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APPLICATION OF X-BAND RADAR AND LIDAR WIND MEASUREMENT AT FRANKFURT AND MUNICH AIRPORTS FOR AIR TRAFFIC MANAGEMENT (ATM)

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1. INTRODUCTION

As a consequence of aircraft accidents arising from wind shear ICAO Annex 3 (2007) prescribes to warn on wind shear. In general, wind shear information originates from PIREPs which basically are issued rarely. Besides the low frequency of recording this method is not favorable since PIREPs are issued when at least one aircraft already passed the hazardous area. However, using classical measurement methods wind can be observed just selectively.

In particular, during landing and take-off operations wind shear plays a crucial role. Therefore ICAO Annex 3 (2007) recommends that information of wind shear between runway level and 1600 ft shall be updated at least every minute. Those criteria can be fulfilled consistently only by using remote wind measurement instruments. Consequently at the international airports of Munich and Frankfurt a X-band radar and a lidar have been installed to detect, quantify and warn automatically on wind shear during almost all weather situations (Weipert et al. 2014).

Despite basis for a low-level wind shear system, the measurement of the radar and lidar can be used for a variety of applications concerning weather observation and forecasting. This article will show different possibilities in meteorological usage of the remote sensing instruments X-band polarimetry radar and 1.6 µm lidar.

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2. SYSTEM OVERVIEW

In 2013 a SELEX Meteor 50DX radar and a Lockheed Martin WTX WindTracer lidar have been installed at the international airports of Munich (MUC) and Frankfurt (FRA). They are collocated on top of a parking deck in the middle of the airport (MUC and FRA; Figure 1).

The radar is a X-band system and the lidar emits 1.6 µm IR radiation. In general both instruments radar and lidar measure physical variables of the atmosphere in which the propagation time of the impulses is used to determine the distances. In case of X-band radar the emitted radio signals theoretically interacts with drops whereas in case of lidar the emitted IR light basically interacts with aerosols. By using the Doppler shift of reflected/backscattered signals radial velocity vector fields are determined.

In order to obtain similar high resolution measurements of both sensors lidar and radar the sampling rate has been adapted individually. Consequently, radar scan speed is set up faster than lidar scan speed (Table 1). The scan strategy is adapted to detect horizontal (microbursts, gust fronts, and runway-oriented wind shear) and vertical wind shear (see section 3). Every minute a 3° PPI glide path scan is performed (radar and lidar); by varying elevations a 3D volume is captured every 5 minutes. In addition, a long distance overview scan (150 km) at 0.5° elevation (azimuthal, radar) and 1 (MUC) to 2 RHI scans (FRA) along the runways (lidar) are performed.

3. APPLICATION

3.1 WIND SHEAR DETECTION

The preliminary goal of LLWAS based on lidar and radar is providing concise information on the observed or expected existence of wind shear which could adversely affect aircraft on the approach path or take-off path. Following wind shear techniques are used on lidar and on radar velocity data after suppression of non-meteorological and ambiguous radar echoes by different filter techniques (DFT clutter filter, multi-trip-echo filter and interference filter; Hannesen et al. 2014) and verification by inter-comparison (Ernsdorf et al. 2014): (1) Runway-oriented shear (ROSHEAR) which essentially provides information on loss and gain of aircraft lift when approaching to or departing from the airport, (2) Gust front (GF) is based on horizontal velocity convergence, (3) Microburst (MB) which uses reflectivity as well as radial shear segments of different heights, (4) Volume velocity processing (VVP) according to Waldteufel and Corbin (1979) in order to derive vertical wind profiles of 100 ft resolution.

In general, horizontal wind shear alerts from ROSHEAR are referred mostly of X-band radar data at FRA and MUC since a large amount of horizontal wind shear is related to precipitation; vertical wind shear events are mostly obtained from VVP wind profiles based on lidar velocity data as a fact of low-level temperature inversions connected with low-level jets (Weipert et al. 2014, Ernsdorf and Beckmann 2015). Figure 2 gives an example of ROSHEAR due to a frontal passage; Figure 3 gives an example of a vertical wind shear event as a consequence of a lifted inversion.

3.2 HYDROMETEOR, CLOUD DETECTION

In the case of FRA and MUC there exist overlapping of the LLWAS lidar and X-band radar measurements with C-band weather radar measurements of the German Weather Service (Deutscher Wetterdienst, DWD). These overlapping can be used as back-up. However, meteorological radar systems often are in some distance of airports; as a consequence there are measurement gaps of the lower atmosphere of the TMA (Terminal Manoeuvring Area). By using the dual polarized X-band radar and the lidar measurements at MUC atmospheric phenomena which influence aerospace management significantly like low stratus clouds connected with snow as well as precipitation types are able to be detected whereas in case of the C-band radar impulses do not interact with these phenomena or cannot be used to distinguish light snow for example. Figure 4 shows that (1) Stratus clouds can be detected either from radar or from lidar data at MUC, (2) measurement data are available either from radar or from lidar or from both sensors until at least 800 m AGL, (3) wind differences between radar and lidar are small.

3.3 3D WIND ANALYZE SYSTEM

In order to summarize all available wind data in the vicinity of airports within one domain for MUC a 3D wind prototype is under development (domain: 100 km x 100 km x 10 km, resolution: 1 km x 1 km x 0.5 km; Figure 5). Basically, X-band radar and lidar measurements are merged by a 3D variational analysis scheme (3DVAR) with additional measurements from C-band radar and radiosondes as well as wind retrievals from aircrafts using the selective mode (Mode-S; De Haan 2011, Sondij and De Haan 2011) of the tracking and ranging radar (TAR) at the airport.

Comparison studies with model results from COSMO-DE show a high benefit of the 3D wind system. In general, the RMSE decreases stepwise with growing data sets (Figure 6). In particular, the quality of the horizontal wind vector increases for the upper troposphere (higher than 5.5 km) by ingesting radar and Mode-S EHS data. First results show that the benefit of LLWAS data is valuable especially for the lower atmosphere.

3.4 NWP MODEL ASSIMILATION

Towards improving weather prediction at airports a highly regionalized prototype of the COSMO-DE (Consortium for Small-Scale Modelling - Germany) model has been developed for MUC the so-called COSMO-MUC (1.4 km; see Figure 7 for domain). Besides the observations in the vicinity of the airport which are used routinely for assimilation into COSMO-DE new data sources of the lidar and radar are used for assimilation into COSMO-MUC. In addition, the update cycle is increased from 3 hours to 1 hour.

In order to value the benefit of data assimilation for COSMO-MUC sensitivity studies have been performed using COSMO-MUC in comparison with COSMO-DE. In general, the results of COSMO-MUC show a high sensitivity as a fact of precise mapping of the atmosphere. Local effects on the atmosphere are displayed shown by the COSMO-MUC profiles in Figure 8. However, the effect of higher resolution on the quality of the forecasts for the TMA MUC is slightly positive on average concerning RMSE and bias. Figure 9 shows that the RMSE of COSMO-MUC wind is of maximum 0.5 m/s lower than of COSMO-DE wind for predictions of 0 - 3 hours. In general, an extrapolation of the observation by assumption of continual conditions show a positive impact on the nowcast quality. However, the decrease of the quality coming along with forecast time depends on the atmospherical dynamics.

3.5 TIME-BASED SEPARATION

According to the regulation no. 716/2014 of the European Commission (2014) distance based aircraft separation shall be replaced by Time-Based aircraft Separation (TBS) for example at MUC and FRA. TBS consists in the separation of aircraft in sequence on the approach to a runway using time intervals instead of distances. The replacement aims on enhancement of airport capacities by reduction of distances between aircrafts when wind thresholds are reached. A TBS support tool is required to be developed based on local meteorological information providing actual glide slope wind conditions. However, wind speed and wake-vortices dissipation are correlated; when the aircraft head wind component increases wake-vortices dissipate faster thus distances can be reduced.

Since the X-band radar and lidar at MUC are located in such a way that scanning directions are rather parallel of all runways head and tail wind can be approximated precisely (averaged maximum RMSD and bias of 1.45 m/s respectively 0.17 m/s; Ernsdorf 2014). Consequently, these high-resolution X-band radar and lidar wind data are suitable as input for TBS.

4. SUMMARY AND CONCLUSIONS

Abrupt changes of wind velocity can cause serious aircraft hazards. Wind shear poses a great danger during climb-out and approach operations since aircraft air speed and height are near critical values, thus rendering the aircraft susceptible to the adverse effects of wind shear. In order to detect, quantify and alert on the presence of vertical and horizontal low-level wind shear a novel combined system based on X-band Doppler polarimetric radar and 1.6 µm Doppler lidar measurements has been developed and installed at the international airports of Frankfurt (FRA) and Munich (MUC). As a fact of the combination of both sensors the wind field can be observed in rain as well as in clear air conditions. In general, horizontal wind shear alerts are referred mostly of X-band radar data since a large amount of horizontal wind shear is related to precipitation. By comparison vertical wind shear is linked to low-level jets as a fact of temperature inversions during clear-sky conditions.

In the case of FRA and MUC there exist overlapping of airport X-band radar and lidar measurements with C-band radar measurements of the German Weather Service. The overlapping can be used as back-up of each system. However, as a consequence of different frequencies as well as different measurement points the reflected impulses are of different range and magnitude. On the other hand, gaps of the lower atmosphere of the TMA can be closed by X-band radar measurements. By using the dual polarized X-band radar and lidar measurements atmospheric phenomena which influence ATM significantly like low stratus clouds are able to be detected.

During adverse weather conditions air traffic separations have to be regulated adequately. Therefore a 3D wind analyze system (domain: 100 km x 100 km x 1 km, resolution: 1 km x 1 km x 0.5 km) based on a 3DVAR scheme as well as COSMO-MUC (1.4 km, 1 h update cycle) a highly regionalized version of COSMO-DE have been developed for the TMA of MUC. Consequently, analyze and prediction qualities are improved. Enhanced studies will be on development of now-casting of wind by a linear Kalman filter using the X-band radar and lidar measurements. Instead of assimilation of measurement data into NWP models, model data are foreseen to be used for now-casting of wind. Additional information for example about precipitation or thunderstorms could be depicted by ensembles or probabilistic tools which are useful information for regulation and separation of aircrafts as well.

In order to minimize delays and cancellations the goal of the European Commission (2014) is to develop ATC including increase of landing capacities. Landing capacities intend to be increased by substitution of Distance Based Separation (DBS) by Time Based Separation (TBS) of aircrafts at big European airports for example FRA and MUC. In context of TBS implementation, the X-band radar and lidar wind data of the glide paths will play a key role since wake-vortices dissipation depends significantly on wind conditions.

ACKNOWLEDGEMENTS

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TABLE

Table 1: Specifications and scan strategy of radar and lidar.

Parameter	Radar (SELEX Meteor 50DX)	Lidar (Lockheed Martin WTX WindTracer)
Wave length	3.2 cm (X-band)	1.6 µm
Tracer	Hydrometeors	Aerosols
Polarization	Dual	Linear
PRF	2000:1600 Hz	750 Hz
Scan speed	18°/sec (3D: up to 36 deg/sec)	14°/sec
Scan range	75 km	12-15 km
Radial resolution	0.15 km	0.10-0.12 km
Azimthual resolution	1°	≈ 2.5°
Scan per minute	PPI @ 3°	PPI @ 3°
Scan once per 5 minutes	3D scan (11 PPIs 1.0-60.0°)	3D scan (5 PPIs 1.5-20.0°)
	PPI scan @ 150 km range @ 0.5°	1-2 RHI scans

FIGURES

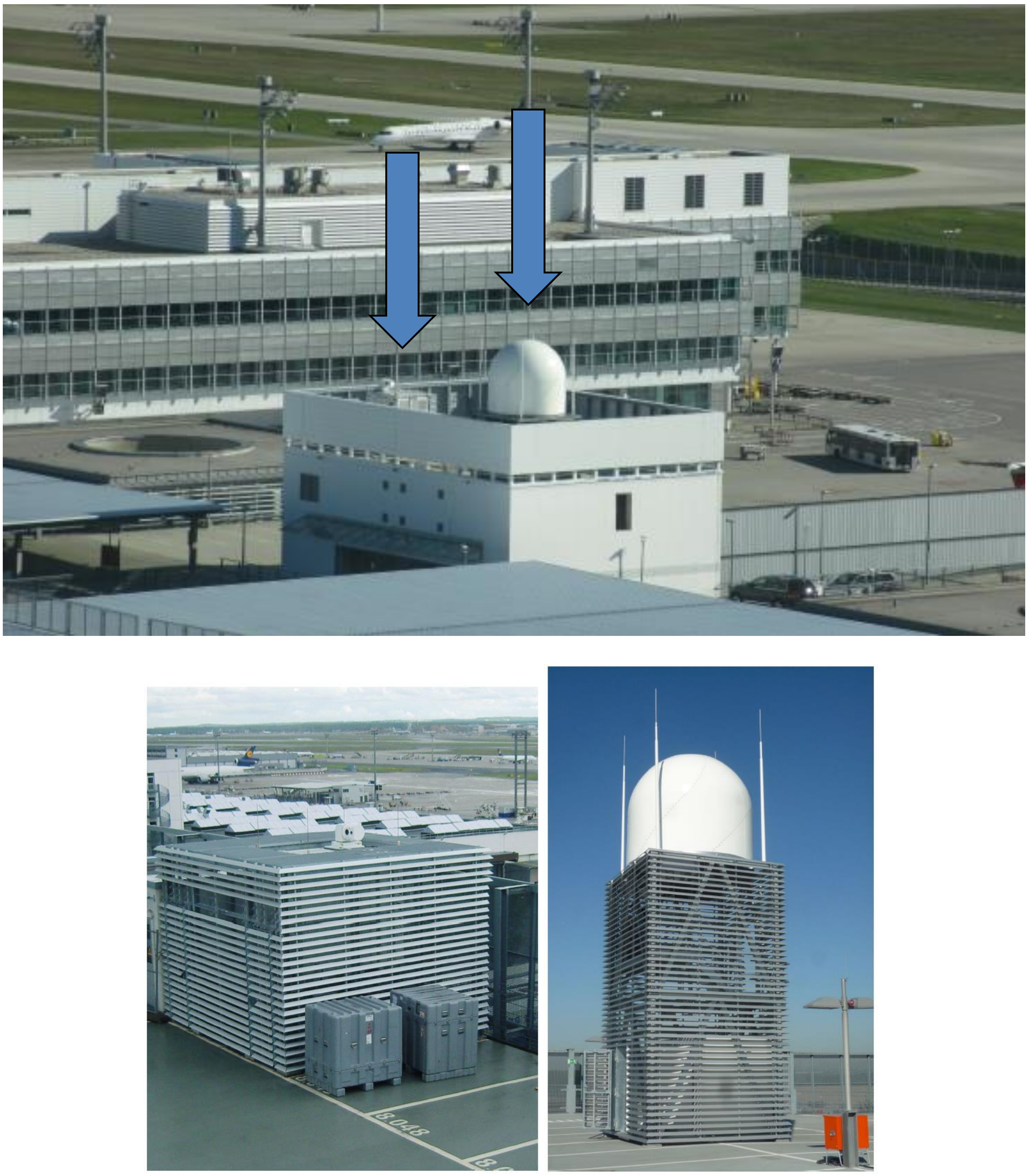


Figure 1: Lidar (left) and radar (right) at Munich Airport (top photo: Ernsdorf) and Frankfurt Airport (bottom photo: Weipert et al. 2014).

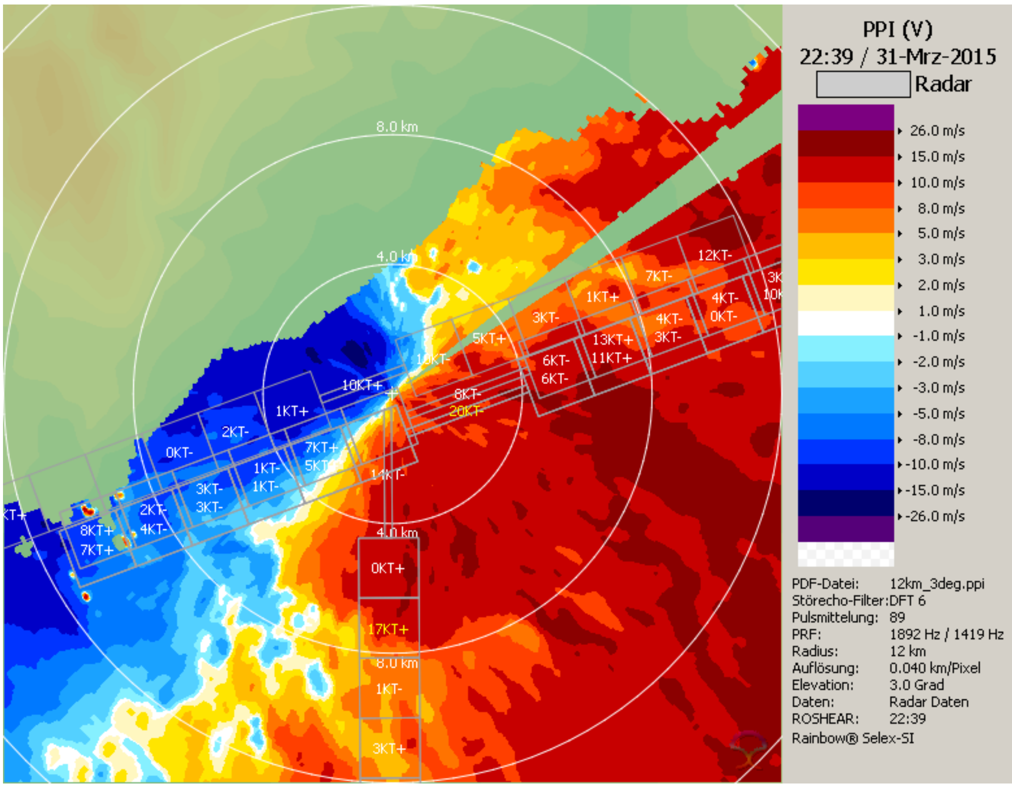


Figure 2: Radar radial velocity and ROSHEAR for Frankfurt airport.

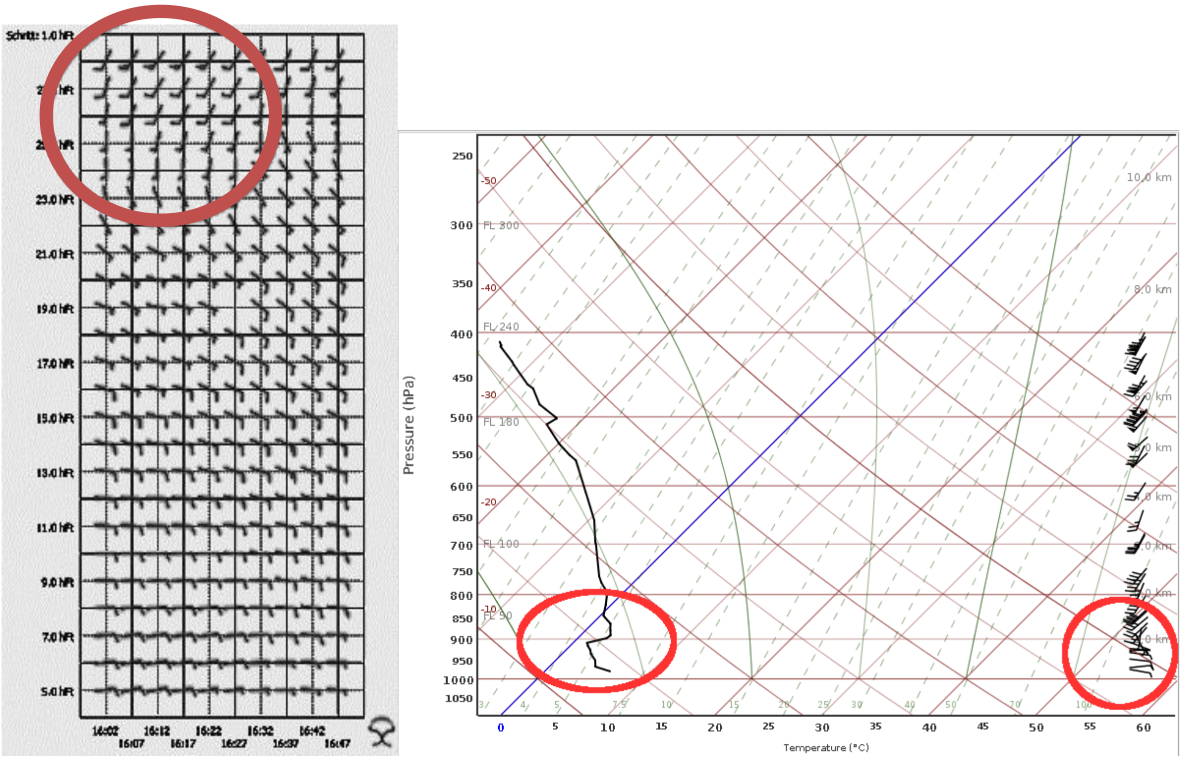


Figure 3: LLWAS vertical wind profiles for 16:02 UTC – 16.47 UTC (left panel), AMDAR vertical temperature and wind profiles for 16.30 UTC (right).

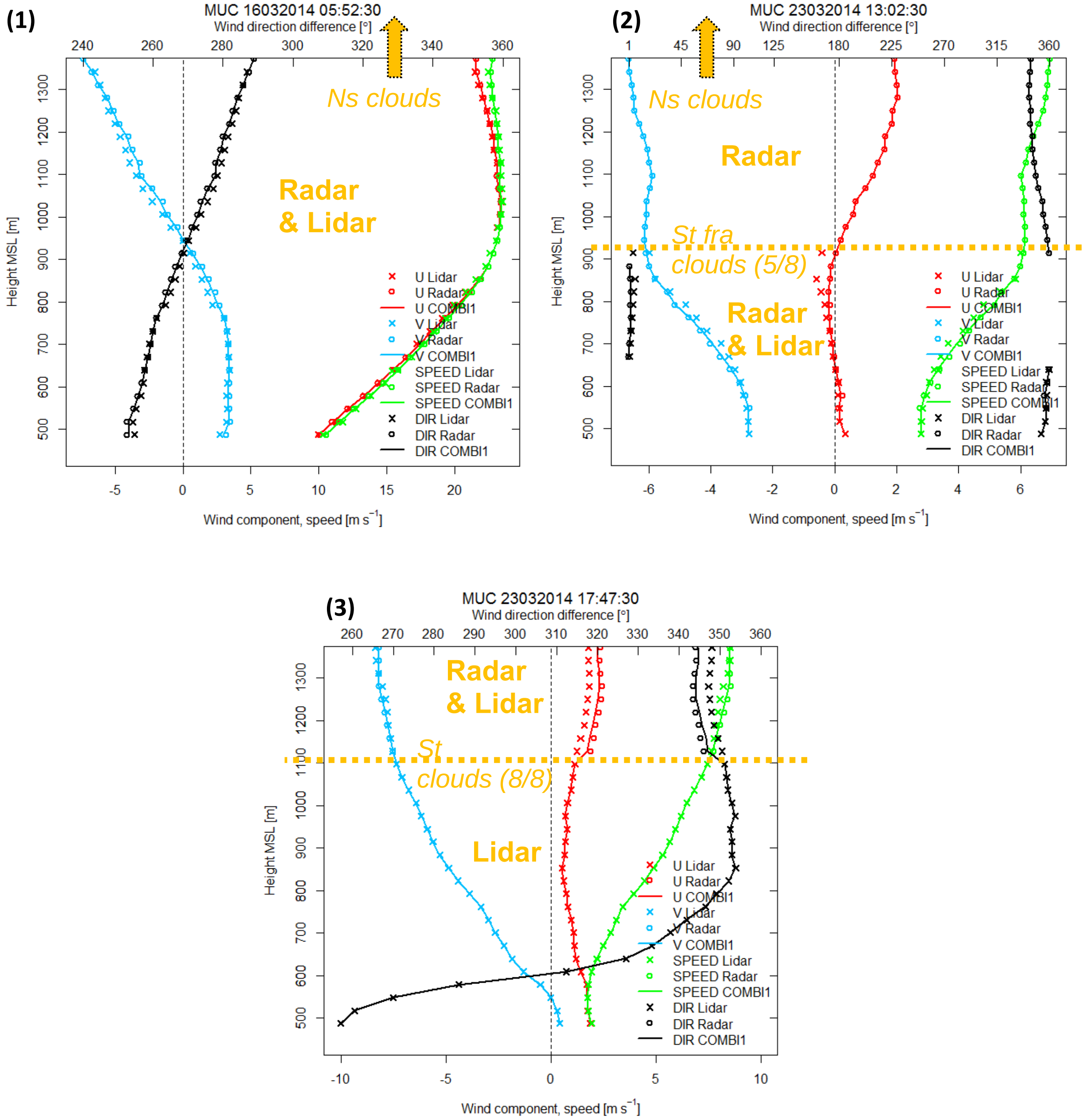


Figure 4: VVP vertical profiles of U and V wind components, wind speed (SPEED) and direction (DIR) of lidar, radar and the combination of both sensors (COMBI1) at MUC. Dates: (1) 16 March 2014, 5.52 UTC; (2) 23 March 2014, 13.02 UTC, (3) 23 March, 17.47 UTC.

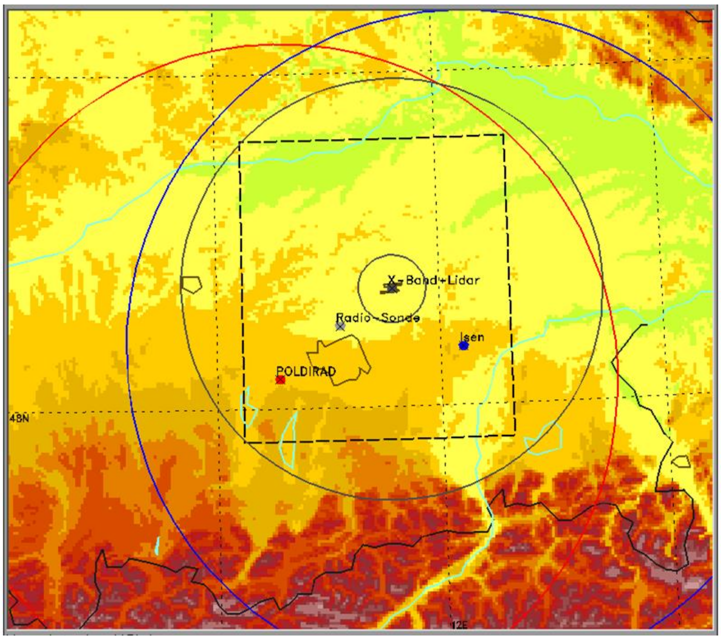


Figure 5: Domain of the 3D wind cube for Munich airport. Radar/lidar ranges are indicated.

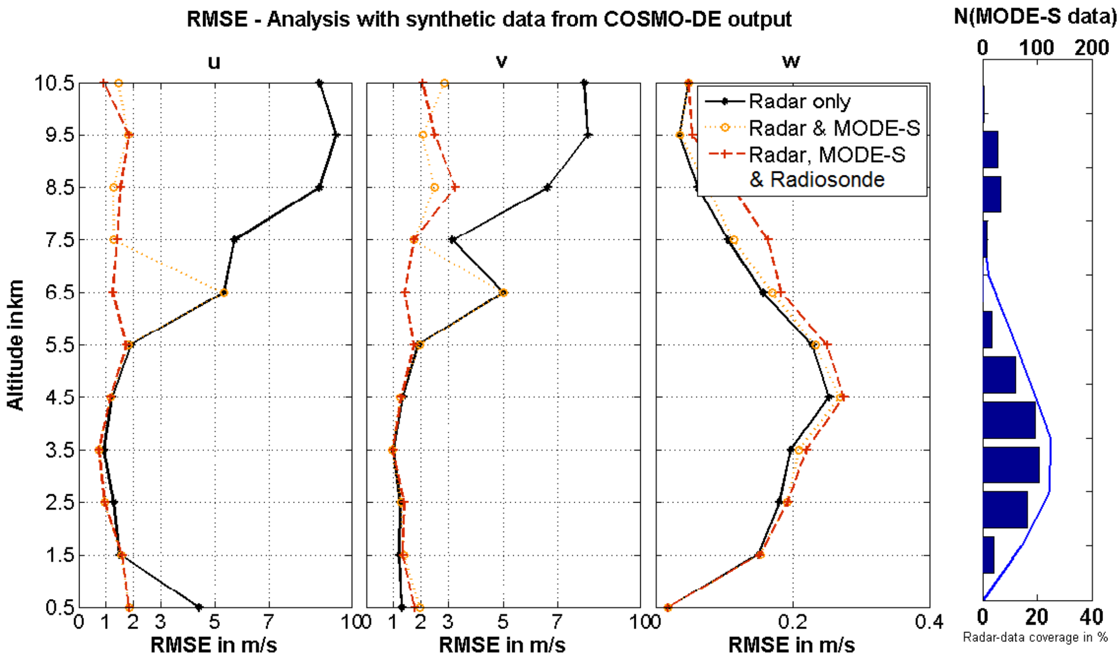


Figure 6: Impact of different data sources on wind RMSE for different heights.

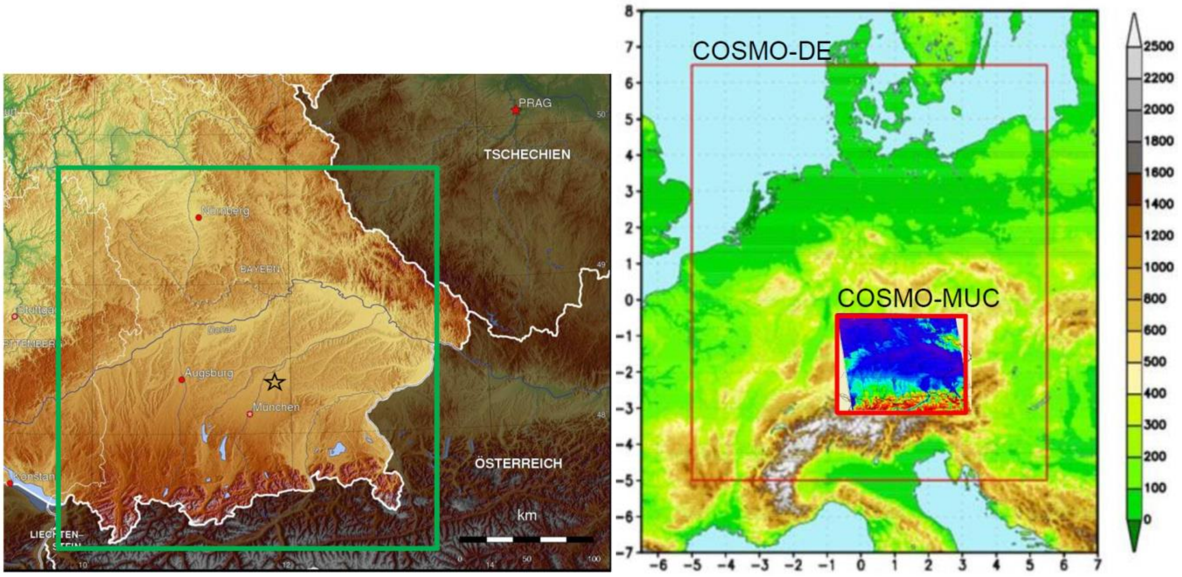


Figure 7: Left panel: COSMO-MUC domain of 290 km x 290 km. Right panel: COSMO-MUC domain nested into COSMO-DE. The orography of COSMO-MUC is based on a GDEM using ASTER data.

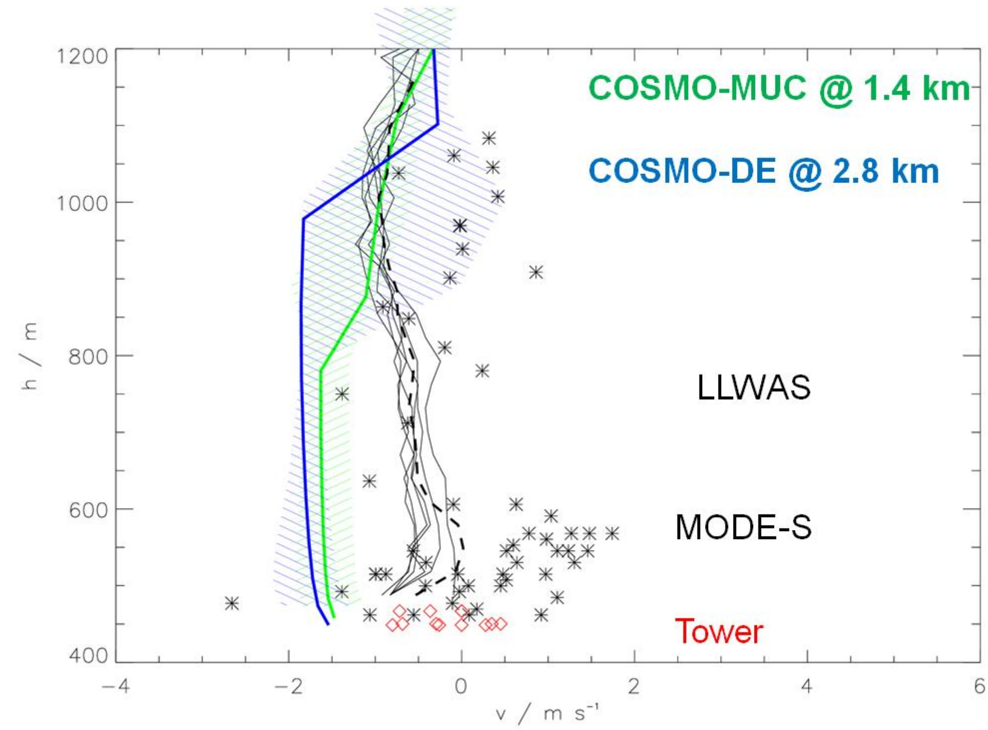
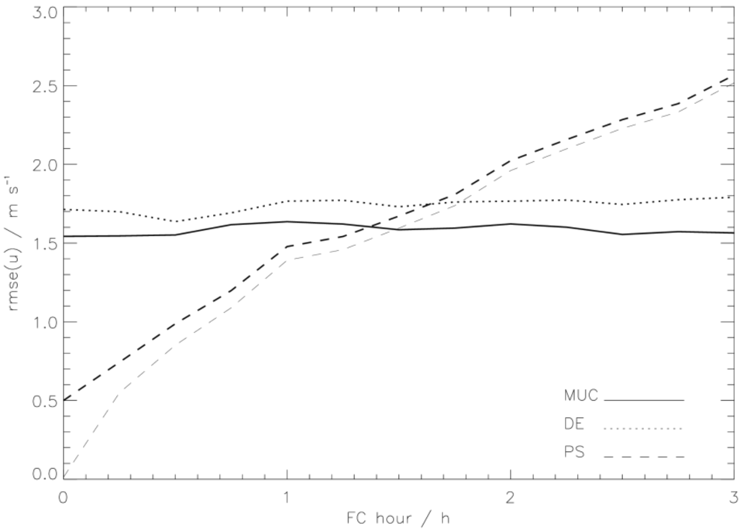


Figure 8: Comparison of v wind component of COSMO-MUC, COSMO-DE, lidar and radar (black lines), Mode-S EHS (black crosses), and tower in-situ measurements for a certain time; as a function of height.



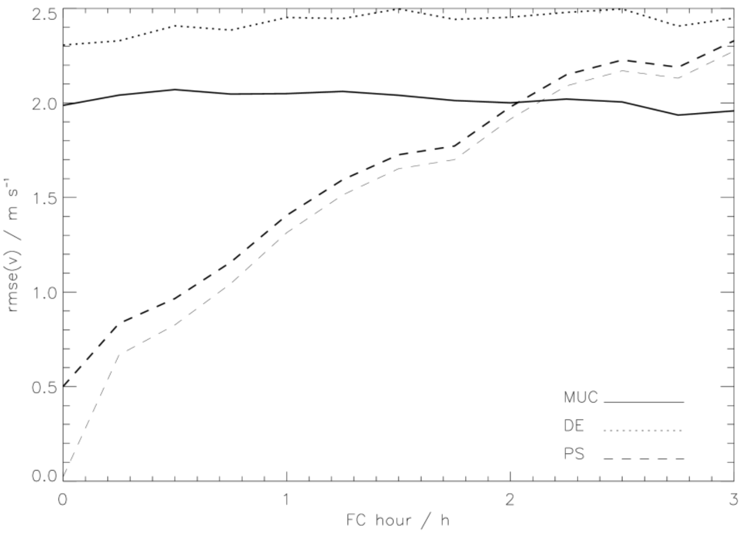


Figure 9: Example of u wind (top panel) and v wind component RMSE (bottom panel) of 15 minutes COSMO-DE, COSMO-MUC and nowcast outputs for a lead time of 3 hours. The observations (initial of nowcast) are assumed to have a RMSE of 0 m/s (light dashed line) respectively 0.5 m/s (dark dashed line).