Quality of clear-air radar radial velocity data: Do insects matter?

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1 Introduction

Doppler weather radar provides measurements of radial velocity. Such data are widely used for various applications, such as wind profile calculations with Velocity Azimuth Display (VAD) or Volume Velocity Processing (VVP) algorithms, wind shear detection, or numerical weather prediction model (NWP) assimilation. While precipitation can normally be regarded as tracer of the horizontal air flow, this is questionable for clear air radar returns from non-stationary targets, in particular from insects. Such insect echoes are common in European radar data during the summer season.

In several publications, insects are considered being rather passive tracers which would justify taking their radial velocity data for true radial wind data (e.g. Wilson et al., 1994; Michelson and Seaman, 2000; Huuskonen at al., 2009). Other studies found that radial velocities should not be used for such purpose, i.e. insects cannot be generally considered as passive tracers (e.g. Achtemeyer, 1991; Rennie et al., 2010; Rennie, 2014; Melnikov et al., 2014). In these studies, insect data derived winds were usually compared with "true" wind data using NWP results or radiosonde data for comparison, leaving room for speculation about the accuracy of such comparisons.

In this study, radar radial velocity data are compared with radial velocity data of an IR lidar co-located to the radar. The measurement setup and data processing are described in section 2. Results are presented in the sections thereafter.

2 Instrumentation setup and data processing

Clear air returns, in particular from insects, are investigated using data of two Meteor 50DX X-band polarimetric radars from Selex ES GmbH, Germany, at the German airports in Frankfurt and Munich. Each instrument is operated together with a co-located 1.6 µm scanning Doppler lidar from Lockheed Martin Coherent Technologies, Colorado, USA. More details about the systems can be found in Weipert et al. (2014).

During the period of the study, radar and lidar repeated 3D scans with ranges of 75 km for the radar and 12 to 15 km for the lidar every five minutes. Each 3D radar scan consists of 11 PPI slices between 1 and 60 deg elevation angle, and each 3D lidar scan consists of 5 PPI slices between 1.5 and 20 deg elevation angle. The lidar returns are almost entirely from aerosols, which are perfect tracers of the wind. 3D polar Radar data, obtained from a GDRX signal processor using (among other features) a DFT clutter filter, a multi-trip-echo filter and an interference filter, were processed using a two-step polarimetric fuzzy-logic radar echo and hydrometeor classification (ECLASS; Selex ES, 2013):

1. Meteo-/Non-meteo classification
2. Hydrometeor-classification of the meteorological data

For normal wind algorithm application, all non-meteorological data are removed. Thus rain events can be used to determine the accuracy of the instruments. Ernsdorf et al. (2014) have compared the radial velocity data on range gate basis, using the 3.0 deg PPI slice which was available in the 3D scans of both radar and lidar. They found a mean bias of about 0.1 m/s and a root mean square error of about 1.5 m/s. When comparing horizontal wind vectors derived by a VVP algorithm (Waldteufel and Corbin, 1979) and using a sophisticated quality control (Selex ES, 2013), the mean wind speed bias was also around 0.1 m/s, with a root mean square error around 0.5 m/s. This demonstrates that radar radial velocities of precipitation are excellent proxies for the true wind, at least at low elevation angles when the fall speed effect can be neglected.

For this study, similar comparisons as in Ernsdorf et al. (2014) have been performed. VVP wind profiles with a layer spacing of 100 Ft (approximately 30 meters) were obtained using a range of 3 NMi (approximately 5.5 km) around the sensors. Radar radial velocities of insects only were considered. For this purpose, the first step of the above mentioned polarimetric radar echo classification was modified to biological/non-biological classification. For "biological", the fuzzy-logic membership functions were tuned to typical insect returns in order to avoid bird echo contamination. All non-insect data have then been removed.

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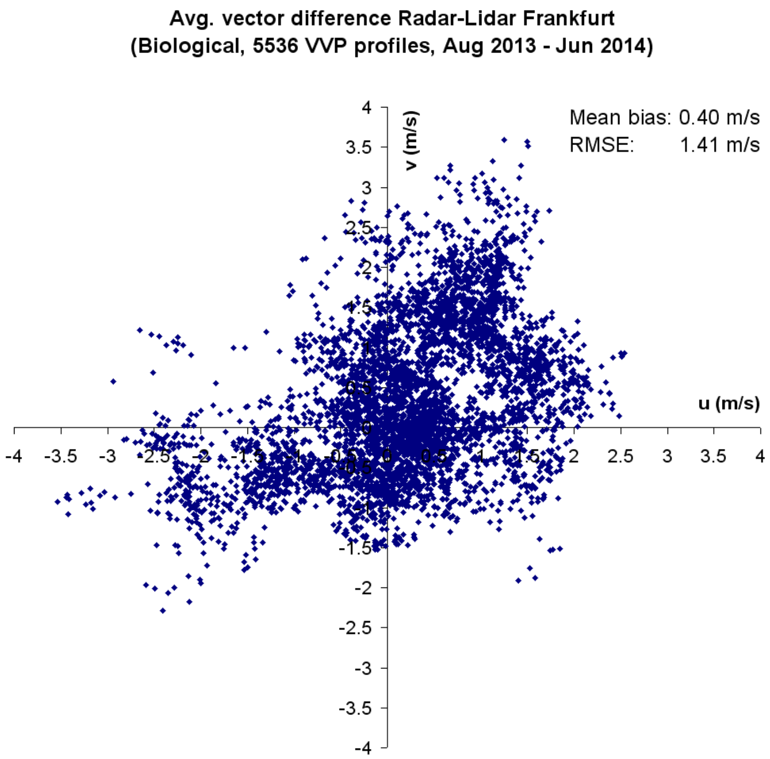
3 Radar and lidar VVP vector comparison: general results

Figure 1 shows differences of the VVP horizontal wind vectors between radar and lidar. For the data shown in these figures, the lowest 30 VVP layers (i.e. approximately the lowest kilometer of the atmosphere) were averaged, so that one data pair was available for each 3D scan (where only VVP profiles with at least 15 layers containing valid data for both sensors have been considered). In Figure 1, all data of eleven-month periods in Frankfurt and Munich have been used. The results demonstrate that radar derived wind vectors from insects can differ by several meters per second from the true wind. Differences in radial wind data on range gate basis are likely to be even larger.



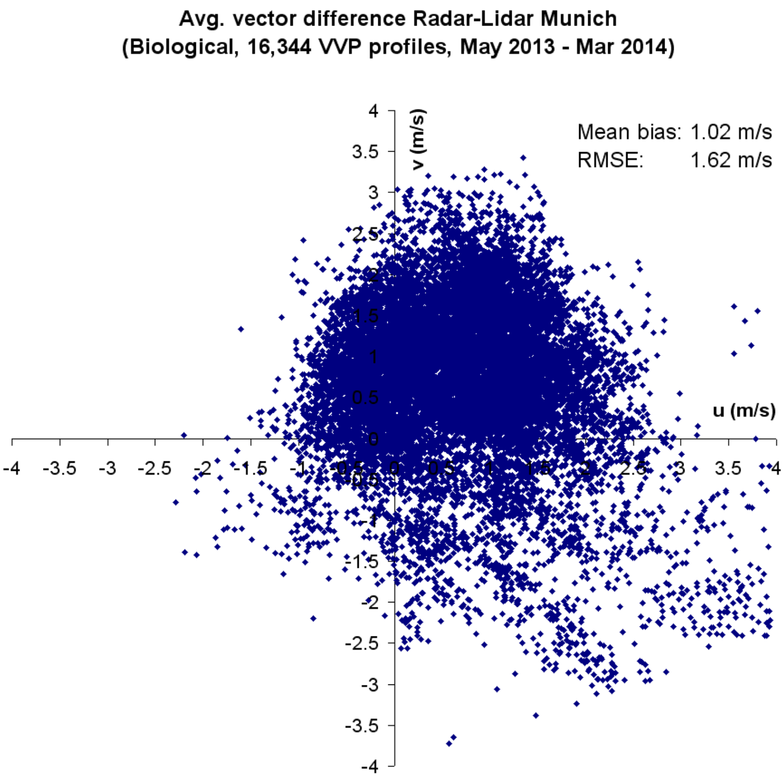


Figure 1: Differences between radar and lidar data derived horizontal wind vectors, using radar data of insect returns only, for Frankfurt (top) and Munich (bottom). Both figures are based on 11 months of data.

The differences shown in the above figure are indeed due to the fact that insects are often not passive tracers. Only a fraction of the observed differences is due to uncertainties in the methods of measurement and data processing. This can be seen from the following Figure 2, where radar derived VVP data have been obtained from meteorological echoes only. It becomes clear that both instruments measure practically the same wind vector in case of passive tracers.

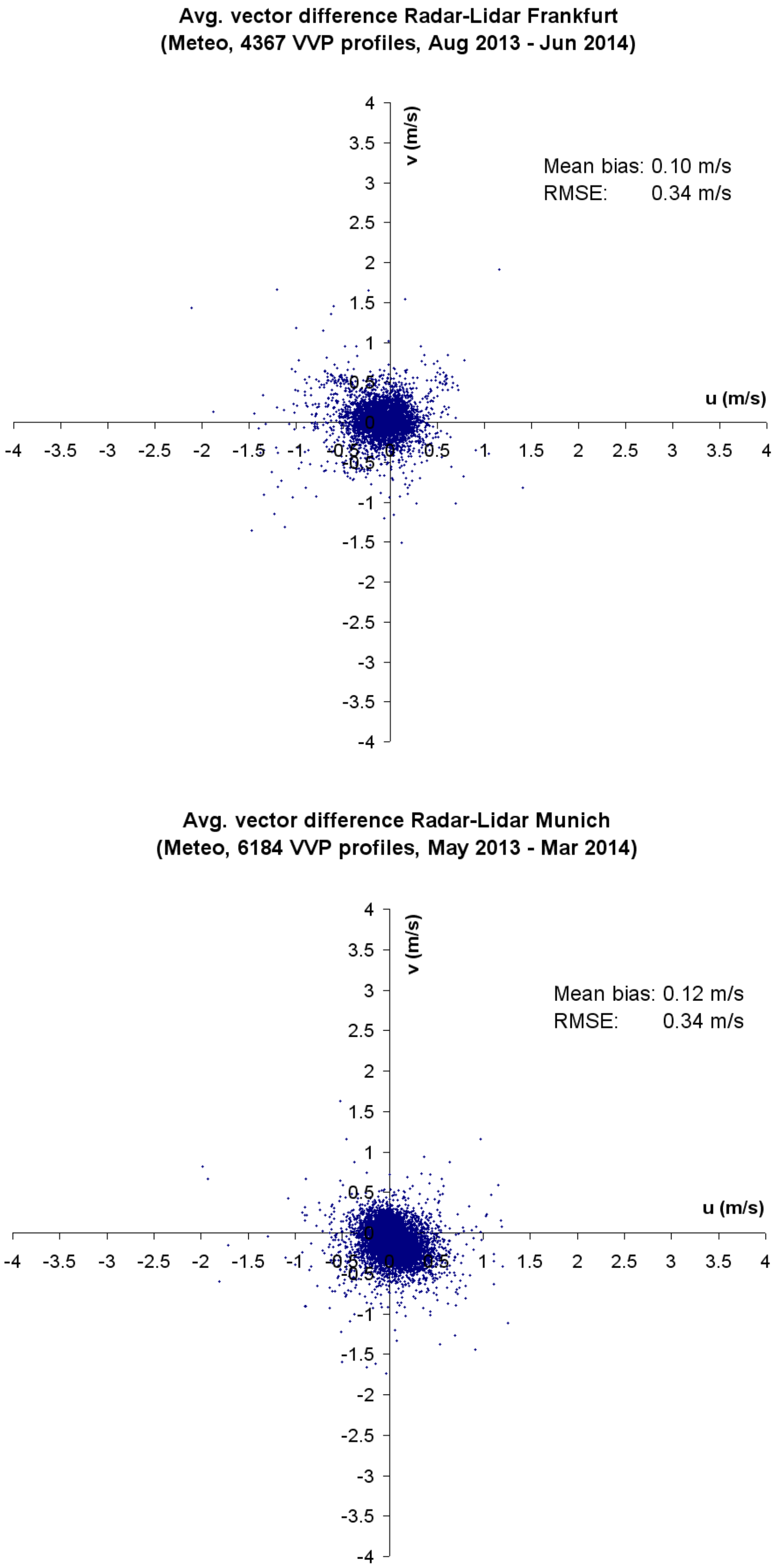
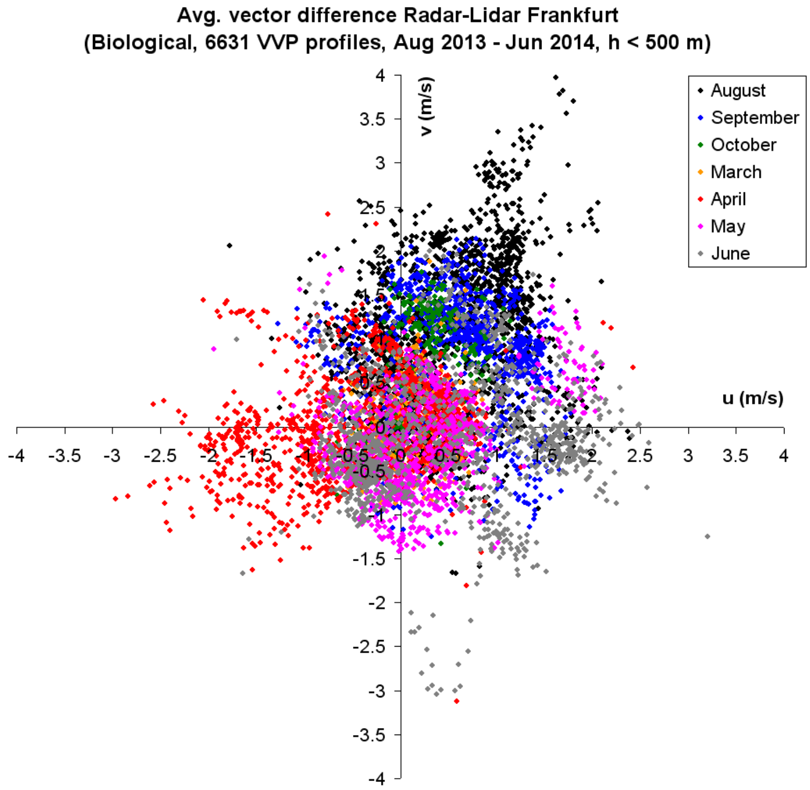


Figure 2: Differences between radar and lidar data derived horizontal wind vectors, using radar data of precipitation only, for Frankfurt (top) and Munich (bottom). Both figures are based on 11 months of data.

For insects, the differences tend to increase with increasing altitude. The following figure shows similar data as Figure 1, but first the 15 lowest and then the 15 second-lowest VVP layers have been averaged. Figure 3 also shows the differences for the various months (where the cold period being rather void of insect echoes has been omitted): it is obvious that insect migration depends on the season and/or weather conditions.



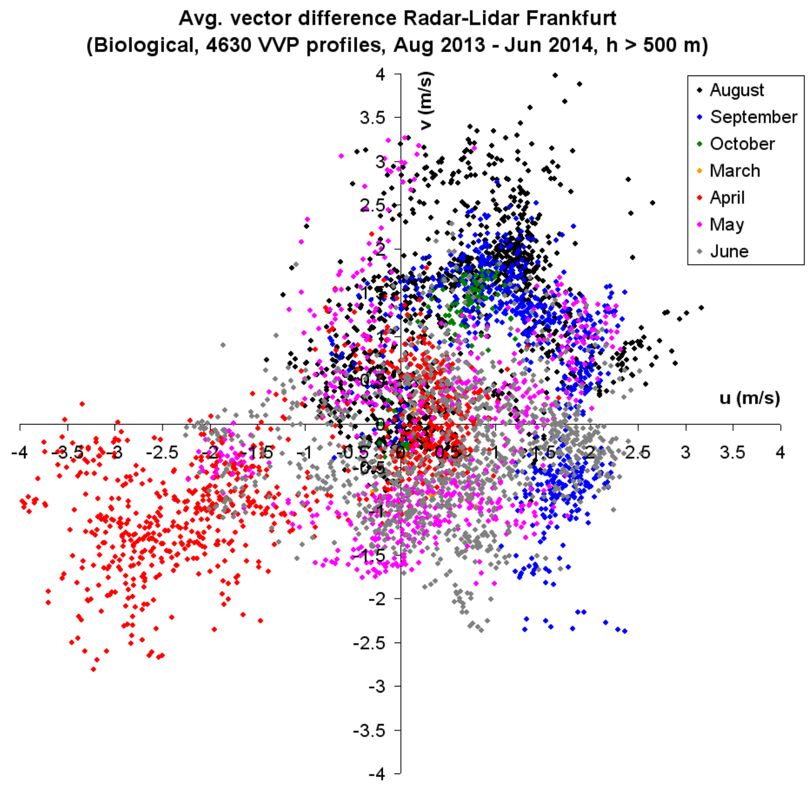
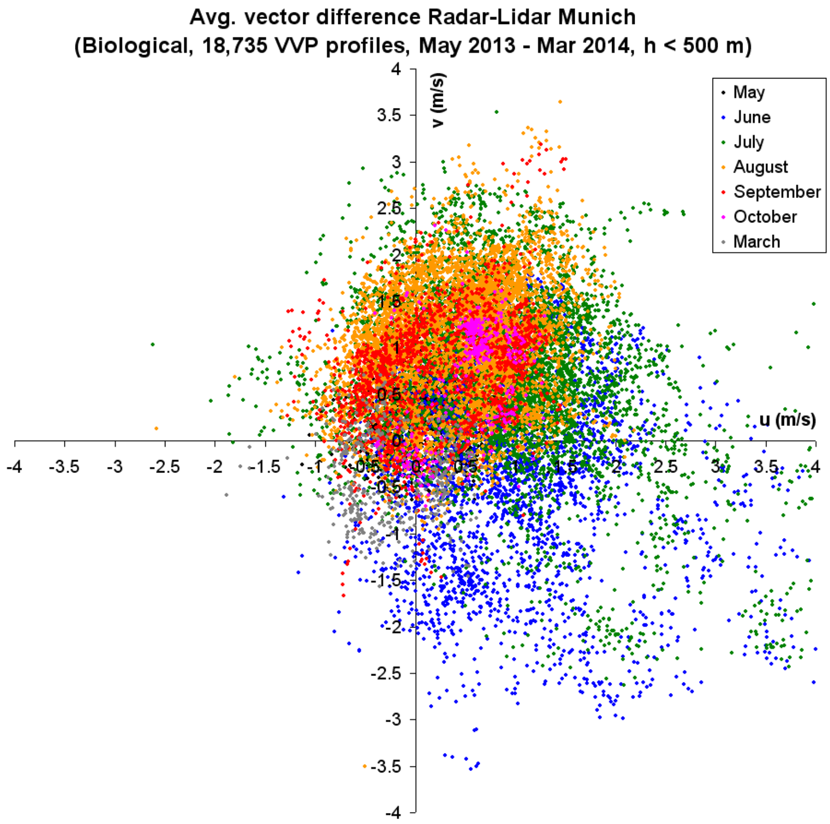


Figure 3: Differences between radar and lidar data derived horizontal wind vectors for Frankfurt, using radar data of insect returns only. The figure shows the monthly variation in the data of the lowest 15 VVP layers (i.e. lowest 500 meters; top) and of the second-lowest 15 VVP layers (i.e. second-lowest 500 meters; bottom).



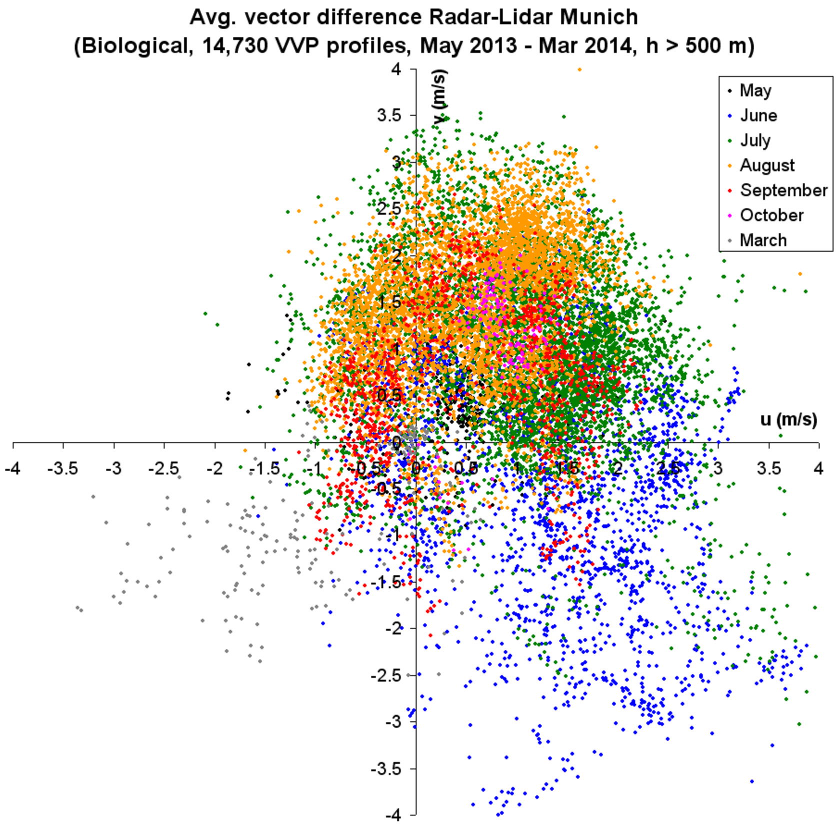


Figure 3 (continued): Data for Munich.

Sometimes, but not always, a diurnal cycle of the differences between radar and lidar wind vectors can be found, as e.g. shown in Figure 4. This means that insect migration depends on time of day. The analysis of what particular weather situation may cause insects to migrate as well as the potential findings of a dependency of this on wind direction and speed, however, are beyond the scope of this paper. We here limit our research to the analysis of the amount of difference. Table 1 gives the mean bias and the root mean square error (RMSE) for each month for the data shown in Figure 3. All values are significantly larger than for precipitation, where the mean bias is about 0.1 m/s and the RMSE about 0.3 m/s.

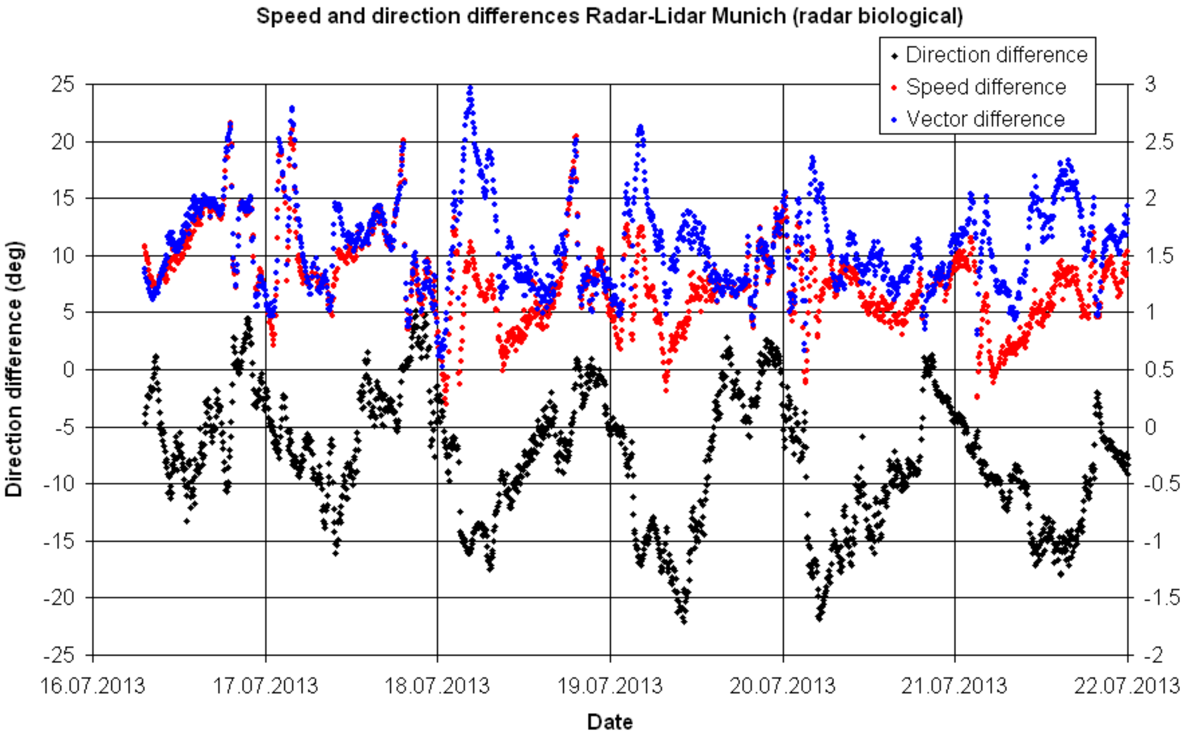


Figure 4: Differences between radar and lidar data derived horizontal wind vectors, using radar data of insect returns only, as a function of time (for Munich). The figure shows the differences of vector direction (black) and speed (red), and the absolute vector difference (blue). The fact that the speed difference (red) always is positive means that the insects move faster than the air, i.e. make use of tailwind.

Table 1: Mean bias and RMSE of the Frankfurt (top) and Munich (bottom) VVP vectors from radar insect data shown in Figure 3.

Frankfurt (m/s)	Aug	Sep	Oct	Mar	Apr	May	Jun
Mean bias (h < 500m)	1.12	1.01	0.78	0.12	0.40	0.30	0.50
RMSE (h < 500m)	1.57	1.37	1.06	0.58	1.04	0.89	1.23
Mean bias (h > 500m)	1.40	1.43	1.20	0.63	1.33	0.31	0.57
RMSE (h > 500m)	1.89	1.91	1.43	0.80	2.11	1.47	1.39

Munich (m/s)	May	Jun	Jul	Aug	Sep	Oct	Mar
Mean bias (h < 500m)	0.36	0.97	1.11	1.15	0.76	0.84	0.45
RMSE (h < 500m)	0.60	1.64	1.64	1.45	1.15	1.37	0.79
Mean bias (h > 500m)	0.52	1.34	1.47	1.56	0.79	1.40	1.33
RMSE (h > 500m)	1.19	2.10	1.97	1.88	1.47	1.57	1.80

4 Profile examples for Frankfurt

Figure 3 already indicates that sometimes insects can be considered as passive tracers (i.e. radar radial velocity data are then useful), and sometimes not. In this section we present typical examples of both cases.

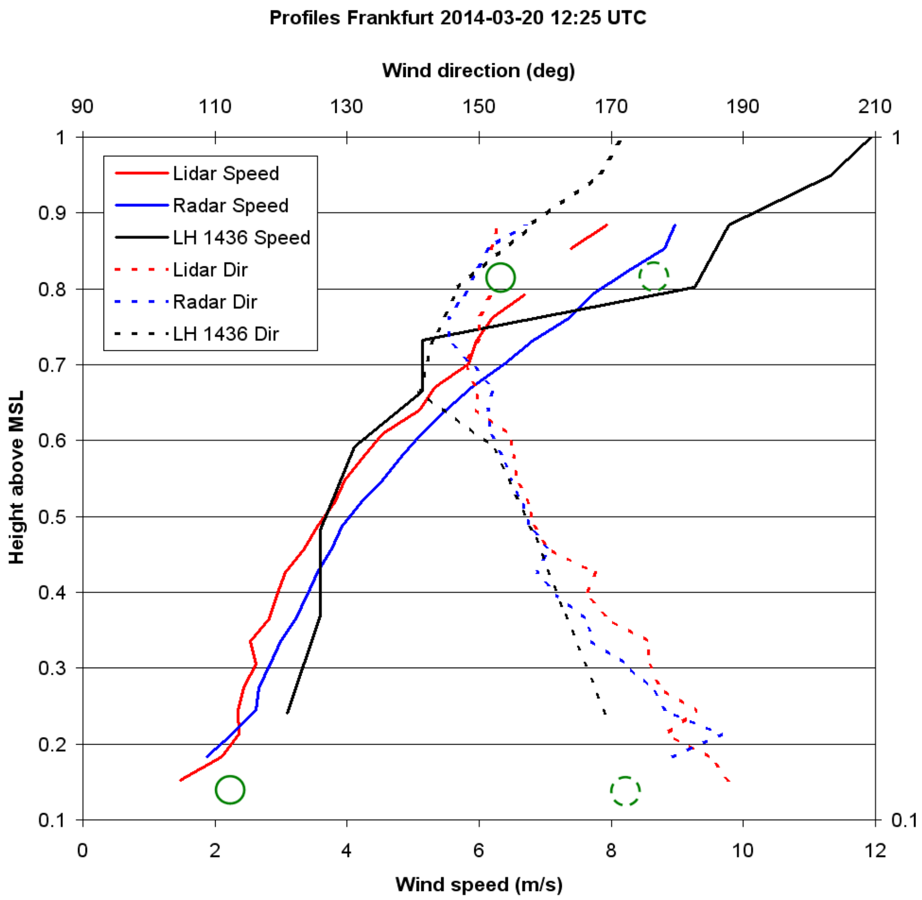


Figure 5: VVP profiles from 20th March 2014, 12:25 UTC, from radar (blue) and lidar (red), and AMDAR wind profile of a departing aircraft (black). Also shown by green circles are AWOS wind observations at the airport and on the close-by Feldberg Mountain.

Figure 5 shows a wind profile example where radar and lidar wind profiles match well and fit to other sensor measurements. Figure 6, showing the 8 deg PPI radial velocity data confirms the similarity of both sensors' wind data. Figure 7 shows the polarimetric radar data from the same scan: all data are rather homogeneous, with very weak reflectivity, very high differential reflectivity and low polarimetric correlation coefficient.

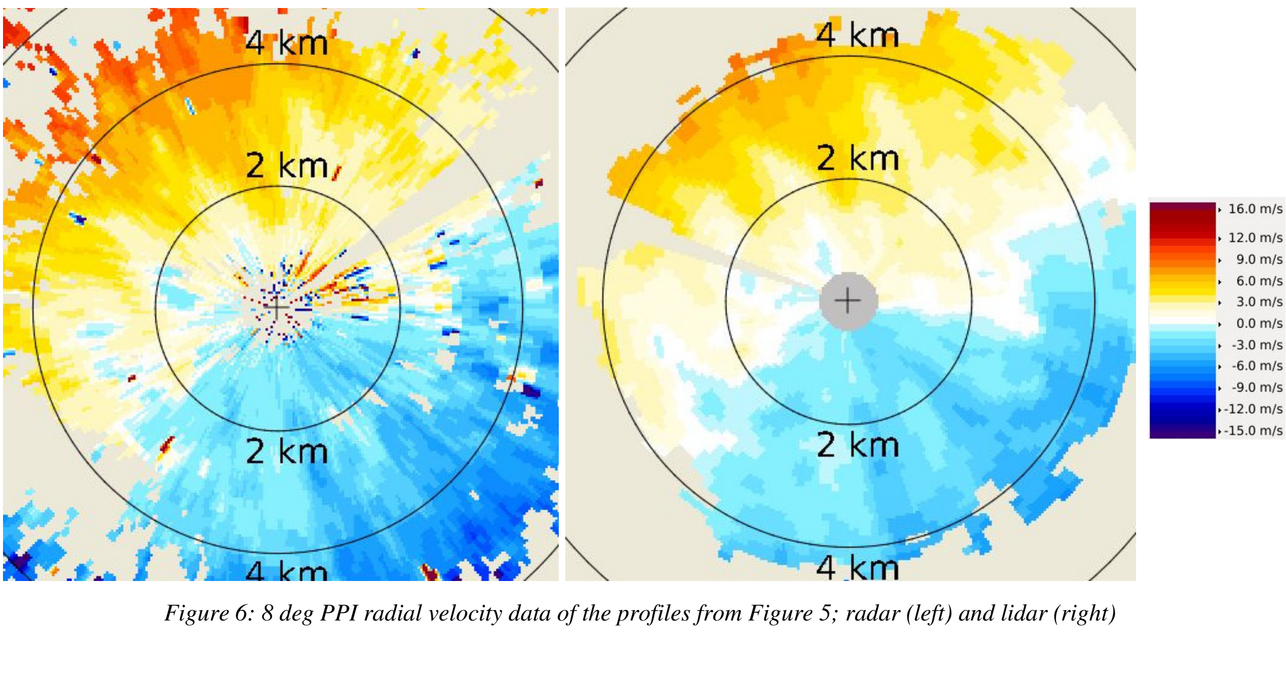


Figure 6: 8 deg PPI radial velocity data of the profiles from Figure 5; radar (left) and lidar (right)

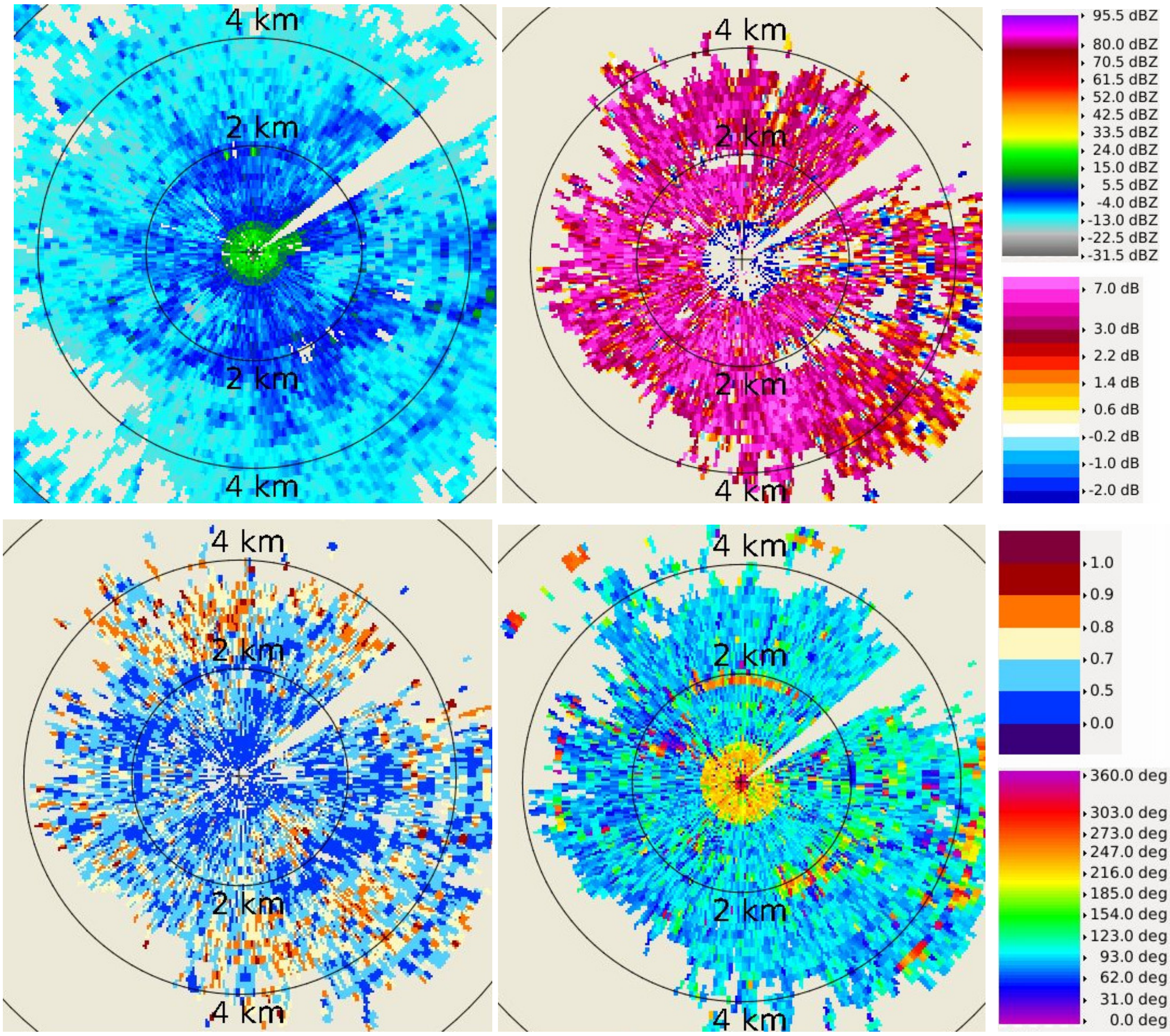


Figure 7: Polarimetric radar data for Figure 6: reflectivity (top left), differential reflectivity (top right), correlation coefficient (bottom left), and differential phase shift (bottom right)

A few days later, an example of significant differences between radar and lidar wind observations occurred. Figure 8 illustrates how poorly the wind profiles of radar and lidar match. AMDAR wind profile data of a departing aircraft and weather station observations from the airport and a nearby, 800 meters high mountain confirm the lidar data and disproof the radar data (with an exception of the AMDAR wind directions below about 500 m, which is due to the AMDAR wind speed below 1 m/s and the AMDAR wind vector uncertainty of approximately the same order).

Figure 9, showing the 20 deg PPI radial velocity data confirms this mismatch. Figure 10 shows the polarimetric radar data from the same scan: for reflectivity and differential reflectivity, two peaks can be seen north and south of the radar at distances around 3 to 4 km corresponding to altitudes of about 1000 to 1300 meters above MSL.

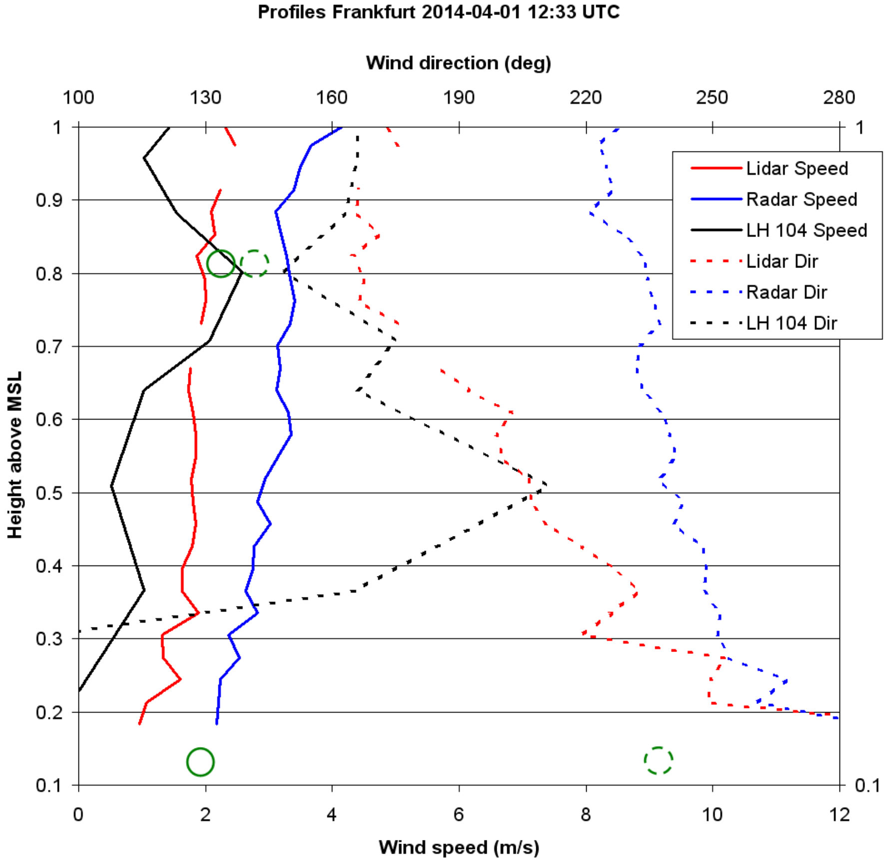


Figure 8: VVP profiles from 1st April 2014, 12:33 UTC, from radar (blue) and lidar (red), and AMDAR wind profile of a departing aircraft (black) Also shown by green circles are AWOS wind observations at the airport and on the close-by Feldberg mountain.

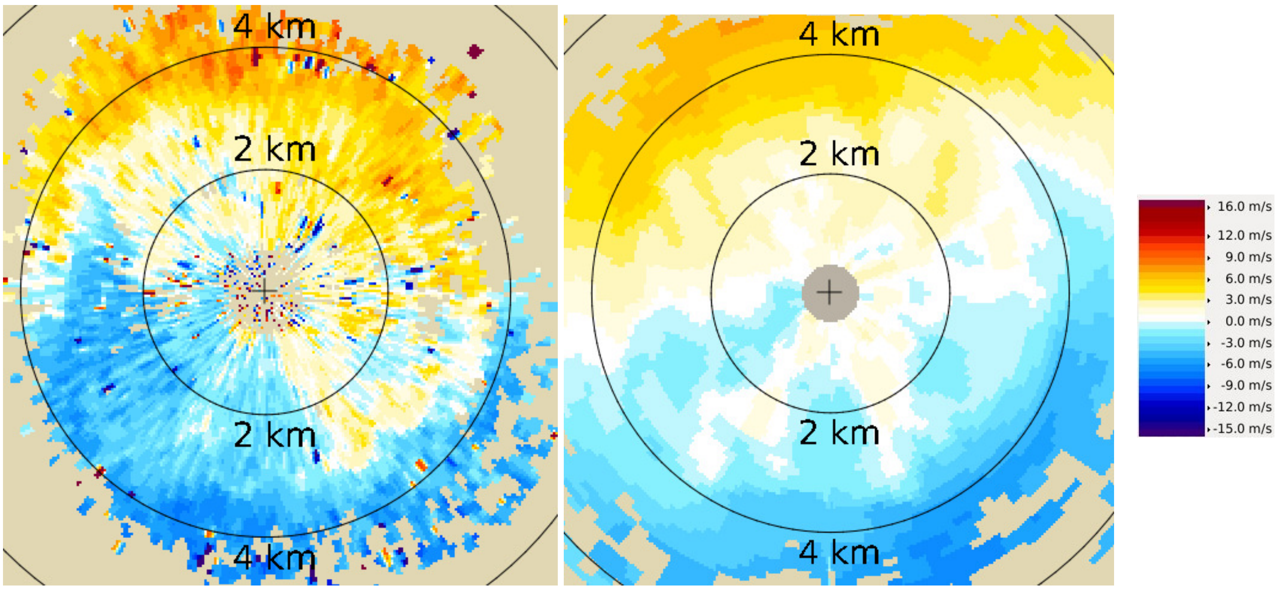


Figure 9: 20 deg PPI radial velocity data at of the profiles from Figure 8; radar (left) and lidar (right)

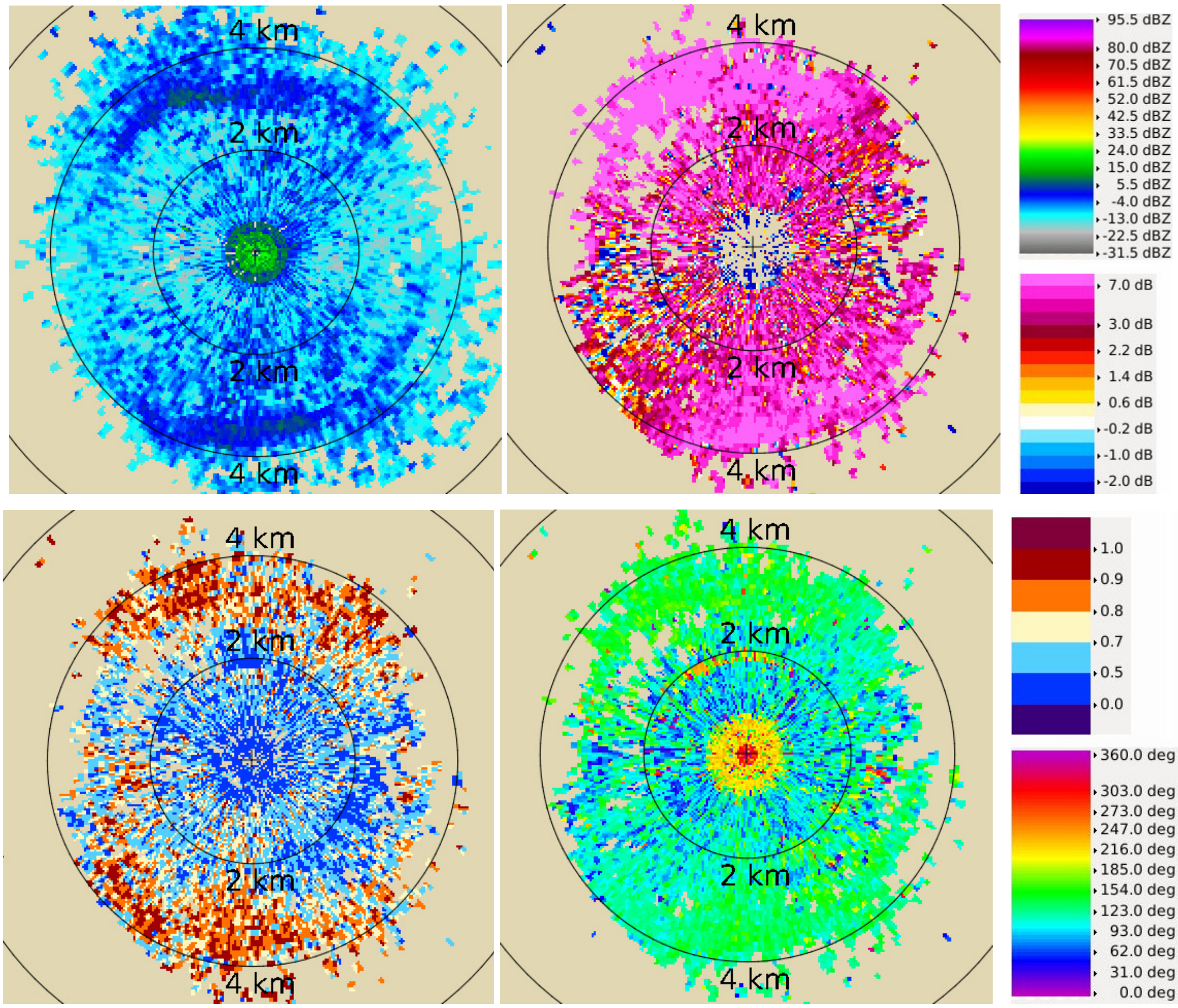


Figure 10: Polarimetric radar data for Figure 9: reflectivity (top left), differential reflectivity (top right), correlation coefficient (bottom left), and differential phase shift (bottom right)

A conceptual model of migrating insects explains both the observed radar wind profile deviations and the peaks in reflectivity and differential reflectivity data. Figure 11 illustrates that migrating insects with rather common orientation (heading) exhibit a smaller reflectivity and differential reflectivity when seen from front or rear than when seen from the side. The reflectivity and differential reflectivity patterns shown in Figure 10 can be explained by insects which are mainly oriented approximately along East-West. This fits well to the vector difference between the radar and lidar derived horizontal winds in that altitude (Figure 12).

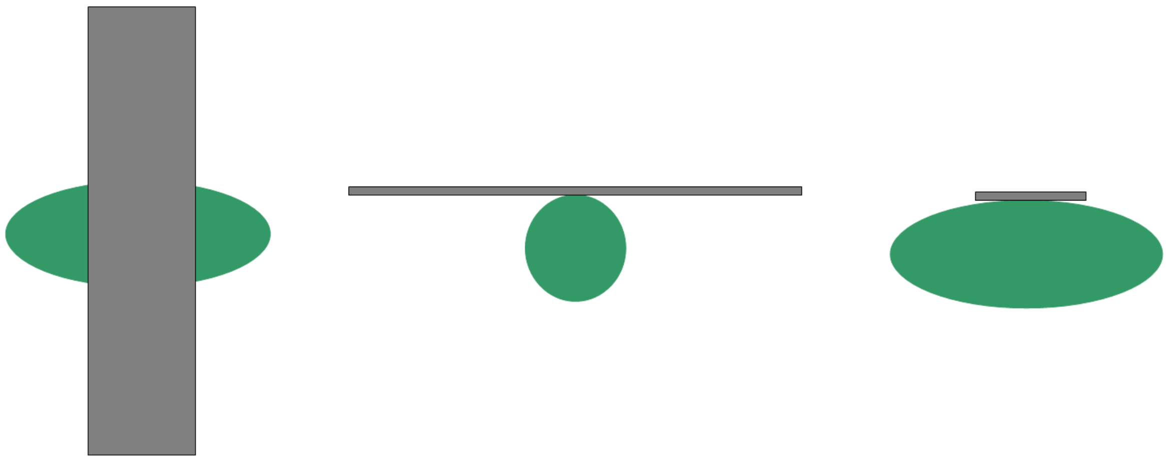


Figure 11: Conceptual model of an insect (green body, gray wings), seen from top (left part), from front or rear (center), and from aside (right part)

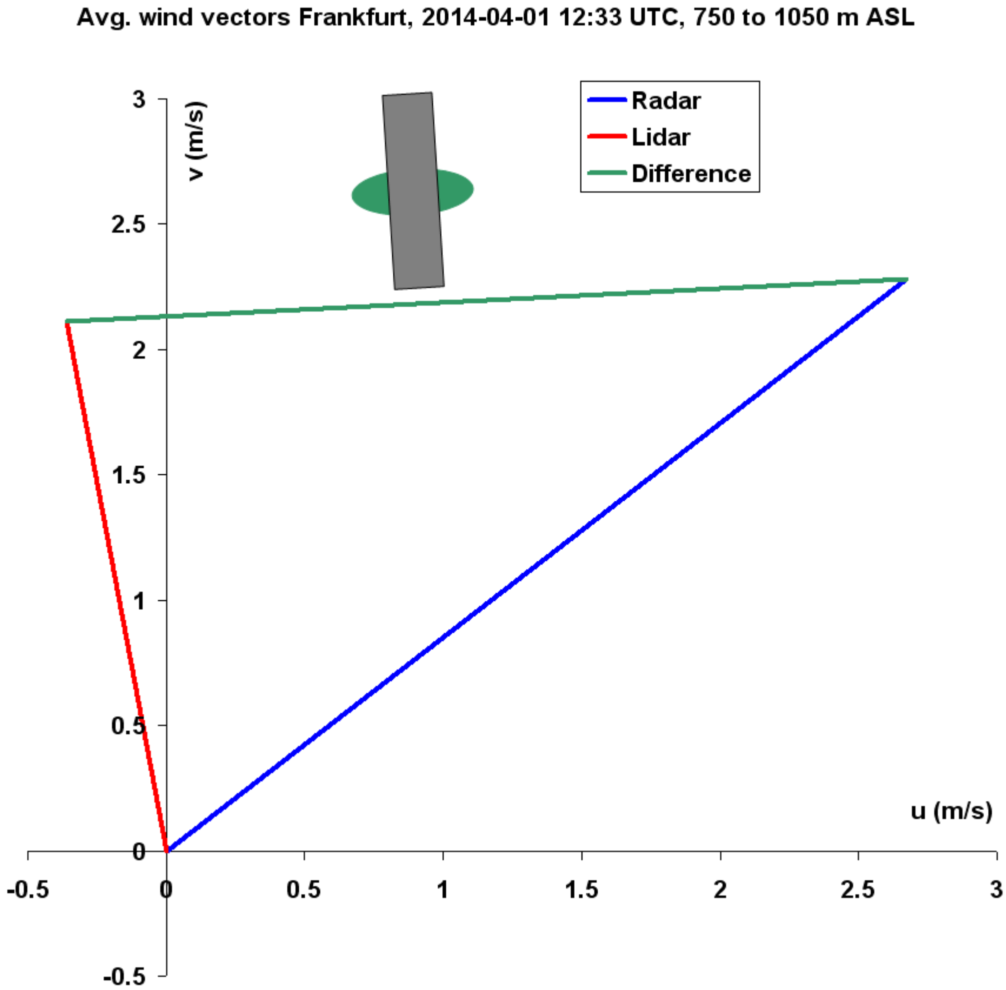
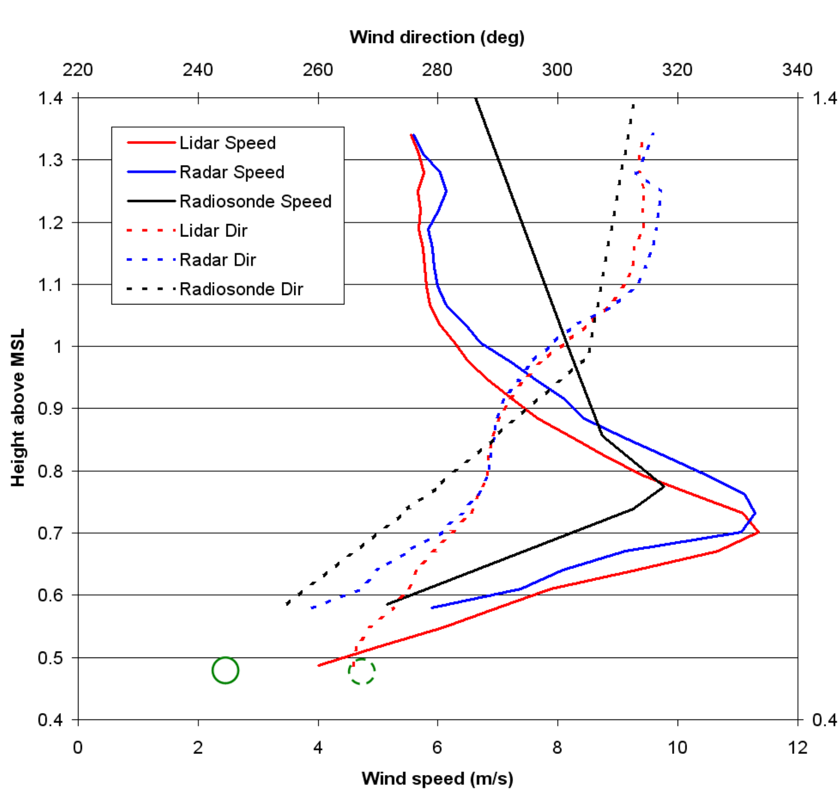


Figure 12: Explanation of the radar-lidar wind vector difference by commonly oriented insects heading approximately towards East at a speed relative to the air of about 3 m/s (green). With the true wind as observed from the lidar being from South-Southeast at about 2 m/s (red), this results in an insect migration (ground track) towards approximately Northeast with about 3.5 m/s, as observed by the radar (blue).

5 Profile examples for Munich

During the 10th of August 2013, wind profiles from radar and lidar match well. Figure 13 shows examples for 01:03 and 12:03 UTC on that day, including data from two radiosonde launches at Munich-Oberschleißheim, located 21 km southwest of the airport (UWYO, 2014). In the night, a distinct low-level jet was established. During day, winds were rather calm.



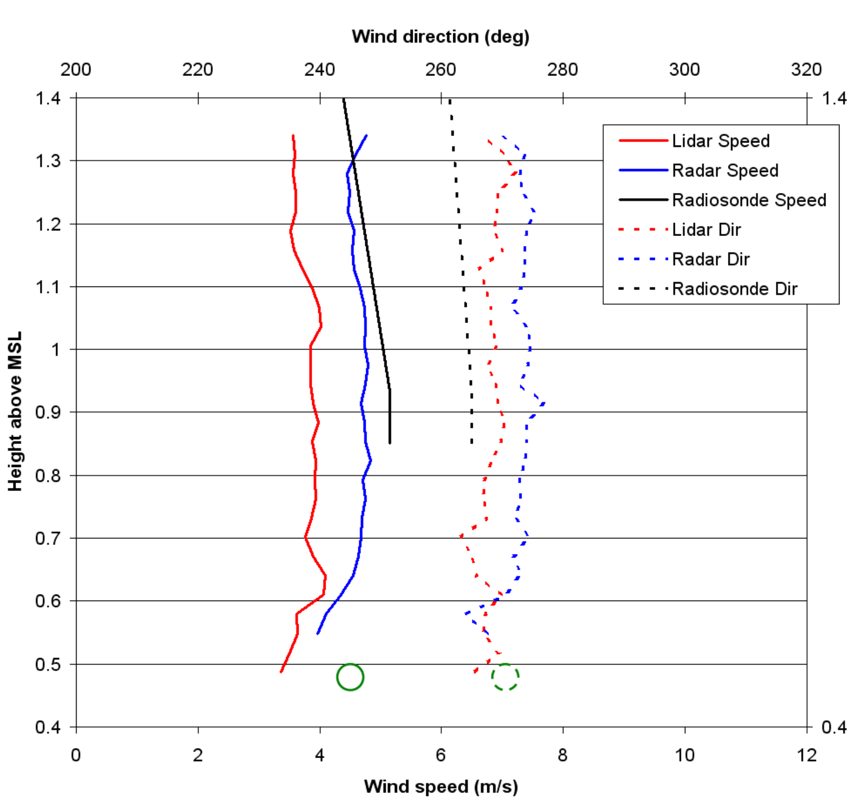


Figure 13: Wind profiles from 10th August 2013 at 01:01 UTC (top) and 12:03 UTC (bottom). The figure shows VVP data from radar (blue) and lidar (red) and the radiosonde profile (black). Also shown by green circles are AWOS wind observations at the airport.

Figure 14, showing the 4.5 deg PPI radial velocity data of the night case, confirms the similarity of both sensors' wind data. Figure 15 shows the polarimetric radar data from the same scan: all data are rather homogeneous, with very weak reflectivity, very high differential reflectivity and low polarimetric correlation coefficient.

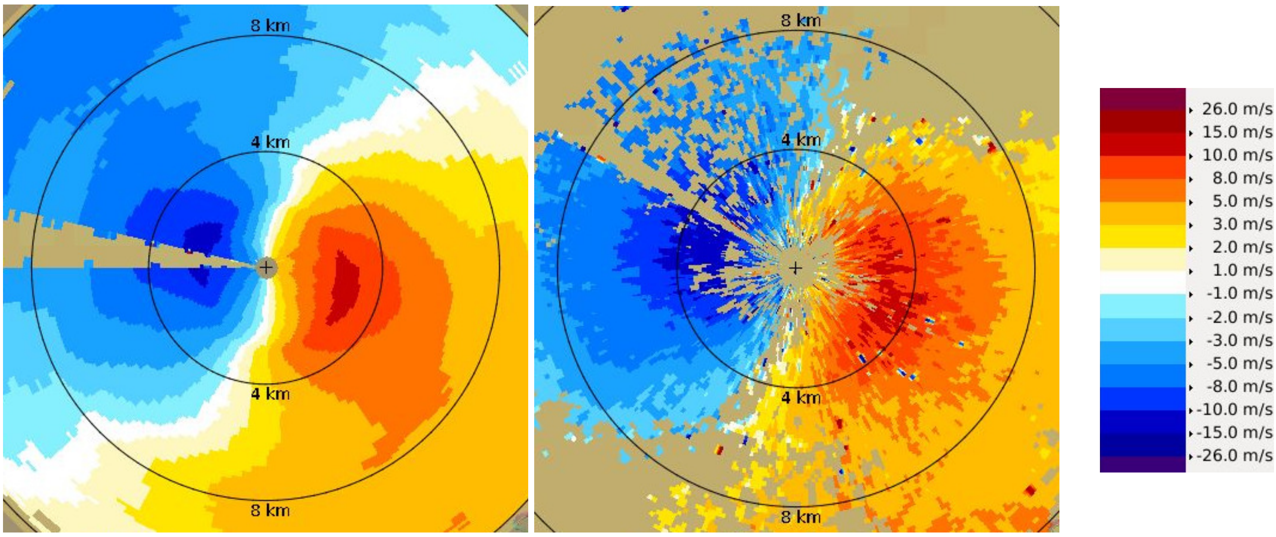


Figure 14: 4.5 deg PPI radial velocity data at of the profiles from 10th August 2013 at 01:01 UTC; radar (left) and lidar (right)

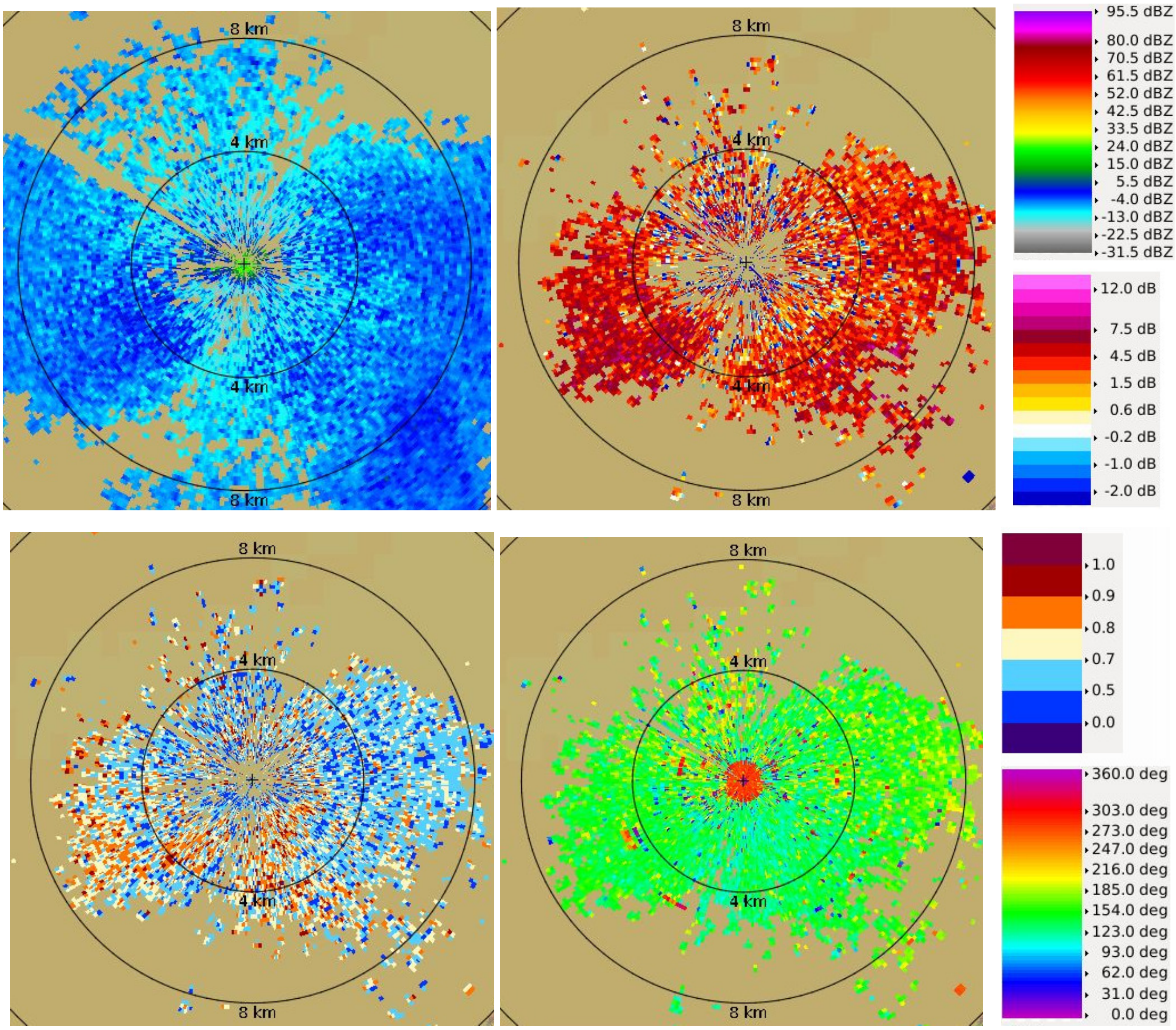


Figure 15: Polarimetric radar data for Figure 14: reflectivity (top left), differential reflectivity (top right), correlation coefficient (bottom left), and differential phase shift (bottom right)

On the 15th July 2013, however, significant differences between the radar and lidar wind vector data appeared. Figure 16 illustrates how poorly the wind profiles of radar and lidar match. Data from the radiosonde launch at Munich-Oberschleißheim and weather station observations from the airport better fit to the lidar data than to the radar data.

Figure 17, showing the 8 deg PPI radial velocity data, confirms this mismatch. Figure 18 shows the polarimetric radar data from the same scan: for reflectivity and differential reflectivity, two peaks can be seen weat-northwest and east-southeast of the radar, at distances around 2 to 8 km, corresponding to altitudes of about 700 to 1500 meters above MSL. Figure 19 links the observed vector differences and polarimetric radar data signatures, using again the conceptual model of an insect.

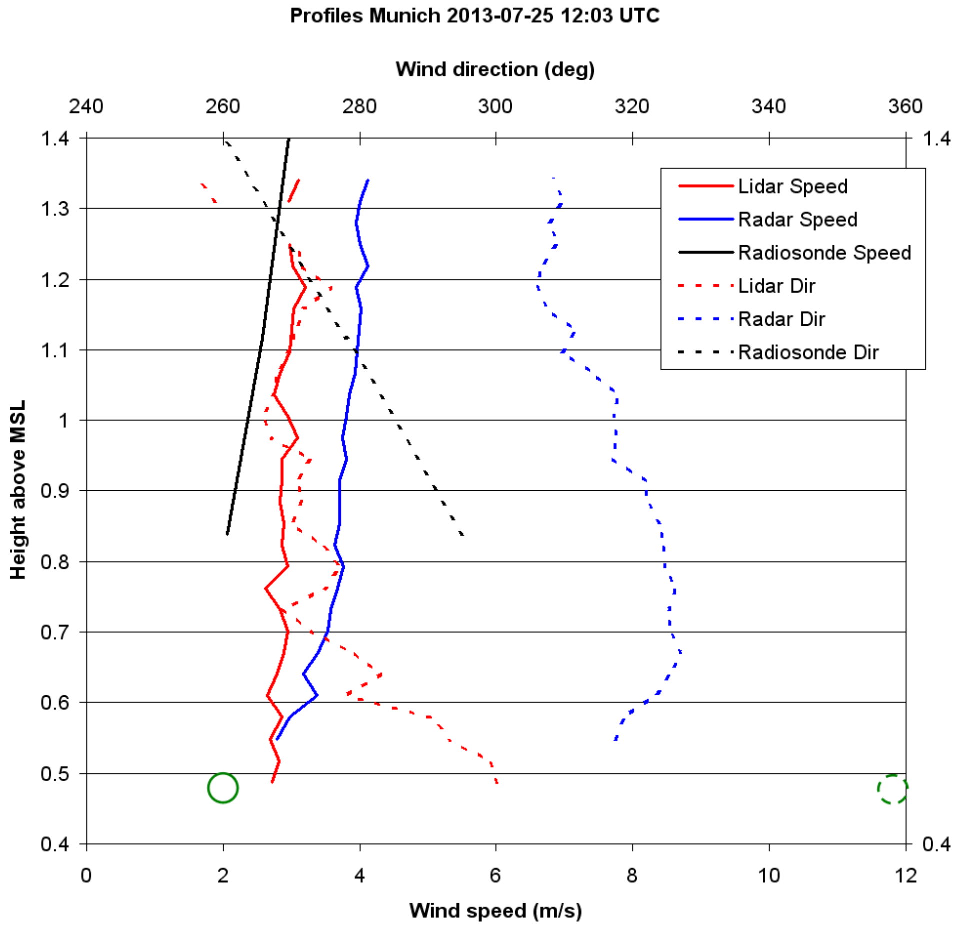


Figure 16: VVP profiles from 25th July 2013, 12:03 UTC, from radar (blue) and lidar (red) and the radiosonde profile (black). Also shown by green circles are AWOS wind observations at the airport.

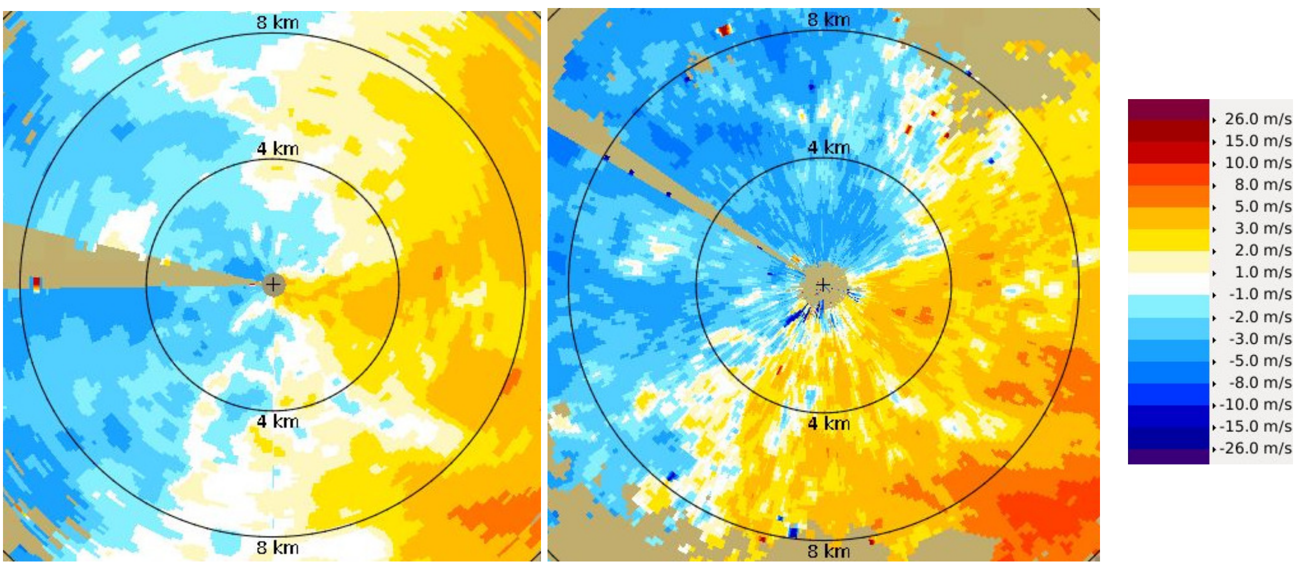


Figure 17: 8 deg PPI radial velocity data at of the profiles from Figure 16; radar (left) and lidar (right)

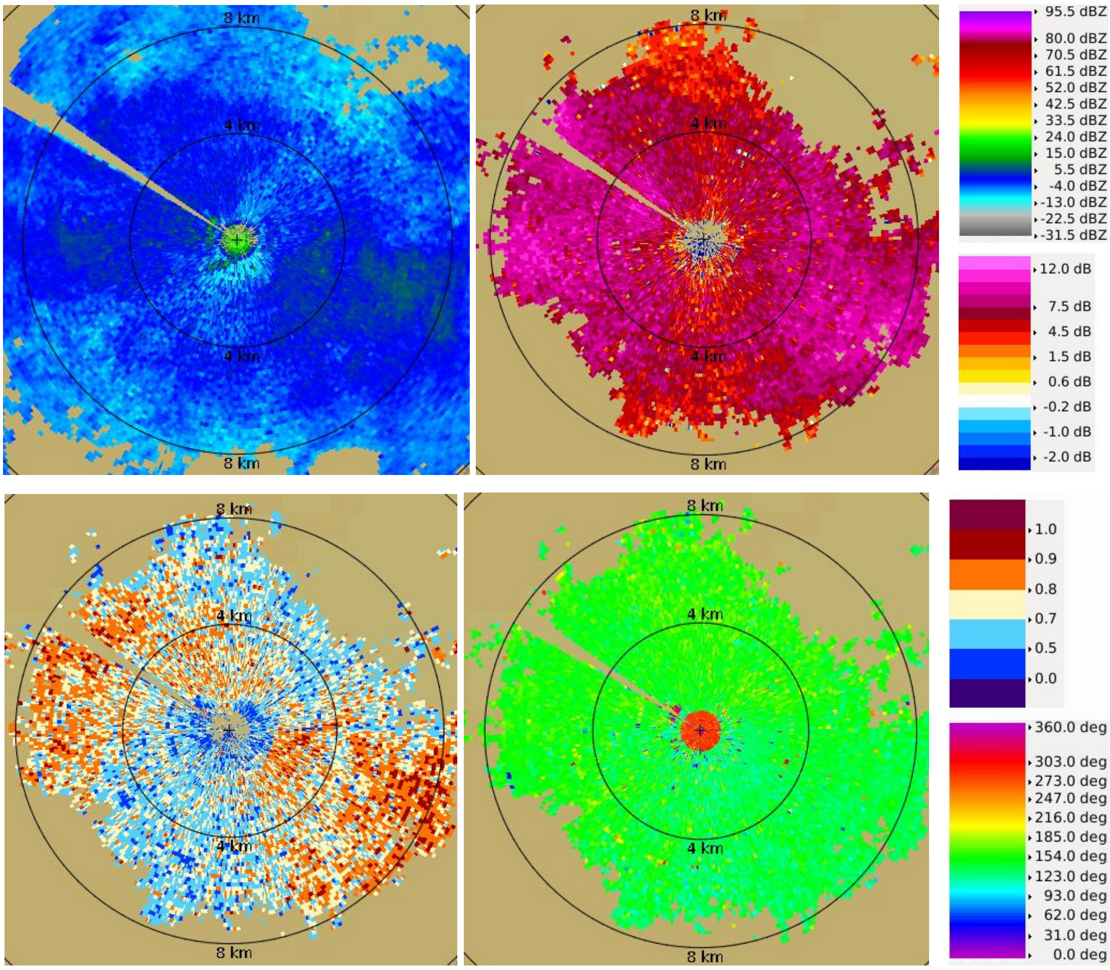


Figure 18: Polarimetric radar data for Figure 17: reflectivity (top left), differential reflectivity (top right), correlation coefficient (bottom left), and differential phase shift (bottom right)

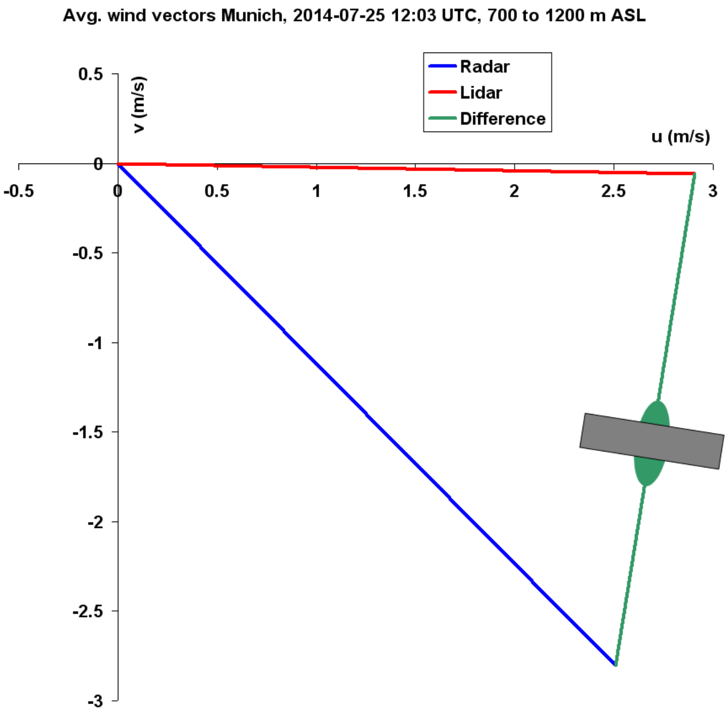


Figure 19: Explanation of the radar-lidar wind vector difference by commonly oriented insects heading approximately towards South-southwest at a speed relative to the air of about 3 m/s (green). With the true wind as observed by the lidar being from West at about 3 m/s (red), this results in an insect migration (ground track) towards approximately Southeast with about 4 m/s, as observed by the radar (blue). The insects' orientation towards South-southwest exactly explains the observed reflectivity and differential reflectivity patterns shown in Figure 18.

6 Potential correction of radar derived wind vectors obtained from insects

In the previous sections it has been shown that insects can sometimes be regarded as passive tracers, but sometimes are migrating with speeds of several meters per second relative to the actual flow of air. In the first case, polarimetric radar data are rather homogeneous. In the second case, reflectivity and differential reflectivity (and to a smaller extent also correlation coefficient and differential phase shift) show quite distinct bimodal variation with azimuth angle, with peaks into directions perpendicular to the insect heading. This information could be used to potentially correct the radar derived wind vectors resulting from insect data, even when no independent measurement e.g. from lidar is available.

Taking for example the Frankfurt radar data from Figure 9 and Figure 10, one gets a “wind” vector of about 3.5 m/s towards Northeast, and obtains that insects are oriented approximately in West-East direction, i.e. are either heading towards East or towards West. If a stable relation between insects’ relative speed and some signatures in polarimetric radar data, e.g. the amplitude of the bimodal reflectivity and differential reflectivity variation, could be established, one might calculate the true wind vector from (i) the radar “wind” vector, (ii) the radar observed orientation of insects, and (iii) the radar data based calculation of insects’ relative speed. The only unknown would then be into which one of the two possible directions the insects are heading (either West or East in the given example), but this might potentially be found from other information. Currently some work on such correction possibilities is in progress.

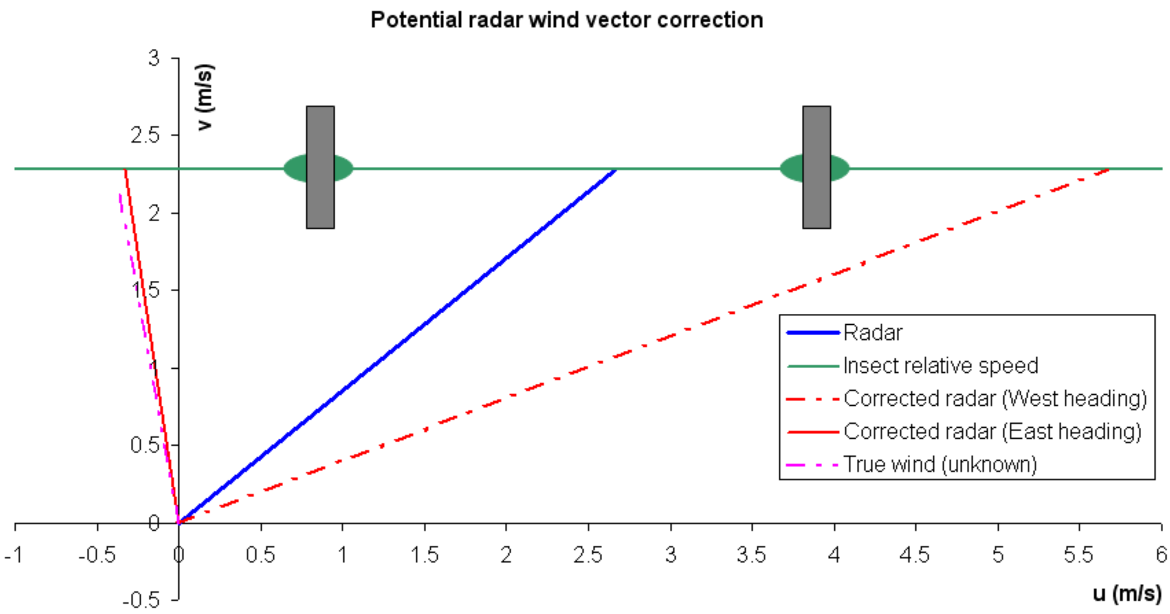


Figure 20: Potential radar wind vector correction for data from insects, based on the example given in Figure 9 and Figure 10: The radar “wind” vector is approximately 3.5 m/s towards Northeast (blue vector line). From the orientation of the bimodal reflectivity and differential reflectivity patterns in Figure 10, insect heading is either towards West or towards East (green line). Potentially from the amplitude of the bimodal patterns, an insect relative speed of about 3 m/s could be calculated. This would lead to two possible calculations of the wind: If the insects are heading towards West, the wind vector would be that one of the radar plus 3 m/s towards East (dash-dotted red vector line). Otherwise, i.e. insects are heading towards East, the wind vector would be that one of the radar plus 3 m/s towards West (solid red vector line). The latter solution is very close to the unknown true wind vector (pink dashed line).

7 Summary and conclusions

At Frankfurt and Munich airports, eleven months of data from a X-band polarimetric radar and a co-located IR Doppler lidar have been analyzed. The focus was on low-level vertical profiles of the horizontal wind vector, calculated using a VVP algorithm for data from each sensor. Radar data were pre-classified such that all data not originating from insects were removed. For a verification purpose, radar data were separately classified such that all non-meteorological echoes were removed. VVP wind vector differences between radar and lidar were examined, leading to the following main results:

- For precipitation, the mean bias is about 0.1 m/s, and the root mean square error (RMSE) is about 0.3 m/s, which demonstrates that radar derived wind profiles from precipitation are very good indicators of the true wind profile.

- For insects, bias and RMSE are almost one order of magnitude larger, with monthly mean biases mostly between 0.3 and 1.2 m/s and RMSE mostly between 1.0 and 1.7 m/s. Mean bias and RMSE tend to slightly increase with altitude.
- For cases with small bias, i.e. when insects can be considered as passive tracers, polarimetric radar data are rather homogeneous. In case of large bias, typical signatures can be found in the data, in particular a bimodal azimuthal variation of reflectivity and differential reflectivity.

Polarimetric radar data allow for two steps to improve wind vector information obtained from insect data:

1. Based on presence or absence of specific patterns in radar polarimetric data, radar derived wind vector data from insects can be classified as reliable or unreliable.
2. Potentially, based on a quantitative analysis of specific patterns in radar polarimetric data, the relative speed of insects could be calculated and thus the radar derived wind vector be corrected.

Currently, work is in progress in particular on the second improvement step. A successful correction of radar derived wind vectors from insect would have significant impact on the amount of reliable wind information. For an almost one year period of radar and lidar data from Germany, Weipert at al. (2014) found that precipitation derived radar wind profiles are only available during about 10 percent of time, whereas meteorological or insect echoes are present in summer almost half of the time. Thus huge potential to use clear air radar returns for wind derivation exists.

Acknowledgements

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