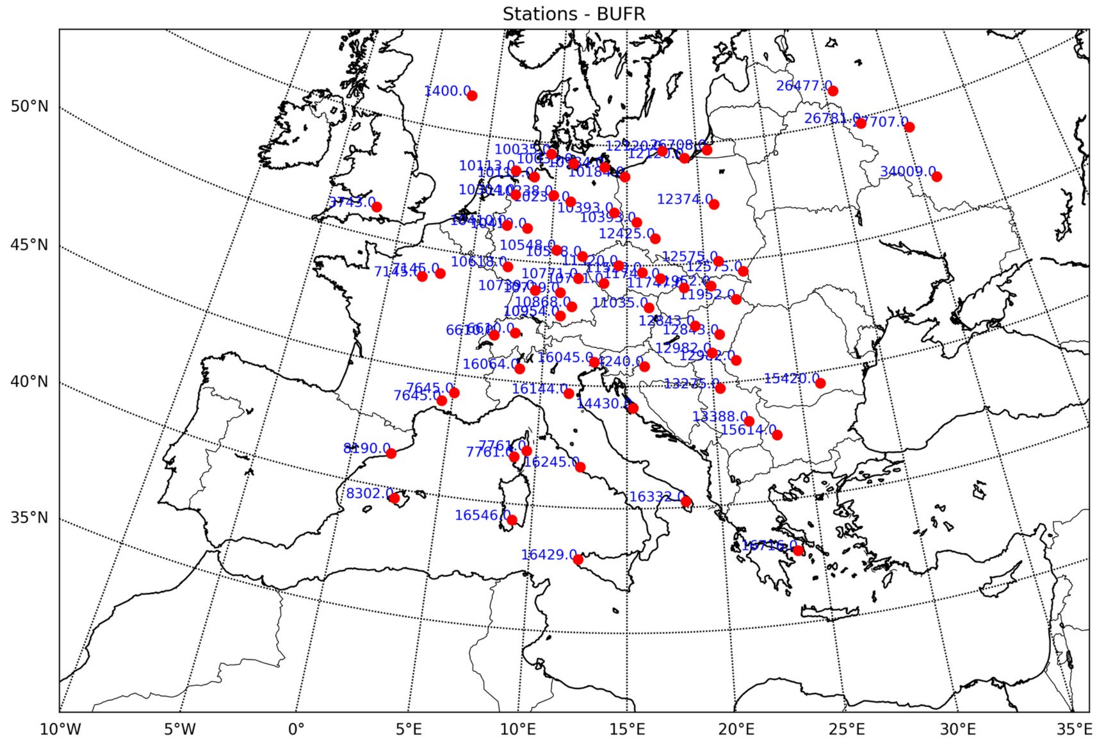
Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

Usage of high resolution radiosonde measurements in BUFR format in ALARO and AROME



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Purpose: Report from RC LACE stay
Place: SHMU, Slovakia, Bratislava
Date(s): 4 November - 29 November 2024

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Introduction

Radiosonde measurements are crucial components of data assimilation cycles of the upper air. While this data is still available and used in the old OBSOUL data format (or TAC - Traditional Alphanumeric Code), the newer BUFR format is also provided by many meteorological stations making radiosonde measurements. The BUFR TEMP data have higher vertical resolution than the OBSOUL TEMP and contains measurements from the descending radiosonde. The goal of this work was to try using this data format and examine its effect.

To compare the BUFR and OUBSOUL TEMP we needed a list of stations that report both data format and exclude the rest from the data assimilation via a blacklist. We also checked these data for some selected stations and examined the influence of just one sounding on the data assimilation. For the selected time period (second half of October 2024) we made an experiment with ALARO using BUFR TEMP and a second using OBSOUL TEMP. These experiments were recreated after the stay with AROME.

By using BUFR TEMP we got access to data measured during the descend of the radiosonde. We made experiments to determine the effect of these data too. There was also the possibility to take into account the drift of the radiosonde when we use BUFR TEMP data. However this requires much more computational memory and we had technical issues with it. There is a detailed description of this option in the work of Peter Štrbáň (ref. 1.).

Stations

We collected the number of OBSOUL and BUFR TEMP reports provided by the meteorological stations in the domain of the operational ALARO used at the SHMU for the times 00, 06, 12 and 18 UTC from periods 15 - 31 May 2024 and 15 - 31 October 2024. This was done by using the BATOR binary and extracting the station lists from the created database via the odbsql tool. The resulted numbers of TEMP reports can be seen in table 1. The stations where during the observed periods the number of OBSOUL and BUFR TEMP reports are not equal are highlighted with red (more BUFR) and blue (more OBSOUL) colors. Where only one type of TEMP was provided (highlighted with darker color and bold font) was put in the blacklist. This blacklist was used to exclude those stations from the experiments which would put one format into advantage. The following stations got into the blacklist: 6458, 10304, 10954, 11010, 11120, 11240, 17064, 17130, 17220, 17240, 26435.

Station ID	OBSOUL (Oct)	BUFR (Oct)	OBSOUL (May)	BUFR (May)	Station ID	OBSOUL (Oct)	BUFR (Oct)	OBSOUL (May)	BUFR (May)
1400	33	33	31	31	**12575**	33	33	33	33
3238	22	23	17	18	**12843**	34	34	34	34
3354	28	28	20	22	**12982**	33	33	34	34
3743	18	23	20	26	**13275**	68	68	68	68
3882	0	0	25	25	**13388**	68	66	68	65
6260	20	21	19	19	**14015**	17	17	17	17
6458	**4**	0	**4**	0	**14240**	17	17	34	34
6610	34	36	36	36	**14430**	17	17	34	34
7145	34	35	29	29	**15420**	34	34	34	34
7645	34	35	34	36	**15614**	34	34	34	34
7761	34	35	34	35	**16045**	40	40	33	34
8190	32	32	34	36	**16064**	34	34	34	34
8302	33	36	22	23	**16113**	16	16	17	17
10035	31	31	34	34	**16144**	33	33	28	28
10113	34	34	34	34	**16245**	34	34	34	34
10184	34	34	34	34	**16332**	34	34	34	34
10238	33	34	34	35	**16429**	34	35	33	33
10304	0	**36**	6	35	**16546**	34	41	33	34
10393	68	69	68	69	**16622**	34	34	17	17
10410	35	36	34	39	**16716**	16	15	17	17
10548	35	35	33	33	**16754**	16	16	15	15
10618	68	68	68	68	**17064**	**34**	0	**34**	0
10739	35	35	28	28	**17130**	**10**	0	**21**	0
10771	29	29	34	34	**17220**	**34**	0	**34**	0
10868	34	34	34	34	**17240**	**34**	0	**34**	0
10954	0	**31**	11	43	**26435**	**1**	0	**4**	0
10962	5	5	5	5	**26477**	34	33	34	26
11010	0	**17**	0	**12**	**26629**	17	17	17	17
11035	34	35	34	34	**26708**	33	33	34	34
11120	1	16	0	**16**	**26781**	34	34	34	34
11240	1	16	0	**11**	**27459**	0	0	1	1
11520	51	51	51	51	**27707**	34	34	33	33
11747	34	35	34	34	**27713**	33	33	30	30
11952	34	34	34	35	**34009**	34	32	33	32
12120	34	34	32	32	**60390**	17	17	17	17
12374	34	34	33	33	**60715**	5	5	4	4
12425	34	34	32	32					

Table 1 - Number of TEMP reports at different stations

We compared the OUBSOUL (TAC) and BUFR data from some selected stations on 15 October 2024 at 12 UTC (and on 15 May 2024 at 12 UTC, but not shown). The selected stations were: 10113 - Norden, 12843 - Budapest, 08302 - Palma, 26781 - Smolensk, 16716 - Athen. The raw data from the odb database were made by the BATOR, then selected with odbsql and visualized with R. Figures 1-5 shows these comparisons where red means the OBSOUL (TAC) data and blue the BUFR data. There are 6 graphs in this figures showing the vertical distribution of measurements. The y axis represents the pressure and the x axis the observations of geopotential (GEO [m^2s^{-2}]), temperature (T [K]), specific humidity (Q), relative humidity (RH), wind direction (WINDDIR [deg]) and wind speed (WINDSPEED [ms^{-1}]). The BUFR TEMP data have higher resolution and not always the same values as the OBSOUL data. The reason for the differences is probably caused by the lower resolution of the OBSOUL which couldn't follow the profile of data like the BUFR. It is also notable that the differences occur manly in the wind and humidity, probably because the geopotential is basically the vertical coordinate and the temperature changes slower. The effect of these differences on the assimilation were tested in a single observation experiment (next section). Figure 6 shows the stations where the radiosonde reports come from on 15 October 2024 at 12 UTC. It can be seen that not all stations gave both type of radiosonde report.

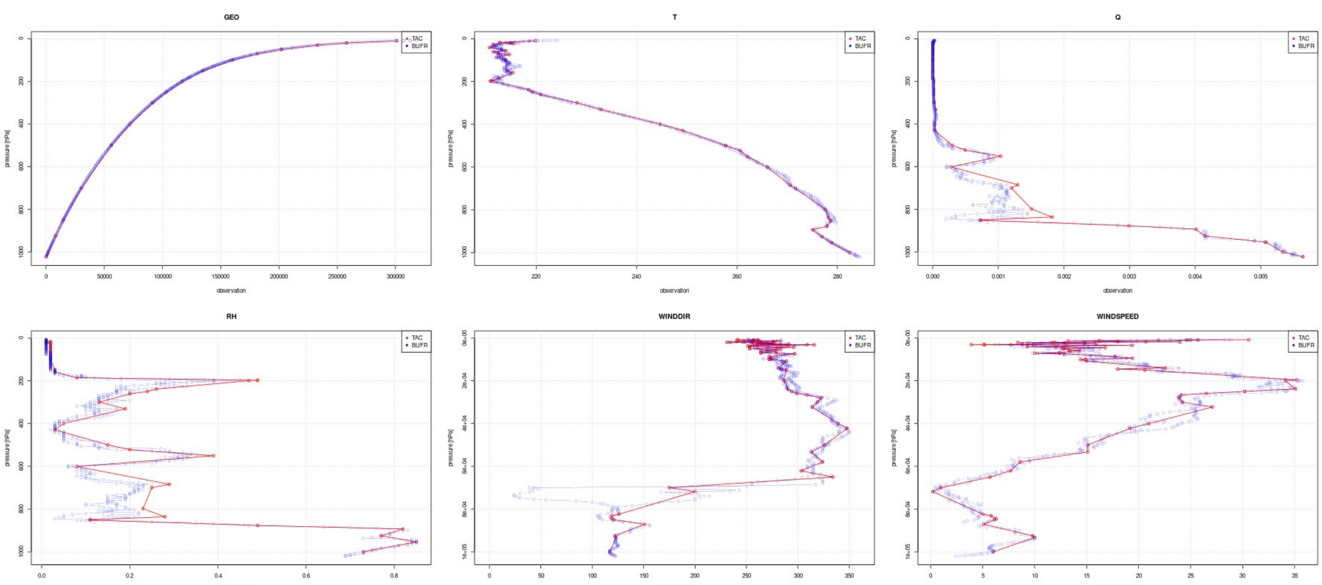

Fig. 1 - Radiosonde measurements (top from left to right : geopotential [m^2s^{-2}], temperature [K], specific humidity; bottom from left to right: relative humidity, wind direction [deg], wind speed [ms^{-1}]) at station 10113 (Norden) of OBSOUL - TAC (red color) and BUFR (blue color) format on 15 October 2024 at 12 UTC.

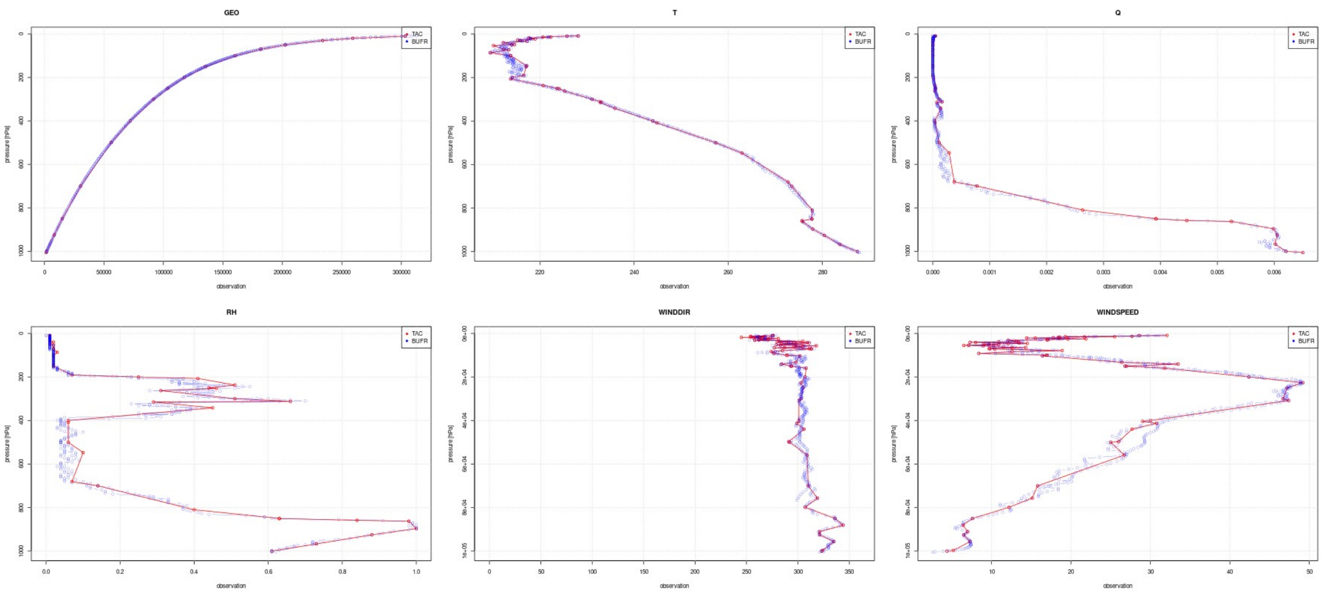

Fig. 2 - Radiosonde measurements (top from left to right : geopotential [m^2s^{-2}], temperature [K], specific humidity; bottom from left to right: relative humidity, wind direction [deg], wind speed [ms^{-1}]) at station 12843 (Budapest) of OBSOUL - TAC (red color) and BUFR (blue color) format on 15 October 2024 at 12 UTC.

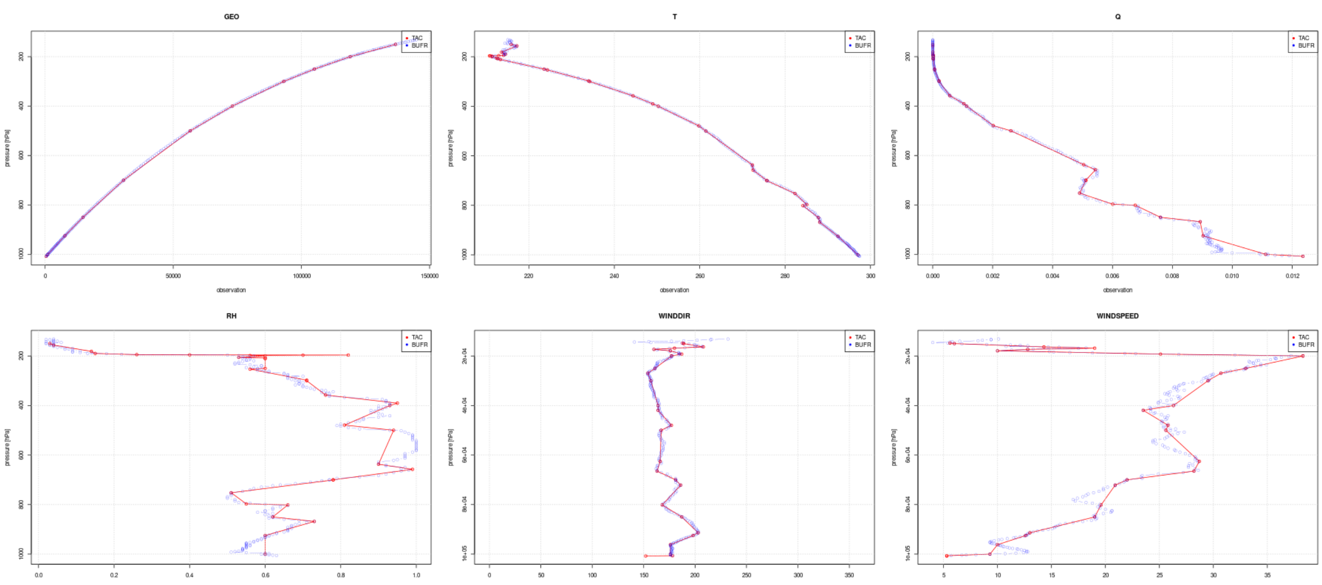

Fig. 3 - Radiosonde measurements (top from left to right : geopotential [m^2s^{-2}], temperature [K], specific humidity; bottom from left to right: relative humidity, wind direction [deg], wind speed [ms^{-1}])

at station 08302 (Palma) of OBSOUL - TAC (red color) and BUFR (blue color) format on 15 October 2024 at 12 UTC.

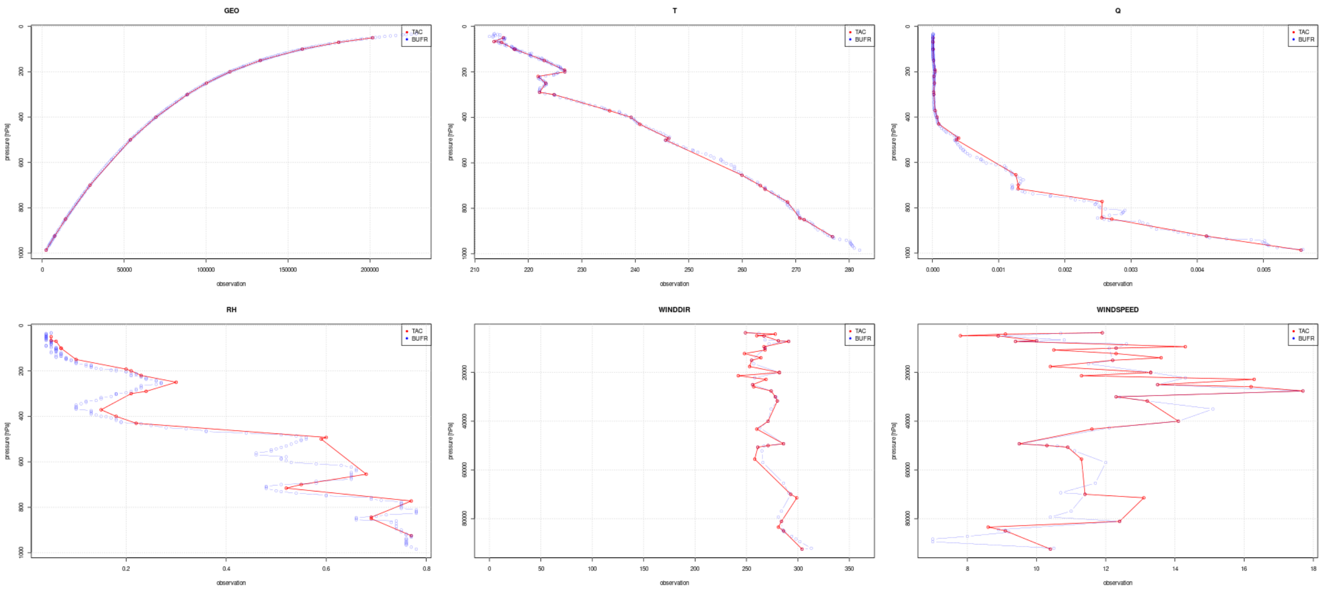

Fig. 4 - Radiosonde measurements (top from left to right : geopotential [m^2s^{-2}], temperature [K], specific humidity; bottom from left to right: relative humidity, wind direction [deg], wind speed [ms^{-1}]) at station 26781 (Smolensk) of OBSOUL - TAC (red color) and BUFR (blue color) format on 15 October 2024 at 12 UTC.

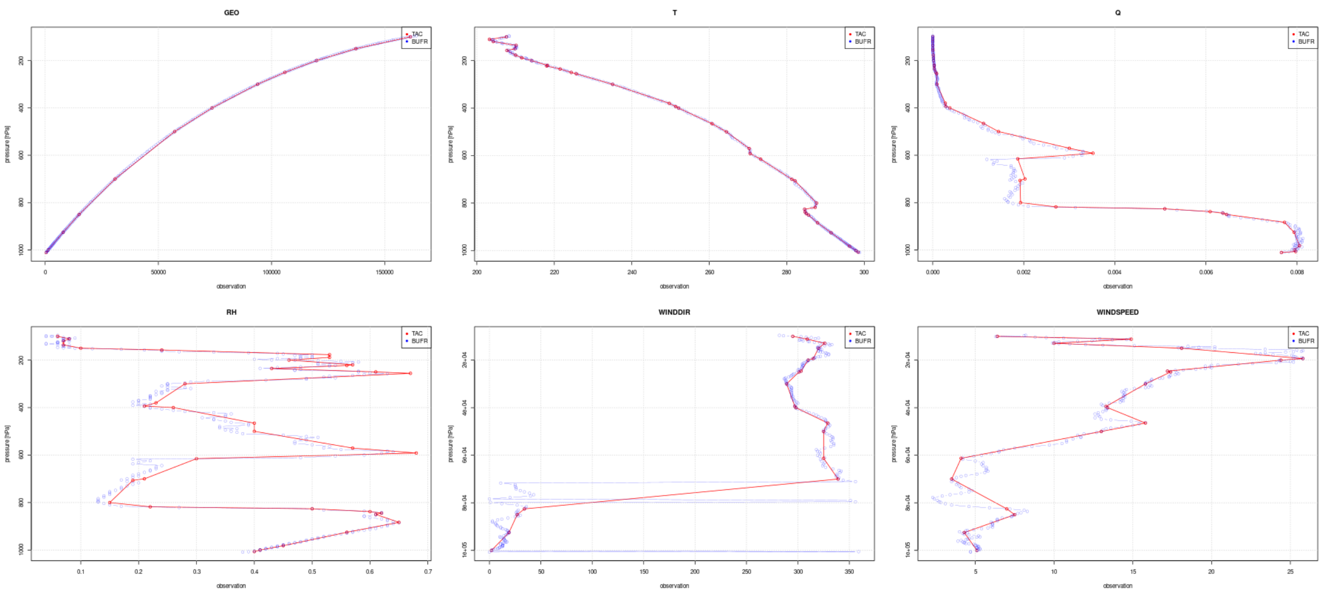

Fig. 5 - Radiosonde measurements (top from left to right : geopotential [m^2s^{-2}], temperature [K], specific humidity; bottom from left to right: relative humidity, wind direction [deg], wind speed [ms^{-1}]) at station 16716 (Athen) of OBSOUL - TAC (red color) and BUFR (blue color) format on 15 October 2024 at 12 UTC.

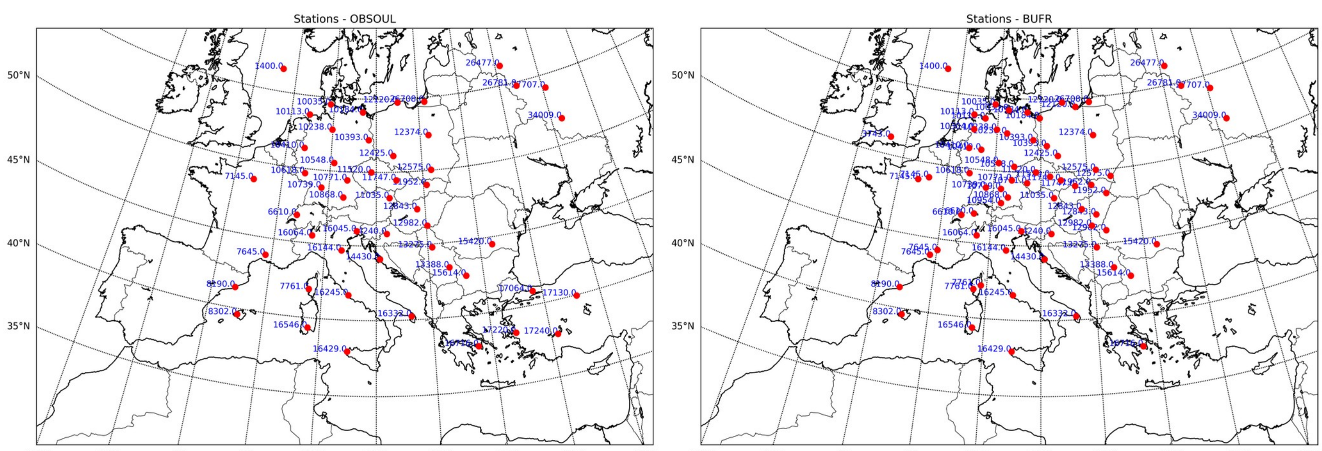

Fig. 6 - Maps of stations on 15 October 2024 from where the OBSOUL (left) and BUFR (right) TEMP reports came.

Impact of one radiosonde

We examined the effect of BUFR TEMP with only one station's data in it on the data assimilation. The BUFR TEMP on the date 3 November 2024 at 12 UTC was modified with bufr_filter to contain only data from station 12843 (Budapest) and used in the minimalization. Figure 7 shows the place of the station 12843 and figure 8 the vertical cross-sections (meridional and zonal) of temperature difference between the analysis that was made with OBSOUL and BUFR data, thus the impact of the switch from OBSOUL to BUFR TEMP. Figure 9 shows the same effect at the top model level (S001) and at the 20th model level (S020). The extent of the differences is around 1-2 K. It is also notable, that at higher altitude, the center of the effect of the switch from OBSOUL to BUFR moved to south-east (even if the trajectory following of the radiosonde is turned off). It seems, that the differences shown in the previous section do have an impact on the data assimilation, even if the final result is mostly neutral (shown later). That is probably because the positive and negative differences between the analyses are in balance (Fig. 8) and diminish by time.

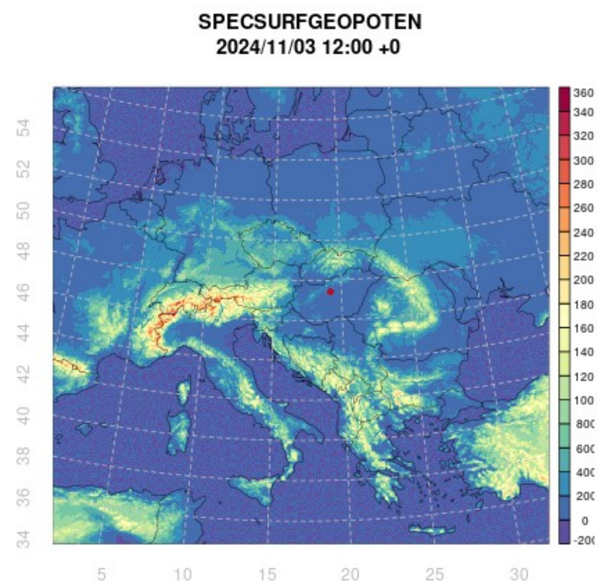

Fig. 7 The place of the station 12843 (Budapest)

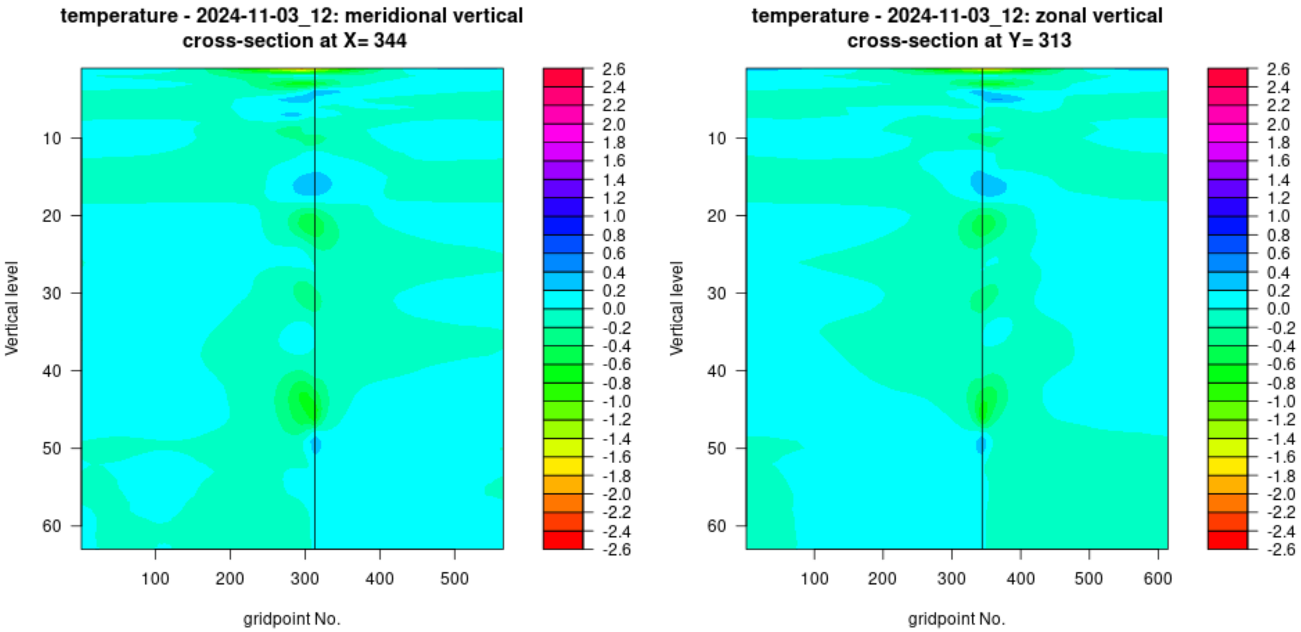

Fig. 8 - Meridional and zonal cross section of temperature difference [K] on 3 November 2024 at 12 UTC at station 12843 (Budapest) between the analyses (OBSOUL - BUFR)

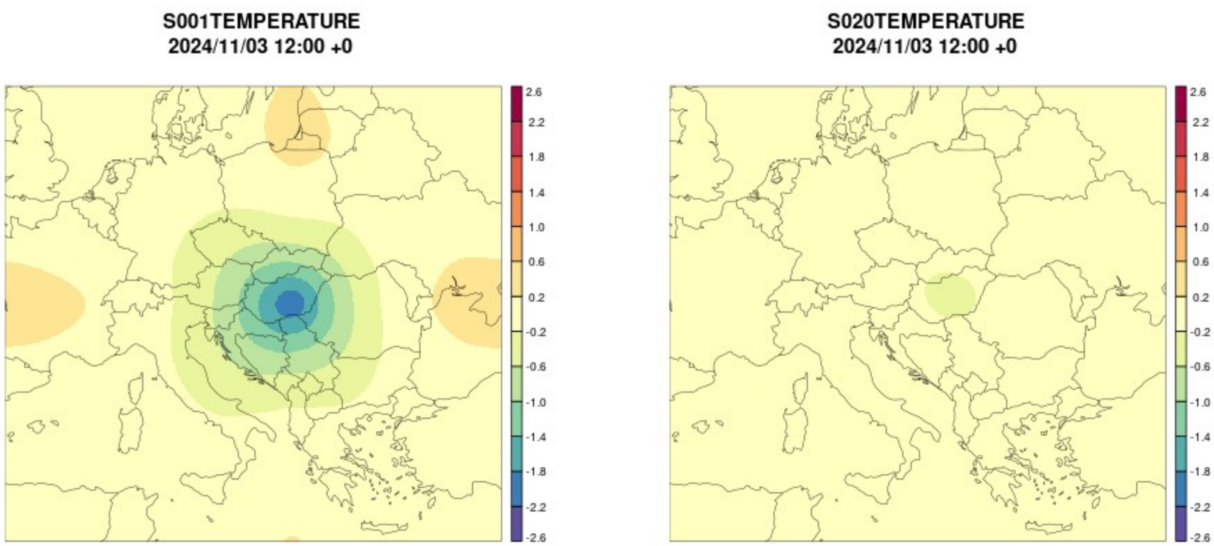

Fig. 9 - Temperature difference [K] on 3 November 2024 at 12 UTC at the top (S001) and 20th model level (S020) between the analyses (OBSOUL - BUFR)

Experiments with ALARO

To test the influence of the BUFR TEMP we made 3 experiments with the ALARO (cy46) model with operational settings at the SHMU (4.5 km horizontal resolution, 63 vertical levels, 3-hour-frequency LBC coupling with ARPEGE, data assimilation: BlendVar in upper-air and CANARI at surface, European domain - Fig. 6). The examined period was from 15. October 2024 to 31. October 2024. 48 hour long forecasts were made at 0, 6, 12 and 18 UTC and the guesses from these forecasts were used in the data assimilation of the next run. The first and second experiments used the blacklist prepared previously to use only the stations which provide both type of TEMP reports. The first experiment used OBSOUL TEMP and was considered as the reference to the other experiments. The second used BUFR TEMP and the third experiment not only BUFR TEMP, but also the data from the descending radiosonde. These data have the 135 codetype in the odb database (the codetype of the data from the ascending radiosonde is 35). Wether these descending radiosondes use parachute or not, can be found in the following online spreadsheet for the particular stations (for example station 12843 (Budapest) does not use parachute): https://docs.google.com/spreadsheets/d/1obiSDkcD0m-TVs8zjQpcZy3HkXGKRYfxEk1i_iH_YiI. According to this document from 103 station 67 report data from descending radiosondes and 55 equip the radiosonde with parachute. The effect of the usage of parachute on the quality of measurements is not an object of this work, but it is planed to examine this subject. The results of the 3 experiments and the operational ALARO (note that operational ALARO uses the original blacklist) were evaluated in the vfld framework. Figures 10 - 12 show the vertical layout of bias and RMSE values for the 12, 24, 36 and 48 hour forecasts for the following variables: wind direction, wind speed, specific humidity, relative humidity, dew point, temperature. There are not much notable differences between the experiments, the biggest deviations are shown by the third experiment, where the data from the descending radiosonde are used.

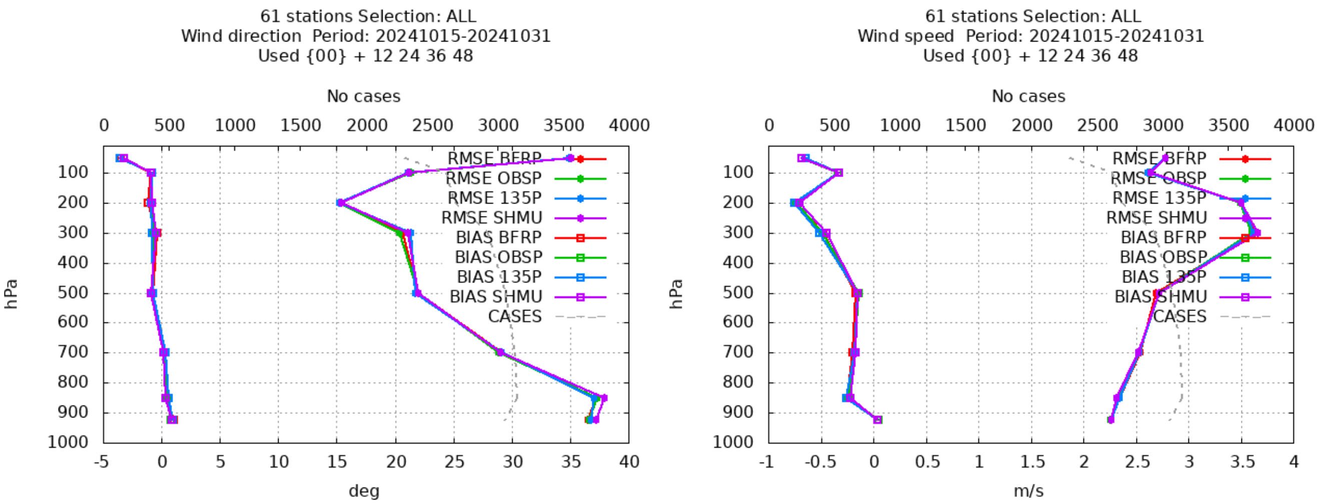

Fig. 10 - Vertical distribution of bias (lines with squares) and RMSE (lines with dots) of ALARO experiments OBSP (OBSOUL TEMP - green), BFRP (BUFR TEMP - red), 135P (BUFR TEMP + data from descending radiosonde - blue) and SHMU (operational ALARO - purple) for wind direction (left) and wind speed (right).

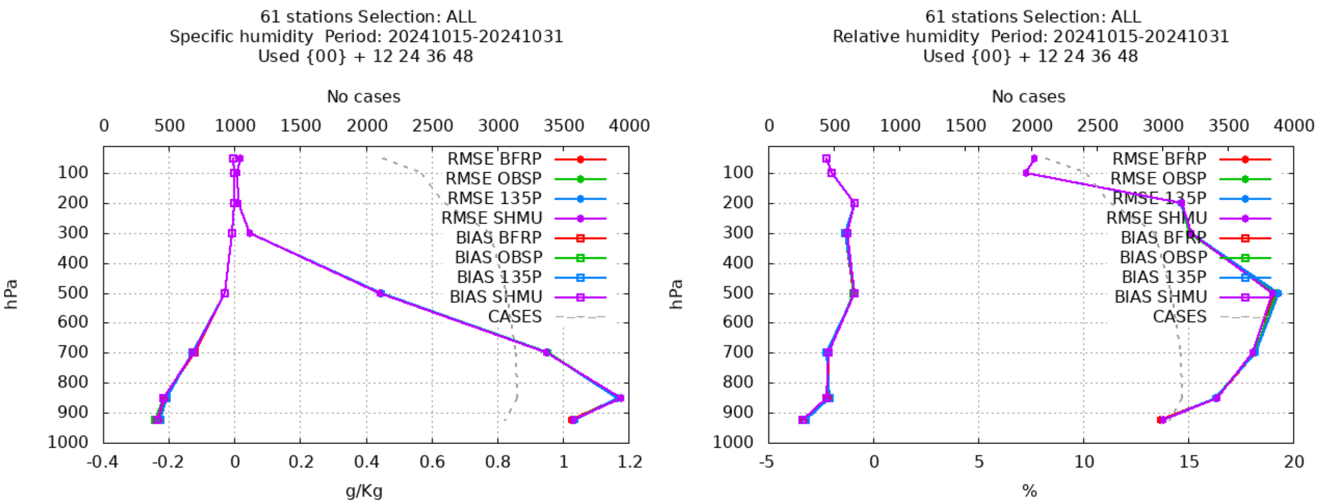

Fig. 11 - Vertical distribution of bias (lines with squares) and RMSE (lines with dots) of ALARO experiments OBSP (OBSOUL TEMP - green), BFRP (BUFR TEMP - red), 135P (BUFR TEMP + data from descending radiosonde - blue) and SHMU (operational ALARO - purple) for specific humidity (left) and relative humidity (right).

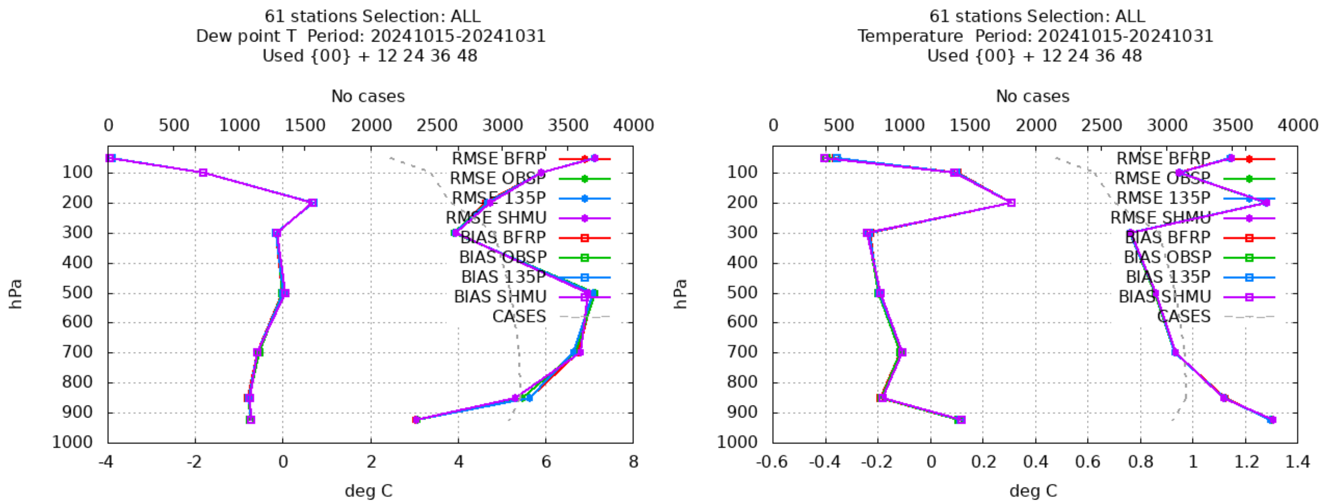

Fig. 12 - Vertical distribution of bias (lines with squares) and RMSE (lines with dots) of ALARO experiments OBSP (OBSOUL TEMP - green), BFRP (BUFR TEMP - red), 135P (BUFR TEMP + data from descending radiosonde - blue) and SHMU (operational ALARO - purple) for for dew point (left) and temperature (right).

Experiments with AROME

Corresponding experiments to the runs with ALARO were made with AROME (cy46) at the Hungarian Meteorological Service (2.5 km horizontal resolution, 60 verical levels, 1-hour-frequency LBC coupling with ECMWF HRES, data assimilation: 3D-Var in upper-air and SEKF at surface, Middle-European domain - Fig. 13) for the time period from 15. October 2024 to 1. November 2024. Just like the expeiments with ALARO the first one used OBSOUL TEMP, the second and third used BUFR TEMP. The experiments used the blacklist which filters out stations providing only one type of TEMP and in case of the first and second experiments the data from descending radiosonds are also filtered out, while the third experiments blacklist allows the data from descending radiosonds to be used. The length of the forecasts were 48 hours at 00 UTC and a 3-hour assimilation cycle was used through the period. The verification of the results of these experiments were made by the OVISYS system and the reults can be seen in figures 14 - 22.

These results showed slightly bigger differences between the OBSOUL and BUFR experiments than at the ALARO model. The bias and RMSE of AROME experiments (and operationl AROME, which are archived results from the operational runs which differs in the blacklist from the OBSOUL experiment and it used the cy43 in the time of the examined period) usually differ only minimally, the bigger differencies are connected to the third experiment (BUFR TEMP + descending radiosonde data). For example the first 12 hours of the wind gust forecast were higher than the other experiments (Fig. 20). The 2 m temperature bias with BUFR TEMP shifted into lower values (Fig. 14) and the 2 m relative humidity bias shifted to the higher values (Fig 17). There are also notable differences at higher altitude in forecast scores (Fig. 15-16, 18-19), but at these heights there are less observations which influence the verification and results in courser resolution in time.

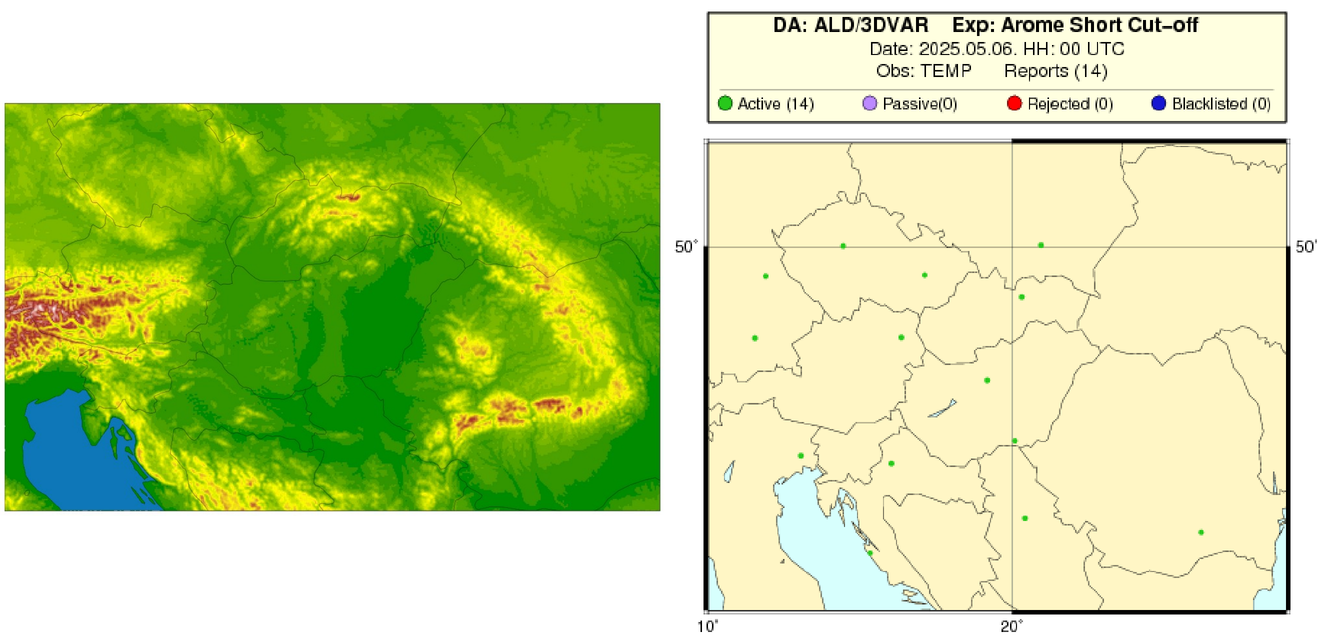

Fig. 13 - AROME domain (left) and places of TEMP measurments (right)

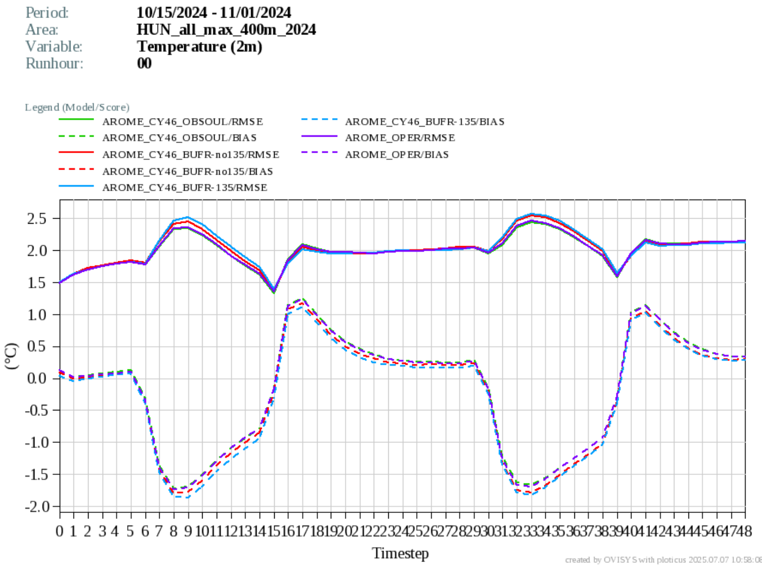

Fig. 14 - Bias (dashed line) and RMSE (solid line) of 2 m temperature forecasts in function of time steps from AROME experiments with OBSOUL TEMP (green), BUFR TEMP (red), BUFR TEMP and data from descending radiosonde (blue) and operational AROME (purlpe).

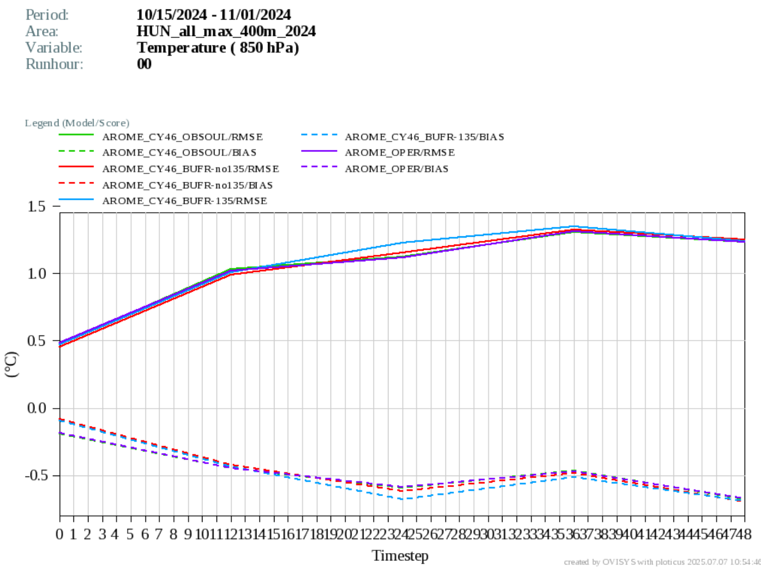

Fig. 15 - Bias (dashed line) and RMSE (solid line) of 850 hPa temperature forecasts in function of time steps from AROME experiments with OBSOUL TEMP (green), BUFR TEMP (red), BUFR TEMP and data from descending radiosonde (blue) and operational AROME (purlpe).

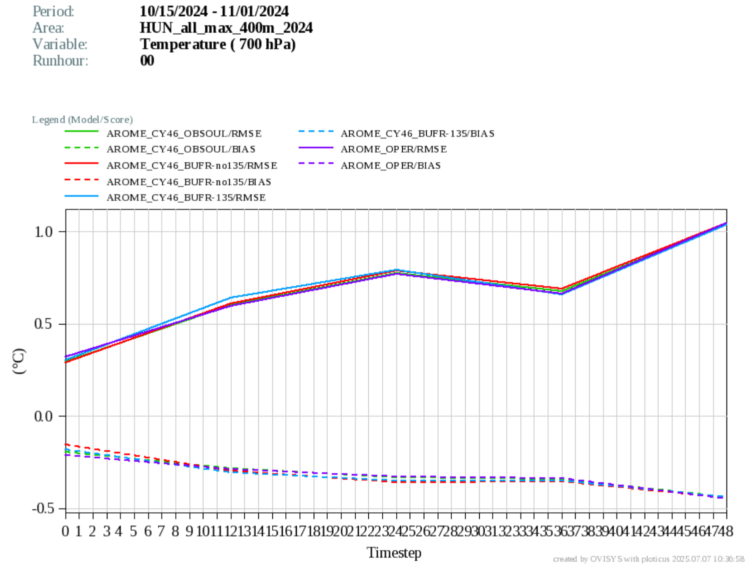

Fig. 16 - Bias (dashed line) and RMSE (solid line) of 700 hPa temperature forecasts in function of time steps from AROME experiments with OBSOUL TEMP (green), BUFR TEMP (red), BUFR TEMP and data from descending radiosonde (blue) and operational AROME (purlpe).

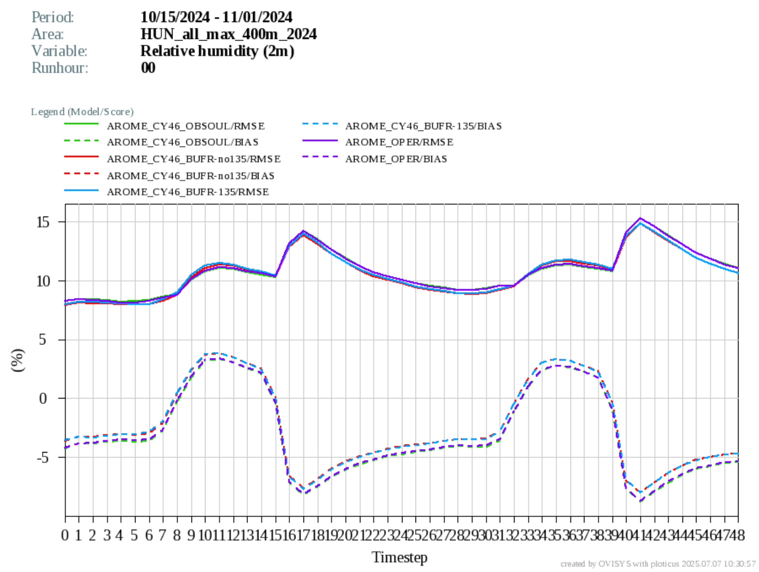

Fig. 17 - Bias (dashed line) and RMSE (solid line) of 2 m relative humidity forecasts in function of time steps from AROME experiments with OBSOUL TEMP (green), BUFR TEMP (red), BUFR TEMP and data from descending radiosonde (blue) and operational AROME (purlpe).

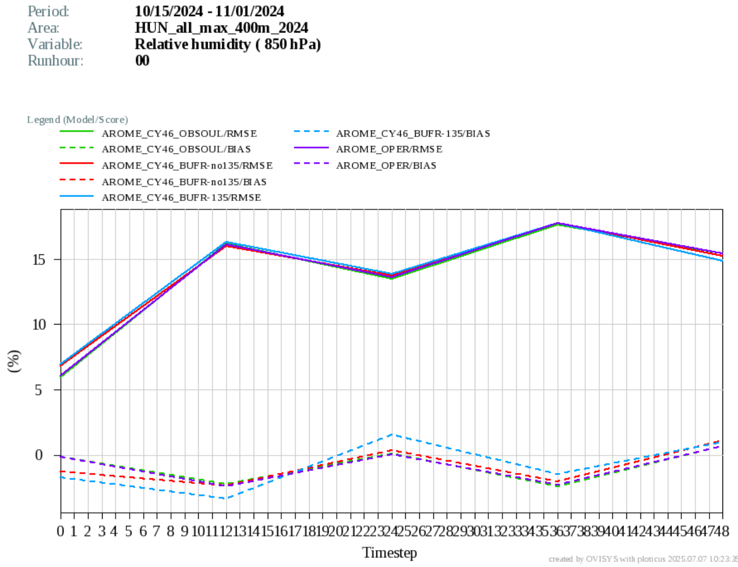

Fig. 18 - Bias (dashed line) and RMSE (solid line) of 850 hPa relative humidity forecasts in function of time steps from AROME experiments with OBSOUL TEMP (green), BUFR TEMP (red), BUFR TEMP and data from descending radiosonde (blue) and operational AROME (purlpe).

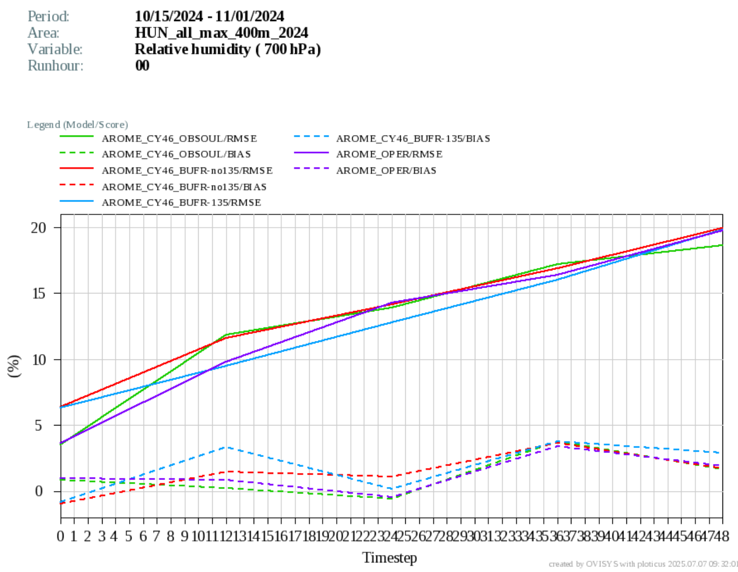

Fig. 19 - Bias (dashed line) and RMSE (solid line) of 700 hPa relative humidity forecasts in function of time steps from AROME experiments with OBSOUL TEMP (green), BUFR TEMP (red), BUFR TEMP and data from descending radiosonde (blue) and operational AROME (purlpe).

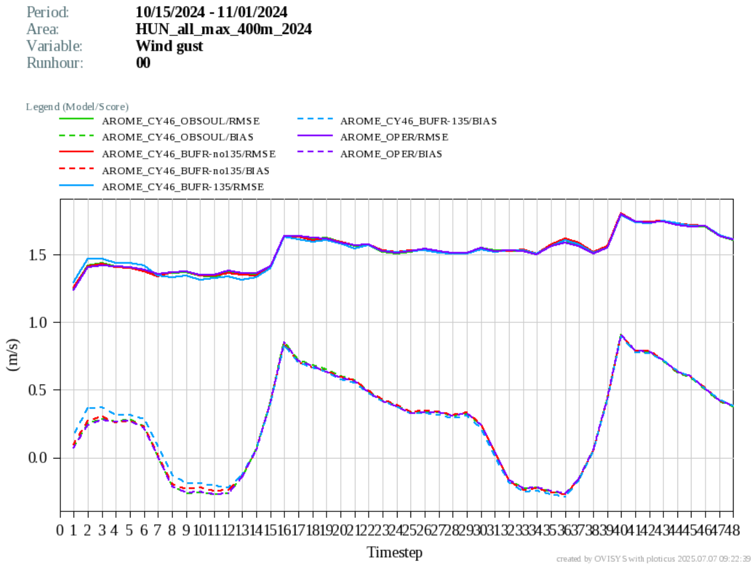

Fig. 20 - Bias (dashed line) and RMSE (solid line) of wind gust forecasts in function of time steps from AROME experiments with OBSOUL TEMP (green), BUFR TEMP (red), BUFR TEMP and data from descending radiosonde (blue) and operational AROME (purlpe).

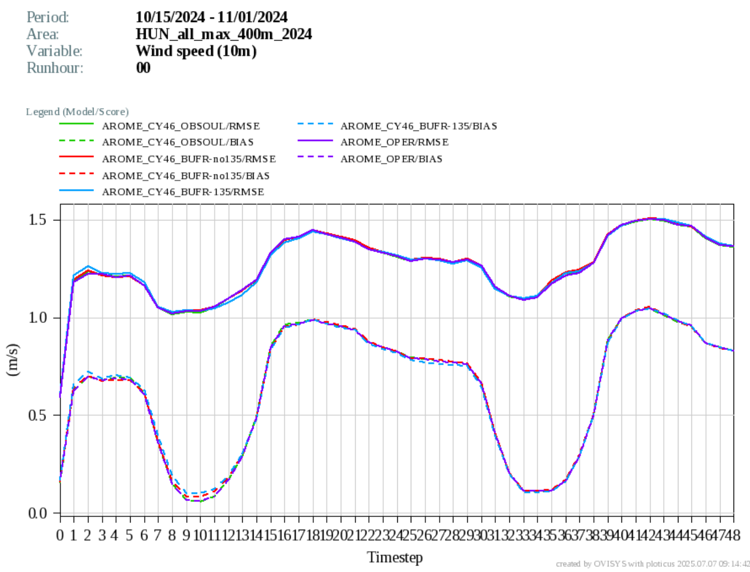

Fig. 21 - Bias (dashed line) and RMSE (solid line) of 10 m wind speed forecasts in function of time steps from AROME experiments with OBSOUL TEMP (green), BUFR TEMP (red), BUFR TEMP and data from descending radiosonde (blue) and operational AROME (purlpe).

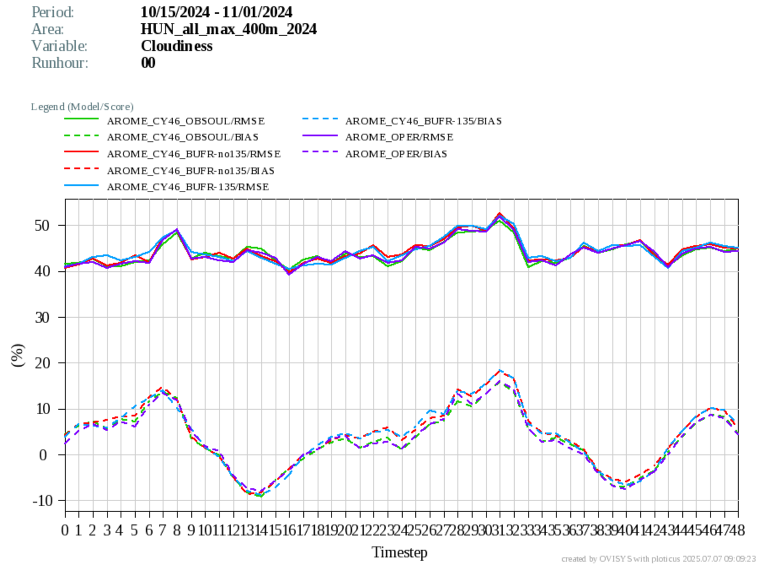

Fig. 22 - Bias (dashed line) and RMSE (solid line) of cloudiness forecasts in function of time steps from AROME experiments with OBSOUL TEMP (green), BUFR TEMP (red), BUFR TEMP and data from descending radiosonde (blue) and operational AROME (purlpe).

Conclusions

During the stay at the Slovak Hydrometeorological Institute we examined the effect of using the BUFR format of TEMP data opposing to the older OBSOUL format, which is still widely used. The BUFR format provides data with higher vertical resolution which was shown by plotting some exemplary data with its OBSOUL pair. There are differences between them caused by the different data-sampling frequency. The effect of BUFR TEMP from only one station on the data assimilation was also examined and caused by this difference, which ultimately could change the forecast.

The BUFR format also makes possible to take into account the trajectory of the radiosonde and use the data measured during the descend of the radiosonde. The trajectory following option was not examined due to technical difficulties but through a series of experiments with ALARO and AROME model the difference of using BUFR and OBSOUL TEMP and the effect of the data from the descending radiosonde were explored. We found, that upgrading from OBSOUL to BUFR format had minimal effect on the forecasts in case of ALARO and slightly bigger (and not always positive) in case of AROME. Probably this effect would be better, if we accounted with the drift of the radiosonde, also the differences in the verification potentially could be more significant on the unexamined vertical levels. The additional data from the descending radiosonde made bigger difference and made both negative and positive effect, but in overall they had neutral impact. It should be noted that at the verification were used the same radiosonde measurements we used at the data assimilation. The results show that the switch from OBSOUL TEMP to BUFR TEMP and the usage of data from descending radiosonde had rather neutral effect in overall.

At the Hungarian Meteorological Service it is planed to make further examinations of the BUFR TEMP data and the effect of the usage of parachute on the descending radiosonde measurements based on a campain done in 2023 at the hungarian stations. We want to make experiments for longer periods to study differences, also maybe some case stuies. We also plan to change our operational data assimilation from using OBSOUL TEMP to using BURF TEMP and the data from descending radiosonde.

References

- Štrbáň P. (2021): Impact of the radiosonde drift in the data assimilation of the ALADIN/SHMU numerical weather prediction system. Master thesis, Univerzita Komenského, Bratislava.

Acknowledgment

I would like to thank all the help I got during my stay at the Slovak Hydrometeorological Institute (SHMU) mainly Michal Nestiak for the technical help and my supervisor, Mária Derková, for overseeing and supporting my work there.

Technical notes

- The usage of **odbsql** tool:

Makes list of data in the observation database. Used to make a list of stations for blacklist.

Example:

HPC in SHMU:

```
export ODB_ROOT=/users/p5621/wrk/odb/ && source
$ODB_ROOT/bin/use_odb.sh

cd `ls -trd /work/users/x2048/${DATE}/bfrX*/e002/ECMA.temp |tail -1`

odbsql -q 'select statid, date, time, lat, lon, obstype, codetype
from hdr,body' -k >> ~/lacework/check_odb_bfrX.out 2>/dev/null
```

HPC in HungaroMet:

```
export ARCH=ia64_no_motif

export ODB_DIR=/home/tothh/tools/odb/viewer

export ODB_VERSION=CY35R2.003

alias use_odb=". $ODB_DIR/$ARCH/$ODB_VERSION/bin/use_odb.sh"

use_odb

cd assim/rundir/131/00/ecma_db_var/ECMA.temp

odbsql -q 'select statid, date, time, lat, lon, obstype, codetype
from hdr,body' -k > out 2>/dev/null
```

- Example of blacklist excerpt for station 26435 (file LISTE_NOIRE_DIAP):

```
 5 TEMP         35 -1   1 26435    01012000
 5 TEMP         35 -1   2 26435    01012000
 5 TEMP         35 -1   3 26435    01012000
 5 TEMP         35 -1   4 26435    01012000
 5 TEMP         35 -1   7 26435    01012000
 5 TEMP         35 -1  29 26435    01012000
 5 TEMP         35 -1  39 26435    01012000
 5 TEMP         35 -1  58 26435    01012000
 5 TEMP         35  2   1 26435    01012000
```

```
 5 TEMP          35   2    2 26435     01012000
 5 TEMP          35   2    3 26435     01012000
 5 TEMP          35   2    4 26435     01012000
 5 TEMP          35   2    7 26435     01012000
 5 TEMP          35   2   29 26435     01012000
 5 TEMP          35   2   39 26435     01012000
 5 TEMP          35   2   58 26435     01012000
 5 TEMP         135   2    1 26435     01012000
 5 TEMP         135   2    2 26435     01012000
 5 TEMP         135   2    3 26435     01012000
 5 TEMP         135   2    4 26435     01012000
 5 TEMP         135   2    7 26435     01012000
 5 TEMP         135   2   29 26435     01012000
 5 TEMP          35   1    1 26435     01012000
 5 TEMP          35   1    2 26435     01012000
 5 TEMP          35   1    3 26435     01012000
 5 TEMP          35   1    4 26435     01012000
 5 TEMP          35   1    7 26435     01012000
 5 TEMP          35   1   29 26435     01012000
 5 TEMP          35   1   39 26435     01012000
 5 TEMP          35   1   58 26435     01012000
 5 TEMP         135   1    1 26435     01012000
 5 TEMP         135   1    2 26435     01012000
 5 TEMP         135   1    3 26435     01012000
 5 TEMP         135   1    4 26435     01012000
 5 TEMP         135   1    7 26435     01012000
 5 TEMP         135   1   29 26435     01012000
```

- Modification of BUFR file for the 1 station experiment:

rule6.txt file:

```
set unpack=1;
```

```
transient statid=1000*blockNumber+stationNumber;


if (statid == 12843) {
  write "12843_new.bufr";
}
```

command:

```
bufr_filter rule6.txt  bufr_5_test01_xx_2024110312
```

- AROME namelist settings (namel_bator):

```
 &BUFR
GPSSOLMETHOD='CENT',
NBTEMPMAXLEVELS=4000, ! has to be large enough as burtemp data have sometimes several 1000 levels
TEMPSONDSPLIT=.TRUE.,
!TEMPSONDORTRAJ=.TRUE., ! if this is set to false, trajectory information of the radiosonde is applied (balloon is not assumed just to rise vertically), but this causes memory issues for us so far, if more than one sonde used.
ELIMTemp0=.TRUE.,
NFREQVERT_TPHR=360, ! vertical prethinning switch 400 is MF setting and also works for us.
TS_AMSUA(206)%t_select%SclStart=1,
TS_AMSUA(206)%t_select%SclJump=0,
TS_AMSUA(206)%t_select%FovInterlace=.TRUE.,
…
/
```