of snow, the "newsnow" parametrizations produce better radiation balance and temperatures than the reference HIRLAM (not shown). Here the still incorrect soil flux heat flux is isolated from the atmosphere by the thick snow cover. At an on-land station (U2, 50 m a.m.s.l), where there is no snow or ice in the nature, both the reference HIRLAM and "newsnow" produce fairly good results. Here both schemes assume that there is ice but with thermal properties of bare land without ice.

Simple tuning of the thermal properties, albedo and surface emissivity of the continental ice towards the observed values leads to significant improvements at station I6 (Fig. 5), although unrealistic values occur on individual days.[1] However, at other stations the impact is small or negative because of the incorrect definition of surface type. Table 4 summarizes some aspects related to the quality of the surface energy balance and surface temperature in the experiments.

[1]The sudden temperature drops are most probably related to incomplete treatment of freezing in the model. As melted water on the surface is not allowed to freeze and release heat, cooling of the air close to freezing point may trigger unrealistic surface temperature decrease (Stefan Gollvik, personal communication).

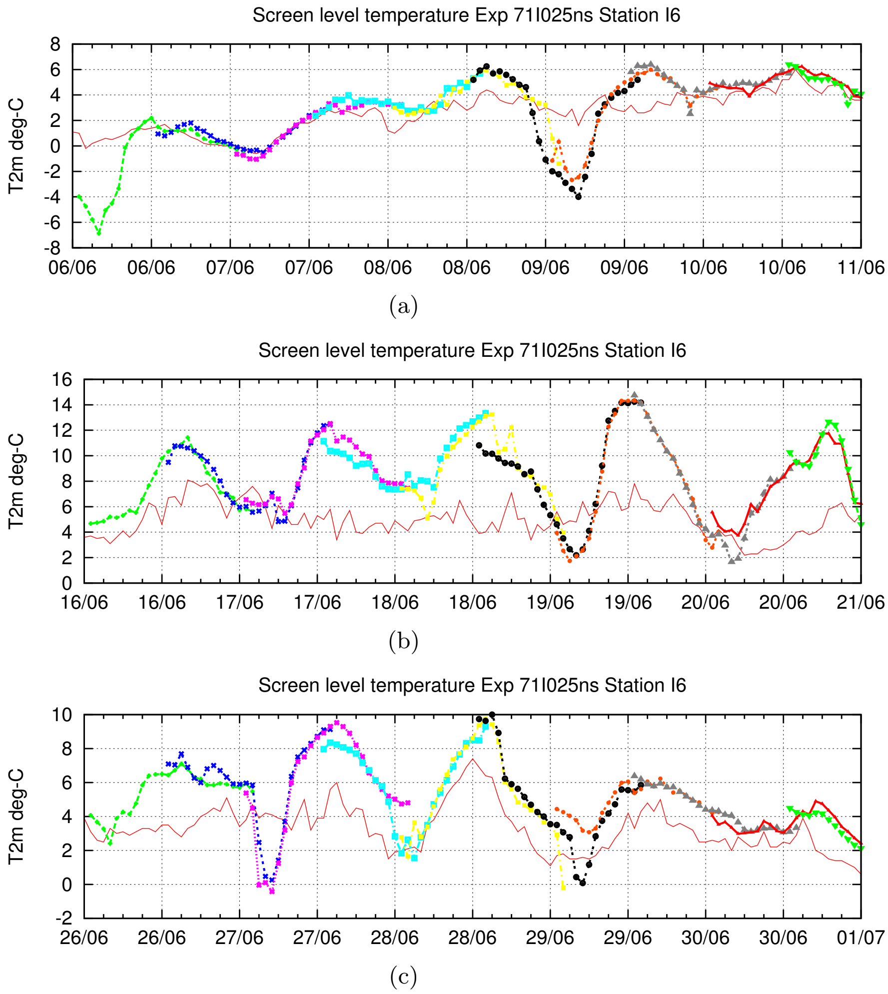

Figure 4: Vatnajökull two-metre temperatures at station I6 (y-axis, unit ^{o}C) in the beginning (a), middle (b) and end (c) of June. Lines in figure as in Fig. 2.

5 A word about the comparison methods

Observations both in Sodankylä and at Vatnajökull provide a wealth of details to compare model simulations with. The model parameters were extracted from the model gribs as follows:

1. Pick the needed parameters of required levels and domain from HIRLAM fc- and fc-md files to a minigrib. Use HIRLAM horizontal interpolation, grads wgrib and conversion tools from pure grib to asimoff for this.

2. Use grads to pick from minigrib the needed nearest gridpoint values for required stations, store in ASCII files for each station.

3. Use gnuplot to draw the observation and model values in the same pictures.

The method (except the minigrib creation) is based on that applied for the operational HIRLAM/RCR - Sodankylä comparison (http://fminwp.fmi.fi). The enhancements and new parameters could also be applied for improvement of the operational comparison.

Table 2: Impact of the HIRLAM modifications at different stations

Station	Elevation (m)	Ice Nature	Ice HIRLAM	Snow Nature	Snow HIRLAM	T_s quality reference	T_s quality newsnow	T_s quality tuned
I6	715	yes	yes	partly	no	poor	poor	good
U7	1530	yes	yes	yes	yes	fair	good	good
U2	50	no	yes	no	no	fair	fair	poor

6 Conclusions

According to the present study, the "newsnow" parametrizations improved the model simulations in the sharp surface inversion cases in Sodankylä, thus solving large part of the "Nordic temperature problem". The problem of too small temperature gradient between the lowest model level and surface (canopy) level requires further attention. The new parametrizations improved simulation results over Vatnajökull snow-covered areas, but had no effect on snow-free areas of the glacier. Here, the main problems of the "newsnow" (also of the reference HIRLAM) are related to the incorrect properties (albedo, heat conductivity) of the continental ice over Iceland. This calls for improvement of the physiographic data base and surface data assimilation methods in HIRLAM. Already a simple modification of the surface albedo, emissivity and heat conductivity of ice led to improved results in case HIRLAM also had correct information about the surface type (glacier/land, snow/no snow).

Only some aspects of the model-observation comparison were touched in this study. Unused possibilities remain especially in the analysis of observed and simulated humidity and clouds. The Sodankylä spring problem, showing up in unrealistic sensible and latent heat fuxes, requires further study. In Vatnajökull, local orography-related circulations (mountain wave-related and thermal) could be studied in selected cases. The sensitivity of improved vertical resolution in the boundary layer (e.g. 90 model levels) could also be studied in the three-dimensional model experiments.

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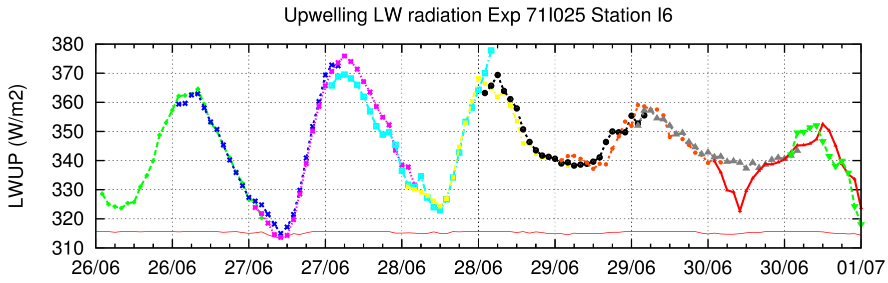

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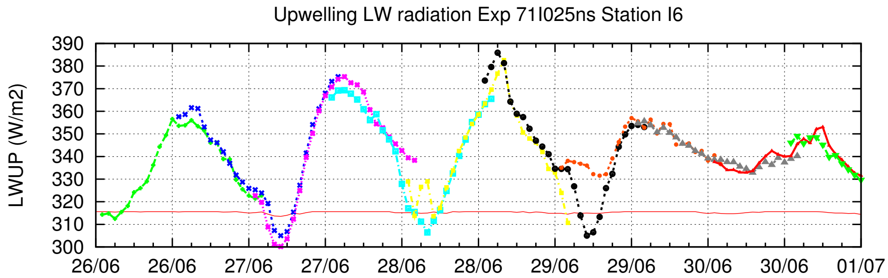

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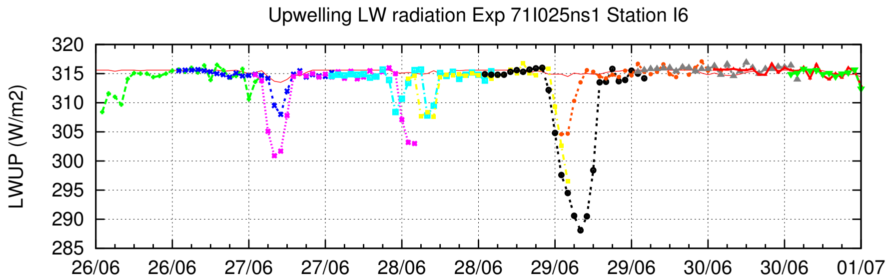

(c)

Figure 5: Upwelling long-wave radiation (y-axis, unit Wm^{-2}) at station I6 according to the reference (a), "newsnow" (b) and tuned "newsnow" (c) experiment during the last days of June. Lines in figure as in Fig. 2. Note the different scales on the y-axis.

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