Assimilation of Mode-S data 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). Quality assessment of new aircraft Mode-S observations available in the airspace of the Czech Republic and the first results of an impact of the Mode-S observations on very short range forecast are presented.

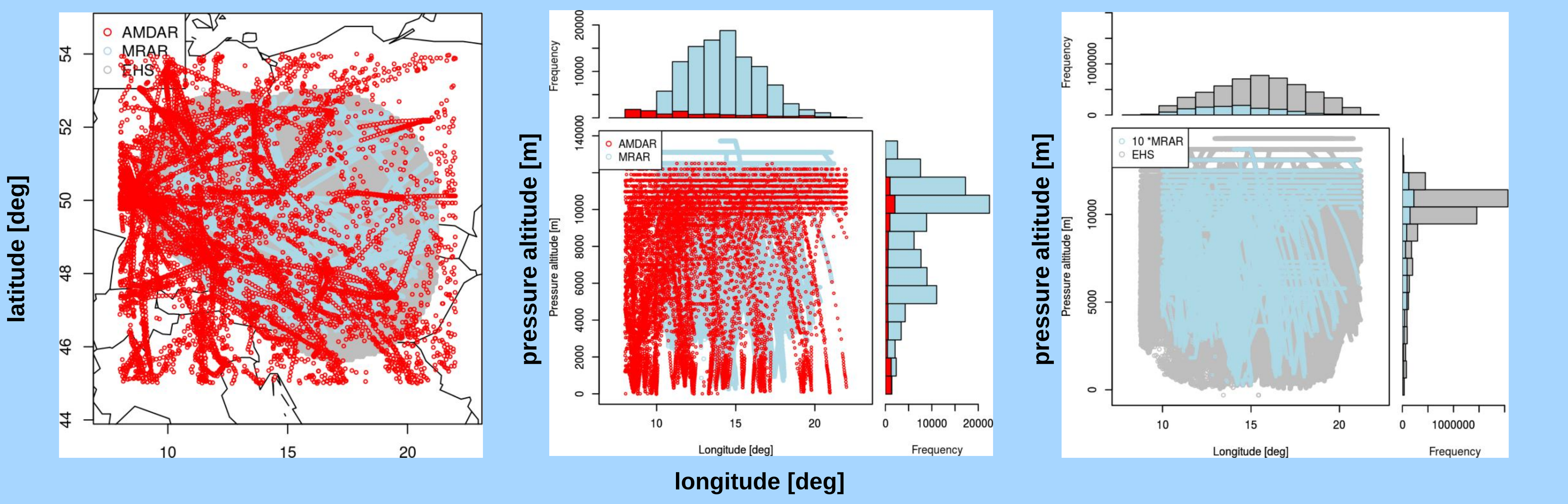
Mode-S data in the Czech airspace

Mode-S radar can determine from an active transponder-equipped aircraft:

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 steps for the heading is essential as aircraft orientation can have biases
- available mainly in Western Europe

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

ground speed (V_g)
wind
true airspeed (V_air)



Figures: Horizontal (left) and vertical (middle,right) coverage of Mode-S EHS/MRAR and AMDAR. observation on 1 August 2015.

Mode-S and AMDAR collocation

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 1 Jul – 20 Oct 2015.

AMDAR preprocessing, which comprises smoothing and averaging, precludes the absolute space and time match of AMDAR and Mode-S data. A predefined time and space separations are allowed to find collocated pairs:
- time mismatch 30s
- vertical separation 50m
- horizontal separation 15km

Histograms of Mode-S and AMDAR collocated pairs differences are normally distributed and have small spread for MRAR, which means good agreement with AMDAR, see Figure 2. 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 3. Difference statistics aggregated in one km layers (Figure 4) show there 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 to be an issue due to the higher atmospheric variability close to ground.

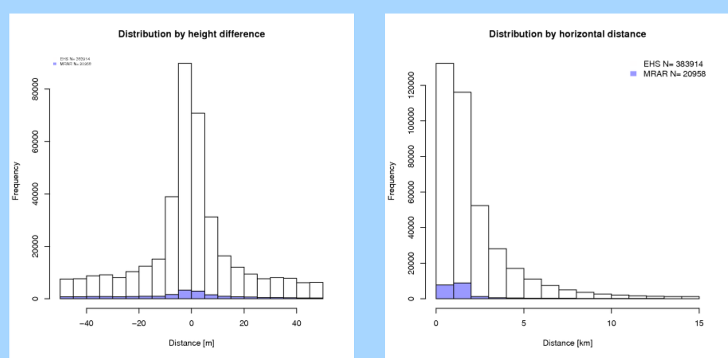


Figure 1: Distribution of Mode-S EHS/MRAR and AMDAR horizontal/vertical separations.

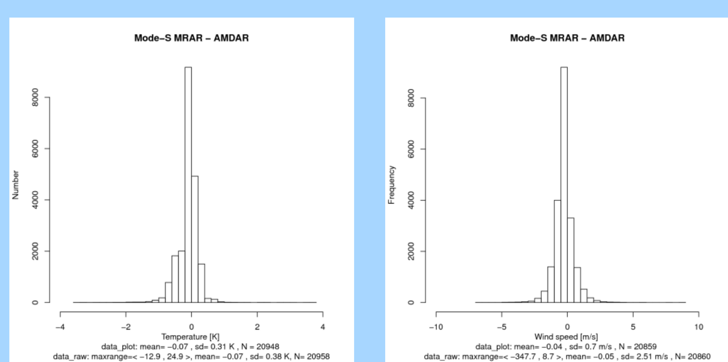


Figure 2: Histogram of MRAR and AMDAR differences for temperature and wind speed.

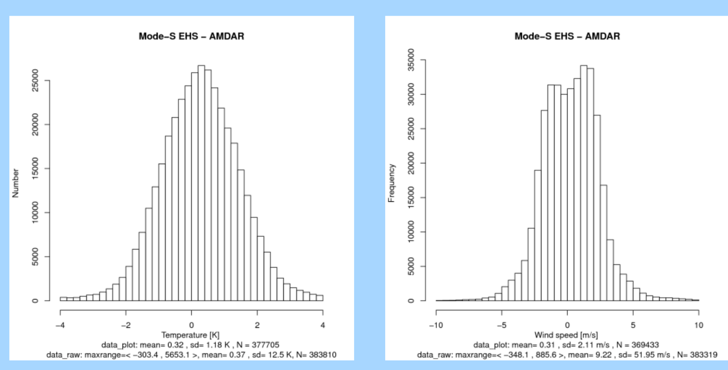


Figure 3: Histogram of EHS and AMDAR differences for temperature and wind speed.

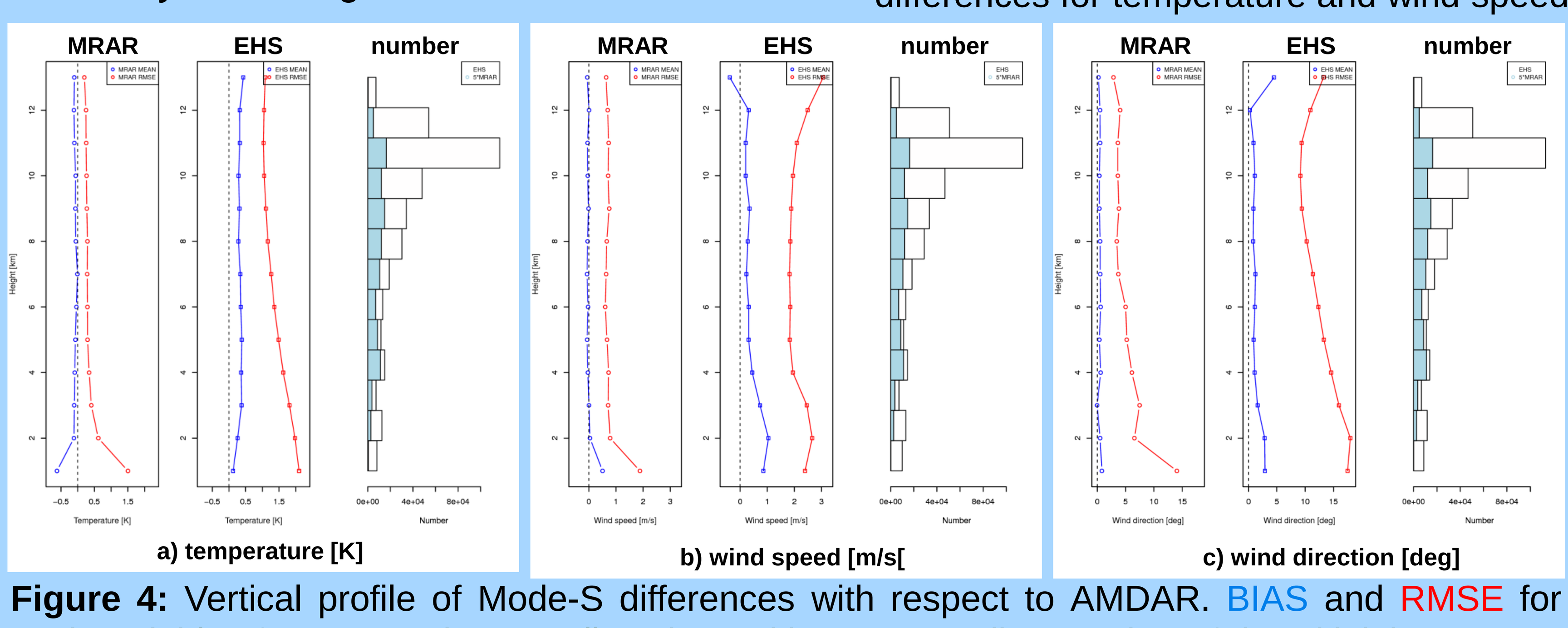


Figure 4: Vertical profile of Mode-S differences with respect to AMDAR. BIAS and RMSE for each variable of MRAR and EHS collocations with corresponding number of data (right).

Summary: 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. AMDAR offers a good observation reference but it is limited to AMDAR equipped aircraft. Moreover, over 99% of MRAR collocations come from single aircraft type Canadair CRJ and over 95% of EHS collocations come from Airbus A321 (32%), A319 (26%), A320 (24%), Canadair CRJ (8%) and Boeing 737 (5%).

Impact of Mode-S MRAR on assimilation cycle

Only Mode-S MRAR observations were used in the first assimilation impact study.

Mode-S MRAR "white list"

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

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

Table 1: Criteria used to create MRAR white list of aircraft

Set up of experiment

The impact of MRAR data was investigated by running two experiments in 6-hour assimilation cycle for period 1 – 30 June 2015. Production forecast were omitted as an impact is expected in the first hours of a forecast.
- **REF** – **reference** used operational ALADIN/CHMI **BlendVar** configuration with SYNOP, TEMP, AMDAR, AMV and SEVIRI data assimilated
- **EXP** – **MRAR** data assimilated on the top of the reference observations.

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 1. 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.

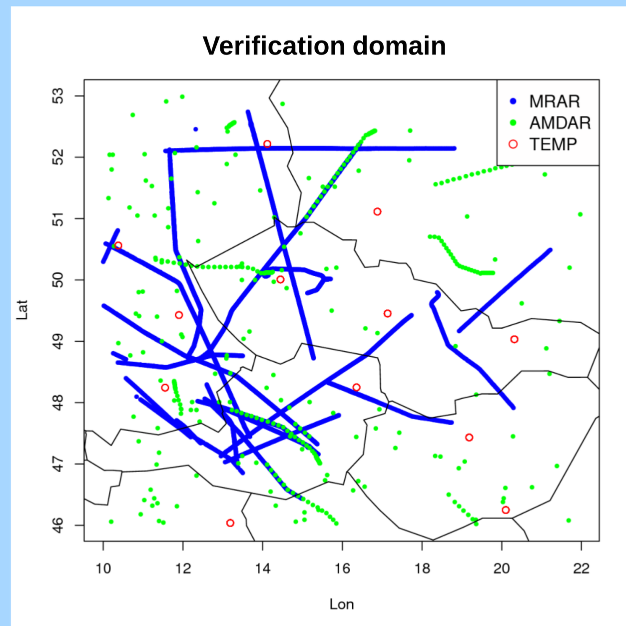


Figure 1: Horizontal coverage of observations for 18 July 2015 at 12UTC

Results

Verifications with respect to AMDAR (not shown) and TEMP 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 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.

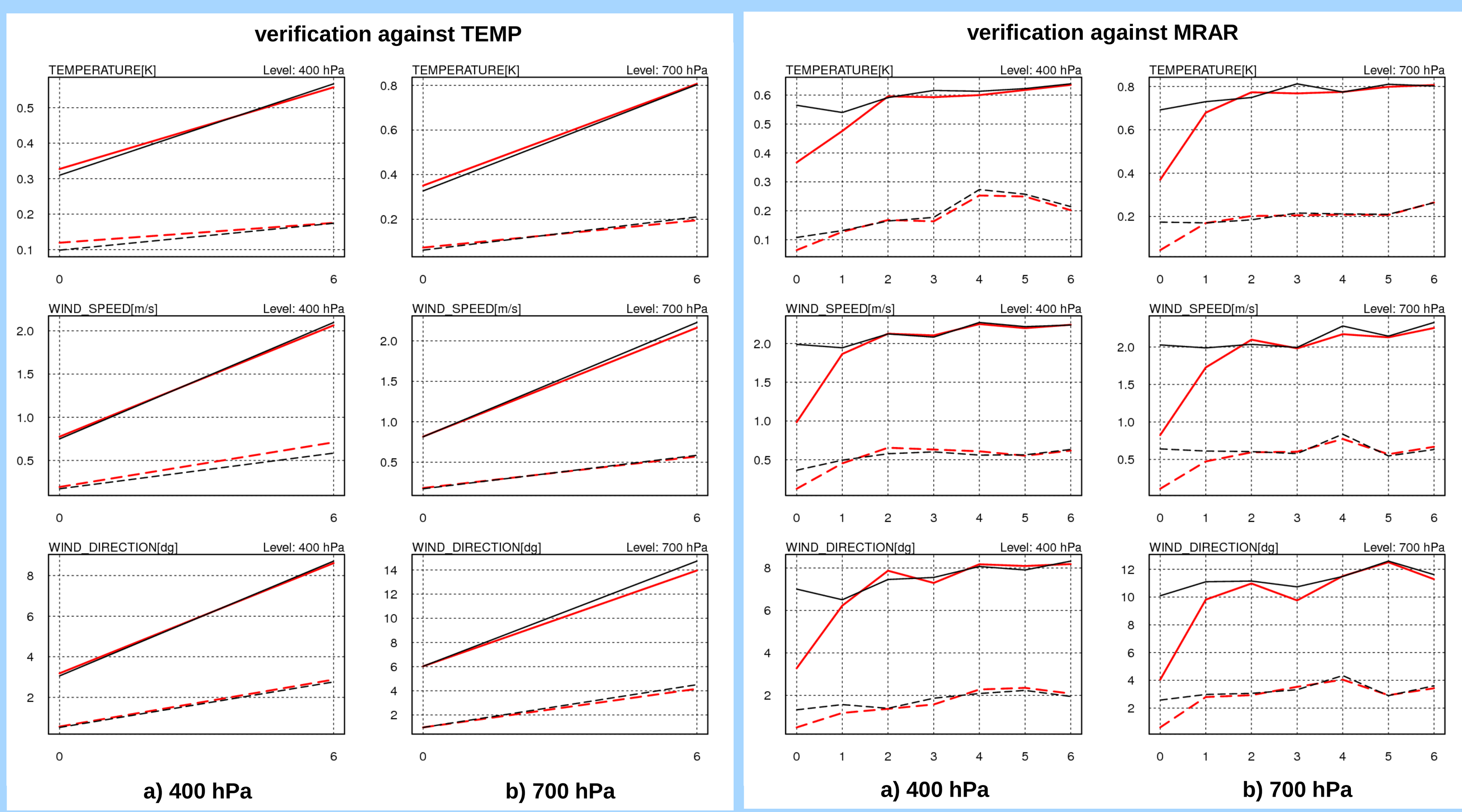


Figure 2: RMSE and MAE statistics for **REF** and EXP with respect to TEMP and MRAR data.

Conclusions

Impact of new aircraft 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 soundings and AMDAR aircraft observations showed mostly neutral impact, slight degradation was found at higher levels, while slight positive impact was observed at lower levels for wind. Verification against independent Mode-S MRAR observations, which are considered as suitable high resolution reference, showed clear positive impacts in the first forecast hours. The preliminary results are encouraging and an optimization of MRAR data assimilation, e.g. tuning of the observation errors and optimal thinning, will be a subject of the further investigation.

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