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RESEARCH ARTICLE

Comparison of bird migration in a radar wind profiler and a dedicated bird radar

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Abstract

Various types of radar systems are increasingly being used to monitor aerial biodiversity. Each of these types has different detection capabilities and sensitivities to environmental conditions, which affect the quantity and quality of the measured objects of interest. Radar wind profilers have long been known to detect birds, but their use in ornithology has remained limited, largely because of biologists' unfamiliarity with these systems. Although the potential of radar wind profilers for quantitative bird monitoring has been illustrated with time series of raw data, a comparison with a similar radar system more established in biology is missing. Here, we compare nocturnal bird migration patterns observed by a radar wind profiler during October 2019 and April 2021 with those from a dedicated bird radar BirdScan MR1. The systems were located 50 km apart with an altitudinal difference of about 850 m. The nightly migration intensities measured with both systems were highly correlated in both spring and autumn (Pearson correlation coefficient ≈ 0.8, $P < 0.001$), but estimated traffic measured by the radar wind profiler was on average five times higher in spring and nine times higher in autumn. Low ratios of the migration traffic rates of the Birdscan MR1 to those of the radar wind profiler occurred primarily in clear conditions. In both radar systems, migration occurred at significantly higher altitudes in spring than in autumn. Discrepancies in absolute numbers between both systems are likely due to both system-inherent and external environmental and topographical factors, but also different quantification approaches. These findings support the capacity of radar wind profilers for aerial biomonitoring, independent of environmental conditions, and open up further avenues for studying the impact of weather on bird migration at detailed temporal and altitudinal scales.

Introduction

The use of different types of radar systems has prospered over the past decades owing to significant technological advances and the development of data processing tools (*e.g.* Dokter et al., 2019). Radars have become more accessible to a broader user group, including biologists, enabling them to explore new avenues of aerial biomonitoring, especially of birds (*e.g.* Nilsson, Dokter, Verlinden, et al., 2018; Tschanz et al., 2019; Weisshaupt, Dokter, et al., 2018), but increasingly also of insects (*e.g.* Hu et al., 2016; Leskinen et al., 2012; Noskov et al., 2021) and bats (Haest, Stepanian, et al., 2021; Stepanian et al., 2019). Especially networks of operational radar systems have attracted aeroecologists' attention in recent years as they offer comparable continuous databases from hundreds of radars. Extensive spatial and temporal coverage, along with long-term data archives are in high demand for biodiversity monitoring in today's world of global change (Shamoun-Baranes et al., 2021). Operational networks of radar (and other) systems are typically available from meteorological institutions providing continuous monitoring of the atmosphere and storing data over long time periods otherwise unavailable from non-operational systems. One operational radar type, the radar wind profiler (RWP), is distributed globally and arranged in several networks with overall about 150 systems (Weisshaupt, Arizaga, & Maruri, 2018). Existing databases may hold 15–20 years of data or more (Weisshaupt, Arizaga, & Maruri, 2018, M. Hervo pers. comm.), which makes them an attractive, yet underexplored, data source for long-term studies.

Radar wind profilers have long been known to detect birds (Wilczak et al., 1995). In RWPs, birds are particularly strong scatterers and are not masked by precipitation contrary to radars of shorter wavelengths. Additionally, RWPs are typically located close to other meteorological instruments, creating an ideal study system with both bird and additional environmental data being collected in the same location. This makes RWPs a convenient tool to study birds' response to all kinds of atmospheric conditions (*e.g.* Weisshaupt et al., 2022). Despite the advantages mentioned, the use of RWPs in ornithology has been negligible because most biologists are unfamiliar with the technology and data (Weisshaupt, Arizaga, & Maruri, 2018). There are, to the best of our knowledge, currently only a handful of scientists familiar with the analysis of raw RWP data (I/Q time series). Early biological studies using processed RWP data dismissed the potential of RWPs to quantify bird movements and determine flight heights (Weber, 2005). Later studies using RWP time series data, however, confirmed the potential of RWP data for the detection of individual birds (Lehmann & Teschke, 2008), as well as for the robust quantification of bird activity (Weisshaupt et al., 2017). The extracted numbers have so far, however, shown only limited consensus with other monitoring systems. Thermal imaging was likely too sensitive to the presence of droplets in the air and too inaccurate in vertical profiling resulting in low correlations during rainy conditions (Pearson correlation coefficient $r = 0.17$), but in high correlations during dry conditions ($r = 0.95$, Weisshaupt et al., 2017). Weather radars yielded only poor correlations for spatiotemporal bird migration patterns (Liechti et al., 2019: $R^2 < 0.25$). The short overlapping calibration period (9 days), the different scan mode of the radars (vertical *vs.* quasi-horizontal), and the (physical) distance between the involved systems (about 100 km) and topography were put forward as the main reasons for a lack of correlation. A long-term comparison and calibration with a comparable more established vertical detection system nearby could thus provide a more conclusive assessment of the RWP's potential in aeroecology and create further impetus to tap into the potential of the existing RWP network.

Here, we compare data from a radar wind profiler and a dedicated vertically looking bird radar (BirdScan MR1) during two migration seasons (7–31 October 2019 and 1–30 April 2021). The aim was to compare migration intensities and vertical profiles under different meteorological conditions, to advance the understanding of the RWP's capacity for biomonitoring purposes. We hypothesize that the relative migration flux measured by the RWP correlates well with the bird radar measurements in clear conditions, though less so in precipitative conditions because of possible inter-site variations in weather and different susceptibility to precipitation of the two radar systems. We expect that both the different elevations of the study sites and the detection range of the systems may have an impact on the comparability of altitudinal flight distributions.

Materials and Methods

Radar wind profiler

Data were retrieved from the L-band boundary-layer radar wind profiler at the MeteoSwiss research site in Payerne, Switzerland (N46.813174, E6.942726, 491 m a.s.l.). The RWP has been operated continuously since 2007. The RWP is a Doppler radar from the manufacturer Degreane (PCL1300) operating at a frequency of 1290 MHz (23 cm wavelength). The system provides continuous, real-time vertical profiles of winds measured by a five-beam sampling configuration. There are five antenna panels, *i.e.* one per beam, and each panel consists of an array of 64 collinear dipole antennas. The nominal beam width is 8°. For the present study, the low mode of the RWP was used with a vertical resolution of 57 m (pulse width 1000 ns) making up 55 gates covering a vertical range from 106 m up to 3202 m a.g.l. The 55 altitudes of the gates represent the centre of the resolution volume. The measurements are taken with a dwell time between 9 and 30 s per beam. Depending on the dwell time, the sequential switching between the five beam directions defines a full-scan cycle of 2–6 min. For wind measurements, data from several full scans are used. Here, we used the vertical beam only, yielding between 11 and 24 measurements per hour. Bird echoes in the RWP data were identified and classified by visual inspection of the time series of the in-phase and quadrature components (I/Q) and derived spectrograms following Weisshaupt et al. (2017). The method was adapted to the Swiss Degreane RWP using a lower threshold of 200 units of SNR as an inclusion criterion for bird echoes. RWP time series and spectrogram data were visualized and screened in MATLAB. Time series data has been recorded and stored since 2015.

BirdScan MR1

The BirdScan MR1 is a 25 kW X-band (9.4 GHz, 3.2 cm wavelength) pulse radar with a vertical-looking, optionally nutating Horn antenna (nominal beam width at −3 dB is approximately 17.5°, nutation 2°). The radar was operated at Grenchenberg, Switzerland (N47.231217, E7.396731, 1347 m a.s.l.), from 7 to 31 October 2019 and throughout April 2021 continuously for 24 h/day. The radar is situated about 50 km from the Payerne site on a NO-SW axis matching the expected direction for passerine migration in Central Europe. Despite the distance but given the absence of any significant ecological barrier between the radars, we expect this alignment to result in the detection of the same migration fluxes.

During October 2019, the radar was sequentially operated for 20 min in nutating and 20 min static (*i.e.* non-nutating) short-pulse mode (pulse length 65 ns, pulse rate frequency 1800 Hz, range resolution about 7.5 m), followed by 20 min in nutating long-pulse mode (pulse width 750 ns, pulse rate frequency 785 Hz, range resolution about 110 m). During April 2021, the radar was measuring in nutating short pulse mode throughout the whole period. Based on a dataset of annotated radar echo samples (Haest, Schmid, et al., 2021), objects detected by the BirdScan MR1 system are automatically classified into birds and other objects. Birds are further subdivided into 'passerines', 'waders', 'large birds', 'swifts', 'flocks' and 'unidentified birds' (Schmid et al., 2019; Zaugg et al., 2008).

Meteorological data

Precipitation at ground level was obtained from the rain gauges at Payerne and Moutier, which was the closest station near Grenchenberg (about 5 km away). All other meteorological data was obtained from the research site at Payerne only because they were not available at Grenchenberg. Cloud base height was measured by a ceilometer. Hydrometer types were derived from vertical wind speed (w) measured by the radar wind profiler, where $w > 0$: no precipitation, updraft; $-0.5 < w < 0$: no precipitation, downdraft; $-0.5 > w > -2$: likely snow or drizzle; $-2 > w > -5$: liquid and/or solid precipitation; $-5 > w > -9$: likely rain; $w < -9$: hail. A Present Weather and Visibility Sensor (PWD22) provided visibility measurements at ground level.

Correlation analysis of the migration intensities from the two radar systems

For each radar system, the bird echo counts were converted into migration traffic rates (MTR, number of birds/km/h) for 30-min time bins. MTRs provide a measure of the number of birds passing a virtual transect line of 1 km within 1 h (*sensu* Lowery, 1951). We chose to calculate MTR values for 30-min intervals (but still expressed as the number of birds per km per hour) to increase the detectability of MTR fluctuations throughout the night. As radar wind profilers provide discrete (intermittent) measurements based on the scan cycles in specific intervals, bird counts were extrapolated for the MTRs until the beginning of the next scan cycle to achieve pseudo-continuous data (see Weisshaupt et al., 2017). RWP bird counts were limited to 0–1500 m in spring and 0–2500 m in autumn to cover the same altitudinal range as the BirdScan MR1 in the respective season.

MTRs of the bird classes in the BirdScan MR1 data were computed using the R package '*birdscanR*' (Haest et al., 2022), taking into account the size-specific (theoretical) monitored volume for each detected bird (Schmid et al., 2019). For the calculation of the October 2019 MTRs, we restricted the computation to the echoes detected using short-pulse to between 50 and 800 m a.g.l. because the theoretical maximal detection range of small birds (*e.g.* Chaffinch) using short-pulse is limited to about 800 m (Nilsson, Dokter, Schmid, et al., 2018). For the range of 800–2500 a.g.l., we used echoes detected with long-pulse only. For the calculation of the April 2021 MTRs, we used all birds detected by the Birdscan in short pulse mode between 50 and 1500 m. We computed no MTR if the effective monitoring time fell below 6 min for a 30 min time bin because of rain or technical shutdown.

To compare mean bird traffic rates per night, we calculated mean nightly MTRs from the 30-min MTRs between 6 PM and 7 AM UTC in April and 5 PM and 6 AM UTC in October. We checked for autocorrelation in the nightly MTR time series by inspecting autocorrelation function plots for significantly correlated lags. To ensure correlations were not spurious because of autocorrelation in the time series, we performed correlation analyses between the MTR values of both radars on both original and differenced MTR values. All analyses were performed in R (R Core Team, 2022).

Characterisation of height distributions

We calculated mean nightly MTRs per height interval (50 m for the BirdScan MR1 and 57 m for the radar wind profiler) to compare altitudinal distributions estimated with each radar. To assess the potential effect of the difference in elevation of the radar sites (1347 m for the Birdscan and 491 m a.g.l. for the RWP) on the height distribution, we tested the alternative of using the sea level (instead of the height above ground) as a reference for measured heights, in case birds continued on the same height level after passing the BirdScan MR1 radar. On average 90 and 69% of the migration in the RWP, however, passed below 900 m in autumn and spring, respectively, that is, below the BirdScan elevation. This means we could not directly compare the height distributions, so we used the actual measurement heights above ground level only to calculate the median MTRs (50th percentiles) of the height profiles for seasonal comparisons within each radar type. To assess whether the limited height range of the BirdScan resulted in differences in migration intensities, the differences between the estimated altitudinal MTR distribution in RWP cut at 1500 m in spring and 2500 m in autumn (the ranges of BirdScan in the respective season) were compared to the altitudinal estimates of the full height profile in the RWP of about 3 km in both spring and autumn.

Results

Correlations between migration traffic rates of the two radar systems, and the influence of the weather

In autumn, the R-squared of the original nightly MTR values was 0.72 (Pearson's $r = 0.85$, $F = 56.75$, $P < 0.001$) and 0.63 (Pearson's $r = 0.80$, $F = 36.5$, $P < 0.001$) for the differenced MTRs (Fig. 1A, only undifferenced correlation shown). In a total of 24 nights, the mean ratio of the nightly MTRs was 8.9. Nightly ratios were between 0 and 3 for three nights ($2 < 1$), between 4 and 10 for 12 nights, 10 and 20 for 8 nights and between 20 and 30 in 1 night (Table S1). The ratios (of <1) were observed for nights with intermittent to continuous rain. The cases with ratios between 4 and 10 exhibited a variable meteorological context with practically the entire range from clear conditions with good visibility (*e.g.* 14 and 26 October) to continuous heavy rain with low clouds and bad visibility of 1–10 km (28 October). A similar variability in weather conditions from clear to rainy conditions with good to poor visibility was observed in the higher ratios. October exhibited more frequent precipitation events distributed across the entire month and with more variability in precipitation amounts between the sites (Figure S1).

In spring, the R-squared (r^2) for the original nightly mean MTR values was 0.66 (Pearson's $r = 0.81$, $F = 51.73$, $P < 0.001$) and 0.65 (Pearson's $r = 0.81$, $F = 49.13$, $P < 0.001$) for the differenced MTRs (Fig. 1B, only undifferenced correlation shown), with an average RWP/Birdscan MTR ratio of 5.4. Nightly MTRs differed by 0 to 3 times in 18 nights, between 4 and 10 times in 10 nights, and once RWP MTRs were 59 times higher than BS MTRs (Table S2). Lowest ratios (<4) were generally measured on days with clear conditions, high clouds and good visibility of 10–20 km. Of these days, there was moderate precipitation only on 9 and 27 April from about 3 to 6 AM and 1 to 4 AM, respectively. The cases with ratios between 4 and 10 include more variable cases with rain events of variable duration (5 nights), but also clear conditions (4 nights). On 11 Apr (ratio: 6.7) rain lasted all night, clouds were low and visibility somewhat worse (between 5 and 20 km) and there was practically no migration. On 12 and 13 April, conditions were clear, but migration activity was low. The highest ratios of 59 and 9 were observed on 5 April with continuous light to

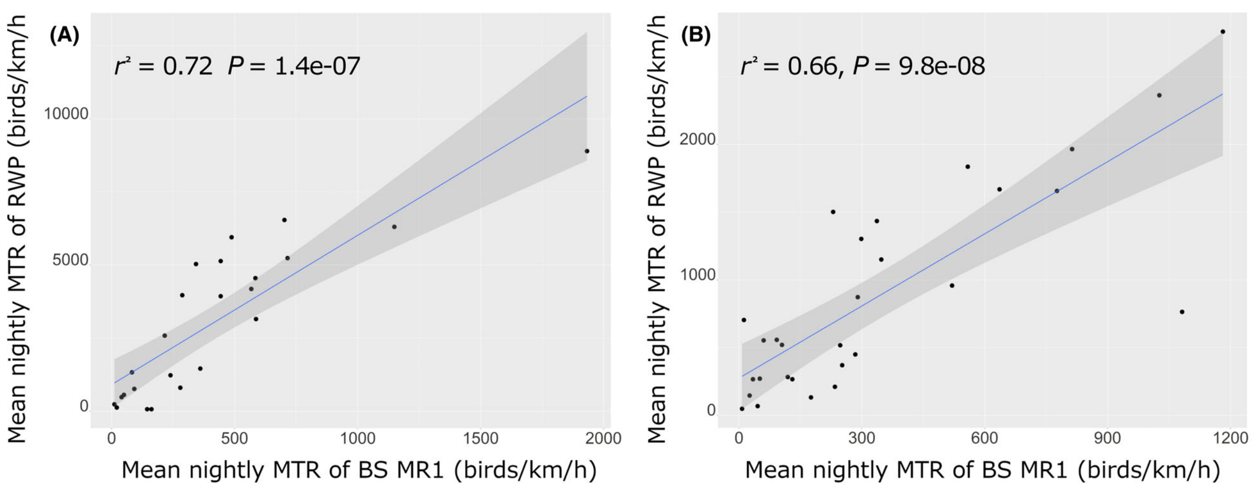

Figure 1. Correlation plot of mean nightly migration traffic rates (MTR) of BirdScan MR1 and radar wind profiler with the R-squared r^2 and probability p in (A) Oct 2019 and (B) April 2021 in a height interval of 0–1500 m a.g.l.

moderate rain from 6 to 8 PM and 10 PM to 3:30 AM and variable cloud height between 300 and 1500 m, and 28 April with heavy rain from 8 PM to 4 AM and low clouds between 500 and 2500 m, respectively. Overall, April was a rather dry month, with high precipitation only on 11 April at both radar sites (Figure S1A, B).

The nightly correlation coefficients obtained from the 30-min MTRs for both spring and autumn nights were overall lower than the correlation coefficients between the mean nightly MTRs. High correlation coefficients occurred during dry conditions ($r = 0.64$), but the results were overall highly variable and the correlation coefficients during clear and rainy conditions highly overlapped.

Altitudinal distributions

Median migration altitudes were on average higher in spring in both radar systems compared to autumn and there were significant differences in medians between the seasons (Fig. 2A, B). Nightly altitudinal distributions are shown in Figure S2A, B.

In autumn, migration was confined to altitudes below 2500 m, that is, within the range of both radars (Fig. 3B, D). 50% of the migration occurred below 390 and 250 m a.g.l. in RWP and BirdScan, respectively; 90% was below 900 and 550 m a.g.l. in RWP and BirdScan, respectively. The difference between the MTRs of the full RWP profile and the profile adapted to 2500 m was therefore small and the restricted range captured between 99 and 100%. Using only short-pulse data between and 1500 m, the restricted range would have captured 95–100% of the full profile. In spring, migration was distributed in a wider altitudinal range including all gates of the RWP (Fig. 3A, C). 50% of the migration occurred below 620 and 400 m a.g.l. in RWP and BirdScan respectively; 90% occurred below 1700 and 900 m a.g.l. in RWP and BirdScan, respectively. Given the more extensive altitudinal range and the limited short-pulse detection range of the BirdScan (0–1500 m) in spring, differences were more pronounced between the restricted and full range of the RWP with the limited range capturing 53–100% of the entire migration profile.

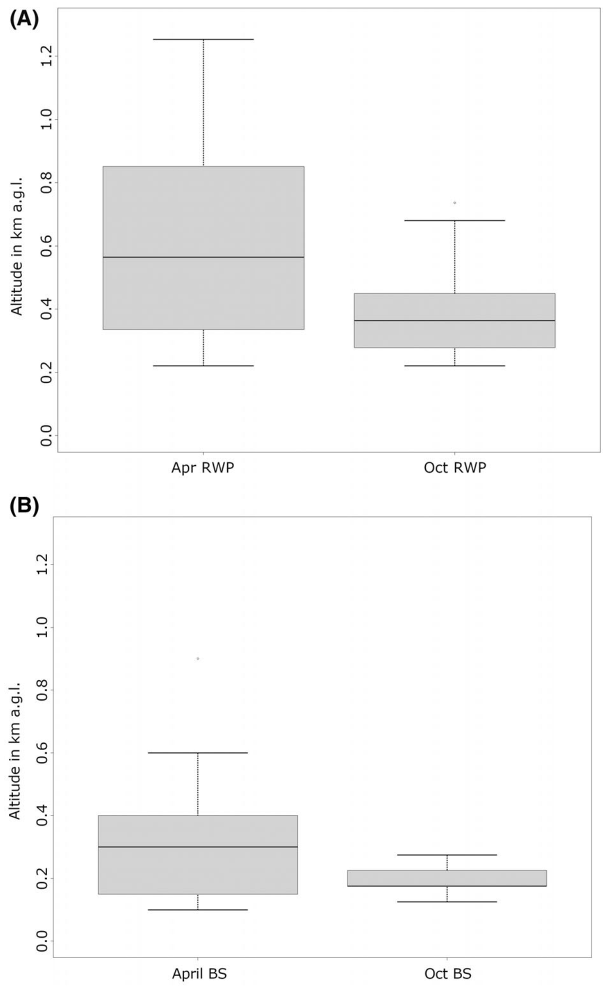

Figure 2. Median heights of altitudinal migrant distribution in radar wind profiler (RWP; A) and BirdScan MR1 (BS; B) in April 2021 and October 2019 (all measured heights included).

Discussion

Nightly migration traffic rates (MTRs) of the Radar Wind Profiler (RWP) and BirdScan MR1 were highly correlated in both spring and autumn, corroborating the potential of RWPs to quantify migratory bird movements. On average, nightly RWP MTRs were five times higher in spring and nine times higher in autumn than Birdscan MTRs. Like previous calibration studies (*e.g.* Weisshaupt et al., 2017; Liechti et al., 2019), absolute differences in nightly MTRs, however, varied strongly between systems. Compared to the previous studies with other radar combinations, ratios between absolute numbers were relatively large in October, though comparable in April, *e.g.* differences of only up to four times in Liechti et al. (2019). These observed differences in MTRs between the two radar systems may originate from (1) differences in the sensitivity and range of object detection because of system-inherent properties and the specific system settings during measurements; (2) algorithmic differences in the calculation of the MTRs; (3) the radars being in different geographic locations and topography (*i.e.* 50 km apart); and (4) the difference in meteorological conditions during measurements which can both influence a system's detection performance and the behaviour of the birds.

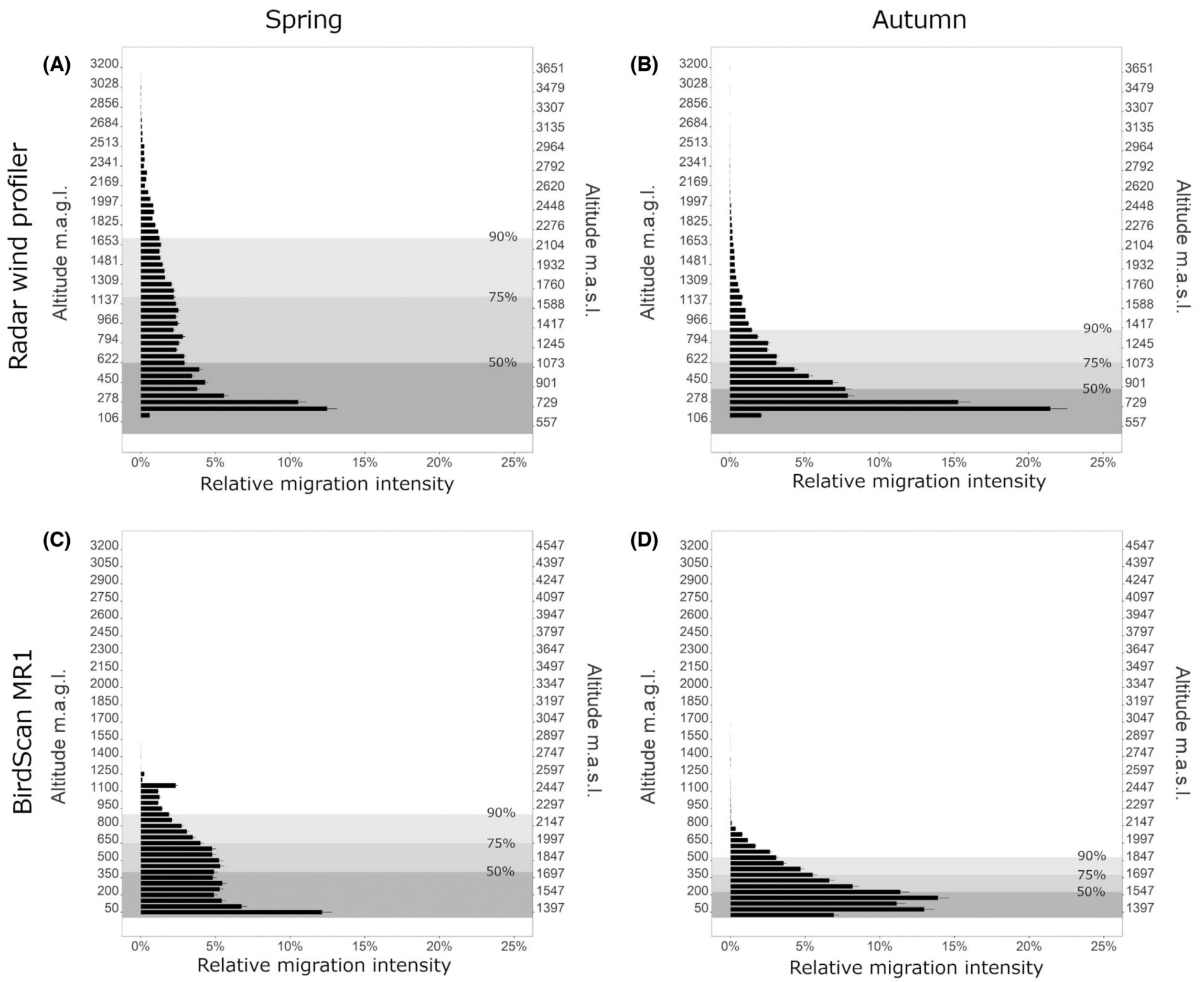

Figure 3. Height profiles with relative migration intensity in intervals of 57 m measured by the radar wind profiler at Payerne (A, B) and BirdScan MR1 (C, D) in spring (A, C) and autumn (B, D). For each range gate, the 95% CI is given for the migration traffic rates and 50% (dark grey), 75% (intermediate grey) and 90% quantiles (light grey) of the overall altitudinal migrant distributions for both altitudes m a.g.l. and m a.s.l.

Although both radar systems operate in vertical mode, their system specifications are very different. The RWP is extremely sensitive and designed to measure vertical winds in clear air up to several kilometres high (Balsley & Gage, 1980), so birds represent strong scatterers in the RWP data pool (Wilczak et al., 1995). Hence, birds are detected in the entire range of the low mode even in precipitative events and bias through deteriorating detection capacity can be neglected. The BirdScan MR1 measures up to about 2500 m a.g.l. in long-pulse mode and up to about 1500 m a.g.l. in short-pulse mode, but spring analysis indicates a rapid decline in detection capacity beyond 1000 m in the short-pulse mode. The observed lower MTRs in the Birdscan could, hence, be partly due to imperfect detection of targets with increasing height. This aspect could be verified in a future comparison with both systems at the same elevation and location.

Quantification in both radar types is based on single targets, though on different MTR calculations (Schmid et al., 2019; Weisshaupt et al., 2017). As put forward in previous studies (*e.g.* Liechti, Bruderer & Paproth 1995; Weisshaupt et al., 2017), the nominal beam width may deviate from the actual operational beam width, which, as a variable in the MTR equation, affects quantification. Also in the present comparison, this discrepancy between the nominal and actual beam width likely plays a decisive role in the dissimilarity of the absolute MTR estimates.

External environmental factors, such as topography and small-scale weather conditions, leading to heterogenous migration flow may also have an impact on the MTR estimates. Deviations through topography and precipitation paired with a time lag for migrants to pass above each system are probably the main reasons behind relatively low correlations within the nights. Environmental factors are often overlooked in calibration studies, *e.g.* omitted entirely in Liechti, Bruderer & Paproth (1995) and Liechti et al. (2019) or addressed marginally in Nilsson, Dokter, Schmid, et al. (2018), and only rarely in a thorough manner (*e.g.* Weisshaupt et al., 2017). While spatial proximity of the devices is typically aimed for, the actual distances can still be up to several tens of kilometres. Even though the radars in this study were separated by only about 50 km, this distance probably still results in differences in MTRs because of the structurally heterogenous habitat at the local and regional scale. It is well known from the Alpine regions that valleys influence the flight directions of birds (*e.g.* Liechti & Bruderer, 1986; Zehnder et al., 2001). As the BirdScan was located in the Jura mountains at 1347 m a.s.l. and the RWP in the adjacent lowlands at 491 m a.s.l., it may well be that the same migrants did not necessarily pass over both radars, especially if diverted by wind or precipitation, despite the radars' alignment on the average migration axis. The impact of spatially uneven topography on absolute measurements can be expected to decrease with proximity, *i.e.* if a BirdScan were placed next to a RWP. This would also alleviate potential biases because of weather factors. Precipitation may deviate or regulate migration activity through local changes in rain quantity when passing the Jura mountains, which would affect the favourability of the migration conditions at the study sites. In the present study, especially in October, ground-based precipitation amounts varied to some extent on a small scale of about 60 km probably because of the mountain range. Unfortunately, the full set of meteorological variables was not available for the BirdScan site, *i.e.* the presence of overhanging precipitation in altitude is not equally well known there as in Payerne. Overhanging precipitation might additionally lower birds' motivation to migrate through impaired visibility. The role of precipitation remains, however, ambiguous as it may have an impact both on the detection capacity of the systems and as an external driver in spatial bird distributions. For instance, in autumn, MTR ratios were lowest on rainy nights, which was likely due to birds' general reluctance to migrate in precipitation and resulting in low MTRs in both radars and not due to system performance. Precipitation was, in any case, identified previously as one of the factors influencing remote sensing measurement outputs (*e.g.* Weisshaupt et al., 2017; Zehnder et al., 2002).

Autumn migration was distributed across a more limited height range and compared to spring, occurred on a lower altitudinal level in both radar systems. In this study, 50% of the birds travelled up to about 225–390 m and 90% up to 525–900 m a.g.l., which is lower than found in other studies (*e.g.* Bruderer, 2017). In spring, 50% of the migration travelled up to 400–620 m a.g.l. and 90% up to 900–1700 m a.g.l., which is also lower compared to other findings (*e.g.* Bruderer, 1971). The BirdScan captured thus most of autumn migration in both long- and short-pulse mode, while in spring, using short-pulse only, about 50% of birds might have been missed in certain extreme cases, had it been placed beside the RWP. Despite the broader height distribution in spring, including up to altitudes where the bird detectability of BirdScan levels off, the ratios of the absolute MTRs of both systems were smaller in spring compared to autumn, when the BirdScan MR1 was expected to capture the entire flight range. It can be ruled out that the RWP could have missed high-flying birds captured by BirdScan as the RWP's altitudinal range of 3.2 km in the low mode covers the entire BirdScan range irrespective of the different site elevations. In spring, clear nights were more frequent than in autumn and ratios were lower, so this suggests that clear conditions contributed to lower ratios in absolute numbers, be it through favourable measurement settings or less deviation of bird flows.

Even though in this study we cannot disentangle the relative contributions by the differences in system specifications, algorithmic processing, measurement location and the associated weather conditions to the absolute differences in MTRs from the RWP and Birdscan, our results clearly show how strongly correlated the estimated relative bird migration fluxes from the RWP are to those from the more-established Birdscan MR1 radar system. These findings, as such, effectively demonstrate and corroborate the previously suggested potential (Weisshaupt et al., 2017; Weisshaupt, Lehmann, et al., 2018) of RWPs for bird migration monitoring. With their ability to produce high-quality detections of birds during not only dry but also precipitative conditions, and the customary close positioning of existing RWPs to additional atmospheric measurement systems, the automated quantification of bird migration from RWP radars would enable studying migratory bird responses during weather conditions where other radar systems suffer from detection bias or fail entirely, opening up research into largely unexplored aspects of migratory bird behaviour. Such software tools currently already exist for, for example, weather radars (bioRad, Dokter et al., 2019) and BirdScan radars (Haest et al., 2022), though not for RWPs. Our results provide further impetus to indeed also develop such software tools for RWP data analysis, enabling tapping into the potential of the already existing RWP radars.

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Author Contributions

Nadja Weisshaupt conceived the study; Nadja Weisshaupt and Birgen Haest analysed the data; Maxime Hervo provided the RWP and meteorological data, and tools for the RWP data analysis. Nadja Weisshaupt wrote the initial draft of the manuscript with substantial contributions from all authors.

Data Availability Statement

The radar wind profiler and BirdScan MR1 data as well as meteorological data used in the analyses of the manuscript can be accessed at https://doi.org/10.23728/fmi-b2share.4379946398bf4b4fa9a4f2562dda0f40.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Migration traffic rates (MTR) of BirdScan MR1 and RWP, MTR ratios, nightly 30-min correlation coefficients (in brackets differenced values), weather conditions and cloud base height in October 2019.

Table S2. Migration traffic rates (MTR) of BirdScan MR1 and radar wind profiler, MTR ratios, nightly 30-min correlation coefficients (in brackets differenced values), weather conditions and cloud base height in April 2021.

Figure S1ab. Precipitation [mm] on ground level measured by rain gauges in Moutier (red) and Payerne (green) in (a) Oct 2019 and (b) April 2021.

Figure S2a. Nightly altitude distributions of migration traffic rates in autumn 2019 for the BirdScan MR1 (BS, red) and radar wind profiler (RWP, green).

Figure S2b. Nightly altitude distributions of migration traffic rates in spring 2021 for the BirdScan MR1 (BS, red) and radar wind profiler (RWP, green).

