Assimilation of high-resolution aircraft Mode-S observations in ALADIN/CHMI

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Introduction

Modern air traffic surveillance systems (Mode-S radars) have received substantial attention in recent years due to its capability to provide not only an accurate knowledge of the position of the aircraft, but also meteorological information (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 NWP system ALADIN operated at Czech Hydrometeorological Institute (ALADIN/CHMI) is used to evaluate impact of the Mode-S observations on very short range forecast. Finally, data assimilation aspects such as the data thinning and weight of Mode-S observations are discussed.

NWP system

ALADIN/CHMI couples hydrostatic dynamics and the set of ALARO-1 physical parametrizations 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

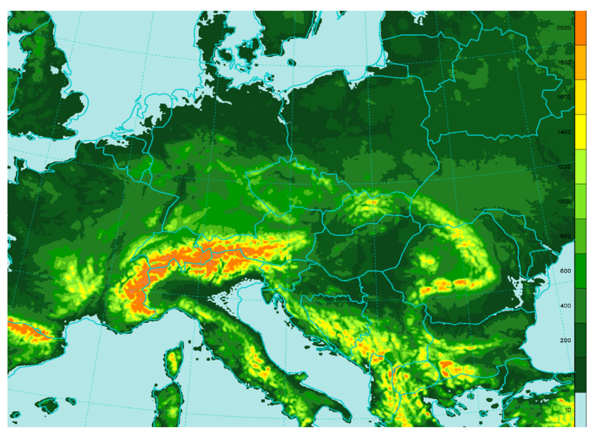


Figure 1: Orography of model domain

Data assimilation includes surface analysis based on an optimal interpolation 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).

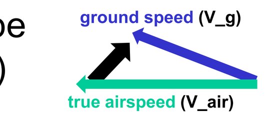
- digital filtering at truncation E87x69; space consistent coupling
- no DFI in long cut-off 6h cycle; incremental DFI in short cut-off analysis

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

- Meteorological Routine Air Report (MRAR)
- optional (only ~4% aircraft)
- **direct air temperature** measurement
- **wind** = f(V_air,V_g) computed on board
- available in Central Europe (Slovenia, Czech Republic)



Mode-S EHS data

- Enhanced Surveillance (EHS)
- mandatory
- **indirect temperature**=f(V_air, Mach no.)
- **wind** = f(V_air,V_g) computed on ground, preprocessing step for the heading is crucial as aircraft orientation can have biases
- available mainly in Western Europe

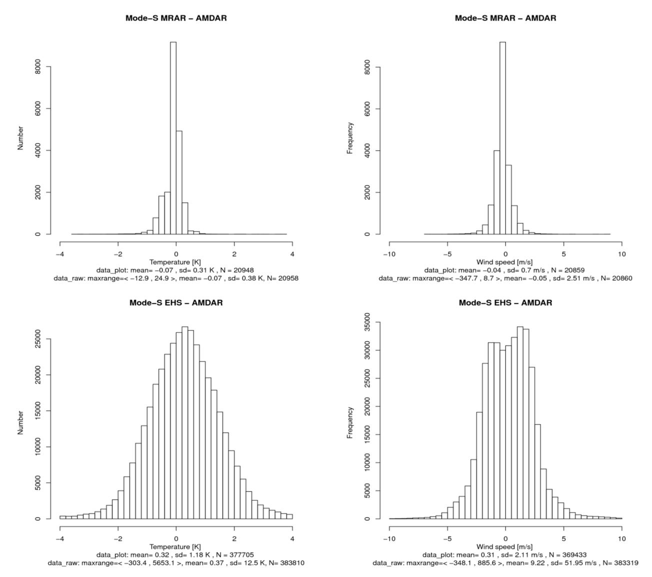


Figure 2: Histogram of Mode-S MRAR (top) / EHS (bottom) and AMDAR differences for temperature (left) and wind speed (right).

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. Mode-S EHS data are slightly more biased and RMS is 3-5 times larger than MRAR RMS.

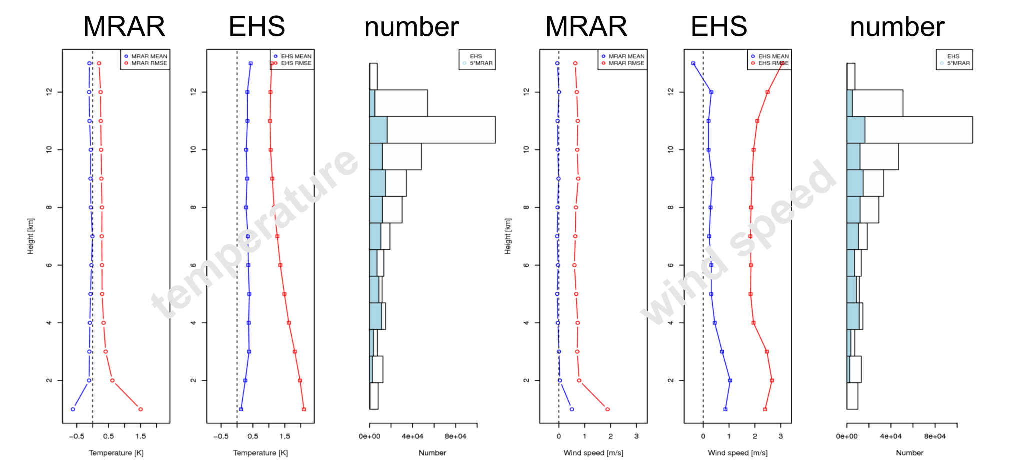


Figure 3: Vertical profile of Mode-S differences with respect to AMDAR, BIAS and RMSE for MRAR and EHS collocations with corresponding number of data.

Impact of Mode-S MRAR on very short range forecast

Only Mode-S MRAR observations were used in the first assimilation impact studies. The impact was investigated by running two experiments in 6-hour assimilation cycle for period 1 – 30 June 2015.

- REF – reference used operational ALADIN/CHMI BlendVar with SYNOP, TEMP, AMDAR, AMV and SEVIRI data
- EXP – MRAR data assimilated on the top of the reference

Table 1: Criteria for MRAR aircraft whitelist

	obs number	MEAN	STD
Temperature	3000	< 1 K	< 2 K
Wind speed	3000	< 1 m/s	< 5 m/s
Wind direction	3000	< 10deg	< 100deg

Following Strajnar et al. (2015) only a good quality MRAR observations were selected based on observation minus guess departures criteria from Table 1.

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. 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 4.

All data were used for verifications. MRAR and AMDAR were considered ±30 minutes around each hour. The verification sample of MRAR observations includes the subset of independent observations not assimilated in analysis time.

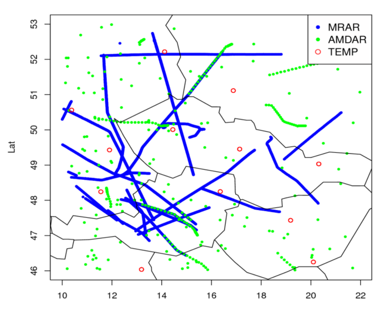


Figure 4: Horizontal coverage of observations for 18 July 2015 at 12UTC

Verifications results with respect to AMDAR (not shown) **and TEMP** (see Figure 5) showed a small degradation at analysis time for EXP using MRAR observations and in the next 2-6 hours of forecast the impact was almost neutral on RMSE. For MAE only small degradation of wind speed at higher levels and a small improvement for the wind direction at 700 hPa was observed.

Verifications with respect to Mode-S MRAR showed an obvious improvement at analysis time for both RMSE and MAE. However this impact disappear after few hours (1-2h). The duration of the positive impact differs for different levels and parameters. A slight positive impact on RMSE is observed up to 3 hours for temperature as well as up to 6 hours of forecast for both wind parameters.

Overall, the results indicate that MRAR data assimilation has a positive impact on the wind at the lower levels, while at the higher levels, there is a neutral impact on all parameters in RMSE and a small degradation of the wind speed MAE. The negative effect is probably due to over fitting of the MRAR observations in analysis

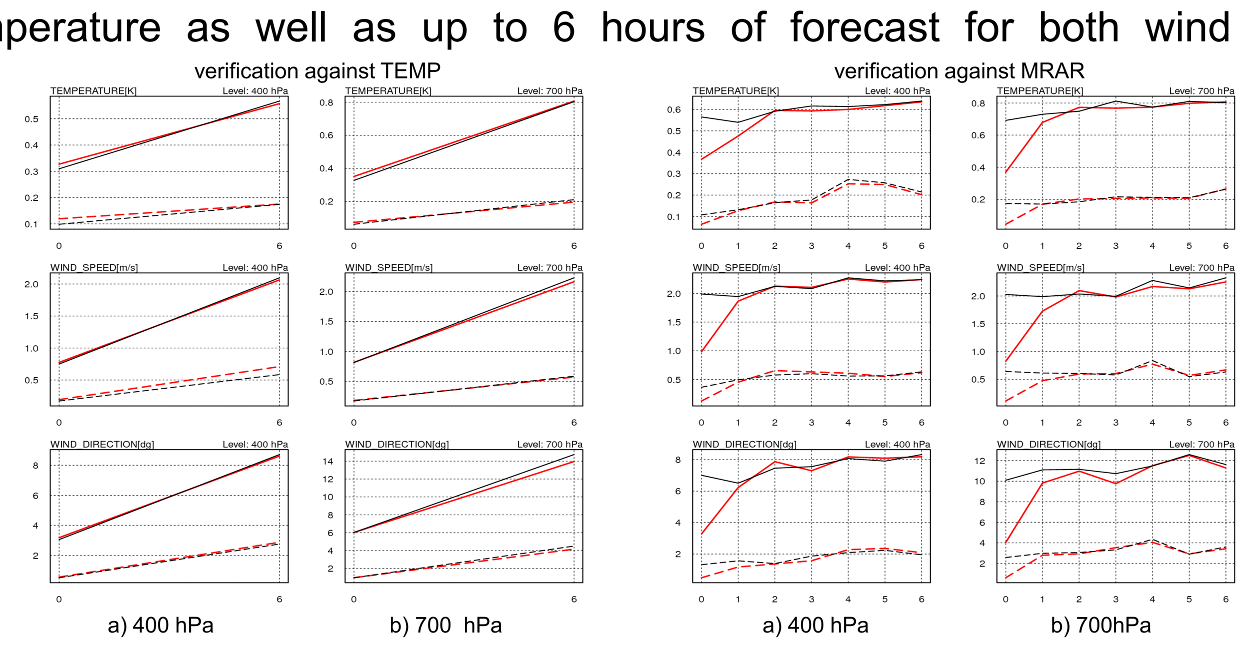


Figure 5: RMSE and MAE statistics for **REF** and **EXP** with respect to TEMP and MRAR data,

Optimization of Mode-S MRAR data assimilation

An optimal MRAR **data thinning** was studied. The method of Desroziers etal. (2005) was used to estimate spatial error correlations, see Figure 6. The threshold-error correlation 0.2 (see Liu and Rabier, 2003) was found for separations larger than 25-35km, which suggest that currently used thinning of 50km can be further reduced.

The impact of the thinning setting to 25km was evaluated for period of 25 Feb – 5 Mar 2016. Verifications scores showed a very small positive impact of the new setting for +3h forecast of temperature and wind speed, see Figure 7.

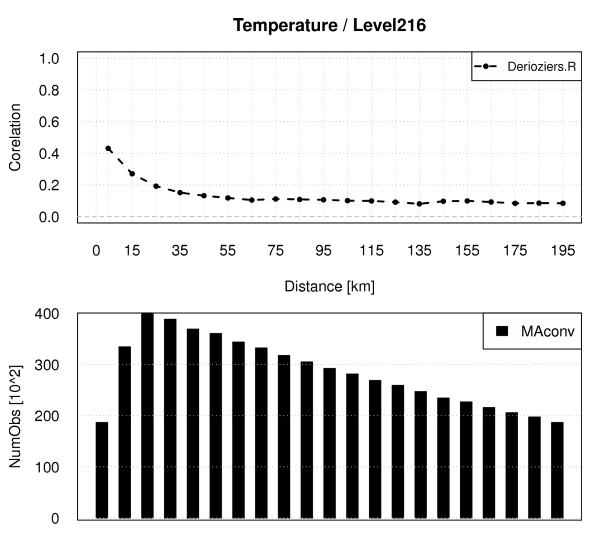


Figure 6: Estimate of spatial error correlations for MRAR temperature at 216hPa and number of collocations as a function of separation distance.

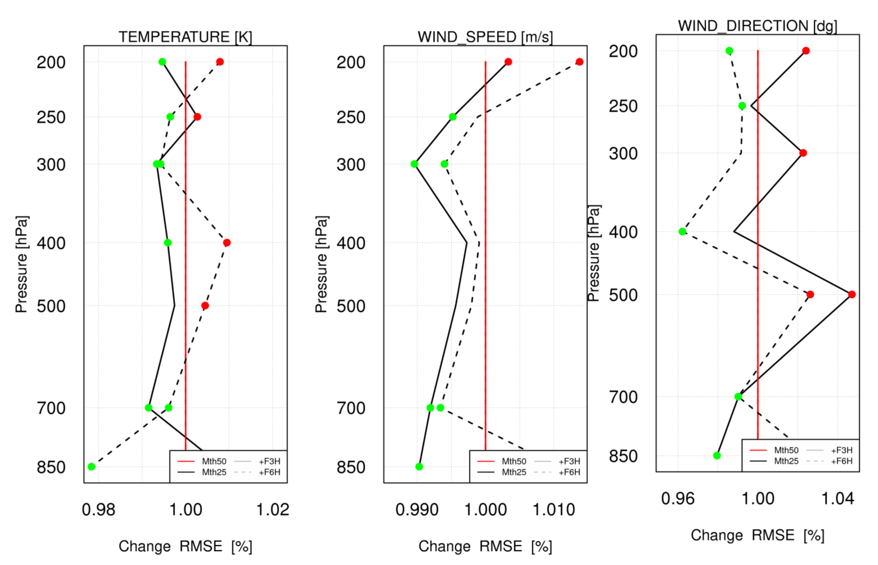


Figure 7: The relative change of RMSE of 3h (solid) and 6h (dashed) forecast for the thinning of 50km (red) and 25km (black) wrt MRAR data.

The setting of **observation errors** is being revised. Preliminarily results suggest that the aircraft (AMDAR and MRAR) observation errors are underestimated. Sensitivity tests with ad-hoc increased observation errors (by factor of 1.5 and 3) showed mostly a small positive impact of +6h forecast of all parameters in the verifications with respect to MRAR (not shown) and TEMP (see Figure 8).

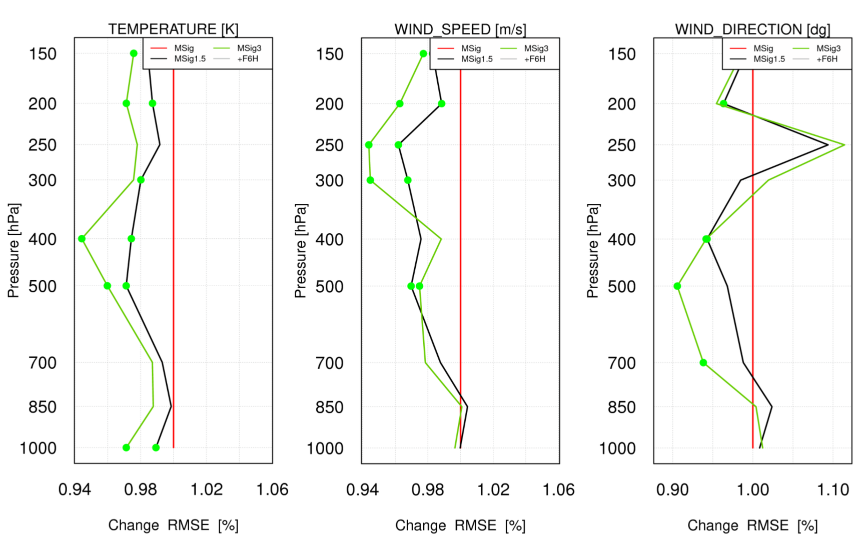


Figure 8: The relative change of RMSE of 6h forecast wrt TEMP for default σ_o (red),1.5*σ_o (black) and 3*σ_o (green) .

The combined effect of both tunings is illustrated on the case study on 2nd March 2016. There are almost no differences between the reference and default MRAR experiment (not shown), while the optimized assimilation of MRAR simulates much better the precipitation band over the northwest of the Czech Republic, see Figure 9.

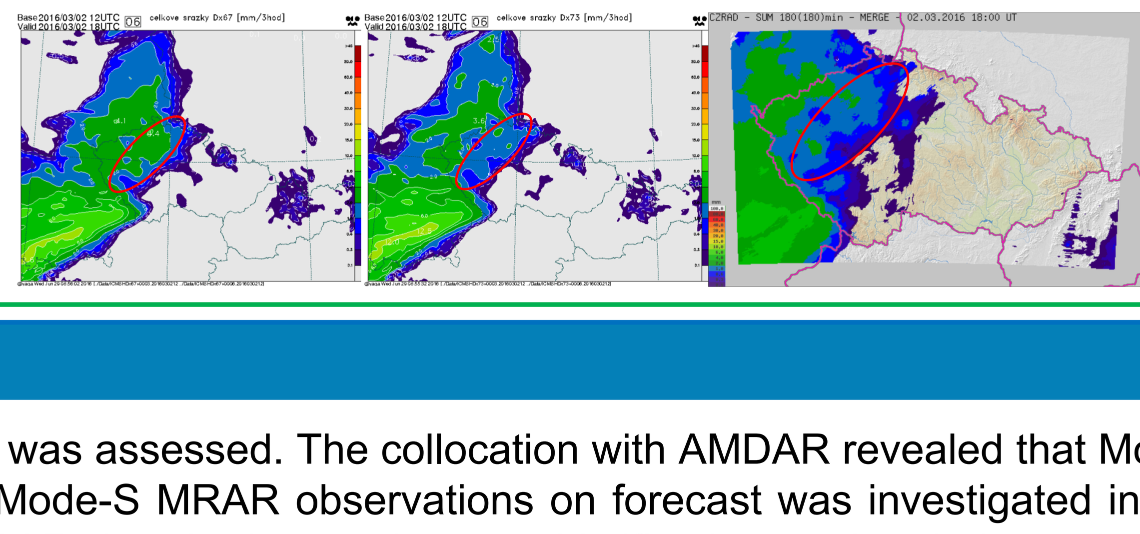


Figure 9: 3h precipitation forecast for 2 March 2016 12UTC for lead time of +6h for reference (left), MRAR experiment (middle) and observation - radar based quantitative precipitation estimate (right).

Conclusions

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 impact of Mode-S MRAR observations on forecast was investigated in ALADIN/CHMI. An appropriate observational reference for verification is questionable considering very high resolution of MRAR data in time and space. Verification against independent Mode-S MRAR observations, which are considered as suitable high resolution reference, showed clear positive impact in the first hours of the forecast. Further optimization of Mode-S MRAR data was investigated and preliminary results using 25km aircraft data thinning and increased observation errors are encouraging.

Acknowledgements

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