New nowcasting frame-work in ALADIN/CHMI

Alena Trojáková, Antonín Bučánek, Patrik Benáček

Numerical Weather Prediction Department, Czech Hydrometeorological Institute, Prague, Czech Republic

Introduction

Adapted mesoscale NWP systems have shown a capability to be used successfully for nowcasting thanks to the use of recent observations. Particularly high-resolution wind information is essential for formation of small horizontal scale features and deep vertical structures in extra-tropics. Therefore, modern air traffic surveillance systems (Mode-S radars) have received substantial attention since they are able to provide high-resolution observation of wind and temperature (de Haan, 2011; Strajnar, 2012).

The quality assessment of new aircraft Mode-S observations available in the airspace of the Czech Republic is presented. The new nowcasting frame-work based on adaptation of the NWP system ALADIN operated at Czech Hydrometeorological Institute (ALADIN/CHMI) is described. Finally, the impact of Mode-S MRAR data assimilation is explored in a nowcasting context via near real time high resolution analyses.

NWP system

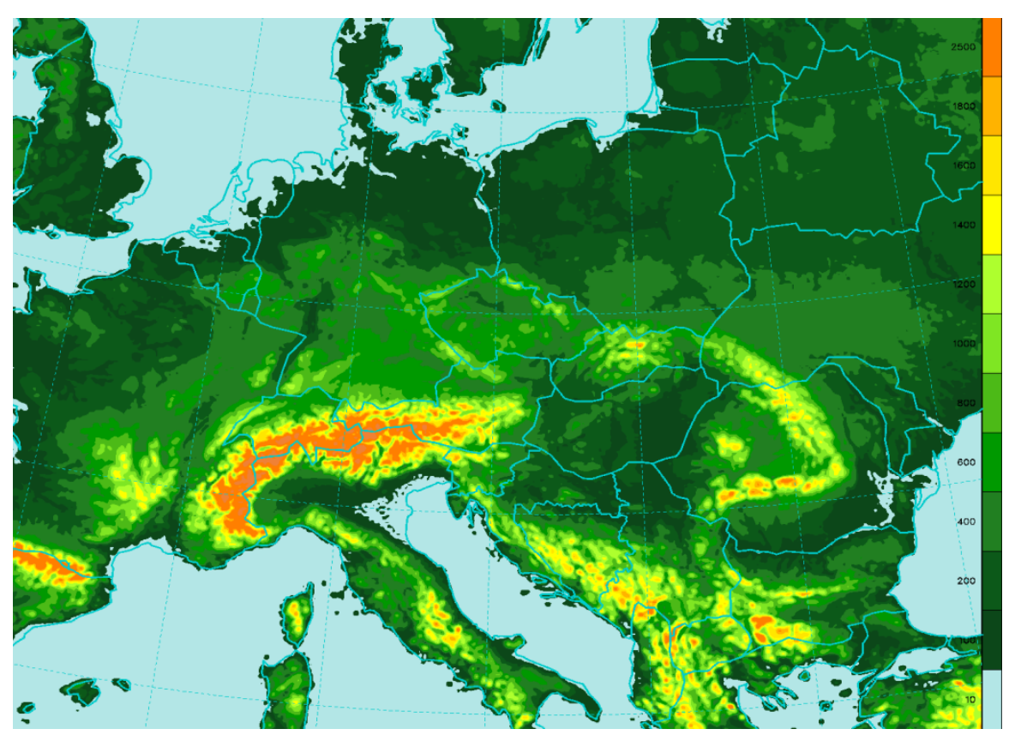


Figure 1: Orography of model domain

ALADIN/CHMI couples hydrostatic dynamics and the set of ALARO-1 physical parameterizations suited for modeling atmospheric motions from planetary up to the meso-gamma scales.

- domain (529x421 grid points, linear truncation E269x215, Δx~4.7km)
- 87 vertical levels, mean orography
- time step 180 s, 3h coupling interval
- 00, 06, 12/18 UTC forecast to +72/54h

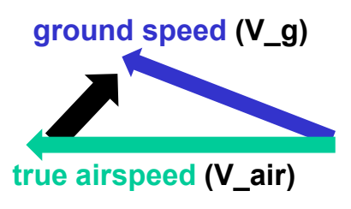
Data assimilation includes surface analysis based on an optimal interpolation (OI) and **BlendVar** analysis for upper air fields, which consists of the digital filter spectral blending (Brozkova etal., 2001) followed by 3DVAR analysis based on the incremental formulation originally introduced in the ARPEGE/IFS global assimilation (Courtier etal., 1994).

- digital filtering at truncation E87x69; space consistent coupling
- no DFI in long cut-off 6h cycle; incremental DFI in short cut-off analysis

Quality assessment of Mode-S data in the Czech airspace

The Mode-S radar can determine from an active transponder-equipped aircraft two type of meteo data:

Mode-S MRAR data	**Mode-S EHS** data
• Meteorological Routine Air Report (MRAR)	• Enhanced Surveillance (EHS)
• optional (only ~4% aircraft)	• mandatory
• **direct air temperature** measurement	• **indirect temperature**=f(V_air, Mach no.)
• **wind** = f(V_air,V_g) computed on board	• **wind** = f(V_air,V_g) computed on ground, preprocessing step for the heading is crucial as aircraft orientation can have biases
• available in Central Europe (Slovenia, Czech Republic)	• available mainly in Western Europe



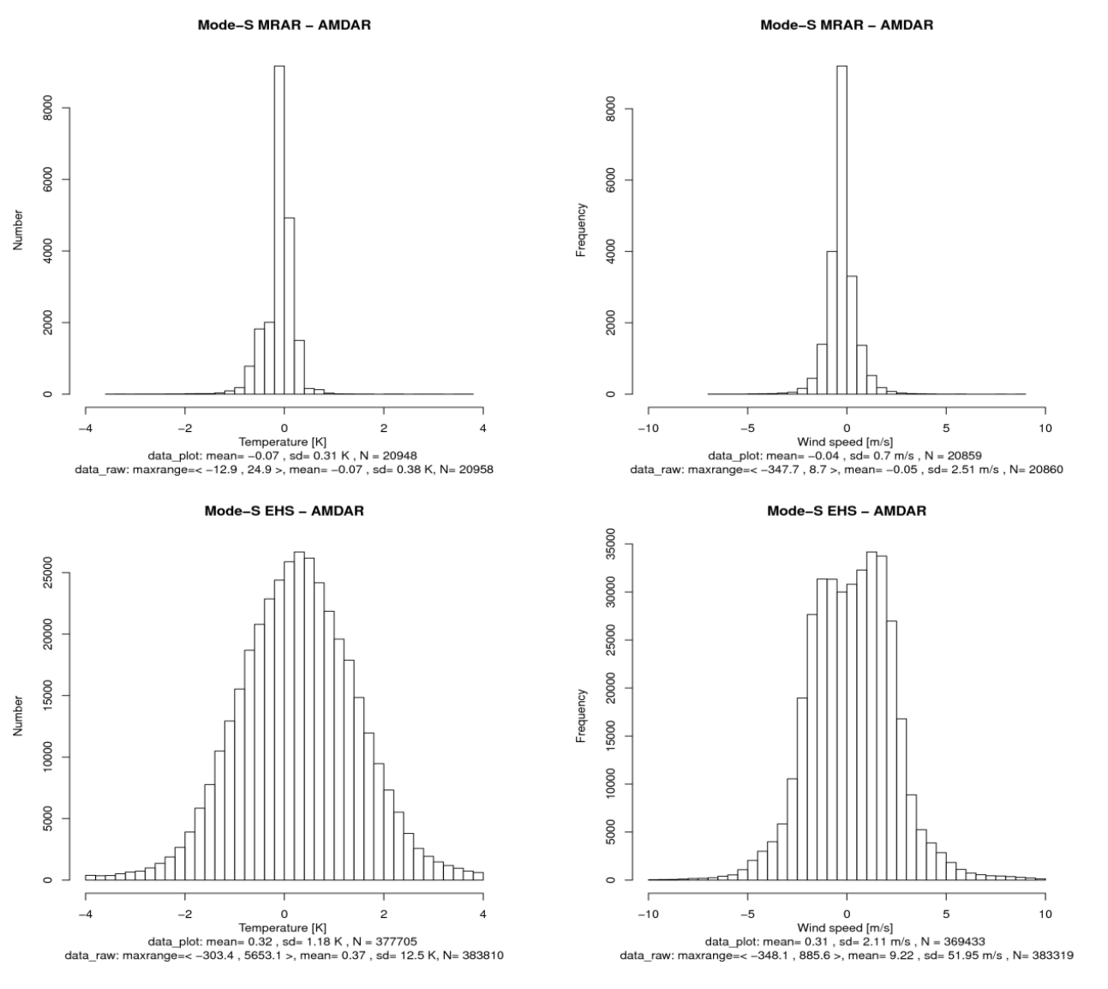


Figure 2: Histogram of Mode-S MRAR (top) / EHS (bottom) and AMDAR differences for temperature (left) and wind speed (right).

Mode-S and AMDAR collocations

Quality of new meteorological observations is widely assessed by comparison with other measurements or NWP model. Such a comparison provides only indirect error estimation, since it combines errors of both new and reference data. Following studies of de Haan (2011) and Strajnar (2012) a collocation technique with respect to AMDAR is used to validate Mode-S data in Czech airspace over period of July – 20 October 2015. Histograms of Mode-S and AMDAR collocated pairs differences are normally distributed and have small spread for MRAR, which means good agreement with AMDAR. Mode-S EHS differences except for wind speed are also normally distributed and the spread of EHS differences is much larger then for MRAR, see Figure 2. Collocation statistics aggregated in 1km layers (Figure 3) show no bias for MRAR differences above 1km and small bias for EHS ones, while RMS of EHS differences is 3-5 times larger than MRAR RMS. Reasons of the large increase of the collocation statistics below 1km are not yet clear, but height assignment and/or preprocessing of AMDAR is suspected due to the higher atmospheric variability close to ground. The RMS of Mode-S MRAR – AMDAR differences are comparable with uncertainty of AMDAR measurements, which means that quality of Mode-S MRAR is similar to AMDAR and they are suitable for data assimilation after the quality check with respect to NWP model. Mode-S EHS data are slightly more biased and RMS is 3-5 times larger than MRAR RMS. The latter results are in agreement with de Haan (2011) who proposed more advanced preprocessing to improve EHS data quality.

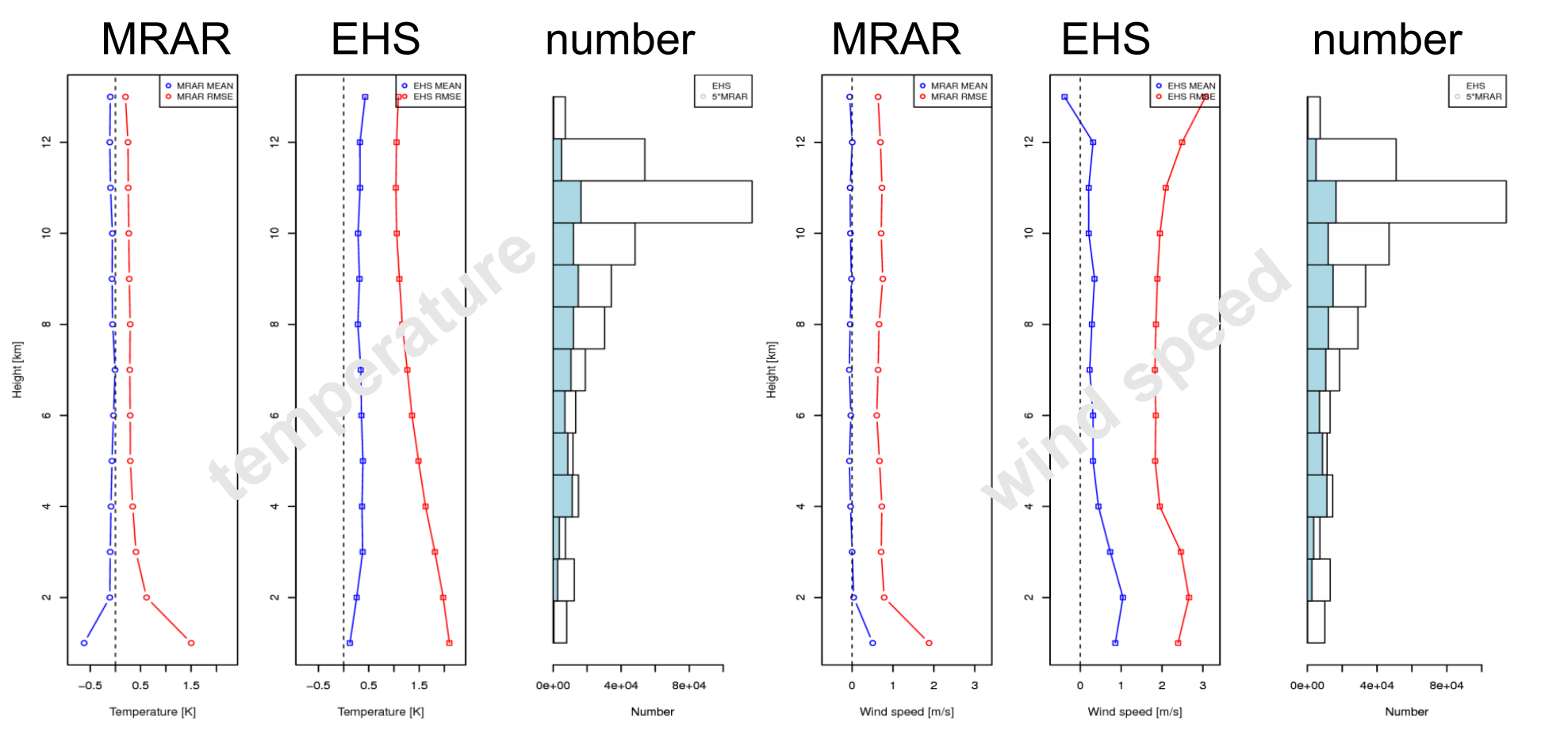


Figure 3: Vertical profile of Mode-S differences with respect to AMDAR, BIAS and RMSE for MRAR and EHS collocations with corresponding number of data.

Design of the nowcasting frame-work

The new nowcasting frame-work is based on adaptation of the operational NWP system ALADIN/CHMI. Only hourly analyses (0 hour fcst) are considered as starting point, but the system can be further extended by +6h forecast. The goal is to produce atmospheric state as close as possible to reality taking into account all available information, such as observations, NWP model and physical constrains, to identify regions where severe weather could appear.

The 3DVAR and OI algorithm are employed and the operational forecast with different lead times are used as the first guess, see Figure 4. The 3DVAR analysis (of T, div, vor, q and p_s) is done first, the hydrometeors are not analyzed but copied from the first guess. The B matrix has not been particularly tuned, but tuning of background and observation errors is planned.

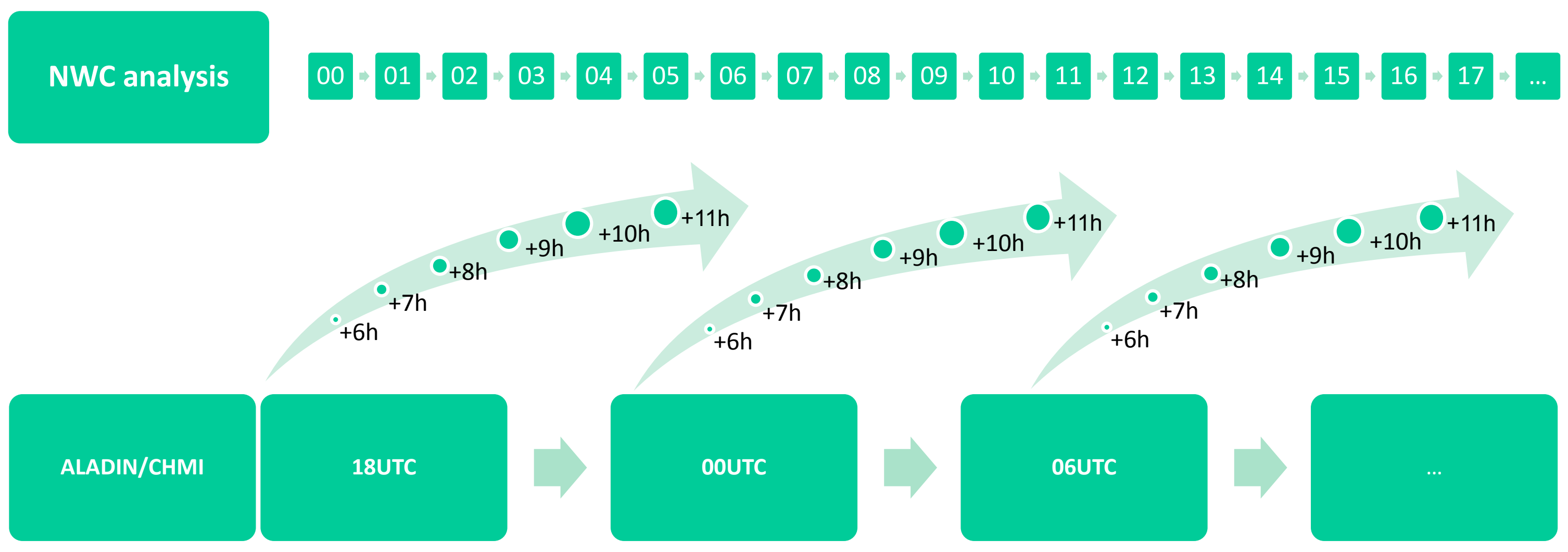


Figure 4: The scheme of the ALADIN/CHMI operational forecast used as the first guess for hourly analyses.

Afterwards the OI method is used to analyze screen-level parameters, such as 2m temperature and relative humidity and 10m wind. This concept is not used in the operational NWP setup because the screen-level parameters are diagnosed and can not be incorporated into the subsequent forecast. This can be also seen as a simple approach to overcome a difficulty of the 3DVAR to minimize the screen-level parameters being functions of the last model level and the surface variables, e.g. T_{2m}= f(T_N ,T_{surf}), see Auger etal. (2014).

Observations are essential to constrain the analysis. The observation cut-off time is reduced to 20min to provide the hourly results as soon as possible approx. 30min after validity time. SYNOP, AMDAR, AMV and SEVIRI data are considered (TEMP are not available due to a very short cut-off). The number of available observations is varying during time of a day, see Figure 5. Overall around 2500 observations are assimilated in the upper-air analysis in the day-time. Around half of used data comes from aircraft and this number can be further increased by Mode-S MRAR observations (by ~50%).

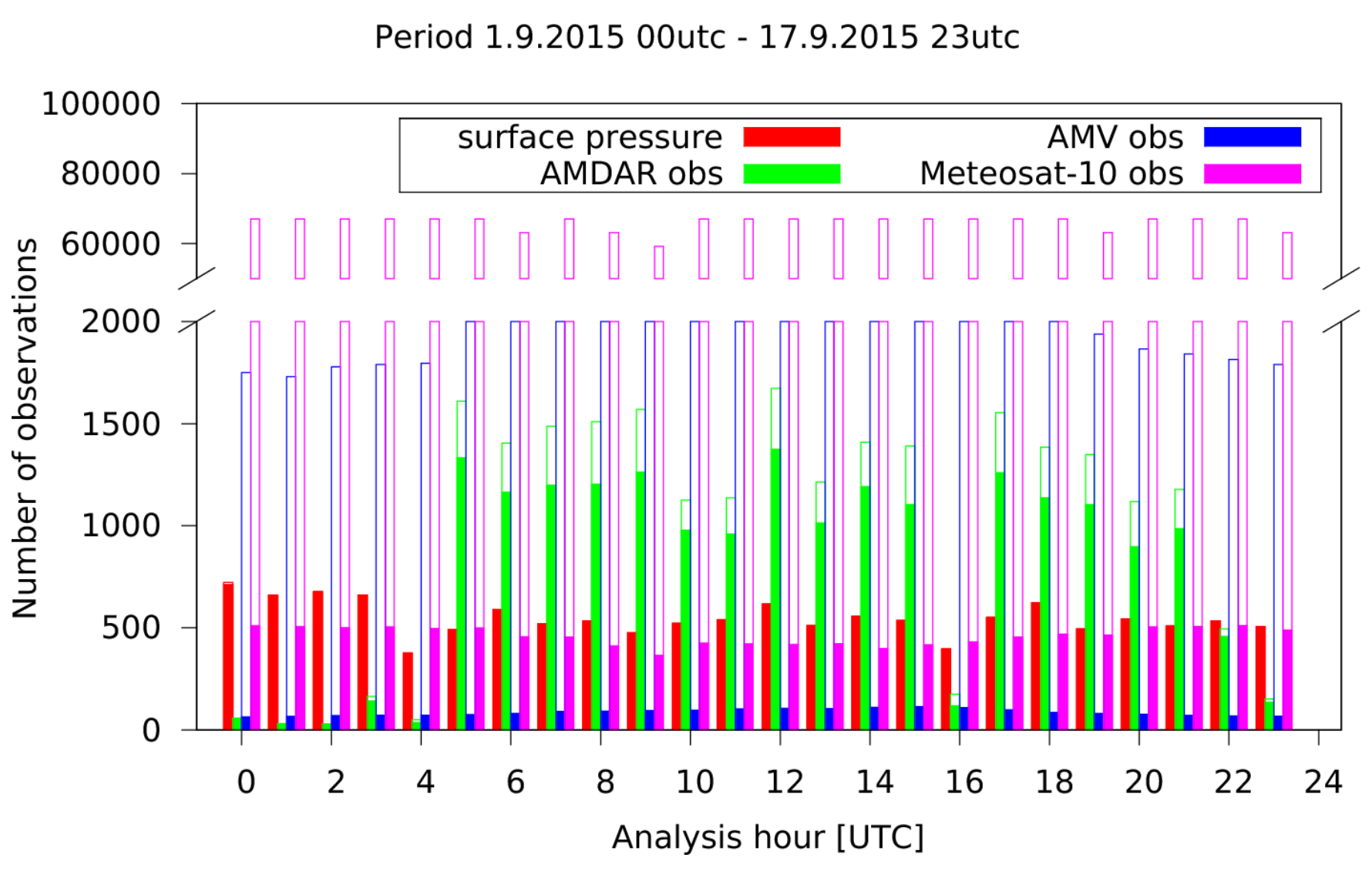


Figure 5: The average number of available observations at analysis start (empty boxes) and the average number of used observations in the upper-air analysis (filled boxes).

First results of hourly nowcasting analyses

The impact of new aircraft Mode-S MRAR data assimilation was evaluated for analyses over the period of 1–17 Sep 2015.

- REF – analyses used SYNOP, AMDAR, AMV and SEVIRI
- REF+MRAR – MRAR data assimilated on the top of the REF data

Verification methodology

Mode-S MRAR data are high resolution and local, covering only the Czech Republic and its surroundings. Verification focused to a sub-area of the model domain covered by Mode-S data. The verification domain is well covered by aircraft data and by limited TEMP (12 stations for 00,12 UTC and 5 stations for 06,18UTC), see Figure 6. Keep in mind that TEMP are not available within +20min cut-off and provides independent data for verifications. MRAR were considered ±30 minutes around each hour. The verification sample of MRAR observations includes the subset of independent observations not assimilated at analysis time.

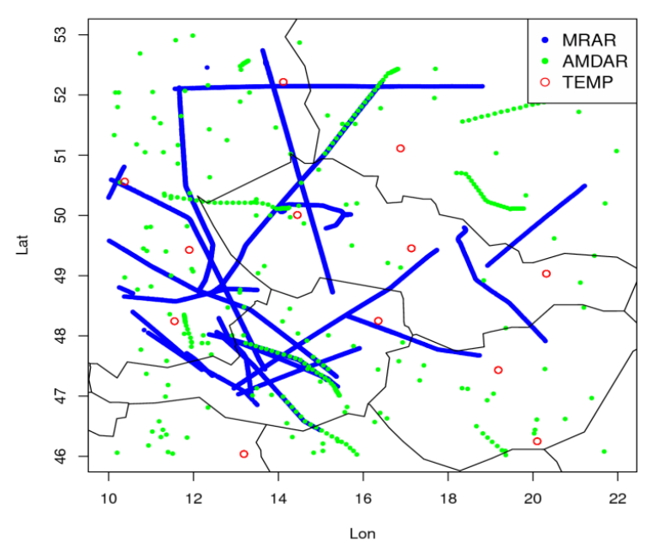


Figure 6: Observation coverage for 18 July 2015 at 12UTC.

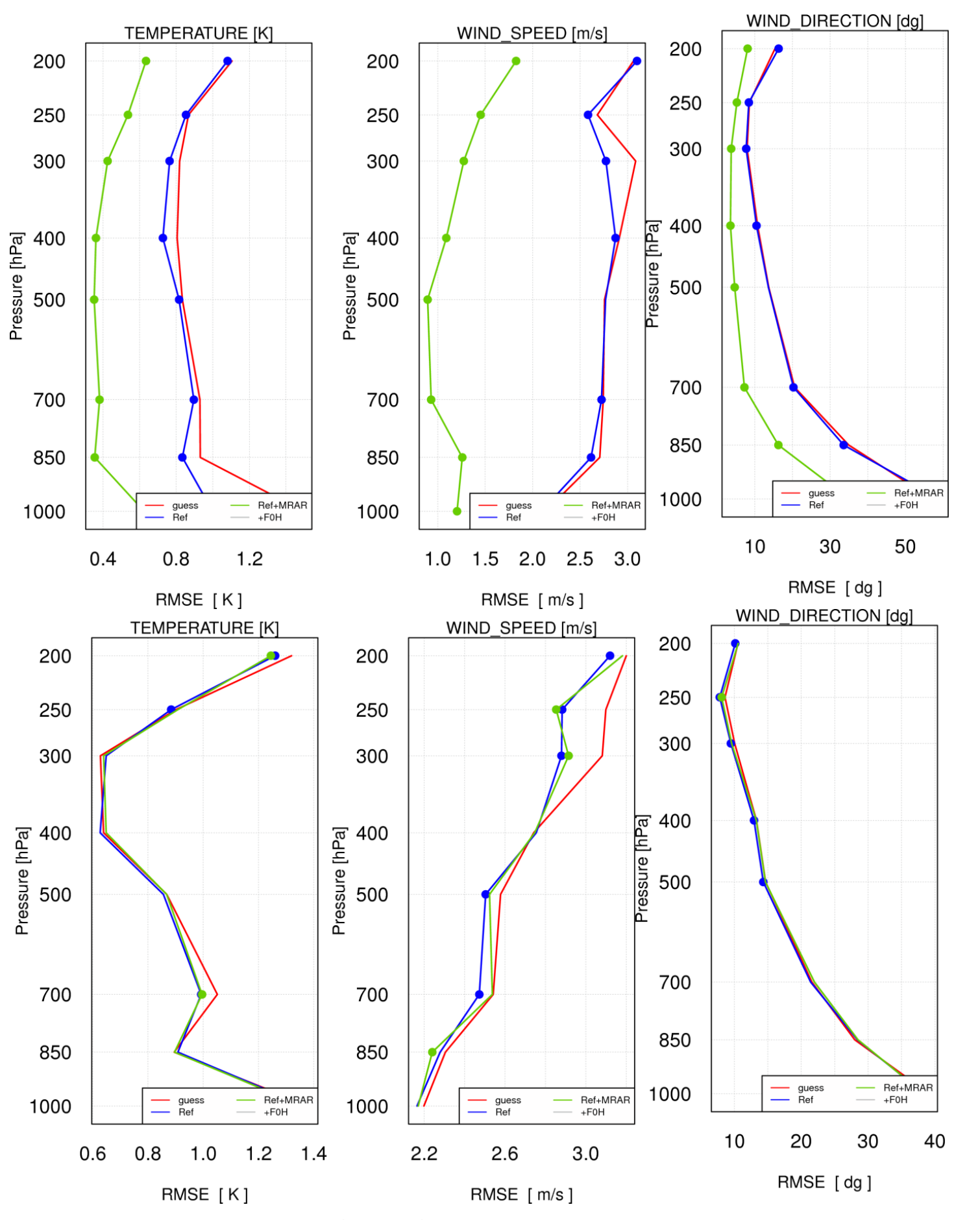


Figure 7: The RMSE of analyses with respect to MRAR (top) and TEMP (bottom) observations for the first guess (red), REF analyses (blue) and REF+MRAR (green).

Verifications scores with respect to TEMP observations showed a very small positive impact of the REF analyses for temperature around 700hPa and 200hPa and wind speed above 700hPa, see Figure 7 (bottom). The impact of MRAR data assimilation is mostly neutral.

Verifications scores with respect to MRAR observations, which are considered as suitable high resolution reference, showed similar improvements of the REF analyses as against TEMP and a clear positive impact of MRAR data assimilation for all parameters, see Figure 7 (top).

The impact of MRAR data assimilation is illustrated on the case study on 3rd December 2015, see Figure 8. A temperature inversion over Prague was captured quite well by the first guess (red), the REF analysis assimilating SYNOP, AMDAR, AMV and SEVIRI did not improve the inversion description (blue), while the analysis with added assimilation of MRAR data (green) is much closer to the aerological sounding (black).

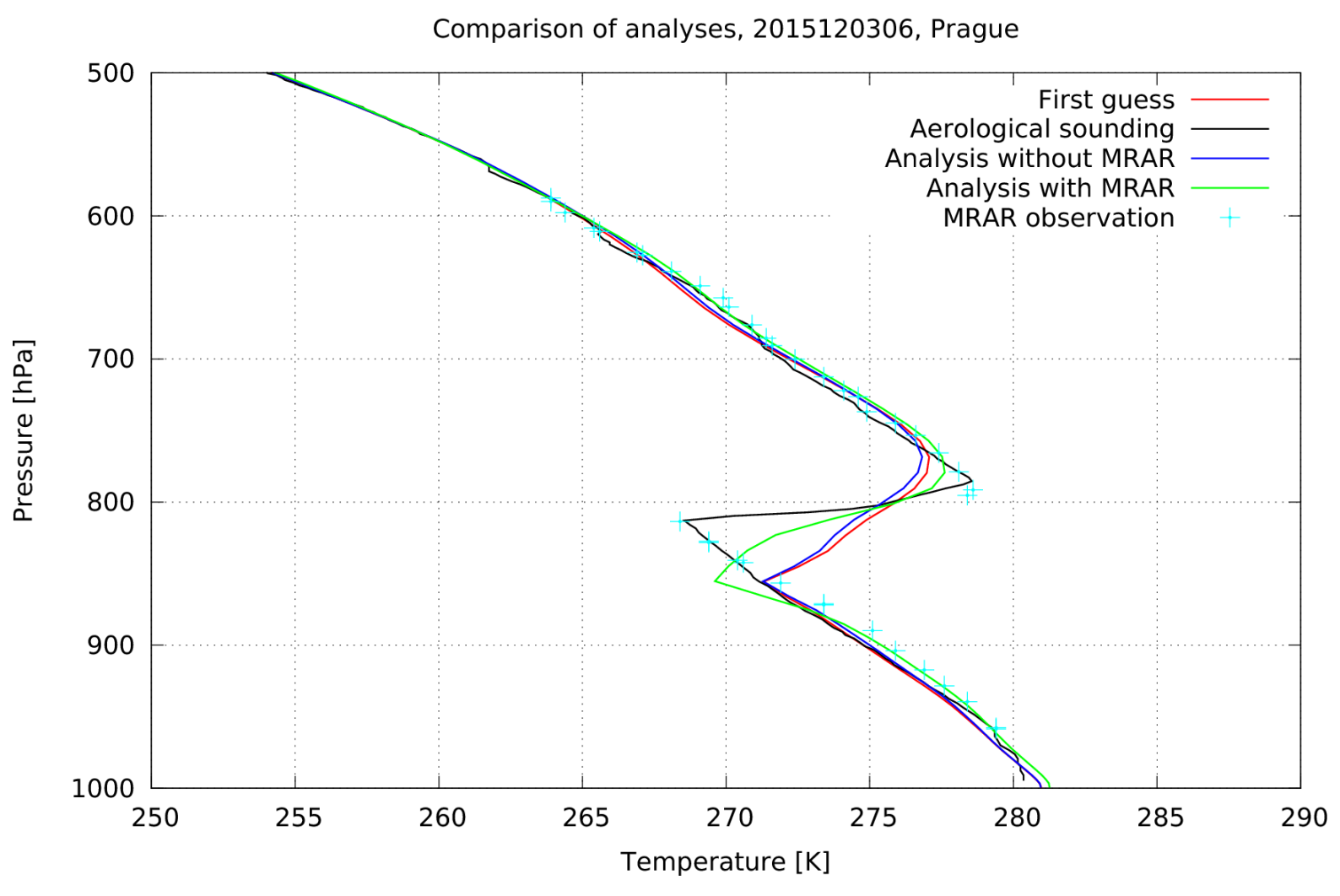


Figure 8: The comparison of analysis with and without MRAR data and corresponding observations.

Conclusions

The nowcasting frame-work based on adaptation of the operational NWP system was designed using 3DVAR and OI method. Only hourly analyses are considered at the moment, but the system can be further extended by subsequent forecast. The quality of new aircraft Mode-S observations available in the airspace of the Czech republic was assessed. The collocation with AMDAR revealed that Mode-S MRAR are of comparable quality to AMDAR, while Mode-S EHS data have larger variability and errors. The potential of Mode-S MRAR observations was explored in a nowcasting context via near real time high resolution analyses of upper-air wind and temperature. Verification against independent observations showed encouraging results. Mode-S MRAR observation have potential to improve the analysis and can be beneficial for the aviation community both as observations and via improved weather forecast.

Acknowledgements

The authors wish to acknowledge Air Navigation Service of the Czech Republic for the Mode-S data. This study was supported by the project of the Technology Agency of the Czech Republic (TA CR) TH01010503.